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Compositional signatures of SSZ-type peridotites from the northern Vourinos ultra-depleted upper mantle suite, NW Greece

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ABSTRACT

The northern Vourinos massif, located in the Dinarides-Hellenides mountain belt in the Balkan Peninsula, forms a section of the so-called Neotethyan ophiolitic belt in the Alpine-Himalayan orogenic system. It is comprised mainly of a well-preserved mantle sequence, dominated by voluminous massive harzburgite with variable clinopyroxene and olivine modal abundances, accompanied by subordinate coarse- and fine-grained dunite. The harzburgite rock varieties are characterized by high Cr# [Cr/(Cr + Al)] values in Cr-spinel (0.47–0.74), elevated Mg# [$Mg/(Mg + Fe^{2+})$] in olivine (0.90–0.93), low Al_2O_3 content in clinopyroxene (≤1.82 wt.%) and low average bulk-rock concentrations of CaO (0.52 wt.%) and Al_2O_3 (0.40 wt.%), which are indicative of their refractory nature. In addition, dunite-type rocks display even more depleted compositions, containing Cr-spinel and olivine with higher Cr# (0.76–0.84) and Mg# (0.91–0.94), respectively. They also display extremely low average abundances of CaO (0.13 wt.%) and Al_2O_3 (0.15 wt.%). The vast majority of the studied peridotites are also strongly depleted in REE. Simple batch and fractional melting models are not sufficient to explain their ultra-depleted composition. Whole-rock trace element abundances of the northern Vourinos mantle rocks can be modeled by up to 22–31% closed-system non-modal dynamic melting of an assumed primitive mantle (PM) source having spinel lherzolite composition. The highly depleted compositional signatures of the investigated peridotites indicate that they have experienced hydrous melting in the fore-arc mantle region above a SSZ. This intense melting event was responsible for the release of arc-related melts from the mantle. These melts reacted with the studied peridotites causing incongruent melting of pyroxenes followed by considerable olivine and Cr-spinel addition in terms of cryptic metasomatism. This later metasomatic episode has obscured any geochemical fingerprints indicative of an early mantle melting event in a MOR setting. The lack of any MOR-type peridotites in the northern Vourinos depleted mantle suite is quite uncommon for SSZ-type Neotethyan ophiolites.

1. Introduction

In the last decades a major breakthrough in our understanding of the compositional heterogeneity of the Earth's upper mantle has come through meticulous geochemical and petrological researches of abyssal (e.g., Dick and Bullen, 1984; Hellebrand et al., 2002; Niu, 2004; Piccardo et al., 2007; Seyler et al., 2007; Rampone et al., 2008; Tamura et al., 2008; Singh, 2013) and ophiolitic peridotites (e.g., Pearce et al., 2000; Zhou et al., 2005; Shi et al., 2008; Dai et al., 2011; Dokuz et al., 2011; Ahmed, 2013; Rajabzadeh et al., 2013). Abyssal peridotites are dominated by spinel lherzolites or clinopyroxene-rich, spinel harzburgites, which are considered as complementary residues of small melt fractions (~5–15%) produced by adiabatic melting of the mantle region beneath spreading centers (e.g., Niu, 2004; Marchesi et al., 2011). On the other hand, ophiolitic peridotites may show surprisingly diverse variations (Parkinson et al., 1992; Parkinson and Pearce, 1998; Pearce et al., 2000), ranging from relatively fertile peridotites to depleted restites formed after extraction of larger melt fractions (>20%) under hydrous conditions (e.g., Ishii et al., 1992; Jean et al., 2010; Uysal et al., 2012).

