Lithos 108 (2009) 72–105

Contents lists available at ScienceDirect

Lithos

journal homepage: www.elsevier.com/locate/lithos

New data on Mesozoic Radiolaria of Serbia and Bosnia, and implications for the age and evolution of oceanic volcanic rocks in the Central and Northern Balkans

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ARTICLE INFO

Article history:
Received 30 November 2007
Accepted 16 October 2008
Available online 5 November 2008

Keywords:
Mesozoic
Radiolaria
Serbia
Bosnia
Palaeogeography

ABSTRACT

The Dinaridic Ophiolite Belt (DOB) includes Middle Triassic cherty limestones, Upper Triassic radiolarian cherts associated with basaltic lavas and volcaniclastic sediments, and also Jurassic continental slope sequences. Sedimentary sequences grade upwards into Cretaceous red limestones with planktonic foraminifers of the Genus *Hedbergella*. Many of the Late Triassic to Late Jurassic cherts probably accumulated in an oceanic setting, and now crop out as blocks in olistostromal deposits. Jurassic radiolarite sequences of the margin of the Dinaride Ophiolite Belt are represented by Aalenian, Upper Bajocian–Lower Bathonian and Upper Bathonian–Lower Callovian, Middle Callovian–Oxfordian, Upper Callovian–Upper Oxfordian and Kimmeridgian–Tithonian-aged strata. These are overlain by Upper Tithonian–Valanginian sedimentary sequences with spongolite–radiolarites, volcaniclastic sediments and other continental slope deposits. The oldest units outcropping in the DOB are Mid-Triassic (Ladinian) red cherts and limestones. These are associated with alkaline and tholeiitic basalts in the Bistrica area, and with tholeiitic basalts in the Visoka area. In contrast, in the Vardar Zone Western Belt the oldest basalt–radiolarite formation is represented by cherts associated with tholeiitic basalt in the Ovčar Banja area. Upper Triassic red radiolarites of the Čačak area lie in direct stratigraphical contact with MORB-type pillow lavas and contain a Carnian–Norian radiolarian assemblage. The youngest radiolarian-bearing units are in the Upper Cretaceous part of the Vardar Zone Western Belt, in the Struganik area, where Coniacian–Santonian radiolarians occur in chert–clay–tuff sediments. In addition, cherty limestones from the northern slope of Kozara Mt. contain a Campanian radiolarian assemblage, together with Campanian–Maastrichtian planktonic foraminifers. Volcanic units associated with the siliceous sediments of Dinaride Ophiolite Belt and the Vardar Zone Western Belt are of MOR- and SSZ types, respectively. The ocean-related basalts of the Dinaride Ophiolite Belt and the Vardar Zone Western Belt show some geochemical differences, irrespective of age. Compared to those of the Dinaride Ophiolite Belt, the basalts of the Vardar Zone Western Belt are more variable chemically and exhibit much higher LREE/HREE and Th/REE ratios. Finally, possible paleo-reconstructions of the radiolarian sediments and the volcanic rocks are proposed.

1. Introduction

The present paper is the first attempt to summarize all of the data concerning biostratigraphic investigations of Triassic, Jurassic and Cretaceous Radiolaria-bearing ophiolitic and non-ophiolitic sequences in Bosnia and Serbia.

The main purposes of this paper are:

1) To illustrate the nature of Triassic, Jurassic and Cretaceous radiolarian sequences from Bosnia and Serbia;
2) To provide additional geochemical data for basaltic volcanic rocks that are associated with the radiolarian cherts in the northern part of the Balkan Peninsula.

The Dinaridic Ophiolite Belt (DOB) marks a tectonic suture zone or boundary between the Bosnian Mountain terranes and the Western belt of the Vardar zone (VZWB). The Vardar Ocean, representing the northwestern part of Tethys, finally closed along this suture zone during a late Maastrichtian–Early Cenozoic collision between Eurasia and Gondwana (Karamata et al., 2005). Most of the oceanic crust of the Dinaride and Vardar oceans was subducted during the convergence, obducted during collision, or incorporated into melange. Only remnants of oceanic crust now occur within the DOB and VZWB as ophiolitic zones up to several hundred kilometers wide Knowledge of the timing of formation of radiolarites (e.g. as a sedimentary cover of ophiolites) is important to understand the development of sedimentary basins and

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doi:10.1016/j.lithos.2008.10.015

the sequence of events related to ophiolite genesis, and also has implications for tectonic models of Tethyan evolution.

Siliceous sedimentary rocks in the form of cherts and radiolarites are widespread in the central part of the Balkan Peninsula. They originated in different geological settings and during different geological time intervals (Dimitrijević, 1997; Karamata, 2006a,b). The cherts include lithological types ranging from radiolarites and spongolites–radiolarites, to spongolites, and spiculites. The cherts were deposited in settings ranging from the base of the continental slope, to the abyssal plain, oceanic trench and continental rift. They also occur associated with oceanic ophiolitic rocks. Their time of formation was in the Middle and Upper Triassic and also in the Jurassic and Cretaceous. In addition, radiolarians also occur in siliceous limestones related to other, non-ophiolite-related settings in the Carpatho–Balkan region.

Siliceous sedimentary rocks of the ophiolite belts of the Balkan Peninsula are closely associated with several types of oceanic volcanic rocks. Age determination based on radiolarian assemblages allows the time intervals of major volcanic pulses to be identified and thus sheds light on key aspects of the evolution of the paleo-oceanic basins.

In this paper we present the principal results of research on basalt–radiolarite associations that are exposed in the Dinaridic Ophiolite Belt (DOB) and the Western Belt of the Vardar Zone (VZWB) in the central and northern parts of Balkan Peninsula.

2. Previous work

Until the 1960s the ages of Triassic and Jurassic cherts and radiolarites in western Serbia and Bosnia were determined according to their geological setting and the occurrence of Middle Triassic gastropods in limestones. However, since the end of the l980s, Radiolaria of Middle Triassic and Upper Triassic–Upper Jurassic age were discovered in cherts, and in addition foraminifera of Late Cretaceous were found in cherty limestone (e.g. Obradović and Goričan, 1988; Karamata et al., 2005, etc.). However, these results were mainly from widely separated olistoliths and blocks. The age of the chert of the Dinaridic Ophiolite Belt in Bosnia was inferred to be Triassic to Jurassic in accordance with its stratigraphic position between a Triassic “carbonate formation” and a Tithonian–Neocomian “flysch formation”. There were also scarce findings of Upper Triassic conodonts within interlayered limestones problematically associated with Middle? to Late Jurassic radiolarian chert (Karamata et al., 2004a). In addition, the age of chert associated with pillow lavas of the Vardar Zone Western Belt in the northern part of Bosnia was determined as Campanian–Maastrichtian based on foraminifers from interlayered limestone (Karamata et al., 2005).

The first findings of Triassic radiolarians in the Dinaride and Vardar ophiolite belts, in Serbia were by Š. Goričan (Obradović et al., 1986a; Obradović and Goričan, 1988).

Cherts and related lithologies occur in the Dinaride and Vardar ophiolite belts as variably sized blocks within olistostrome mélange (i.e. subduction trench deposits; Karamata, 2006b). In Serbia, in the Dinaridic Ophiolite Belt, Jurassic as well as Triassic Radiolaria were first described by Š. Goričan (i.e. written communication, 1988, 1990; Obradović and Goričan, 1988; Obradović et al., 1986a,b, 1987/1988).

The existing scientific literature also provides information on several locations of Jurassic radiolarians in Serbia. Mid-Jurassic radiolarians occur between Bistrica-Nova Varoš, in Mileševa, Krš Gradac, Lokvice and Pavlovića Brod (Goričan, written communication, 1988; Obradović et al., 1987/1988; Djerić et al., 2007). Late Jurassic radiolarians are more abundant in the following areas of Serbia: Krš Gradac, Bistrica, Sjenica, Trijebinska Reka (unpublished data by Goričan and Đerić). During the previous investigations Triassic and Jurassic radiolarians from Bosnia and Serbia have been determined, or noted within siliceous deposits, but there have been no systematic descriptions of the radiolarian microfauna or recognition of any radiolarian assemblages. Also, there have been no previous findings of Jurassic radiolarians in the Vardar zone.

3. Geological outline

The Balkan Peninsula (BP) is situated in the northwestern part of the Eastern Mediterranean region and includes units of different provenance, now sutured (see e.g. Robertson et al., 1996, Robertson,

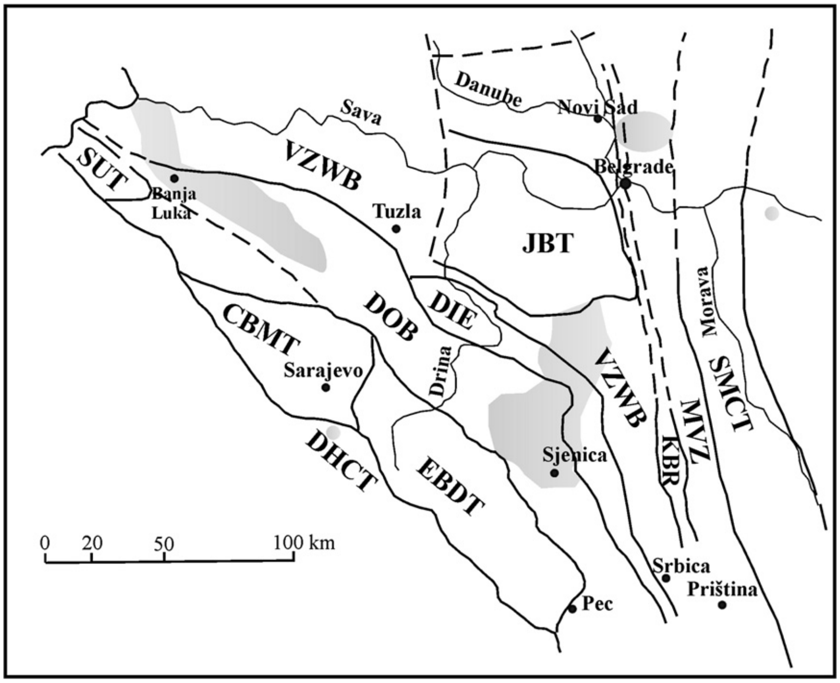


Fig. 1. Schematic tectonic map of the Balkan Peninsula (Karamata et al., 1997) with location of the studied localities. DHCT — the Dalmatian–Herzegovian composite terrane, from the Carboniferous geological unit with post-Carboniferous cover; SUB — Sana–Una–Banija–Kordun terrane, since the middle of Cretaceous geological assembly CBMT — the Central Bosnian mountains terrane, since the Permian geological assembly with flysches at the northeast; EBDT — the East Bosnian–Durmitor terrane, since the Upper Jurassic geological assembly; DOB — the Dinaridic ophiolite belt; DIE — the Drina–Ivanjica terrane/element; VZWB — the Vardar zone Western Belt; JBT — the Jadar block terrane, since the middle of Cretaceous geological assembly; KBR — the Kopaonik block and ridge; MVZ — the Main Vardar zone; SMCT — the Serbo-Macedonian composite terrane, since the middle of Carboniferous geological assembly; Localities: shaded area.

2007). The Balkan Peninsula includes two key tectonic units: the Dinaridic Ophiolite Belt, a complex mosaic of units including some continental crust, and the Vardar Zone which marks the trace of a large oceanic realm (Dimitrijević, 1997). The Dinaridic Ophiolite Belt extends from western Serbia, westwards to northwestern Bosnia and southwards into Albania (Fig. 1), western and central Greece and further east (Karamata et al., 2004a).

The name of the Vardar Zone is derived from the Vardar River that runs from Skopje to its mouth (Kossmat, 1924) and was later extended to include the Belgrade area. It represents the scar of the Vardar Ocean; i.e. the western part of Neotethys in the Mesozoic Alpine paleogeography. The Vardar Zone Western Belt, the Kopaonik Block and Ridge unit (KBR) and Main Vardar Zone (MVZ) (Fig. 1) are also distinguished in this region (Karamata et al., 1997).

According to Karamata (2006a), the Balkan Peninsula includes the following main units: (1) the Moesian microplate, part of the southern margin of Eurasia; (2) Adria (often termed Apulia), a microplate forming a promontory of Gondwana; (3) remnants of Tethys and related marginal seas. During the Paleozoic and Mesozoic different terranes were transported together with Tethyan oceanic crust and then docked to continental units forming larger entities. This process of terrane accretion lasted from the Early Paleozoic until almost the end of the Cretaceous and was contemporaneous with subduction of oceanic lithosphere (Karamata, 2006a). According to Djerić et al. (2007) radiolarian cherts can be found in several different tectonic settings in the Internal Dinarides: (1) Jurassic radiolarites that form part of the *in situ* preserved stratigraphic cover of an ophiolitic sequence (Dinaric Ophiolite Belt and/or West Vardar Ophiolite Belt); (2) radiolarian chert

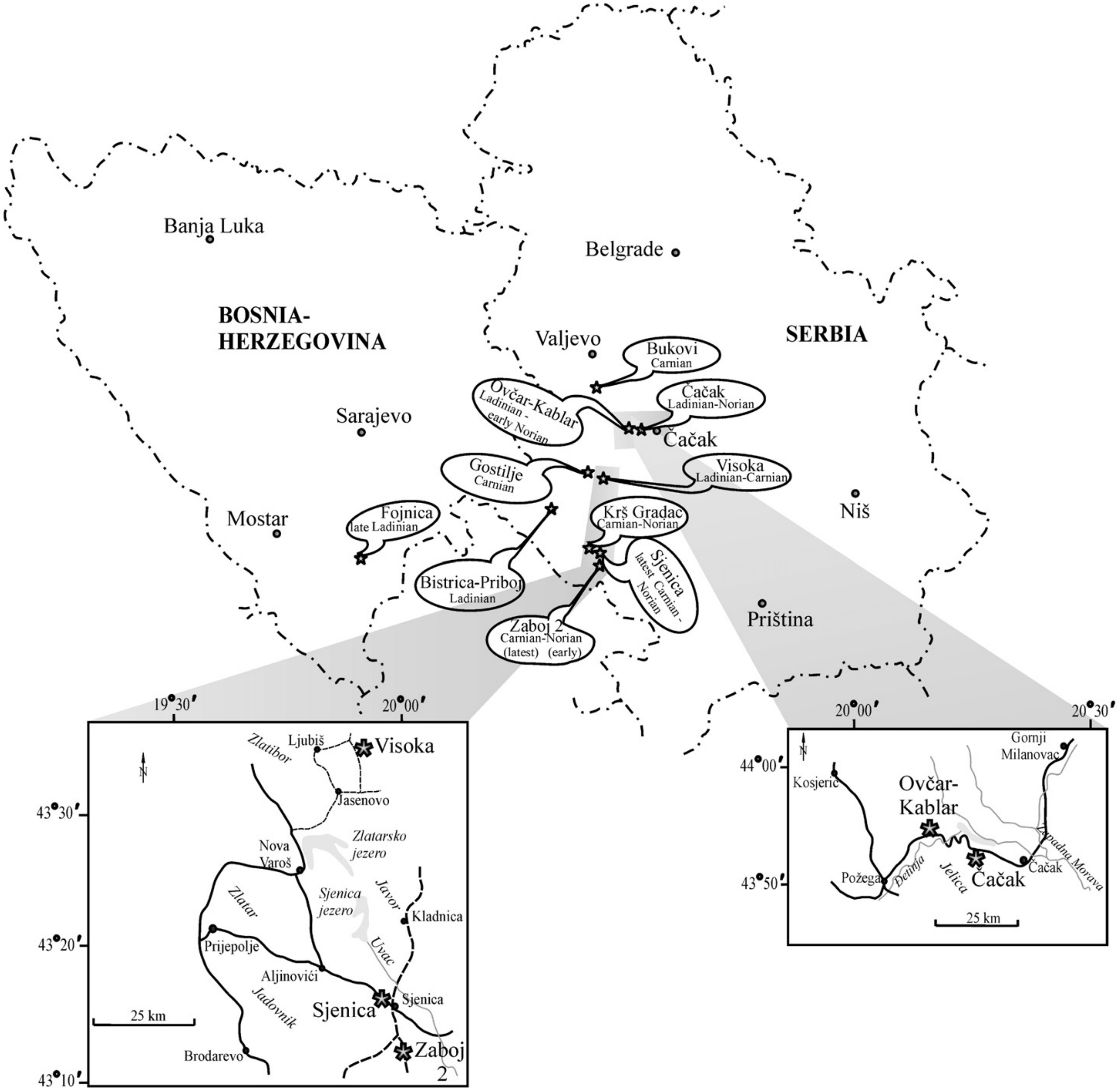


Fig. 2. The locations of the Triassic sections studied: 1.1 Visoka; 1.2 Sjenica; 1.3 Zaboj 2; 1.4; Ovčar-Kablar gorge; 1.5 Čačak, and other Triassic sections from other authors (see text).

Tectonic zone	**DOB**			**VZWB**		**DHCT**	**DOB**			**VZWB**
Location	Visoka	Sjenica	Zaboj 2	Ovčar-Kablar	Čačak	Fojnica	Bistrica-Priboj	Krš Gradac	Gostilje	Bukovi
Lithology	basalt, chert and cherty limestone	chert	chert, basalt	chert, limestone, tuffites	chert, basalt	limestone with radiolarite-tuff intercalation	cherty tuff, basalt	chert	chert	chert, basalt
Other fossils		conodonts	conodonts			conodonts				
Age	Ladinian to Carnian	latest Carnian-Norian	latest Carnian-early Norian	Ladinian-early Norian	Ladinian-Norian	late Ladinian	Ladinian	Carnian-Norian	Carnian	Carnian
Radiolarian zone	*Muelleritortis cochleata*	*Kahlerosphaera kemerensis, Capnodoce sarisa*		*Capnodoce sarisa*	*Kahlerosphaera kemerensis, Capnodoce sarisa*	*Muelleritortis cochleata*				
References	Vishnevskaya & Djerić, 2006b and this paper	Goričan et al., 1999 and this paper	this paper	Obradović & Goričan, 1988 and this paper	Obradović & Goričan, 1988 and this paper	Kozur & Mostler, 1996, 2006 Tekin & Mostler, 2005a,b	Obradović & Goričan, 1988	Karamata et al., 2006a	personal comm. of Dosztaly	Karamata et al., 2006b

Fig. 3. Lithostratigraphic scheme for the Triassic radiolarian-bearing sequences. See text for explanation.

sequences of either Triassic or Jurassic age which were incorporated into a mélange underlying obducted ophiolites (i.e. Dinaric or West Vardar) in the form of gravitationally emplaced olistoliths or "olistoplaka" (Dimitrijević, 1997), or alternatively as tectonically incorporated slivers scraped from the Adriatic margin (Schmid et al., 2008), and (3) Jurassic-age radiolarian cherts that are an integral part of a passive margin sedimentary sequence located in the footwall of the ophiolitic mélange. Radiolarites of settings (2) and (3) were probably deposited onto older carbonate platform sediments of the distal Adriatic margin, indicating drowning below the CCD.

4. Methods

Recently, much work has been carried out to determine the ages of the radiolarian-bearing rocks (Karamata et al., 2004a,b, 2006a,b, c; Djerić and Vishnevskaya, 2005, 2006; Vishnevskaya and Djerić, 2005, 2006a,b; Djerić et al., 2007), and as a result some new radiolarian assemblages were discovered in Bosnia and Serbia. Well-preserved radiolarians were extracted from 70 samples of chert and siliceous limestone beds that are interstratified in a sequence of basalt–chert in different units of Dinaride and Vardar zones. Here, we report the radiolarian assemblage of well-preserved samples.

The chert samples were treated with hydrofluoric acid (1–3%). Siliceous limestone samples were treated with acetic acid (10%) and with hydrofluoric acid (1–5%). The residues of the acid treatment provided well-preserved microfauna that were studied for taxonomic and biostratigraphic purposes.

