IRREGULAR COMPOSITIONAL ZONING IN GARNETS FROM METASOMATISED HIGH-TEMPERATURE PERIDOTITES FROM THE JAGERSFONTEIN KIMBERLITE PIPE

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Introduction

Occurrences of chemical variations preserved in garnets from kimberlite hosted xenoliths are widely reported. The preservation of these variations provides evidence of metasomatic events within the mantle, and may provide information on the mechanisms and time scales of such events. Recent detailed studies by Griffin et al. (1989) and Matthews et al. (1992) have shown that growth around rims and in cracks within garnets are two mechanisms of metasomatic enrichment recorded by garnets. To study this problem further extensive major and trace element analysis has been undertaken on chemically heterogeneous garnets from the Jagersfontein kimberlite pipe, South Africa. A combination of backscatter (BSE) imaging, line profiling, X-ray mapping (by electron probe) and trace element analysis (by ion probe) has enabled detailed information on the 2D geometry of chemical variations as well as their actual magnitude to be determined.

Sample Description

The suite of samples studied includes both coarse low-T and deformed high-T xenoliths. The coarse xenoliths were modally metasomatised before 1Ga (Winterburn et al. 1990), whilst the deformed xenoliths underwent Fe-Ti cryptic metasomatism prior to eruption (Hops et al. 1989). Garnet from one coarse low-T xenolith, a garnet harzburgite which shows no evidence of modal metasomatism seen in many of the coarse xenoliths, was studied. The deformed xenolith suite includes both garnet harzburgites and lherzolites showing a range of textures from porphyroclastic to fluidal mosaic porphyroclastic. Garnet porphyroclasts generally appear unaffected by the deformation, except for two samples; one where garnet is elongated with the fabric, the other where strings of garnet are aligned with the fabric. Kelyphite is developed around the rims of most of the garnets studied. The garnets are chrome pyropes and are chemically heterogeneous in many, but not all, samples.

Experimental Techniques

Quantitative major element analysis was carried out on the Cameca-Camebax electron microprobe at the University of Edinburgh (WDS analysis). Most of the analysis consisted of auto-profiling (beam current 80nA). X-ray maps were collected on the Cameca-SX50 electron microprobe at the University of Leeds (512X512 images) and on the Cameca-Camebax at Edinburgh (256x256 images). Beam currents were 100nA at Leeds, 80nA at Edinburgh, and counting times per pixel were 40ms at Leeds, 400ms at Edinburgh. The spatial resolution of the maps varied from 2 to 8µm. Trace element analysis was carried out on the Cameca-4f ion microprobe at the University of Edinburgh. The sample was spluttered with an O^- beam, with beam current 8nA. A voltage offset of 20-25eV was used in order to collect high energy ions. The elements analysed were: Rb, Sr, Y, Zr, Nb, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Yb, and Lu.

Results

A combination of line profiling and X-ray mapping shows a very large range of styles of chemical variation within the garnets studied. Some typical geometries of chemical heterogeneity, are reproduced in figs. 1 and 2. Two moderately simple situations may be identified: firstly concentric zonation, and secondly variation across roughly linear features which cross-cut the garnet. Concentric zonation may be interpreted as resulting from growth (Griffin et al. 1989) or diffusion (Harte et al. 1987) or both. Cross-cutting linear features were interpreted as due to fluid/melt infiltration into cracked garnets, whose cracks were infilled by garnet precipitation by Matthews et al. (1992). Between these end-member cases are a range of geometries which appear to represent a mixture of both. A few samples cannot be described this way, and show highly complex patterns (eg fig. 2c). The extent to which these different geometries dominate the garnet population was investigated by X-ray mapping nine garnets from one xenolith. These garnets showed the complete range of concentric and crack-related geometries described above. Garnets less than 1mm apart can show vastly different mechanisms of metasomatic interaction. The range of chemical substitutions resulting from metasomatic interaction are as varied as the range of geometries. The elements substituting can change across a mineral grain, or between garnets within a xenolith to a limited extent. Garnets from the coarse xenolith show the substitution Mg + Al = Cr + Ca + Fe (where elements enriched in the later garnet are given first). This is the only heterogeneous sample where titanium remains constant. The most common substitution in the deformed xenoliths is Mg + Al + Ti + Na (±Fe) = Cr + Ca. The role of Cr and Al can however vary with either, or neither (though not both) being an enriching element. This behaviour commonly changes in different parts of one mineral grain. Other substitutions include Ti + Cr + Ca = Al + Mg + Fe which occurs in multiply zoned garnets from two samples (Fig. 1c) and Na + Ti + Ca = Al + Mg + Cr. Detailed profiling and X-ray mapping of one grain, (fig. 1d, 2b) reveals that its linear, crack-like feature is actually made up of two broadly parallel features of similar chemistry; however one is low in Cr the other in Al. It is probable that this grain suffered infiltration by two fluids. Such a model could explain the highly variable behaviour of Cr and Al in some grains. Calculation of Fe^{3+} by a charge balance cation calculation method shows this feature to be anomalously high in ferric iron. In general however Fe^{3+} is not found to vary significantly over the garnets studied. Trace element analysis on two predominantly concentrically zoned samples show that the garnets are being enriched in Zr, Y and HREE. Garnets from the coarse xenolith are homogeneous with respect to the trace elements studied. The chondrite normalised REE pattern of the coarse garnets is sinusoidal, peaking at Nd, similar to the patterns reported by Hoal et al (1994), whilst the deformed garnets show more 'normal' patterns (with low LREE and high HREE).