Recent geochemical studies on abyssal and ophiolitic peridotites revealed that several of their striking structural, textural and compositional characteristics cannot be explained solely as a result of separate melting episodes in diverse geotectonic regimes (e.g., Bizimis et al., 2000; Piccardo, 2003; Le Roux et al., 2007; Uysal et al., 2007; Liu et al., 2010; Merlini et al., 2011). Reactive porous

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flow and refertilization are two vital processes that are potentially proficient in modifying textures, mineral modes and compositions of depleted mantle peridotites (Seyler et al., 2007). In particular, their characteristic U-shaped primitive mantle-normalized rare earth element (REE) patterns combined with the presence of unstrained, rich in light REE (LREE), interstitial clinopyroxene and TiO_2-rich, euhedral, Cr-rich spinel even in depleted peridotites provide evidence for their interaction with melts causing cryptic metasomatism.

Numerous researches have pointed out that the mantle sections from the majority of Neotethyan ophiolites in the eastern Mediterranean region are predominantly characterized by depleted components in melt signatures (e.g., Beccaluva et al., 1984; Bizimis et al., 2000; Dilek and Furnes, 2009; Morishita et al., 2011). In addition, many Neotethyan peridotites belonging even to the same ophiolite complex display remarkable structural and compositional discrepancies, which indicate their composite petrological history, spanning multiple episodes of deformation, melting, depletion and metasomatism in a progressively changing geodynamic regime (e.g., Liu et al., 2010; Uysal et al., 2012, 2013a,b; Dai et al., 2013; Moghadam et al., 2013).

The Vourinos mantle unit is thought to represent a typical example of depleted peridotites that have experienced a rather complex evolution in the northern branch of the Neotethyan Ocean. In the current paper, new mineral and whole-rock major- and trace-element compositions of mantle peridotites from the northern sector of the Vourinos ophiolite complex are presented. The aim of this study is to characterize the petrogenesis of the exposed northern Vourinos peridotites and determine the petrological process responsible for their depletion in the mantle wedge above a supra-subduction zone (SSZ) setting, as it has been already proposed by previous studies.

2. General geological framework

Ophiolites of northwestern continental Greece represent part of the Tethyan ophiolitic belt, which extends from central Europe throughout the eastern Mediterranean area and into the Himalayas. The majority of Neotethyan ophiolites in Greece occur in two NNW–SSE trending sub-parallel belts, separated by the Gondwana-derived Pelagonian microcontinent (Beccaluva et al., 1984): (i) the Jurassic-Early Cretaceous 'Eastern Hellenic Ophiolites' (EHO; Smith, 1993), located east of the Pelagonian block (Bébien et al., 1986; Robertson, 2002) and (ii) the Jurassic 'Western Hellenic Ophiolites' (WHO), emplaced to the west of the Pelagonian ribbon continent (e.g., Smith, 1993; Bortolotti et al., 2004; Saccani et al., 2008; Fig. 1). According to the most valid geodynamic model the Pindos basin, located to the west of the Pelagonian microcontinent, gave rise to the 'WHO', whereas the Vardar basin, placed in the east-end of the Pelagonian block, generated the 'EHO'. Among the ophiolitic nappes of western Greece the mid-Jurassic Vourinos ophiolite complex represents one of the most complete and coherent sequences of Mediterranean ophiolites (Rassios and Smith, 2000), being analogous to the Penrose-type oceanic lithosphere (e.g., Moores, 1969; Anonymous, 1972; Rassios and Moores, 2006).

The Vourinos ophiolitic massif is over 40 km long and 25 km wide, tectonically resting on a thick south-west dipping sequence of limestones and clastic sediments (Wright, 1986; Fig. 1). The entire Vourinos section is 90° overturned to the west (e.g., Rassios and Dilek, 2009) and its approximate thickness is 12 km from its

