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New insights into tectonic relations between the Eastern Vardar Ophiolitic and Serbo-Macedonian units: inferences from a microtectonic study in central Serbia

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Abstract. A microtectonic study was conducted in the Levač region of central Serbia. Here, the tectonic contacts between the Europe-derived units, including the Serbo-Macedonian unit and Jurassic sedimentary cover of the European margin, and the Eastern Vardar Ophiolitic unit, are exposed at the surface. The results indicate that the contact zone underwent at least two ductile contractional deformation phases. The older contraction was associated with the formation of isoclinal folding and top-to-SE shearing in the immediate contact between the Eastern Vardar ophiolites and the Jurassic sedimentary cover of the European continental margin. This older contractional phase was likely associated with thrusting during the latest Jurassic obduction of the Eastern Vardar ophiolites over the European margin. The thrusting of the Eastern Vardar ophiolites created a sub-ophiolitic mélange currently preserved in a narrow zone at their contact with the underlying Jurassic sediments, which in turn underwent metamorphism in the lower greenschist facies. The obduction-related deformation was highly overprinted by a younger, top-to-W contraction associated with the Cretaceous–Paleogene continental collision between Europe- and Adria-derived units.

Key words:
Eastern Vardar Ophiolitic unit, Serbo-Macedonian unit, microtectonic analysis, latest Jurassic obduction, post-obductional deformations.

Апстракт. Микротектонска студија спроведена је у области Левач у централној Србији, где су тектонски контакти између јединица европског афинитета, које укључују Српско-македонску јединицу и јурски седиментни покров европске маргине, и јединице Источно-вардарских офиолита откривени на површини терена. Добијени резултати указују на то да је зона контакта претрпела најмање две дуктилне фазе контракционих деформација. Старију контракциону фазу одликује формирање изоклиних набора и смицање ка југоистоку у зони непосредног контакта између Источно-вардарских офиолита и јурског седиментног покрова европске континенталне маргине. Ова фаза контракционих деформација највероватније је повезана са навлачењем током обдукције Источно-вардарских офиолита преко европске маргине, која се одиграла крајем јуре. Навлачење Источно-вардарских офиолита довело је до

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Кључне речи:
Источно-вардарски офиолити, Српско-македонска јединица, микротектонска анализа, касно-јурска обдукција, пост-обдукционе деформације.

формирања субофиолитског меланжа, који је очуван у виду уске зоне на контакту са јурским седиментима у подини, који су, заузврат, претрпели метаморфизам у фацији зелених шкриљаца. Деформације изазване обдукцијом су у великој мери поништене млађом контракцијом у смеру ка западу, која је изазвана континенталном колизијом јединица европског и адријског афинитета на прелазу из креде у палеоген.

Introduction

The Middle Jurassic to Paleogene geodynamic evolution of the junction area between the Dinarides and Carpathians (Fig. 1) was controlled by the progressive closure of the northern branch of the Neotethys Ocean (i.e., the Vardar Ocean sensu Dimitrijević, 1997) situated between the Adria-derived tectonic units of the Internal Dinarides and the Europe-derived Tisza and Dacia tectonic mega-

