OXYGEN ISOTOPE COMPOSITION OF METASOMATISED MANTLE PERIDOTITE XENOLITHS- A LASER FLUORINATION AND ION MICROPROBE STUDY

BURGESS[1], S. R., GRAHAM[1], C. M., VALLEY[2], J. W., HARTE[1], B.

1 Department of Geology and Geophysics, University of Edinburgh, West Mains Road, Edinburgh, U.K.
2 Department of Geology and Geophysics, University of Wisconsin, Madison, WI 53706, USA.

Introduction

Oxygen isotope studies of mantle xenoliths may in principle constrain metasomatic processes within the mantle. However the occurrence and scale of oxygen isotopic disequilibrium in mantle-derived xenoliths remains controversial. Conventional studies have commonly indicated oxygen isotopic disequilibrium between coexisting olivine and pyroxene, interpreted to be due to open system exchange of oxygen between olivine and metasomatic fluid or melt. Recent oxygen isotope analyses by laser fluorination (Mattey et al. 1994) have indicated that coexisting minerals in mantle peridotites are commonly in oxygen isotope equilibrium. To improve our understanding of this problem and of the scale of isotopic equilibrium/ disequilibrium, a detailed micro-sampling laser fluorination and ion microprobe study has been undertaken on a suite of·peridotite xenoliths from the Jagersfontein kimberlite pipe, South Africa. The laser technique permits analysis of small (>0.5mg) samples, with 100% oxygen yields, at a precision better than conventional analysis. The spatial resolution of the micro-sampling technique (750µm) enables the determination of inter- and intra-grain variations of oxygen isotope compositions, and facilitates the removal of secondary serpentinous alteration (pervasive in kimberlite hosted xenoliths) prior to analysis. Recent technical advances in ion probe analysis of the oxygen isotope compositions of silicates have permitted analysis at even higher spatial resolution (<40µm), so fine-scale textural relationships, for example between porphyroclasts and neoblasts, can be investigated in detail.

Sample Description

The samples analysed include both coarse low-T and deformed high-T peridotite xenoliths. The coarse xenoliths were modally metasomatised, with the introduction of amphibole and phlogopite before 1Ga (Winterburn et al 1990). The deformed porphyroclastic xenoliths have undergone high-T Fe-Ti-incompatible element cryptic metasomatism prior to eruption. Metasomatism occurred shortly before the eruption of the kimberlite as shown by complex chemical heterogeneities preserved in garnet porphyroclasts (Burgess et al. this volume).

Experimental Procedure

Laser fluorination was carried out with an IR laser (CO_2) and Finnigan/MAT 251 mass-spectrometer at the University of Wisconsin. Samples analysed consisted of mineral grains, parts of grains, or aggregates of grains separated from thick (500µm) rock slabs by a micro-saw, hand picking technique. Detailed photographic documentation allows the position of each micro-sample within the slab to be determined (fig. 1). Secondary alteration was generally removed during hand picking with a razor blade; however crushing and picking of fresh grains were required for serpentinized olivine aggregates. Ion probe analysis was carried out on the Cameca 4f ion microprobe at the University of Edinburgh. The sample was sputtered by a

primary $^{133}Cs^+$ beam, charge neutralisation being attained using a normal incidence electron gun. Negative secondary oxygen ions were filtered with an extreme energy offset (-350eV). Instrumental mass fractionation necessitated standardisation to a standard (Kilbourne Hole olivine, KHOL $\delta 18O=5.30\%0$, Fo89), with a composition similar (within 1mol% Fo.) to the unknowns analysed.
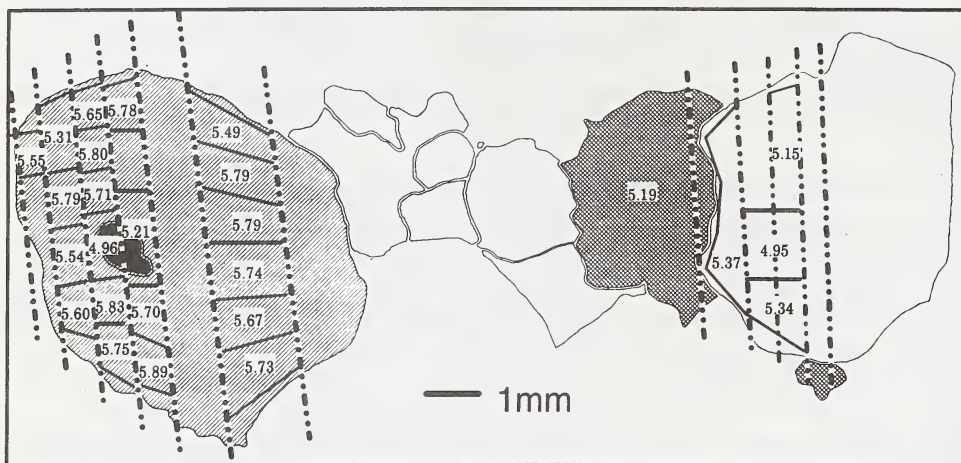

Fig. 1 Part of an analysed rock slab from coarse xenolith J154. Olivine is unshaded; orthopyroxene, diagonal stripes; phlogopite, crosshatch; serpentine inclusion, black. Vertical lines represent micro-saw cuts. Numbers indicate $\delta^{18}O$-SMOW of micro-samples.

