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RECONNAISSANCE RE-OS ISOTOPE STUDY OF INDIAN KIMBERLITES AND LAMPROITES: IMPLICATION FOR THEIR MANTLE SOURCE REGIONS

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The nature of the mantle reservoirs of kimberlites and lamproites and their depths of derivation are controversial and debatable. The favoured source regions of the kimberlite ranges from core-mantle boundary (Torsvik et al., 2010; Collerson et al., 2010) and transition zone (Ringwood et al., 1992), through asthenosphere (Mitchell, 2006) to sub-continental lithospheric mantle (Tainton and McKenzie, 1994; Le Roex et al., 2003) with some of the most recent models favouring involvement of multiple reservoirs including cratonic- as well as sub-lithospheric sources (Tappe et al., 2011). An analogous scenario prevails for lamproites as well with their envisaged sources varying from sub-lithospheric (Murphy et al., 2002) and sub-continental lithospheric (Mirnejad and Bell, 2006) mantle.

Many previous studies involved trace elemental abundances, their ratios, experimental studies and various radiogenic isotope systems (Nd-Sr-Hf-Pb) to constrain the source regions of kimberlites and lamproites (e.g., Smith, 1983; Chalapathi Rao et al., 2004; Becker and Le Roex, 2006; Chakrabarti et al., 2007; Woodhead et al 2009). However, in recent years the ^{187}Re-^{187}Os system has been used to chemically fingerprint distinct reservoirs. The compatibility of Os (wherein it becomes concentrated in the peridotitic portions) and incompatibility of Re (preference for a melt phase) during partial melting of the mantle leads to large variation in Re/Os ratios between mantle and crust, as well subsequent Os isotopic composition in crust and mantle. The high mantle Os content may renders it relatively immune to influence of metasomatic processes relative to other isotope systems such as Sr, Nd and Pb (Shirey and Walker, 1998; Carlson, 2005).

Substantial Re-Os isotopic data is available for the mantle-derived spinel and garnet peridotite xenoliths (e.g., Carlson et al., 2007; Schilling et al., 2008; Rudnick and Walker, 2009) entrained by kimberlites and other alkaline magmas. However, such data is relatively sparse for the host potassic –ultrapotassic continental magmas and limited to a few occurrences such as those from Yilgarn craton, Australia (Graham et al., 1999), Italian peninsula (Conticelli et al., 2007), S.W. Arkansas, U.S.A. (Lambert et al., 1995), Alto Paranaiba Province, Brazil (e.g., Carlson et al., 1996; Araujo et al., 2001) and southern African kimberlites (Pearson et al., 2008).

The main purpose of this paper is to report reconnaissance Re-Os isotopic data for the Mesoproterozoic kimberlites and lamproites from the Eastern Dharwar craton, southern India and end-Cretaceous Kodomali orangeite from the Bastar craton, central India. Contrasting petrogenetic models exist as to the depths of derivation of kimberlite and lamproite samples incorporated in this study (e.g., Chalapathi Rao et al., 2004; Chalapathi Rao et al., 2010; Chakrabarti et al., 2007; Paton et al., 2009; Patel et al., 2010) and their genesis has been investigated via a Re-Os isotopic perspective.

Finally, we compare the data obtained from this study with that of global occurrences to decipher their similarities and differences.

The kimberlites, lamproites and orangeite investigated in this study are well characterised in terms of their petrography and mineralogy and details are available in the literature (Fig.1A and B): Pipes P-10, P-11, P-12, CC-3, CC-4, CC-5 and KL-3 from the Wajrakarur kimberlite field (WKF) (Neelakantam, 2001; Paul et al., 2006; Chalapathi Rao et al., 2004; Chalapathi Rao and Srivastava, 2009); SK-1 from the Raichur kimberlite field (RKF) (Sridhar et al., 2004; Chalapathi Rao et al., 2010); KK-6 from the Narayanpet kimberlite field (NKF) (Chalapathi Rao and Dongre, 2009); Kodomali (KDK-2) from Mainpur orangeite field (Chalapathi Rao et al., 2011a) and Ramapuram, Pochampalle and Reddikunta lamproites from the Krishna lamproite field (KLF) (Reddy et al., 2003; Paul et al., 2007; Chalapathi Rao et al., 2010).

