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PETROLOGY, BULK-ROCK GEOCHEMISTRY, INDICATOR MINERAL COMPOSITION, AND ZIRCON U-PB GEOCHRONOLOGY OF THE END-CRETACEOUS DIAMONDIFEROUS MAINPUR ORANGEITES, BASTAR CRATON, CENTRAL INDIA

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It was Wagner (1914) who first recognised, based essentially on petrographic grounds, two main sub-groups of kimberlites in the Kaapvaal craton of southern Africa which he termed them as basaltic (mica-poor) and lamprophyric (mica-rich) varieties. Based on their distinct radiogenic isotopes the basaltic kimberlites have been renamed (Smith, 1983) as Group I (characterised by lesser radiogenic Sr and more radiogenic Nd and Pb) variety whereas the micaceous variety have been termed as Group II (characterised by more radiogenic Sr and lesser radiogenic Nd and Pb) variety. Further studies have brought out several distinctions between these two groups in terms of their age, distribution, mineral chemistry, geochemistry and mantle-derived xenoliths and xenocrysts (e.g., Fraser and Hawkesworth, 1992; Mitchell, 1995; Coe et al., 2008; Howarth et al., 2011).

However, recent studies have established unambiguous occurrence of end-Cretaceous orangeites in the Mainpur area of the Bastar craton, Central India (Lehmann et al., 2010; Chalapathi Rao et al., 2011a). In this study, we report new data involving petrology, bulk-rock geochemistry (including Platinium Group of elements), indicator mineral chemistry (garnet, cr-diopside and spinel xenocrysts) and U-Pb zircon geochronology of the Behradih, Kodomali, Payalikhand and Kosambura pipes from the Mainpur orangeite field. We also estimate oxygen fugacity (fO_2) of the Mainpur orangeite magmas by applying Fe-Nb oxybarometry to their perovskite chemistry and attempt to assess the role of oxidation state in their diamond grade. The findings of this study provide additional insights into the (i) origin of these pipes, (ii) diamond prospectivity, (iii) nature and composition of the sub-Bastar lithosphere and (iv) in furthering our understanding on the petrological and geochemical differences between the Mainpur orangeites and well studied Mesoproterozoic kimberlites from the Wajrakarur (WKF) and Narayanpet (NKF) fields, Dharwar craton, southern India as well as those from southern Africa.

Preserval of diatreme (Behradih) as well as hypabyssal facies (Kodomali) in this domain imply differential erosion. Behradih samples are pelletal and tuffisitic in their textural habit whereas those of the Kodomali have inequigranular texture and comprise aggregates of two generations of relatively fresher olivines. The Kosambura pipe displays high degrees of alteration and contamination with silicified macrocrysts and carbonated groundmass and rest others are either not exposed or their samples are not amenable for petrological and geochemical studies. Olivine, spinel and clinopyroxene in the Behradih and the Kodomali pipes share overlapping compositions whereas the groundmass phlogopite and perovskite show conspicuous compositional differences.

In terms of mineral chemistry similarities as well as differences have been noticed between Kodomali and Behradih pipes. Olivine, spinel and clinopyroxene in both the pipes have overlapping compositions whereas the groundmass phlogopite (TiO_2) and perovskite (Nb_2O_5 and Fe_2O_3) show marked differences. Distinctness in the composition of clinopyroxene of the Kodomali samples of this study and those reported by earlier workers (Fareeduddin et al., 2006) raises the possibility of multiple eruptions within in the same pipe as autoliths of earlier kimberlite intrusions were also recorded (Chatterjee et al., 1994). As multiple kimberlite eruptions (up to 8) within a short span of a few million years have been recorded from Prieska region, southern Africa (Smith et al., 1994) and Fort á La Corne field, Canada (Kjarsgaard et al., 2009) radiometric dating on mineralogically distinct samples is in progress to ascertain such episodes within the Kodomali pipe. Nevertheless, mineral compositions of the Behradih and Kodomali pipes together show considerable differences than those from the Mesoproterozoic kimberlites of Wajrakarur Kimberlite Field (WKF) and Narayanpet Kimberlite Field (NKF), southern India and resemble the southern African orangeites in this regard (Fig. 1).