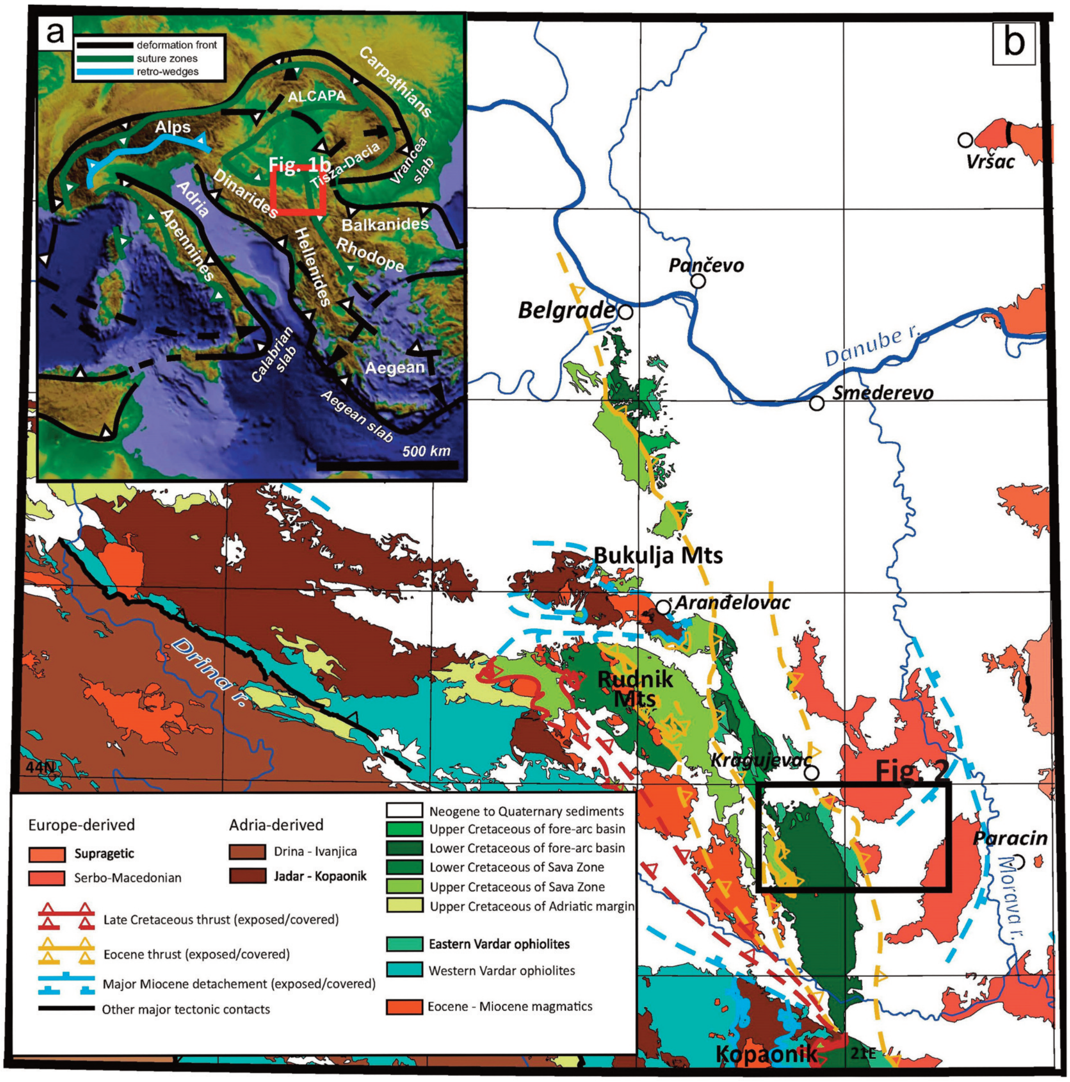

Fig. 1. ***a.*** *Topographic map of Central Mediterranean orogens, displaying suture zones, orogenic fronts, and retro-wedges (modified after Krstekanić et al., 2020). The red rectangle marks the position of Figure 1b;* ***b.*** *Geological map of the connection between the Dinarides, Serbian Carpathians, and Pannonian Basin (modified after Stojadinovic et al., 2022). The black rectangle indicates the location of the geological map in Figure 2.*

units. The convergence between Adria and Europe since the Middle Jurassic culminated during the latest Jurassic bi-vergent emplacement of the Vardar Ocean-related ophiolites over both continental margins (the Western and Eastern Vardar Ophiolitic units of Schmid et al., 2008; Fig. 1b). The latest Jurassic obduction of the Western Vardar Ophiolitic unit in the Internal Dinarides has been well constrained in terms of thrusting-related deformation and the metamorphic overprint associated with the burial of the Triassic–Jurassic pre-obduction sedimentary sequence (see Porkoláb et al., 2019). In contrast, the mechanisms of the tectonic juxtaposition of the Eastern Vardar Ophiolitic unit against the Serbo-Macedonian unit, which comprises the innermost segments of the Dacia mega-unit in central Serbia (Fig. 1b), are still not well constrained.

In the Levač region of central Serbia, the tectonic contacts between the Eastern Vardar Ophiolitic and Serbo-Macedonian units were not fully overprinted by the complex Late Mesozoic and Cenozoic deformations (see Chapter 2) and are still exposed at the surface (Fig. 2). Therefore, in this area we conducted a micro-scale structural analysis supported by petrological observations on samples collected in several rock formations along the contacts between the two tectonic units. Such a methodological approach enabled the determination of mineral assemblages, metamorphic grades, and the sequence of micro-scale deformations and tectonic transport on the thin-section scale. The obtained results allowed for drawing new inferences about the succession and kinematics of the main deformation phases, which affected the contact between the Eastern Vardar Ophiolitic and Serbo-Macedonian units in central Serbia.

Tectonic framework

The Serbo-Macedonian unit represents a belt of medium-grade metamorphic rocks between the Pannonian Basin in the north and the Hellenic-Rhodope orogens in the south (Fig. 1a; Dimitrijević, 1997). Tectonically, it comprises the innermost segments of the Europe-derived Dacia mega-unit at the contact with Adria-derived units of the Internal Dinarides (Fig. 1b). The Serbo-Macedonian metamorphics derive from a late Neoproterozoic–Silurian volcano-sedimentary complex (von Raumer et al., 2003), which underwent medium-grade metamorphic overprint during the late Paleozoic Variscan orogeny (Antić et al., 2016a). The Alpine geodynamic evolution of the transition area between the Adria- and Europe-derived continental units were associated with the Triassic opening and the Middle Jurassic to Eocene closure of their intervening northern branch of the Neotethys Ocean (i.e., Vardar Ocean, Dimitrijević, 1997). In the Middle Jurassic, a Europe-dipping (i.e., dipping towards Europe) subduction zone developed near the former Neo-Tethyan ridge, resulting in the formation of the Western Vardar ophiolites, which were subsequently obducted over the Adria-derived continental margin of the Internal Dinarides during the latest Jurassic (see Schmid et al., 2008). However, several regional studies from the Apuseni Mts. in the north to the Hellenic-Rhodope orogens in the south provided different models for explaining the formation of the Eastern Vardar ophiolites and their subsequent tectonic juxtaposition against the various segments of the Dacia mega-unit (Saccani et al., 2008; Bortolotti et al., 2013; Petrović et al., 2015; Gallhofer et al., 2017; Maffione and van Hinsbergen, 2018). The Eastern Vardar ophiolites originate from an intra-oceanic spreading centre formed above another Middle to Late Jurassic subduction zone developed further east, close to the European continental margin (Božović et al., 2013). During the subduction, calc-alkaline granites, formed in an intra-oceanic island arc setting (Gallhofer et al., 2017), intruded the Eastern Vardar ophiolites. Several studies imply that the Eastern Vardar ophiolites formed above a Europe-dipping Neo-Tethyan subduction zone developed along the continental margin of the Dacia mega-unit after the closure of Paleo-Tethys (e.g., Saccani et al., 2008 and references therein). Gallhofer et al. (2017) suggest a sudden flip in subduction polarity (from Europe- to Adria-dipping) towards the end of the Jurassic to explain the emplacement of the Eastern Vardar ophiolites onto the Dacia. Contrastingly, other recent studies (Maffione & van Hinsbergen, 2018) propose that the Eastern Vardar ophiolites formed by spreading above an existing Adria-dipping subduction zone ac-

