Xenolith evidence for melt-rock reaction at the lithosphere-plume boundary

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Poikiloblastic harzburgite xenoliths from Borée, French Massif Central have been interpreted as the deepest spinel facies mantle segments sampled by alkali basalts (Mercier, 1977). However, there exists considerable debate about their petrogenesis (selective recrystallisation of the granular peridotites within a diapir *vs* precipitation from tholeiitic melts). We thus undertook a comprehensive study on these particular rocks with a strategy of understanding the nature of processes in the lower lithosphere which is imparted by an upwelling plume (Granet *et al.*, 1995).

Petrography and geochemical characteristics. The Borée xenoliths can be classified into two groups. The G-type samples are mainly spinel lherzolites and are similar to Group I peridotites (Frey and Prinz 1978) with a textural variation from protogranular, porphyroclastic to equigranular. The equilibrium temperatures are 850–1000°C. The P-type samples are harzburgites which are divided into two subgroups in terms of the degree of recrystallisation/deformation. The first subgroup, referred to as non-recrystallised P-type, is characterised by large (>1 cm) and essentially unstrained olivines, whereas the second subgroup, the recrystallised P-type, is characterised by the presence of two generations of olivine and orthopyroxene with some samples being mylonitic in texture. The P-type peridotites are equilibrated under a high temperature (majority > 1200°C).

The olivines in the two groups of peridotites are similar in Mg# and in NiO content. However, distinctive compositions are observed in P-type and G-type spinels. The P-type spinels display inhomogeneous composition at grain-scale and have much higher Cr contents and calculated ferric ion contents than G-type spinels. In $Cr\#_{sp}$-$Mg\#_{ol}$ diagram, the G-type and non-recrystallised P-type samples follow the progressive partial melting trend, whereas the recrystallised P-type samples tend to plot below the trend. The deviation from the progressive partial melting trend is even more obvious for the Ti contents in all P-type samples which are significantly higher than the normal mantle values.

Clinopyroxenes in the G-type peridotites display *REE* patterns similar to those commonly observed in peridotites from world-wide occurrences. A strong correlation between *REE* patterns and texture is observed for the P-type samples. The recrystallised samples have bell shaped *REE* patterns with apex at Nd and Pr. In contrast, cpxs in non-recrystallised samples have lower total *REE* and Ti contents, and display a relatively flat pattern.

The isotopic compositions of cpxs correlate with texture despite a restricted range in isotopes. G-type peridotites have slightly higher ε_{Nd} (11.8–14.9) and low $^{87}Sr/^{86}Sr$ (0.7022–0.7030) than the P-type peridotites (ε_{Nd} = 6.0–8.3; $^{87}Sr/^{86}Sr$ = 0.7031–0.7035), defining a depleted mantle reservoir. The P-type peridotites plot between the MORB field and bulk Earth composition.

A percolation-reaction model for the origin of Borée P-type harzburgites. The previous cumulative model is inadequate when following lines of evidences are taken into account. (1) In terms of major element chemistry, the 'refractory' characteristics and homogeneous silicate phases of the P-type peridotites are different from those magmatic segregates which are commonly pyroxene-rich and high in CaO and Al_2O_3; (2) The relatively constant Mg# and NiO contents of P-type samples are not consistent with the hypothesis of large volume of cumulates; (3) The concentrations of hypothetical melts in equilibrium with P-type samples are highly variable, attesting to a very strong fractionation processes associated with the formation of P-type xenoliths. This is not consistent with the lack of fractionation revealed from the major chemistry; and (4) A small, but significant difference in Sr-Nd isotopic composition exists between the P-type xenoliths and alkali basalts and megacrysts from Massif Central.

Mercier (1977) has alternatively interpreted these rocks as having formed by annealing and grain growth of the G-type peridotites. However this model cannot account for the contrasted modal compositions, mineral chemistry, *REE* patterns and Sr-Nd isotopic compositions exhibited by the G- and P-type peridotites. We thus propose that the P-type peridotites were formed as a result of melt-percolation in a lherzolite precursor during lithospheric erosion by an upwelling plume.

Mineralogical constraints. All P-type peridotites deviate from the progressive partial melting trend by significantly higher Ti contents in spinel, which are commonly related to melt infiltration in peridotites. In this percolation-reaction model, the nearly constant Mg# and Ni values would be nicely accounted for by buffering effect of the percolated peridotites in contrast with the cumulates, since both Mg and Ni are compatible elements. The melt infiltration would ensure wetting of the significant part of grain boundaries and thus enhance grain boundary diffusion kinetics. As a consequence, grain boundary migration and grain growth are accelerated, giving rise to the formation of particular texture in the P-type samples. The recrystallised P-type harzburgites plot below the melting trend because of their low Mg#. This can be explained by their high melt/rock ratio. In other words, in terms of chromatographic effect, these samples were traversed by the chromatographic front of Mg#. Hence their Mg# was imposed by the infiltrated melt.

Geochemical constraints. Either convex-upward or rather flat *REE* patterns strongly suggest that the P-type samples are not simple residues of partial melting processes. In fact, the huge range in *REE* patterns at similar major element compositions provides evidence for an open-system during the formation of P-type peridotites. It is also noted that the P-type peridotites tend to plot between the isotopic compositions of G-type and of alkali basalts. This is expected for melt-peridotite reaction experienced by the P-type samples. The fact that the P-type samples do not plot on a simple mixing curve between protolith and melt may be related to the subtle Sr-Nd chromatographic fractionation.

Numerical simulations. In order to quantitatively define such a process, we used the plate model of Vernieres *et al.* (1997) for the simulation of trace element variations during partial melting and reactive porous flow at transition between conductive and advective geothermal gradients. Recent work in orogenic peridotites suggests the existence of a high porosity domain at this boundary. During erosion of the lithosphere by a plume, basaltic melts would infiltrate into its base and react with peridotites, and melt flow will be channelled into this high porosity domain. This process will lead to melt accumulation at the topographic heights of the asthenosphere-lithosphere boundary. To account for this melt accumulation, the proposed model involves a semi-permeable barrier which corresponds to the isotherm where the plume-derived melts crystallise most of their mass. The results show that the Borée *REE* patterns can be nicely fitted and further indicate that the different textured xenoliths may represent mantle from different levels in a percolation-reaction column.

Decoupled grain growth and recrystallisation and its geodynamic implication. The striking correlation between texture and chemistry for the P-type peridotites can be accounted for by the higher melt/rock ratio in the recrystallised P-type harzburgites than in the non-recrystallised ones. Such a positive correlation between melt/rock ratio and degree of recrystallisation is reminiscent of Ronda massif in which the grain growth and recrystallisation are coupled (Van der Wal and Bodinier, 1996). But in the case of Borée xenoliths, grain growth and recrystallisation are decoupled. It seems that grain growth occurred first and would be triggered by instantaneous high melt fraction giving rise to the formation of the non-recrystallised P-type. Recrystallisation occurred upon further percolation with increasing melt/rock ratios.

The thermomechanic erosion of the lithosphere as a result of conductive heating by upwelling asthenosphere is now recognized as an important mechanism for lithospheric thinning in the early stage of rifting (Davies, 1994). It is generally agreed now that the thermal erosion of the lithosphere is accompanied by pervasive reactive porous flow of the asthenospheric melts. This study provides the evidence that the later process can also play an important role in the erosion processes by modifying microstructure and modal composition of peridotites and then enhancing permeability of the MBL. Coupled with the thermal effect, this process is able to weaken the lithosphere allowing its mechanical removal by asthenosphere.

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