LATE JURASSIC RADIOLARITES IN THE SUB-OPHIOLITIC MÉLANGE OF THE FRUŠKA GORA (NW SERBIA) AND THEIR SIGNIFICANCE FOR THE EVOLUTION OF THE INTERNAL DINARIDES

Uroš Stojadinović*,✉, **Nevenka Djerić***, **Dejan Radivojević***, **Nemanja Krstekanić***,**, **Miloš Radonjić***
and **Bojana Džinić***

* *University of Belgrade, Faculty of Mining and Geology, Belgrade, Serbià.*
** *Utrecht University, Faculty of Geosciences, Utrecht, The Netherlands.*
✉ *Corresponding author, email: uros.stojadinovic@rgf.bg.ac.rs*

Keywords: *radiolarians; sub-ophiolitic mélange; Late Jurassic; Internal Dinarides.*

ABSTRACT

The Fruška Gora in north-western Serbia exposes the northernmost surface occurrences of ophiolites that derive from the obduction of the Vardar Ocean over the Adriatic continental margin. The late Oxfordian - early Kimmeridgian to late Kimmeridgian - early Tithonian radiolarians were determined from the blocks of radiolarites that constitute part of the sub-ophiolitic mélange along the southern flanks of the mountain. The newly obtained ages represent the youngest so-far determined radiolarites ages in this segment of the Dinarides. The mélange formation postdates the obtained ages of radiolarian assemblages, and it plausibly occurred during the latest Jurassic - earliest Cretaceous obduction-related thrusting in the Internal Dinarides.

INTRODUCTION

The Fruška Gora Mountain in north-western Serbia represents an E-W oriented inselberg situated at the south-eastern rim of the Pannonian Basin (Fig. 1). The Fruška Gora comprises a part of the innermost Dinarides and is located along the suture zone formed during the latest Cretaceous - Paleogene collision between the Adria-derived units of the Dinarides and the Europe-derived Tisza and Dacia Mega-Units (i.e., the Sava Zone, Fig. 1 a-b; Pamić 2002a; Schmid et al., 2008, 2020). The mountain is predominantly made up of Mesozoic to Cenozoic sedimentary, magmatic, and metamorphic rocks, including the northernmost surface occurrences of ophiolites and associated mélange that derive from the latest Jurassic - earliest Cretaceous obduction of the Vardar Ocean over the Adriatic continental margin (Dimitrijević, 1997). The aim of this study is to define the age of ophiolitic mélange in the Fruška Gora. For this purpose, we used high-resolution biostratigraphy based on radiolarian dating in ophiolitic sequences exposed in outcrops along the southern flanks of the mountain (Fig. 2a).

GEODYNAMIC EVOLUTION OF THE INTERNAL DINARIDES

The Dinarides are dominantly made up of continental units that derive from the passive margin of Adria (e.g., Schmid et al., 2020). The Dinarides orogen was structured following the Triassic opening and subsequent Late Jurassic to Paleogene closure of the northern segment of the Neotethys Ocean located between the continental units of Adria and Europe (i.e., the Vardar Ocean, Dimitrijević, 1997). The distal continental margin of Adria is characterized by gradual Triassic to Middle Jurassic deepening of carbonate platform to pelagic conditions (e.g., Djakovic et al., 2021), which is documented by dating of radiolarites that can be traced across the Internal Dinarides either in the coherent succession of the tectonic units or as blocks within the ophiolitic mélange (Djerić et al., 2007, 2012; Vishnevskaya et al., 2009; Gawlick et al., 2009, 2017). The subsequent latest Jurassic-earliest Cretaceous obduction of the Vardar Ocean resulted in the emplacement of a ~180 km long thrust sheet of ophiolites over the continental margin of Adria (i.e., the Western Vardar Ophiolites, Schmid et al., 2008; Chiari et al., 2011; Porkoláb et al., 2019). During the Early Cretaceous, the ongoing convergence resulted in renewed subduction of the remaining oceanic segment of the lower Adria plate beneath the overriding Europe-derived units (i.e., the Sava subduction system; Schmid et al., 2008). The Western Vardar Ophiolites overstepping sequence along the distal Adria margin is represented by the Cretaceous transgressive sediments, comprised of Albian-Cenomanian clastic-carbonate shelf deposits, followed by Turonian to Santonian slope carbonates, and Campanian to Maastrichtian deep pelagic sediments (Gajić, 2014; Nirta et al., 2020). The latest Cretaceous - Paleogene Adria-Europe continental collision led to the large-scale WSW-wards thrusting of the Sava subduction trench sediments over the Adria-derived continental units (Pamić, 2002a; Ustaszewski et al., 2010). The following Oligocene - Miocene extension in the south-eastern Pannonian Basin is the result of joint effects of the two evolving slabs, the Carpathian and Dinaridic (Matenco and Radivojević, 2012). In the early Oligocene, the Neotethys slab break-off beneath the Dinarides initiated the extension (Andrić et al., 2018). The ongoing Oligocene to Middle Miocene extension exhumed the lower Adria plate along a series of extensional detachments (Zelic et al., 2010; Schefer et al., 2011; Stojadinović et al., 2013; van Gelder et al., 2015, Erak et al., 2017). In the segments of the innermost Dinarides which are located north of the rigid Moesian Platform indenter (see Krstekanić et al., 2020), such as the Fruška Gora (Fig. 1b), the aforementioned Oligocene to Middle Miocene extension was partially overlapping with another extension during the early to late Miocene times. However, this Early to Late Miocene extension was triggered by the pull of the retreating Carpathian slab. The extension was followed by an