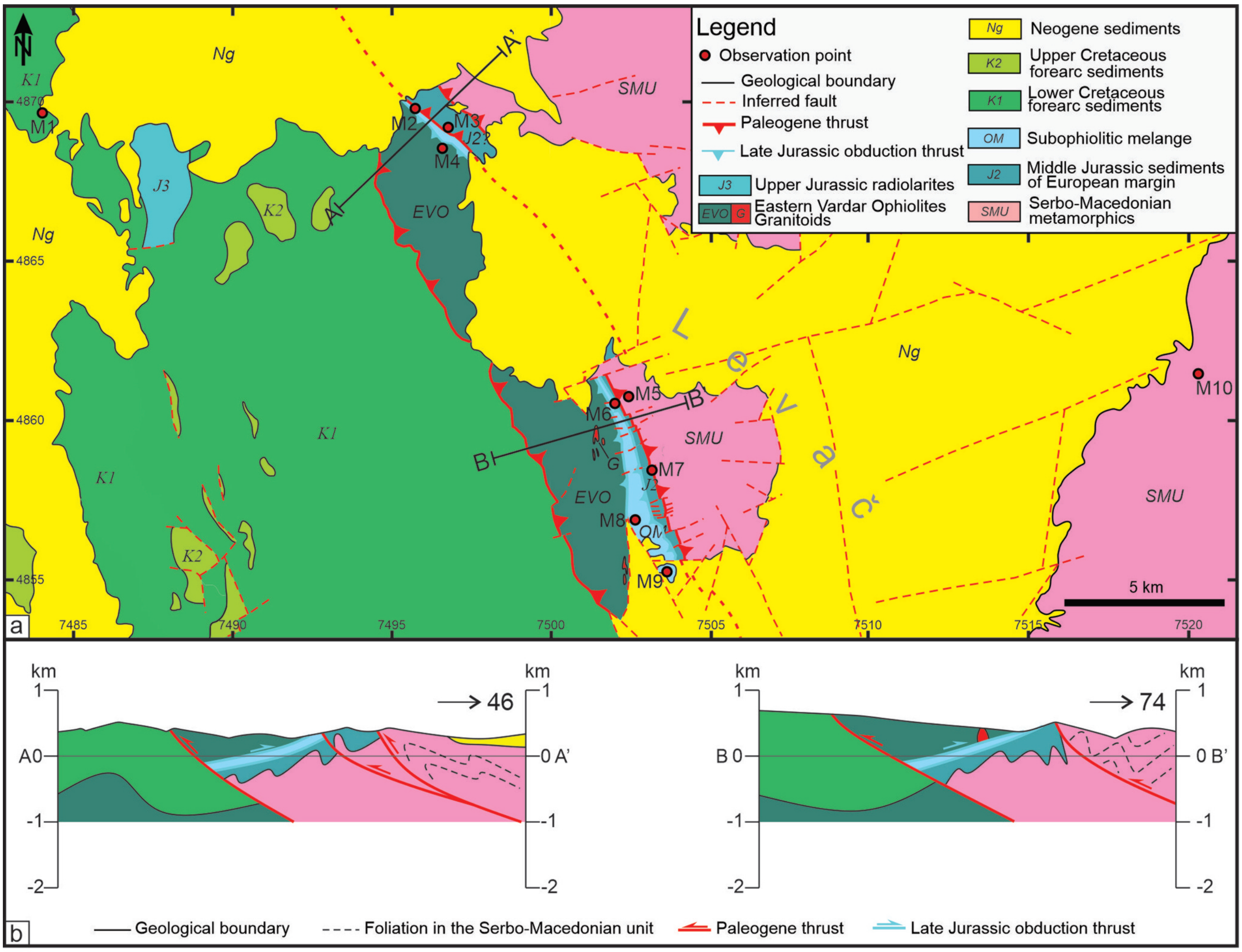

Fig. 2. a. *Geological map of the Levač region in central Serbia (map projection is MGI Balkans 7), modified after the Basic geological map of Yugoslavia scale 1:100.000, sheets Kraljevo (Marković et al., 1963) and Paraćin (Dolić et al., 1978).* ***b.*** *Simplified cross-sections across the two studied areas. Cross-sections implement field data from this study and data available from the Basic geological map of Yugoslavia scale 1:100.000, sheets Kraljevo (Marković et al., 1963) and Paraćin (Dolić et al., 1978). Cross-section locations are indicated in Fig. 2a.*

commodating the closure of the Paleo-Tethys Ocean since the Triassic. According to several studies, the latest Jurassic collision of the island arc in the Apuseni Mts. and the continental ribbon in the Hellenic-Rhodope region with the Dacia mega-unit resulted in marginal obduction of the ophiolites and island arc series onto the European continental margin (e.g., Bortolotti et al., 2013; Reiser et al., 2017a,b; Gallhofer et al., 2017). Nevertheless, a geophysical modelling study conducted in Serbia (Petrović et al., 2015) suggests underthrusting of the Eastern Vardar ophiolites beneath the Serbo-Macedonian segment of the Dacia mega-unit.