The $^{187}Os/^{188}Os_i$ isotopic data of WKF, NKF and RKF samples are corrected for their emplacement age of 1100 Ma whereas the lamproite data has been age corrected to 1225 and 1500 Ma. The sole orangeite sample is age corrected to 65Ma. Various parameters such as gOs (which is the percentage between the Os isotopic composition of a sample and the average chondritic composition for a specific time), T_{MA} or model age (time of separation from mantle that is growing according to chondritic evolution) and T_{RD} or Re-depletion model age (time of Re depletion which is considered to be the minimum age) are calculated as per the equations given in Shirey and Walker (1998) and Carlson (2005).

The Re concentration of the kimberlites ranges from 0.077 to 0.290 ppb whereas the Os content varies from 0.311 to 1.98 ppb. The measured $^{187}Os/^{188}Os$ ratios for all except one sample (KL3/1) are higher than chondritic modern mantle (0.13 – 0.16), and the calculated initial $^{187}Os/^{188}Os$ ratios range from 0.0967 to 0.1260. The kimberlites show variable depletion in their

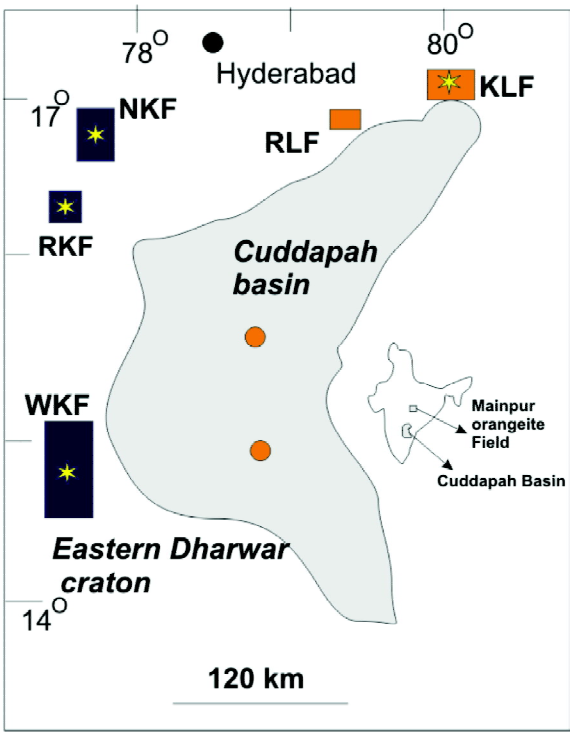

Figure 1A Location map of the Cuddapah basin and Eastern Dharwar craton in southern India showing the kimberlites/lamproites sampled in this study.

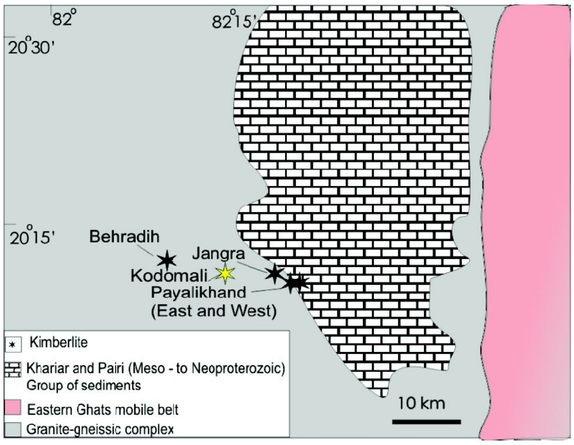

Figure 1B Geological map of the Mainpur orangeite field in the Bastar craton showing the location of Kodomali pipe sampled in this study (adapted from Chalapathi Rao et al., (2011a).

$^{187/188}Os$ relative to chondrite (at 1100 Ma) as expressed by the –ve **g**Os parameter, and for three samples (CC3/1, CC3/2 and P11/1) this value is very low, nearly -20. This is close to the meteorite initial Os at 4.6 Ga (i.e., impossible) and likely means that for these samples, present day Re is too high and may have been added/altered. However, two of the kimberlite samples (Raichur and Narayanpet fields) and the Kodomali orangeite show positive ã Os values ranging from +4.2 to +4.9 which imply slightly radiogenic mantle sources.The Kodomali orangeite has a slightly higher initial $^{187}Os/^{188}Os$ ratio of 0.1330. On the other hand, the lamproites display much lower Re (0.031 to 0.279 ppb) and Os (0.060 to 0.129 ppb) contents and their initial $^{187}Os/^{188}$ ratios are significantly higher, i.e. in the range of 0.1891 to 0.5499 than those of kimberlites, with very radiogenic ãOs values of +59 to +361.