In order to establish the age of the radiolarian assemblages we used the zonation schemes, as proposed by Dumitrica (Dumitrica et al., 1980) and by Kozur and Mostler (1994, 1996a,b, 2006) for the Middle Triassic, and as proposed by Goričan (Ramovš and Goričan, 1995) and by Tekin (1999) for the Late Triassic. The Jurassic and early Cretaceous biostratigraphic ranges of the radiolarian species were determined based on a synthesis of occurrences reported in the literature (Baumgartner et al., 1995; Grill and Kozur, 1986; Jud, 1994; De Wever et al., 2001; Dumitrica and Zugel, 2003; Beccaro, 2006). The late Cretaceous biostratigraphic ranges follow Pessagno (1976), Schaaf (1985) and Vishnevskaya (2001).

The SEM microscope ISI-160 in GIN RAN (Moscow) was utilized for the precise identification and illustration of the radiolarians.

5. Descriptions of stratigraphic sections with radiolarian biostratigraphy

Fifteen sections of radiolarian chert and radiolarites, collected in Serbia and Bosnia, yielded moderately preserved to well preserve radiolarian assemblages in four age groups: Middle–Late Triassic, Middle–Late Jurassic, Late Jurassic–Early Cretaceous and Late Cretaceous.

5.1. Middle–Late Triassic

Triassic radiolarians were found by Kozur and Mostler (1996a,b, 2006) and by Tekin and Mostler (2005a,b) in cherts associated with tuffites (radiolarite–tuffite intercalations), within non-ophiolitic sequences in Bosnia. In addition, some locations of Triassic radiolarians within the ophiolite belts of Serbia were reported by Š. Goričan (Obradović et al., 1986a,b; Obradović and Goričan, 1988; Goričan et al., 1999). We sampled five sections (Visoka, Sjenica, Zaboj 2, Ovčar-Kablar gorge and Čačak). Also, new locations of Triassic radiolarians were found in the Mali Rzav river basin (Location Visoka) on the road between Radoševo and Visoka village and to the west of Sjenica (Zaboj 2), as well as in the Ovčar-Kablar gorge and Čačak areas (Fig. 2).

5.1.1. Visoka

Mid-Triassic radiolarians occur in the basin of the Mali Rzav River, along the road between Radoševo and Visoka village (Figs. 2, 3; Plate 1). In this area, there are sporadic outcrops of reddish cherty limestone and cherts associated with basalt and basalt breccia. Very near Radoševo village one sample (10–11) was taken in the lowest part of the section (Fig. 4). The presence of *Pseudostylosphaera coccostyla* (Rüst) indicates a Ladinian age (Ramovš and Goričan, 1995; Tekin, 1999). The second sample (10-8a) was collected in the upper part of an alternation of red chert and reddish cherty limestone (~7 m from the base of the section). The age is Ladinian (Table 1). The presence of *P. coccostyla* (Rüst), *P. goestlingensis* (Kozur & Mostler), *P. multispinata* Tekin & Mostler and *Oertlispongus inaequispinosus* Dumitrica, Kozur & Mostler (Goričan and Buser, 1990; Tekin and Mostler, 2005a,b) allows a late Ladinian age to be inferred (Table 1). Three samples (Fig. 4) were also collected from chert lenses within basalts. A well-preserved radiolarian assemblage (Plate 2) occurs in Sample 10-8, collected 10.5 m from the base of the section. This sample can be assigned to the late Ladinian–Carnian owing to the coexistence of *Spinotriassocampe carnica* Kozur & Mostler (Kozur and Mostler, 1994) and *P. coccostyla* (Rüst) (Ramovš and Goričan, 1995) (Table 1).

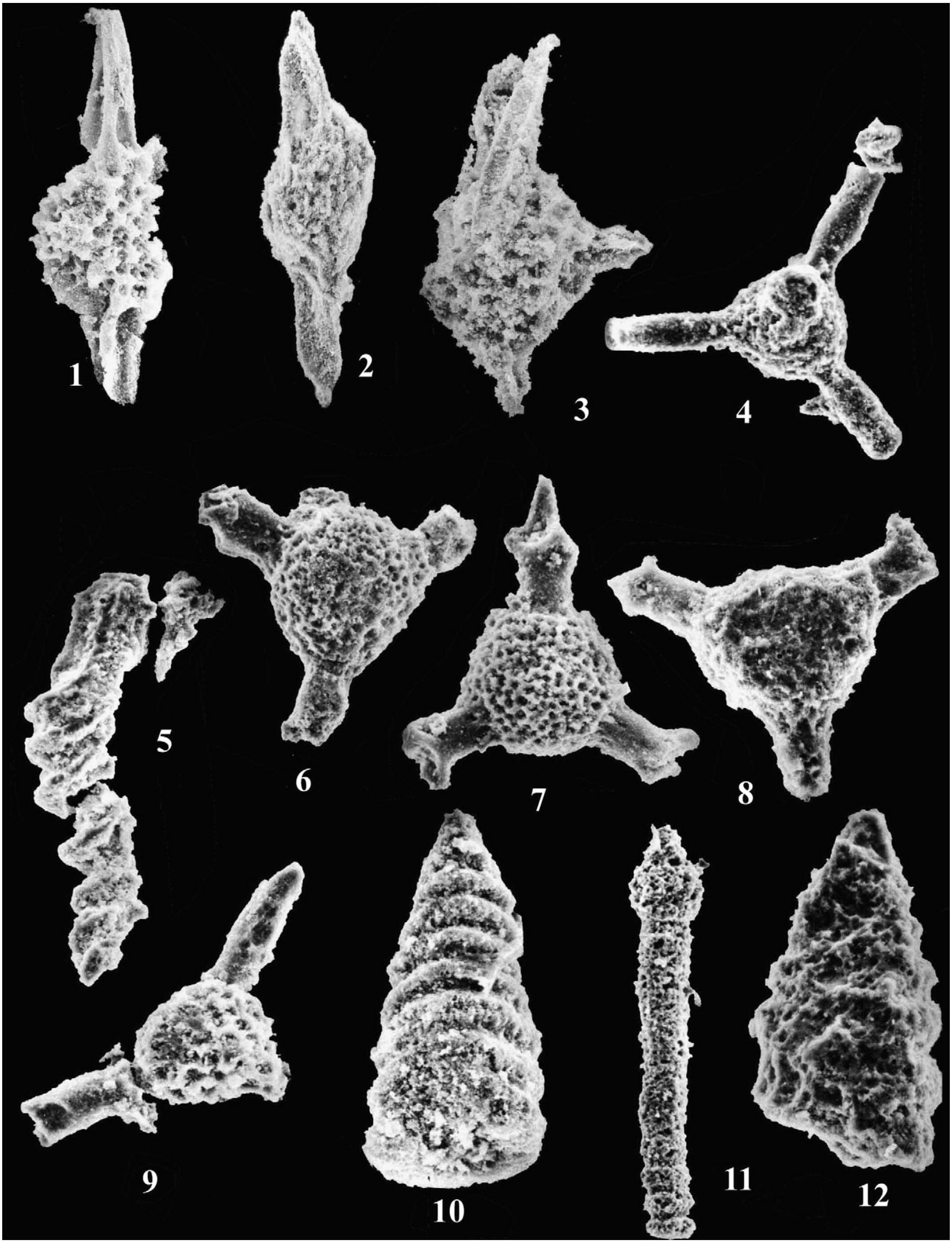


Plate 1. Middle to Late Triassic radiolarians of Serbia. Ladinian radiolarians from Visoka (Figs. 1–3 from Sample 10-11) 1. *Pseudostylosphaera coccostyla* (Rüst), ×260; 2. *Pseudostylosphaera* sp., ×280; 3. *Muelleritortis* ? sp., ×410; 3. PLEASE CHECK Late Carnian–early Norian radiolarians from the Ovčar-Kablar gorge (Figs. 4, 7–11 from Sample 102; Figs. 5, 6, 12 from Sample 100); 4. *Loffa* ? *mulleri* Pessagno, ×200; 5. *Spongotortilispinus carnicus* (Kozur & Mostler), ×350; 6. *Capnuchosphaera* sp., ×200; 7. *Capnuchosphaera theloides* De Wever, ×200; 8. *Capnuchosphaera* sp., ×200; 9. *Capnodoce* sp. cf. *C. extenta* Blome group, ×200; 10. *Japanocampe* sp. cf. *J. nova* (Yao), ×200; 11. *Xiphotecaella rugosa* (Bragin), ×100; 12. *Multimonilis* ? sp., ×200. Magnification factors refer to the printed version of the paper.

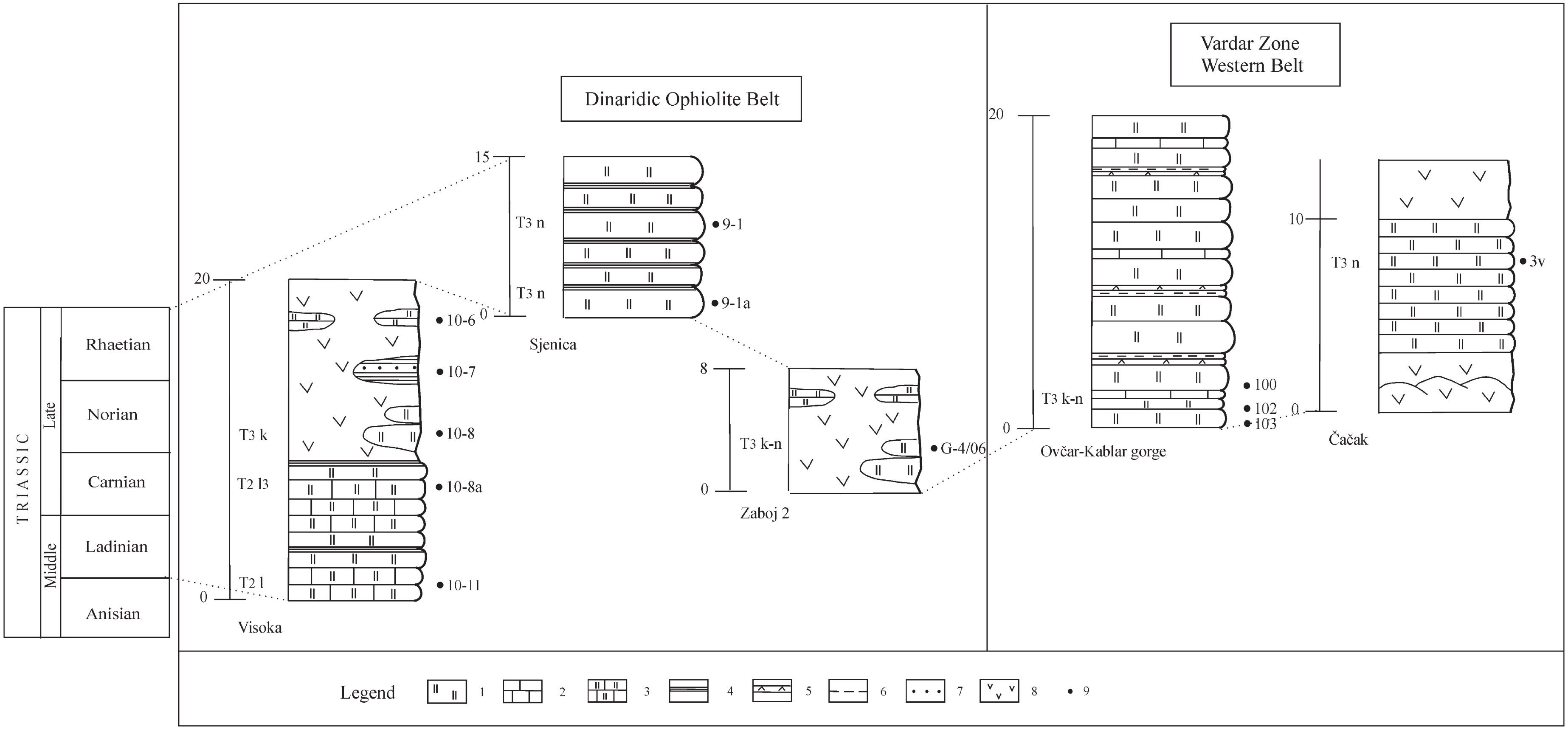


Fig. 4. Sample position and lithological logs of Triassic sections: 1.1 Visoka; 1.2 Sjenica; 1.3 Zaboj 2; 1.4; Ovčar-Kablar gorge; 1.5 Čačak. Legend: 1—chert, 2—limestone, 3—cherty limestone, 4—silicified chert, 5—tuff, 6—claystone, 7—sandstone, 8—basalt and pillow basalt, 9—radiolarian sample position.

Table 1
Triassic radiolarian assemblages from Serbia

Species	Tectonic unit	DOB						VZWB			
	Sample location	Visoka			Sjenica		Zaboj 2	Ovčar-Kablar gorge			Čačak
	Sample no	10-11	10-8a	10-8	9-1a	9-1	G-4/06	103	102	100	3v
Canesium lentum Blome								●			
Canoptum triassicum Yao					●	●					
Capnodoce anapetes De Wever							●				
Capnodoce crystallina Pessagno					●			●			
Capnodoce extenta gr. Blome									cf.		
Capnodoce serisa De Wever					●	●	●				●
Capnuchosphaera ? concava De Wever								●			
Capnuchosphaera ? constricta Kozur & Mock								●			
Capnuchosphaera crassa Yeh							●				
Capnuchosphaera lea De Wever						cf.			cf.		
Capnuchosphaera lenticulata Pessagno					●	●	●	●			
Capnuchosphaera puncta De Wever				●							
Capnuchosphaera theloides s.l. De Wever				●			●		●	●	
C. theloides theloides De Wever									●	●	
Capnuchosphaera triassica De Wever							●		●		
Capnuchosphaera tricornis De Wever					●	●	●	●		●	
Capnuchosphaera sp.										●	
Deflandrecyrtium curvatum Kozur & Mostler						●					
Dicapnuchosphaera sengori Tekin											aff.
Hindeosphaera bispinosa Kozur & Mostler				●							
Japonocampe nova (Yao)						●			cf.		
Icrioma tetrancistrum De Wever											●
Kahlerosphaera kemerensis Tekin					●						
Latium longulum Blome						●					
Loffa ? mulleri Pessagno									●		
Muelleritortis cochleata (Nakaseko & Nishimura)		●									
Muelleritortis ? sp.		●									
Muelleritortis granulosum (Dumitrica, Kozur & Mostler)			cf.								
Multimonilis pulcher Yeh						●					
Multimonilis ? sp.										●	
Oertlispongus inaequispinosus Dumitrica, Kozur & Mostler			●								
Pseudoheliodiscus primitivus (Kozur & Mostler)											cf.
Pseudostylosphaera coccostyla (Rüst)		●	●	●							
Pseudostylosphaera compacta (Nakaseko & Nishimura)			●								
Pseudostylosphaera goestlingensis (Kozur & Mostler)			●								
Pseudostylosphaera ? hellenica (De Wever)			●								
Pseudostylosphaera japonica (Nakaseko & Nishimura)			●								
Pseudostylosphaera multispinata Tekin & Mostler			●								
Pseudostylosphaera nazarovi (Kozur & Mostler)			●								
Pseudostylosphaera sp.		●									
Sarla vetusta Pessagno						●	●			●	
Sarla vizcainoensis Pessagno						●		aff.			
Spinotriassocampe carnica Kozur & Mostler				●							
Spinotriassocampe mesofassanica Kozur & Mostler			●	●							
Spongotortilispinus carnicus (Kozur & Mostler)								●		●	
Spongostylus tortilis Kozur & Mostler								●			
Triassocampe coronata Bragin			cf.	cf.							
Triassocampe deweveri (Nakaseko & Nishimura)			●								

Table 1 (*continued*)

Species	Tectonic unit	DOB						VZWB			
	Sample location	Visoka			Sjenica		Zaboj 2	Ovčar-Kablar gorge			Čačak
	Sample no	10-11	10-8a	10-8	9-1a	9-1	G-4/06	103	102	100	3v
Triassocampe sulovensis Kozur & Mock			cf.								
Triassocampe sp.			●								
Whalenella regia (Blome)							●				
Whalenella ? speciosa (Blome)						●		●			
Xiphotecaella rugosa (Bragin)						●			●		

The samples were collected from the following sections: Zaboj 2, Sjenica, Visoka, Čačak and Ovčar-Kablar gorge.

5.1.2. Sjenica

The outcrop is located 3 km west of Sjenica on the road from Sjenica to Nova Varoš (Fig. 2). This section was described by Goričan et al. (1999) as a block or olistolith in mélange. We sampled an outcrop of bedded chert on the left bank of the river (just opposite a quarry, ~20 m from a bridge). The block is composed of a ~11 m thick sequence of reddish, to dark, red chert (Figs. 3, 4). The chert beds are mostly a few centimeters thick. Between the chert beds interlayers of siliceous shale up to few millimeters thick are commonly present. The block has sharp contacts with a surrounding olistostrome that consists of rounded subgraywacke fragments in shaly matrix. The olistostrome at the contact with the chert–block is mainly sheared and schistose.

Sample 9-1a: Chert collected 1 m from the base of the section. Age: early Norian based on the occurrence of *Kahlerosphaera kemerensis* Tekin (Plate 2), *Capnodoce serisa* De Wever, *Capnuchosphaera lenticulata* Pessagno (Tekin, 1999).

Sample 9-1: Chert collected 10 m from the base of the section. Abundant radiolarians (Table 1) and conodonts *Grodella* sp. cf. *G. deliculata* (Mostler) (Rhaetian) were obtained from the upper part of a fragmentary section. The radiolarian assemblage of this sample can be attributed to the Norian, given the existence of *Xiphotecaella rugosa* (Bragin).

Similar Triassic radiolarian associations were previously described from Albania (Kellici and De Wever, 1994; Chiari et al., 1996; Marcucci and Prela, 1996, Vishnevskaya, 2001; Bortolotti et al., 2006).

5.1.3. Zaboj-2

Just south of Sjenica, near the Ozren ultramafic massif (Fig. 2) a new occurrence (Zaboj-2) is represented by an isolated outcrop of basalt with chert (Figs. 3, 4). Sample G-4/06 was taken 30 cm from the basalt and contains late Triassic (latest Carnian–early Norian) radiolarians (Table 1). The radiolarian assemblage of this sample can be attributed to a latest Carnian–early Norian age owing to the presence of *Sarla vetusta* Pessagno, *Whalenella regia* (Blome), *Capnuchosphaera crassa* Yeh, *Capnuchosphaera theloides* De Wever and *Capnuchosphaera triassica* De Wever (Tekin, 1999). This assemblage is similar to coeval radiolarian assemblage from Serbia (Obradović and Goričan, 1988; Goričan et al., 1999) and Albania (Kellici and De Wever, 1994; Marcucci and Prela, 1996).

5.1.4. Ovčar-Kablar gorge

This outcrop is located 2 km NE of Ovčar Banja on the road from Čačak to Požega (Fig. 2) and is composed of a ~20 m-thick sequence within a block of red and green chert, tuff and tuffite (Figs. 3, 4). The chert is interbedded with siliceous shale and rare limestone. Chert beds are up to 20 cm thick, and siliceous shale layers are up to 5 cm thick. The first finding of radiolarians in cherts of Ovčar-Kablar gorge was by Obradović (1986) and Obradović et al. (1986a, 1987/1988). Latest Illyrian–Longobardian-aged radiolarians were reported from an olistolith (Obradović and Goričan, 1988). Additional data are as follows:

Sample 103. Chert was collected 20 cm from the base of the section (Fig. 4). The radiolarian assemblage (Table 1) is attributed to a late Carnian–early Norian age owing due to the co-existence of *Capnodoce crystallina* Pessagno (Plate 2), *Capnuchosphaera tricornis* De Wever, *Spongotortilispinus carnicus* (Kozur & Mostler), *Spongostylus tortillus* (Kozur & Mostler) and *C. lenticulata* Pessagno (Tekin 1999; Moix et al., 2007).

Sample 102. Chert was collected 1 m from the base of the section. The age is latest Carnian–early Norian (Table 1; Plate 1) based on the co-occurrence of *C. triassica* De Wever and *X. rugosa* (Bragin) (Tekin, 1999; De Wever and O'Dogherty, 2007). The presence of *Loffa* ? *mulleri* Pessagno implies an early Norian age (Tekin, 1999).

