# PETROGENESIS OF KIMBERLEY GROUP I HYPABYSSAL KIMBERLITES: EVIDENCE FROM BULK ROCK GEOCHEMISTRY

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## INTRODUCTION

To date, little attempt has been made to quantify the petrogenetic processes giving rise to the Group I kimberlites, so well exposed in the Kimberley mines, through use of high quality trace element data. The close spatial proximity of the five major kimberlite pipes and the comparatively fresh, hypabyssal facies material exposed in the deep mines, makes this group of intrusive kimberlites ideal to study with respect to gaining a quantitative understanding of the process involved in their formation and subsequent evolution en route to the surface.

In order to ensure an internally coherent dataset for optimum use in quantitative petrogenetic modeling, and to make use of more modern analytical techniques, covering a wider range of trace elements than previously available, the major kimberlite intrusions from the Kimberley area have been re-sampled and reanalyzed. The primary aims of this study are to quantify as best possible the melting process giving rise to the Kimberley kimberlites, to estimate the likely trace element composition and mineralogy of the mantle source region, and evaluate subsequent shallow level processes that have modified the original primary magma compositions.

## ANALYTICAL

Samples of fresh hypabyssal kimberlite were cleaned and passed through a jaw crusher and then powdered with the use of a Sieb swing mill and a carbon-steel vessel. Prior to powdering, all fragments containing visible xenolithic material or carbonate veins were removed by hand picking. Major element abundances were determined by X-ray fluorescence (XRF) using a low dilution fusion technique and a Philips X'Unique wavelength spectrometer. Trace elements were determined by both XRF and solution ICP-MS. Errors and detection limits associated with the XRF analyses are similar to those reported in le Roex et al. (1981). ICP-MS analyses were determined on a Perkin Elmer ELAN 6000 ICP-MS following the method, and with accuracy and detection limits, as outlined in le Roex et al. (2001); precision was generally better than 3%

relative.  $CO_2$  was determined in selected samples using the karbonat-bombe method of Birch (1981). Estimated precision for this technique is on the order of 5% relative.

#### **GEOCHEMICAL DATA**

The sample suite includes both aphanitic and macrocrystic kimberlite varieties, with macrocrystic phases being dominantly olivine with very minor phlogopite, clinopyroxene and garnet. In conjunction with petrographic observations, the geochemical data allow clear identification of the influence of crustal contamination in certain samples. This is best illustrated in terms of raised SiO<sub>2</sub> content and negative correlation with MgO in contrast to an otherwise well constrained, broad, positive correlation with MgO (Fig. 1), positive Pb anomaly (relative to adjacent incompatible elements Ce and Pr) when normalized to primitive mantle abundances, and low Gd/Lu<sub>n</sub> ratios (raised HREE).



**Figure 1**:  $SiO_2$  versus MgO in Kimberley kimberlites showing effect of crustal contamination. Solid symbols aphanitic, open symbols macrocrystic.

Samples devoid of such crustal contamination show remarkably uniform major and particularly fluid immobile trace element variations. The latter, e.g. Zr-Hf, Ce-Th, Zr-Nb-Ta, define highly coherent trends. In contrast, fluid mobile trace elements, e.g. Rb, Ba, K are highly scattered in their variations. Rare earth element patterns and primitive mantle normalized patterns are remarkably sub-parallel (Fig. 2), with the aphanitic samples being displaced to higher absolute abundance levels relative to macrocrystic samples.



Fig. 2 Chondrite normalized rare earth element patterns of selected Kimberley kimberlites. Normalising values form Sun and McDonough (1989).

#### PETROGENESIS

The macrocryst-rich kimberlites are shown to reflect substantial (up to 35%) entrainment of mantle peridotite, with Ni-SiO<sub>2</sub> and Sc-SiO<sub>2</sub> variations clearly defining mixing trajectories towards garnet lherzolite (rather than pure olivine) (Fig. 3). The change in compositional trajectories between the macrocrystic kimberlites and aphanitic kimberlites suggests that the primary magma(s) parental to the Kimberley kimberlites had a composition of 28-29% MgO, 27-28% SiO<sub>2</sub>, ~2% Al<sub>2</sub>O<sub>3</sub> and Mg# = 0.87.



Figure 3: Ni versus  $SiO_2$  showing trend of macrocrystic kimberlite towards lherzolite rather than pure olivine. Solid symbols aphanitic kimberlite, open symbols macrocrystic kimberlite.

Forward modeling of rare earth elements shows that subtle differences in chondrite normalize REE abundance patterns can be explained by small variations in degree of partial melting within the range 0.7-1.5%, leaving residual garnet. The data are satisfied by melting a source enriched by a factor of ~10 in LREE and deleted relative to chondrites in HREE by a factor of 0.4. Inclusion of the full trace element suite and normalization to primitive mantle values argues for a source enriched by a factor of ~0.2 in HREE elements, when normalized to primitive mantle abundances (Fig. 4). HREE depletion in the calculated source is dependant on the proportion of residual garnet.



Figure 4: Primitive mantle normalized trace element abundances in inferred primary Kimberley kimberlite magma and evolved aphanitic kimberlite. Predicted source calculated by forward modeling assuming generation of the primary magma by 1% melting of garnet lherzolite. Shaded region is average garnet lherzolite composition from the Kimberley region (Gregoire et al., in press) Normalising values from Sun and McDonough (1989).

Extension of this semi-quantitative model to incorporate other incompatible trace elements allows constraints to be placed on likely residual phases at the time of melt extraction. Significant negative K, Rb, Sr and Ti anomalies when normalized to primitive mantle abundances (Fig. 4) require derivation from a source region that had previously experienced metasomatism, inferred to be a carbonated alkaline fluid that had already crystallized phases such as phlogopite, FeTioxides and carbonate and as such imposed these anomalies on the depleted lithospheric mantle prior to melt generation giving rise to the kimberlite parental magma(s).

The strong similarity of incompatible trace element (and isotope) ratios of these Group I kimberlites to those found in ocean island basalts from the South Atlantic, suggests that the fluids responsible for the metasomatism of the source region likely derived from a sub-lithospheric source (Fig. 5), inferred to be an upwelling mantle plume associated with the opening of the South Atlantic (le Roex, 1986).



Figure 5: Covariation of selected incompatible trace element ratios in Kimberley Kimberlites. Solid symbols aphanitic, open symbols macrocrystic kimberlite. OIB = South Atlantic ocean island basalts, MORB=mid-ocean ridge basalts, Karoo = Karoo lavas, PM = primitive mantle from Sun and McDonough (1989).

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