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Os-isotope constraints on the dynamics of orogenic mantle: The case of the Central Balkans

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ABSTRACT

We used Os isotopic systematics to assess the geochemical relationship between the lithospheric mantle beneath the Balkans (Mediterranean), ophiolitic peridotites and lavas derived from the lithospheric mantle. In our holistic approach we studied samples of Tertiary post-collisional ultrapotassic lavas sourced within the lithospheric mantle, placer Pt alloys from Vardar ophiolites, peridotites from nearby Othris ophiolites, as well as four mantle xenoliths representative for the composition of the local mantle lithosphere. Our ultimate aim was to monitor lithospheric mantle evolution under the Balkan part of the Alpine-Himalayan belt. The observations made on Os isotope and highly siderophile element (HSE) distributions were complemented with major and trace element data from whole rocks as well as minerals of representative samples. Our starting hypothesis was that the parts of the lithospheric mantle under the Balkans originated by accretion and transformation of oceanic lithosphere similar to ophiolites that crop out at the surface.

Both ophiolitic peridotites and lithospheric mantle of the Balkan sector of Alpine-Himalayan belt indicate a presence of a highly depleted mantle component. In the ophiolites and the mantle xenoliths, this component is fingerprinted by the low clinopyroxene (Cpx) contents, low Al_2O_3 in major mantle minerals, together with a high Cr content in cogenetic Cr-spinel. Lithospheric mantle-derived ultrapotassic melts have high-Fo olivine and Cr-rich spinel that also indicate an ultra-depleted component in their mantle source. Further resemblance is seen in the Os isotopic variation observed in ophiolites and in the Serbian lithospheric mantle. In both mantle types we observed an unusual increase of Os abundances with increase in radiogenic Os that we interpreted as fluid-induced enrichment of a depleted Proterozoic/Archaean precursor. The enriched component had suprachondritic Os isotopic composition and its ultimate source is attributed to the subducting oceanic slab. On the other hand, a source–melt kinship is established between heterogeneously metasomatised lithospheric mantle and lamproitic lavas through a complex vein + wall rock melting relationship, in which the phlogopite-bearing pyroxenitic metasomes with high $^{187}Re/^{188}Os$ and extremely radiogenic $^{187}Os/^{188}Os > 0.3$ are produced by recycling of a component ultimately derived from the continental crust.

We tentatively propose a two-stage process connecting lithospheric mantle with ophiolites and lamproites in a geologically reasonable scenario: i) ancient depleted mantle "rafts" representing fragments of lithospheric mantle "recycled" within the convecting mantle during the early stages of the opening of the Tethys ocean and further refertilized, were enriched by a component with suprachondritic Os isotopic compositions in a supra-subduction oceanic environment, probably during subduction initiation that induced ophiolite emplacement in Jurassic times. Fluid-induced partial melts or fluids derived from oceanic crust enriched these peridotites in radiogenic Os; ii) the second stage represents recycling of the melange material that hosts above mantle blocks, but also a continental crust-derived terrigenous component accreted to the mantle wedge, that will later react with each other, producing heterogeneously distributed metasomes; final activation of these metasomes in Tertiary connects the veined lithospheric mantle and lamproites by vein + wall rock partial melting to generate lamproitic melts. Our data are permissive of the view that the part of the lithospheric mantle under the Balkans was formed in an oceanic environment.

1. Introduction

The Alpine-Himalayan accretionary orogen represents a diffuse and long lived convergent boundary between Eurasia and Gondwana. This

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convergent zone has been active since Permian–Mesozoic times, resulting in the consumption of major Tethyan ocean(s) along the Alpine-Himalayan system (e.g., Argand, 1924; Şengör and Yılmaz, 1981; Dercourt et al., 1986; Schmid et al., 2008). The convergence involved accretion of thin continental slivers that mostly originated by rifting from northern Gondwanaland (the so called Cimmerian continent), and numerous oceanic island arcs, which eventually formed an orogenic system consisting of multiple belts during late Mesozoic–Cenozoic times. Accretion resulted in a complex collage comprising numerous continental crustal blocks intercalated with ophiolitic terrains of various sizes and ages forming superimposed orogenic belts. In terms of lithological and chemical composition of lithosphere, including its mantle section, the agglomeration of continental blocks and oceanic arcs constitutes a fundamental difference when comparing Alpine-Himalayan accretionary orogeny with any “steady state” long active subduction zone. The net effect of this accretion is “mingling” of geologically and geochemically contrasting and severely mismatched compositions.

