

# Experimental evidence for the nature of upper mantle metasomatism

N.W.A. Odling

*Department of Geology and Geophysics, University of Edinburgh*

## Introduction

Amongst the xenolith types that occur in the Gp.I kimberlites of southern Africa there are some that show evidence of a deep-seated metasomatic process of mantle origin (e.g. Erlank *et al.*, 1987). These 'metasomites' contain distinctive mineralogies of phlogopitealkali-rich amphibole and in some cases Nb-Cr rutile and Ba titanates. Trace element studies have shown that the metasomatism has also resulted in the development of high Rb/Sr, Rb/Ba, K/Ba and a LREE-enriched signature. Present-day Nd and Sr isotopic signatures are characterised by high  $^{87}\text{Sr}/^{86}\text{Sr}$  ( $\epsilon_{\text{Sr}}$ : +18 to +80) at  $^{143}\text{Nd}/^{144}\text{Nd}$  only slightly lower than bulk earth ( $\epsilon_{\text{Nd}}$ : 0 to -7) (Hawkesworth *et al.*, 1990). Metasomatism of the lithosphere is, therefore, an important process by which the lithosphere may be enriched in trace elements and consequently develop distinctive isotopic signatures. Although it is widely accepted that this metasomatism is the result of interaction between peridotitic lithosphere and melts and/or volatile-rich fluids ascending from the asthenosphere, there is still uncertainty about the composition of these melts/fluids and the nature of the metasomatic reactions.

To test the idea that the metasomite xenolith assemblages are the product of interaction between a low-volume melt and refractory lithosphere, a novel experimental design has been devised in which natural aphanitic, Gp.I kimberlite (S30, Dawson and Hawthorne, 1970) has been interacted with refractory harzburgite (LBM10: Cox *et al.*, 1973) in a dyke/wall-rock relationship. The run products show mineralogical, major and trace element (and by implication isotopic) characteristics very similar to those of the metasomite xenoliths and thus support such an origin for these xenolith types.

## Experimental Procedure

The thermal and compositional consequences of injection of a kimberlite dyke into cool peridotitic lithosphere have been experimentally modelled at high temperature and pressure experimentally by using piston cylinder apparatus. A 10mm long Pt capsule was loaded with a sandwich consisting of a

lower layer (90wt.%) of harzburgite (synthesised by sintering of oxide components) and an upper layer (10 wt.%) of the natural aphanitic kimberlite. This capsule was then sealed and placed in an outer Pt capsule along with a MgO/MgCO<sub>3</sub>/C/H<sub>2</sub>O mixture to control the oxygen fugacity close to the EMOG buffer. At run conditions (30 kbar/24hrs.) the kimberlite layer occupies the 'hot-spot' at 1225°C while the harzburgite layer extends into the thermal gradient inherent in apparatus, so that the base of the capsule is at ~1025°C (i.e. P/T conditions close to the 40mW/m<sup>2</sup> geotherm). After the run the capsule liberated 1.2wt.% of vapour indicating the presence at run conditions of a similar amount of a volatile-rich fluid phase. The capsule was then sectioned longitudinally. One half was polished for electron-probe micro-analysis of mineral phases, whereas the other was split into eight, sub-equal portions and fused to allow bulk analysis of the mineral assemblages.

## Run Products

The run product shows that the harzburgite has differentiated into six transverse and compositionally distinct metasomatic layers. The uppermost, high temperature layer consists of a small volume (approx. 0.5mm thick) of radiating, bladed crystals, interpreted to be quench after residual kimberlite melt. Below this are a series of peridotite types of decreasing grain size. The two upper-most peridotite layers consist of a Cr-spinel dunite (2mm) overlying a Cr-spinel wherlite (1mm) both of which contain interstitial glass and phlogopite crystals. Below these are a sequence of porous peridotites containing no material identifiable as quench products after a melt phase. With decreasing temperature, these are: phlogopite wherlite (1.2mm); phlogopite lherzolite (2.2mm); phlogopite, K-richterite lherzolite (0.2mm) with minor Nb-Cr rutile and zircon.

