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Spatial variability of pyroxenite layers in the Beni Bousera orogenic peridotite (Morocco) and implications for their origin

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ABSTRACT

The Beni Bousera peridotite contains a diversity of pyroxenite layers. Several studies have postulated that at least some of them represent elongated strips of oceanic lithosphere recycled in the convective mantle. Some pyroxenites were, however, ascribed to igneous crystal segregation or melt–rock reactions. To further constrain the origin of these rocks, we collected 171 samples throughout the massif and examined their variability in relation with the tectono-metamorphic domains. A major finding is that all facies showing clear evidence for a crustal origin are concentrated in a narrow corridor of mylonitized peridotites, along the contact with granulitic country rocks. These peculiar facies were most likely incorporated at the mantle–crust boundary during the orogenic events that culminated in the peridotite exhumation. The other pyroxenites derive from a distinct protolith that was ubiquitous in the massif before its exhumation. They were deeply modified by partial melting and melt–rock reactions associated with lithospheric thinning.

1. Introduction

Orogenic peridotites contain a variety of pyroxene-rich mafic to ultramafic layers, often collectively referred to as 'pyroxenites', although they may also include garnet granulites and eclogites (Bodinier and Godard, 2014). These rocks were given a peculiar attention, with several studies aiming to assess the suggestion by Allègre and Turcotte (1986) that the mafic layers represent elongated strips of oceanic lithosphere recycled in the convective mantle (the 'Marble Cake' model). The Beni Bousera orogenic peridotite, in the Rif mountains of northern Morocco, is well known for containing a wide variety of pyroxenite layers (Kornprobst et al., 1990; Pearson et al., 1989, 1993). A large proportion of the published works supporting a 'Marble Cake' origin for the orogenic pyroxenites are based indeed on samples from Beni Bousera and, to a lesser degree, from the neighbouring Ronda massif, southern Spain (e.g., Allègre and Turcotte, 1986; Kornprobst et al., 1990; Morishita et al., 2003; Pearson and Nowell, 2004). However, several studies of the Beni Bousera pyroxenites also reported evidence for

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igneous garnet crystallisation and suggested that at least part of them originated as high-pressure crystal segregates in magma conduits, variably modified by metamorphic or metasomatic reactions (Gysi et al., 2011; Kornprobst et al., 1990; Pearson et al., 1989, 1993). This interpretation was classically suggested for pyroxenite layers in other orogenic lherzolites (e.g., Bodinier and Godard, 2014).

The different interpretations may partly reflect the diversity of pyroxenite layers in Beni Bousera. The studies supporting the recycling scenario were mostly performed on relatively rare, peculiar rock types including a graphitized diamond-bearing pyroxenite (Pearson et al., 1989) and corundum-bearing aluminous pyroxenites (Kornprobst et al., 1990). Gysi et al. (2011) studied different types of pyroxenites, including more 'classic' garnet pyroxenite layers, collected along two tens of meters long river sections. However, none of the published studies embraces the full range of the pyroxenite variability and the approaches generally do not consider the relationships between pyroxenite layers and the petro-structural variations in host peridotites (Frets et al., 2014). Studies of pyroxenites in the neighbouring Ronda peridotite have shown that their variability is strongly correlated with the peridotite tectono-metamorphic domains (Garrido and Bodinier, 1999). Recent studies in Beni Bousera indicate that the massif underwent an evolution comparable to Ronda, including extreme lithospheric thinning (Frets et al., 2014) and melt–rock interactions involving a subduction component (Gysi et al., 2011). During this evolution, which culminated in thrusting of the peridotite bodies amidst continental crust, the massif may have incorporated varied crustal components, including slab-derived melts possibly crystallized as high-pressure segregates (Pearson et al., 1993) or solid granulite components delaminated from the crust and intermingled with lithospheric peridotites (Gysi et al., 2011).

