Lithos 208–209 (2014) 67–80

Contents lists available at ScienceDirect

Lithos

journal homepage: www.elsevier.com/locate/lithos

Amphibole genesis in pyroxenites from the Beni Bousera peridotite massif (Rif, Morocco): Evidence for two different metasomatic episodes

Fatima El Atrassi [a,*], Gilles Chazot [b], Fabrice Brunet [c], Christian Chopin [a], Mohamed Bouybaouene [d]

[a] Laboratoire de Géologie, Ecole Normale Supérieure, CNRS, 24 Rue Lhomond, 75005 Paris, France
[b] Université Européenne de Bretagne, France et Université de Brest, CNRS, UMR 6538 Domaines Océaniques, Institut Universitaire Européen de la Mer, Place Copernic, 29280 Plouzané, France
[c] ISTerre, Université de Grenoble 1, CNRS, F-38041 Grenoble, France
[d] Laboratoire d'Océanologie, Géodynamique et Genie Géologique, Université Mohammed V, Avenue Ibn Battouta, B.P. 1014, Rabat, Morocco

ARTICLE INFO

Article history:
Received 18 December 2013
Accepted 1 August 2014
Available online 7 September 2014

Keywords:
Metasomatism
Amphibole
Silicate melt
Beni Bousera
Garnet websterite
Garnet clinopyroxenite

ABSTRACT

The presence of variable amounts of amphibole ± phlogopite in a garnet websterite and a garnet clinopyroxenite from the Beni Bousera peridotite massif provides evidence for post-formation metasomatism. Textural observations associated with major- and trace-element mineral compositions allowed us to distinguish two metasomatic episodes, which occurred at different stages of the Beni Bousera massif evolution. The garnet websterite has recorded interaction with LREE-rich silicate melts before the uplift of the massif. Amphibole/clinopyroxene and amphibole/garnet trace-element ratios closely approach partition coefficient values, indicating that chemical equilibrium was attained between amphibole and pyroxenite matrix minerals. The geochemical signatures of the putative alkaline interacting melts are similar to those of recent basaltic magmas erupted in Morocco, suggesting a common peridotite mantle source. In contrast, amphibole from the garnet clinopyroxenite is in chemical disequilibrium with the pyroxenite matrix minerals. In this clinopyroxenite the crystallization of amphibole and plagioclase occurred at lower T (and P) conditions, most probably during the ascent of the Beni Bousera massif and its emplacement into the crust. The melt responsible for this later metasomatic episode was LREE-depleted and HREE-enriched, suggesting that it resulted from decompression melting of a garnet-bearing source (with garnet as a melting phase), similar to the garnet-bearing pyroxenites outcropping in the Beni Bousera massif.

1. Introduction

Most of the ultramafic rocks found in the Earth's continental crust are generally emplaced in suture zones along mountain belts during orogenesis. Such rocks are commonly referred to as Alpine-type peridotites or orogenic peridotites. These massifs are generally characterized by the predominance of lherzolite equilibrated in any of the garnet-, spinel- or plagioclase-peridotite facies defined by O'Hara (1967), except the Finero peridotite, in the Italian Alps, which is mainly composed of amphibole and phlogopite harzburgites (e.g. Cawthorn, 1975; Grieco et al., 2001; Zaccarini et al., 2004; Zanetti et al., 1999), but all these massifs contain in addition numerous pyroxenite layers which can be quite variable in frequency, thickness and composition. These complex lithologies provide evidence for significant heterogeneities in the upper mantle, as well as for melt/rock interactions at large scale.

These orogenic peridotites provide direct information for a better understanding of mantle processes as well as tectonic history of the orogenic belt into which they have been emplaced.

During the exhumation of the peridotite massif, the ultramafic rocks can be affected by several processes such as partial melting or/and metasomatism.

Metasomatism is a complex phenomenon involving percolating fluids interacting with mantle rocks in diverse tectonic settings (e.g. Arai et al., 2003, 2004; Morishita et al., 2003; Vannucci et al., 1998; Wulff-Pedersen et al., 1999). The agents responsible for mantle metasomatism include silicate melts, carbonate melts or C–O–H-rich fluids (e.g. Menzies and Chazot, 1995; Menzies and Hawkesworth, 1987).

