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New radiolarian data from the Jurassic ophiolitic mélange of Avala Mountain (Serbia, Belgrade Region)

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Abstract
An ophiolitic mélange of Avala Mountain located south of Belgrade was studied to obtain age data from blocks of radiolarian cherts and to enable better understanding of age and nature of this mélange. The studied area is located south of Avala Mt. and its geotectonic position is rather obscure. The obtained data allow us to determine radiolarians from five samples; one is of Late Anisian to Early Ladinian, and four of them are of Middle Jurassic (Late Bathonian–Early Callovian) age. The finding of Triassic as well as Jurassic age radiolarians in one and the same mélange suggests that this mélange formed during obduction of the Western Vardar ophiolites.

Keywords Radiolaria · Mélange · Triassic · Jurassic · Stratigraphy · Serbia

1 Introduction

The inner Dinarides of the Balkan Peninsula are characterized by a very complex geology because the area is located at or near the suture zone between the European and the Adriatic plates. The wider area of Belgrade (Fig. 1) exposes a mosaic made up of continental units of either European (Dacia) or Adriatic (Jadar) affinity, separated from each other by the Sava suture and intermingled with remnants of domains of oceanic lithosphere (West Vardar and East Vardar ophiolites sensu Schmid et al. 2008) whose origins and relationships with the continental blocks still are a matter of debate. There are numerous open issues regarding number and location of oceanic basins, timing of their closure and geodynamic setting in which ophiolites were formed, as well as the time and direction of the ophiolites emplacement (e.g. Bernoulli and Laubscher 1972; Robertson and Shallo 2000; Stampfli and Borel 2002; Bortolotti et al. 2004, 2005, 2013; Beccaluva et al. 2005; Gawlick et al. 2008, 2009a, 2016; Karamata 2006; Dilek et al. 2008; Schmid et al. 2008; Robertson et al. 2009, 2013; Saccani et al. 2011; Ferriere et al. 2012; Robertson 2012; and references therein).

The study of radiolarians is of great importance for stratigraphic and geologic research within such mobile belts comprising areas with a complicated structure in which radiolarian cherts are widespread. Radiolarian age data obtained from cherty rocks have great and even decisive importance for dating the ophiolite complexes, mélanges and/or olistostrome bodies.

The remnants of oceanic lithosphere found in the area between the Dinarides and the Carpatho-Balkanides were derived from the northern branch of the Neotethys Ocean (Sengör and Yilmaz 1981) which, according to most authors, finally closed at the end of the Cretaceous

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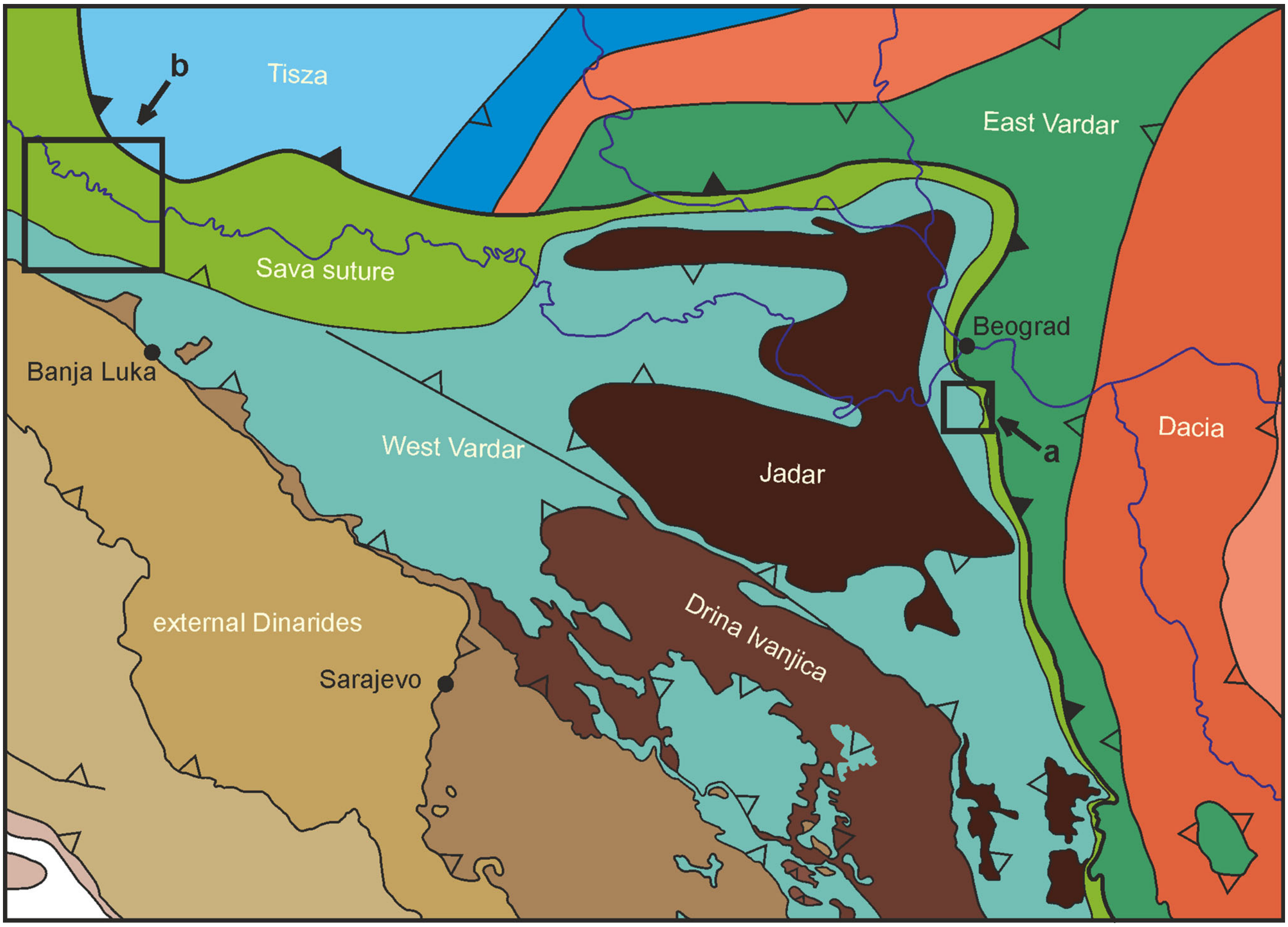


Fig. 1 Main tectonic units in the central part of Balkan Peninsula (modified after Schmid et al. 2008). Area labelled "a" locates the detailed map of Fig. 2; area labelled "b" locates an area in Bosnia representing a kind of "type locality" of the Sava Zone Sava Zone (see Karamata et al. 2005; Ustaszewski et al. 2009, 2010; Cvetković et al. 2014)

(Karamata 2006; Ustaszewski et al. 2010) along a suture zone referred to as Sava–Vardar Zone (Pamić 2002) or Sava Zone (Schmid et al. 2008). The idea that the Sava Zone represents the suture zone of the northern branch of Neotethys is partly based on the presence of Late Cretaceous (ca. 80 Ma) magmatic rocks (basalt, diabase and gabbro) in Bosnia (area labelled "b" in Fig. 1) and Macedonia which resemble an ophiolite complex (Karamata et al. 2005; Ustaszewski et al. 2009; Cvetković et al. 2014; Prelević et al. 2014, 2017), and partly, on the presence of Alpine-age metamorphism whose temperature peak was dated at around 65 Ma ago (Ustaszewski et al. 2010). In the territory of Serbia, however, the Sava Zone, located somewhere within a wide belt of Upper Cretaceous flysch sediments, is more difficult to define. The location of this suture can only be defined on the basis of characteristic differences, such as the facies of Triassic sediments, between the pre-Upper Cretaceous Adriatic continental units below the West-Vardar ophiolites to one side, and the European continental units below the East-Vardar ophiolites to the other side of the suture (see Fig. 1). Also, the West Vardar ophiolites are found in a structurally lower position, while the East Vardar Ophiolites structurally lie above the Sava Zone (Schmid et al. 2008).