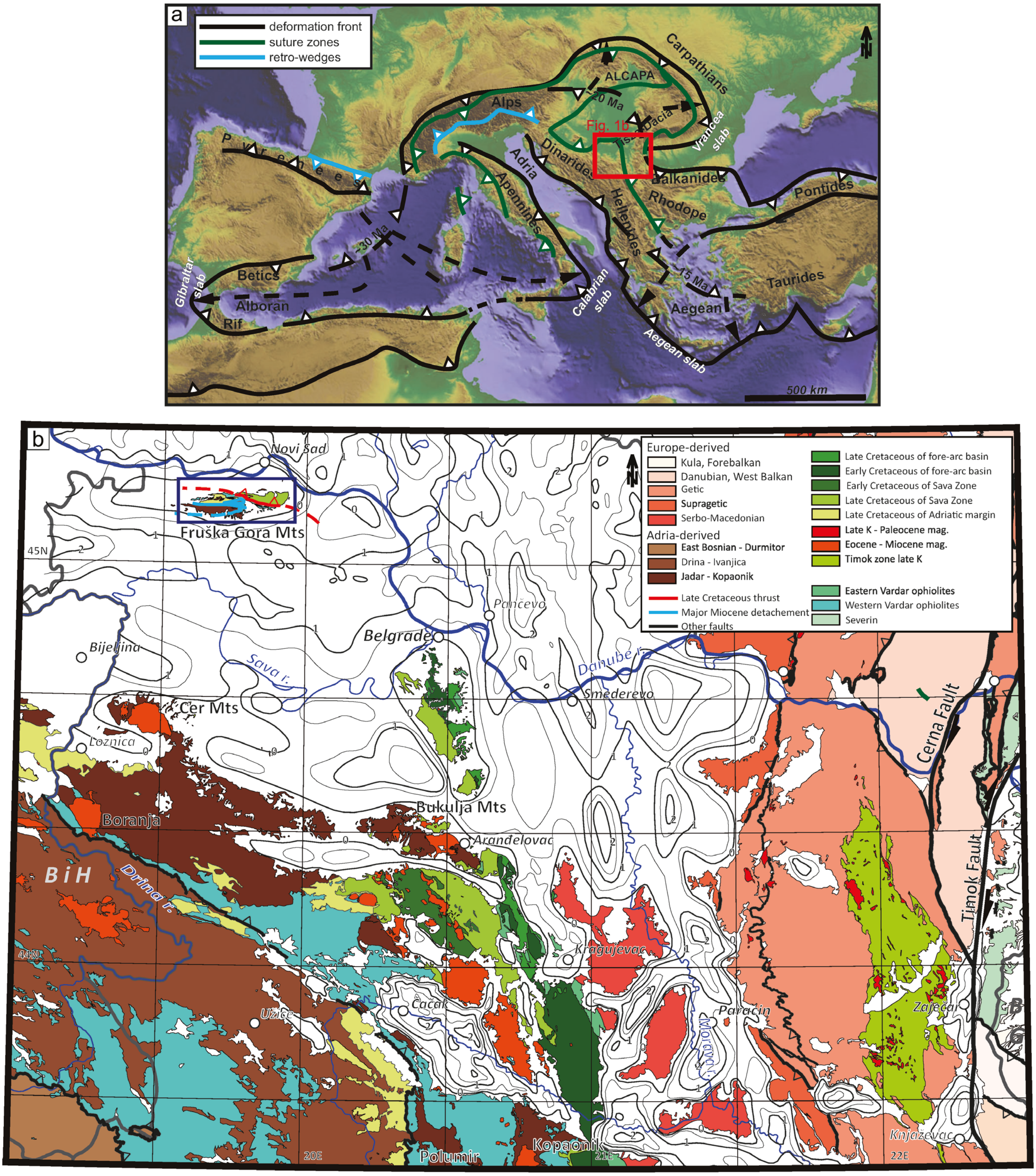

Fig. 1 - a) Topographic map of Mediterranean Mesozoic-Cenozoic orogens, displaying suture zones, orogenic fronts, and retro-wedges (modified after Krstekanić et al., 2020). The red rectangle marks the position of Fig. 1b; b) Geological map of the connection between the Dinarides, South Carpathians, and Pannonian Basin (modified after Matenco and Radivojević, 2012). The blue rectangle marks the position of Fig. 2a.