In the Balkan sector of the Alpine-Himalayan belt, the Eurasian and Gondwanan margins are represented by the Moesian microplate and Adria block, respectively. These major units were assembled during the Early Paleozoic and several microplates were docked on later until late Mesozoic time (Fig. 1). During the accretion, north to north(east) ward subduction of the Tethyan oceanic lithosphere and southwestward obduction of huge ophiolitic masses took place (Robertson and Karamata, 1994; Karamata et al., 1999; Karamata, 2006; Schmid et al., 2008). Finally, Tertiary postorogenic relaxation and orogenic collapse resulted in voluminous magmatism, mostly of high-K calkalkaline and ultrapotassic character (Cvetković et al., 2004a; Prelević et al., 2004, 2005).

Geochemical studies of ophiolites and mantle xenoliths revealed that both ophiolitic peridotites and lithospheric mantle of the Balkan sector of the Alpine-Himalayan belt experienced a high degree of previous melt extraction (Maksimović and Majer, 1981; Maksimović and Kolomejceva-Jovanović, 1987; Cvetković et al., 2004b, 2007a, 2007b). Moreover, Tertiary postorogenic ultrapotassic volcanic rocks derived from lithospheric mantle also show the presence of a component with a comparably high extent of depletion (Prelević et al., 2005). Based on this resemblance, Prelević and Foley (2007) and Cvetković et al. (2007a, 2007b) speculated that the Balkan lithospheric mantle shares a common history with SSZ (supra-subduction zone) oceanic lithosphere obducted to the surface as ophiolites (Fig. 1).

Studies of Os isotopes and highly siderophile element (HSE) i.e., Rhenium and Platinum Group Element (PGE) abundances have great potential for unravelling the genetic relationship between these mafic and ultramafic lithologies. The Os isotope system can provide the age of the last episode of melt extraction in peridotites (Walker and Morgan, 1989; Walker et al., 1989; Carlson and Irving, 1994; Pearson et al., 1995). Percolation of large volumes of mantle-derived melts (Büchl et al., 2004a, 2004b; Dale et al., 2012) or fluids derived either from the subducting slab (Brandon et al., 1996; Chesley et al., 1999; McInnes et al., 1999, 2001; Reisberg et al., 2004) or enriched deeper mantle (Alard et al., 2011), result in radiogenic Os enrichment in peridotite. Finally, HSE fractionation may differentiate between these two types of transport because of their considerable differences in geochemical behaviour. Therefore, constraining the age of the last depletion and monitoring the distribution and fractionation of HSE should help to decipher the origin of Serbian lithospheric mantle, and its potential relationship with ophiolites and ultrapotassic lavas may be clarified.

Here, we study the potential genetic kinship between lithospheric mantle and ophiolitic peridotites. Our holistic approach includes determination of the Os isotopic composition of Tertiary postcollisional ultrapotassic lavas, which tapped ultradepleted and heavily metasomatised lithospheric mantle in Oligocene–Miocene times. We combine these with new Os isotopic data of four mantle xenoliths sampled by Eocene alkaline volcanic rocks, aiming to monitor lithospheric mantle evolution at the beginning of the Tertiary. Finally, we compare all these data with that retrieved from Balkan ophiolites, including placer Pt alloys and whole rock samples, in order to characterize the oceanic mantle domains before the major collisional episode had taken place. The hypothesis to be tested is that lithospheric mantle under the Balkans has at least partly originated by accretion and transformation of oceanic lithosphere similar to ophiolites related to suprasubduction zone (SSZ).

