Geochemistry

The leucite lamproites are characterised by extremely high K_2O (up to 12% with $K_2O \simeq Al_2O_3$), TiO_2 (3-8%) and BaO contents, and very low Na_2O contents (Wade and Prider, 1940; Prider, 1960). They show a wide range in MgO and SiO_2 contents (3-15% MgO, 45-60% SiO_2), and most follow an orenditic differentiation path of increasing silica saturation, coupled with increasing TiO_2 and K_2O contents.

In contrast, the kimberlitoids have much higher MgO contents (15-28% MgO), have MgO/K_2O ratios significantly greater than unity (typically 4-6, cf $\leq$1 for the leucite lamproites), and have lower SiO_2, TiO_2, Al_2O_3 and K_2O contents than the lamproites. Ni and Cr contents in the kimberlitoids are higher than those in the lamproites, typically 600-1000 ppm Ni, 1000-1500 ppm Cr.

Both the lamproites and the kimberlitoids are extremely enriched in 'incompatible' elements, typically containing >750 ppm Zr, >75 ppm Nb, $\geq$5000 ppm Ba, $\geq$200 ppm Rb, $\geq$20 ppm Th, $\geq$200 ppm La and $\leq$300 ppm Ce. Both the kimberlitoids and the lamproites have extremely fractionated REE patterns, typical of kimberlitic rocks in general. LREE abundances in the lamproites range from 600-2000 x chondrites whereas the kimberlitoids range from 500-1000 x chondrites. Contents of Nb are higher, and Zr/Nb ratios lower (<10, cf >10), in the kimberlitoids than the lamproites.

It is concluded that the leucite lamproites are alkalic (potassic) basic rocks whereas the kimberlitoids are alkalic ultrabasic rocks resembling kimberlite.

Relationship between leucite lamproites, kimberlitoids and kimberlites

Diamond has been found in both the kimberlitoids and the leucite lamproites, implying a similar, deep-seated origin for the suite as a whole. The similarities in mineralogy and geochemistry of the two rock types and their close spatial association also favours a genetic relationship. Observed differences are thought to be due to fractionation (cf. Prider, 1960).

In general, the West Kimberley kimberlitoids have a similar chemistry to 'typical' kimberlites but their SiO_2, K_2O and TiO_2 contents are higher and their CaO contents lower. However, there are several important mineralogical and petrographic features which combined indicate that the kimberlitoids are not 'typical' kimberlite. These include the rarity of garnet and picro-ilmenite, the presence of groundmass amphibole, the apparent absence of primary carbonate, and the close association with leucite-bearing rocks. These features are consistent with equilibration at lower pressures and, possibly, higher temperatures than 'typical' kimberlite.

Since economic diamond-bearing kimberlites have so far been restricted to cratons which have not been deformed since the Precambrian the discovery of diamond in kimberlitic rocks of unusual composition and in leucite-bearing basic rocks in a shelf environment, outside the craton, has important implications for diamond exploration. If, as we suspect, the rich Argyle pipe in the East Kimberley district proves to be of similar composition to the kimberlitoids of the West Kimberley then clearly a new class of potentially economic diamond-bearing rocks exists.

References

Atkinson W.J., F. Hughes, and C.B. Smith, 1982: This volume.

Garlick H.J., 1979: Indust. Miner. 137, 17-29.

Prider R.T., 1960: J. Geol. Soc. Australia 6, 71-118.

Wade A., and R.T. Prider, 1940: Q.J. Geol. Soc. London 96, 39-98.

Wellman P., 1973: J. Geol. Soc. Australia 19, 471-474.

H6 KIMBERLITE – LAMPROITE CONSANGUINITY

P.H. NIXON, M.F. THIRLWALL, F. BUCKLEY,
Department of Earth Sciences, Leeds University, Leeds, LS2 9JT, U.K.

The discovery of kimberlites associated with lamproites, both containing diamonds, in the West Kimberley, Western Australia (Atkinson, 1982 and pub. comm) has prompted investigation of the implied genetic relationship. However, lamproites embrace a range of rock types which we demonstrate, using the Spanish occurrences, can have different origins.

