## KIMBERLITE/LAMPROITE PETROGENESIS: GEOCHEMICAL AND ISOTOPE EVIDENCE FROM NORTH AMERICA, SOUTH AFRICA AND WESTERN AUSTRALIA

## K.J. Fraser and C.J. Hawkesworth

## Department of Earth Sciences, The Open University, Milton Keynes, MK7 6AA, England

Major, trace element and isotope results are reported for lamproites from the Leucite Hills, Wyoming, W. Australia and Smoky Butte, Montana and Group II kimberlites from Finsch Mine, South Africa. The W. Australia lamproites form more than 100 separate intrusions and grade petrographically from olivine lamproites through leucite bearing olivine-diopside lamproites to leucite lamproite lamproites with phlogopite, diopside and K-richterite. The lamproites from Smoky Butte occur in a small (3 km long) area of thin dykes and plugs and they contain armacolite, sanidine, alkali amphiboles and Ti phlogopite. Finsch Mine is a composite intrusion and the rocks are hypabyssal kimberlites containing phlogopite, olivine, diopside, serpentine and calcite.

All samples have low  $\varepsilon_{\rm Nd}$ , implying at least a contribution from old, low Sm/Nd material. However, 2 groups may be recognised on the basis of  $\varepsilon_{\rm Sr}$  values. Smoky Butte lamproites have low  $\varepsilon_{\rm Sr}$  (10 to 19) with very low  $\varepsilon_{\rm Nd}$  = -22 to -26. Despite containing 8% K<sub>2</sub>O and 290-380 ppm Nd, they have low Sm/Nd and Rb/Sr consistent with their  $\varepsilon_{\rm Nd}$  and  $\varepsilon_{\rm Sr}$  values. In contrast the W. Australia lamproites and Finsch kimberlites have high  $\varepsilon_{\rm Sr}$  and  $\varepsilon_{\rm Nd}$ ;  $\varepsilon_{\rm Sr}$  = 118 to 228,  $\varepsilon_{\rm Nd}$  = -10 to -19 and  $\varepsilon_{\rm Sr}$  = 56 to 110,  $\varepsilon_{\rm Nd}$  = -6 to -7 respectively. The isotope variations cannot readily be explained by crustal contamination processes, rather they indicate that these lamproites and kimberlites were derived from old segments of the subcontinental mantle.

Trace element considerations of the Finsch kimberlite suite exhibit positive correlations between x/Nd vs Sm/Nd, where x = Th, Ta, La, Ce, Sr, Hf, Zr, Sm, Y and Yb. If such trends reflect varying degrees of partial melting they require Nd to be more incompatible than, for example, Th, Ta and La. This is considered unlikely assuming that at least the relative  $k_{\rm D}$  values for basaltic systems  $^1$  are appropriate at the depths of kimberlite genesis, and so the alternative interpretation of a mixing model is preferred. The ubiquitous presence of macrocrystic olivine and the high garnet content in the Finsch concentrate all point towards significant entrainment of upper mantle peridotite material within the kimberlites. Such peridotite would hence represent one endmember of the mixing lines, and the depleted and fertile xenoliths of Nixon et al. have trace element ratios consistent with this model. In terms of Ni and Cr contents the Finsch kimberlites Ni = 1063-1544 ppm, are intermediate between peridotites, Ni = 2000-3000 ppm, and primary melts, 400-800 ppm. A strong positive correlation between Ni contents and Sm/Nd ratios suggests that for an average peridotite Ni content of 2000 ppm the Sm/Nd ratio is  $\sim$  0.2. The Finsch kimberlites Sm/Nd ratios vary between .112 and .166. The low Sm/Nd, 'primary melt', endmember is restricted to Sm/Nd ratios < .112 and > .06, the latter reflecting the minimum Sm/Nd ratio for all x/Nd's to be positive. Dero For Sm/Nd  $\sim$  .1 Ni = 900 ppm, which is high for a primitive melt (i.e. D = C1/Co = 2.2), for Dni values appropriate to basaltic systems, e.g. 4-7. However, there is evidence to suggest that lower Dni values may be applicable to some mantle processes  $, \circ$ .

Assuming Sm/Nd = .1 for the 'melt' endmember and Sm/Nd = .2 for the peridotite endmember then x/Nd values for each component can be estimated. An average Nd content for peridotite is  $\sim 2$  ppm and for the simplest model the 'melt' Nd content must be > 165 ppm and < 4800 ppm. For Nd = 165 ppm then the whole Finsch range can be attributed to mixing of > 15% melt and < 75% peridotite. Even with such a high 'peridotite' content the trace element profile of the kimberlite is dominated by that of the melt endmember owing to the disparity in trace element content between peridotite and melt. Petrographic estimation of the peridotite content is difficult as the olivine macrosrysts are rounded and corroded (i.e. partial assimilation) while the orthopyroxene fraction is not present (total assimilation). However, point counting has shown that olivine macrocrysts may constitute up to 45 vol% of the rock.