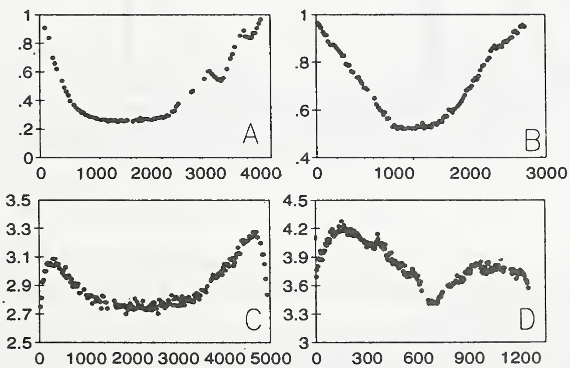

fig. 1 Oxide (Wt%) Against Distance (μm) for Analysis profiles across a) J22C (TiO_2), b) J110 (TiO_2), c) J115 (Cr_2O_3) and d) JJH37 Garnet B (Cr_2O_3). b) represents concentric zoning, a) zoning with possible infiltration in one rim, c) multiple zoning, and d) infiltration into the garnet centre.

Discussion

Mantle metasomatism prior to the eruption of the kimberlite has resulted in chemical heterogeneities preserved in garnets. The chemistry of the garnet rims and of infiltration features suggests that the garnets were mostly being enriched in Ti, Mg, (±Fe), HFSE, and HREE. For one grain increases in Fe^{3+} suggest the fluid may have been more oxidising than the surrounding mantle. Variations in the elements being added indicate that the composition of the fluid was variable (possibly due to fractionation as it percolated through the mantle) or that fluids, of different chemical composition were involved. The coarse xenolith shows a vastly different enrichment style, without enrichment in Ti, probably because its source was spatially removed from the event affecting the deformed xenoliths. It is probable that the enrichment of garnet occurred both due to growth and chemical exchange and diffusion. The large variations in chemical geometry suggest the fluid was not moving simply along grain edges due to surface tension, but that the fluid pressure was large enough to cause some garnets to undergo hydraulic fracturing. Some of the complexities of spatial relationships might relate to crystallographic controls, but the geometrical shapes of the chemical zones do not suggest control by rational crystallographic forces. Evidence of the time-scale of the metasomatic event can be inferred for these xenoliths. The homogenisation time by diffusion for a 1mm spherical garnet grain at 1200°C, assuming a diffusion coefficient of $10^{-17}m^2s^{-1}$ is less than 1000 years.

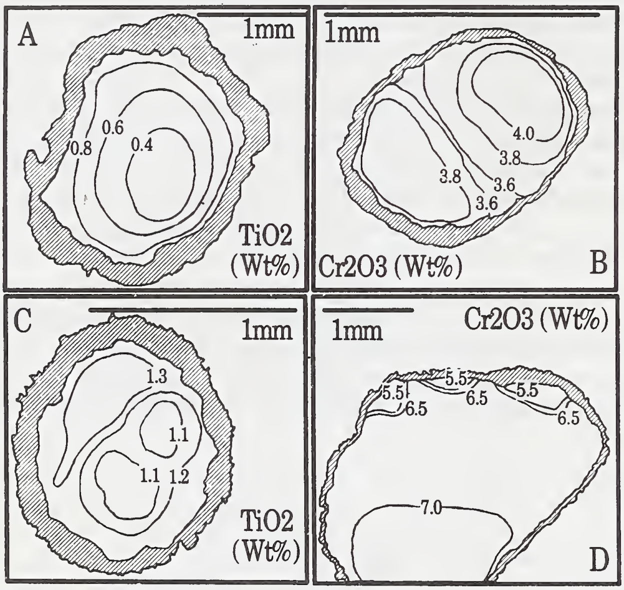

fig. 2 Schematic Contour Maps showing change in TiO_2 (a JJH19, c J112) and Cr_2O_3 (b JJH37, d J22C) across garnets from deformed xenoliths. a) represents concentric zoning, b) infiltration, and c),d) more complex histories. Diagonal hatch is kelyphite.

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