S.F.Foley

Geology Department, University of Tasmania, Hobart, Australia, 7001.

Lamproites include a range of compositions which have high Mg-number, Ni and Cr, and carry mantle-derived ultramafic nodules, and thus appear to represent little-modified mantle-derived liquids. These range in SiO₂ content from about 40 wt% to at least 51 wt%, and experimental work has indicated that leucite lamproites as silica-rich as 55 wt% could be in equilibrium with mantle minerals at high pressures [Barton and Hamilton 1982]. Petrogenetic models must explain this range of apparently primary magmas, which may be greater than 10 wt% SiO₂ within a single volcanic field, such as the West Kimberley region of Western Australia.

Previous experimental studies on lamproites, kimberlites and other mafic alkaline rocks have emphasised the importance of volatile constituents. These have shown that a range of SiO₂ contents may be attributed to variation in the H₂O/CO₂ ratio, with more siliceous melts resulting from a higher H₂O/CO₂ ratio. However, most lamproites, both silica-rich and silica-poor, have high H₂O but low CO₂ contents, so that the H₂O/CO₂ ratio does not appear to be the controlling factor of the composition of most lamproite suites.

With the aid of experimental results, the discussion of volatile effects is extended to include fluorine and methane. Fluorine contents are high in lamproites [0.3-0.8 wt%], and the presence of methane is compatible with the survival of diamonds in a carbon-bearing, but CO₂-poor mantle.

In simple system experimental studies, fluorine has been shown to increase the stability of mica so that melt compositions will be rich in K_2O and MgO due to the control of melting by residual phlogopite to greater temperatures than in water-rich, fluorine-free conditions [Foley et al. 1986a].

For a water-bearing mantle, the maximum fO_2 stability of diamonds can be modelled by the 'CW buffer' [carbon (as graphite or diamond) + H₂O], which lies midway between IW and MW for temperatures and pressures likely to exist in the mantle. Fluid compositions at CW are dominated by water [~90%], and CH₄ increases with decreasing fO_2 from CW towards IW, where CH₄>H₂O [Taylor, this volume].

Foley et al. [1986b] developed the hypothesis that the range of lamproite primary magma compositions can be explained simply by pressure variation in melting of a reduced mica-harzburgite mantle with fO_2 between CW and IW due to the effects of the major volatile components H_2O , CH_4 and HF. The effect of all these components on melt structure is to expand the liquidus phase volume of the least polymerised phase, which promotes the production of silica-rich melts such as leucite lamproites. The range in silica content of primary magmas down to those of typical olivine lamproites [40-42 wt%] may correspond to increasing pressure, which is known to cause generation of melts with lower silica contents. Both fluorine and water cause a decrease in the viscosity of the melt, and thus will increase the flow rate of melts in the mantle, facilitating the escape of low-degree melts.

The oxygen fugacity of lamproitic magmas at the time of phenocryst crystallisation can be estimated from the compositions of chrome-spinels occurring as inclusions in olivine phenocrysts, thereby avoiding any weathering effect on measured whole-rock oxidation state. Estimates of fO_2 by this method range from MW to above NNO for different lamproites [Foley 1985]. The proposition of a reduced source thus requires oxidation during magma ascent, which can be achieved by dissociation of ~0.1 wt % H₂O (driven by diffusive loss of H₂) for oxidation between CW and NNO during ascent. This amount of dissociation will be lower still if carbon species are involved in the oxidation.

EXPERIMENTAL STUDIES OF TWO LAMPROITE COMPOSITIONS

In order to test the model for lamproite genesis outlined above, high pressure liquidus experiments with reduced volatile mixtures were undertaken on two lamproite compositions spanning the range of silica contents characteristic of primary lamproites [table 1]. The olivine lamproite composition is a likely primary magma composition for the West Kimberley region (estimated by A.L.Jaques). The leucite lamproite is the Gaussberg olivine leucitite, which does not differ greatly from leucite lamproites of the West Kimberley region.