The term lamproite was used by Niggli (1923 and subsequent publications) within his classification scheme based on Niggli norms, for volcanic rocks rich in K and Mg. Subsequently, Tröger (1935) stated that lamproite was the effusive equivalent of lamprophyres rich in K and Mg. However, no rocks were described under this heading in Johannsen's (1938) comprehensive petrographic classification. Following Tröger (1935), Wade and Prider (1940) adopted the term for the Australian occurrences (which are mostly minor intrusions) and made the following subdivisions - fitzroyite, cedricite, mamilite, wolgidite and wyomingite. All but latter were new (see also Prider, 1960) and were described as differentiated members containing combinations of phlogopite, leucite, clinopyroxene, magnophorite (K-richterite) with commonly altered olivine.

The Spanish occurrences (Borley, 1967) - termed lamproites by Fuster et al. (1967) - consist of fortunite, verite and jumillite and contain sanidine (or K bearing glass) unlike the Australian rocks, together with clinopyroxene, phlogopite and apatite with or without orthopyroxene, olivine, amphibole, leucite, plagioclase, calcite and quartz. Xenoliths include sporadic mantle-type spinel lherzolites.

Even allowing for the range of petrographic types within each lamproite group it can be seen from the Table below that the Spanish lamproites have a relatively low K_2O/Na_2O ratio and TiO_2 content but with higher Al_2O_3. Of the minor elements, Nb (33ppm) and Zr (571ppm) are significantly lower than in the Australian rocks (150 and 942 ppm respectively).

	Spain	W. Australia		S. Africa
wt%	Lamp.(15)	Lamp.(9)	Kimb.(3)	Kimb.(80)*
SiO_2	54	52	37	36
TiO_2	1.4	5	3.5	1
Al_2O_3	10	7	4	3
Fe_2O_3	6	7	8	8
MgO	10	8	16	17
CaO	5	4	6	11
Na_2O	1.5	0.6	0.4	0.4
K_2O	6	8	3	1.5

*Gurney and Ebrahim (1973)

Numbers of samples analysed given in parentheses.

A major problem in Western Australia is the petrographic differentiation of rocks of kimberlite affinity which may be altered and contain serpentinised olivine (reflected by increased MgO content) and which may also contain deep seated xenoliths and

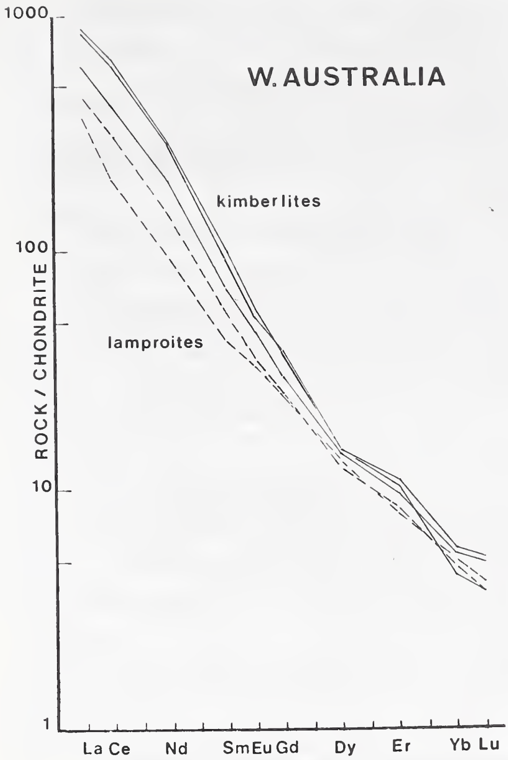

FIGURE 1. *REE patterns showing relative light earth enrichment of Western Australian kimberlites compared with the associated lamproites. (Analyses by I.C.P. analyst : F. Buckley).*

