COMPOSITIONAL HETEROGENEITIES IN MINERALS IN PERIDOTITE NODULES

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The homogeneity of minerals in peridotite inclusions from kimberlites in southern Africa has been studied by high-precision electron probe analysis. Equilibration temperatures of the rocks examined span the range 710^o to 1460^{o}C. Most of the observed heterogeneities are attributable to one or more of the following processes: (1) metasomatism by an introduced fluid, in general probably a silicate melt; (2) mechanical mixing of phases from volumes with different mineral compositions; (3) changes in temperature and pressure prior to eruption. The observed heterogeneities provide keys not only to these processes but also to their timing. In rocks with calculated equilibration temperatures below 1100^{o}C, and in rocks with coarse textures regardless of equilibration temperature, heterogeneities commonly involve only Cr-Al zoning and related element variations in garnet; such Cr-Al variations are most apt to be responses to changes in temperature and pressure. More complex heterogeneities were analyzed in the inclusions with porphyroclastic textures and equilibration temperatures above 1100^{o}C; these are the rocks primarily considered here.

The most common heterogeneity detected in minerals of the high-temperature, sheared rocks is zoning in garnet; garnets have core-to-rim increases in Ti and decreases in Cr in more than half of such rocks examined (Table 1). Perhaps as common is rim enrichment in Na, and P, but it is more difficult to detect because absolute values are low. Garnets are zoned in Fe-Mg in 5 of the 13 samples. Well-developed Ti, Fe, and Cr gradients are illustrated in Figure 1. Such zoning has not yet been correlated with equilibration temperature, phase assemblage, or Fe enrichment in olivine. For instance, though garnet is apparently homogeneous in the rock studied with the highest equilibration temperature (1460^{o}C), other high-temperature rocks have garnet with pronounced zoning (Table 1 and Smith and Boyd, 1986). The steepest Ti and Cr gradients, essentially step changes, were observed in a rock (PHN2766/8, Table 1) with a relatively low calculated temperature (1100^{o}C) and magnesian olivine (Fa7). Pronounced zoning is present in garnets in both lherzolite (PHN1611) and garnetiferous dunite (FRB 450).

In each of three rocks, phases have heterogeneities in addition to zoning. In rock FRB76, for instance, two contiguous garnets, each with cross sections about 3 mm in diameter, have similar contents and gradients of Ti, Fe, and P but distinctly different core contents of Cr; the opposing gradients of Cr converge to a common value at the crystal rims (Fig. 1). The garnets appear first to have acquired distinct Cr contents in different environments, then to have been brought into proximity and rims equilibrated to a common composition and also enriched in Ti, Fe, and P. The hypothesis that garnets of contrasting compositions can be mixed together is supported by mineral associations in rock PHN 1611 (Table 1). In this rock, relatively magnesian and iron-rich volumes of peridotite are juxtaposed, apparently by deformation within tens of days of eruption of the host kimberlite (Smith and Boyd, 1986): garnets in the more magnesian volume are more chrome-rich.

Enrichment of Ti, Fe, P, and Na in garnet rims most plausibly is due to the introduction of these elements into the rocks by a fluid phase. Because most of the garnets with Ti zoning are in rocks with equilibration temperatures above 1100^{o}C, and because the extrapolated solidus temperature for peridotite in the presence of water and carbon dioxide is near 1100^{o}C at 40 kb (Olafsson and Eggler, 1983), the fluid probably was a silicate melt. Boullier and Nicolas (1973) noted that rocks appear to have been mixed together during deformation at the margins of some dikes in several crustal peridotite masses, and they hypothesized that mixtures of minerals might also occur in nodules with sheared textures. Textures of the porphyroclastic rocks may be related to the formation of conduits for erupting kimberlites (Mercier, 1979), and the metasomatism and mixing also may have occurred during conduit formation.