Sample 100. Chert was collected 2 m from the base of the section. An age of latest Carnian/earliest Norian–early Norian is inferred from the known range of *S. vetusta* Pessagno (De Wever et al., 1979; Bragin and Krylov, 1999; Tekin, 1999).

5.1.5. Čačak

Radiolarites occur associated with pillow lavas (10 m) along the road from Čačak to Ovčar Banja near a first dam (Fig. 2). This section was first described by Obradović et al. (1986a), who reported Ladinian to Norian radiolarian associations (Obradović et al., 1986a; Obradović and Goričan, 1988). We sampled radiolarites intercalated in the pillow basalts, and also the surrounding basalts (Figs. 3, 4).

Sample 3v: Radiolarites were collected 7.5 m from the base of the section (Fig. 4). The age of the fauna is late early to middle Norian (Tekin, 1999) (Table 1) based on the co-occurrence of *C. serisa* De Wever and *Icrioma tetrancistrum* De Wever.

5.1.6. Other sections of previous authors

Fojnica. Middle Triassic (upper Ladinian, Longobardian) radiolarians are well documented from tuffaceous cherts of a carbonate platform succession that is exposed (Fig. 3) in the southern part of Bosnia and Herzegovina (Kozur and Mostler, 1996a,b, 2006; Tekin and Mostler, 2005a,b). This unit outcrops as a float block of cherty limestone at Varoški Potok creek, 2 km west of Fojnica in the vicinity of Gacko near the Gacko–Mostar road (latitude 43°13′40″N; longitude 18°25′50″E). This outcrop forms part of the external Dinarides of the Dalmatian–Herzegovinian Zone, known as the "High Karst Nappe". This is composed of Mesozoic carbonates (Dimitrijević, 1997) or is considered as the Dalmatian–Herzegovinian composite terrane (DHCT) (Karamata et al., 2004a). Because the radiolarian sample was taken from a float block, it is not clear whether it came from the limestone sequence below or above a tuffaceous claystone–chert intercalation within this succession (Tekin and Mostler, 2005a).

We report the Fojnica section here because it is the only one which forms a part of the Dalmatian–Herzegovinian composite terrane (Fig. 1). A rich radiolarian allows an assignment to the early late Longobardian Spongoserrula fluegeli Subzone of the Muelleritortis cohleata Zone. Moreover, this age is confirmed by presence of the conodont *Budurovignathus mungoensis* (Diebel) (Kozur and Mostler, 1996a,b). Regionally, these radiolarian-bearing sequences include pelagic sediments such as cherty limestone, tuffaceous claystone, radiolarites (Mudrenović and Gaković, 1964), and can be used for correlation and paleogeographic reconstruction.

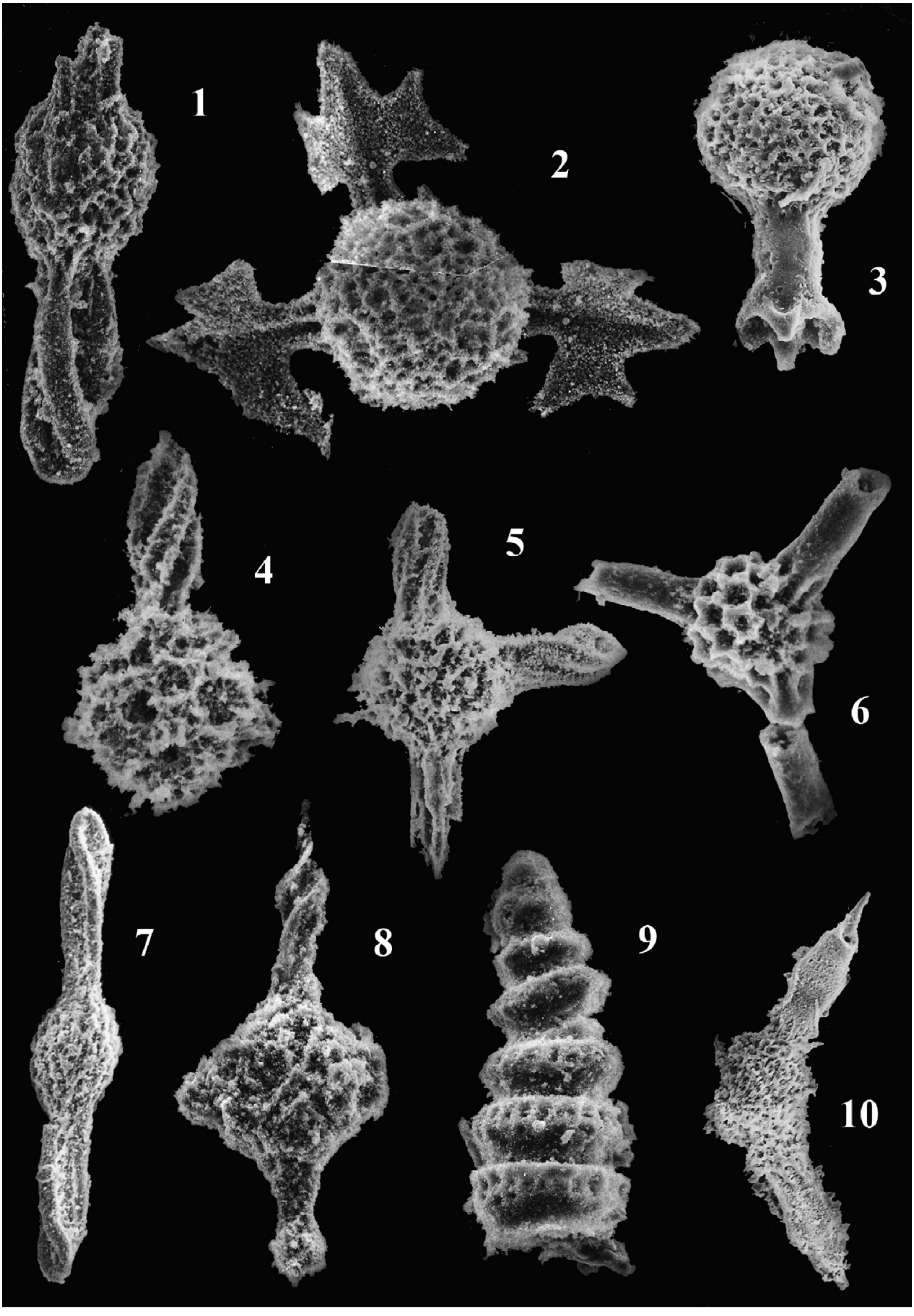


Plate 2. Characteristic species and marker species of Triassic radiolarians (1, 7, 8, 9—Sample 10-8a; 2—Sample 9-1a; 3, 6, 10—Sample 103; 4, 5—Sample 10-11). 1— *Pseudostylosphaera ? hellenica* De Wever , ×300. 2. *Kahlerosphaera kemerensis* Tekin, ×400. 3. *Capnuchosphaera* ? *concava* De Wever, ×200. 4. *Muelleritortis* sp., ×410. 5. *Muelleritortis cochleata* (Nakaseko & Nishimura), ×350. 6. *Capnodoce crystallina* Pessagno, ×200. 7. *Pseudostylosphaera* ? *hellenica* De Wever, ×200. *8. Pseudostylosphaera multispinata* Tekin & Mostler, ×280. 9. *Triassocampe* sp., ×200. 10. *Capnuchosphaera* ? *constricta* Kozur & Mock, ×200. Magnification factors refer to the printed version of the paper.

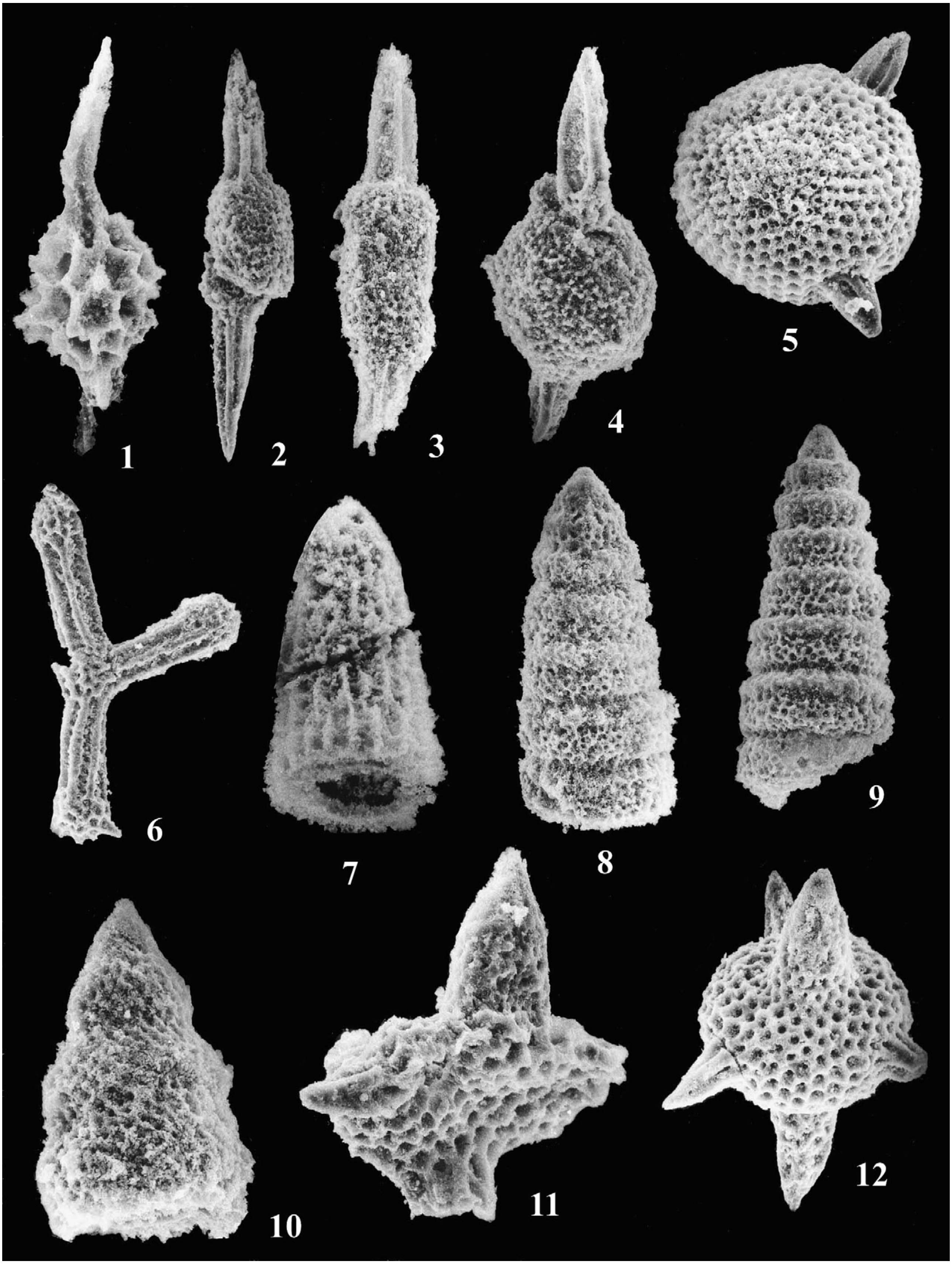


Plate 3. Uppermost Callovian–Oxfordian (Late Jurassic) radiolarians from northern Bosnia. Location Jezeračka. Sample 1-12. 1. *Pantanellium whalenae* Pessagno & MacLeod, ×530. 2. *Archaeospongoprunum elegans* Wu,×300. 3. *Archaeospongoprunum* sp. cf. *A. elegans* Wu, ×310. 4. *Archaeospongoprunum* ex gr. *imlayi* Pessagno ×340. 5. *Triactoma mexicana* Pessagno & Yang, ×210. 6. *Tritrabs* sp. cf. *T. ewingi* Pessagno, ×220. 7. *Hsuum* sp., ×470. 8–9. *Cinguloturris carpatica* Dumitrica, ×300, ×270. 10. *Stichomitra* ? *annibill* Kocher, ×550. 11. *Podobursa* sp. cf. *P. helvetica* (Rüst), ×350. 12. *Podobursa triacantha* (Fischli), ×280. Magnification factors refer to the printed version of the paper.

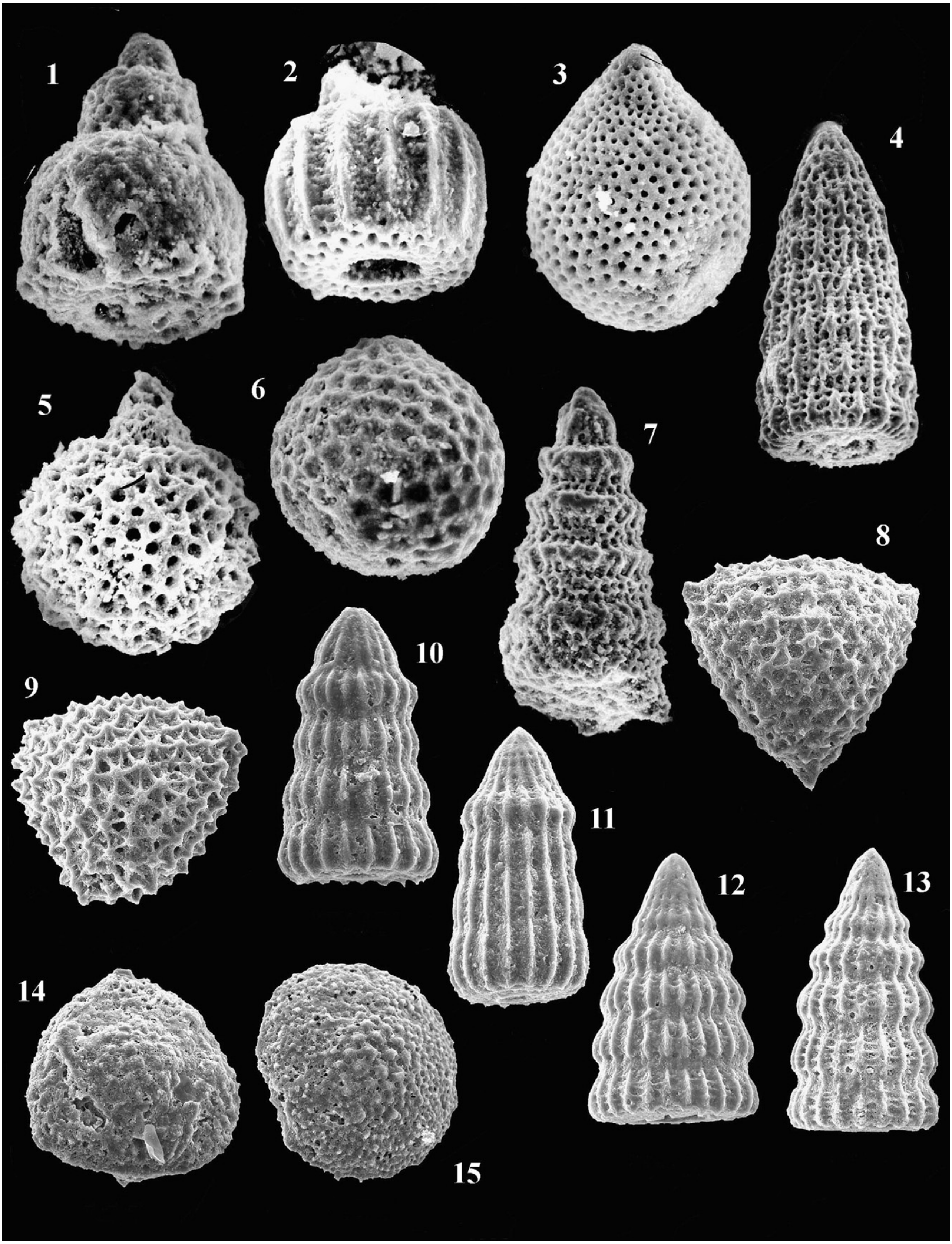


Plate 4. Jurassic radiolarians of Bosnia and Cretaceous radiolarians of Serbia. Late Bathonian–early Callovian radiolarian assemblage of the Maslovare–Teslić Section (Sample 174, Figs. 1–7). 1. *Eucyrtidiellum unumaense pustulatum* Baumgartner, ×400. 2. *Eucyrtidiellum ptyctum* (Riedel & Sanfilippo), ×500. 3. *Stichocapsa robusta* Matsuoka, ×250. 4. *Transhsuum maxwelli* (Pessagno), ×470. 5. *Sethocapsa funatoensis* Aita, ×300. 6. *Gongylothorax* sp. aff. *G. favosus* Dumitrica, ×300. 7. *Cinguloturris carpatica* Dumitrica, ×300. The Coniacian–Santonian radiolarian assemblage of the Location Struganik (Sample 212, Figs. 8–14). *Alievium* sp. cf. *A. praegallowayi* Pessagno, ×240. 9. *Alievium* sp. cf. *A. superbum* (Squinabol), ×260. 10., 11. *Dictyomitra koslovae* Foreman, ×300. 12., 13. *Dictyomitra formosa* Squinabol, ×230. 14. *Pseudoaulophacus* sp. cf. *P. praefloresensis* Pessagno, ×200. 15. *Pseudoaulophacus* sp., ×220. Magnification factors refer to the printed version of the paper.

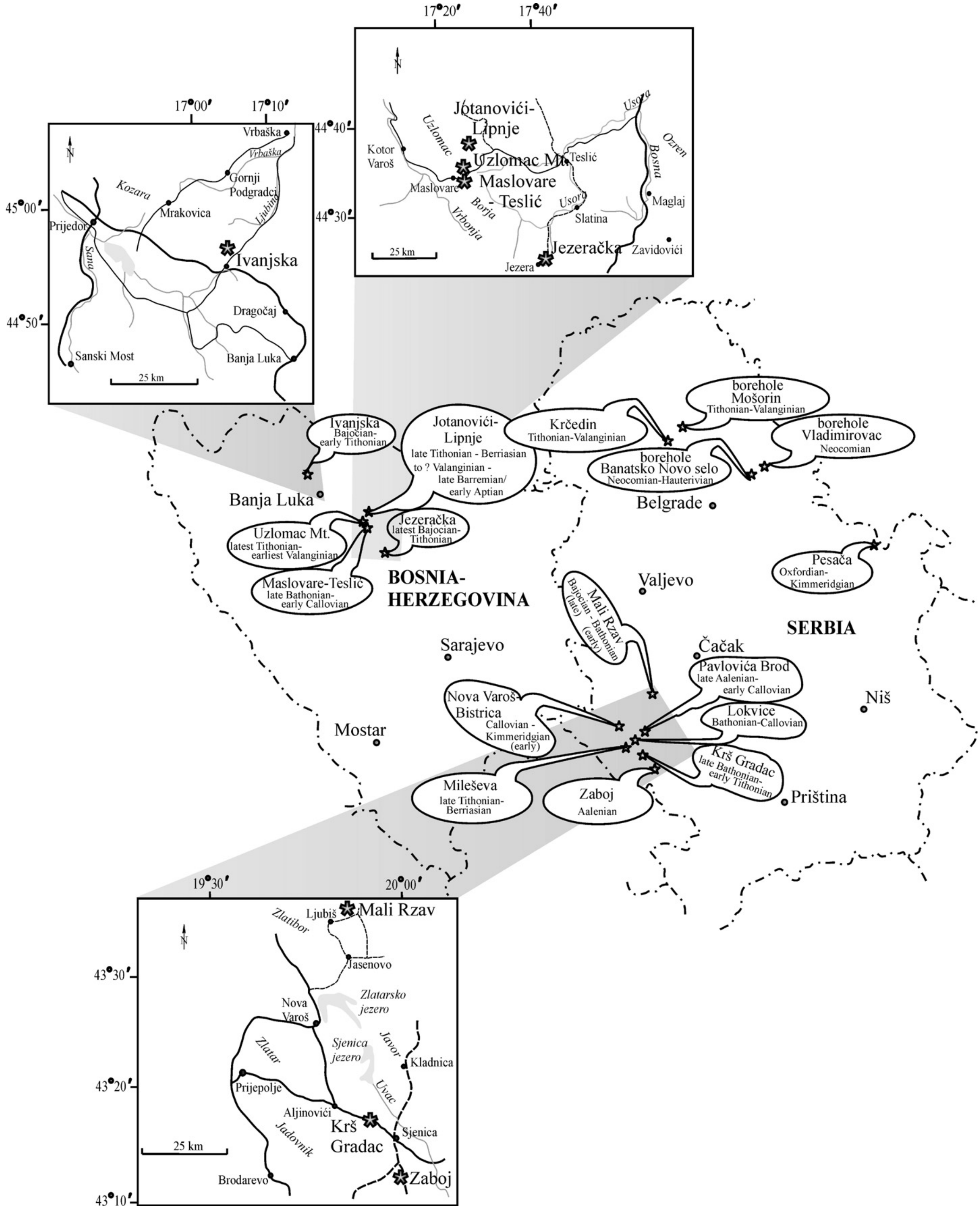


Fig. 5. Location of sampled Jurassic–early Cretaceous sections: 2.1 Jezeračka reka; 2.2 Maslovare–Teslić: 2.3 Ivanjska quarry; 2.4 Zaboj; 2.5 Krš Gradac; 2.6 Mali Rzav; 3.1 Uzlomac Mt.; 3.2 Jotanovići–Lipnje; also, Jurassic–early Cretaceous sections from other authors (see text).