The major element contents viz., SiO_2, MgO, Fe_2O_3*, K_2O and TiO_2 of the Behraidh and Kodomali pipes are clearly different from bulk of

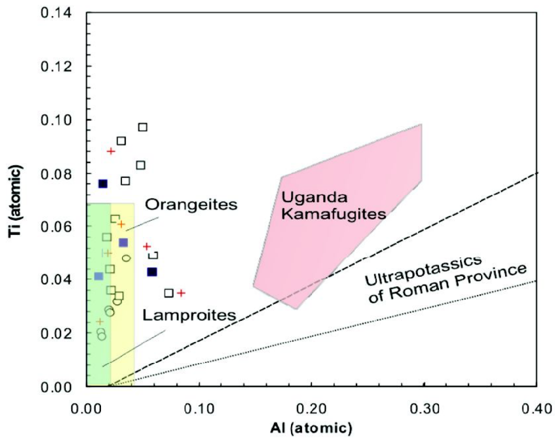

Figure 1 Al $_{total}$ versus Ti $_{total}$ expressed as atoms per formula unit for clinopyroxene for the Kodomali and Behradih . Also shown are the data for clinopyroxene from the Krishna lamproites (open squares) and Narayanpet kimberlites (open circles).

the WKF and NKF which have relatively lower SiO_2 and a much wider range in their MgO. Furthermore, when compared to the archetypal kimberlites and orangeites of southern Africa, the Mainpur pipes as well as kimberlites from NKF and WKF clearly display more fractionated nature and show show strong affinities towards those of orangeites (Fig.2A and B). Incompatible element abundances involving elements such as Ba, Nb, La and Rb distinguish the Behradih and Kodomali pipes from a majority of the WKF and NKF kimberlites

PGE in kimberlites are limited with such data reported for only few occurrences from Kapvaal craton, southern Africa, Sao Francisco craton, Brazil and North China craton (e.g., McDonald et al., 1995; Zhang et al., 2010). PGE abundances in both studied Mainpur pipes are indistinguishable thereby implying a similarity in the petrogenesis of their magmas. The PGE contents of the Mainpur orangeites are also similar that of the southern African and Brazilian kimberlites and Mengyin and Fuxian kimberlites from North China craton with slightly lower Rh abundances for some samples (Fig.3).

The pyrope garnet population in the Behradih, Kodomali, Payalikhand and Kosambura

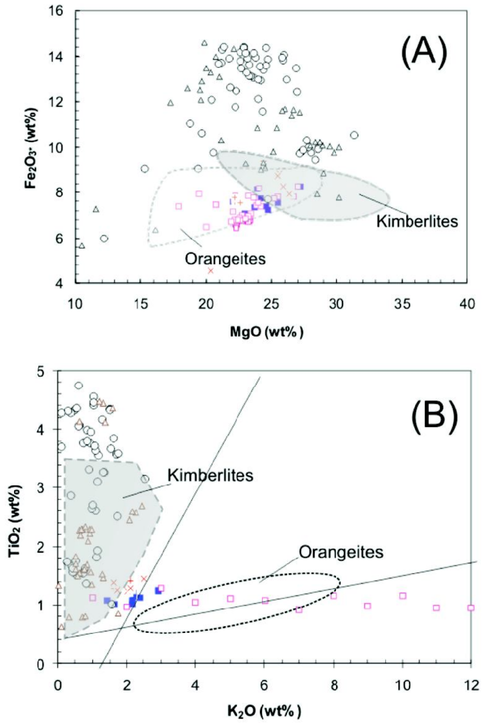

Figure 2 (A) Whole-rock variations of (A) MgO (wt%) versus Fe_2O_3* (wt%) and (C) K_2O (wt%) versus TiO_2 (wt%) for the Mainpur pipes (filled circles). Kimberlite and orangeite fields are from Donnelly et al., 2011 and the references therein. Open circles, squares and triangles are the data for kimberlites from the Dharwar craton, southern India (after Chalapathi Rao et al., 2004; Chalapathi Rao and Srivastava, 2009; Chalapathi Rao and Dongre, 2009; Chalapathi Rao et al., 2011b).

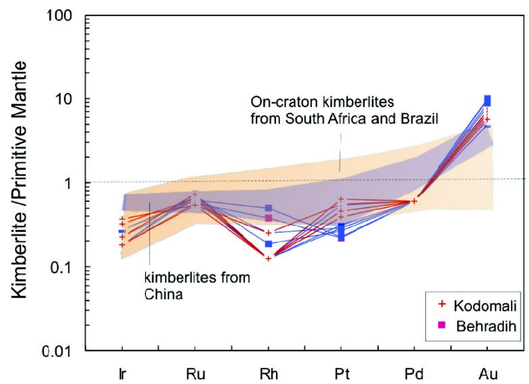

Figure 3 Primitive mantle-normalized (after Barnes et al., 1988) PGE and Au diagram for Behradih and Kodomali orangeites (this study) compared with those from on-craton kimberlites from South Africa and Brazil (McDonald et al., 1995) and China (Zhang et al., 2010).