The Eastern Vardar (sensu Schmid et al. 2008), corresponding to the Central Vardar Subzone of Dimitrijević (1997) or the Main Vardar Zone of Karamata (2006) is a narrow zone of dismembered ophiolite bodies that can be traced from the Apuseni Mountains in Romania to northern Greece (e.g. Bortolotti et al. 2002; Schmid et al. 2008). This Eastern Vardar belt is interpreted as a short-lived Jurassic back-arc basin (e.g. Božović et al. 2013; Gallhofer et al. 2015). The Eastern Vardar ophiolites, and their equivalents in the Guevgeli ophiolites and the Circum-Rhodope Belt of northern Greece (Kockel et al. 1971, 1977; Michard et al. 1994) were metamorphosed and tectonically emplaced eastward on the Serbo-Macedonian Massif during the Late Jurassic, either by obduction

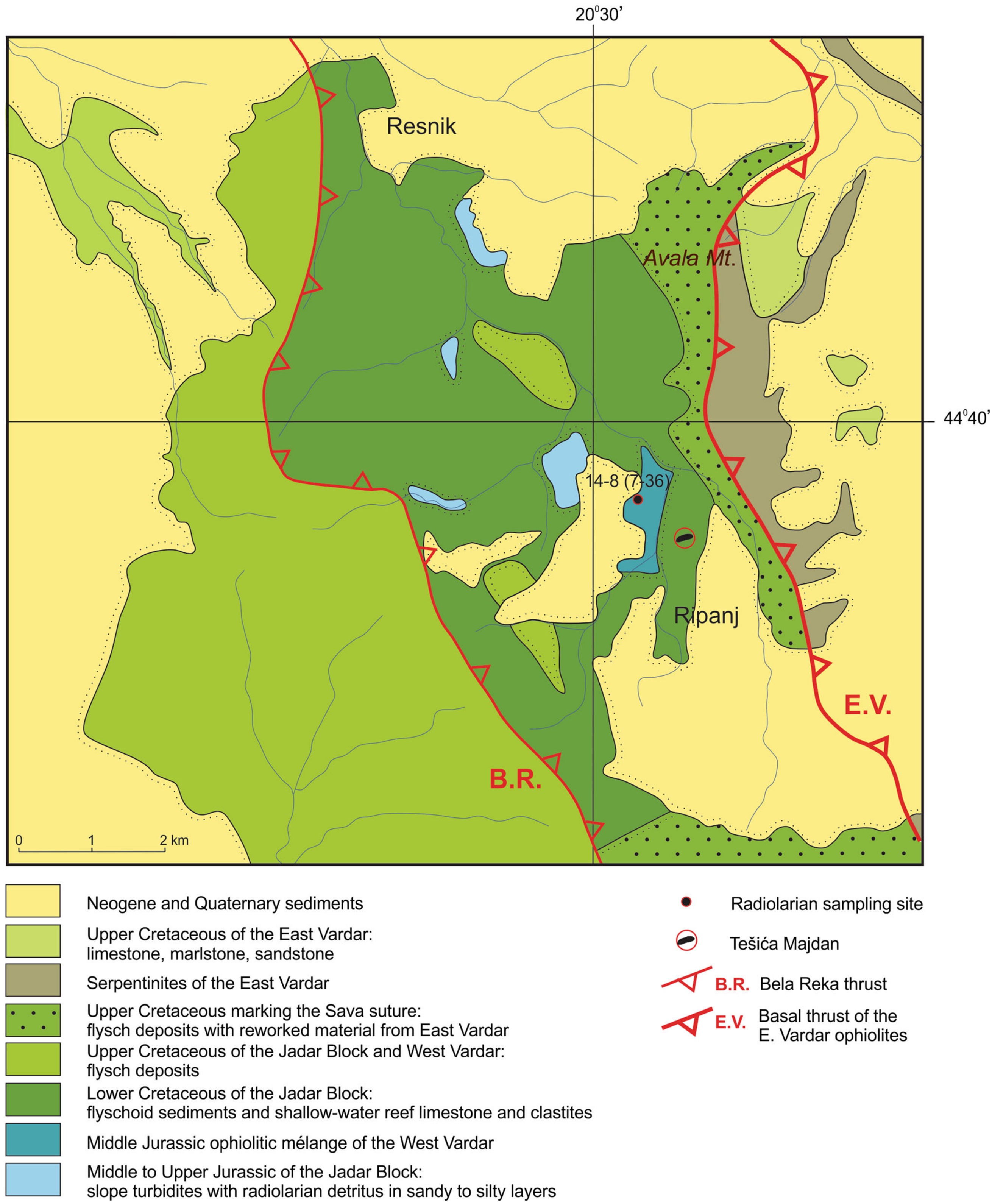


Fig. 2 Schematic geological map of the Avala Mt. area, modified after a detailed map compiled by Toljić et al. (2018); see also the map sheets published by Marković et al. (1985), Filipović et al. (1979) and Pavlović et al. (1979)

(Schmid et al. 2008) or by thrusting (Gallhofer et al. 2017). In contrast to the West-Vardar ophiolites, a sub-ophiolitic mélange is mostly missing.

The Western Vardar ophiolites are regarded as parts of the Neotethyan oceanic crust that was obducted onto the Adriatic passive margin in the Late Jurassic (Bernoulli and Laubscher 1972; Baumgartner 1985a, b; Pamić 2002; Bortolotti et al. 2004, 2013; Bortolotti and Principi 2005; Schmid et al. 2008) or Middle to early Late Jurassic (Gawlick et al. 2009b, 2010, 2016). This zone comprises huge ophiolitic massifs that are typically underlain by a high-grade metamorphic sole of Middle to early Late Jurassic age (e.g. Spray et al. 1984; Dimo-Lahitte et al. 2001). The Western Vardar is characterized by the presence of sub-ophiolitic mélange, formed during obduction in Middle to Late Jurassic times (e.g. Vishnevskaya et al. 2009; Gawlick et al. 2009a, b, 2017a). The sub-ophiolitic mélange comprises blocks derived from both upper and lower plates. Most importantly, the mélange of the Western Vardar ophiolite belt frequently contains radiolarites of Triassic as well as of Jurassic age (e.g. Vishnevskaya et al. 2009). The Triassic radiolarites are either scraped off from subducted older oceanic crust (e.g. Vishnevskaya et al. 2009; Gawlick et al. 2017b) or from the subducted Adriatic passive margin (e.g. Gawlick et al. 2016). Jurassic radiolarites may be derived from the subducting continental margin (e.g. Djerić et al. 2007, 2012; Vishnevskaya et al. 2009; Gawlick et al. 2017a), or alternatively, represent olistoliths gravitationally emplaced from the obducted ophiolite cover. Moreover, radiolarites may be part of the mélange matrix (e.g. Djerić et al. 2010, Gawlick et al. 2017a). We regard most if not all of these mélanges to be of tectonic origin (Hsü 1968) although mélange formation may well have overprinted former olistostromes in some cases. They basically define the thrust contact between obducted Jurassic ophiolite including attached metamorphic sole above the sediments of the subducting Adria continental margin including remnants of the Triassic Meliata Ocean (Schmid et al. 2008).