Bistrica to Priboj road (*Podpeć Dom*) Ladinian radiolarians were determined from an olistolith of the "porphyrite–chert assemblage" of the Dinaride Ophiolite Belt in a section located along the Bistrica to Priboj road (Obradović and Goričan, 1988) (Figs. 2, 3).

Krš Gradac L. Dosztaly (from Hungary) determined late Triassic (Carnian–Norian) radiolarians (without a species list) from a radiolarite in an olistostrome ~8 km west of Sjenica, at a location known as Krš Gradac (Karamata et al., 2006a) (Figs. 2, 3).

Gostilje A Carnian radiolarian assemblage was found in a block of radiolarite associated with basalt on the left side of the Katušnica River, near Gostilje (Dosztaly, personal communication) (Figs. 2, 3).

Bukovi A Carnian radiolarian assemblage was found in a block of red chert associated with basalt and an intercalation of violet red shales in a section along the Valjevo to Kosjerić road (Karamata et al., 2006b) (Figs. 2, 3).

5.2. Middle–Late Jurassic

Initial findings of Jurassic radiolarians in Bosnia were achieved as results of joint Russian–Serbian research in 2000 on the Maslovare–Teslić transect (Karamata et al., 2004a). New data on the radiolarian ages of siliceous cherts in Western Serbia and Central Bosnia were obtained during 2003–2006 and were partly presented at the 32nd session of the IGC in Florence (Karamata et al., 2004a) and at INTERRAD-XI in Wellington, New Zealand (Vishnevskaya and Djerić, 2006a).

The Jurassic radiolarite outcrops are situated along the western margin of the Dinaridic Ophiolite Belt. The best-exposed section, Uzlomac Mt., is located north of Maslovare (~35 km southeast of Banja Luka), in Bosnia. The richest radiolarian samples, of Mid-Late Jurassic age, were discovered in the Jezeračka reka and Maslovare–Teslić sections (Plates 3 and 4). Well preserved Late Jurassic–Early Cretaceous samples were found in the Jotanovići–Lipnje section.

5.2.1. Jezeračka reka section

A chert sequence occurs in the Jezeračka reka section, east of Jezera (Figs. 5 and 6). The section is exposed on both sides of a small road on the left bank of the Jezeračka reka, just south of the Maslovare–Teslić auto road. The lower member or part of the section (165 m) is mainly composed of massive red-to-violet, locally gray chert (Fig. 4; Fig. 7).

Sample 1-15 (30 m above the base of the section) yielded a scarce radiolarian fauna. The presence of *Striatojaponocapsa plicarum plicarum* (Yao) (4–5 UAZs; Baumgartner et al., 1995) and *Eucyrtidiellum unumaense pustulatum* Baumgartner (5–8 UAZs; Baumgartner et al., 1995) indicates a latest Bajocian to early Bathonian age (UAZ 5).

Sample 1-13 (75 m above the base of the section) is characterized by well-preserved, abundant marker radiolarian species (Table 2). A late Bathonian to early Callovian age (UAZ 7) can be determined based on the presence of *Stichocapsa robusta* Matsuoka (5–7 UAZs; Baumgartner et al., 1995), and *Parahsuum officerence* (Pessagno & Whalen) (1–7 UAZs; Baumgartner et al., 1995). The latter has its last occurrence in the early Callovian, together with *Cinguloturris carpatica* Dumitrica (7–11 UAZs; Baumgartner et al., 1995).

Sample 1-12 (145 m above base of the section) is assigned to a late Callovian to late Oxfordian age (UAZ 7–9) based on the coexistence of *Triactoma mexicana* Pessagno & Yang, and *Eucyrtidiellum nodosum* Wakita (Baumgartner et al., 1995; Hull, 1997; De Wever et al., 2001), together with *C. carpatica* Dumitrica (7–11 UAZs; Baumgartner et al., 1995) (Plate 3; Table 2).

The middle part of the section is mainly composed of red clayey chert, chert and cherty limestone.

Sample 1-1 was taken from the red clayey chert (3–5 cm) alternating with chert (8–12 cm), 167 m above the base of the section (Fig. 7). A late Kimmeridgian–early Tithonian age (UAZ 11) is given by the first appearance of *Alievium helenae* Schaaf (11–22 UAZs; Baumgartner et al., 1995) and the last occurrence of *Homoeoparonaella argolidensis* Baumgartner (4–11 UAZs; Baumgartner et al., 1995), *Eucyrtidiellum ptyctum* (Riedel & Sanfilippo) (5–11 UAZs; Baumgartner et al., 1995), *Tethysetta dhimenaensis* s.l. (Baumgartner) (3–11 UAZs; Baumgartner et al., 1995), *Transhsuum brevicostatum* gr. (Ozvoldova) (3–11 UAZs; Baumgartner et al., 1995) and other marker species (Table 2).

Tectonic zone	DOB								
Location	Jezeračka reka	Maslovare - Teslić	Ivanjska quarry	Zaboj	Krš Gradac	Mali Rzav River	Lokvice	Nova Varoš – Bistrica	Pavlovića Brod
Lithology	radiolarites, cherty limestone	chert, shale, limestone	chert	chert, limestone	chert, limestone	chert	radiolarities	chert, shale, limestone	chert, clay chert, limestone
Other fossils	calpionellidae (Tithonian-Berriasian) benthic forams (Tithonian-Berriasian) spicules (Bathonian-Callovian, Tithonian)			sponge spicules (Aalenian)	ammonites (Toarcian)				
Age	latest Bajocian – Berriasian	late Bathonian - early Callovian	Bajocian – early Tithonian (J3)	Aalenian	late Bathonian – early Tithonian	late Bajocian - early Bathonian	Bathonian - Callovian	Callovian – early Kimmeridgian	late Aalenian - early Callovian
References	Vishnevskaya & Djerić, 2006a,b and this paper	this paper	Vishnevskaya & Djerić, 2005 and this paper	this paper	Karamata et al., 2006a and this paper	this paper	Karamata et al., 2006c	Obradović & Goričan, 1988	Djerić et al., 2007

Fig. 6. Lithostratigraphic scheme for the Middle–Late Jurassic radiolarian-bearing sequences of the Dinaride Ophiolite Belt.

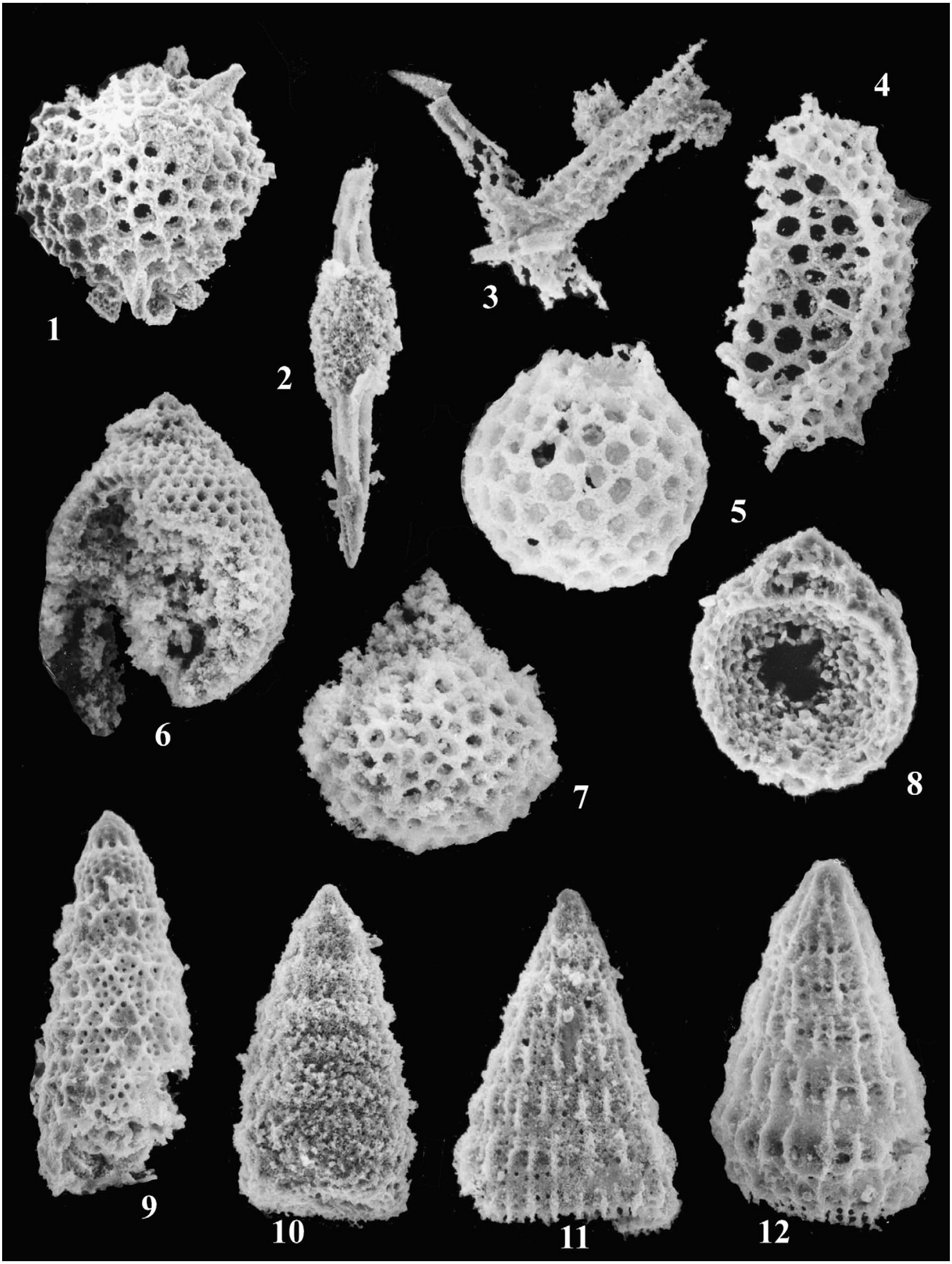


Plate 5. Bajocian–Bathonian radiolarians of Ivanjska quarry (Figs. 1–8, Sample 4-6, Figs. 9–12, Sample 4-1). 1. *Triactoma* sp., ×110. 2. *Archaeospongoprunum elegans* Wu,×155. 3. *Tetraditryma* ? sp., ×170. 4. *Palinandromeda* sp., ×150. 5. *Zhamoidellum* ? sp., ×200. 6. *Stichocapsa* sp.,×290. 7. *Hiscocapsa* sp., ×330. 8. *Praewilliriedellum* ? *spinosum* Kozur,×270. 9. *Eoxitus hungaricus* Kozur,×220. 10. *Canoptum* sp., ×180. 11, 12. *Transhsuum maxwelli* (Pessagno) group, ×205, ×255. Magnification factors refer to the printed version of the paper.

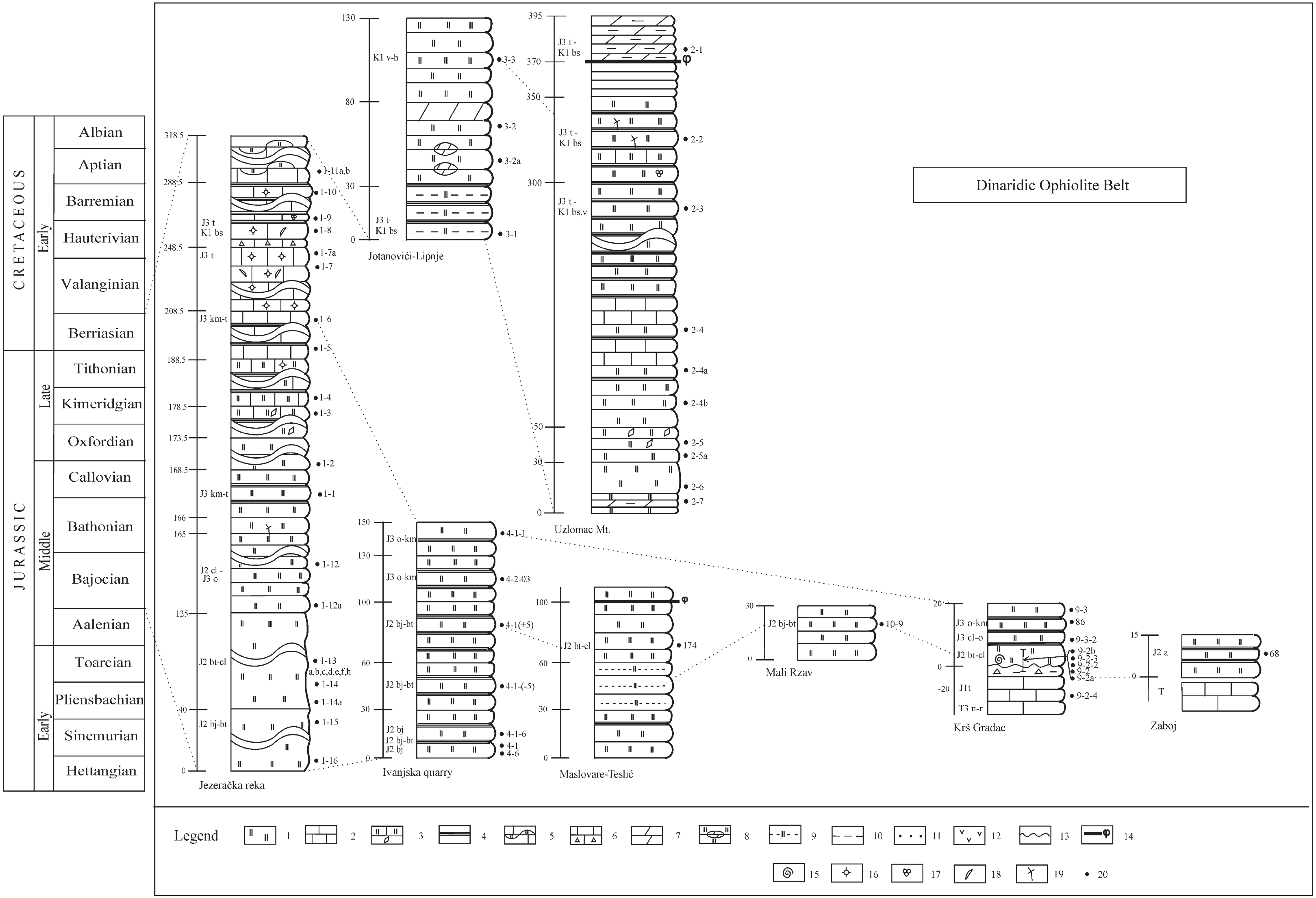


Fig. 7. Sample position and lithological logs of Jurassic–early Cretaceous sections: 2.1 Jezeračka reka; 2.2 Maslovare–Teslić: 2.3 Ivanjska quarry; 2.4 Zaboj; 2.5 Krš Gradac; 2.6 Mali Rzav; 3.1 Uzlomac Mt.; 3.2 Jotanovići–Lipnje. Legend: 1—chert, 2—limestone, 3—dolomitic limestone chert, 4—silicified chert, 5—lens of chert in limestone, 6—clastic and organic—detrital limestone, 7—marlstone, 8—lens of marlstone in chert, 9—clayed chert, 10—claystone, 11—sandstone, 12—basalt and pillow basalt, 13—disconformity, 14—tectonic contact, 15—ammonite, 16—radiolarians, 17—foraminifers, 18—calpionellids, 19—sponge spicule, 20— radiolarian sample position.

Table 2
Jurassic radiolarian assemblages within the Dinaridic Ophiolite Belt in Bosnia

Species	Tectonic unit	DOB																			
	Sample location	Jezeračka reka						Maslovare–Teslić	Ivanjska quarry							Uzlomac Mt.			Jotanovići–Lipnje		
	Sample No	1-15	1-13	1-12	1-1	1-6	1-7a	174	4-6	4-1	4-1-6	4-1-(-5)	4-1-(+5)	4-2-03	4-1-1	2-1	2-2	2-3	3-1	3-2	3-3
Acanthocircus minispineus Yang					●												●				
Alievium helenae Schaaf					●		●														
Angulobracchia ? portmanni s.l. Baumgartner																		●			●
Archaeodictyomitra apiara (Rüst)					●																
Archaeospongoprunum elegans Wu				●					●												
Archaeospongoprunum ex gr. imlayi Pessagno			●	●				●	●		●		●		●						
Bernoullius spelae Jud																					●
Canoptum dixoni Pessagno & Whalen			cf.																		
Canoptum latiannulatum Grill & Kozur											●										
Canoptum sp.										●											
Cinguloturris carpatica Dumitrica				●				●						●	●						
Crolanium pythiae Schaaf																	cf.				
Emiluvia splendida Carter			cf.																		
Eoxitus hungaricus Kozur										●	●										
Eucyrtidiellum nodosum Wakita				●				●													
Eucyrtidiellum ptyctum (Riedel & Sanfilippo)				●	●	●	●	●						●							
Eucyrtidiellum pyramis (Aita)																			●		●
Eucyrtidiellum unumaense pustulatum Baumgartner		●						●													
Gongylothorax sp. aff. *G. favosus* Dumitrica								●													
Hiscocapsa sp.									●												
Homoeoparonaella argolidensis Baumgartner					●																
Homoeparonaella peteri Jud																					●
Hsuum baloghi Grill & Kozur											●										
Hsuum bipartitum Grill & Kozur												●									
Hsuum fuschi Grill & Kozur												●									
Hsuum raricostatum Jud																		●			cf.
Hsuum rosebundense Pessagno & Whalen										●											
Hsuum sp.				●						●											
Obesacapsula breggiensis Jud																●					cf.
Obesacapsula cetia (Foreman)					●												●				●
Obesacapsula rusconensis Baumgartner					●																
Obesacapsula rusconensis rusconensis Baumgartner																			●		
Obesacapsula rusconensis umbriensis Jud							●												●		
Obesacapsula verbana (Parona)																					●
Paculinapora marsupiala Dumitrica & Zugel						●															
Paliandromeda sp.									●												
Pantanellium whalenae Pessagno & MacLeod				●																	
Pantanellium squinaboli (Tan)																					●
Parahsuum magnum Takemura												cf.									
Parahsuum officerence (Pessagno & Whalen)			●																		
Parvicingula usotanensis (Tumanda)																					●
Podobursa helvetica (Rüst)				cf.									●								

(continued on next page)

Table 2 (*continued*)

Species	Tectonic unit	DOB																			
	Sample location	Jezeračka reka						Maslovare–Teslić	Ivanjska quarry							Uzlomac Mt.			Jotanovići–Lipnje		
	Sample No	1-15	1-13	1-12	1-1	1-6	1-7a	174	4-6	4-1	4-1-6	4-1-(-5)	4-1-(+5)	4-2-03	4-1-1	2-1	2-2	2-3	3-1	3-2	3-3
Podobursa spinosa Ozvoldova					●																
Podobursa triacantha (Fischli)				●																	
Podocapsa amphitreptera Foreman																●	●	●			
Praewilliriedellum ? spinosum Kozur									●												
Pseudodictyomitra depressa Baumgartner																	●				●
Pseudodictyomitrella spinosa Grill & Kozur												●									
Ristola ? turpicula Pessagno & Whalen												●	●								
Sethocapsa funatoensis Aita								●													
Sethocapsa ? orca Foreman																					●
Sethocapsa testata (Jud)																	●				●
Spongocapsula palmerae Pessagno					●											●			●		
Staurosphaera antique (Rüst)			●																		
Stichocapsa robusta Matsuoka			●					●					●								
Stichocapsa sp.									●												
Stichomitra ? annibill Kocher				●																	
Striatojaponocapsa plicarum plicarum (Yao)		●																			
Suna hybum (Foreman)																				●	●
Tethysetta boesii gr. (Parona)														●							●
Tethysetta cosmoconica (Foreman)																					●
Tethysetta dhimenaensis s.l. (Baumgartner)					●								●		●						
T. dhimenaensis dhimenaensis (Baumgartner)							●														
Tetraditryma pseudoplena Baumgartner			●																		
Tetraditryma sp.									●												
Transhsuum brevicostatum gr. (Ozvoldova)					●	●		●													
Transhsuum maxwelli (Pessagno)					cf.			●		●											
Transhsuum okamurai (Mizutani)				cf.																	
Triactoma jonesi (Pessagno)			cf.		cf.	●															
Triactoma mexicana (Pessagno)				●																	
Triactoma sp.									●												
Tritrabs ewingi Pessagno				cf.																	
Unuma echinatus Ichikava & Yao											●										
Xitus ? channelli Jud																					●
Xitus horridus Jud																					●
Xitus spicularius (Aliev)																					●
Zhamoidellum ovum Dumitrica															●						
Zhamoidellum ? sp.									●						●						

The samples were collected from Jezeračka reka, Ivanjska quarry, Maslovare–Teslić, Uzlomac Mt. and Jotanovići–Lipnje.