Fig. 1 shows the trace element patterns (determined by secondary-ion mass spectrometry of bulk glasses) for the starting materials (kimberlite and harzburgite) and the experimental phlogopite and phlogopite + K-richterite bearing

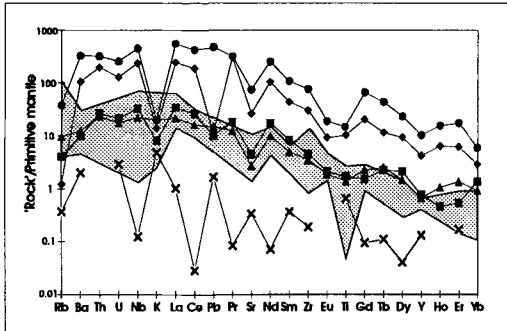


FIG. 1. Trace element characteristics for experimental starting materials and metasomite assemblages. circles - S30 kimberlite; crosses - synthetic LBM10 harzburgite; diamonds - residual kimberlite melt; Squares - phlogopite lherzolite; triangles - phlogopite/K-richertite lherzolite. Shaded area - range shown by natural phlogopite/K-richertite assemblages

assemblages. The sintered-oxide harzburgite starting composition has a highly irregular pattern but is characterised by low overall abundances of trace elements. The natural aphanitic kimberlite has high abundances of large ion lithophile elements (LILE) and REE, with the LREE enrichment and relative depletions in K and Sr characteristic of Gp.I kimberlites (Bergman, 1987). The two experimental metasomite assemblages show trace element patterns that fall within, or close to the range displayed by the K-richertite-bearing xenoliths in kimberlites (shaded area in figure 1). Both of the metasomite patterns are similar and have a profile similar to the aphanitic kimberlite, but at a concentration level approximately twenty times lower. Close inspection of the patterns, however, shows that there are significant relative enrichments in K, Rb, Ba and Pb in both phlogopite-bearing assemblages. The experimental 'metasomatism', therefore, has resulted in increases in Rb/Sr, Pb/U and Pb/Th, and a Sm/Nd similar to the metasomatising kimberlite.

### Implications

In the experiment, the unmetasomatised lithosphere beneath southern Africa is modelled by the refractory harzburgite. The changes in the Rb/Sr and Sm/Nd of the harzburgite as a consequence of metasomatism can be used to assess whether the isotopic signatures that would develop with time are comparable to those of the natural metasomite xenoliths (Hawkesworth *et al.*, 1990). The increase

in Rb/Sr in both of the experimental phlogopite-bearing assemblages will lead to an increase in the  $^{87}\text{Sr}/^{86}\text{Sr}$ . The relatively small net gain in Sr compared to Rb, however, will mean that the metasomite will be relatively insensitive to the isotopic signature of the Sr introduced. By contrast, the Nd isotopic signature produced by metasomatism will be strongly influenced by isotopic nature of the Nd introduced from the kimberlite for two reasons. First, the combination of the long half-life of  $^{147}\text{Sm}$  and the low Sm/Nd produced by the metasomatism will result in only a small corresponding time-integrated increase in the  $^{143}\text{Nd}/^{144}\text{Nd}$ . Second, a large proportion of the Nd of the final metasomite assemblage is derived from the kimberlite and so is of relatively high  $^{143}\text{Nd}/^{144}\text{Nd}$  (Frazer *et al.*, 1985). Thus the net effect of metasomatism, in the short term, will be to increase the  $^{143}\text{Nd}/^{144}\text{Nd}$  signature from the relatively low value of the garnet harzburgite protolith towards the high values shown by Gp.I kimberlite. The combined effect of metasomatism on a conventional  $^{143}\text{Nd}/^{144}\text{Nd}$  vs.  $^{87}\text{Sr}/^{86}\text{Sr}$  diagram will be, therefore, a vector towards the upper-right-quadrant - a trend similar to that reported for metasomite xenoliths from southern Africa (Hawkesworth *et al.*, 1990).

### Conclusions

A novel experimental technique has been developed to examine the mineralogical and compositional consequences of the interaction between kimberlite and refractory harzburgite in a magma/wall-rock relationship. The run products show that the harzburgite is metasomatised to produce a sequence of distinct mineral assemblages which show mineralogical and bulk trace element characteristics (and by implication isotopic features) which match closely those of the natural metasomite xenoliths described from southern African kimberlites. These results, therefore, support previous arguments (e.g. Kinny and Dawson, 1993), that metasomatism is the result of interaction between ascending Gp.I kimberlite and refractory lower lithosphere harzburgites.

### References

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