Recent investigations carried on in SW Serbia (Gawlick et al. 2017a and references therein) suggest that there are different types of mélanges in the Inner Dinarides. Besides the sub-ophiolitic mélange, these authors also distinguish different sedimentary mélanges that originated by sedimentation processes in deep-water trench-like basins in front of the propagating nappes during obduction. These deep-water basins were supplied by the erosional products of the advancing nappe stack embedded in a radiolarite bearing argillaceous matrix.

Many of these implications have been and still need to be supported by radiolarian dating. In Serbia, a series of works concerned with the study of radiolarians and dating the cherty rocks have been published in recent decades (Obradović and Goričan 1988; Goričan et al. 1999; Djerić et al. 2007; Djerić and Gerzina 2008; Gawlick et al. 2009b, 2010, 2016, 2018; Vishnevskaya et al. 2009; Bragin et al. 2011; Chiari et al. 2011). Following these earlier investigations, this contribution aims at a detailed taxonomic and age analysis of the radiolarian assemblages from cherty rocks in a sub-ophiolitic mélange from an area south of Belgrade, including Avala Mountain (area labelled "a" in Fig. 1).

2 Geological setting of the study area

The studied area shown in Fig. 2, located in Fig. 1, is located on the southern flanks of Avala Mt. south of Belgrade. In this region, the attribution of rocks to any of the geotectonic units distinguished in the Fig. 1 is a controversial issue due to the fact that most of the area is covered by Cretaceous and Neogene sediments that unconformably overlie older rocks. According to Toljić et al. (2018) Cretaceous deposits in the area of Fig. 2 and the surrounding areas were interpreted either as trench to foredeep deposits deposited onto the Adria margin (Jadar block plus West Vardar ophiolites), or as deposits belonging to a fore-arc basin installed on the European side (Serbo-Macedonian plus East Vardar ophiolites). The area is also characterized by mafic and felsic dykes which are partly post-tectonic and partly pre-tectonic. They are part of a magmatic belt formed at around 80 Ma ago in or in the vicinity of the Sava Zone (Prelević et al. 2014, 2017), including the Tešića Majdan intrusion whose location is marked in Fig. 2.

Fig. 3 Outcrop of the sub-ophiolitic mélange attributed to the West-Vardar ophiolite belt with blocks of radiolarian cherts floating in an intensely tectonized claystone matrix from the area where the radiolarians were dated (see Fig. 2 for the location). Note E-dipping (E is to the right) extensional fractures related to late stage normal faulting in the area

Table 1 Species occurrence list of radiolarians from the Jurassic chert blocks in Ripanj, Avala Ophiolitic Mélange

Samples	14-8-2	14-8-8	14-8-11	14-8-12a
Radiolarian taxa				
Acaeniotylopsis oregonensis Yeh and Pessagno				C
Angulobracchia sp. cf. *A. digitata* Baumgartner				R
Arcanicapsa funatoensis (Aita)				C
Arcanicapsa sp. cf. *A. trachyostraca* (Foreman)				R
Archaeodictyomitra (?) *mirabilis* Aita	C	C		
Archaeodictyomitra sp.	C		C	
Archaeospongoprunum elegans Wu			C	
Archaeospongoprunum sp. cf. *A. elegans* Wu				R
Archaeospongoprunum imlayi Pessagno				C
Bernoullius rectispinus Kito, De Wever, Danelian & Cordey			R	
Canoptum sp.			R	
Cenodiscaella sphaeraconus (Rüst)		A		
Cinguloturris carpatica Dumitrica				A
Cinguloturris sp. cf. *C. carpatica* Dumitrica			C	
Crococapsa sp. cf. *C. hexagona* (Hori)	R			C
Emiluvia sp.				R
Eoxitus baloghi Kozur		C		
Eoxitus dhimenaensis (Baumgartner)			C	R
Eoxitus sp.		C		
Favosyringium sp.				R
Guexella nudata (Kocher)			C	
Hemicryptocapsa sp. cf. *H. carpathica* (Dumitrica)			C	
Homoeoparonaella sp. cf. *H. argolidensis* Baumgartner			C	
Homoeoparonaella sp. cf. *H. pseudoewingi* Baumgartner			C	
Hsuum sp.	C	C		
Loopus sp.	C			
Mirifusus sp. cf. *M. fragilis* s.l. Baumgartner		R		
Mirifusus guadalupensis Pessagno		R	C	R
Obesacapsula morroensis Pessagno			C	
Parahsuum sp.				R
Paronaella sp. cf. *P. mulleri* Pessagno		C		C
Praewilliriedellum robustum (Matsuoka)			A	
Pseudoeucyrtis sp.			R	
Pseudoristola sp. cf. *P. durisaeptum* (Aita)		C		
Pseudoristola tsunoensis (Aita)		C		
Semihsuum sp. cf. *S. rutogense* (Yang and Wang)			R	
Spinosicapsa sp. aff. *S. andreai* (Beccaro)				R
Spinosicapsa chandrika (Kocher)				C
Spinosicapsa sp. cf. *S. chandrika* (Kocher)				R
Spinosicapsa sp. cf. *S. rosea* (Hull)				R
Spinosicapsa triacantha (Fischli)				C
Spinosicapsa sp. cf. *S. vannae* (Beccaro)				R
Spongocapsula sp. cf. *S. perampla* (Rüst)			C	C
Transhsuum brevicostatum gr. (Ozvoldova)				R
Transhsuum sp. cf. *T. brevicostatum* (Ozvoldova)	C		A	
Transhsuum maxwelli gr. (Pessagno)			C	
Triactoma blakei (Pessagno)			C	R
Triactoma foremanae Muzavor				C
Tritrabs ewingi (Pessagno)				C
Tritrabs sp. cf. *T. exotica* (Pessagno)				R
Xitus sp.				R

A abundant, *C* common, *R* rare

The Jurassic ophiolitic mélange found in the area of Ripanj village (Fig. 2) has been attributed to the East Vardar ophiolite belt by Toljić et al. (2018) while our paleontological findings rather indicate its attribution to the West Vardar ophiolite belt. This alternative attribution will be discussed later, i.e. after presenting the paleontological findings. It has to be kept in mind that in the study area, the ophiolites of the West Vardar ophiolite belt obducted onto the Jadar block have been completely eroded to the underlying sub-ophiolitic mélange before being unconformably overlain by Lower Cretaceous sediments (called "Lower Cretaceous of the Jadar block" in Fig. 2). In most places, also the melange was completely eroded to its base, thus uncovering the underlying Upper Jurassic sediments, represented by slope turbidites with radiolarian detritus in sandy to silty layers (Filipović et al. 1979; Marković et al. 1985; Bragin et al. 2011). As discussed later, we attribute these sediments to the youngest Jurassic cover of the Jadar block (Fig. 2). The transgressive Lower Cretaceous sequence in the Belgrade area is composed mostly of flyschoid sediments made up of sandy limestone, sandstone, siltstone and limestone, or by their lateral equivalents, i.e. shallow water reef limestones and clastics (Anđelković 1973; Pavlović et al. 1979; Filipović et al. 1979; Marković et al. 1985). In certain places, the W-Vardar ophiolites are overlain by the Uppermost Jurassic (Tithonian) reef limestone (Dimitrijević 1997; Filipović et al. 1979). Such limestone is here preserved in the form of large blocks (olistoliths) at the base of the Lower Cretaceous flysch in the study area.