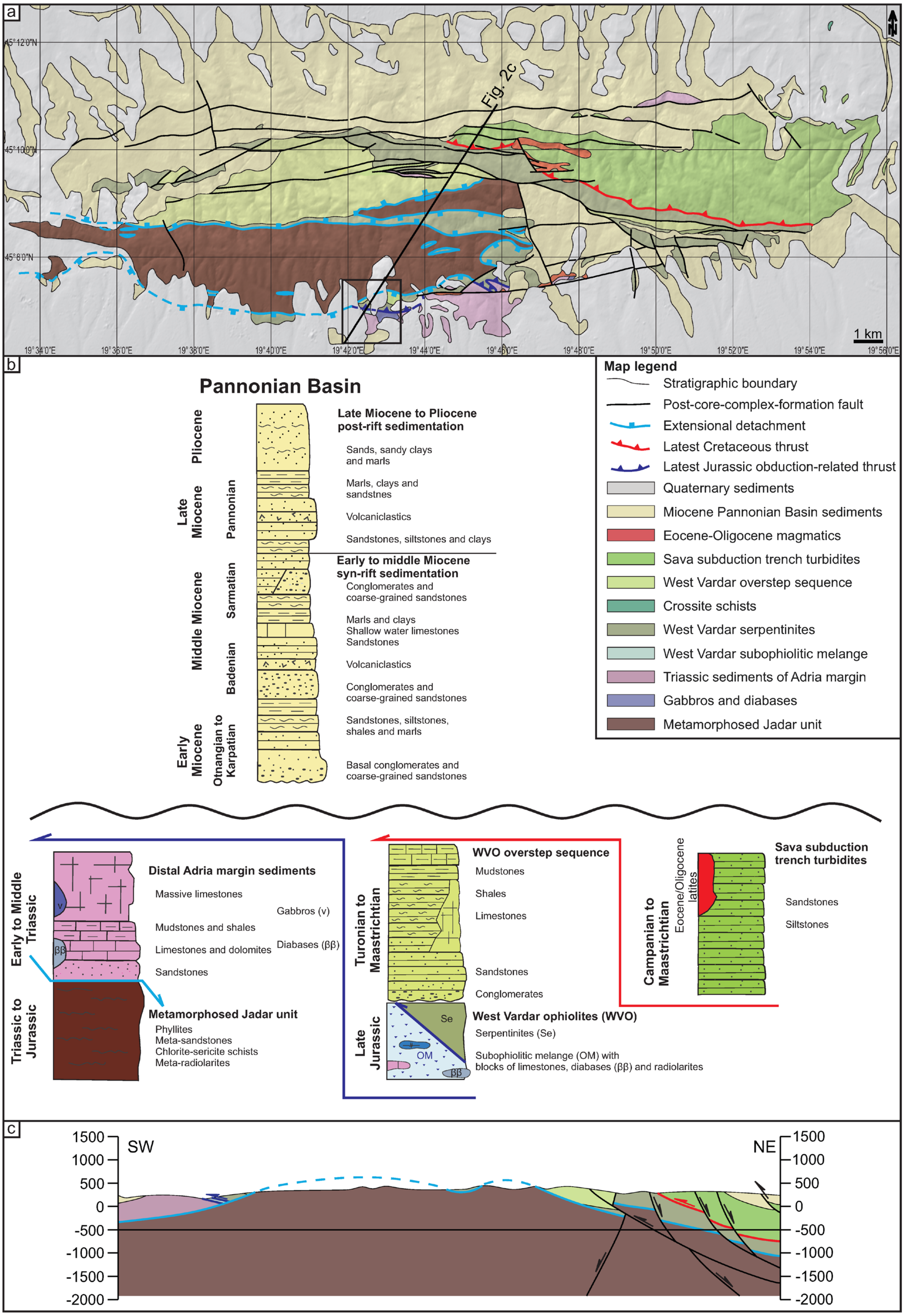

Fig. 2 - a) Detailed geological map of the Fruška Gora (modified after Čičulić-Trifunović and Rakić, 1976). The black rectangle marks the position of Fig. 3a; b) Correlation scheme of Mesozoic to Cenozoic sedimentary facies in the Fruška Gora; c) NE-SW oriented cross-section across the Fruška Gora.

overall tectonic inversion in the Pannonian Basin that started in the latest Miocene and is presently active. The inversion represents the effect of shortening due to the Adria plate indentation (Bada et al., 2007).

GEOLOGICAL SETTING OF THE FRUŠKA GORA

The Fruška Gora represents an antiform composed of a metamorphic core located in the central and south-western part of the mountain, which is surrounded by a Mesozoic sedimentary sequence, ophiolites, and volcanites (Fig. 2a, Toljić et al., 2013). Along the flanks of the mountain, the older rocks are unconformably overlain by Miocene - Quaternary sediments of the Pannonian Basin.

The metamorphic core of the Fruška Gora is comprised of low-grade greenschist facies metamorphics that can be correlated with Carboniferous to Jurassic metamorphosed sediments of the Internal Dinarides' Jadar-Kopaonik and Drina-Ivanjica composite units (sensu Schmid et al., 2008; Fig. 1b; see also Trivić et al., 2010; Spahić et al., 2018). The metamorphics are made up of chlorite and chlorite-sericite schists, with intercalations of phyllites, meta-sandstones, marbles, and meta-radiolarites (Fig. 2). The existing micropaleontological investigations indicate the presence of scarce Middle to Late Triassic conodonts and Late Triassic radiolarians in these metamorphics (Toljić et al., 2013). Furthermore, the metasediments located in the central part of the Fruška Gora contain scarce Late Jurassic microfauna (Čičulić and Rakić, 1977).

