

PETROGENESIS OF SOUTH AFRICAN AND AUSTRALIAN KIMBERLITIC SUITES

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Kimberlites have unique geochemical and petrologic features that must reflect their mantle source and the fractionating processes occurring during ascent. In particular, the common occurrence of Mg-rich olivine (Fo₉₄, Mitchell, 1973) and characteristic very high abundances of compatible (e.g., Ni > 800 ppm) and incompatible trace elements (Dawson, 1962) are not features found in basalt suites. In order to determine the composition of their mantle source and to constrain petrogenetic models we are obtaining petrological and geochemical (major and trace element) data for kimberlitic and associated rock suites from South Africa and Australia. The study includes rock types, melilitites, carbonatites and peridotites so that we can evaluate the relationships of these rocks to kimberlite petrogenesis. Where possible kimberlite samples are autoliths which are believed to represent uncontaminated kimberlite (Ferguson et al., 1973; Danchin et al., 1975).

Ferguson et al. (1973) and Danchin et al. (1975) have shown that the major element composition of South African kimberlites and associated rocks can be used to form 7 cluster groups. When projected into a CMAS diagram (O'Hara, 1968) the trend defined by the cluster groups suggests that olivine and orthopyroxene are early fractionating phases in kimberlite magma evolution whereas the more evolved non-kimberlitic rocks lie on a simple olivine control line (Fig. 1 and 2). Ni and Cr abundances decrease systematically from kimberlites to the more evolved cluster groups; but heavy REE and Sc, elements sensitive to eclogite fractionation, increase in abundance by a factor of 2.

In terms of composition the eastern Australian kimberlites are similar to olivine nephelinites, and in the CMAS projections they are distinct from the South African cluster groups. However, as typical of kimberlites, they have high Ni and Cr contents (>800 ppm). When projected from diopside into the C₃A-M-S plane the eastern Australia kimberlites lie in the vicinity of the 20 kb pseudo-invariant point (consistent with an estimate of 22 kb equilibration pressure for a lherzolite inclusion, Ferguson et al., 1977) whereas the trend line of the cluster groups is unrelated to pseudo-invariant points at 20 and 30 kb (Fig. 2).

A well-established geochemical feature of all kimberlitic rocks is their enrichment in incompatible trace elements. For example, light REE typically range from 100 to 1000 x chondrites (Frey et al., 1971; Fesq et al., 1975; Mitchell and Brunfelt, 1975; Paul et al., 1975; and this work). Although there is a general trend of positive correlation among P, Sr, Ba, Th, U and light REE abundances (Fesq et al., 1975) there are distinct differences in trace element composition between different kimberlite

localities. Considering all kimberlites and associated rocks in terms of the cluster groups, there are only weak correlations of increasing incompatible element contents with increased major element differentiation. However, among our samples the olivine melilitite from Saltpetrekop has the highest REE concentrations (Fig. 3), and it also has the most evolved major element composition (Fig. 1 and 2). These South African olivine melilitites have much higher REE concentrations than Hawaiian nepheline and melilite-bearing basalts, but eastern Australian kimberlites have REE abundances similar to highly SiO_2 undersaturated Hawaiian basalts and a Tasmanian olivine melilitite (Fig. 4). Compared to African kimberlites the lower incompatible element abundances of the Australian kimberlites are consistent with an origin by higher degrees of melting and at relatively shallower depths (20-25 kb); for example, Frey et al. (1977) propose 5% melting for a Tasmanian melilite nephelinite.

There is a consensus (Gast, 1968; Frey et al., 1971; Fesq et al., 1975; Mitchell and Brunfelt, 1975; Paul et al., 1975) that the low Sc (<20 ppm) and Y contents and highly fractionated REE distributions of kimberlites reflect an origin by small degrees of melting of a garnet peridotite source. In order to obtain the very high incompatible element abundances it has been suggested that kimberlites derive from an incompatible element enriched source and are affected by zone refining processes. There is evidence that the upper mantle is light REE enriched (relative to chondrites) in some kimberlite areas (Fig. 5). Another popular model for some incompatible elements, such as REE, is that their abundances are strongly controlled by volatile transfer (e.g., Loubet et al., 1972; Mitchell and Bell, 1976). The very high REE abundances in carbonatites has been cited as strong evidence for the role of volatile transfer. However, in the Benfontein sill where Dawson and Hawthorne (1973) documented magmatic sedimentation structures with the formation of spinel-perovskite cumulates and calcite layers (classified as carbonatites), the calcite has relatively low REE concentrations (Fig. 6; also low Y, Zr, Nb and Th), very much unlike carbonatites. Even lower REE abundances were found in the Lashaine carbonatite (Ridley and Dawson, 1975).

As in South African kimberlites, eclogite inclusions occur in eastern Australia kimberlites, but our data do not require an extensive role for eclogite fractionation during kimberlite petrogenesis. For example, small amounts of melting of a moderately light REE enriched (relative to chondrites) garnet peridotite can adequately explain the large La/Yb ratio in kimberlites. However, we point out that the evaluation of eclogite fractionation in terms of REE geochemistry given by Mitchell and Brunfelt (Fig. 8, 1975) is incorrect. For their choice of partition coefficients less than 15% fractionation of eclogite (50% cpx, 50% gar) causes a La/Yb increase of 100 (Fig. 7). A more realistic choice of garnet partition coefficients for heavy REE (Yb garnet/liquid of 4) requires 70% fractionation for a similar La/Yb enrichment.