Ultramafic rocks show two styles of metasomatism: 1) cryptic metasomatism, resulting in major and trace element exchanges between wall-rock minerals and the metasomatic agent without any visible mineralogical or textural changes (e.g. Dawson, 1984; Roden and Rama Murthy, 1985); 2) modal metasomatism (e.g. Harte, 1983; Roden and Rama Murthy, 1985) characterized by petrographically well recognizable replacement textures and/or presence of secondary minerals like amphibole and/or phlogopite and more rarely apatite, sulfides, carbonates and oxides (e.g. Dawson, 1984; Harte, 1983; Menzies, 1983; O'Reilly and Griffin, 1988). In some cases, the occurrence of glass, intergranular or as inclusions in primary mantle minerals, is observed and can be ascribed to in situ partial melting of the mineral phases (Chazot et al., 1996a; Francis, 1976).

* Corresponding author at: Laboratoire G-Time, Université Libre de Bruxelles, Belgium. Tel.: +32 2 65 06 616.
E-mail address: fatima.el.atrassi@ulb.ac.be (F. El Atrassi).

http://dx.doi.org/10.1016/j.lithos.2014.08.014
0024-4937/

Geochemical studies on orogenic peridotites revealed that evidence of mantle metasomatism is commonly found in some peridotite massifs (e.g. Marocchi et al., 2009; Rampone and Morten, 2001; Scambelluri et al., 2006; Woodland et al., 1996; Zanetti et al., 1999). In the Beni Bousera massif, amphibole grains occur along pyroxene grain boundaries in garnet pyroxenites. This has been taken as evidence that metasomatism affected some pyroxenite bands at grain boundaries (Gysi et al., 2011). However, in previous studies of garnet pyroxenites in the Beni Bousera massif (e.g. El Atrassi et al., 2013; Gysi et al., 2011; Kornprobst et al., 1990), no detailed geochemical investigation of hydrous phases was undertaken. In order to better constrain the metasomatic process(es) that affected the Beni Bousera massif, we provide new textural and geochemical data on hydrous minerals from garnet clinopyroxenite and garnet websterite samples, collected from two different localities in the massif (Fig. 1). These samples appeared to contain varying amounts of amphibole and, possibly, phlogopite, which is reported here for the first time from a Beni Bousera pyroxenite.

Both garnet clinopyroxenite and garnet websterite samples described in this paper correspond to Type-I pyroxenites of Kornprobst et al. (1990). They are similar to, respectively, Type-IIIA garnet clinopyroxenites and Type-IIIB garnet–kelyphite websterites of Gysi et al. (2011). However, no phlogopite was described by Gysi et al. (2011) in these pyroxenites.

2. Geological setting

The Beni Bousera peridotite massif is situated in the Rif Mountains of northern Morocco; it is one of a number of peridotitic bodies located in the Betic-Rif orogen, which wraps around the western end of the Alboran Sea, the largest of which is the Ronda massif in southern Spain.

Their tectonic setting and the mechanism of emplacement in the Alboran area are still debated (e.g. Chalouan and Michard, 2004; Jolivet et al., 2008; Loomis, 1972; Platt and Vissers, 1989; Platt et al., 2003; Reuber et al., 1982; Tubia and Cuevas, 1986; Van der Wal and Vissers, 1993; Zeck, 1996, 1997).