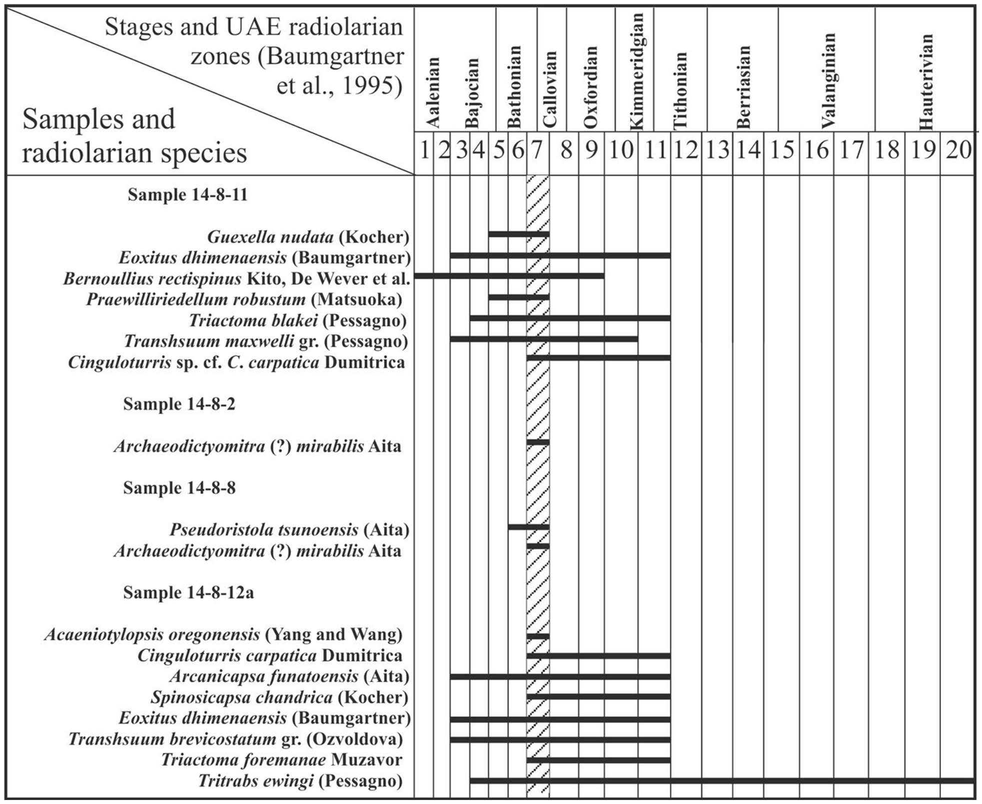
At the end of the Cretaceous, the Upper Jurassic sedimentary cover of the Jadar block, together with the overlying Upper Jurassic mélange and the flyschoid Lower Cretaceous sediments, were thrusted over Upper Cretaceous flysch deposits, also belonging to the Jadar and West-Vardar area, along the Bela Reka thrust recently mapped by Toljić et al. (2018; see Fig. 2).

A narrow band of Upper Cretaceous flysch underlying the basal thrust of the East Vardar ophiolites (marked E.V. in Fig. 2) separates the western parts of Fig. 2, we attribute to the Jadar block (Adria) and West-Vardar domain from the easterly adjacent serpentinites and the overlying Upper Cretaceous limestone, marlstone and sandstone that we attribute to the East Vardar domain that overlies the European continental margin (Dacia, see Fig. 1). We propose that this band of Upper Cretaceous flysch, which contains reworked material from the East Vardar, marks the Sava suture in the sense that it divides two fundamentally different geotectonic assemblages from each other, namely the Jadar block plus West Vardar ophiolites in the west (Adria plate) from the Serbo-Macedonian massif plus East Vardar ophiolites in the east (European plate). In contrast to the situation in Bosnia (Ustaszewski et al. 2009; 2010) is not possible, however, to properly define a distinct geotectonic unit named the Sava Zone in the wider Belgrade area.

Table 2 Radiolarian zonation of Middle Triassic interval for Mediterranean Region (Kozur 2003) and stratigraphic ranges of radiolarian taxa used for age determination (Kozur et al. 1996; Stockar et al. 2012; Tekin et al. 2016)

System	Triassic										
Series	Middle										
Stage	Anisian				Ladinian						
Substage	Upper (Illirian)				Lower (Fassanian)			Upper (Longobardian)			
Radiolarian Zone	S. transitus	S.italicus		L. multiperforata		Unnamed zone	M. firma	M. cochleata			
Radiolarian Subzone / Taxa		O. primitivus	O. inaequispinosus	L. annuloperforata	L. vicentinensis			P. priscus	S. rarauana	S. fluegeli	T. kretaensis dispiralis
Triassospongosphaera multispinosa											
Cryptostephanidium cornigerum								?			
Triassistephanidium laticorne								?			
Pseudostylosphaera canaliculata											
Spongoxystris tricostata					?						

Table 3 Radiolarian zonation of Middle Jurassic–Early Cretaceous interval (Baumgartner et al. 1995) and stratigraphic ranges of radiolarian taxa used for dating



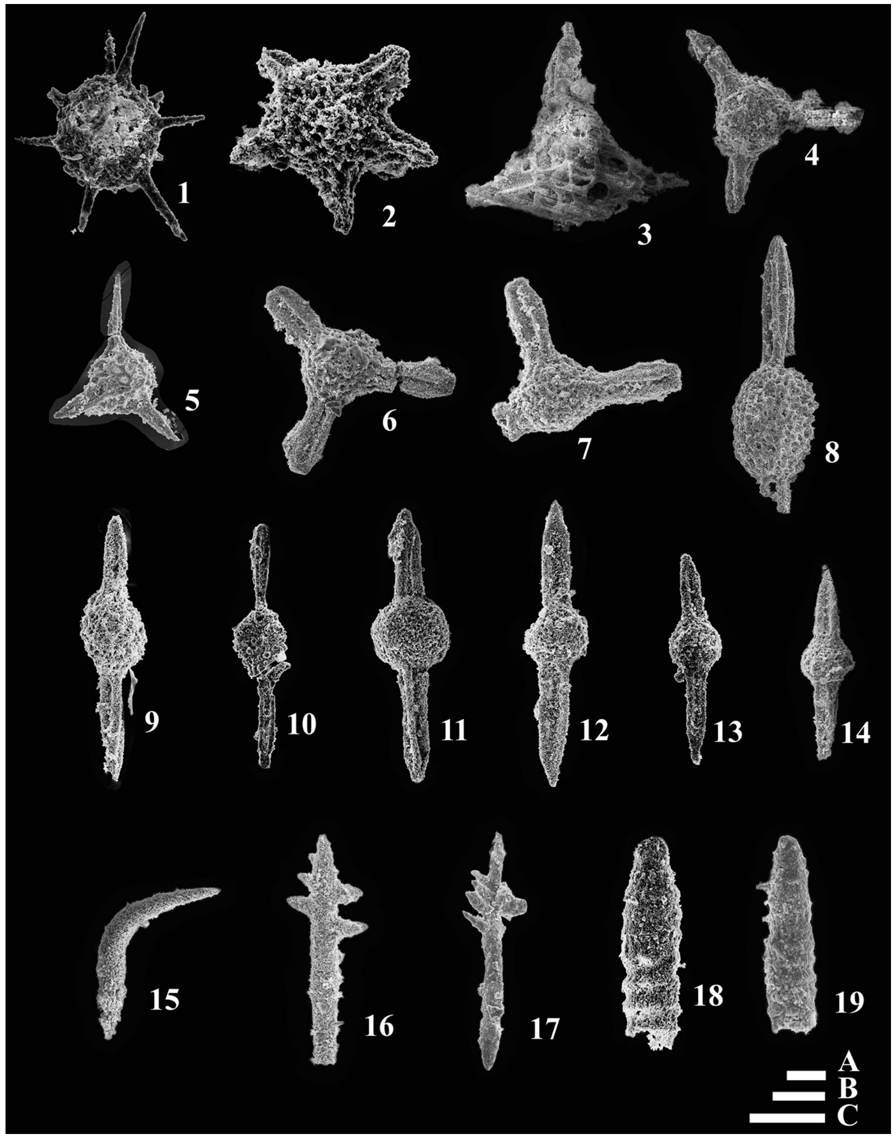
The recently dated lamprophyres of Tešića Majdan (about 87 Ma; Sokol et al. 2017), located immediately SE of the mélange outcrops of Ripanj Village (Fig. 2) belong, together with many other mafic and felsic dykes not mapped in Fig. 2 to a magmatic association that is typical for the Sava Zone at a much lager scale and which is only slightly younger elsewhere (about 80 Ma; Prelević et al. 2017). Such dykes also occur on both sides and in the vicinity of the narrow strip of Upper Cretaceous marking the boundary between West and East Vardar units (Fig. 2). This raises the question after what exactly should be considered as Sava Zone and what should be part of the adjacent geotectonic domains east and west of this important suture between Adria and Europe. In any case, the area intruded by these late Cretaceous magmatic rocks appears wider than the small strip of Upper Cretaceous sediments dividing West and East Vardar ophiolites (Fig. 2).