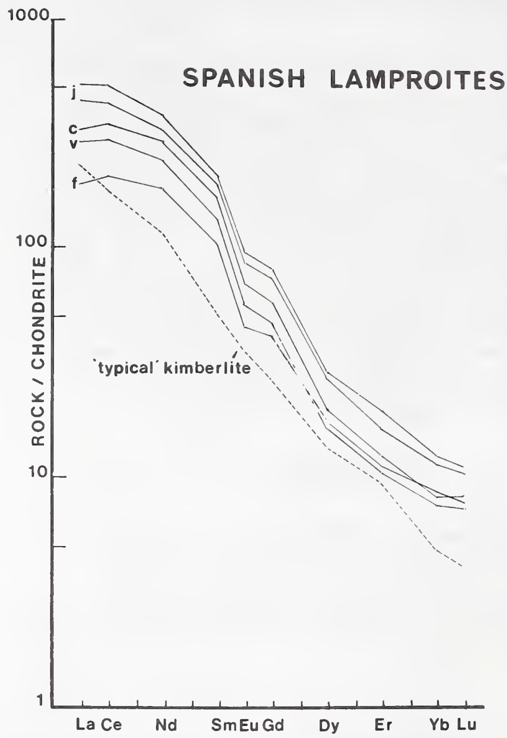

FIGURE 2. *Selection of Spanish lamproite data illustrating a close relationship between fortunite, f; verite, v; cancarix type, c; and jumillite, j. Compared with kimberlites light rare earth enrichment is not sustained for La and Ce, and there is a negative Eu anomaly, reflecting significant genetic differences compared with the Australian kimberlites and lamproites.*

diamonds. Three such rocks, see Table above, are undersaturated and lower in alkalis relative to the lamproites, and are chemically closer to accepted kimberlite composition.

Rare earth data obtained by I.C.P. (Walsh et al, 1981) are used to study the relationship (Fig.1). Australian lamproites show La/Yb ratios which are clearly "kimberlitic" but which, nevertheless, are lower than in associated kimberlites which are heavily enriched in LREE. Both suites are high in Ba (up to $>$ 2 wt%) and Sr (800 - 1800 ppm). The kimberlites have Rb/Sr ranging between 0.27 - 0.52 (lamproites 0.17 - 0.32) see also Powell and Bell (1970), Cr 651 - 886 ppm (297 - 465 ppm and a single result of 1133 ppm), Ni 557 - 1240 (262 - 722), and Nb 203 - 260 (118 - 185). These results show a wide range but have a distinct common imprint. Further evidence of consanguinity is provided by the Nd isotope data given below:

	PHN	$^{143}Nd/^{144}Nd$	Sm/Nd	Nd	ε_{Nd}*
Lamproites	3808	.512143 $\pm$ 7	.145	61	-9.4
	3812	.511974 $\pm$ 12	.118	95	-12.7
	3817	.512068 $\pm$ 19	.123	93	-10.9
Kimberlite	3826	.512004 $\pm$ 12	.113	130	-12.1
	3829	.511979 $\pm$ 13	.105	186	-12.6
	3833	.512249 $\pm$ 15	.110	188	-7.3

*There is some controversy about ages of the W. Australian rocks. A new age for the Howes Hill (west) fitzroyite determined by D.C. Rex (K/Ar = 19 m.y.) agrees with the 17-21 m.y. ages reported by Wellman (1973) and 20 m.y. is used in our calculations. For comparison a hypothetical age of 200 m.y. would make PHN 3808 ε_{Nd} = -7.0.

These data suggest that both suites have been derived from a (common) strongly enriched sub-continental mantle. If they plot on the mantle array (De Paolo and Wasserburg, 1979; O'Nions et al, 1979) then $^{87}Sr/^{86}Sr$ ratios of 0.7067 may be anticipated (even this figure is substantially lower than the range, in W. Australian lamproites, recorded by Powell and Bell, 1970).

