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The origin and age of the metamorphic sole from the Rogozna Mts., Western Vardar Belt: New evidence for the one-ocean model for the Balkan ophiolites

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ABSTRACT

This study brings new geochronological and petrochemical data from the metamorphic sole beneath the Rogozna Mts., Western Vardar ophiolite belt. The Rogozna metamorphic sole is located at the base of a serpentinite nappe and consists of amphibolites and talc-chlorite schists. The Rogozna amphibolites are medium- to fine-grained rocks with nematoblastic texture and pronounced foliation. They consist of green amphibole (~70 vol.%) with variable silica contents (6.4 to 7.8 Si apfu), as well as Mg# (molMg/[Mg + Fe_{tot}]; 0.53 to 0.77) and variably albitized plagioclase (~30 vol.%; Ab_{24}–Ab_{98}). Amphibolites are overprinted by a retrograde assemblage containing actinolite, epidote, clinoclore, sericite, chlorite, and magnetite. The amphibolites formed due to metamorphism of two basaltic suites: subalkaline/tholeiitic and alkaline. Subalkaline/tholeiitic amphibolites possess low Zr, Nb, Y, Th, Hf, TiO_2, and P_2O_5 values and a LREE-depleted pattern, typical for the N-MORB (normal mid ocean ridge basalt) to BAB (back-arc basalt) origin. Alkaline amphibolites show elevated concentrations of Zr, Nb, Y, Th, Hf, TiO_2, and P_2O_5 with a LREE-enriched pattern typically displayed by OIB (ocean island basalt). Amphibolites were crystallized during intra-oceanic thrusting at temperatures between 685 °C and 765 °C and at a depth of 12–17 km. $^{40}Ar/^{39}Ar$ cooling ages of amphibole, ranging from 165 to 170 Ma, slightly postdate the sole formation. Talc-chlorite schists are related to retrograde greenschist-facies metamorphism. They consist of Fe-rich talc and Cr-rich chlorite (peninite-diabantite) pseudomorphs after amphibole and MORB-type Cr-Al spinel, surrounded by Al- and Mg-poor ferrit chromite. The occurrence of ferrit chromite is related to earlier, amphibolite facies metamorphism. Chlorite pseudomorphs after amphibole were formed at 300–410 °C.
This study suggests that there is no essential difference in the emplacement age of the Dinaric and West Vardar ophiolite belts supporting the interpretation involving a single Mesozoic ocean in the Balkan sector.

1. Introduction

One of the most intriguing questions that puzzle geologists working in south-eastern Europe is the number of oceans which existed between the coastlines of Africa and Europe throughout the Triassic–Jurassic time. The ocean or oceans left behind hundreds of kilometers of ophiolites that stretch along the central part of the Balkan Peninsula. The ophiolites are geographically separated by the Adria-derived Drina-Ivanjica, Jadar, Pelagonian, and Kopaonik Paleozoic units, and therefore crop out as three subparallel belts. These belts are commonly named Dinaric, Western Vardar (WV) and Eastern Vardar (EV) ophiolites, from the southwest to the northeast, respectively (Fig. 1; sensu Robertson et al., 2009; Schmid et al., 2008). The south-westernmost belt of Dinarides is also referred to as the External belt whereas the Western and Eastern Vardar belts together compose the so-called Internal belt (sensu Bortolotti et al., 2012; Schmid et al., 2008). Previous authors pointed out that the Dinaric ophiolite belt consists of fertile spinel lherzolite whereas the Western and Eastern Vardar ophiolite belts contain depleted spinel lherzolites, harzburgites, and dunites (Bazylev et al., 2009; Garašić et al., 2004; Karamata et al., 1980; Lugović et al., 1991; Trubelja et al., 1995). This general compositional pattern was mainly used for arguing that these presumably 'lherzolite-' and 'harzburgite-belts' originated in a mid-ocean ridge (MOR)/back-arc basin (BAB) and supra-subduction zone (SSZ) geotectonic setting, respectively (e.g. Robertson and Karamata, 1994). Data acquired during the last two decades showed that this division is an oversimplification both in terms of peridotite composition and with respect to their geotectonic setting.

The existing geodynamic interpretations of the Balkan ophiolites can be roughly systematized into two contrasting opinions. There are authors arguing that all the ophiolites outcropping within the Dinaric, Western and Eastern Vardar belts represent remnants of a single