The results obtained in this study demonstrate that Re-Os abundances as well as the $^{187}Os/^{188}Os$ isotopic ratios are markedly different for kimberlites and lamproites. The Os abundances of the kimberlites (0.311-1.94 ppb) are clearly higher than those in lamproites (0.060 – 0.129 ppb) but all of their Re contents (0.054-0.290 ppb) are indistinguishable. All the kimberlites and orangeite essentially have Re/Os <1 and are strikingly similar to those of the Mesozoic kimberlites and orangeites from the Kaapvaal craton, southern Africa and also show overlap with those of Palaoproterozoic kimberlites from the Eastern Gold field province, Yilgarn craton, Australia; whereas lamproite samples are confined to the compositional field of those from the Italian peninsula (Graham et al., 2004; Conticelli et al., 2007; Fig.2). The initial $^{187}Os/^{188}Os$ isotopic ratios and Os abundances of the kimberlites and orangeite of this study are also remarkably similar to those from the Alto Paranaiba alkaline Province, Brazil (Carlson et al., 1996; Aruajo et al., 2001) on the other hand, the lamproites from KLF share similar compositions as those from Italian peninsular and to some extent with those from the Alto Paranaiba alkaline Province (Fig.3). Importantly, the initial $^{187}Os/^{188}Os$ isotopic ratios of the samples of this study are very different from those of the

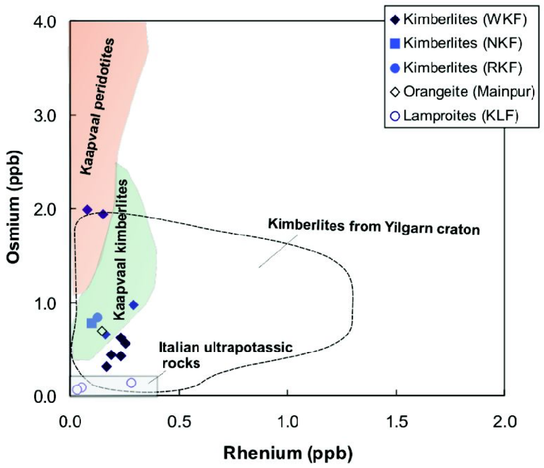

Figure 2 Re vs Os concentration diagram for the samples of this study. The fields for Kaapvaal peridotites and kimberlites and those for Yilgarn craton kimberlites are from Graham et al (2004) and the field for Italian ultrapotassics is from Conticelli et al., (2007).

continental crust shown for a comparison in Fig.3 and thus exclude significant crustal contamination.

The negative γOs of WKF kimberlite samples therefore imply derivation of Os from a depleted or unradiogenic source with long-term lowered $^{187}Re/^{188}Os$ source such as previously melt-depleted subcontinental lithosphere. However, several samples show unrealistically low Os values, despite realistic measured $^{187}Os/^{188}Os$ values, implying that the age-correction based on measured Re/Os ratios is inaccurate for some samples. In particular, three samples (CC3/

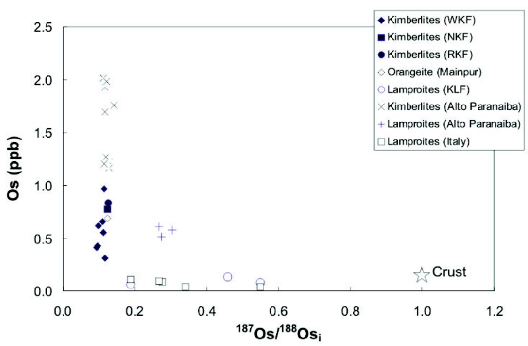

Figure 3 $^{187}Os/^{188}Os_i$ versus Os (ppb) diagram for the samples of this study. The data for Alto Paranaiba kimberlites and lamproites is from Carlson et al., (1996) and Aruazo et al., (2001). The data for Italian lamproites as well as the composition of Crust is from Conticelli et al., (2007).

1, CC3/2 and P11/1) appear to have vastly lower γOs than most remaining samples, which range from -1 to -8. The degree to which this correction bias affects each sample is difficult to quantify, but the most Re-depleted sample (KL3/1) with lowest present day ^{187}Os/^{188}Os (0.1143) and lowest ^{187}Re/^{188}Os ratio (<0.2) has an γOs of -7 and yields a model age (T_{MA}) of 3.4 Ga and a Re-depletion age (T_{RD}) of 1.9 Ga. The age correction for this sample is minimal, and as such the resulting γOs value likely to be the most reliable. The T_{RD} depletion age of 1.9 Ga point to the involvement of Proterozoic lithosphere in the genesis of the kimberlites and it strikingly corresponds with the Nd model ages of the Krishna and Cuddapah lamproites (Chalapathi Rao et al., 2004, 2010 and Osborne et al., 2011) but also the emplacement of Large igneous provinces of similar age and magmatism in the Dharwar and Bastar cratons (India), the Superior Craton (Canada) and the Kaapvaal craton (southern Africa; French et al., 2007). The argument for a Proterozoic lithosphere as source region for the EDC kimberlites is also supported by the similarity of T_{RD} depletion age with that of Nd-depleted mantle model ages of 1.4-1.6 Ga recently determined on their perovskites (Chalapathi Rao et al., 2012).