According to our observations, the new radiolarian findings presented below are from the only locality (Ripanj village) in a wider area that exposes true sub-ophiolitic mélange. It contains Triassic and Jurassic radiolarians in chert blocks that were first found by Bragin et al. (2011; their "section Ripanj"). A narrow east–west running band of outcrops of such mélange is located along an unpaved road near Ripanj Village between point N44°39′15.9″ and E020°30′26.4″ (beginning of outcrop) and point N44°39′15.0″ and E020°30′16.2″ (end of outcrop), whose location is indicated in Fig. 2. The outcrops are found in a small narrow ravine that is approximately 200 m long. The mélange in this outcrop (Fig. 3) is characterized by highly tectonized matrix composed of brown or greenish claystone. Sheared medium sized clasts (ranging from 1–2 to 15–20 cm) embedded in the clayey matrix are made up of fine-grained micaceous sandstone, tectonized sandy marl and radiolarites, mostly greenish-grey or yellowish-grey, rarely light-grey, pink and red, and light-grey cherty tuffs. Dark-brown ferruginous to manganese concretions with possible braunite or siderite content are also common.

3 Methods

Material from blocks of radiolarian cherts and cherty mudstones enclosed in the mélange was used for micropalaeontological analysis. Thirteen samples were collected in the vicinity of Ripanj Village (see location in Fig. 2). Five of them yielded well-preserved radiolarians. The standard processing method with usage of dilute 5–10% hydrofluoric acid (Pessagno and Newport 1972) has been applied for the preparation and subsequent analyses of the radiolarian content of the siliceous rocks. Radiolarian shells were mounted, studied and illustrated on the

Plate I **1** *Triassospongosphaera multispinosa* (Kozur & Mostler) **2** *Beturiella* ? sp. **3** *Cryptostephanidium* sp. **4** *Triassistephanidium* sp. **5** *Cryptostephanidium cornigerum* Dumitrica **6, 7** *Triassistephanidium laticorne* Dumitrica **8** *Pseudostylosphaera canaliculata* (Bragin) **9** *Pseudostylosphaera* sp. cf. *P. acrior* (Bragin) **10** *Pseudostylosphaera* sp. **11, 13, 14** *Spongoxystris* sp. **12** *Spongoxystris tricostata* Kozur, Krainer and Mostler **15** *Oertlispongus* sp. cf. *O. primus* Kozur **16, 17** *Paroertlispongus* sp. cf. *P. daofuensis* Feng and Liang **18, 19** *Triassocampe* sp. *Scale bar*: 100 µm. A—10; B—8; C—1–7, 9, 11–19. All specimens are from sample 07-36-2



scanning electron microscope SEM Tescan 2300 using a BSE detector. This work was done at the Geological Institute RAS, Moscow where the micropalaeontological material is housed.

4 Results

Five samples with well-preserved radiolarians were collected from the studied outcrop near Ripanj Village area during field seasons in 2007 and 2014. The taxonomic composition of the recovered radiolarian assemblages is characterized by the presence of well-known taxa of Tethyan affinity (Table 1). This allows for application of the Middle Jurassic–Early Cretaceous radiolarian zonation (Baumgartner et al. 1995), and the radiolarian zonal scale for the Mediterranean Triassic (Kozur 2003). The following analyses are based on taxa determined on species level (Tables 2, 3). Forms determined in open nomenclature were not used for age determinations and only are of supplementary value. We followed the radiolarian nomenclature of Mesozoic Catalogue of Radiolarian Genera (O'Dogherty et al. 2009a, b).

4.1 Sample 07-36-2

This sample was already discussed and illustrated by Bragin et al. (2011). Here we complement these results with some additions. In this pinkish-grey radiolarite with moderately preserved radiolarians 11 species could be determined, 6 of them in open nomenclature. *Beturiella* sp., *Cryptostephanidium cornigerum* Dumitrica, *C.* sp., *Oertlispongus* sp. cf. *O. primus* Kozur, *Paroertlispongus* sp. cf. *P. daofuensis* Feng and Liang, *Pseudostylosphaera*