Further isotope studies are required to evaluate the effect of crustal contamination of

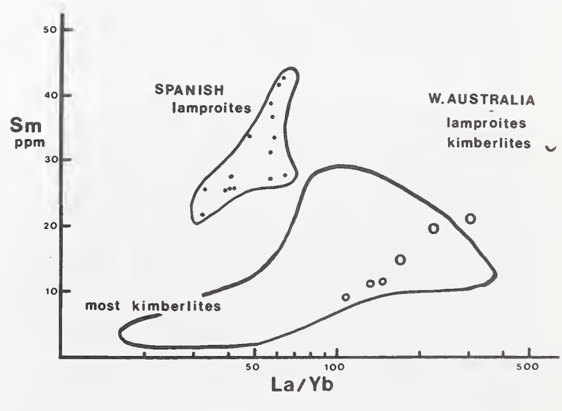

FIGURE 3. *Summary of the La/Yb ratios versus Sm for Australian and Spanish lamproites, compared with kimberlite data mainly obtained from Rogers (1979).*

the magma(s) or post emplacement alteration of the rocks by circulating groundwater (Barrett and Berg, 1975).

The Spanish lamproites show marked REE differences from the W. Australian suites and from "typical" kimberlites (Figs. 2 and 3). The REE pattern could be interpreted to indicate magma derivation from a more depleted source than that of kimberlite but with a similar (metasomatic) overprint of LREE and incompatible elements. The comparatively high HREE content suggests derivation from shallower mantle depths than that in which garnet is stable and correlates with observed lherzolite xenoliths containing spinel rather than garnet. A -ve Eu anomaly persists through the jumillite, cancarix-type, verite and fortunite suites. This feature may be due to removal of plagioclase from the magma or be present in the source region, particularly that of the metasomatising fluids (cf. Hawkesworth and Vollmer, 1979). It is another reason for regarding the Spanish rocks as genetically distinct from the Australian lamproite - kimberlite suite.

ACKNOWLEDGEMENTS : We thank David Gellatly and Amax Exploration for assistance in the field in Western Australia and for specimens of the Big Spring kimberlitic rock; David Rex for the age determination; Alan Grey for some lamproite analyses; and John Lewis and Richard Jones for helpful comments.

Atkinson, W. J. 1982: Trans. Inst. Mining Metal. (in press).
Barrett, D. R. and Berg, G. W. 1975: Phys. Chem. Earth, 9, 619 - 636.
Borley, G. D. 1967: Miner. Mag. 36, 364 - 379
De Paolo, D. P. and Wasserburg, C. J. 1979: Geochem. Cosmochim. Acta, 43, 615 - 628
Derrick, G. M., and Gellatly, D. C. 1972: Extract No. 10. Bull. 135, Bureau Mineral. Res. Canberra.
Fuster, J. M., Gastesi, P., and Fermoso, M.L. 1967: Estudios Geologicos, 23, 35 - 69.
Gurney, J. J., and Ebrahim, S. 1973: (In P.H. Nixon, ed.) Lesotho Kimberlites. Lesotho Nat. Devel. Corp. Maseru, Lesotho.
Hawkesworth, C. J., and Vollmer, R. 1979: Contrib. Mineral. Petrol. 69, 151 - 165.
Johannsen, A. 1938: A descriptive petrography of igneous rocks. The University of Chicago Press.
Niggli, P. 1923: Gesteins-und mineralprovinzen, Bd. 1., Berlin.
O'Nions, R. K., Carter, S. R., Evenson, N. M., and Hamilton, P. J. 1979: Ann. Rev. Earth Planet. Sci. 7, 11 - 38.
Powell, J. L., and Bell, K. 1970: Contr. Mineral Petrol. 27, 1 - 10.
Prider, R. T. 1960: J. Geol. Soc. Aust. 6, 71-118.
Rogers, N. W. 1979: Trace element analysis of kimberlites and associated rocks and zenoliths. Ph.D. thesis, Univ. London.
Troger, W. E. 1935: Spezielle Petrographie de Eruptivgesteine, Berlin. 360 pp.
Wade, A., and Prider, R. T. 1940: Quart. J. geol. Soc. Lond. 96, 39 - 98.
Walsh, J. N., Buckley, F., and Barker, J. 1981: Chem. Geol. 33, 141 - 153.
Wellman, P. 1971: J. Geol. Soc. Aust. 19, 471 - 474.