Therefore, before considering the pyroxenite layers of Beni Bousera and their host peridotites as a case study for the convective 'Marble Cake' mantle, it is essential to assess the effect of lithospheric processes. In this study, we provide an overview of the different pyroxenite facies in the Beni Bousera peridotite based on a large dataset of 171 samples collected throughout the massif. We examine their spatial distribution in relation with the tectono-metamorphic domains recently defined by Frets et al. (2014) and use major and trace elements to constrain their origin. The aim was to determine the extent of the chemical perturbations attributable to the late evolutionary stages of the massif and evaluate the original heterogeneity degree of the Beni Bousera parent body.

2. The Beni Bousera orogenic peridotite

The Beni Bousera peridotite massif crops out in the Septides complex, in the lower internal zones of the Alpine Rif belt, in northern Morocco (Kornprobst, 1974). Foliations and lineations are consistent in peridotites and their crustal host rocks. According to Kornprobst (1974), the peridotite body records a polybaric evolution starting at depths > 150 km. A comparison of the structures in the massif and in the overlying crustal units led Afiri et al. (2011) to propose that the peridotites were exhumed in the footwall of a lithospheric extensional shear zone. Detailed structural and petrological mapping of the massif by Frets et al. (2014) showed that it is composed of four tectono-metamorphic domains with consistent kinematics. From top to bottom, these domains include (Fig. 1): (1) garnet-spinel mylonites, (2) Ariégite subfacies fine-grained porphyroclastic spinel peridotites, (3) Ariégite–Seiland subfacies porphyroclastic spinel peridotites, and (4) Seiland subfacies coarse-porphyroclastic to coarse-granular spinel peridotites. Microstructures and crystal preferred orientations point to deformation dominantly by dislocation creep in all domains, but continuous increase in average olivine grain size indicates decreasing plastic work rates from top to bottom. This evolution in deformation conditions is consistent with the change in synkinematic pressure and temperature conditions, from 900 °C at 2.0 GPa in the garnet-spinel mylonites to 1150 °C at 1.8 GPa in the Seiland domain. A diffuse dunitic-websteritic layering subparallel to the foliation suggests deformation in the presence of melt in the Seiland domain. To account for the consistent kinematics and the tectono-metamorphic evolution, implying a temperature gradient of c. 125 °C km^{-1} preserved across the massif, Frets et al. (2014) proposed that the entire peridotite body was a low-angle shear zone, a few kilometres wide, which accommodated exhumation of the base of the lithosphere from 90 to 60 km depth.

3. Classification, petrography and spatial distribution of pyroxenite layers

Kornprobst et al. (1990) recognized two main types of garnet pyroxenite layers in the Beni Bousera massif. Type I is characterized by relatively low (< 10wt%) and nearly constant Al_2O_3 content in bulk rocks, but variable FeO/MgO ratio (0.1–0.8). In contrast, type II has a narrower range of FeO/MgO values (0.1–0.3) but variable Al_2O_3 content; most samples are more enriched in alumina (up to 15%) than type-I pyroxenites. Type-I layers were considered as high-pressure crystal segregates while type-II layers, which notably include corundum-bearing pyroxenites, were interpreted as metamorphosed oceanic gabbros. Thereafter, Pearson et al. (1993) reported a wide diversity of pyroxenite lithologies but it was Gysi et al. (2011) who first proposed a classification of the Beni Bousera pyroxenite layers aiming to embrace their whole diversity range. The classification proposed here is roughly comparable to that of Gysi et al. (2011) and comprises four main groups. It is, however, based on a larger database of 171 samples collected throughout the massif and examined in thin sections (Fig. 1). Our sampling therefore includes rock facies that were incompletely documented by Gysi et al. (2011), such as the peculiar corundum-bearing pyroxenites studied by Kornprobst et al. (1990). Table 1 in the Supplementary material gives the mineral assemblages of the different groups and sub-groups of our classification and summarizes their main characteristics. Fig. 1 shows the distribution of the pyroxenite groups with respect to the tectono-metamorphic domains defined by Frets et al.