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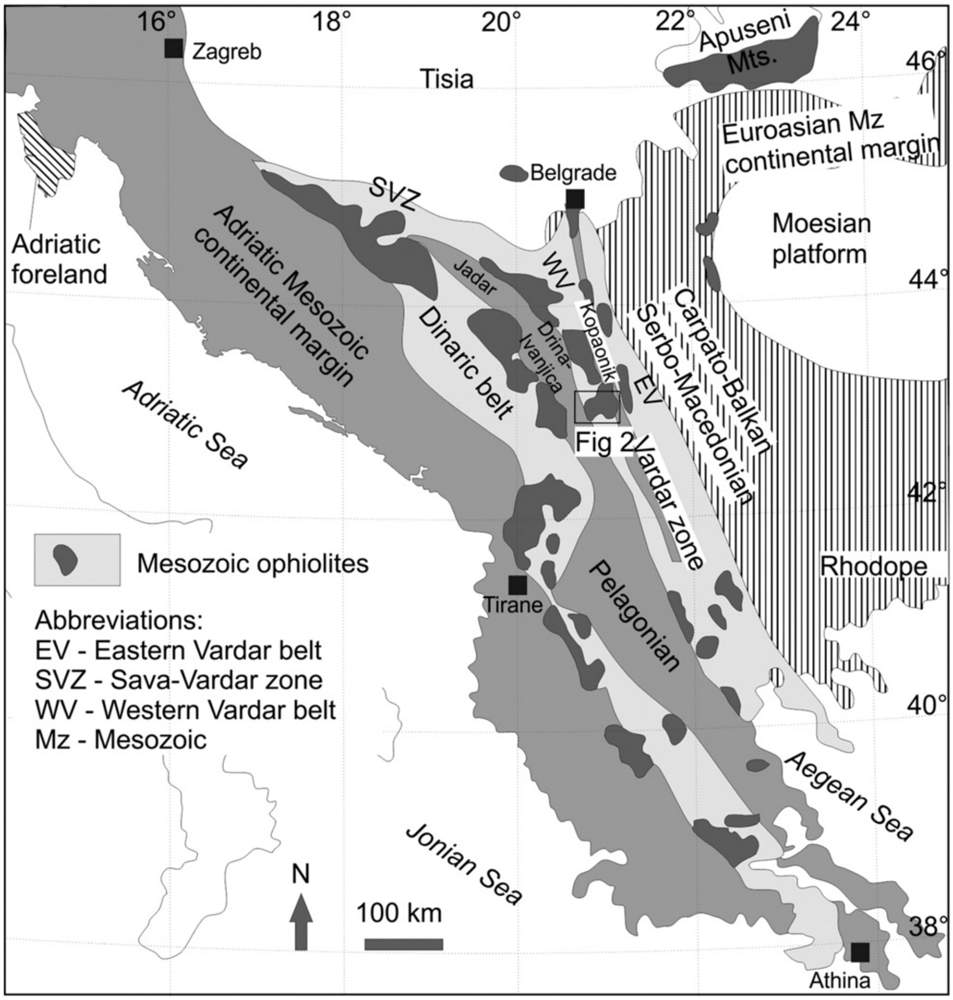

Fig. 1. Simplified map of the main tectonostratigraphic units of the Central Balkan Peninsula. Frame indicates location of Fig. 2.

Meliata-Vardar ocean, which opened in Mid to Late Triassic and closed in the Upper Jurassic time (Bortolotti et al., 2012; Schmid et al., 2008, and references therein). According to this opinion, the closure of this ocean was associated with westward obduction of huge ophiolite nappes over the passive margin of the Adria plate. Both Dinaric and West Vardar ophiolites should represent remnants of these obducted ophiolites, whereas the narrow East Vardar belt would be associated with obduction onto the European plate, possibly associated with another geodynamic event. Consequently, all Paleozoic units, which presently geographically separate the Dinaride and West Vardar ophiolite belts, represent marginal parts of the Adria plate now exposed due to erosion effects and post-obduction out-of-sequence thrusting (Schmid et al., 2008). In contrast to the 'one-ocean view', there are a number of interpretations involving more than one ocean in explaining the origin of the Balkan ophiolites (e.g. Bazylev et al., 2009; Hoeck et al., 2002; Lugović et al., 1991; Pamić et al., 1998, 2002; Robertson and Karamata, 1994; Smith and Spray, 1984; Trubelja et al., 1995). Although they differ in many specific points of geodynamic interpretation, most of these authors believe that the spatially separated ophiolites derive from different (pre-)Mesozoic oceans, which may or may not partially overlap in their spreading and closure age. In this context, the Paleozoic tectonic units in-between the ophiolite belts should represent continental terranes, i.e. microcontinents, which were once separated by areas floored by the oceanic crust (e.g. Dimitrijević, 1982; Karamata, 2006; Robertson and Karamata, 1994). One line of evidence that was used by all interested authors was related to the age of emplacement, which was unraveled from studies of metamorphic soles, although this aspect appeared to be unequally constrained in these ophiolite belts. The emplacement history of the External belt (i.e. Dinaric ophiolite belt) is relatively well recorded by radiometric dating. It is hence generally accepted that this ophiolite belt was obducted onto the Adria plate during Mid to Late Jurassic times (Dimo-Lahitte et al., 2001; Gartzos et al., 2009; Karamata and Lovrić, 1978; Lanphere et al., 1975; Lugović et al., 2006; Pomonis et al., 2002; Spray and Roddick, 1980). On the other hand, radiometric ages of the emplacement of the internal belts (i.e. Western and Eastern Vardar ophiolites) are poorly constrained with a single published data from the Tejići locality (Povlen, west Serbia) revealing ages of 150–160 Ma (Srećković-Batoćanin et al., 2002).

Generally, metamorphic sole rocks develop during the onset of the intra-oceanic thrusting (sensu Hacker, 1994; Hacker and Mosenfelder, 1996; Wakabayashi and Dilek, 2003). This mechanism can be described as welding of the oceanic crust of the footwall over the young and hot oceanic lithosphere of the hanging wall. General characteristics of the metamorphic sole rocks are the following: (i) they structurally underlie ophiolite complexes or occur as dismembered parts within the ophiolite melange (ii) their thickness does not exceed 500 m, and iii) they are characterized by a high (>1000 °C/km) and, sometimes, by an inverted thermal gradient starting with peak metamorphic conditions at the base of the ophiolite and decreasing downward. Their geochemical composition usually reflects the geochemistry of the footwall, while their age is related to post-metamorphic cooling through closure temperatures of the given mineral assemblage.