Trace-element signatures of kyanite-eclogites from a southern Indian kimberlite

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Eclogite xenoliths found in kimberlites provide important information about geodynamic processes that were involved in the cratonic evolution of a region. Most eclogite xenoliths are demonstrably Precambrian in age and have equilibrated over a range of temperature and pressures throughout the subcratonic mantle (Jacob, 2004). Many eclogite xenoliths are diamondiferous (e.g., Anand et al., 2004) and thus they are not only of economic significance but they also provide information on the chemical and isotopic nature of deeper parts of Earth's mantle (> 150 km), which is otherwise directly inaccessible. Although eclogite is apparently a minor component of the Earth's mantle, it plays an important role in mantle geodynamics by facilitating subduction of the oceanic crust and imparting chemical heterogeneity to the mantle. Nevertheless, there has been some debate about the origin of eclogite xenoliths as to whether they are high-pressure cumulates from mantle melts or remnants of subducted ancient oceanic crust (e.g., see Jacob, 2004). Eclogite xenoliths from a number of locations worldwide have been studied for their detailed geochemical and isotopic characteristics, except those from India. Very little data exist on lithospheric materials of any nature for the cratonic roots in this region and the aim of this study is to redress this situation. Here we report on trace-element signatures of minerals and bulk-rock rhenium-osmium (Re-Os) isotope systematics of eclogite xenoliths recovered from the KL-2 kimberlite pipe in the Kalyandurg cluster of the Proterozoic Wajrakarur kimberlite field (WKF) of southern India. A detailed textural and mineralogical description of these samples can be found in an accompanying abstract (Misra et al., this volume).

Petrography

In general, the WKF eclogites are bimineralic, consisting of omphacite and garnet, and occasionally containing accessory rutile. Kyanite also occurs as a minor phase in many of eclogites xenoliths and such kyanite-eclogites are termed grospydites (gros = grossular, py = pyroxene, di = disthene) if they contain > 50 mol% grossular component in their garnets (Dawson, 1980; Sobolev et al., 1977). There are very few occurrences worldwide of kimberlites containing kyanite-eclogite xenoliths. Notable examples are the kimberlite pipes of Zagadochnaya and Udachnaya (Siberia) and Roberts Victor (South Africa). In these localities, kyanite eclogites form a minor part of the main population. The WKF eclogites we have studied are overwhelmingly kyanite-bearing eclogites. The primary mineralogy of the eclogites studied consists of omphacite, garnet and kyanite. Rutile is less common but present in some samples. The xenoliths have undergone variable degrees of mantle metasomatism and post-emplacement alteration in the upper crustal environment. The primary clinopyroxene grains seem to have suffered the highest degrees of alteration, but some unaltered core regions are preserved as tiny islands. Garnets are relatively fresh and display alteration features only around rims or along cracks propagating through the crystals. The kyanite laths are also affected by alteration but rutile crystals are relatively pristine.

Mineral trace element systematics

We have measured trace element abundances in primary and secondary minerals from these eclogites using laser-ablation ICP-MS technique following analytical protocol described in Jeffries (2004). Trace-element signatures in most clinopyroxene grains seem to have been influenced by the infiltration of the kimberlite melt, resulting in elevated LREE's ($(La)_n$ up to 100 and $(La/Yb)_n$ up to 500) and other large ion lithophile elements. However, relatively pristine clinopyroxenes (> 4.5 wt% Na_2O) have much lower abundances of REEs and display a typical convex up chondrite-normalized REE pattern ($(La)_n$ ~ 4 to 65 and $(La/Yb)_n$ up to 15; Fig. 1); a feature in common with previous studies of clinopyroxenes from worldwide eclogite samples (e.g., Jacob, 2004; Pearson et al., 2005). In contrast, garnets display a much narrower range in their trace element abundances although there are resolvable differences among garnets from different xenoliths such that they can be grouped into two main categories. On a chondrite-normalized multi-element plot (Fig. 1a), all garnets display variable depletions in Sr, Zr, Hf and Ti but it is not possible to distinguish garnets from individual samples on this basis. However, the chondrite-normalized REE patterns for garnets from samples KL 2.1, 2.3 and 2.6 are different than those from samples KL 2.2, 2.4, 2.5 and 2.7 (KL 2.2 and 2.5 are rutile-bearing samples). Garnets belonging to the former category display stronger positive europium anomalies compared to the latter, which also has slightly more depleted LREE and high-field-strength-element (HFSE) patterns (Fig. 1). All

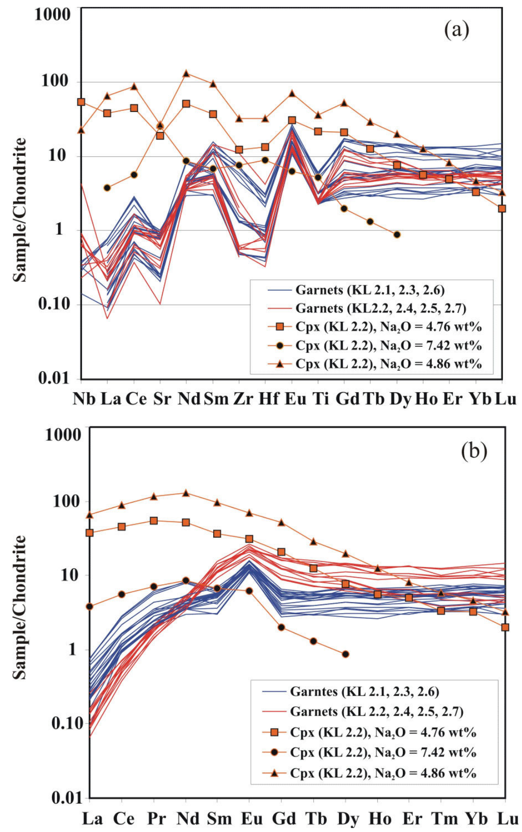

Fig. 1: Chondrite-normalized trace- and rare-earth-element (REE) patterns for garnets and clinopyroxenes in eclogite xenoliths recovered from Kalyandurg kimberlite pipe, southern India. The chondrite-normalization values are from Anders and Grevesse (1989).