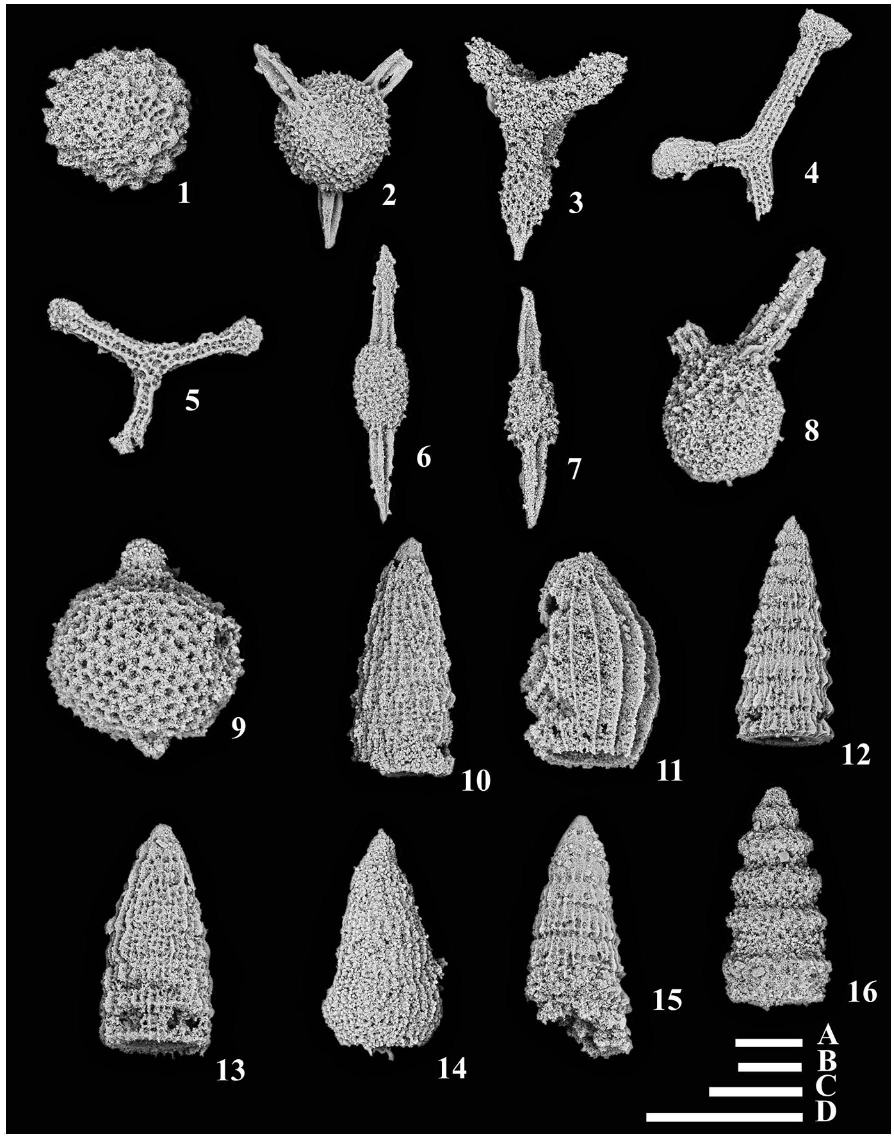


Plate II **1** *Cenodiscaella sphaeraconus* (Rüst) **2** *Triactoma blakei* (Pessagno) **3** *Paronaella* sp. cf. P. *mulleri* Pessagno **4** *Homoeoparonaella* sp. cf. *H. pseudoewingi* Baumgartner **5** *Homoeoparonaella* sp. cf. *H. argolidensis* Baumgartner **6, 7** *Archaeospongoprunum elegans* Wu **8** *Bernoullius rectispinus* Kito, De Wever, Danelian & Cordey **9** *Hemicryptocapsa marcucciae* (Cortese) **10** *Hsuum* sp. **11** *Semihsuum* sp. cf. *S. rutogense* (Yang and Wang) **12***Transhsuum* sp. cf. *T. brevicostatum* (Ozvoldova) **13** *Transhsuum maxwelli* gr. (Pessagno) **14** *Archaeodictyomitra* (?) sp. cf. A. (?) *mirabilis* Aita **15** *Loopus* sp. **16** *Cinguloturris* sp. cf. C. *carpatica* Dumitrica. *Scale bar*: 100 microns. A —1, 6, 8; B—2–4, 5, 7; C—10–13, 15, 16; D—9. 14. Samples 14-8-8 (1, 3, 7, 10, 14), 14-8-11 (2, 4, 5, 6, 8, 9, 11, 13, 16), 14-8-2 (12, 15)

canaliculata (Bragin), *P.* sp. cf. *P. acrior* (Bragin), P. sp., *Spongoxystris tricostata* (Kozur, Krainer and Mostler), *S.* sp. *Triassistephanidium laticorne* Dumitrica, *T.* sp., *Triassocampe* sp., *Triassospongosphaera multispinosa* (Kozur and Mostler).

The age of this sample can be determined as Late Anisian to Early Ladinian (Table 2) due to known ranges of determined taxa (Plate I). It should be noted that the ranges of some taxa like *Spongoxystris tricostata* are still not sufficiently well known. Therefore, we cannot exclude an early Ladinian age.

4.2 Sample 14-8-2

This yellowish-grey chert yielded moderately to poorly preserved radiolarians. Five species were determined, mostly in generic level or in open nomenclature. The age of this sample is determined by the range of *Archaeodictyomitra* (?) *mirabilis* Aita (Zone 7, Middle Jurassic, Late Bathonian–Early Callovian; Plates II, III). It should be noted that Auer et al. (2009) determined a wider stratigraphic range of *Archaeodictyomitra* (?) *mirabilis*—up to the lowermost Upper Oxfordian. Hence we cannot exclude a younger age of this sample.

4.3 Sample 14-8-8

This light blue to grey chert with moderately preserved radiolarians contained ten species. The presence of *Pseudoristola tsunoensis* (Aita) (Zones 6 and 7) and *Archaeodictyomitra* (?) *mirabilis* Aita (Zone 7) allows to date this sample as Middle Jurassic, namely to be of Late Bathonian–Early Callovian age (Plates II, III). It should be noted that Aita (1988) previously determined the range of

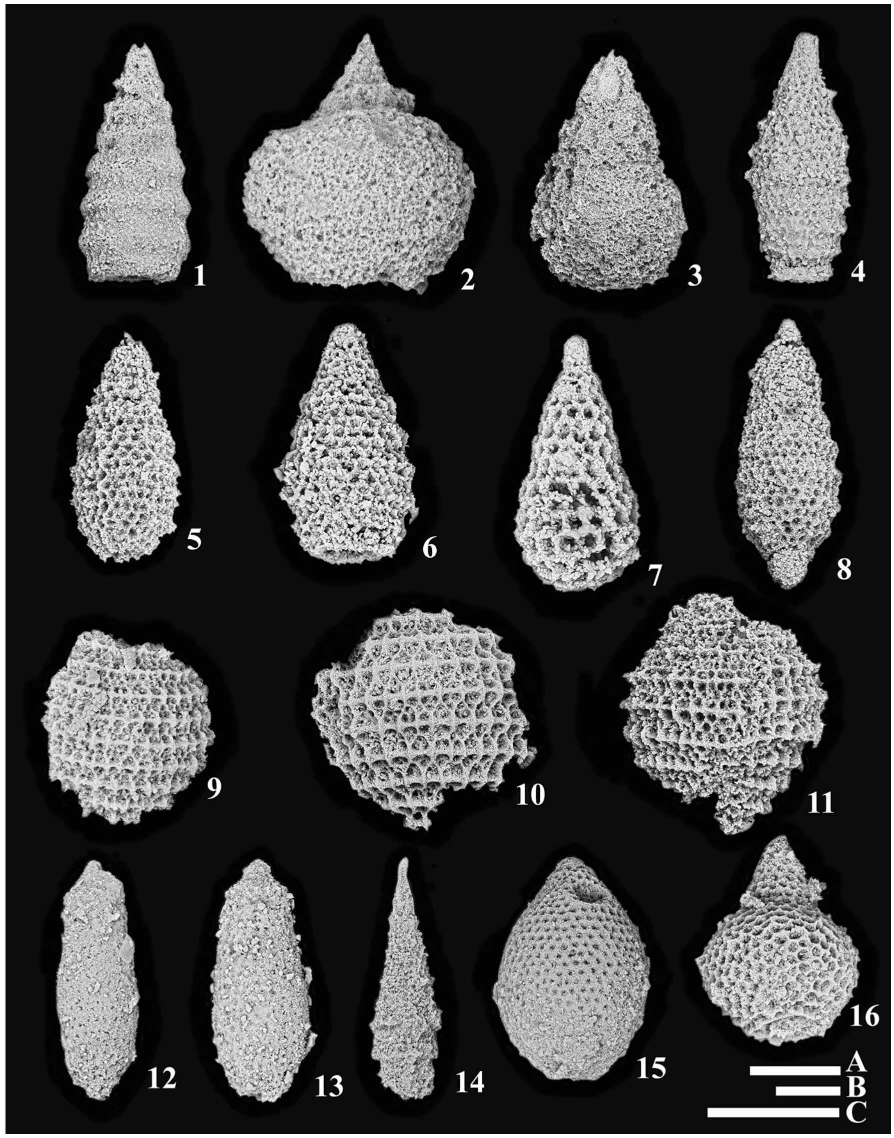


Plate III **1** *Canoptum* sp. **2** *Obesacapsula morroensis* Pessagno **3** *Spongocapsula* sp. cf. S. *perampla* (Rüst) **4** *Eoxitus dhimenaensis* (Baumgartner) **5** *Eoxitus baloghi* Kozur **6** *Eoxitus* sp. **7** *Pseudoristola tsunoensis* (Aita) **8** *Pseudoristola* sp. cf. *P. durisaeptum* (Aita) **9, 10** *Mirifusus guadalupensis* Pessagno **11** *Mirifusus* sp. cf. *M. fragilis* s.l. Baumgartner **12, 13** *Guexella nudata* (Kocher) **14** *Pseudoeucyrtis* sp. **15** *Praewilliriedelum robustum* (Matsuoka) **16** *Crococapsa* sp. cf. *C. hexagona* (Hori) *Scale bar*: 100 microns. A—1, 8–11, 14; B—2, 3; C—4–7, 12, 13, 15, 16. Samples 14-8-11 (1, 2, 3, 4, 9, 12, 13, 14, 15), 14-8-8 (5, 6, 7, 8, 10, 11), 14-8-2 (16)

Pseudoristola tsunoensis up to the lowermost Oxfordian. Taking into account the disputed range of *Archaeodictyomitra* (?) *mirabilis* we cannot exclude a younger age of this sample (up to the Oxfordian).