Sample 1-6 was taken from light-gray chert (2–5 cm) alternating with red cherty limestone (208 m above the base of the section). A Kimmeridgian–early Tithonian age was assigned due to the first appearance of *Paculinapora marsupialia* Dumitrica & Zugel in the Kimmeridgian (Dumitrica and Zugel, 2003) and the last occurrence of *E. ptyctum* (Riedel & Sanfilippo), *T. brevicostatum* gr. (Ozvoldova) and *Triactoma jonesi* Pessagno in the early Tithonian (Baumgartner et al., 1995).

Sample 1-7a was taken from the upper part of the middle member sequence (230 m above the base of the section), mainly composed of light-gray limestone with lenses of red to black chert or siliceous limestone. A Tithonian age is indicated by the first appearance of *Obesacapsula rusconensis umbriensis* Jud and the last occurrence of *E.ptyctum* (Riedel and Sanfilippo), *T. dhimenaensis dhimenaensis* (Baumgartner) in the Tithonian (Baumgartner et al., 1995).

The upper member of the sequence mainly comprises red clayey limestone with lenses of red and green chert containing abundant recrystallized radiolarians. Siliceous limestones locally include benthic Foraminifera (*Lenticulina*) and sponge spicules.

Sample 1-8 (260 m above the base of the section) is of Tithonian–Berriasian age, based on the presence of *Calpionella alpine* and *C. elliptica* (Vasić, 1993).

5.2.2. Maslovare–Teslić section

Samples were collected along a new road from Maslovare to Teslić. The radiolarite section (~ 2 km in length) begins 5 km after Maslovare (Fig. 5). A continuous sequence of reddish and dark gray radiolarian cherts is intercalated with several decimeter-thick levels of red shales with varying degrees of silica enrichment (Figs. 6, 7). In some part of section radiolarian cherts are intercalated with limestone or clay and the section is tectonically disturbed.

Sample 174 (about 70 m from the initial point) is dark red laminated chert with moderately well preserved radiolarians (Plate 4). The assemblage corresponds to UAZ 7 (late Bathonian–early Callovian) (Table 2). This zonal assignment is indicated by the co-occurrence of *C. carpatica* Dumitrica (first occurrence in UAZ 7), *S. robusta* Matsuoka (last occurrence in UAZ 7) and *Gongylothorax* sp. aff. *G. favosus* Dumitrica (UAZs 7–8) (Baumgartner et al., 1995).

5.2.3. Ivanjska quarry section

A chert sequence (~150 m thick) was discovered in the Ivanjska quarry section, NW of Banja Luka (Figs. 5–7). This is represented by alternating red and violet cherts at the base (i.e. samples 4-6, 4-1, 4-1-6), green and violet cherts in the middle part (i.e. from sample 4-1(-5) to sample 4-2-03) and red and gray cherts in the upper part (i.e. sample 4-1-1).

Sample 4-6 (8 m above the base of the section) (Fig. 7) is dated as Bajocian age, based on the presence of *Praewilliriedellum ? spinosa Kozur* (Kozur, 1984).

Sample 4-1 (10 m above the base of the section) is attributed to the late Bajocian–Bathonian (Table 2) based on the presence of *Eoxitus hungaricus* Kozur (Grill and Kozur 1986) (Plate 5) and *Hsuum rosebundense* Pessagno & Whalen (De Wever et al., 2001).

Sample 4-1-6 (15 m above the base of the section) yielded the following marker species indicating a Bajocian age: *E. hungaricus* Kozur (late Bajocian; Kozur, 1985), *Unuma echinatus* Ichikava and Yao (UAZs 1–7; Beccaro, 2006), *Hsuum baloghi* Grill & Kozur (Aalenian–Bajocian; Grill and Kozur, 1986), *Canoptum latiannulatum* Grill & Kozur (Aalenian–early Bajocian; Grill and Kozur, 1986).

Sample 4-1-(−5) (45 m above the base of the section) of Bajocian–middle Bathonian age (probable latest Bajocian–middle Bathonian) is indicated by the co-occurrence of *Hsuum fuchsi* Grill & Kozur and *Ristola* (?) *turpicula* Pessagno & Whalen (Grill and Kozur, 1986; Baumgartner et al., 1995; De Wever et al., 2001).

Sample 4-1-(+5) (85 m above the base of the section) is dated as latest Bajocian–middle Bathonian (5–6 UAZs) based on the co-occurrence of *Ristola* (?) *turpicula* Pessagno & Whalen (5–6 UAZs; Baumgartner et al., 1995), *S. robusta* Matsuoka (5–7 UAZs; Baumgartner et al., 1995) and *Podobursa helvetica* (Rüst).

Sample 4-2-03 (115 m above the base of the section) is dated as Middle/late Oxfordian to late Kimmeridgian/early Tithonian (9–11 UAZs) by the co-occurrence of *C. carpatica* Dumitrica (7–11 UAZs; Baumgartner et al., 1995), *E. ptyctum* (Riedel and Sanfilippo) (5–11 UAZs; Baumgartner et al., 1995) and *Tethysetta boesii* gr. (Parona) (9–22 UAZs; Baumgartner et al., 1995).

Sample 4-1-1 from the uppermost part of section was taken just outside the entrance to the quarry. Its age is Middle/late Oxfordian to late Kimmeridgian/early Tithonian (9–11 UAZs) owing to the ranges of *Zhamoidellum ovum* Dumitrica (9–11 UAZs; Baumgartner et al., 1995), *C. carpatica* Dumitrica (7–11 UAZs; Baumgartner et al., 1995) and *T. dhimenaensis* s.l. Baumgartner (3–11 UAZs; Baumgartner et al., 1995) (Table 2).

5.2.4. Zaboj

Chert was sampled 8 km south of Sjenica, in western Serbia. Sample 68 was taken in the upper part of a 15 m-thick chert sequence (Figs. 5, 7), above Triassic limestone. Radiolarians occur together with abundant sponge spicule fragments and sponge bodies (Fig. 6, Plate 6). The assemblage corresponds to UAZs 1–2 (Aalenian) (Table 3). This zonal assignment is indicated by the presence of *Hexasaturnalis hexagonus* (Yao) (UAZs 1–4) and *Ristola* (?) *praemirifusus* Baumgartner & Bartolini (UAZs 1–2) (Baumgartner et al., 1995). The radiolarian association also includes *Parahsuum* sp. cf. *P. officerense* (Pessagno & Whalen), *Transhsuum* sp. cf. *T. hisuikyoense* (Isozaki & Matsuda) and *Triactoma* sp. cf. *T. jakobsae* Carter.

5.2.5. Krš Gradac

The outcrop is located near the road from Prijepolje to Sjenica (Fig. 5) in a creek below the main road where a local road branches towards Rainovići. The lower part of the sequence is composed of Liassic grey limestone. Just above a hardground, limestone contains large ammonites. The upper part of the sequence, 18 m thick, is mostly red to green–gray clayey chert, characterized by very thin bedding (5–10 cm, rarely up to 15 cm) (Fig. 7).

Sample 9-2b. Limestone and cherty limestone occur 2 m above the hardground (Fig. 7). The age of this sample is late Bathonian to early Callovian (Table 3) based on the coexistence of *Pterotrabs marculus* Dumitrica, Baumgartner & Goričan and *C. carpatica* Dumitrica (Baumgartner et al., 1995; Dumitrica et al., 1997).

Samples 9-3-2. Red clayey cherts occur 8 m above the hardground (Fig. 7). The age is probably middle Callovian to Oxfordian (UAZs 8–9) based on the coexistence of *Archaeodictyomitra minoensis* (Mizutani), *E. unumaense* s.l. (Yao) and *Z. ovum* Dumitrica (Baumgartner et al., 1995).

Sample 86. The upper part of the sequence (14 m above the hardground) is represented by dark green radiolarites. The age is determined as middle Oxfordian to early Tithonian (UAZs 9–11) by the co-existence of the species *A. minoensis* (Mizutani), *Z. ovum* Dumitrica and *T. brevicostatum* (Ozvoldova) (Baumgartner et al., 1995).

5.2.6. Mali Rzav River

The outcrop is located 5 km north of Ljubiš village on a small road in the Mali Rzav river basin (Fig. 5), and is represented by an isolated olistolith of alternating red and green cherts (30 m) (Figs. 6, 7). A Mid-Jurassic radiolarian assemblage (Table 3) was obtained from an isolated outcrop (Sample 10-9) of this area. The age is late Bajocian to latest Bajocian/early Bathonian (UAZ 5) based on the coexistence of *S. plicarum plicarum* (Yao) (4–5 UAZs; Baumgartner et al., 1995) and *E. ptyctum* (Riedel & Sanfilippo) (5–11 UAZs; Baumgartner et al., 1995).

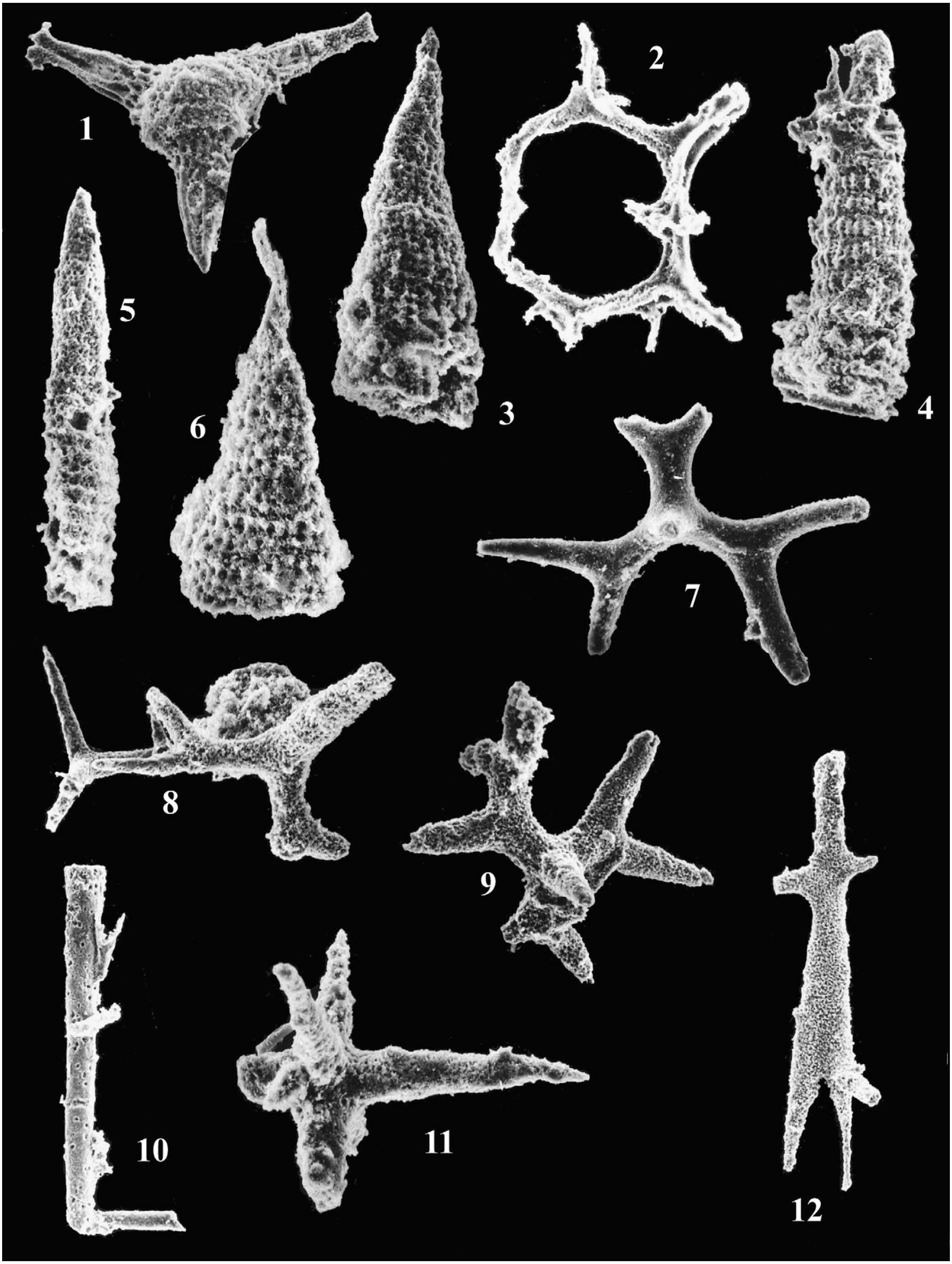


Plate 6. Aalenian radiolarian assemblage of the Zaboj (Sample 68). 1. *Triactoma jakobsae* Carter, ×120. 2. *Hexasaturnalis hexagonus* (Yao), ×140. 3, 6. *Parahsuum* sp. cf. *P. officerense* (Pessagno & Whalen), ×180, ×100. 4. *Transhsuum* sp. cf. *T. hisuikyoense* (Isozaki & Matsuda), ×130. 5. *Ristola* (?) *praemirifusus* Baumgartner & Bartolini, ×140. 7-12. Fragments of sponge spicules, ×70: 7, 10. Prodichotriaenes with very short conical shaft and slender straight clads. 11. Massive dermal pentactines. Magnification factors refer to the printed version of the paper.

Table 3
Distribution of Jurassic radiolarians in Serbia

Species	Tectonic unit	DOB				
	Sample location	Zaboj	Krš Gradac			Mali Rzav
	Sample no.	68	9-2b	9-3-2	86	10-9
Acaeniotyle umbilicata (Rüst)				cf.	cf.	
Archaeodictyomitra minoensis (Mizutani)				●	●	
Archaeohagiastrum munitum Baumgartner						
Cinguloturris carpatica Dumitrica			●			
Eucyrtidiellum nodosum Wakita						●
Eucyrtidiellum ptyctum (Riedel & Sanfilippo)						●
Eucyrtidiellum unumaense s.l. (Yao)				●		●
Hexasaturnalis hexagonus (Yao)		●				
Homoeoparonaella elegans (Pessagno)						
Hsuum maxwelli Pessagno						cf.
Mirifusus dianae minor Baumgartner						
Parahsuum officerense (Pessagno & Whalen)		cf.				
Pterotrabs marculus Dumitrica, Baumgartner & Goričan			●			
Ristola (?) praemirifusus Baumgartner & Bartolini		●				
Stichocapsa globosa Vishnevskaya						cf.
Striatojaponocapsa plicarum plicarum (Yao)						●
Transhsuum brevicostatum gr. (Ozvoldova)					●	●
Transhsuum hisuikyoense (Isozaki & Matsuda)		cf.				
Triactoma jakobsae Carter		●				
Williriedellum crystallinum Dumitrica				cf.	cf.	
Zhamoidellum ovum Dumitrica				●	●	

The samples were collected from the following sections: Zaboj, Krš Gradac and Mali Rzav.

5.2.7. Other sections from previous authors

Lokvice This section consists of 20 m of reddish to dark gray, bedded radiolarites (Figs. 5, 6) of Bathonian–Callovian age (Karamata et al., 2006c).

Nova Varoš–Bistrica road A Callovian–early Kimmeridgian radiolarian association was determined by Š. Goričan (Obradović et al., 1986b; Obradović and Goričan, 1988) from the “Diabase–Chert Formation” section (Sp. 37) located on the Nova Varoš–Bistrica road (Figs. 5, 6).

Pavlovića Brod Siliceous deposits from the Pavlovića Brod locality consist of radiolarian cherts with clayey and limestone interlayers (Figs. 5, 6). On the basis of the radiolarians these cherts were deposited between the late Aalenian and the early Callovian (Djerić et al., 2007).

5.3. Late Jurassic–Early Cretaceous

5.3.1. Uzlomac Mt. section

A description of this section was given in Karamata et al. (2004a). The upper part of the Uzlomac Mt. section was sampled (Samples 2-7 to 2-1) along a southwest–northeast profile from Maslovare to Jotanovići (Fig. 5). These cherts are coeval with the upper member of the Jezeračka reka section.

Samples 2-2 and 2-3 were taken from a sequence, which is mainly composed of red clay and alternating limestone and chert, including light-green spiculite chert (Figs. 7, 8). The samples contain sparse planktonic foraminifers and moderately preserved radiolarians (Table 2).

The age of Sample 2-3 (280 m from the base of the section) is constrained using *Hsuum raricostatum* Jud (Tithonian–lower Valanginian, UAZs 13–15), and *Angulobracchia* (?) *portmanni* s.l. Baumgartner (Berriasian–Hauterivian, UAZs 13–22) which co-existed in latest Tithonian to late Berriasian–early Valanginian time, UAZs 13–15 (Jud, 1994; Baumgartner et al., 1995).

Sample 2-2 (320 m from the base of the section) is dated as Tithonian–earliest Berriasian owing to the ranges of *Acanthocircus minispineus* Yang (late Tithonian), *Obesacapsula cetia* (Foreman) (UAZs 10–17), *Sethocapsa testata* (Jud) (UAZs 23–35), *Podocapsa amphitreptera* Foreman (UAZs 9–18), *Pseudodictyomitra depressa* Baumgartner (UAZs 13–18). Only *S. testata* (Jud) indicates a probable, up to Valanginian age (Baumgartner et al., 1995).

Sample 2-1 (380 m from bottom) is assigned to the latest Tithonian–earliest Berriasian (UAZ 13) based on the coexistence of *P. amphitreptera* Foreman (UAZs 9–13), *Spongocapsula palmerae* Pessagno (UAZs 6–13) and *Obesacapsula breggiensis* Jud (UAZs 13–16) (Baumgartner et al., 1995; De Wever et al., 2001).

