SPECULATIONS CONCERNING THE IMPORTANCE OF METASOMATIC MELT MIGRATION IN THE FORMATION OF PYROXENITE SHEETS IN GARNET-PERIDOTITE XENOLITHS FROM MATSOKU, LESOTHO

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METASOMATISM AND MELT INJECTION AT MATSOKU

Many xenoliths show the development of modal and textural inhomogeneities, which vary from discontinuous stringers (~1 mm wide) to layers (2-5 cm wide), in which original garnet peridotite is modified to give garnet + orthopyroxene-rich and/or clinopyroxene-rich material which commonly includes IRPS minerals (ilmenite, rutile, phlogopite and sulphides). Since the petrographic evidence indicates the modification to be occurring in largely solid rock the phenomena are described as metasomatic, even though the infiltrating fluid appears to have been basic-ultrabasic silicate melt (Harte et al., in press).

In association with the obvious metasomatic phenomena noted above, the Matsoku garnet peridotites host a series of discrete pyroxenite sheets (1-16 cm wide), which have the general form of minor magmatic intrusions. These sheets show a number of curious features and it is suggested that they in part may also be the result of an essentially metasomatic process involving melt migration through a solid matrix.

DESCRIPTION OF THE PYROXENITE SHEETS

Although they are generally rich in orthopyroxene and/or clinopyroxene, the pyroxenite sheets often show considerable structural and textural complexity. Lenticles, foliae or seams enriched in olivine, garnet, clinopyroxene or IRPS minerals may occur. Where complete sections are preserved across larger (10-15cm thick) sheets clinopyroxene-rich margins are often present (Fig. 1) and may be accompanied by concentrations of garnet and IRPS minerals. Sometimes a discontinuous selvedge of garnet occurs along the contacts of the sheets.



Table 1 illustrates the variety of modal proportions seen in the sheets: with 88 and 171 representing fairly homogeneous sheets; 139CM and 139I respectively representing clinopyroxene-rich margin and clinopyroxene-poor interior of a single sheet; and 137CM and 129CM representing the margins of sheets richer in garnet and ilmenite.

Table 1. Modal Proportions in Pyroxenite Sheets and other rocks

Rock No.	88	171	139CM	139I	137CM	129CM	108M	108H
olivine	18.2	8.0	18.9	17.2	1.2	0.5	19.2	48.0
orthopyroxene	74.9	39.5	39.1	63.6	20.5	47.2	58.9	43.0
clinopyroxene	4.1	42.5	36.0	14.5	56.0	12.1	3.5	3.5
garnet	2.3	8.9	4.5	2.2	19.9	24.2	10.8	5.5
IRPS minerals	0.5	1.1	1.5	2.5	2.4	16.0	7.6	0.0

In one case (LBM 99) a parallel pair of apparently similar garnet selvedges are seen crossing layering within a pyroxenite sheet, thereby suggesting multiple injec tions of melt. Boundaries between layers within sheets are usually gradational. Whilst contacts with host peridotite often appear roughly planar in gross form, they are irregular on the scale of a few mm.

The grain size within the sheets is dominantly below 1mm, and grains show a mixture of granuloblastic and irregular shapes. Garnets are usually poikiloblastic, and pyroxenes frequently show the patchy and sometimes zoned development of fine ilmenite and silicate inclusions. Curious garnet-rich "pools" (Harte et al., 1975, p. 500) are often present in these rocks.

INTERPRETATION OF THE PYROXENITE SHEETS

The above features clearly show that despite their gross intrusive appearance the pyroxenite sheets do not represent the straightforward homogeneous crystallisation products of a silicate liquid. Differential movement of crystals and liquid is clearly indicated in many cases and it is evident that this is not a straightforward plating of early crystals on relatively cool wallrock margins.

Given that many other phenomena in the Matsoku xenoliths appear to result from metasomatic melt migration, the question arises as to what extent such phenomena are responsible for the varied features seen in the pyroxenite sheets. Rock LBM 108M shows textural and modal (Table 1) similarities to some parts of pyroxenite sheets, but also preserves textures suggesting its conversion from a normal garnet peridotite (108H). Thus large garnets are seen in a state of transition to poikiloblastic garnets (see also Fig. 11a of Harte et al., 1975).

One of the most striking features of the sheets, certainly the larger and better preserved ones, is their development of clinopyroxene-rich (+ garnet and IRPS) margins (Fig. 1) in contrast to relatively orthopyroxene-rich and sometimes olivine-rich interiors. The broadly symmetrical nature of this layering is reminiscent of the metasomatic zoning developed where rock units with different chemical potentials (e.g. limestone within pelite) are present during metamorphism. However, such situations involve changes in mineral species, and in the present case the same silicate minerals occur from sheet core to within the host rock. Given the likely order of crystallisation from the melt of olivine, orthopyroxene, clinopyroxene and finally garnet, it is as if the melt has crystallised outwards from the centres of the sheets towards the margins. Obviously with the crystallisation of a sheet-like body of liquid one would expect the temperature gradient to cause crystallise in the opposite sense. If, however, melt were able to move sideways into the wallrocks, and also from the centre of the sheets into their largely crystalline margins, then concentration of clinopyroxene and garnet towards the margins might be achieved.