The Betic-Rif belts are subdivided into two zones, internal and external. The Beni Bousera massif is situated in the internal zone of the Rifean belt. It is structurally enveloped by high-pressure, high-temperature

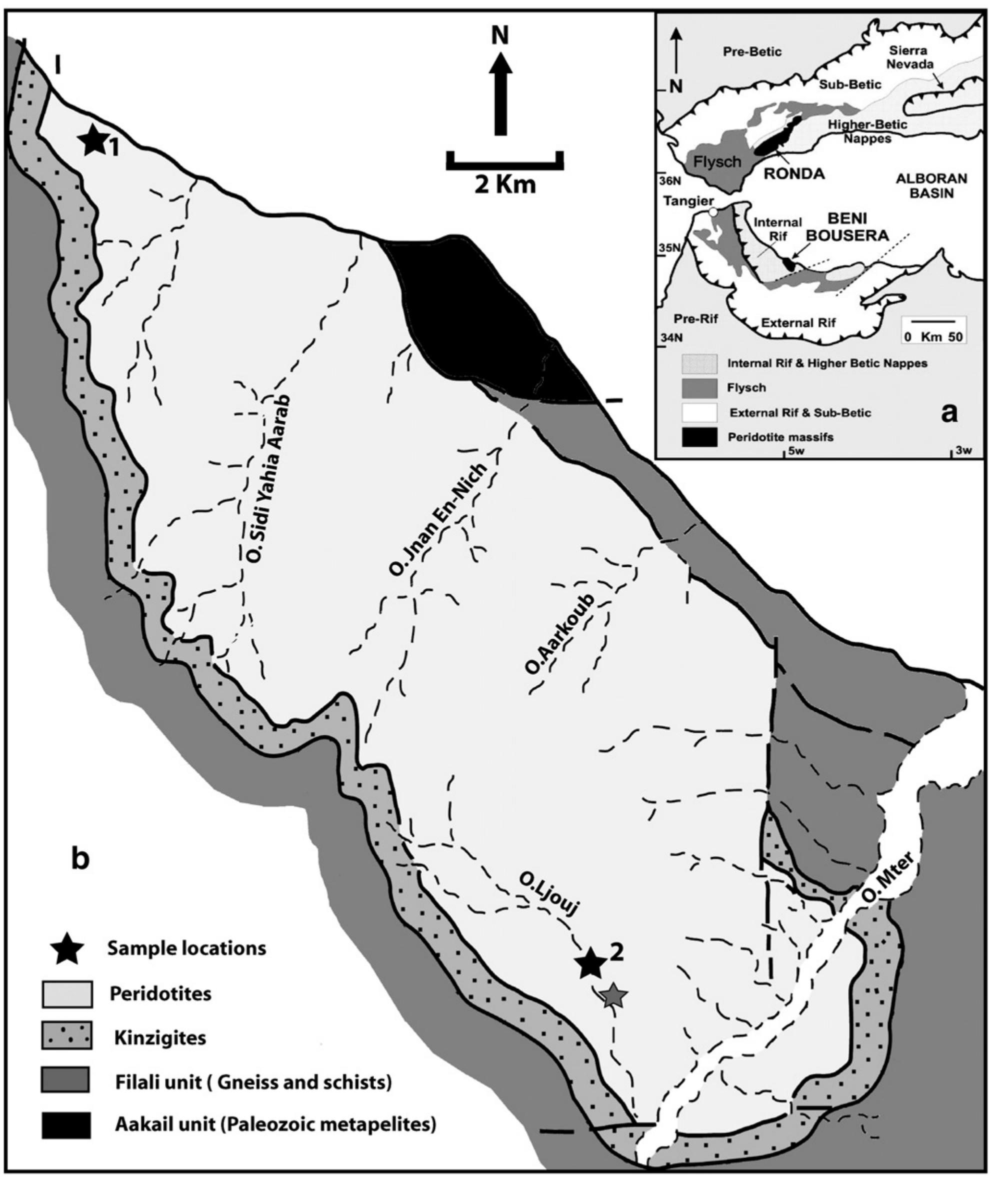

Fig. 1. (a) Geographic location of the Beni Bousera massif in the Betic-Rif orogen (northern Morocco), modified after Pearson and Nowell (2004). (b) Simplified geological map of Beni Bousera massif, modified after Kornprobst et al. (1990) and Draoui et al. (1995); the black stars indicate the locations of sampling localities. (1) Garnet clinopyroxenite; (2) garnet websterite. Gray star: garnet pyroxenite with graphite pseudomorphs after diamond.