Following the latest Jurassic emplacement of the Vardar ophiolites, the ongoing Cretaceous convergence between Adria and Europe was controlled by the Europe-dipping subduction of the remaining Neo-Tethyan oceanic lithosphere (i.e., the Sava subduction system of Schmid et al., 2020). The Cretaceous overstep sedimentary sequence of the Eastern Vardar Ophiolitic unit was deposited in a fore-arc basin developed over the Europe-derived Serbo-Macedonian continental margin (see Toljić et al., 2018). The Late Cretaceous retreat and steepening of the Neo-Tethyan subduction zone triggered the syn-subductional extension in the European upper plate of the Sava subduction system. This extension resulted in the exhumation of the medium-grade Serbo-Macedonian metamorphics (Antić et al., 2016b; Erak et al., 2017; Stojadinovic et al., 2021) while coevally creating subsidence and syn-depositional bimodal magmatism in the fore-arc basin in the frontal parts of the European continental margin (Toljić et al., 2020). The latest Cretaceous–Paleogene Adria-Europe continental collision along the Sava Zone (Ustaszewski et al., 2010) resulted in large-scale WSW-wards thrusting of the European fore-arc basin and its basement over the Cretaceous basins on the distal Adriatic margin (Stojadinovic et al., 2022). During the Oligocene–Miocene, the northern segment of the Serbo-Macedonian unit was strongly influenced by the processes associated with the Pannonian Basin extension (Matenco & Radivojević, 2012; Radivojević et al., 2022), which overprinted the effects of earlier deformation phases to a large extent. Consequently, large segments of the northern Serbo-Macedonian unit are currently buried beneath the Neogene deposits of the Morava Valley Corridor (Figs 1b, 2; Stojadinovic et al., 2021).

Geological setting of the Levač area

The Serbo-Macedonian medium-grade metamorphics outcrop in the eastern parts of the Levač region as several domes predominantly made up of gneisses and micaschists, surrounded by the Neogene sediments of the Morava Valley Corridor (Figs. 2, 3, and 4a). According to the available K-Ar dating obtained in the Batočina area, located around 20 kilometers north-eastwards from our research area, the youngest heating event recorded in the medium-grade Serbo-Macedonian metamorphics occurred in the Late Jurassic (before 150.6±5.8 Ma at temperatures around 350 °C, Balogh et al., 1994). The thermochronological data obtained in the Jastrebac extensional dome, located around 60 kilometers further south, indicate that Serbo-Macedonian metamorphics subsequently underwent two stages of cooling and exhumation associated with the two separate extensional phases in the Late Cretaceous and Oligocene–Miocene (Erak et al., 2017). In very few locations, the Serbo-Macedonian metamorphics are found in tectonic contact with scarce carbonates and clastics, representing remnants of the Mesozoic pre-obductional sedimentary sequence of the European continental margin that underwent lower greenschist facies metamorphism (Figs. 2, 3, and 4b, c). Based on the palynomorphs association depositional age of these metasediments' was determined as the Middle Jurassic (Dolić et al., 1978). However, other metasediments of the Middle Triassic age were also found in a similar tectonic position in the broader area (Erak et al., 2017 and references therein). The Eastern Vardar ophiolites, located in the central parts of the research area (Fig. 2), are mainly composed of gabbros and dolerites with sub-