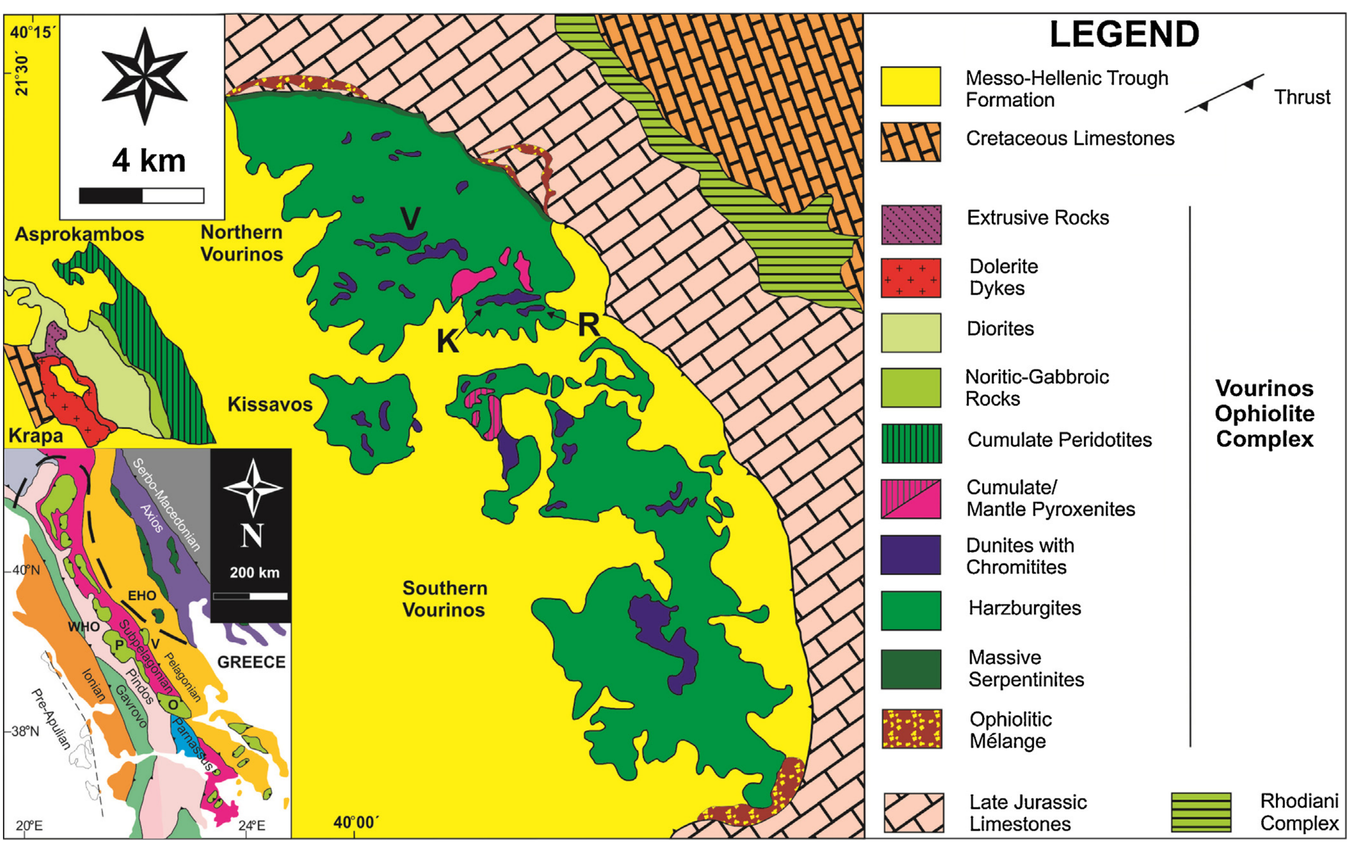

Fig. 1. Simplified geological map of the Vourinos ophiolite complex, showing the location of the studied areas (V: Voidolakkos district, K: Korsoumia district, R: Rizo district; modified after Moores, 1969; Rassios and Moores, 2006; Ghikas, 2007; Ghikas et al., 2010). Additionally, an inset simplified geological map of the west-central Balkan Peninsula is present, showing major tectonic zones and the distribution of ophiolite occurrences. Note that the "Western Hellenic Ophiolites" (WHO) are separated from the "Eastern Hellenic Ophiolites" (EHO) by a black dashed line. Key to lettering for different Jurassic ophiolites in the region: V, Vourinos; P, Pindos; O, Othrys (modified after Dilek et al., 2007).