pipes is predominated by calcic lherzolitic variety with <5% belong to high interest sub-calcic harzburgitic category and rest to other fields such as eclogitic types (Fig.4). The lherzolitic trend is suggestive of garnets in equilibrium with clinopyroxene (see Gibson et al., 2008) which is consistent with the garnet-peridotite affinities of the Mainpur diopside xenocrysts. The findings of our study are also consistent with those reported earlier by (i) Jha et al., (2002) wherein pyrope population in the Mainpur pipes has been inferred to be dominated by calcic-lherzolite variety corresponding to G9 and some eclogitic (G3, G4 and G5) and iron-titanian-low calcium (G1 and G2) garnets with the sub-calcic harzburgitic category (G10) pyrope garnet population between 1 and 5% and (ii) Mukherjee et al., (2000) who reported garnets of eclogitic paragenesis from the Behradih pipe.

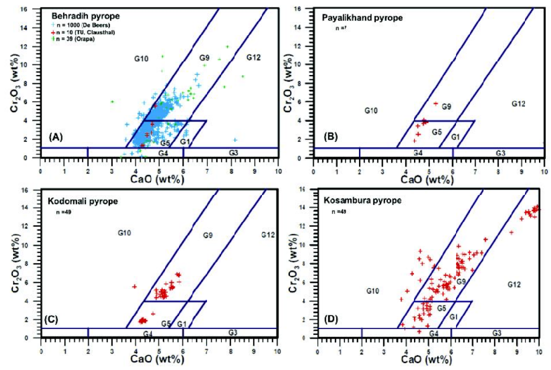

Figure 4 A–D Cr_2O_3 vs CaO (wt%) variation plots of pyrope garnet separates from orangeites of this study. The fields are adopted from Grutter et al., (2004)

The presence of "sinusoidal" REE_N patterns in garnets of this study (Fig.5) is significant since such patterns are regarded to be resultants of two stage process involving an (i) initial extensive komatiite melt extraction event which result in extreme LREE and HREE depletion leading to a depleted lithosphere followed by (ii) a second stage involving fluid metasomatism wherein repeated pulses of fractionated melt with low

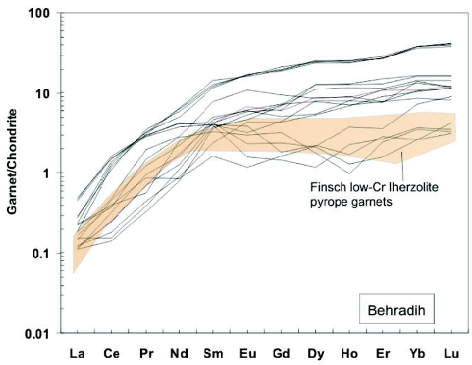

Figure 5 Chondrite-normlized Rare-earth element distribution patterns for pyrope garnet separates from Behraidh orangeite. The field of Finsch low-Cr lherzolite pyropes, shown for comparison, is from Gibson et al., (2008).

HREE and variable LREE/MREE into the already depleted lithosphere (Stachel et al., 2004; Creighton et al., 2010). The sub-calcic harzburgitic garnets displaying sinusoidal REE_N are only confined to depths <175 km and temperatures of 1150°C where as lherzolitic garnets and Ti-rich pyrope megacrysts originate from depths in excess of 175 km (e.g., Stachel et al., 2004; Lehtonen, 2005). Therefore the present study identifies, for the first time, the presence of a compositionally layered mantle in the end-Cretaceous sub-Bastar craton similar to that reported from other cratons elsewhere such as Kaapvaal craton (e.g., Gregoire et al., 2003; Gibson et al., 2008) western Guyana shield (e.g., Schulze et al., 2006), Slave craton (e.g., Griffin et al., 1999; Kopylova and Caro, 2004), Siberian craton (e.g., **Ashchepkov et al., 2010), North Atlantic craton (Sand et al., 2009) and Karelian craton (Lehtonen et al., 2004).**

Some of the chromites from the Behradih Kodomali and Kosambura pipes are compositionally similar to those found as inclusions in diamonds (Fig.6) implying their derivation from a diamond stability field, which also additionally finds support from the diamondiferous nature of these pipes.

