Geochemistry of the West Australian, West Kimberley Province Lamproites.

Rachel F. Chesler

School of Earth sciences, The University of Melbourne, Melbourne, Australia

The West Kimberley Province (WKP) is located along the southwest margin of the Kimberley Block, Western Australia. It is host to over 100 Miocene age lamproites, which intrude Devonian to Triassic sediments. Significant geochemical variation exists throughout the region, from olivine-rich, diamondiferous bodies, to leucite-rich, non-diamondiferous bodies. Geochemical analysis of 26 lamproite intrusions was undertaken with the aim of determining the intrinsic geochemical differences between leucite and olivine lamproites, as well as the processes leading to lamproite genesis in this region.

Results

Olivine and leucite lamproites display distinctly different mineralogy, geochemistry and isotopic signatures. Bulk rock major and trace element compositions, as well as Sr-Nd-Hf isotopic compositions were measured. The lamproites show extreme enrichment in incompatible elements, and show a pronounced enrichment in light REE (average La/Lu_{cn} 205). There is no significant difference in trace element schematics for olivine and leucite lamproites, with both displaying similar trends on the rare earth element plot. Leucite lamproites display slightly more elevated average REE concentrations than olivine lamproites.

Initial $^{87}Sr/^{86}Sr$ ratios measured for leucite lamproites ($^{87}Sr/^{86}Sr$ range 0.714486- 0.724391) are more radiogenic and exhibit a larger range than olivine lamproites ($^{87}Sr/^{86}Sr$ range 0.710557 - 0.713038). Leucite lamproites display less radiogenic initial $^{143}Nd/^{144}Nd$ ratios ($^{143}Nd/^{144}Nd$ range 0.511847 to 0.511928) than olivine lamproites ($^{143}Nd/^{144}Nd$ range 0.511953 to 0.512230). Both lamproite types are characterised by extremely negative εNd, with values ranging from -7.4 to -15.7.

Initial $^{176}Hf/^{177}Hf$ ratios are less radiogenic in leucite lamproites ($^{176}Hf/^{177}Hf$ range 0.282052-0.282119) than olivine lamproites ($^{176}Hf/^{177}Hf$ range 0.282186-0.282236). The lamproites from the WKP plot well below the oceanic array. Leucite lamproites have more negative $\Delta\varepsilon_{Hf}$ (-22.98 to -25.03) than olivine lamproites (-18.53 to -20.30), but there is no significant difference, with the entire province displaying very negative $\Delta\varepsilon_{Hf}$ characteristics.

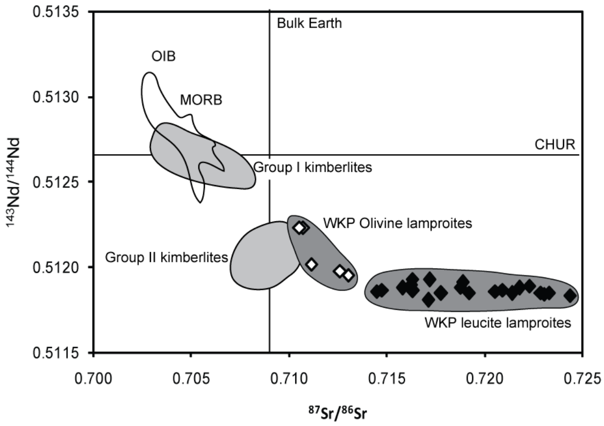

Fig. 1 $^{87}Sr/^{86}Sr$ vs. $^{143}Nd/^{144}Nd$ for olivine and leucite WKP lamproites (Data from this study). Regions for group I and II kimberlites (Data from Nowell et al., 2004) MORB and OIB (Data from Saunders et al., 1998) shown for comparison.

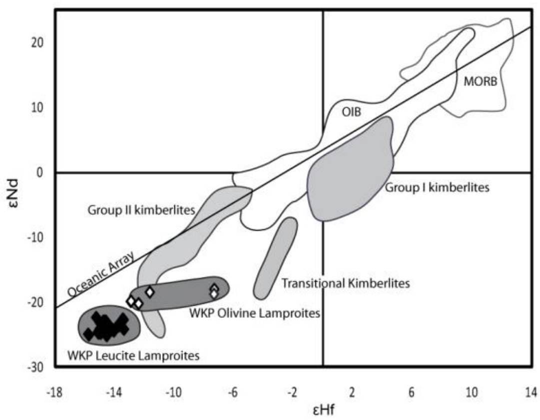

Fig. 2 εNd vs. εHf for olivine and leucite WKP lamproites (Data from this study). Regions for group I and II kimberlites, MORB and OIB are shown for comparison (Data from Nowell et al., 2004). The oceanic array is taken from Vervoort et al. (1999).

Lamproite primary magma

The occurrence of both leucite and olivine lamproites within the WKP gives us a rare opportunity to constrain the processes which result in the compositional variation seen. The two groups of lamproites are clearly differentiated in major and trace element as well as isotopic diagrams, showing that olivine and leucite lamproites cannot be simply related by fractional crystallisation.