garnet trace-element data have been screened for any possible contamination by the kimberlitic fluid by rejecting analyses with > 0.2 ppm Ba. In general, garnets in Indian eclogites studied here have very similar abundances and chondrite-normalized patterns to other worldwide occurrences, typified by LREE depleted and HREE enriched patterns. The HREE's are relatively unfractionated with average $(Dy/Yb)_n$ values of ~ 1 (ranges from 0.8 to 2). The depletions in Sr, Zr, Hf, and Ti in garnets and the presence of a positive Eu anomaly, combined with the presence of kyanite in the Kalyandurg samples, suggests a plagioclase-rich protolith for these eclogites. This is consistent with observations made for other occurrences of kyanite and/or corundum- bearing eclogite xenoliths around the world (Snyder et al., 1997; Jerde et al., 1993, Harte and Kirkley, 1997, Jacob, 2004). This can be taken as a strong indicator for subduction-related origin for Indian eclogites.

Re-Os isotope systematics

A subset of 6 eclogite xenoliths were analysed for their bulk-rock Re-Os isotopic composition following the protocol described in Dale et al. (2008). In general, the Os contents are low (29 – 100 ppt) and more akin to Siberian eclogites (Pearson et al., 1995) rather than the generally more Os-rich South African eclogites. Re contents of the WKF eclogites are surprisingly low (9.6 to 92 ppt) and are at the lower end of any so far reported. This results in low Re/Os ratios. The low Os Siberian eclogites are characterized by high Re/Os and have developed very radiogenic Os isotopes ($^{187}Os/^{188}Os$ of up to 9.8; Pearson et al., 1995). In contrast, the WKF eclogites are considerably less radiogenic ($^{187}Os/^{188}Os$ of 0.16 to 0.66). These unradiogenic Os isotope compositions are at the lower end of the range defined by the southern African eclogites, with those from Bellsbank being the only locality to show such consistently unradiogenic Os isotopes. The low Re contents of the WKF eclogites are considerably lower than all MORB and are only matched by pirates and komatiites among crustal magmatic protoliths. However, the Os contents of these latter lithologies are considerably higher than most of the WKF eclogites and this raises the possibility that their Re contents have been lowered during subduction (although there is little evidence for this in the study of modern gabbro to eclogite series – Dale et al., 2007). Other alternatives are that Re was lowered during an intense period of mantle metasomatism or that secondary alteration has mobilized Re (and possibly Os).

Unfortunately the data do not lend themselves to any straightforward interpretation. Re-Os model ages range from ~1.7 to > 4 Ga and these samples therefore cannot have originated via single-stage formation from a chondritic reservoir. The spread in model ages argues for either disturbance or derivation from a very heterogeneous protolith, or both. A sub-group of the suite (KL 2.3, 2.5 and 2.1) have Os-evolution curves that closely intersect at circa 2.1 Ga and regression of these samples gives an isochron age of 2123 ± 52 Ma with a reasonable MSWD (3.4) and an elevated initial ratio (γOs_i = 18.7 ; Fig. 2).

A number of basaltic dykes of ages ranging in age from 2.4 Ga to 650 Ma (Ikramuddin and Stueber, 1976; Rao et al., 1995; Radhakrishna et al., 1995) occur in the vicinity of the kimberlites from which the eclogite xenoliths were recovered or in this region of southern India. In addition, a large mafic-ultramafic volcanic complex occurs inside the Proterozoic Cuddapah

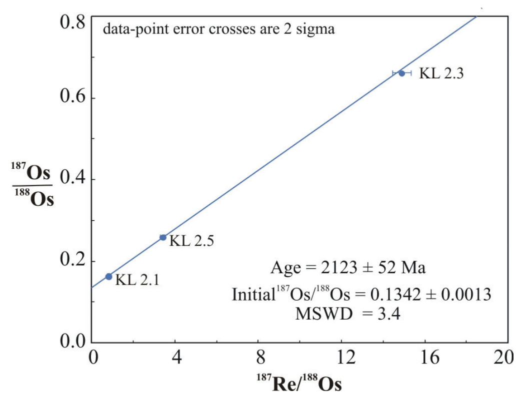

Fig. 2: Bulk-rock Re-Os isochron diagram for three eclogite xenoliths (KL 2.1, 2.3, 2.5) recovered from Kalyandurg kimberlite cluster, southern India.

Basin, situated less than 100 km east of the kimberlite locality. A basaltic unit near the base of the volcanic sequence has been dated at ~1.9 Ga (Anand et al., 2003) and thus it is possible that the Re-Os ages of eclogites are recording some of these large-scale regional tectono-thermal events or some other precursor events.

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