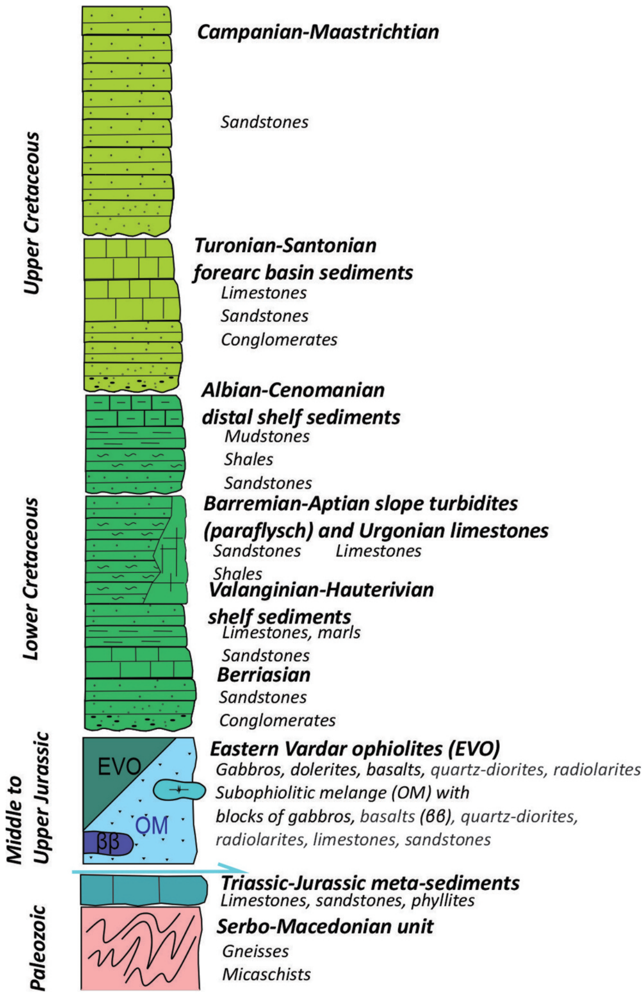

Fig. 3. *General geological column of the metamorphic basement units and Mesozoic sedimentation along the European continental margin in central Serbia (after Marković et al., 1963; Dolić et al., 1978; Toljić et al., 2018). Cyan arrow marks obduction-related thrusting.*

Fig. 4. a. *The Serbo-Macedonian gneisses at the observation point M10;* ***b.*** *Middle Jurassic sheared meta-sandstones at the observation point M3;* ***c.*** *Recrystallized Middle Jurassic limestones at the observation point M7;* ***d.*** *Gabbros from the Ždraljica Ophiolitic Complex at the observation point M4;* ***e.*** *Block of basalts and limestones in the sub-ophiolitic mélange at the contact between the Eastern Vardar Ophiolites and the Middle Jurassic metamorphosed sediments at the observation point M8;* ***f.*** *Lower Cretaceous Urgonian reef limestones at the observation point M1.*

ordinate pillow basalts (Figs. 3 and 4d), intruded by the shallow quartz-diorites (i.e., the Ždraljica Ophiolitic Complex, Šarić et al., 2009). The age of the quartz-diorites intrusions was dated to 168.4 ± 6.7

(Resimić-Šarić et al., 2005). In the north-western part of the research area, a few meters thick succession of Upper Jurassic radiolarites in alternation with shales and siliceous mudstones is found (Figs. 2 and 3, Marković et al., 1963). These radiolarian-bearing rocks represent the seafloor sediments deposited on top of the Eastern Vardar ophiolites. Callovian to the latest Oxfordian ages, which were obtained in the Belgrade area further north from radiolarites in a similar tectonic position on top of the Eastern Vardar ophiolites, yield evidence for the active seafloor spreading in the Eastern Vardar domain during the Late Jurassic (see Djerić et al., 2010). Sub-ophiolitic mélange is found in a narrow zone at the contact between the Eastern Vardar ophiolites and the Middle Jurassic metamorphosed sediments (Figs 2, 3). It is composed of blocks of gabbros, basalts, radiolarites, quartz-diorites, altered sandstones, and limestones, which are embedded in a matrix made up of slightly metamorphosed, sheared reddish shales (Fig. 4e). The post-obductional overstep sedimentary sequence of the Eastern Vardar Ophiolitic unit is represented by the Lower to Upper Cretaceous sediments deposited in a fore-arc basin along the European continental margin (see Toljić et al., 2018). The onset of fore-arc deposition could even be in the latest Jurassic, according to Tithonian ages of the reef limestones, which were determined in the broader area (Dimitrijević, 1997). The initial coarse-clastic transgressive sequence is followed by Lower Cretaceous distal shelf clastics and proximal slope turbidites in the central parts of the basin and the Urgonian reef limestones along the basin margins (Figs. 3 and 4f).

Methodological approach

Three oriented and four non-oriented samples were analyzed by optical microscopy to determine mineral assemblages, metamorphic grade, and micro-scale deformation located at the contact between the Eastern Vardar Ophiolitic and Serbo-Macedonian units. For the oriented samples, each thin-section was cut parallel to the stretching lineation in the taken sample. The microstructures were analyzed to determine a deformation sequence and the tectonic transport at the thin-section scale. The locations of collected samples are shown in Fig. 2, and the results of analyses are presented in Fig. 5 and Table 1.

Results

Two thin sections taken in the lithologically heterogeneous unit, representing sub-ophiolitic melange below the Eastern Vardar ophiolites and above the European Jurassic sediments (observation points M8 and M9, Figs. 4e and 5a-c), show a rock assemblage made of angular, weakly sorted fragments of fine-grained clastics and metabasalts/metaspilite. The dimensions of individual fragments in the thin section are highly variable, ranging from less than half a millimeter to several millimeters (up to more than a centimeter), with no systematic orientation of the clasts (Figs. 5a, b). A very fine-grained section of this heterogeneous unit (Fig. 5c) is built of well-sorted quartz, sericite, and chlorite grains with subordinate stilpnomelane smaller than 0.01 mm, indicating pelitic protolith. Based on the mineral assemblages (both in coarse and fine-grained sections) and by following the criteria of Bucher & Grapes (2011), we estimate that the sub-ophiolitic melange underwent low-grade greenschist facies metamorphism reaching 350 °C and 300-400 MPa.