Oxygen fugacity (fO_2) estimates based on perovskite oxybarometry (Canil and Bellis, 2007)

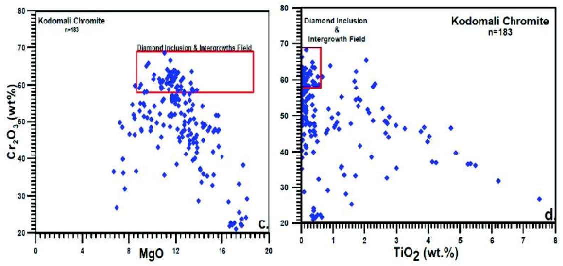

Figure 6 Cr_2O_3 (wt%) versus MgO (wt%) and Cr_2O_3 (wt%) versus TiO_2 (wt%) variation plots of Kodomali chromite xenocrysts. Diamond inclusion and intergrowth field is after Fipke et al., (1995).

highlight that (i) the ÄNNO conditions of the Mainpur pipes are higher from those from non-prospective NKF pipes as well as other prospective diamondiferous kimberlites located elsewhere such as Dutoitspan, southern Africa, Somerset Island, Canada and (ii) are indistinguishable in the redox conditions of the highly diamondiferous Lac de Gras kimberlites, Canada (Fig.7). We therefore conclude that oxidation state cannot explain the high incidence of diamonds in the Mainpur field and other factors very likely have played a significant role. The Mainpur orangeites are thus indeed "anomalous"

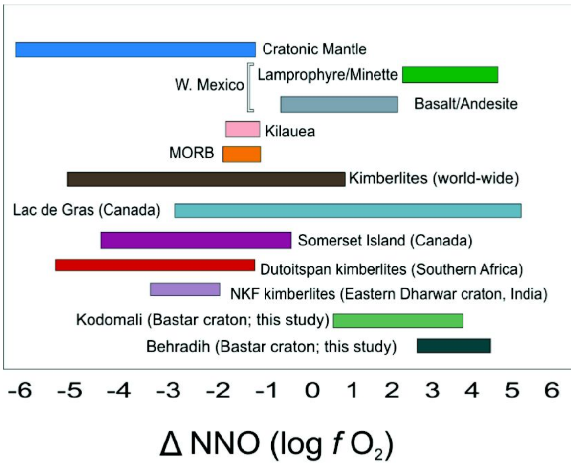

Figure 7 Oxygen fugacity (fO_2) (ΔNNO) conditions of the Behradih and Kodomali orangeites compared with those recorded by cratonic mantle lithosphere, mantle-derived magmas and global kimberlites (adapted from Canil and Bellis, 2007). Data for Dutoitspan kimberlites is from Ogilvie-Harris et al., (2009); NKF kimberlites (Chalapathi Rao et al., 2011b).

in terms of their high diamond incidence considering the preponderance of calcic-lherzolitic garnets and high oxidising conditions available at the time of their eruption.

All the zircons recovered from the Behradih pipe are crustal-derived xenocrysts, and not mantle-derived megacrysts, as revealed by their composition and U-Pb ages (Fig.8). However, paucity of Archaean age in any of the dated grains is surprising since Bastar craton is regarded as the oldest continental nuclei in the Indian shield

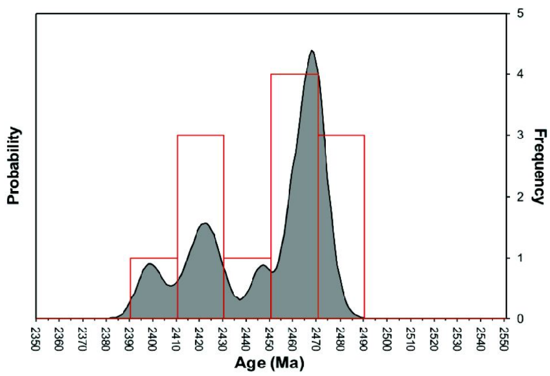

Figure 8 Frequency plot of the U-Pb zircon ages from the Behradih pipe. Lack of zircons of Archaean zircons is striking.

with an Eoarchaean crust as evidenced by the 3.50-3.6 Ga zircons from the exposed tonalities and granites (Sarkar et al., 1993) and a thickened modern-day crust of 35-40 km (Jagdeesh and Rai, 2008). Therefore, non-recovery of Archaean aged zircons could well be a reflection of the sampling. Alternately, it may also represent modification of the sub-Bastar lithosphere by the invading Deccan plume-derived melts during the end-Cretaceous synchronous with the eruption of the Mainpur orangeites (see Chalapathi Rao and Lehmann, 2011 for a detailed discussion). Further studies involving the U-Pb dating of zircons from the Mainpur field is expected to provide further clues in this direction.

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