The KK6/1 (NKF), SK1(RKF) and KDK-2 (Mainpur orangeite) samples have +ve γOs values that are considered as enriched or radiogenic and imply derivation long term elevated ^{187}Re/^{188}Os sources (Walker and Shirey, 1998). An enriched mantle source for the Mainpur orangeites is additionally supported by their εNd_i values that range from -6.4 to -10.4 which imply derivation dominantly from melt source regions with lower time-integrated Sm/Nd ratios than Bulk Earth (Lehmann et al., 2010; Chalapathi Rao et al., 2011b). Likewise, the slightly radiogenic nature of ^{187}Os/^{188}Os isotopic ratios displayed by KK6/1 (NKF) and SK1(RKF) are also supported by their geochemical distinctness, compared to other EDC occurrences, which has been explained to be due to involvement of mixed (plume and subduction-related) source regions in their genesis (Chalapathi Rao and Dongre, 2009 and Chalapathi Rao et al., 2010). The involvement of a metasomatised sub-continental lithospheric mantle in the generation of EDC kimberlites and Mainpur orangeite is also strongly supported by Re/Os vs γOs plot (Fig.4) wherein their compositions are strikingly similar to those of the metasomatised Archaean

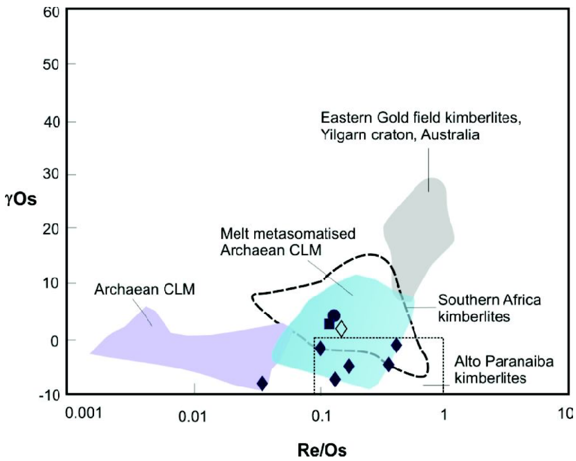

Figure 4 Re/Os versus gOs for the samples of this study. Various fields are taken from Graham et al., (2004) and the field for Alto Paranaiba kimberlites is from Calrson et al., (1996) and Aruajo et al., (2001).

lithospheric mantle and kimberlites from southern Africa and Alto Paranaiba Province. A broad similarity in ^{187}Os/^{188}Os$_i$ between southern African kimberlites and Kaapvaal peridotites was also highlighted by Pearson et al., (2008).

The KLF lamproite samples, on the other hand, are clearly very different, with very radiogenic γOs values (+59 to +369), indicated high Re/Os materials in their source, possibly subducted component in their source region, and have a strong similarity to the compositions of subduction-related lamproites of Italian peninsula and also those from Alto Paranaiba alkaline province (Figs. 2 and 3). However, they are different from the non-radiogenic initial γOs values of -3.2 to -3.6 and -2 to -6 reported for the 106Ma Prairie Creek lamproites, S.W. Arkansas, U.S.A (Lambert et al., 1995) and 1200 Ma Argyle lamproite, Western Australia (Graham et al., 1999) respectively implying their distinct genesis. Our results provide compelling evidence for an isotopically heterogeneous lithospheric mantle sources for the Mesoproterozoic kimberlites and lamproites in and around the Cuddapah basin and Eastern Dharwar craton inferred earlier from Nd isotopic systematics (Chalapathi Rao et al., 1998, 2004).

Our proposal, from a Re-Os isotopic perspective, for the involvement of SCLM in the generation of Indian kimberlites, lamproites and orangeites is also consistent with most recent models which invoke involvement of multiple sources for such rocks from southern Africa (Le Roex et al., 2003; Becker and Le Roex, 2006; Donnelly et al., 2011) and Greenland (Tappe et al., 2011).

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