Outward migration of melt from within the pyroxenite sheets will be controlled by textural considerations. In order for a fluid to penetrate matrix grains, it must be able to form a continuous framework; all pores must be connected along grain edges. The contiguity of a fluid phase in a matrix of grains in textural equilibrium is controlled by the pore geometry; specifically by the dihedral angle (θ) which occurs at the junction of the fluid (f) and adjacent grains (s). This is controlled by the ratio of intergrain: interphase ($X_{SS}:Y_{Sf}$) surface energies, and is resolved as $\delta_{SS} = 2X_{Sf} \cos^{\theta}/2$. For values of $\theta < 60^{\circ}$, the fluid is able to disperse along grain edges. For values of $\theta > 60^{\circ}$, small proportions of fluid form isolated pockets at grain corners (Beeré, 1975; Park and Yoon, 1985).

Experimental measurements of dihedral angles for relevant fluid-matrix systems are few: Waff and Bulau (1979, 1982) measured values of θ between 30-50° for melts ranging from tholeite to nepheline basanite in equilibrium with a matrix of olivine; Hunter and McKenzie (in prep.) have measured values of $\theta < 60^\circ$ for dolomitic carbonatites in equilibrium with a peridotite matrix at 30kb. Watson (1982) conducted a "melt-infltration" experiment using a synthetic basaltic composition and an olivine matrix. The fluid became dispersed along the, initially dry, grain edges, thereby experimentally confirming the feasibility of the outward infiltration of the melt.

During the migration of melt from the core of pyroxenite sheets towards the wallrock, changes in grain boundary shape can occur by solution-reprecipitation or Oswald ripening. In order for a fluid to penetrate along dry grain edges, solution must occur at the grain boundary. If the fluid were initially out of equilibrium (chemical) with the matrix, it would rapidly become saturated in matrix components by dissolution at grain edges. Once the melt has crystallised, its configuration and geometry will no longer be controlled by $\gamma_{\rm SS}$ ($\gamma_{\rm Sf}$ but by the intergrain-boundary energies alone. The grain boundaries of the new mineral assemblage will change shape through solution-reprecipitation or Oswald ripening to achieve a new minimum-energy configuration. If the new silicates and oxides have intergrain dihedral angles greater than 60°, as many do, then grains of minor phases will be isolated at the corners of principal phases and the original contiguity and geometry of the fluid phase will no longer be conserved. The rocks will have a mineralogy and chemistry that has been modified by infiltration of a fluid, evidence for which will not be present.

The physico-chemical model operating in formation of the pyroxenite sheets requires closer definition, and questions concerning the magnitude of temperature gradients between sheet and wallrock, and the possible repetition of injections of melt into the centres of pyroxenite sheets, require resolution. However, we suggest that the migration of melt, within a crystalline matrix in accordance with the principles of textural equilibration discussed above, may have played an important role in the development of the pyroxenite sheets. The outward infiltration of melt into the cooler margins of the pyroxenite sheets and the adjacent wallrocks may have created the clinopyroxene and garnet rich margins seen in some sheets.

REFERENCES

- BEERÉ W. 1975. A unifying theory of the stability of penetrating liquid phases and sintering pores. Acta Metallurgica 23, 131-138.
- HARTE B., COX K.G. and GURNEY J.J. 1975. Petrogaphy and geological history of upper mantle xenoliths from the Matsoku kimberlite pipe. Physics and Chemistry of the Earth 9, 477-506.
- HARTE B., WINTERBURN P.A. and GURNEY J.J. In press. Metasomatic and enrichment phenomena in garnet-peridotite facies mantle xenoliths from the Matsoku kimberlite pipe, Lesotho. In Menzies M.A. and Hawkesworth C.J. eds. Mantle Metasomatism. Academic Press, London.
- PARK H.-H. and YOON D.N. 1985. Effect of dihedralangle on the morphology of grains in a matrix phase. Metallurgial Transactions 16, 923-928.

WAFF H.S. and BULAU J.R. 1979. Equilibrium fluid distribution in an ultramafic partial melt under hydrostatic conditions. Journal of Geophysical Research 84, 6109-6114.

WAFF H.S. and BULAU J.R. 1982. Experimental determination of near-equilibrium textures in partitially molten silicates at high pressures. Advances in Earth and Planetary Sciences 12, 229-236.

WATSON E.B. 1982. Melt infiltration and magma evolution. Geology 10, 236-240.