For D = Cl/Co and using known  $K_D$  values<sup>1</sup> for olivine, orthopyroxene, clinopyroxene and garnet, and using Cl = concentration of mineral in melt as inferred above, the source characteristics of the 'melt endmember' (Co) can be estimated. Small degrees of

partial melting of garnet lherzolite with trace element concentrations comparable with those of mantle peridotites can account for the trace element contents of the 'melt' endmember. However, the source to the melt endmember must differ from the entrained peridotites: the Sr and Nd isotopes imply an old enriched source and the high  $K_2O$ contents of the kimberlites (0.81, 2.64-4.23 wt %) suggest the presence of a K bearing phase within the kimberlite source. Also in order to maintain a generally increasing degree of incompatibility (i.e. decreasing D) from Yb, Y, Sm, Zr, Hf, Nd, Sr, Ce, La, Ta up to Th requires that at least Th/Nd, Ta/Nd, La/Nd, Ce/Nd and Sr/Nd ratios within the source of the melt endmember are less than those exhibited by either the melt itself and the peridotite endmember.

Mixing is also evident from the Pb isotopes where further data have not substantiated the tentative 1.4 Ga age inferred previously . On a 207pb/204pb vs 206pv/204pb diagram the peridotite endmember could plot close to the Stacey and Kramers<sup>8</sup> growth curve while the 'melt' endmember would exhibit low 206pb/204pb and 207pb/204pb ratios. The most unradiogenic Finsch sample (207Pb/204Pb = 15.43, 206pb/204Pb = 17.51) suggests a minimum age of 2.5 Ga for the 'melt' endmember.

Further trace element considerations reveal something of the nature of the ancient source enrichment events. In many of the Finsch kimberlites high Rb/Sr (and 87Sr/86Sr) ratios occur with low Rb/Ba (< .1) whereas in the remaining samples high Rb/Sr ratios are accompanied by high Rb/Ba - as is also observed in metasomatised PP and PKP mantle xenoliths (Erlank et al., this vol.). High Rb/Sr with high Rb/Ba are attributed to the migration of  $H_2O$  rich fluids, while the trend to high Rb/Sr with low Rb/Ba is often characterised by relatively high La, Ta and Ti, and appears to be due to the introduction of small volume partial melts with the stabilisation of melt related phlogopite.

Similar models may be constructed for the less differentiated members of the W. Australia lamproite suite, however subsequent differentiation and sample collection over a wide geographical area combine to obscure original mixing relationships. High Rb/Sr with low Rb/Ba ratios can again be attributed to melt related enrichment processes while low 206Pb/204Pb = 17.3 - 17.6 together with high 207Pb/204Pb = 15.7 -15.8 requires a complex 3 stage evolution. The lamproites from Smoky Butte, Montana, on the other hand exhibit extremely unradiogenic Pb isotope ratios (206Pb/204Pb = 16.0- 16.6) compatible with a 2 stage evolution history and very low Rb/Ba (.01-.004) with high K/Rb (500-900) ratios suggest that amphibole may have been a feature of the source regions.

In the rocks considered here diamonds tend to be restricted to those with more primitive characteristics: Cr > 500 ppm, MgO > 10%, Zr < 850 ppm and Ni > 485 ppm, and it is interesting to speculate whether they originate as xenocrysts from upper mantle peridotite or as xenocrysts from within the enriched 'kimberlitic/lamproitic melt' source which in the case of Finsch Mine would suggest from ages on diamond inclusions a source age of 3.2 Ga.

1

Frey, F.A., Green, D.H. and Roy, S.D. (1978). <u>J. Pet</u>. Vol. 19, Pt. 3, 463-513. Kramers, J.D., Smith, C.B., Lock, N.P., Harmon, R.S. and Boyd, F.R. (1981). 2 Nature 291, 53-56.

- 3 Gurney, J.J. and Switzer, G.S. (1973). Contrib. Mineral. petrol. 39, 103-116.
- 4
- Nixon, P.H. <u>et al</u>. (1981). <u>Ann. Rev. Earth Planet. Sci</u>. 9, 285-309. Bickle, M.J., Ford, C.E. and Nisbet, E.G. (1977). <u>Earth Planet. Sci. Lett</u> 37, 97-106 5
- Hanson, G.N. and Langmuir, C.H. (1978). <u>Geochim. Cosmochim. Acta</u> 42, 725-741. Fraser, K.J., Hawkesworth, C.J., Erlank, A.J., Mitchell, R.H. and Scott-Smith, B.H. 6 7
- (1985). Earth Planet. Sci. Lett. 76, 57-70.
- Stacey, J.S. and Kramers, J.D. (1975). Earth Planet. Sci. Lett. 26, 207-221. Richardson, S.H., Gurney, J.J., Erlank, A.J. and Harris, J.W. (1984). Nature 310, 8 9 198-202.