The Mesozoic sedimentation in the Fruška Gora starts with Early Triassic continental to shallow water clastites that show a gradual transition to Middle Triassic deeper water carbonates (Figs. 2a, b; Čičulić and Rakić, 1977). The mafic magmatites, emplaced during a phase of Middle to Late Triassic volcanism associated with the Vardar Ocean continental rifting (Pamić, 1984), are here represented by gabbros and diabases (Fig. 2a; Čičulić and Rakić, 1977). The Fruška Gora ophiolitic sequence, represented mainly by the large E-W oriented stripes of serpentinized peridotites and subordinate mélange, is interpreted as a part of the Western Vardar Ophiolites unit (Fig. 1b; Toljić et al., 2013). Tectonic contact between serpentized peridotites and the underlying mélanges along the southern flanks of the mountain is indicating top- S to SW reverse kinematics in present-day coordinates (Figs. 2c, 3a, b). This is in agreement with the south-vergent isoclinal asymmetric folding observed in the metamorphic core of the mountain and adjacent Triassic sediments (see Toljić et al., 2013). Sub-ophiolitic mélange is here comprised of decimeter-scale blocks of clastites, carbonates, gabbros, diabases, and radiolarites, embedded in a matrix made up of slightly metamorphosed, sheared reddish to grey shales (Fig. 2 and 3c, d). Cretaceous sedimentation in the western part of Fruška Gora represents a typical Western Vardar Ophiolites transgressive overstepping sequence, distributed across the innermost Dinarides (Nirta et al., 2020). The sedimentation starts with Turonian coarse-grained clastic deposits, which are passing upwards into Campanian to Maastrichtian carbonates (Fig. 2b; Čanović and Kemenci, 1999). Another Cretaceous sedimentary sequence, which is exposed in the NE segment of the Fruška Gora, is represented by the Sava subduction trench sediments, mainly comprised of Campanian to Maastrichtian cyclic deep-water turbidites (Figs. 2a, b; Dunčić et al., 2017). The ages of high-pressure epidote-blueschist (sub) facies metamorphism obtained from the crossite schists located along the northeastern flanks of the mountain (Fig. 2a) are evidence of ongoing Early Cretaceous Neotethys oceanic subduction within the Sava Zone (Milovanović et al., 1995). The Sava Zone trench turbidites were thrust over the Fruška Gora ophiolites during the latest Cretaceous - Paleogene collision between the Adriatic and European continental units along the Internal Dinarides margin (Fig. 2).

The Late Eocene - Early Oligocene intermediary volcanites in the Fruška Gora, represented by latites, dacites and trachy-andesites (Fig. 2a), are interpreted to be a precursor of magmatism associated with the Pannonian Basin extension (Knežević et al., 1991). Such late Paleogene intermediary magmatism can be traced in the Internal Dinarides and the adjoining southernmost Pannonian Basin further towards the west (Pamić et al., 2002b), and may be associated with the break-off of Neotethys slab beneath the Dinarides (Andrić et al., 2018). The ongoing extension during the Oligocene to Middle Miocene exhumed the metamorphic core of the mountain along the top-E extensional detachment (Toljić et al., 2013). During its final phases, the Oligocene - Miocene extension in the Fruška Gora metamorphic core was overlapping with the second stage of Middle to Late Miocene extensional exhumation, which affected the entire pre-Miocene sequence of the mountain, thus creating its present dome geometry (Stojadinović et al., 2013). The subsequent Pliocene - Quaternary contractional inversion of the Pannonian Basin had limited effects, mainly documented by the tilting of coevally deposited sediments (Toljić et al., 2014).

METHODOLOGY

A well-preserved radiolarian fauna was analyzed from one sample (Sr2, coordinates 19°42'29''E, 45°07'02''N), representing radiolarite block collected from the outcrop of sub-ophiolitic mélange along the southern flank of the Fruška Gora (Figs. 3a, e). The preparation and subsequent analyses of the radiolarian content followed the standard processing method with the usage of dilute 7% hydrofluoric acid (Pessagno and Newport 1972). An SEM microscope JEOL JSM-6610LV SEM at the University of Belgrade - Faculty of Mining and Geology, was utilized for precise identification of the radiolarians shown in Figs. 4 and 5. The assemblage was dated according to the zonation of Baumgartner et al. (1995). The generic names are adjusted according to the catalogue of Mesozoic radiolarian genera (O'Dogherty et al., 2009). The species inventory is given in Table 1.

RESULTS OF RADIOLARIAN DATING

The sample Sr2 is characterized by a well-preserved radiolarian assemblage. The most common-to-abundant elements are species of *Cinguloturris*, *Xitus, Zhamoidellum, Triactoma* and *Praeconosphaera*.

The coexistence of species *Xitus* sp. aff. *X. spicularis* (Aliev) sensu Baumgartner et al. (1995) (first appearance datum in UAZ 10; Baumgartner et al., 1995) and several species with the last appearance in UAZ 11 (see Table 1), such as *Dibolachras chandrika* Kocher, *Emiluvia orea* s.l. Baumgartner, *Eoxitus dhimenaensis* (Baumgartner), *Eucyrtidiellum ptyctum* (Riedel & Sanfilippo), *Triactoma foremanae* Muzavor, *Williriedellum crystallinum* Dumitrica and *Zhamoidellum ovum* Dumitrica indicates a late Oxfordian - early Kimmeridgian to late Kimmeridgian - early Tithonian age (UAZs 10-11).