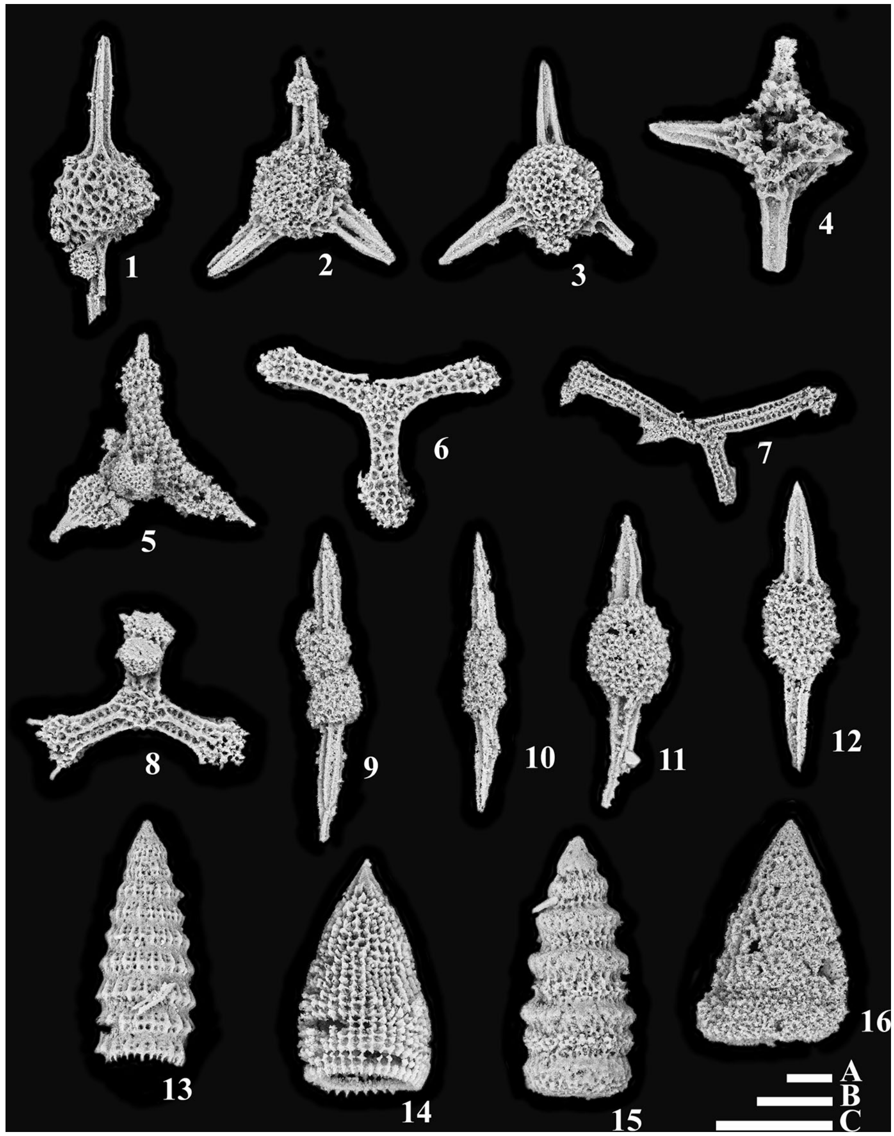
4.4 Sample 14-8-11

This yellowish-grey chert yielded well-preserved radiolarians; twenty species were determined from this sample. The lower age limit of the sample is determined by the presence of *Cinguloturris carpatica* Dumitrica (Zones 7–11). The upper age limit is determined by the presence of *Guexella nudata* Kocher (Zones 5–8), and *Praewilliriedellum robustum* (Matsuoka) (Zones 5–7) and *Semihsuum amabile* (Aita) (Zones 3–7). Therefore, the age of the sample is Middle Jurassic, namely Late Bathonian–Early Callovian (Zone 7) (Plates II, III).

4.5 Sample 14-8-12a

Also this yellow to pink chert contained well-preserved radiolarians and 26 species could be determined. The upper age limit of this assemblage is determined by the ranges of *Acaeniotylopsis oregonensis* Yeh and Pessagno known in the present time only from the Middle Jurassic, i.e. the Late Bathonian (Yeh and Pessagno 2013). Other taxa have wide intervals. *Eoxitus dhimenaensis* (Baumgartner), *Spinosicapsa chandrika* (Kocher) and *Triactoma foremanae* Muzavor, are present from Zone 7 (Late Bathonian–Early Callovian) to Zone 11 (Late Kimmeridgian–Early Tithonian). We have opportunity to date this sample as Middle Jurassic, Late Bathonian (Zone 7) (Plates IV, V), but it should be noted that *Acaeniotylopsis oregonensis* is known only from a locality in Oregon. Its stratigraphic range could be wider. Therefore, we cannot completely exclude a

Plate IV **1** *Acaeniotylopsis oregonensis* Yeh and Pessagno **2** *Triactoma blakei* (Pessagno) **3** *Triactoma foremanae* Muzavor **4** *Emiluvia* sp.**5** *Paronaella* sp. cf. *P. mulleri* Pessagno **6** *Angulobracchia* sp. cf. *A. digitata Baumgartner* **7** *Tritrabs ewingi* (Pessagno) **8** *Tritrabs* sp. cf. T. *exotica* (Pessagno) **9, 10** *Archaeospongoprunum* sp. cf. A. *elegans* Wu **11, 12** *Archaeospongoprunum imlayi* Pessagno **13** *Transhsuum brevicostatum* gr. (Ozvoldova) **14** *Parahsuum* sp. **15** *Cinguloturris carpatica* Dumitrica**16** *Spongocapsula* sp. cf. S. *perampla* (Rüst) *Scale bar*: 100 microns. A—1, 3, 7; B—2, 4–6, 8–13, 16; C—14, 15. All specimens are from sample 14-8-12a