H7 MEGACRYSTS FROM THE HAMILTON BRANCH KIMBERLITE PIPE, KENTUCKY: DISCRETE NODULES AND CUMULATE ROCKS

Daniel J. SCHULZE,
Geosciences Department, The University of Texas at Dallas, Box 688, Richardson, Texas, U.S.A. 75080

The southeasternmost kimberlite pipe in Elliot County, Kentucky, the Hamilton Branch pipe, contains a wide variety of mantle-derived material. Garnet lherzolites and Cr-poor discrete nodules (terminology of Eggler et al, 1979) are most abundant. Also present is a group of cumulate rocks with "discrete nodule" characteristics and fine-grained intercumulus material. This group has been termed the Na-rich suite, based on the high Na_2O content of the diopside.

Monomineralic garnets, diopsides, and ilmenites dominate the Cr-poor suite. Enstatite, olivine, and phlogopite are rare due to near surface weathering. Large olivines are absent, though mosaic dunites are considered members of the Cr-poor suite, based on rare association with Cr-poor garnet and diopside. There is no overlap in olivine composition of dunites (Fo 88-89) and garnet lherzolites (Fo 89.5-93).

The simple concept of magnesian, ilmenite-free discrete silicates distinct from an Fe-rich "ilmenite association" (of lower T, based on Ca/(Ca+Mg+Fe) of cpx) does not apply to this suite. Ilmenite is present throughout almost the entire compositional range of each silicate (Fig. 1) and its composition is related to its texture. Five textural groups of ilmenite-bearing discrete nodules have been recognized: (1) monomineralic ilmenite nodules, generally with porphyroclastic to mosaic texture, (2) ilmenite-dominated nodules similar to (1) but containing small silicate inclusions, (3) silicate dominated nodules, with tiny included ilmenite, (4) Na-rich suite nodules (see below), and (5) graphic cpx/ilm intergrowths. Except for (4) these seem to form a chemically coherent suite.

The Kentucky ilmenites are magnesian (8-15.2% MgO) and rich in ferric iron (6-16 mole % Fe^{+3}) and approximately form a parabolic curve (Haggerty, 1975) on a Cr_2O_3/MgO plot (Fig. 2). However, the low Cr_2O_2 "trough" is displaced to a higher value (12% MgO) than in many other suites. This parabola is comprised of segments corresponding to the five textural groups. Silicate-dominated nodules (3) fall on the Mg, Cr-rich limb, ilmenite-dominated nodules (2) fall in the trough, and graphic cpx/ilm intergrowths (5) bridge the two. The MgO-poor limb is exclusively monomineralic ilmenites (1), which are also found throughout the curve. Approximately 40% of the samples in this group are more iron-rich (Mg/(Mg+Fe) < 0.38) than any ilmenites associated with silicates. Ilmenites from nodules not related to the Cr-poor suite (the Na-rich suite and an ilmenite garnet lherzolite (2.7% Cr_2O_3, 15.5% MgO) also plot on this parabola.

Silicates of Group 3 are as magnesian (and subcalcic in the case of cpx) as ilmenite-free silicates (Fig. 1). Those from ilmenite dominated nodules (2)

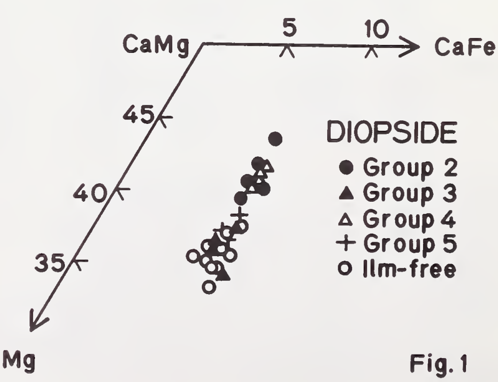

Fig. 1