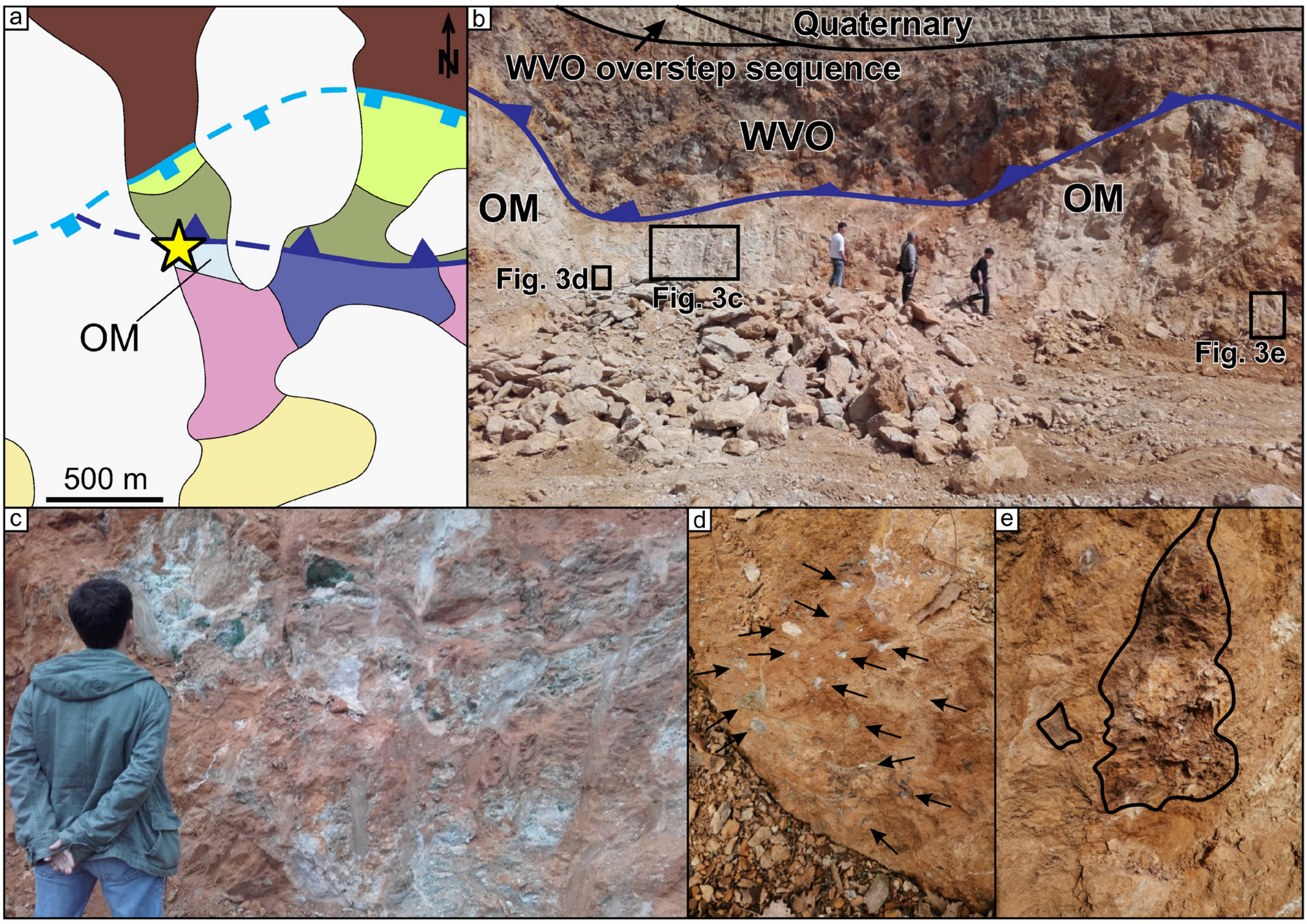

Fig. 3 - a) Local geological map of the southern part of the Fruška Gora where distal Adriatic margin sediments and magmatic rocks are thrust by the Western Vardar ophiolites. The yellow star marks the location of the outcrop in Fig. 3b (coordinates 19°42'29''E, 45°07'02''N). Legend: same as in Fig. 2a; b) Outcrop of sub-ophiolitic mélange thrust by hydrothermally altered serpentinites. The entire ophiolitic sequence is unconformably covered by the Late Cretaceous and Quaternary sediments; WVO-Western Vardar ophiolites; OM-sub-ophiolitic mélange; The black rectangles indicate locations of zoom-ins in Figs. 3c-e; c) Segment of sub-ophiolitic mélange comprised of blocks of clastites, carbonates, gabbros, diabases, and radiolarites, embedded in the matrix made up of reddish to grey shales; d) The sub-ophiolitic mélange with fragments of carbonates and radiolarites (larger fragments are marked by black arrows); e) Block of radiolarite embedded in the shale matrix from which the analyzed sample Sr2 was collected.

DISCUSSION

The most common Jurassic ages of radiolarites that are found as blocks within the mélange in the Internal Dinarides are Bajocian to Callovian (e.g., Gawlick et al., 2009, 2017, 2018; Vishnevskaya et al., 2009; Djerić et al., 2010a; Chiari et al., 2011; Bragin et al., 2019). The youngest radiolarite blocks are of late Middle to Late Jurassic age (Obradović & Goričan, 1988; Bragin et al., 2011; Gerzina & Djerić, 2016; Gawlick et al., 2017), but these ages, however, should be taken with extreme caution because such a wide age interval could be a result of poor level of preservation of the analyzed radiolarian association.