There is currently contention over the identification of the primary lamproite magma composition. Based on extensive analysis of lamproite mineral chemistry, Mitchell and Bergman (1991) have proposed that the composition of leucite lamproites is representative of primary lamproite magma. They have shown that leucite lamproites display more primitive mineral chemistry and higher concentrations of trace elements than olivine lamproites, and are therefore thought to resemble the primary melt. It is proposed that olivine lamproites are hybrid rocks which have been extensively contaminated by mantle material. Foley (1993) has proposed series of primary magmas exist, ranging from olivine to leucite lamproite compositions. It is argued that the silica contents of leucite lamproites (~52%) are incompatible with models placing their source regions at great depth. Previous studies (e.g. O'Hara, 1965) have shown that SiO_2 content decreases and MgO content increases with increasing pressure. The current consensus places the source region for lamproite magmas at great depth (e.g. Nowell, 2004), implying that a primary leucite magma is incompatible with these models.

The most commonly used criteria for distinguishing primary magmas are that they should have Mg number of 70 or higher, have high Ni and Cr contents, and SiO_2 contents not greatly exceeding 50 wt% (Green, 1970). From these classification criteria the characteristics of olivine lamproites in this region are more representative of primary mantle compositions than leucite lamproites. A further important criterion is the presence of mantle derived ultra-mafic xenoliths, which would be expected to be eliminated together with phenocryst phases if any substantial fractionation had occurred (Foley et al., 1987). Mantle xenoliths are rare in the lamproites in the West Kimberley Province, with the majority of xenoliths found in olivine lamproites. Olivine lamproites are also host to diamonds, whereas leucite lamproites are not. This can seen as evidence that olivine lamproites represent the primary magma source, with leucite lamproites having undergone contamination or partial melting during their history, destroying any mantle xenoliths, and resulting in re-sorption of diamond.

In contrast, the leucite lamproites from this region appear to have been significantly affected by crustal assimilation, the effects of which can be partially quantified by the use of the contamination index (C.I.) of Clement (1982). Leucite lamproites exhibit a positive correlation between C.I. and $^{87}Sr/^{86}Sr$ (Fig. 3) and show the highest C.I. values. This suggests that despite the high Sr contents, these samples have been modified by interaction with the continental crust. Olivine lamproites have the lowest C.I. values and show a negative correlation between C.I. and $^{87}Sr/^{86}Sr$. They also display $^{87}Sr/^{86}Sr$ schematics which are more representative of mantle sources (see fields for MORB and OIB in fig. 1).

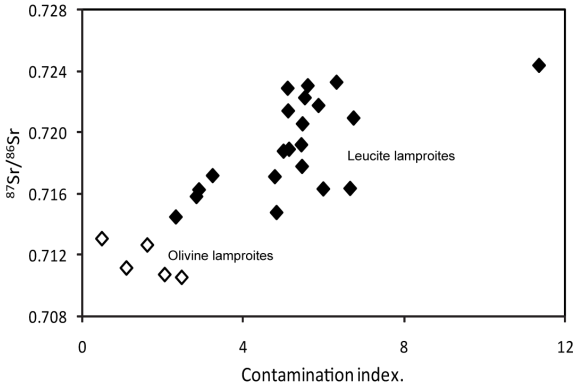

Fig. 3 $^{87}Sr/^{86}Sr$ vs. contamination index (C.I.) of Clement (1982). The leucite lamproite data shows a positive correlation with C.I., which is suggestive of crustal assimilation

By assessing the variation of Hf-Sr-Nd isotopic schematics with MgO content we can further assess the role of crustal assimilation in this province. For all three isotope systems there is a close correlation between isotopic composition and MgO content. Increasing $^{87}Sr/^{86}Sr$ εHf and εNd is correlated with decreasing MgO content. This further supports the arguments above, showing that olivine lamproites within this province appear to display more primary, less contaminated geochemical features, whereas contamination appears to have contributed to the formation of leucite lamproites.

It is plausible that compositional variation in this province is due to varying amounts of crustal assimilation. In order to test this hypothesis simple two component modelling was carried out. By taking into consideration both the radiogenic signature and elemental concentration, we can calculate the isotopic signature required by the crust, for a given amount of assimilation, to create the signatures seen. These calculations show that it is plausible that a magma resembling the composition of average olivine lamproite underwent varying degrees of crustal assimilation, resulting in the observed geochemical continuum from olivine to leucite compositions.

A primary leucite lamproite magma source for this region is difficult to reconcile with the isotopic variation, and geochemical signatures seen. It is proposed, that for this province at least, olivine lamproites represent the composition of the primary magma.

References

Clement, C.R., 1982. A comparative geological study of some major kimberlite pipes in the northern Cape and Orange Free State. Unpublished Ph.D. thesis, University of Cape Town.

Foley, S F., Venturelli, G., Green, D.H., Toscani, L., 1987: The ultrapotassic rocks; characteristics, classification, and constraints for petrogenetic models. Earth-Science Reviews, vol.24, no.2,p.81-134.

Foley, S. F., 1993. An experimental study of olivine lamproite; first results from the diamond stability field. Geochimica et Cosmochimica Acta. 57, 483-489.

Green, D.H., 1970: The origin of basaltic and nephelinitic magmas. Transactions of the Leicester Literary and Philosophical Society. Vol. 64, pp28 – 54.

Mitchell, R.M and Bergman, S.C., 1991. Petrology of Lamproites.

Nowell, G.M., Pearson, D.G., Bell, D.R., Carlson, R.W., Smith, C.B., Kempton, P.D., Noble, S. R., 2004. Hf Isotope Systematics of Kimberlites and their Megacrysts: New Constraints on their Source Regions. Journal of Petrology, 45**,** 1583-1612.

Vervoort, J., Patchett, P., Blichert-Toft, J., Albarede, F., 1999. Relationships between Lu–Hf and Sm–Nd isotopic systems in the global sedimentary system. Earth and Planetary Science Letters. 168, 79–99