The Jurassic sediments of the European margin currently in immediate contact with the Eastern Vardar ophiolites (observation points M2 and M6) are made of weakly metamorphosed limestones (i.e., calcite marbles). These marbles are dominantly built of recrystallized calcite with quartz and muscovite grains within the carbonate sequence (Figs. 5d, e). Locally preserved stylolites are sub-parallel or slightly oblique to the foliation defined by the elongated recrystallized calcite. Quartz demonstrates undulose extinction and locally bulging and weak sub-grain rotation. In addition to quartz and muscovite as non-carbonate impurities, marbles contain chromite grains (Fig. 5e).

The sample taken at direct contact between the European Jurassic limestones/marbles and Eastern Vardar ophiolites (observation point M6) shows a metamorphic rock made of muscovite/sericite, chlorite, and quartz, with subordinate tourmaline (Figs. 5f, g), with protolith likely being a sandstone. Quartz is demonstrating undulose extinction and bulging recrystallization. Mica minerals and elongated quartz lenses are defining a pervasive foliation, along which locally isoclinal fold hinges are preserved (Fig. 5f). The fold hinges indicate a slight drag along the pervasive foliation (Fig. 5f) during the top-to-SE tectonic transport, which is documented by abundant micafish and sigmoidal quartz lenses (Fig. 5g). However, along the same contact zone, at the observation point M2, an originally pelitic rock subjected to