Therefore, the late Oxfordian - early Kimmeridgian to late Kimmeridgian - early Tithonian age (UAZs 10-11) determined from the block of radiolarites in sub-ophiolitic mélange along the southern flanks of the Fruška Gora are the youngest so-far determined radiolarites ages in the Internal Dinarides. Similar Late Jurassic ages (UAZs 9-11; Middle Oxfordian to early Tithonian) were obtained in the Belgrade area, located southwards (see Djerić et al., 2010b and Bragin et al., 2011). However, their position in the tectonic setting of the wider Adria-Europe transition zone is still a matter of debate (see Schmid et al., 2020). Furthermore, previous studies have shown the presence of Late Triassic radiolarian fauna in the metamorphic core of the Fruška Gora (Toljić et al., 2013), which is evidencing the deep-water facies conditions already during the Late Triassic. Following its progressive deepening through the Late Jurassic, the deep marine pelagic facies gradually spread across the entire continental margin of Adria.

The formation of sub-ophiolitic mélange in the Fruška Gora postdates the obtained ages of radiolarian assemblages. It most probably took place during the late stages of obduction in the latest Jurassic to earliest Cretaceous, due to the thrusting of ophiolites over the Adriatic continental margin. The mélange incorporated the rocks underlying the S to SW-wards (in present-day coordinates) progressing thrust, which include blocks of Triassic clastics and carbonates and basic magmatites, as well as the Jurassic radiolarites (Fig. 3).

Regarding the time of Western Vardar ophiolites obduction, intra-Tithonian (~148 Ma) Rb-Sr absolute ages that were recorded in the Fruška Gora metamorphic core may be associated with burial metamorphic event during obduction of the