Results

Detailed laser fluorination studies (e.g. fig. 1) show that there is no evidence of oxygen isotope heterogeneity on the inter- or intra-grain scale. This is also true when comparing different textural types, for example olivine porphyroclasts and neoblasts. Olivine, opx and garnet are in isotopic equilibrium with $\delta^{18}O$ in the range 4.6-5.8 ‰. δ-δ plots (e.g. $\delta^{18}O_{opx}$-$\delta^{18}O_{ol}$ fig.2) show no evidence of disequilibrium oxygen isotope arrays comparable to those of Kyser et al. (1981). $\Delta^{18}O_{opx-ol}$ (0.7-0.0 ‰) and $\Delta^{18}O_{gnt-ol}$ (0.6-0.0 ‰) are consistent with experimentally calibrated equilibrium fractionations at mantle temperatures. Secondary serpentine ($\delta^{18}O<5$ ‰) lowers the measured $\delta^{18}O$ of samples, where alteration has not been completely removed. Clinopyroxene is anomalously ^{18}O-depleted, with $\Delta^{18}O_{ol-cpx} = 0.62$ to -0.05 ‰, in disagreement with experimentally determined negative ol-cpx oxygen isotope fractionations. Primary metasomatic phlogopite is in isotopic equilibrium with its host ($\delta^{18}O=5.53-5.56‰$) whereas amphibole ($\delta^{18}O=4.32-4.85‰$) is very variable and depleted in ^{18}O relative to olivine. The low $\delta^{18}O$ of clinopyroxene and amphibole may indicate isotopic disequilibrium, which may be a result of preferential oxygen exchange of the calcic phases with fluids during either metasomatism or low-T alteration/ serpentinization. Ion microprobe analysis of olivine porphyroclasts and individual olivine neoblast grains from one deformed xenolith (J119) show both textural types to have identical oxygen isotope compositions (4.8±0.9‰ and 4.7±0.7‰ respectively). The large error on each sample set reflects the error on a single analysis (±1‰ 1σ) for this technique. The $\delta^{18}O$ of olivine measured by ion probe is within error of the $\delta^{18}O$ measured by laser (4.7‰ verses 5.15‰). The KHOL standard was also used to check machine stability during analysis of garnet. Garnet from J119 was standardised to the

$\delta^{18}O$ measured by laser ($\delta^{18}O=5.34‰$). The two garnet grains studied are homogeneous and have identical oxygen isotope composition ($\delta^{18}O=5.3\pm1.2‰$ and $5.4\pm0.9‰$ respectively).

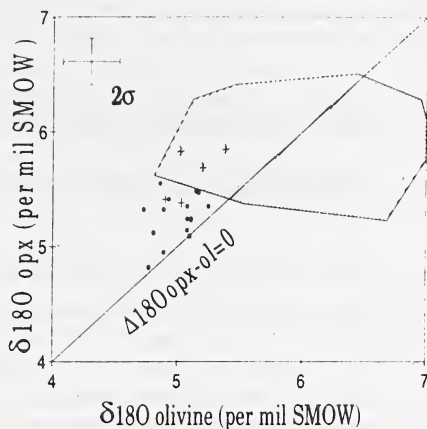Fig. 2 $\delta18O$(opx) Vs $\delta18O$(ol) for Jagersfontein coarse (crosses) and deformed (circles) xenoliths. Hatched area represents the ol-opx data of Kyser et al. (1981).

Discussion

The detailed micro-scale analyses of the Jagersfontein suite represent a unique data set on a suite of metasomatised mantle peridotite xenoliths. The Jagersfontein xenoliths show little variation in oxygen isotope compositions, and their constituent minerals (except clinopyroxene and amphibole) are in isotopic equilibrium on all scales down to the μm level. The deformed xenoliths in particular, however show evidence of retained chemical heterogeneity due to metasomatism prior to kimberlite eruption. Of particular interest is the chemical zoning preserved in garnet. Diffusion of oxygen in garnet may be slower at mantle temperatures ($\sim10^{-19}$ m^2s^{-1} at 1200°C; Elphick et al. In prep.) than at least some major cations, considering commonly invoked diffusion coefficients (eg 10^{-18} m^2s^{-1}; Loomis et al. 1985). Therefore any oxygen isotope heterogeneity resulting from this metasomatic event would also be expected to be preserved within garnet. Two possible end-member cases are possible for the metasomatising fluid. Firstly the fluid may have originated from a well mixed asthenospheric source, and was in isotopic equilibrium with the host mantle peridotite. Secondly the metasomatic fluid had an 'exotic' oxygen source, but was buffered by the host peridotite. This is supported by the lack of veins in the Jagersfontein peridotites and thereby the implication that the metasomatic fluid moved by pervasive boundary flow. It is possible that both end-member cases are relevant.

References
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