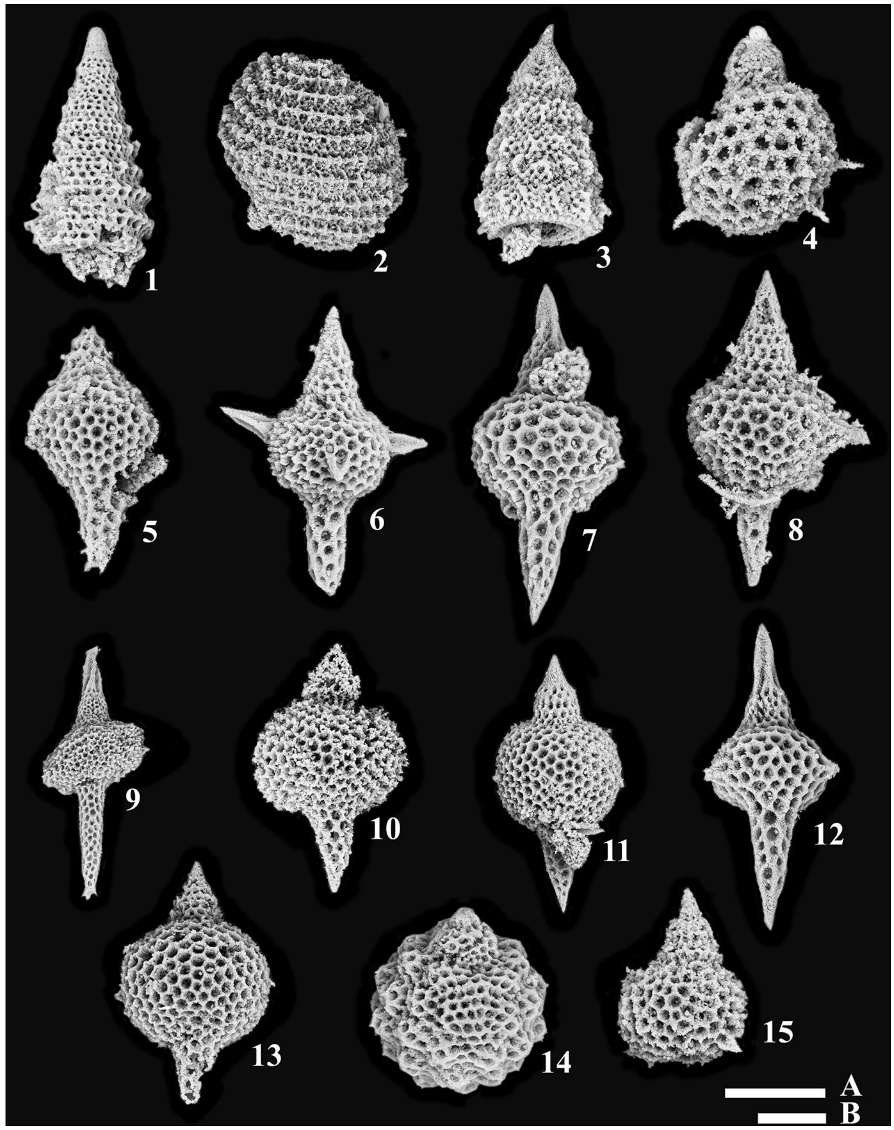
possibility of a younger age of this sample—up to Zone 11 (Table 3).

5 Discussion

The results of this investigation are very similar to previous findings on mélanges associated with Western Vardar ophiolites, which commonly exhibit Middle Jurassic and subordinate Triassic chert-radiolarite blocks. For this reason we propose that the geotectonic position of this particular sub-ophiolitic mélange on Avala Mt. is very likely to be attributed to the Western Vardar ophiolite belt. In view of its proximity to the East Vardar ophiolites (the easternmost part of Fig. 2), this same melange has previously been considered as a part of the East Vardar realm (Bragin et al. 2011; Toljić et al. 2018). However, we argue that the Eastern Vardar ophiolites of Serbia generally lack sub-ophiolitic mélange, as well as a metamorphic sole (e.g. Schmid et al. 2008). Moreover, Eastern Vardar ophiolites are generally considered to represent remnants of a Middle-Upper Jurassic intra-oceanic back-arc basin, which opened above a subduction zone along the Eurasian margin where Triassic radiolarites are neither expected nor have yet been found (Bébien et al. 1986; Brown and Robertson 2003; Saccani et al. 2008; Božović et al. 2013; Robertson et al. 2013). In summary, sub-ophiolitic mélanges yielding Triassic, as well as Jurassic radiolaria, have so far only been found in the West Vardar realm (e.g. Vishnevskaya et al. 2009).

The mixing of radiolarian cherts of grossly different age is due to the fact that some of the radiolarian cherts were scraped off the Triassic parts of the Neotethys (Meliata ophiolites) that became almost completely subducted

Plate V **1** *Eoxitus dhimenaensis* (Baumgartner) **2** *Mirifusus* sp. cf. *M. guadalupensis* Pessagno **3** *Xitus* sp. **4** *Arcanicapsa* sp. cf. *A. trachyostraca* (Foreman) **5** *Favosyringium* sp. **6** *Spinosicapsa triacantha* (Fischli) **7, 8** *Spinosicapsa* sp. cf. S. *vannae* (Beccaro) **9** *Spinosicapsa* sp. cf. S. *rosea* (Hull) **10, 11** *Spinosicapsa chandrika* (Kocher) **12** *Spinosicapsa* sp. aff. S. *andreai* (Beccaro) **13** *Spinosicapsa* sp. cf. *S. chandrika* (Kocher) **14** *Arcanicapsa funatoensis* (Aita) **15** *Crococapsa* sp. cf. C. *hexagona* (Hori). *Scale bar*: 100 microns. A—1, 3–10, 12, 14, 15; B—2, 11, 13. All specimens are from sample 14-8-12a



underneath the obducted Jurassic ophiolites and mechanically mixed with Jurassic-age radiolarites that are either scraped off the Jurassic cover of the underlying Jadar block, or alternatively, where shed gravitationally from the Jurassic cover of the obducted West Vardar ophiolites (Schmid et al. 2008).

A purely sedimentary origin of the mélange, as suggested by e.g. Gawlick et al. (2017a) or Baumgartner (1985a, b) for other occurrences, is not plausible in case of the mélange in Ripanj village because the Triassic cannot have been gravitationally emplaced as olistoliths. Also there is pervasive shearing affecting matrix and clasts and there are no signs of sedimentary organization that would suggest a sedimentary origin. Therefore, mélange in Ripanj village is a true sub-ophiolitic mélange, which has the characteristics of the ophiolitic mélanges found below obducted ophiolites.

In summary, our paleontological findings indicate that the Ripanj mélange is a sub-ophiolitic mélange formed during the obduction of the West Vardar ophiolites. The obtained radiolarian ages suggest that this obduction did not take place before the end of the Middle Jurassic in the Belgrade area, i.e. it post-dates the Early Callovian. These data are in accordance with the widely accepted Late Jurassic age for obduction of the West-Vardar ophiolites in the Internal Dinarides.

6 Conclusions

We conclude that:

1. The radiolarian dating of cherts indicates the presence of Triassic as well as Jurassic radiolarite blocks within the same mélange, which indicates that this mélange is

best attributed to the obduction of the West Vardar ophiolite belt over the Adriatic passive margin.

2. Our findings suggest that the boundary between West Vardar and East Vardar ophiolites (Sava suture) has to be located within a narrow band of Upper Cretaceous sediments located east of the Bela Reka Thrust, a thrust that was taken as marking the Sava suture by Toljić et al. (2018). In contrast to the situation in Bosnia (Ustaszewski et al. 2009, 2010) is not possible, however, to properly define a distinct tectonic unit named the Sava Zone in the Belgrade area.
3. Very often the youngest blocks of radiolarian cherts are of Middle Jurassic age in the case of Western Vardar mélanges (e.g. Vishnevskaya et al. 2009; Gawlick et al. 2009a, b; Chiari et al. 2011). We obtained similar ages in the Belgrade area: Middle Jurassic (Upper Bathonian–Lower Callovian) blocks are common and indicate that mélange formation, being the result of tectonic mixing of Triassic and Jurassic blocks post-dated the Lower Callovian in the Belgrade area.

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