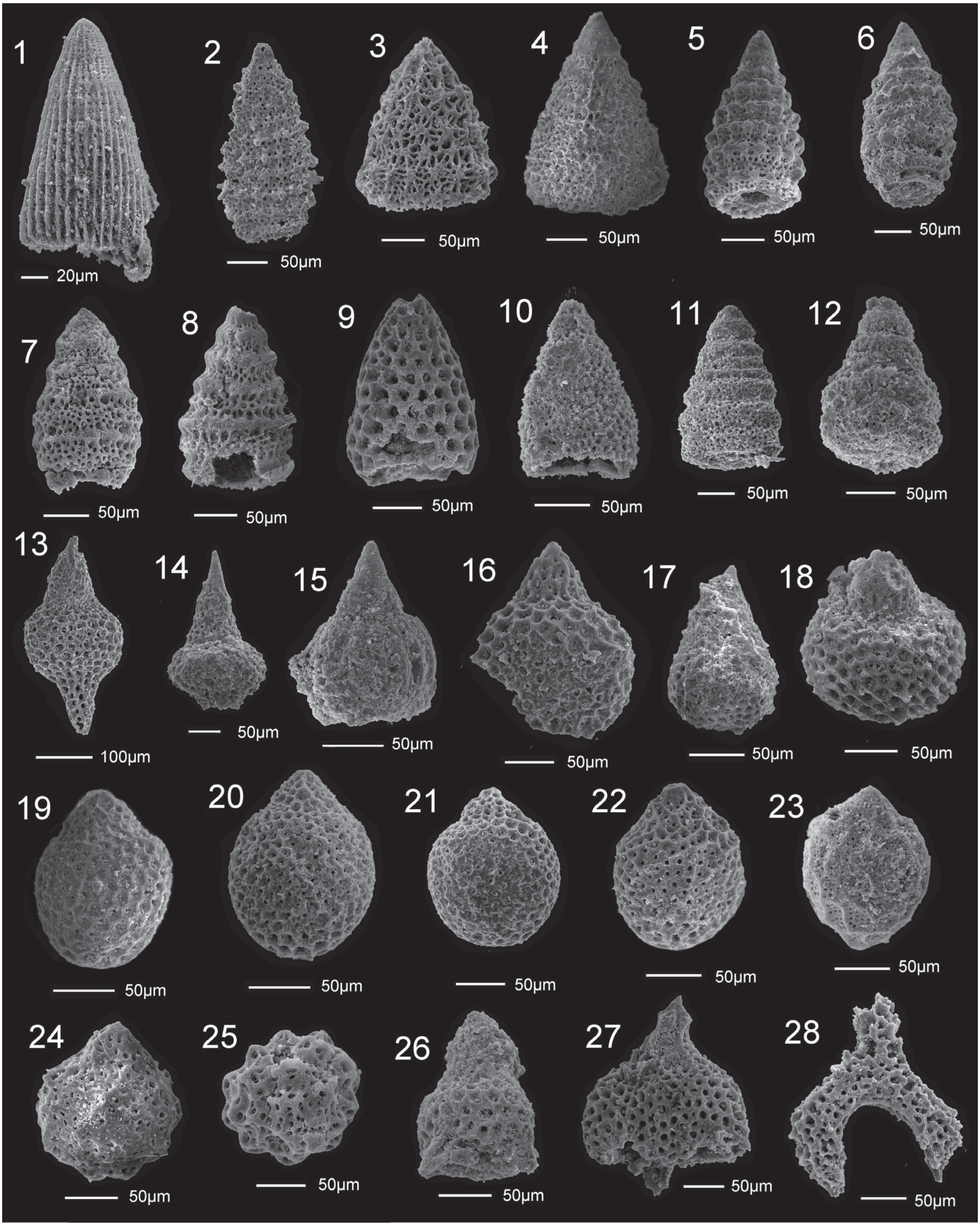

Fig. 4 - Radiolarians from sample Sr2: 1) *Archaeodictyomitra rigida* Pessagno; 2) *Eoxitus dhimenaensis* (Baumgartner); 3) *Xitus* sp. aff. *X. gifuensis* Mizutani; 4) *Spongocapsula* (?) sp.; 5) *Xitus* sp. aff. *X. spicularis* (Aliev) sensu Baumgartner et al. (1995); 6) *Xitus* sp. cf. *X.* sp. aff. *X. spicularis* (Aliev) sensu Baumgartner et al. (1995); 7-8) *Cinguloturris* sp. aff. *C. primorika* Kemkin & Taketani; 9) *Campanomitra tuscanica* (Chiari, Cortese & Marcucci); 10) *Xitomitra* (?) sp.; 11) *Spongocapsula palmerae* Pessagno; 12) *Spongocapsula* sp.; 13) *Dibolachras chandrika* Kocher; 14) *Spinoscicapsa* sp.; 15) *Eucyrtidiellum ptyctum* (Riedel & Sanfilippo); 16) *Crococapsa hexagona* (Hori); 17) *Crococapsa* sp. A sensu O'Dogherty et al. (2017); 18) *Crococapsa* sp.; 19-21) *Zhamoidellum ovum* Dumitrica; 22) *Zhamoidellum* sp.; 23) *Williriedellum crystallinum* Dumitrica; 24) *Williriedellum* sp. cf. *W. yahazuense* (Aita); 25) *Arcanicapsa* (?) sp.; 26) *Fultacapsa* sp. cf. *F. sphaerica* (Ožvoldova); 27) *Napora lospensis* Pessagno; 28) *Deviatus diamphidius* s.l. (Foreman).