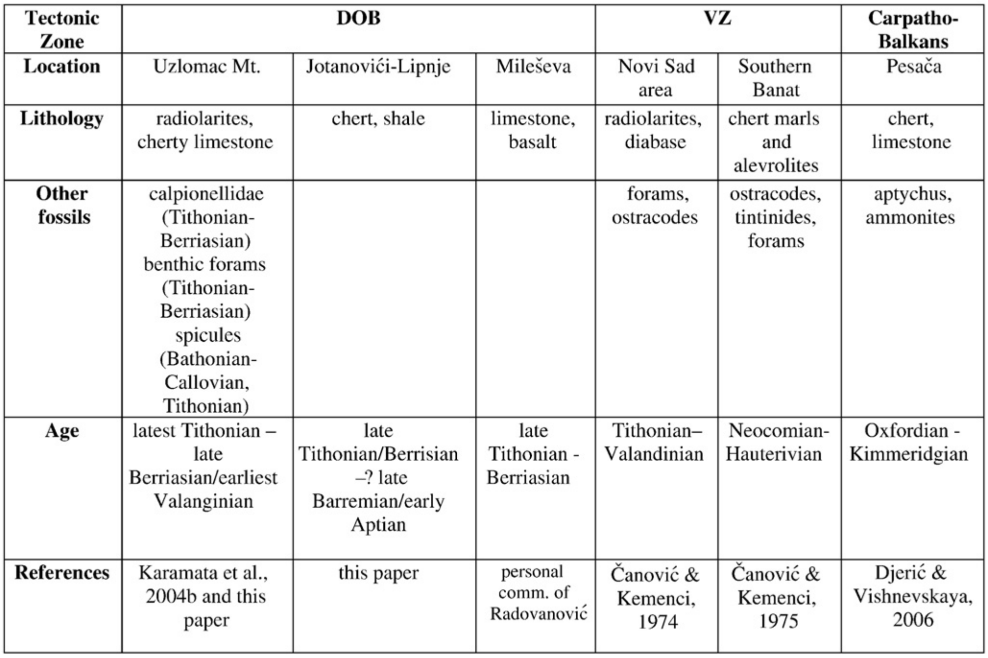
5.3.2. Jotanovići–Lipnje section

A continuous sequence has been investigated in a west–east-striking section at Jotanovići–Lipnje (Fig. 5). The lower part of section consists of radiolarian chert and shale (Figs. 7, 8). Blue, reddish and green radiolarian cherts are intercalated with several decimeter-thick levels of red shales with varying amounts of silica.

Sample 3-1 (3 m from the base of the section) can be assigned a latest Tithonian–earliest Berriasian age (UAZ 13) (Table 2) based on the coexistence of *Eucyrtidiellum pyramis* (Aita) (UAZs 12–13; Baumgartner et al., 1995) and *O. rusconensis umbriensis* Jud (UAZs 13–15; Baumgartner et al., 1995).

Sample 3-2 (60 m from the base of the section) yielded a scarce radiolarian fauna of probable late Tithonian–Berriasian, up to Valanginian–earliest Hauterivian to late Barremian–early Aptian age based on the presence of *T. boesii* gr. (Parona) (UAZs 3–35, Jud, 1994) and *Suna hybum* (Foreman) (UAZs 18–22) (Baumgartner et al., 1995).

Sample 3-3 (100 m from the base of the section) consists of alternations of green and violet chert with well-preserved, diverse radiolarians. This sample is attributed to a latest Valanginian–Hauterivian (UAZs 18–20) age based on the presence of *Pantanellium squinaboli* (Tan Sin Hok) (Berriasian–Albian; UAZs 11–35), *Angulobracchia* (?) *portmanni* s.l. Baumgartner (Berriasian–Hauterivian; UAZs 13–22), *Homoparonaella peteri* Jud (Hauterivian–Barremian; UAZs 19–22), *Suna hybum* (Foreman) (Valanginian–Barremian; UAZs 18–22), *Bernoullius spelae* Jud (Berriasian–Barremian; UAZs 15–22), *Obesacapsula verbana* (Parona) (Berriasian–Barremian; UAZs 11–20), *Xitus horridus* Jud (Hauterivian–Barremian; UAZs 19–20), *P. depressa* Baumgartner (Berriasian–Hauterivian; UAZs 13–18), and *Mirifusus chenodes* (Renz) (UAZs 6–22) (Steiger, 1992; Baumgartner et al., 1995).



Tectonic Zone	DOB			VZ		Carpatho-Balkans
Location	Uzlomac Mt.	Jotanovići-Lipnje	Mileševa	Novi Sad area	Southern Banat	Pesača
Lithology	radiolarites, cherty limestone	chert, shale	limestone, basalt	radiolarites, diabase	chert marls and alevrolites	chert, limestone
Other fossils	calpionellidae (Tithonian-Berriasian) benthic forams (Tithonian-Berriasian) spicules (Bathonian-Callovian, Tithonian)			forams, ostracodes	ostracodes, tintinides, forams	aptychus, ammonites
Age	latest Tithonian – late Berriasian/earliest Valanginian	late Tithonian/Berrisian –? late Barremian/early Aptian	late Tithonian - Berriasian	Tithonian–Valandinian	Neocomian-Hauterivian	Oxfordian - Kimmeridgian
References	Karamata et al., 2004b and this paper	this paper	personal comm. of Radovanović	Čanović & Kemenci, 1974	Čanović & Kemenci, 1975	Djerić & Vishnevskaya, 2006

Fig. 8. Lithostratigraphic scheme with the characteristics of Jurassic–Lower Cretaceous radiolarian-bearing sequences.

5.3.3. Other sections from previous authors

Mileševa Planktonic foraminifers of the genus *Hedbergella* and poorly preserved radiolarians (late Tithonian–Berriasian) were found in a small lens or block of red limestone associated with basalt, along the road between Prijepolje and Sjenica, about 3 km east of Prijepolje (Figs. 5, 8) (Radovanović, personal communication).

Novi Sad area Radiolaria-bearing deposits of the Novi Sad area lie within the Vardar Zone. Radiolarites associated with diabase were reported from the borehole Mošorin-2 in 20 km to the east–northeast of Novi Sad (Figs. 5, 8). A Portlandian age was determined based on the pelagic microfossils, *Cadosina alpina* Leischer, *C.* cf. *carpathica* (Borza), *Stomiosphaera* cf. *molucanna* Wann and *Calpionellae* (Čanović and Kemenci, 1975). The microfacies and sedimentological characteristics of these deposits are similar to that of the "Diabase–hornstone formation" of the Inner Dinarides, as noted by Čanović and Kemenci (1975). Coeval radiolarian-bearing cherty marl was found in Krčedin quarry in the same Southern Bačka area where a late Portlandian to early Valanginian age was proposed (Čanović and Kemenci, 1974).

Southern Banat Neocomian radiolarian-bearing sequences were identified within pelagic and deep-water facies in boreholes to the north of Belgrade in the Southern Banat area (Figs. 5, 8), (i.e. Banatsko Selo and Vladimirovac) (Čanović and Kemenci, 1975). Radiolarites are developed in the Banatsko Novo Selo-1 borehole at a depth of 1112–1243 m and in the Banatsko Novo Selo-borehole 2 at depths between 1205 and 1283 m. The deposits in borehole BNS-2 correspond to the younger horizons of the Neocomian–Hauterivian, without excluding the possibility that they extend into the Barremian (Čanović and Kemenci, 1975). The borehole Vladimirovac-1 includes Neocomian sediments within the intervals 1216–1355 m, as represented by laminated alternations of chert marl and siltstone containing radiolarians, ostracodes and tintinnids (Čanović and Kemenci, 1975).

Pesača In Eastern Serbia (Pesača–Greben area) Mesozoic sediments of Jurassic and Lower Cretaceous age (Fig. 5, 8) discordantly overlie Permian rocks (Vasić, 1993, 1994; Vasić et al., 1999). Red nodular limestones with radiolarians in the Pesača–Greben area occur in the Bathonian–Callovian stratigraphic interval. Bedded cherts and radiolarites of the Pesača River sequences correspond to a late Oxfordian–early Kimmeridgian age, passing upwards into Kimmeridgian–Oxfordian bedded limestone with grey chert, and then into Tithonian red nodular limestones with radiolarian cherts (Vasić, 1993, 1994; Vasić et al., 1999). The sediments of Middle and Upper Jurassic age were deposited on submarine ridges and trenches, according to Vasić (1993). An Oxfordian–Kimmeridgian radiolarian assemblage, determined in red chert from the Pesača–Boljetin road opposite Lepenski Vir museum (Sp. Du-4/05), contains *Transhsuum maxwelli* (Pessagno), *T. brevicostatum* (Ozvoldova), *Mirifusus dianae* s.l. (Karrer), *Obesacapsula morroensis* Pessagno, and *S. palmerae* Pessagno (Djerić and Vishnevskaya, 2006).

Other areas Remnants of Jurassic radiolarites of the Vardar Ocean have been found in other locations of the Carpatho–Balkans, for example in the Trekljano area of Bulgaria not far from the Serbia–Bulgaria border, where they are represented by Aalenian–Tithonian radiolarites of the Rayantsi Formation (Zagorchev, 1986, Zagorchev et al., 1998; Vishnevskaya 2001). Also, Jurassic and Early Cretaceous radiolarians are well known in Montenegro and Slovenia (Goričan, 1994), Albania (Kellici and De Wever, 1994), Greece, Hungary and Romania (Baumgartner et al., 1995). ‘However, Late Cretaceous radiolarians are rare in the Carpatho–Balkan region (Vishnevskaya, 2001).

5.4. Cretaceous

5.4.1. Crna reka

Basalt–chert sequences of the Crna Reka section in the Kozara area (Figs. 9–11) contain radiolarian chert and siliceous limestone with the planktonic foraminifers *Globotruncana arca* (Cushman), *G. stuarti* (De Lapparent) that were determined as Campanian–early Maastrichtian in age by Sladić–Trifunović (in Karamata et al., 2005). We collected three samples for radiolarians. Of these, sample 5-2 (for stratigraphic position see Fig. 11) contains *Amphipyndax enesseffi* Foreman (zonal species of middle–late Campanian) (Schaaf, 1985), *Crucella espartoensis* Pessagno (zonal species of Santonian to early–middle Campanian) (Pessagno, 1976), and *Amphipyndax stocki* (Campbell & Clark). This assemblage (Table 4) indicates a Campanian age (probably middle Campanian) in agreement with the dating of planktonic foraminifers.

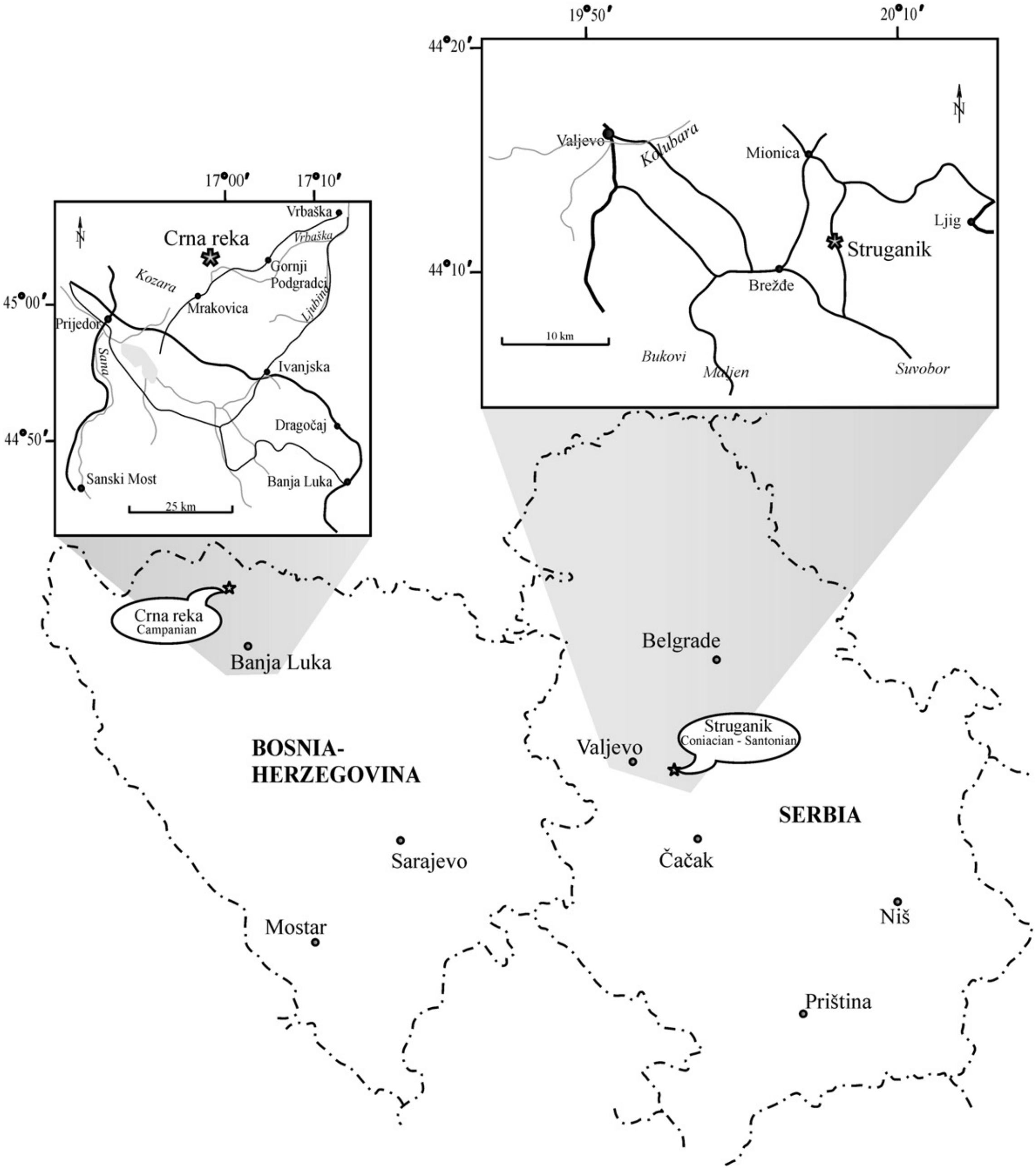
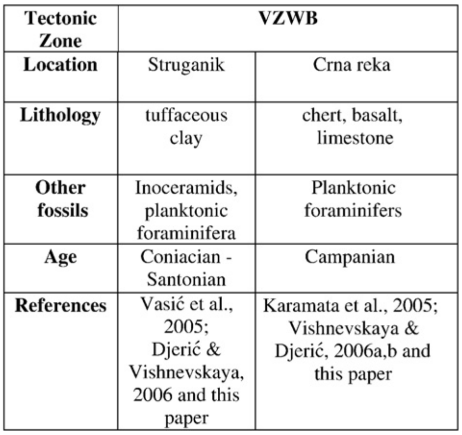


Fig. 9. The detail location of Cretaceous sections: 4.1 Crna reka; 4.2 Struganik.

5.4.2. Struganik

The Struganik section is located in West Serbia, about 100 km SW of Belgrade (Fig. 9). An association of sediments (Figs. 10, 11) including primary pyroclastic material occurs in Upper Cretaceous carbonate sediments there (Vasić et al., 2005). An interlayer within mainly carbonate sediments is represented by marlstone, clayey limestone and limestone in the form of laminae of crystalline quartz, sanidine, plagioclase and biotite and a thin layer of clay (Vasić et al., 2005).

A radiolarian assemblage (Table 4) that was obtained from the clay layer (Sample 212; 1 m from the base) can be attributed to a Coniacian–Santonian age based on the co-existence of *Alievium* sp. cf. *A. superbum* (Squinabol), *Alievium* sp. cf. *A. praegallowayi* Pessagno, *Dictyomitra formosa* Squinabol (Turonian–Santonian; Squinabol, 1904; Bandini et al., 2006), *Dictyomitra koslovae* Foreman (Coniacian–Campanian; Foreman, 1975; Vishnevskaya, 2001), *Dictyomitra torquata* Foreman (Turonian–Campanian; Foreman, 1975; Vishnevskaya, 2001) and *Pseudoaulophacus*



Tectonic Zone	VZWB	
Location	Struganik	Crna reka
Lithology	tuffaceous clay	chert, basalt, limestone
Other fossils	Inoceramids, planktonic foraminifera	Planktonic foraminifers
Age	Coniacian - Santonian	Campanian
References	Vasić et al., 2005; Djerić & Vishnevskaya, 2006 and this paper	Karamata et al., 2005; Vishnevskaya & Djerić, 2006a,b and this paper

Fig. 10. Lithostratigraphic scheme for the Cretaceous radiolarian-bearing sequences.

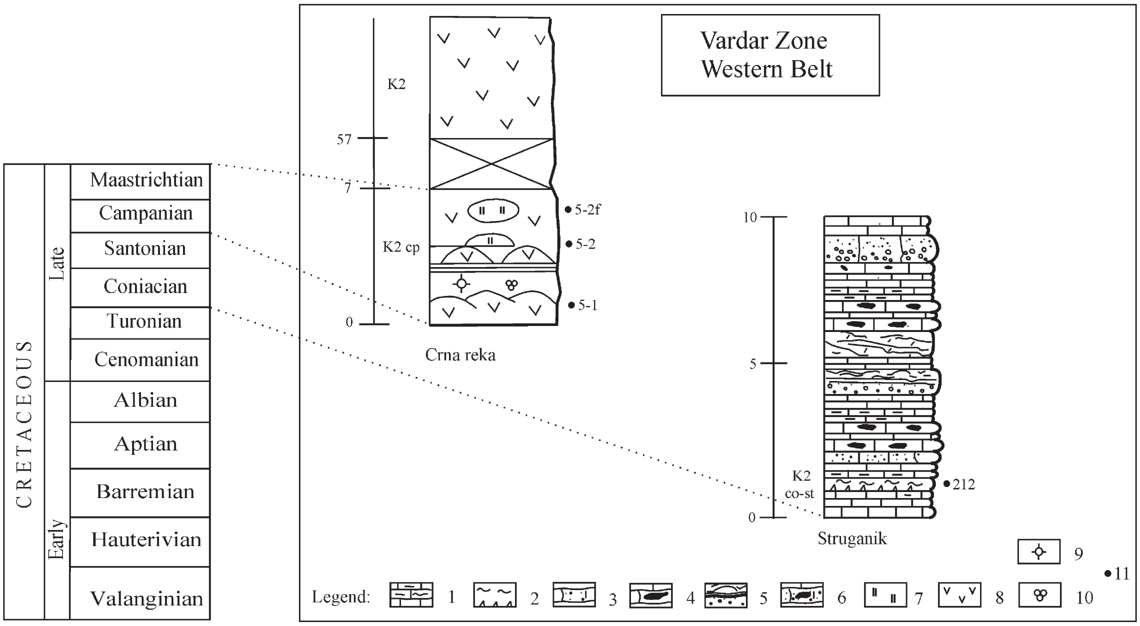


Fig. 11. Sample position and lithological logs of Upper Cretaceous sections: 4.1 Crna reka; 4.2 Struganik. Legend: 1 — layered marly limestone and marlstone; 2 — smectite clay; 3 — gray allochemical limestone; 4 — bedded marly limestone with chert concretions; 5 — calcrudite, calcarenite, biointrasparite; 6— gray allochemical limestone with chert concretions; 7— chert; 8— basalt and pillow basalt; 9— radiolarians; 10— foraminifers; 11 — radiolarian sample position.

sp. cf. *P. praefloresensis* Pessagno (Coniacian–Santonian; Pessagno, 1972, 1976; Vishnevskaya, 2001).

Alievium superbum (Squinabol) is a zonal species for the Turonian of the Pacific province and the Turonian–Coniacian for the Mediterranean province. *Alievium praegallowayi* Pessagno is a zonal species for the Coniacian in California (Pacific province), while *A. stocki* (Campbell and Clark), *D. formosa* Squinabol, and *D. koslovae* Foreman, *D. torquata* Foreman are characteristic species of the Coniacian–Campanian interval (Vishnevskaya, 2001). Some marker species are illustrated in Plate 4. The radiolarians occur together with the macrofauna *Inoceramus lamarki* Park., and some planktonic foraminifers and sponge spicules (Marković and Anđelković, 1953, Vasić et al., 2005). This is the second finding of Upper Cretaceous radiolarians in the Central Balkan region, after Kozara in Bosnia where basalt–cherts sequences contain radiolarian chert with a middle–late Campanian radiolarian assemblage.