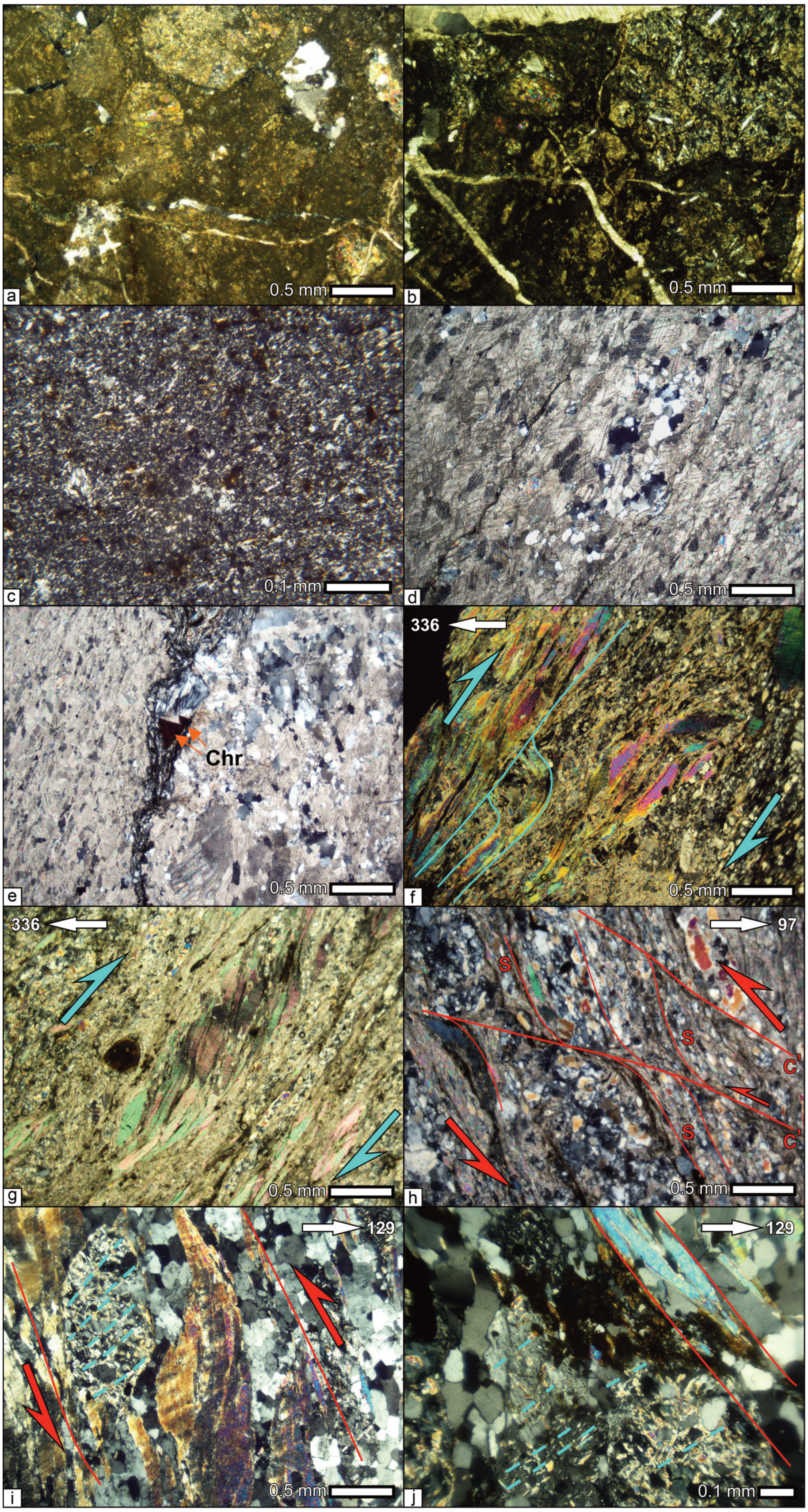

Fig. 5. *Thin sections were taken across the East Vardar Ophiolites/Serbo-Macedonian contact zone. The number in the top left/right corner indicates the strike azimuth of the oriented thin section parallel to the stretching lineation at the sampling site. Locations of sampling sites are displayed in Figure 2.* ***a, b****. Angular fragments in the sub-ophiolitic mélange at observation point M8;* ***c.*** *Fine-grained section of the sub-ophiolitic mélange at observation point M9; d, e) Marbles of the European margin at observation points M6 and M2 respectively;* ***f, g.*** *Greenschist metamorphics at the contact between the Eastern Vardar ophiolites and the Jurassic metamorphosed limestones at the observation point M6;* ***h.*** *Greenschist metamorphics at the contact between the Eastern Vardar ophiolites and the Jurassic metamorphosed limestones at the obser-vation point M2;* ***i, j.*** *Serbo-Macedonian gneiss at observation point M5. Red lines indicate younger foliation, while cyan dashed lines indicate remnants of the older foliation.*

Table 1. *Sampling and mineralogy information about the analyzed thin sections.*

Sample	Latitude	Longitude	Foliation dip-direction/dip	Stretching lineation dip-direction/dip	Mineral/rock assamblage	Tectonic unit	Deformation observation/event
M2-1	43°58'23"N	20°56'26"E	N/A	N/A	calcite, quartz, sericite, chromite	European margin - Jurassic sediments	-
M2-2	43°58'23"N	20°56'26"E	54/70	97/64	muscovite/sericite, chlorite, quartz, pyrite	European margin sediments - Ophiolitic melange contact zone	top-W tectonic transport
M5-1	43°53'29"N	21°01'29"E	47/87	129/70	quartz, muscovite, sericite, chlorite, K-feldspar, limonite, zircon, apatite	European basement (Serbo-Macedonian unit)	Younger: top-W tectonic transport along NE-dipping foliation; Older: ~W-dipping foliation
M6-1	43°53'21"N	21°01'16"E	N/A	N/A	calcite, quartz, sericite, chromite	European margin - Jurassic sediments	-
M6-2	43°53'21"N	21°01'16"E	32/70	336/57	muscovite, sericite, chlorite, quartz, tourmaline	European margin sediments - Ophiolitic melange contact zone	top-SE tectonic transport
M8-1	43°51'11"N	21°01'36"E	N/A	N/A	metabasalt/metaspilite and pelitic angular clasts	Ophiolitic melange	-
M9-1	43°50'27"N	21'02'22"E	N/A	N/A	quartz, sericite, chlorite, stilpnomelane	Ophiolitic melange	-

a greenschist facies metamorphism (with a similar mineral assemblage to that of the above-described observation point M6, see Table 1), demonstrates top-to-W tectonic transport, indicated by c'-s structure in the thin-section (Fig. 5h). Accounting for the mineral assemblages (by following the criteria of Bucher & Grapes, 2011), undulose extinction of quartz and its bulging recrystallization (by following the criteria for natural temperature microgauges such as deformed quartz by Passchier & Trouw, 2005 and references therein), both observed rocks' metamorphic conditions likely reached 300–400 °C and 300–400 MPa.

The gneiss of the Serbo-Macedonian unit (observation point M5, Figs. 2, 5i, j) is made of quartz, muscovite/sericite, chlorite, feldspar and accessory zircon, and apatite. Quartz and micas define the NE-dipping pervasive foliation (Fig. 5i). Quartz grains show undulose extinction and bulging to sub-grain rotation recrystallization. At the same time, the chlorite indicates retrometamorphism by the local transition to limonite. Large micafish and sigma-clasts indicate top-to-WNW tectonic transport along the pervasive foliation (Fig. 5i). Interestingly, within grains that are less overprinted by later deformation/metamorphism phases, an older foliation is preserved, defined by the systematic orientation of small-grained sericite that dip towards WNW (see blue dashed lines in Figs. 5i, j).

Interpretation and discussion

The results of our microtectonic study yield the first structural evidence for the emplacement of the Eastern Vardar ophiolites over the European continental margin in central Serbia. This emplacement was associated with the asymmetric to isoclinal folding and top-to-SE shearing, documented in thin-sections (Fig. 5f, g) and by reconstructing map-scale folding (Fig. 2b), and the formation of sub-ophiolitic melange in the immediate contact between the Eastern Vardar ophiolites and the Jurassic sedimentary cover of the European margin (Figs. 2, 4e, 5a-c), altogether indicating contractional deformation. This top-to-SE thrusting was plausibly associated with the obduction of the Eastern Vardar ophiolites over the Jurassic sedimentary cover of the European continental margin. The obduction most probably took place in the latest Jurassic times since it post-dates the Middle Jurassic intrusion of granitoids that have a subduction-related origin (Šarić et al., 2009) and the deposition of the Late Jurassic radiolarite-bearing seafloor sediments on top of the Eastern Vardar ophiolites (Djerić et al., 2010), and pre-dates the new Berriasian transgressive depositional cycle on the European margin (see Stojadinović & Krstekanić, 2023).