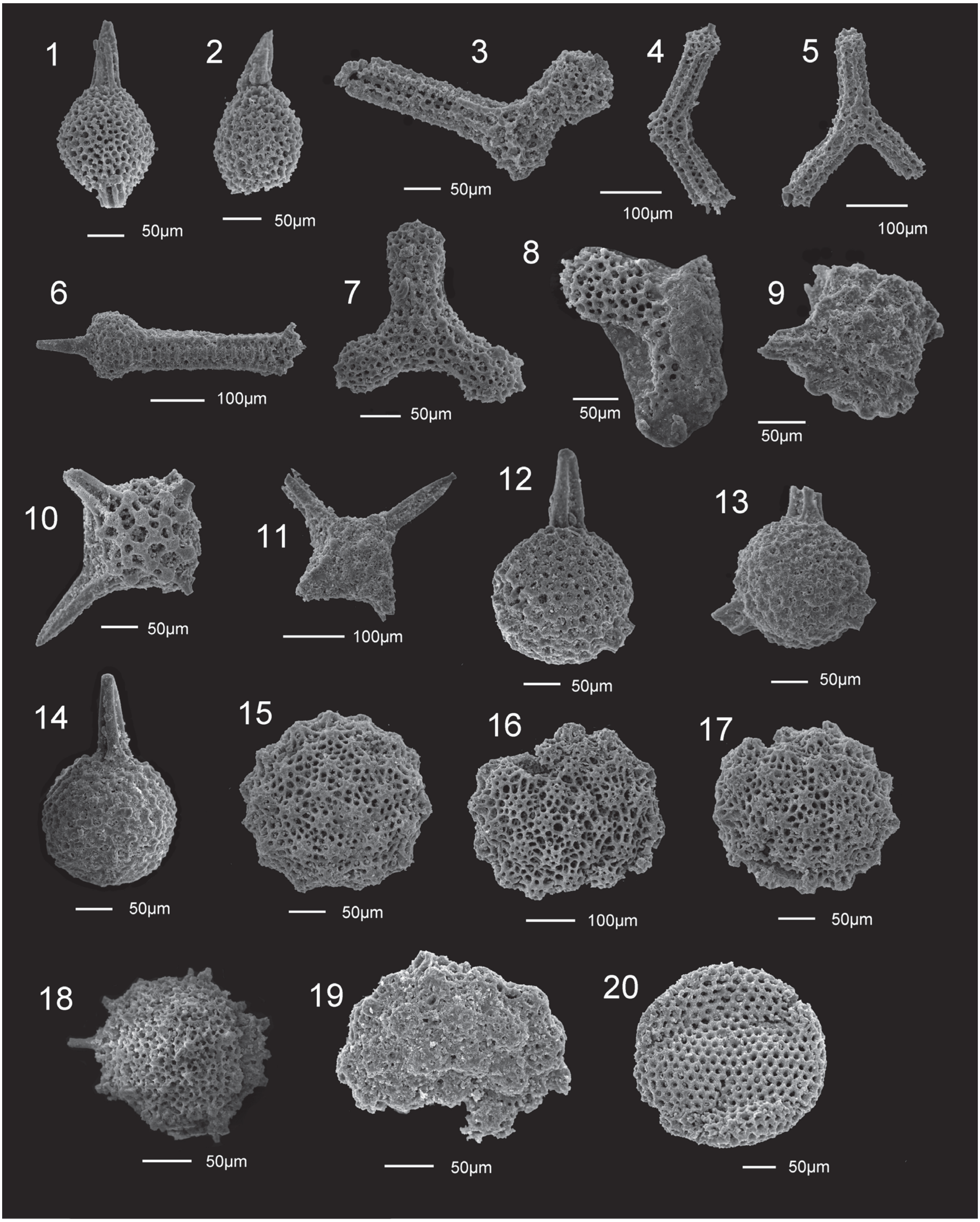

Fig. 5 - Radiolarians from sample Sr2: 1) *Archaeospongoprunum* sp. aff. *A. globosus* Wu; 2) *Archaeospongoprunum* sp.; 3) *Tritrabs ewingi* s.l. (Pessagno); 4) *Tritrabs* sp. cf. *T. rhododactylus* Baumgartner; 5) *Tritrabs* sp.; 6) *Tetratrabs* sp. cf. *T. bulbosa* Baumgartner; 7) *Paronaella* sp. cf. *P. broennimani* Pessagno; 8) *Paronaella* sp.; 9, 10) *Emiluvia orea* s.l. Baumgartner; 11) *Emiluvia* sp. cf. *E. chica* s.l. Foreman; 12) *Triactoma foremanae* Muzavor; 13, 14) *Triactoma* sp.; 15-17) *Praeconosphaera sphaeraconus* (Rüst); 18) *Actinomma matsuokai* Sashida & Uematsu; 19) *Praeconosphaera* sp.; 20) *Archaeocenosphaera* sp.

Table 1 - List of radiolarian species in the analyzed sample Sr2.

Radiolarians	UA zones (Baumgartner et al., 1995)
Actinomma matsuokai Sashida & Uematsu	
Arcanicapsa (?) sp.	
Archaeocenosphaera sp.	
Archaeodictyomitra rigida Pessagno	
Archaeospongoprunum sp. aff. *A. globosus* Wu	
Archaeospongoprunum sp.	
Campanomitra tuscanica (Chiari, Cortese & Marcucci)	
Cinguloturris sp. aff. *C. primorika* Kemkin & Taketani	
Crococapsa hexagona (Hori)	
Crococapsa sp. A sensu O'Dogherty et al. (2017)	
Crococapsa sp.	
Deviatus diamphidius s.l. (Foreman)	8-22
Dibolachras chandrika Kocher	7-11
Emiluvia orea s.l. Baumgartner	4-11
Emiluvia sp. cf. *E. chica* s.l. Foreman	(3-18)
Eoxitus dhimenaensis (Baumgartner)	3-11
Eucyrtidiellum ptyctum (Riedel & Sanfilippo)	5-11
Fultacapsa sp. cf. *F. sphaerica* (Ožvoldova)	(9-11)
Napora lospensis Pessagno	8-13
Paronaella sp. cf. *P. broennimani* Pessagno	(4-10)
Paronaella sp.	
Praeconosphaera sphaeraconus (Rüst)	
Praeconosphaera sp.	
Spinosicapsa sp.	
Spongocapsula palmerae Pessagno	6-13
Spongocapsula sp.	
Spongocapsula (?) sp.	
Tetratrabs sp. cf. *T. bulbosa* Baumgartner	(7-11)
Triactoma foremanae Muzavor	7-11
Triactoma sp.	
Tritrabs ewingi s.l. (Pessagno)	4-22
Tritrabs sp. cf. *T. rhododactylus* Baumgartner	(3-13)
Tritrabs sp.	
Williriedellum crystallinum Dumitrica	7-11
Williriedellum sp. cf. *W. yahazuense* (Aita)	
Xitomitra (?) sp.	
Xitus sp. aff. *X. gifuensis* Mizutani	
Xitus sp. aff. *X. spicularis* (Aliev) sensu Baumgartner et al. (1995)	10-22
Xitus sp. cf. *X.* aff. *X. spicularis* (Aliev) sensu Baumgartner et al. (1995)	(10-22)
Zhamoidellum ovum Dumitrica	← 9-11
Zhamoidellum sp.	

The second column gives ranges of the species according to Baumgartner et al. (1995).

overlying Western Vardar ophiolites (see Toljić et al., 2013). Recent structural and K-Ar geochronological investigations were conducted along the northern rim of the Drina-Ivanjica composite unit of the Internal Dinarides (Fig. 1b, Porkoláb et al., 2019). The obtained results in the Paleozoic basement and Triassic sedimentary cover of the Drina-Ivanjica indicate 135-150 Ma tectonic burial that resulted in low-grade metamorphism and WNW-verging isoclinal folding. This latest Jurassic to Early Cretaceous tectonic burial was correlated with top W to NW obduction of Vardar ophiolites over the distal margin of Adria.

CONCLUSIONS

The formation of sub-ophiolitic mélange along the southern flanks of the Fruška Gora was associated with the latest Jurassic to earliest Cretaceous obduction-related thrusting of the Western Vardar ophiolites over the distal Adriatic margin. The late Oxfordian - early Tithonian radiolarians were determined from the blocks of radiolarites in the sub-ophiolitic mélange of the Fruška Gora. The obtained ages represent the youngest so-far determined radiolarites ages in this segment of the Dinarides, which are evidencing the deep-water facies conditions along the most-distal Adriatic margin through Late Jurassic times.

ACKNOWLEDGEMENTS

This study was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia (Contract no. 451-03-68/2022-14/ 200126). The authors acknowledge the excellent comments and suggestions of Špela Goričan and Michele Marroni that significantly improved the original version of the manuscript. The authors are grateful to editors, Alessandra Montanini and Marco Chiari, for their guidance and constructive comments and suggestions.

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Received, June 23, 2021
Accepted, January 24, 2022