The high-temperature, porphyroclastic nodules may be samples of the asthenosphere, and hence understanding the evolution of the compositional contrast between these rocks and the lower-temperature, coarse nodules is important for models of mantle processes (e.g., Boyd, 1973; Nixon and Boyd, 1973). The higher-temperature rocks generally are distinctly more iron-rich than the nodules sampled from lower temperatures, as evidenced by olivine compositions and as summarized by Boyd (1986). Olivine compositions in peridotite are relatively insensitive to melt infiltration, due to the high modal abundance of the phase, its high magnesium plus iron content, and the melt-olivine distribution coefficients for Fe and Mg. Ti contents of garnets are more sensitive indicators of melt metasomatism. The metasomatism and mixing inferred from chemical heterogeneities in phases may have significantly increased the contents of Ti, Na, P, and some other elements in the high-temperature nodules; nonetheless, important compositional differences between the high and low-T suites, such as differences in Fe/Mg, probably predate the late-stage metasomatism and mixing.

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TABLE 1: XENOLITHS WITH PORPHYROCLASTIC TEXTURES

T*	TiO_2 garnet core-rim	Cr_2O_3 garnet core-rim	% Fa olivine	Sample (Location)
1460	0.70	2.6	8.3	PHN 1596 (Thaba Putsoa)
1400 **	0.65 - 0.95	2.2 - 1.4	11.7 - 13.2	PHN 1611 (Thaba Putsoa)
1300	0.38 - 1.16	3.3 - 1.7	12	FRB 450 (Frank Smith)
1280 **	0.40 - 1.20	varied	9.2	FRB76 (Frank Smith)
1280	0.74	2.6	9.2	PHN 2001 (Mothae)
1220	0.43 - 0.63	6.1 - 5.8	7.5	PHN 2273 (Kao)
1220	0.44	3.2- 2.8	9	FRB 1 (Monastery)
1220	0.24 - 0.52	6.6 - 6.0	9.6	PHN 4402 (Gibeon Townlands)
1200 **	0.21 - 0.25	varied	8.1	PHN 5555 (Abbotsford)
1100	0.25 - 0.60	7.2 - 4.5	7	PHN2766/8 (Bultfontein Floors)
990	0.04	6.65	7	PHN2766/4 (Bultfontein Floors)
970	0.02	4.85	7.5	FRB 351 (Bultfontein Floors)
940	0.02	4.54	7.4	JJG 1289 (Premier)

* Most temperatures are from two-pyroxene equilibria.

** These rocks preserve mineralogic evidence of mixing.

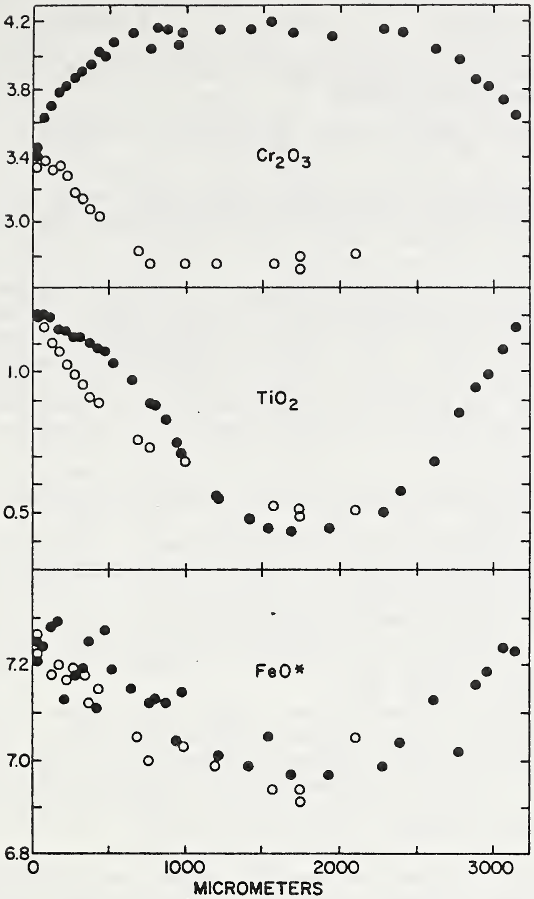

FIGURE 1: Compositional profiles for chrome, titania, and iron in two garnet crystals in rock FRB 76. In one cross section, the profile spans the diameter of a cross section (solid dots), while in the other crystal, the profile extends from interior to rim (open circles). The two crystals are close to one another in the fine-grained, olivine-rich matrix. Crystal rims are also enriched in phosphorus.