In central Serbia, the direct structural evidence for the obduction-related thrusting of the Eastern Vardar ophiolites over the European continental margin is rare because such contacts were mostly overprinted by the subsequent deformation, including the Late Cretaceous extensional exhumation of the Serbo-Macedonian unit, the latest Cretaceous-Paleogene Europe-Adria continental collision, and the Oligocene-Miocene Pannonian Basin extension (Matenco & Radivojević, 2012; Erak et al., 2017; Stojadinovic et al., 2022). However, other indirect evidence favors the latest Jurassic obduction as a cause of the earlier top-to-SE ductile deformation we observed in this study. For example, the lower greenschist facies metamorphic overprint is recognized in Mesozoic sediments adjacent to the Eastern Vardar ophiolites along the frontal parts of the entire European margin in central and southern Serbia and North Macedonia (see Erak et al., 2017 and references therein), and can likely be associated with the burial of these metasediments during the obduction-related thrusting. Furthermore, chromite grains in the Jurassic carbonate sediments of the European margin suggest the erosion of the frontal parts of the ophiolites and the deposition of the eroded material in the Jurassic basin in the front of the obducting ophiolites during the obduction. In addition, the youngest recorded heating event in the medium-grade Serbo-Macedonian metamorphics in central Serbia, which occurred in the Late Jurassic (Balogh et al., 1994), can also be related to burial associated with Eastern Vardar ophiolites obduction.

The obduction-related top-to-SE contraction was highly overprinted by a younger, top-to-W shearing which can be observed along the contact between the European sedimentary cover and the Eastern Vardar ophiolites and larger distances to the contact (Figs. 2, 5h-i). The overprinting criteria are only sometimes evident in thin-sections. However, the top-SE and top-W shearing directions along the same contact in the same area (e.g., Figs. 5g and 5i, respectively) indicate different directions. Furthermore, pervasive top-W shearing overprints older, ~W-dipping foliation (Fig. 5i, j), which could be related to the top-SE obduction. We suggest that this younger top-W shearing, which obscured and overprinted the older deformation in many places (see Stojadinovic et al., 2022), was related to the Cretaceous-Paleogene continental collision between Europe- and Adria-derived units.

Conclusions

The results of our microtectonic study indicate that the contact zone between the Eastern Vardar Ophiolitic and Europe-derived units in central Serbia underwent at least two ductile contractional deformation phases. The older top-to-SE thrusting was plausibly associated with the latest Jurassic obduction of the Eastern Vardar ophiolites over the Jurassic sedimentary cover of the European continental margin. The thrusting of the Eastern Vardar ophiolites created a sub-ophiolitic mélange currently preserved in a narrow zone at their contact with the underlying Jurassic sediments, which in turn underwent metamorphism in the lower greenschist facies. The obduction-related deformation was highly overprinted by a younger, top-to-W contraction associated with the Cretaceous-Paleogene continental collision between Europe- and Adria-derived units.

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Резиме

Нова сазнања о тектонским односима јединице Источно-вардарских офиолита и Српско-македонске јединице: закључци из микротектонске студије у централној Србији

Тектонски контакти између јединица европског афинитета (Српско-македонска јединица и јурски седиментни покров европске маргине) и јединице Источно-вардарских офиолита откривени су на површини терена у области Левач у централној Србији. Резултати микротектонске студије спроведене на овом подручју указују на то да је ова зона контакта претрпела најмање две дуктилне фазе контракционих деформација. Старију контракциону фазу одликује формирање асиметричних и изоклиних набора и смицање ка југоистоку у зони непосредног контакта између Источно-вардарских офиолита и јурског седиментног покрова европске континенталне маргине. Ова фаза контракционих деформација највероватније је изазвана обдукцијом Источно-вардарских офиолита преко европске маргине. Обдукција се одиграла крајем јуре, након утискивања гранитоида који су везани за субдукцију у средњој јури (Resimić-Šarić et al., 2005) и депозиције радиоларита који представљају седименти покров Источно-вардарских офиолита у горњој јури (Djerić et al., 2010), а пре новог депозиционог циклуса који је наступио у беријасу (Stojadinović & Krstekanić, 2023). Навлачење Источно-вардарских офиолита довело је до формирања субофиолитског меланжа, који је очуван у виду уске зоне на контакту са јурским седиментима у подини, који су, заузврат, претрпели метаморфизам у фацији зелених шкриљаца. У централној Србији, директни структурни докази за навлачење изазавано обдукцијом Источно-вардарских офиолита преко европске континенталне маргине су ретки, јер су у већином поништени потоњим деформацијама, које укључују горњо-кредну екстензиону ексхумацију Српско-македонске јединице, континенталну

колизију Европе и Адрије на прелазу из креде у палеоген, као и олигоценско-миоценску екстензију у Панонском басену. Међутим, други посредни докази иду у прилог касно-јурској обдукцији, као узроку југоисточно оријентисаних дуктилних контракционих деформација које су опсервиране у овој студији. Метаморфне промене у фацији зелених шкриљаца препознају се у мезозојским седиментима уз Источно-вардарске офиолите дуж читаве европске континенталне маргине у централној и јужној Србији и Северној Македонији (Erak et al., 2017). Такође, најмлађи забележени термални догађај у српско-македонским метаморфитима у централној Србији одиграо се крајем јуре (пре 150.6±5.8 Ma на температурама око 350 °C, Balogh et al., 1994) и може бити последица тоњења приликом обдукције Источно-вардарских офиолита. Деформације изазване обдукцијом су у великој мери поништене млађом контракцијом у смеру ка западу, која је изазвана континенталном колизијом јединица европског и адријског афинитета на прелазу из креде у палеоген.

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