6. Associated oceanic volcanics of the Dinaride Ophiolite Belt and the Vardar Zone Western Belt

There are a number of similarities between the Dinaride Ophiolite Belt and the Vardar Zone Western Belt (Robertson and Karamata, 1994; Karamata et al., 1999, 2005; Karamata, 2006a). Both belts include extensive paleo-oceanic units that are strongly dismembered into tectonic sheets, slices, or blocks of various sizes within a silty to shelly olistostromal matrix. The oceanic complexes of both belts are dominated by ultra basic mantle restites and basaltic volcanics together with subordinate occurrences of other ultra basic rocks and basic cumulates and isotropic gabbroic rocks.

The volcanic blocks are mostly low-K ($<0.5\%$ K_2O) tholeiitic basalts. They are pillowed to rarely massive lava flows and occur together with sheeted dikes of diabase–dolerite that have been altered by low-grade ocean-floor metamorphism (Lugović et al., 1991; Pamić, 2002). The basalts typically contain plagioclase and pyroxene with subordinate olivine.

The available stratigraphic evidence shows that the Dinaride Ophiolite Belt developed from the Middle Triassic to Tithonian, whereas the Vardar Zone Western Belt existed from the late Triassic to the lower Maastrichtian. Also, the basalts of the Dinaride Ophiolite Belt are of MOR type, whereas MOR and IAB-types with associated SSZ-type high-silica series (trachydacites, trachytes, rhyolites) all occur in the Vardar Zone Western Belt (Lugović et al., 1991; Robertson and Karamata, 1994; Pamić, 2002, Karamata et al., 2005).

Table 4
Cretaceous radiolarian assemblages within the Vardar Zone Western Belt

Species	Tectonic unit	VZWB	
	Sample location	Crna reka	Struganik
	Sample no.	5-2	212
Alievium superbum (Squinabol)			cf.
Alievium praegallowayi Pessagno			cf.
Amphipyndax stocki (Campbell & Clark)		●	
Crucella espartoensis Pessagno		●	
Dictyomitra andersoni (Campbell & Clark)		●	
Dictyomitra formosa Sqinabol			●
Dictyomitra koslovae Foreman			●
Dictyomitra torquata Foreman			●
Dictyomitra multicostata Zittel		●	
Pseudoaulophacus praefloresensis Pessagno			cf.
Pseudoaulophacus sp.			●
Stichomitra campi (Campbell & Clark)		●	

The samples were collected from Crna reka (Kozara) and Struganik.

Table 5
Oceanic volcanic series of the Dinaric Ophiolite Belt

Sample no	V-61-05	v-7	v-9	10v	v-12	v-15	v-17	19V	Lim 5	Lim 7/03	Lim 7/1
	1	2	3	4	5	6	7	8	9	10	11
SiO2	45.88	43.57	48.61	44.54	52.85	49.25	47.10	48.25	41.64	38.14	36.20
TiO2	1.28	0.05	1.08	1.82	0.45	2.44	1.353	2.33	1.21	2.60	2.64
Al2O3	15.68	23.74	12.92	14.25	15.86	15.52	16.02	14.24	8.13	9.42	8.74
FeO	8.93	3.26	9.17	11.02	9.84	10.81	10.34	12.85	10.19	9.73	8.04
MnO	0.15	0.06	0.20	0.16	0.18	0.15	0.23	0.23	0.33	0.24	0.25
MgO	8.03	10.22	5.75	4.28	7.82	7.02	8.53	6.48	1.26	1.44	1.14
CaO	9.54	12.18	16.88	13.23	4.96	5.47	6.7	9.89	18.85	18.16	21.83
Na2O	4.44	0.42	0.80.	3.08	2.80	2.59	2.47	1.68	4.38	2.51	2.59
K2O	0.51	0.25	0.19	0.23	0.33	0.31	0.01	0.13	0.12	1.66	1.58
P2O5	0.12	0.04	0.09	0.23	0.08	0.38	0.09	0.19	0.34	0.30	0.35
LOI	4.18	5.52	5.31	6.46	4.26	5.44	6.54	2.91	11.17	15.09	15.79
SUM	99.76	99.32	100.99	99.33	99.45	99.42	99.48	99.20	98.62	99.28	99.15
Rb	n.d	2	3	2	5	4	3	4	5	48	43
Ba	39	5	30	71	125	1005	44	135	2657	487	407
Th	0.67	0.97	0.16	0.24	0.61	3.30	0.13	0.47	2.10	1.70	0.70
Ta	1.23	1.92	0.99	n.d	0.48	2.89	n.d	0.74	n.d	n.d	n.d
Nb	n.d	2	2	10	2	27	2	7	72	61	56
Sr	246	120	19	89	252	440	187	164	212	221	205
Zr	97	13	57	133	47	167	59	145	222	175	154
Hf	3.99	0.05	1.69	3.72	0.56	3.33	2.51	1.96	n.d	n.d	n.d
Y	28	6	27	36	15	22	24	45	44	35	31
La	3.11	0.17	1.61	7.95	4.29	22.90	1.39	6.52	30.20	36.60	47.40
Ce	9.00	0.40	5.00	18.60	9.08	43.00	4.6	16.70	55.70	66.70	88.90
Pr	n.d	0.06	0.91	2.63	1.06	4.71	0.94	2.51	5.97	7.10	8.98
Nd	7.76	0.32	5.92	12.5	4.28	17.2	6.6	13.2	22.30	25.80	33.10
Sm	2.79	0.11	2.31	3.94	1.13	4.35	2.93	4.50	5.12	6.07	7.78
Eu	0.11	0.41	1.25	1.68	0.57	1.99	2.07	2.04	2.36	3.13	0.95
Gd	3.47	0.2	4.4	5.85	1.7	5.08	4.79	6.90	4.98	6.90	8.60
Tb	0.49	0.04	0.69	0.94	0.27	0.75	0.73	1.10	0.65	1.00	1.20
Dy	2.67	0.26	4.5	5.7	1.71	4.41	4.48	6.92	3.31	5.58	6.75
Ho	0.52	0.06	1.11	1.32	0.42	0.95	1.02	1.59	0.63	1.20	1.38
Er	1.33	0.22	3.40	3.97	1.23	2.53	2.77	4.53	1.49	3.13	3.60
Tm	0.19	0.04	0.53	0.59	0.19	0.37	0.43	0.68	0.19	0.44	0.49
Yb	0.92	0.24	3.23	3.47	1.16	1.79	2.26	4.07	0.90	2.21	2.52
Lu	0.14	0.05	0.57	0.57	0.20	0.31	0.40	0.66	0.13	0.36	0.39

Sample localities.
1. v-61-05; Altered pillow lava, highway Teslić–Jelah (Bosnia–Herzegovina).
2. v-7-00, Banded gabbroic cumulate, Priboj, (Serbia).
3. v-9-00, Aphiric altered basalt, Bistrica–Priboj; Bistrica complex (Serbia).
4. 10v, Pillow basalt, Bistrica–Priboj; Bistrica complex (Serbia).
5. v-12-00, Diabase dike, cutting pillow lavas , Bistrica–Priboj; Bistrica complex (Serbia).
6. v-15-00, Alkaline basalt, Bistrica–Priboj; Bistrica complex (Serbia).
7. v-17-00, Altered pillow lava, Mileševa (3 km east from Prijepolje) (Serbia).
8. v-19-00, Diabase, Nova Varoš (Serbia).
9. 10-12, Lim-5, Lim 7/03, Lim7/1. Alkaline basalt, Bistrica–Priboj (Podpeć dam) (Serbia).

Table 6
Oceanic volcanic series of the Vardar zone Western Ophiolite Belt

Oceanic volcanic series of the Vardar zone Western Ophiolite Belt

Sample	BH-31V	BH-32V	BH-34V	BH-38-03	BH-39-03	BH-35-03	BH-30V	BH-33V	BH-36-03	BH-37-03	V-62-05	3B-1-05	V-46-03	V-47-03	OK-3	V-66-05	V-68-05	4V-2000	V-45-03	1V-2000	20V-2000
	1	2	3	4	5	6	7	8	9	10	12	13	14	15	16	17	18	19	20	21	22
SiO2	47.26	45.09	42.52	46.78	47.16	43.93	72.16	75.02	66.08	72.44	50.82	45.19	47.34	45.88	48.63	49.65	51.80	50.08	45.85	40.96	47.70
TiO2	1.46	2.13	0.16	1.64	0.87	1.31	0.2	0.19	0.31	0.47	1.75	2.19	1.48	1.97	1.50	0.85	1.15	1.19	1.32	1.95	1.58
Al2O3	18.61	14.26	19.34	18.41	14.8	14.84	12.64	10.52	15.57	13.01	14.53	16.06	13.64	16.84	15.45	15.15	14.67	18.42	18.32	16.02	16.23
FeO	10.28	11.14	7.52	9.82	10.44	8.24	3.61	3.68	3.42	2.93	8.24	8.41	9.87	9.61	9.20	9.47	8.79	8.67	9.04	10.94	6.14
MnO	0.17	0.18	0.12	0.17	0.15	0.16	0.14	0.17	0.04	0.07	0.13	0.15	0.48	0.22	0.19	0.15	0.17	0.16	0.20	0.55	0.10
MgO	4.99	5.71	15.24	5.62	9.84	7.78	0.93	0.58	0.46	1.16	4.80	6.29	5.37	6.26	7.30	6.89	6.62	4.40	7.82	4.53	4.41
CaO	10.06	7.8	7.66	10.55	10.91	11.83	0.27	0.26	0.55	0.45	10.58	9.66	14.4	6.61	9.33	6.65	5.69	7.92	6.50	9.88	10.36
Na2O	3.11	3.55	1.83	3.24	2.59	3.11	4.71	3.25	3.12	6.06	5.21	4.38	3.03	5.64	4.10	6.08	6.07	3.42	4.51	2.48	4.98
K2O	0.59	1.31	0.15	0.46	0.42	0.7	3.67	3.93	8.73	1.3	0.98	0.57	0.65	0.35	0.35	0.23	0.10	0.35	0.72	1.06	n.d
P2O5	0.52	0.63	0.02	0.42	0.16	0.24	0.02	0.02	0.12	0.13	0.147	0.490	0.25	0.45	0.18	0.07	0.09	0.15	0.22	0.32	0.19
LOI	2.7	8.02	5.3	2.5	2.3	7.5	1.35	2.1	1.2	1.8	2.30	4.72	3.40	6.02	3.22	2.85	2.57	4.62	5.10	10.51	7.70
SUM	99.74	99.82	99.86	99.60	99.64	99.65	99.69	99.72	99.60	99.82	100.43	99.12	99.91	99.85	100.51	99.11	98.71	99.39	99.60	99.25	99.42
Rb	8	24	2	8	n.d	9	84	68	117	63	10	n.d	10	9	n.d	n.d	n.d	15	16	23	2
Ba	138	265	41	105	75	135	312	306	369	252	80	319	103	147	60	34	26	198	229	168	62
Th	3.9	3.2	3.3	1.7	2.4	3.6	16.1	25.10	16.20	18.40	0.84	3.66	2.8	2.70	0.26	0.17	0.13	1.81	3.7	10.07	0.75
Ta	1.58	8.35	0	2.54	1.82	–	22.4	18.00	8.94	0.45	1.78	1.86	1.34	1.21	n.d	n.d	n.d	0.74	1.77	2.83	n.d
Nb	8	16	1	11	5	9	64								n.d	n.d	n.d	4	3	9	9
Sr	224	236	200	214	150	216	48	36	33	109	284	183	113	231	167	107	67	444	332	311	258
Zr	106	173	22	106	81	111	800	805	392	604	102	180	106	177	110	55	75	94	114	150	123
Hf	1.04	1.48	0.29	1.6	1.17	1.71	15.4	13.90	6.79	10.60	11.20	2.83	2.19	2.90	12.50	2.51	1.95	2.47	2.00	3.00	3.04
Y	31	39	9	30	23	23	103	116	77	68	30	30	26	37	30	25	27	27	36	42	31
La	9.02	16.3	0.47	7.95	2.82	9.11	62.2	59.10	65.50	62.50	2.02	30.10	11.8	17.90	3.48	1.41	1.17	7.27	9.82	8.12	8.21
Ce	19.8	34.3	1.32	17.8	7.85	19.8	120	109.00	127.00	114.00	6.50	59.70	24.6	35.10	10.70	4.20	3.53	16.7	23.2	20.2	19.2
Pr	2.53	4.2	0.22	2.4	1.23	2.49	12.9	11.80	14.20	12.30	n.d	n.d	3.02	4.20	n.d	0.74	n.d	2.26	3.29	3.00	2.71
Nd	11.3	18.2	1.17	11.1	6.42	10.9	49.8	45.20	55.30	46.30	7.60	24.90	12.8	18.20	10.80	4.46	4.02	10.80	15.30	14.70	12.60
Sm	3.3	4.99	0.44	3.35	2.22	3.05	12.8	11.50	14.50	11.50	3.21	6.03	3.57	4.84	4.12	1.79	1.73	3.36	4.94	4.94	3.84
Eu	0.16	2.65	0.1	0.41	0.61	1.86	0.26	0.46	2.13	1.63	0.49	0.45	1.01	0.12	0.34	0.47	0.09	1.82	1.35	1.76	1.21
Gd	4.65	6.85	0.69	4.51	3.18	4.28	17.6	16.2	17.3	14.2	4.32	7.10	4.99	6.48	6.08	2.88	2.03	4.68	6.75	6.81	5.47
Tb	0.73	1.09	0.11	0.67	0.49	0.63	2.76	2.62	2.49	2.23	0.64	1.06	0.8	1.03	1.00	0.49	0.28	0.69	1.06	1.06	0.84
Dy	4.52	6.47	0.71	4.12	2.78	3.8	16.8	17.50	14.60	12.80	3.72	5.88	4.78	6.24	6.10	3.07	1.57	4.31	6.3	6.38	4.92
Ho	1.07	1.46	0.17	0.89	0.62	0.83	4.1	4.12	3.30	2.77	0.79	1.24	1.13	1.43	1.43	0.73	0.33	0.96	1.42	1.43	1.13
Er	3.01	4.21	0.47	2.48	1.7	2.27	11.5	12.10	8.70	7.82	2.22	3.32	3.26	4.18	4.26	2.24	0.81	2.69	4.07	4.10	3.13
Tm	0.47	0.61	0.07	0.37	0.25	0.35	1.75	1.88	1.27	1.16	0.33	0.46	0.49	0.61	0.63	0.37	0.11	0.41	0.59	0.59	0.46
Yb	2.72	3.5	0.43	1.78	1.34	1.78	9.97	11.5	6.78	6.12	1.73	2.38	2.77	3.50	3.82	2.01	0.56	2.02	3.43	3.45	2.60
Lu	0.46	0.56	0.07	0.33	0.22	0.32	1.63	1.92	1.12	1.02	0.28	0.38	0.48	0.57	0.63	0.40	0.08	0.37	0.54	0.55	0.43

Sample localities.
Bosnia–Herzegovina:
Kozara Complex 1–11; 1–2 basalts. 3—gabbro; Kozarevska reka; 4— diabase kamnelom; Gornji Podgradci quarry; 5— gabbro. Bukovica river; 6— pillow basalt; 7–11— trachytes. Rhyolites. Dacites, all Crna Reka river.
Serbia:
12— altered basalt. Road Doboj–Tuzla. v. Lokhinia. 13— basalt. Zvornik, Karakaj.
14–15— basaltic lava flows. the road Valjevo–Bukovi, v. Bačevci. the northern margin of Maljen massif. 16–17— diabase dikes. v. Bukovi. quarry Tavani. 18–19— basaltic lavas, Visoka. 20–21— pillow basalts, Čačak.

Below, we outline the evolution of the oceanic volcanism of the two belts using new analytical data for 33 samples of basaltic and acidic rocks. The results represent all of the major outcrops and age groups of volcanic rocks in the region. Some blocks of volcanic rocks in olistostromes are interbedded with the siliceous sediments that were also studied here.

For the Dinaride Ophiolite Belt the occurrences are: a) Volcanic–chert association, Bistrica Complex (Priboj, r. Lim and Podpeć dom) (middle Triassic, Ladinian; Obradović and Goričan, 1988); basalts v-9, v-10, v-12, v-13, Table 5; b) Ljubiš gravity slice (Visoka, Radoševo, Sirogojno), sediments: 10-8 (late Ladinian–Carnian), 10-8a (late Ladinian), 10-11 (Ladinian); basalts: 4v-2000, v-45-03, Table 6; c) Nova Varoš, sediments: 9-7 (Bajocian-Bathonian), basalt: 19v, Table 5; d) Mileševa (Prijepolje) sediment-M (late Tithonian–Berriasian; Radovanović, personal communication), basalt-v-17.

For the Vardar Zone Western Belt the occurrences are: a) *Čačak*, sediment: 3v (early to middle Norian), basalts: 1v-2000, 20v-2000, Table 6; b) Ovčar-Kablar gorge (Ovčar Banja), sediments: 100, 102, 103 (late Carnian–early Norian); basalt OK-3, Table 6; d) Crna Reka (Kozara Complex); sediments: 5-1, 5-2, 5-2 f (Campanian); basalt— BH-35-03, Table 6.

6.1. Analytical procedures

Major and trace-element (Rb, Sr, Ba, Y, Zr, Nb) analyses were performed in the Russian Academy of Science in Moscow using a Phillips PW-1600 X-ray fluorescence spectrometer. The glass-bead technique was used for major elements and pressed powder pellets for trace elements, using international and domestic basalt standards and the recommended or certified concentrations of Govindaraju (1994). Routine relative standard deviations (%) for different elements correspond were determined as: SiO_2—1.7; Al_2O_3—5.8; FeO—4.5; MnO—2.4; MgO—6.70; CaO—5.4; Na_2O—8.5; K_2O—3.2; TiO_2—4.90; P_2O_5—5.6; Rb—20, Sr—15, Ba—15, Y—20, Zr—15, Nb—20. For Th, U, Ta, Hf and REE the basalts were analyzed by INAA in the Vernadsky Institute of Geochemistry and Analytical Chemistry of the Russian Academy of Science in Moscow. Rock samples were irradiated in the "MIFI"-reactor in Moscow. The spectra obtained were evaluated using the peak-fitting method of Shubina and Kolesov (1998). Concentrations were calculated by irradiating and counting of international standards (ST-1A, SGD-1A) under identical conditions. Routine relative standard deviations for La, Nd, Sm, Eu, Yb, Th, Hf, and Ta correspond to 5% for Ce, Gd, and 10 for Tb %. The analytical data determined are shown in Tables 5 and 6 and Figs. 12–15.

6.2. Results of chemical analysis

Tholeiitic basalts are the most widespread type of paleo-oceanic volcanics in the Dinaride Ophiolite Belt (i.e. Teslić–Jelah, Banija, Borja; Bistrica–Priboj, Varda–Tara–Zlatibor, Nova Varoš, Mileševa). These are predominantly olivine–hypersthene–normative and display relatively small variations in major element contents; i.e. $SiO_2=51.1\pm3.26$; $TiO_2=1.55\pm0.65$; $FeO^*=8.95\pm1.99$; $MgO=7.02\pm1.93$; $Na_2O=3.34\pm1.71$; $K_2O=0.23\pm0.13$; $P_2O_5=0.17\pm0.08$; Mg# = 0.58 ± 0.11. The trace elements clearly indicate an N-MORB type setting, locally transitional to E-MORB; i.e. $(La/Sm)_n=0.89\pm0.48$; $(La/Yb)_n=1.10\pm0.58$; $(Tb/Yb)_n=0.69\pm0.60$; $(Yb)_n=13.4\pm4.5$; REE = 51 ± 22 ppm, Zr/Y = 2.94 ± 0.69; Th/La = 0.03–0.14 etc. Some tholeiitic dikes of the Bitrica Complex (V-12, Table 5) display relatively low titanium contents (TiO_2 0.45%), associated with magmatic depletion. This is together with a slight enrichment in LREE [$(La/Sm)_n=0.49–2.45$] and a decrease in HREE $(Yb)_n=5.17–7.22$, compared to other tholeiitic basalts of the Dinaride Ophiolite Belt. These rocks are characterised as N- and E- type MORB, without any evidence of negative Nb anomalies.