2. Geochemical proxies for the composition of the Balkan lithospheric mantle

2.1. Tertiary lamproites

Oligocene–Miocene post-collisional ultrapotassic mantle-derived lavas of lamproitic affinity occur mainly in the Vardar ophiolite belt (Fig. 1). Similar to volcanic provinces from other parts of the Alpine-Himalayan belt, this volcanism is unrelated to active margin processes because it post-dates these, and it is initiated by post-collisional lithospheric delamination and/or slab roll-back (Davies and von Blanckenburg, 1995; Turner et al., 1996, 1999; Cvetković et al., 2004b; Prelević et al., 2008). The Serbian ultrapotassic mantle-derived lavas erupted at least 30 My after the Tethyan subduction along the Vardar trench had ceased (Cvetković et al., 2004a, 2004b; Prelević et al., 2005). They are interpreted as being derived from recently metasomatised lithospheric mantle that is strongly incompatible element-enriched with elevated $^{87}Sr/^{86}Sr$, $^{207}Pb/^{204}Pb$ and low $^{143}Nd/^{144}Nd$ and $^{176}Hf/^{177}Hf$ ratios (Prelević et al., 2005, 2007, 2008, 2010b). The lavas belong to the shoshonite series ($K_2O = 4–7\%$) of Peccerillo and Taylor (1976). They are near primary melts according to their high Mg#, Ni and Cr contents, and the presence of olivine xenocrysts derived from the mantle (Prelević et al., 2007, 2010a, 2012, 2013). The lavas' extremely high K_2O contents cannot be derived from ordinary mantle peridotite, but require the presence of phlogopite in the source. Based on the geochemical composition of the lavas, at least three components residing in the lithospheric mantle beneath the Balkans are recognized: i) a component derived from the continental crust which is responsible for the enriched isotopic composition of these lavas with radiogenic $^{87}Sr/^{86}Sr$ (up to 0.712) and $^{207}Pb/^{204}Pb$ (up to 15.7), and unradiogenic $^{143}Nd/^{144}Nd$ (as low as 0.5120) and $^{176}Hf/^{177}Hf$ (down to 0.28245)(Prelević et al., 2008, 2010b). This isotopic enrichment complements trace element enrichment indicated by high LILE/HFSE, exceptionally high Th/Nb, predominantly high Hf/Sm, very high Th/La, Sm/La and low Ce/Pb and Nb/U ratios (Conticelli et al., 2002; Prelević et al., 2005; Conticelli et al., 2007; Prelević et al., 2008, 2010b; Tommasini et al., 2011; Prelević et al., 2012, 2013). These tracers represent a hallmark for continental crust, pointing to a component within the mantle source similar to terrigenous sediments; ii) an ultradepleted component identified by the presence of very refractory Cr-spinel, high Fo olivine and relatively low FeO abundances in the lavas (Prelević and Foley, 2007); and iii) a component with an isotopic signature similar to that of MORB with unradiogenic $^{87}Sr/^{86}Sr$ and $^{206}Pb/^{204}Pb$ (Prelević et al., 2005, 2007, 2008).

2.2. Mantle xenoliths

Xenoliths occur in Palaeocene/Eocene mafic alkaline rocks that intrude East Serbian Carpatho-Balkanides along a north–south line parallel to the Vardar ophiolite belt (Fig. 1). The xenoliths dominantly comprise depleted harzburgites and clinopyroxene-poor lherzolites, with subordinate dunites and orthopyroxenites (Cvetković et al., 2004b, 2007a, 2007b). The xenoliths contain mostly <5 vol.% of modal clinopyroxene and are characterized by high Mg# in silicate minerals (>0.91), high Cr# in spinel (up to 0.7), and by distinctively low Al_2O_3 contents in orthopyroxene (as low as 1 wt.%). The mantle represented by these xenoliths had experienced mafic alkaline metasomatism that has slightly obscured their original composition (Cvetković et al.,