Experimental assemblies consisted of an outer Pt or AgPd capsule enclosing two graphite capsules which contained the sample and an iron-wustite mixture respectively. Volatiles were added as a mixture of $Al_4C_3 + Al(OH)_3$ (producing CH_4+H_2O with residual Al_2O_3) between the graphite capsules, and as distilled water in the sample capsule. The iron-wustite mixture did <u>not</u> buffer the vapour composition at IW (discussed elsewhere by Foley and Taylor), but served to prevent oxidation beyond the H_2O -maximum on the carbon saturation curve [=CW]. Vapour compositions were analysed by mass spectrometer and found to be dominated by water with minor methane, indicating fO_2 just below CW [see Taylor this volume]. Several runs with $CH_4 > H_2O$ enable comparison of charges with variable H_2O/CH_4 vapours. Charges generally did not quench well to glass, and contained disseminated graphite from methane breakdown. Discrimination between primary and quench micas was not difficult due to the large, well-formed nature of primary crystals.

Experimental results and implications

Figure 1 depicts liquidus diagrams for olivine lamproite and leucite lamproite compositions with water-rich fluid compositions at fO_2 just below CW. For the olivine lamproite, garnet does not appear in any of the experiments, and clinopyroxene is restricted to well below the liquidus. This is consistent with models for lamproite genesis in a geochemically depleted mantle. Orthopyroxene does not appear at the liquidus at the pressures studied, but its stability field is greatly increased above 30 kbar, indicating that it probably reaches the liquidus between 45 and 55 kbar. At the changeover from olivine to orthopyroxene as the liquidus mineral, there will be a unique point at which mica also becomes a liquidus phase. This point represents the pressure-temperature conditions at which olivine lamproite may have formed by melting of a phlogopite harzburgite; it is interpreted to lie between 45 and 55 kbar, which is consistent with the occurrence of diamonds in many olivine lamproites.

For the leucite lamproite, orthopyroxene is the liquidus phase at and above 25 kbar, but does not appear at 20 kbar. The phase relations of the leucite lamproite can also be interpreted to indicate an origin by melting of mica harzburgite. Once again, there should theoretically be a unique pressure for a primary magma at which mica reaches the liquidus, below which olivine appears as the liquidus phase. It is considered unlikely that the olivine field would remain narrower than 25°C over 5 kbar, which is required for it to fall between the points determined at 15-20 kbar and 1100-1125°C. The appearance of mica at the liquidus over this pressure range can be reconciled with the mica harzburgite melting model by either of the following: [i] the composition studied is not primary, but has crystallised, and subsequently lost, a small amount of olivine at high pressure; or, [ii] the experiments may contain more water than in natural melting conditions. In the latter case the leucite lamproite may represent a primary liquid, but may fall within the phlogopite liquidus phase field at its pressure of origin due to excess H_2O expanding the liquidus phase field of phlogopite. In either case, it is clear that the pressure at which multiple saturation in mica, olivine, and orthopyroxene occurs cannot be much greater than 20 kbar, as constrained by the inflection in the liquidus in figure 1b. These results are taken to support the hypothesis of Foley et al. [1986b] that olivine lamproite and leucite lamproite may both be derived from mica harzburgite in reduced conditions with variation in pressure as the major control on melt composition.

Several experiments had higher measured CH_4/H_2O vapour compositions, and thus oxygen fugacity closer to IW. Under these conditions, all phases are stable to higher temperatures due to the decreased water activity. Mica stability is increased despite the lower water activity since the F/OH ratio of mica is increased. Production of

lamproitic melts from mica harzburgite may also be possible under these very reduced conditions, but further experiments are required to verify this and to ascertain the pressures involved.

Table 1 : Starting compositions used in the experiments (wt %) Figure 1 : Experimental results with H2O-rich, reduced fluids

	Olivine	Leucite
	Lamproite	Lamproite
S102	43.78	51.37
T102	3.86	3.45
A1203	4.49	9.95
FeO	8.67	6.05
MnO	0.17	0.09
MgO	23.79	8.03
Ca0	5.08	4.67
Na20	0.58	1.67
K20	5.08	11.76
P205	1.64	1.50
BaO	1.75	0.63
SrO	0.15	0.23
ZrO2	0.15	0.14
Cr203	0.17	0.10
NiO	0.13	0.03
F	0.53	0.33



= liquid only, X = olivine, ① = mica,
+ = orthopyroxene, o = clinopyroxene,
* = rutile, I = ilmenite.

References

Barton, M., Hamilton, D.L. [1982] Mineral Mag 45, 267-278 Foley, S.F. [1985] Tschermaks Min Petr Mitt 34, 217-238 Foley, S.F., Taylor, W.R., Green, D.H. [1986a] Contrib Mineral Petrol 93, 46-55 Foley, S.F., Taylor, W.R., Green, D.H. [1986b] Contrib Mineral Petrol, in press