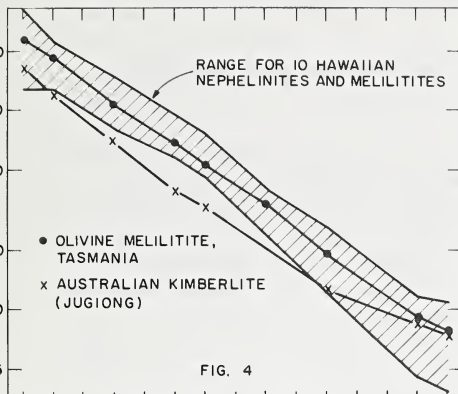


FIG. 4

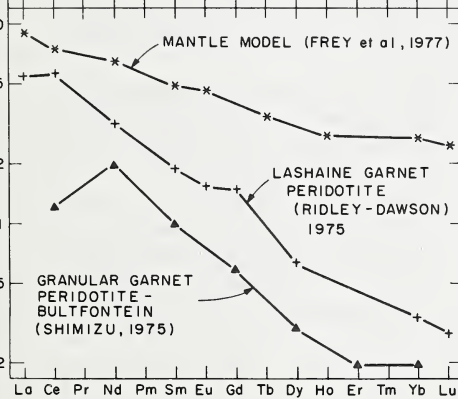


FIG. 5

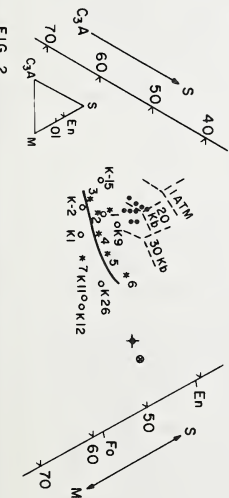


FIG. 2

* GARNET-SPINEL HERCYNITE (JUGIONG, AUST.)
 * GARNET HERCYNITE (S. AFRICA)
 * CLUSTER GROUPS
 * EASTERN AUSTRALIA "KIMBERLITES"
 * KIMBERLITES AND RELATED ROCKS (THIS PAPER)

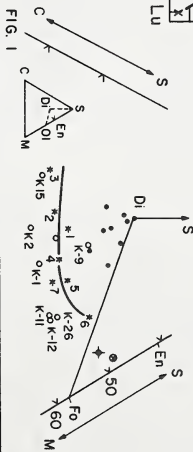


FIG. 1

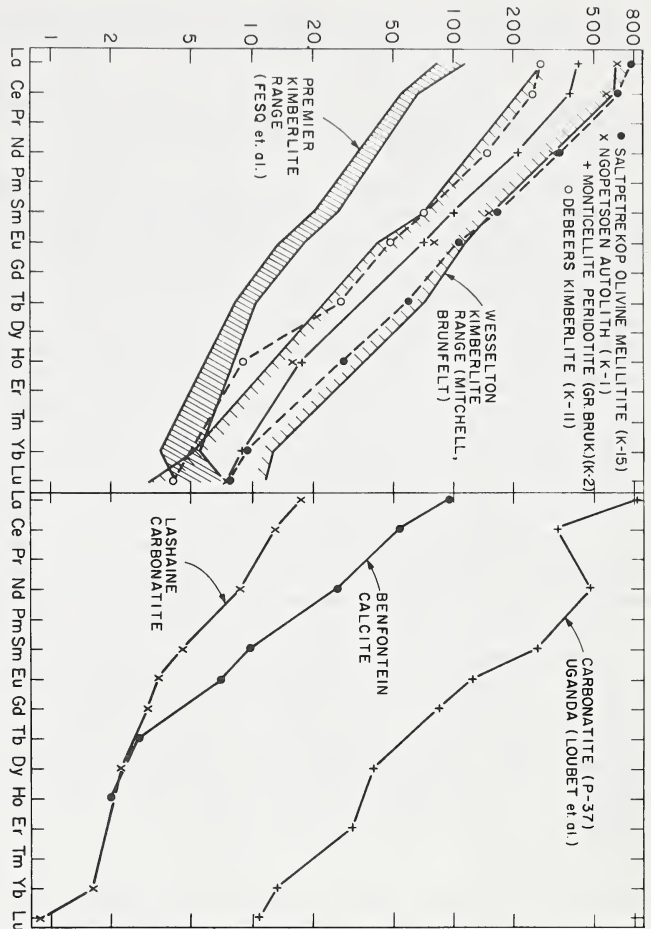


FIG. 6

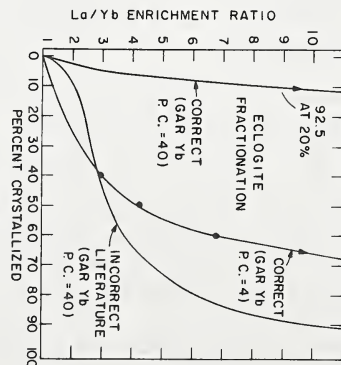


FIG. 7