In addition, a composite body of alkaline basalt, up to 1 km long by up to 30 m thick, occurs within ophiolite-related olistostromes to the east of Priboj, near R. St. Podpeć (i.e. part of the Bistrica Complex; Popević et al., 2006). This body consists mainly of a soft green, altered basaltic hyaloclastitic groundmass with embedded black to dark red/violet amygdaloidal basaltic 'balls'. These features are aphyric, plagioclase-olivine-, and rarely clinopyroxene–phyric. The groundmass is pilotaxitic, to tholeiitic. Chemical analysis of representative samples of the basaltic balls reveals that they are alkaline WP-type basalt; i.e. $SiO_2=47.15\pm3.49$; $TiO_2=2.58\pm0.71$; $K_2O=1.10\pm0.97$; $P_2O_5=0.41\pm0.05$; $(La/Sm)_n=3.91\pm0.40$; $(La/Yb)_n=14.2\pm5.74$; $(Tb/Yb)_n=2.25\pm0.59$ REE = 158.07 ± 38.5 ppm, Zr/Y = 3.22 ± 1.48; Th/La = 0.11 ± 0.02. Rare occurrences of basaltic lavas of WP-type are also known in the Konjuh ophiolite complex of the Dinaride Ophiolite Belt in Bosnia–Herzegovina (Lugović et al., 2006). Popević et al. (2006) assumed that the eruption of the WP-type basalts of the Bistrica Complex coincided with the latest stages of formation of ophiolitic-related olistostromes. However, the cherts (sample v-16) in tectonic contact with the alkaline basaltic body

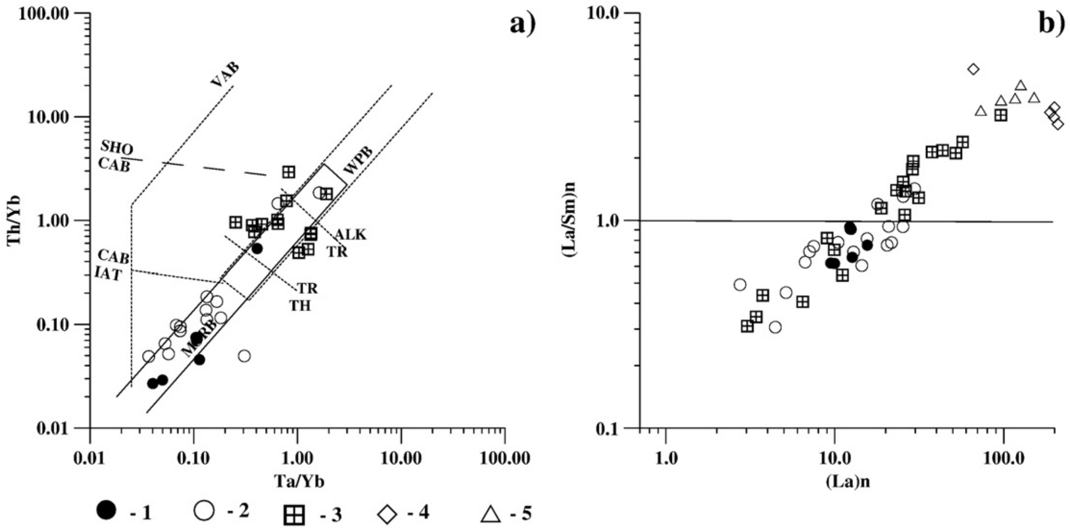


Fig. 12. Th/Yb–Ta/Yb and $(La/Sm)_n$–$(La)_n$ plots for basalts of the Dinaride Ophiolite Belt and the Vardar Zone Western Belt. 1. Basalts from Internal Liguride ophiolite (Rampone et al., 1998); 2. Basalts from Dinaridic ophiolite belt; 3. Basalts from the Vardar Zone Western Belt; 4. Alkaline basalt from the Bistrica Complex (DOB); 5. High-silica paleo-oceanic volcanic from Kozara Complex (VZWB).

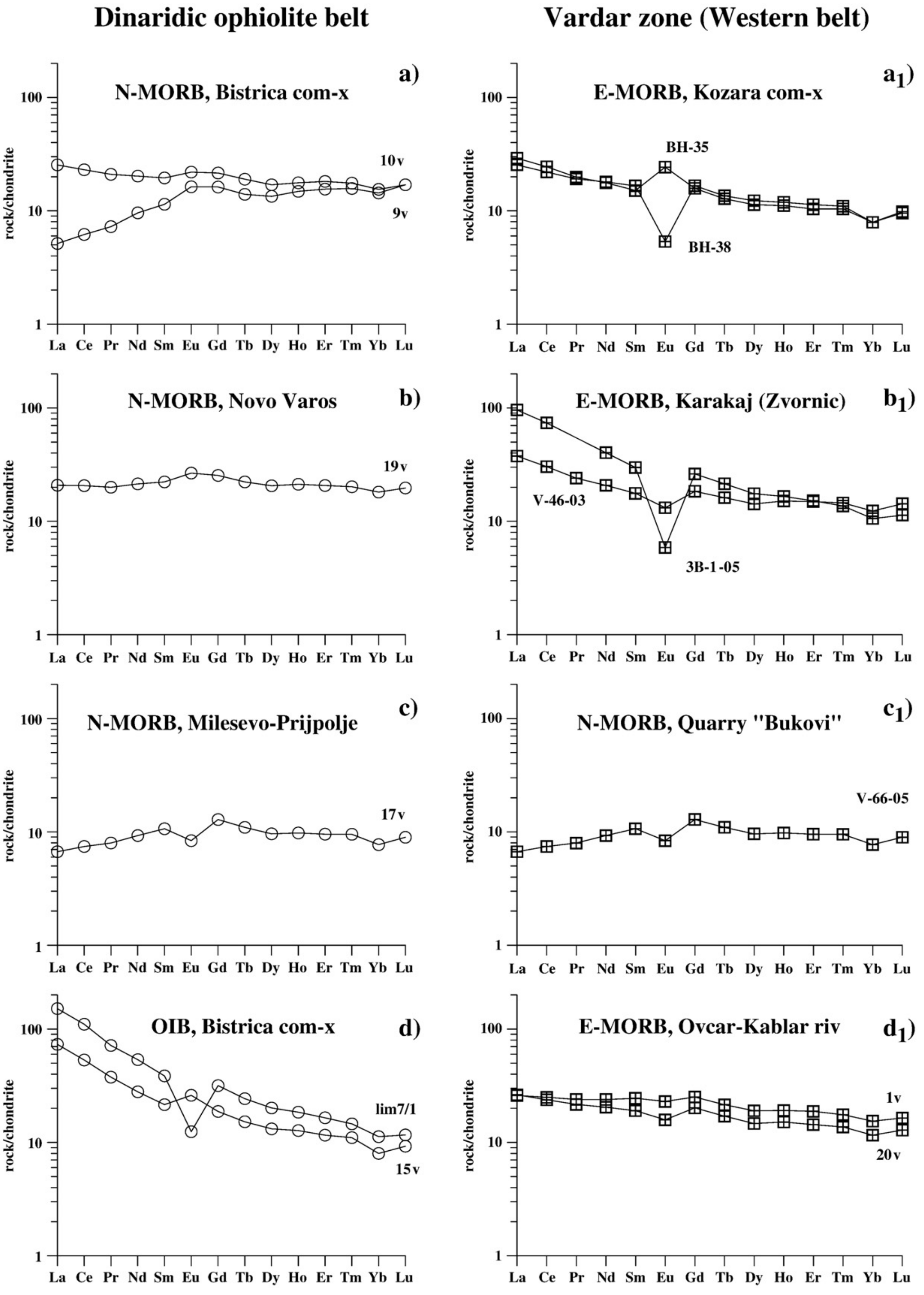


Fig. 13. Chondrite-normalized (Sun and Mc Donough, 1989) REE patterns for basalts of the Dinaride Ophiolite Belt and the Vardar Zone Western Belt.

(samples v-15, Lim 5, Lim 7/03, Lim 7/1) have a Middle Triassic (Ladinian) age. However, the full age range of the WP-basaltic series and any relationship to with the predominant tholeiitic basalts of the Dinaride Ophiolite Belt remain unclear. Suprasubduction zone-type signatures for the Dinaride Ophiolite Belt paleo-oceanic volcanic series are virtually absent. Clear SSZ-type signatures are shown, however, by the mantle restites of the Zlatibor and Bosanski Ozren massifs (Central Serbia; Bazylev et al., 2006), and for the Oxfordian–Tithonian

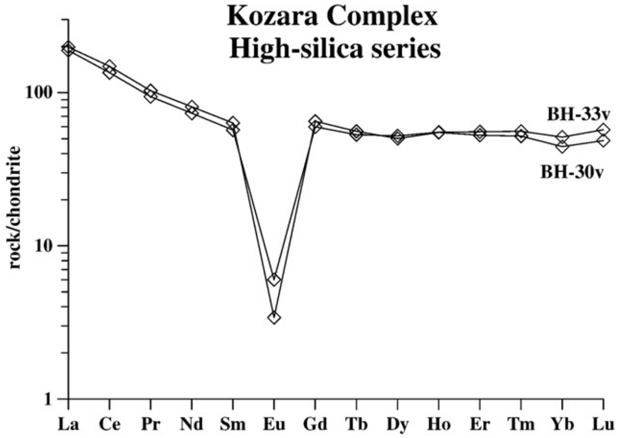


Fig. 14. Chondrite-normalized (Sun and Mc Donough, 1989) REE patterns for rhyolites of Kozara Complex (VZWB).

development of the Konjuh ophiolite complex in Bosnia–Herzegovina (Lugović et al., 2006).

The oceanic volcanic sequence of the Vardar Zone Western Belt is represented by a bimodal basalt–rhyolite association, with tholeiitic basalts strongly dominating (Kozara, Doboj–Tuzla, Karakaj, Bukovi, and Čačak). On major element variation diagrams, the composition of the tholeiitic basalts of theVardar Zone Western Belt and the Dinaride Ophiolite Belt almost completely overlap. However, the basaltic series of the Vardar Zone Western Belt display slight relative enrichments in titanium, iron, alkalis and a stronger under saturation with respect to silica. Trace element patterns also show subtle, but definite differences between the two belts. As a whole the Vardar Zone Western Belt tholeiites display a wider variation of LREE/HREE ratio and a relatively moderate enrichment of LREE over HREE- $(La/Sm)_n = 1.26 \pm 0.69$; $(La/Yb)_n = 2.22 \pm 0.99$ $(Tb/Yb)_n = 1.63 \pm 0.39$, although basalts with highly depleted LREE patterns also are present. The depletion correlates with a clear increase of Th content, wide variation in Th/REE ratios and the presence of a negative Nb anomaly, as particularly seen in the tholeiitic basalts of the Kozara and Maljen complexes of the Vardar Zone Western Belt ($Nb/Nb^* = 0.55 \pm 0.27$).

The gabbro samples studied: i.e. v-7, olivine–clinopyroxene–plagioclase cumulate (Bistrica Complex; Dinaride Ophiolite Belt; Table 5) and BH-34 clinopyroxene–plagioclase cumulate microgabbro and BH-39 olivine–clinopyroxene–plagioclase gabbro (Kozara Complex; Table 6, VZWB) come from ophiolitic blocks in olistostromes, where they are closely associated with fragmentary ophiolitic volcanics, leaving no doubt that all of these rocks belong to the same dismembered oceanic sequence. The analyzed gabbros show clear evidence of a depleted mantle source [$(La/Sm) < 1$; [$(La/Yb) < 1$), as indicated by the Th/Yb–Ta–Yb and $(La/Sm)_n$–$(La)_n$ variation diagrams. On Th/Yb–Ta–Yb and $(La/Sm)_n$–$(La)_n$ variations the gabbric rocks are well in arrays of the studied sequences. None of the three gabbroic samples show a negative Nb anomaly.

A significant feature of the Vardar Zone Western Belt oceanic volcanism is a high-Si series, as seen in the upper levels of the Kozara Ophiolite Complex. These rocks crop out in gorges of the river Crna Reka and the river Vrbaška Reka and are represented by massive flows and magmatic domes that are closely associated with E-MORB type basalts (Campanian–Maastrichtian). The most widespread geochemical type of this series displays a strong enrichment relative to the average composition of upper continental crust (Taylor and McLennan, 1985) for all determined incompatible elements (e.g. REE = 315 ± 17 ppm). Relatively moderate LREE/HREE fractionation and clear negative geochemical anomalies of Nb, Eu and Ti are also present. Characteristic incompatible element ratios of this group of rocks are: $(La/Sm)_n = 3.22 \pm 0.25$; $(La/Yb)_n = 5.61 \pm 1.79$; $(Th/Yb)_n = 1.41 \pm 0.31$; $Th/La = 0.31 \pm 0.08$; $Nb^*/Nb = 0.42 \pm 0.15$. The high-silica series-volcanism is attributed to the formation of an Upper Cretaceous arc-trench system related to the closure of the Vardar Zone Western Belt oceanic basin and the involvement of magma sources/component(s) related to continental crust (Karamata et al., 1999, 2005; Pamić et al., 2000).

Bazylev et al. (2006) and Bazylev et al. (2008) provide sound mineralogical and geochemical data that demonstrate substantial heterogeneity of composition of mantle restites for both of the Mesozoic ophiolite zones of the Central and Northern Balkans. For the Dinaride Ophiolite Belt, sub-continental as well as sub-oceanic types are distinguished, coupled with some features of a SSZ setting. For the Vardar Zone Western Belt mantle restites are mainly represented by spinel harzburgites and depleted spinel lherzolites, indicating a SSZ setting. Thus, the results of the geochemical discrimination of the basaltic rocks and the associated mantle restites of both the Dinaride Ophiolite Belt and the Vardar Zone Western Belt are generally compatible. This conclusion does not contradict an interpretation of the two ophiolite belts as two different sutured marginal basins, each with distinctive chemical features. In a regional context, the Dinaride Ophiolite Belt can be correlated with a Neotethyan oceanic strand linking the Alpine–Northern Apennine oceanic basins to NW with the Western belt of the Mirdita–Pindos zones to the SE (Rampone et al., 1998; Robertson and Shallo, 2000; Piccardo, 2003; Bortolotti et al., 2004; Bortolotti and Principi, 2005; Saccani et al., 2004; Dilek et al., 2007, 2008 and references therein). The tholeiitic basalts of the Vardar Zone Western Belt that exhibit a SSZ influence have possible counterparts in the Mirdita zone Eastern belt. However, evidence of continuous fractionation of basaltic melts (basaltic andesites, andesites, dacites) are not observed in the Vardar Zone Western Belt. Also,

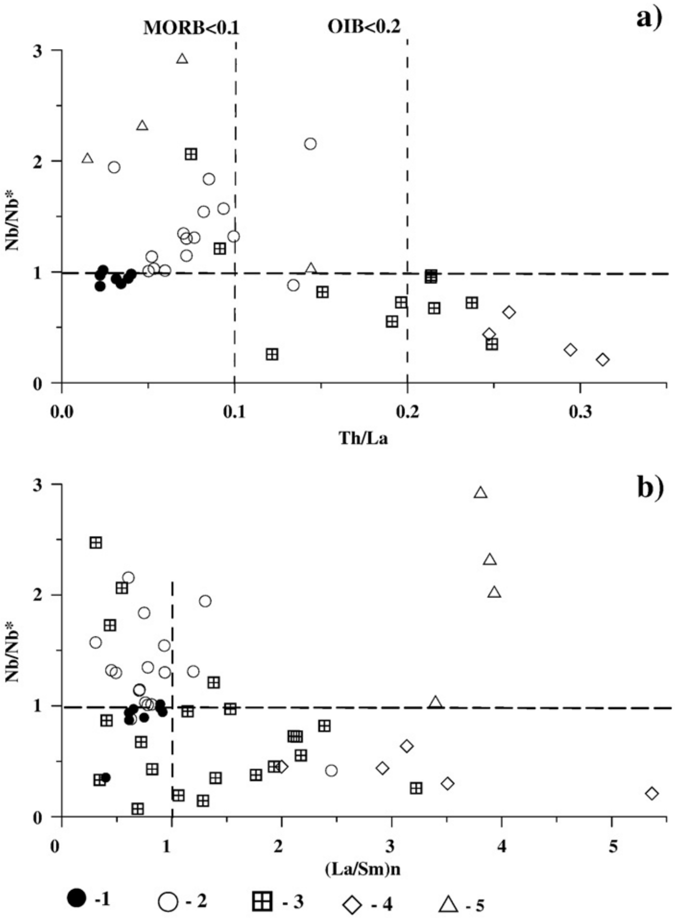


Fig. 15. Nb^*/Nb–Th/La and Nb^*/Nb–$(La/Sm)_n$ relations for volcanic series of the Dinaride Ophiolite Belt and the Vardar Zone Western Belt Captions as in Fig. 12.

the basaltic series of the Vardar Zone Western Belt generally display greater variation and much higher LREE/HREE and Th/REE ratios, compared to the SSZ series of the Mirdita zone (Saccani et al., 2004; Dilek et al., 2007).

7. Paleogeographic and geodynamic evolution

The mapped locations of the Triassic basalts indicate that volcanism related to the rifting stage of marginal basins was regionally extensive in the Dinaride Ophiolite Belt and in the Vardar Zone Western Belt marginal basins. There are three large areas (Bistrica–Priboj, Visoka and Čačak) with a Ladinian basalt–radiolarite association (Figs. 2, 16). All of the Ladinian sections contain limestone alternating with chert and belong to the Dinaridic Ophiolite Belt, while the Čačak section is represented by homogeneous chert associated with MOR-type basalts and belongs to the Vardar Zone Western Belt. The presence of N-MOR-type basalts in association with pelagic radiolarites may document the initiation of the spreading process. Additionally, WP-type volcanism occurs in the Bistrica–Priboj area (Fig. 16). The presence of significant amounts of tuffaceous material in the Fojnica and Bistrica–Priboj areas suggests the existence of volcanic centres between these areas which could supply the pyroclastic material that accumulated in the deep-water basin of the Dinaride Ophiolite Belt (Bistrica–Priboj area), as well as the shallow-water basin of Dalmatian–Herzegovinian composite terrane (Fojnica).

During the Carnian to early Norian we can trace the basalt–radiolarite association within the relatively shallow-water part of the Dinaride Ophiolite Belt (above the CCD as shown by the presence of carbonate material), and probably also within the deeper water basin of the Vardar Zone Western Belt, where basalt and chert alternated (Fig. 16). Mid-Late Triassic rifting was followed by passive margin subsidence (Fojnica area) by which time the Dinaride (Krš Gradac, Visoka, Sjenica, and Zaboj 2) and Vardar Ocean (i.e. western marginal seas (Ovčar-Kablar (Ovčar Banja) and Čačak) had opened. Thus, the fragmental sequences of the basalt–radiolarite association, in the form of isolated outcrops in mélange, olistoliths and olistostromes can be interpreted as fragments of Triassic oceanic crust, possibly similar to the Triassic oceanic crust of the Almopias zone of the Vardar ocean in northern Greece (Robertson, 2007; Sharp and Robertson, 2006).

After this developmental stage, there are no data concerning radiolarite accumulation from Rhaetian to Toarcian time. An apparent gap in sedimentation and volcanism exists in both the Dinaride and Vardar Zone Western Belt basins, suggesting that they were affected by a similar regional deformation during this time. Subsequently, radiolarians occur within red limestones of Toarcian age that are mainly dated by Cephalopods, as seen in the fragmentary Krš Gradac section of the Dinaride Ophiolite Belt (Fig. 17).

Aalenian–Bajocian radiolarites commonly alternate with cherty limestone and contain large amounts of sponge debris (Plate 6), as well as numerous sponge spicules that indicate a paleogeographic position on the continental slope of a passive margin (Pisera, 1997). The geochemistry of chert from Maslovare–Jezeračka areas also supports deposition on the continental slope of an oceanic basin. Coeval chert of the Grivska Formation shows a similar paleo-environment (Karamata et al., 2004b). The beginning of radiolarite–spongolite and radiolarite sedimentation on the subsided carbonate platform (Jezeračka and Krš Gradac sequences) and the absence of associated volcanics are also indicative of a passive margin setting.

Late Bajocian–Callovian radiolarites are relatively homogeneous siliceous deposits with only rare pyroclastic material, as seen in the

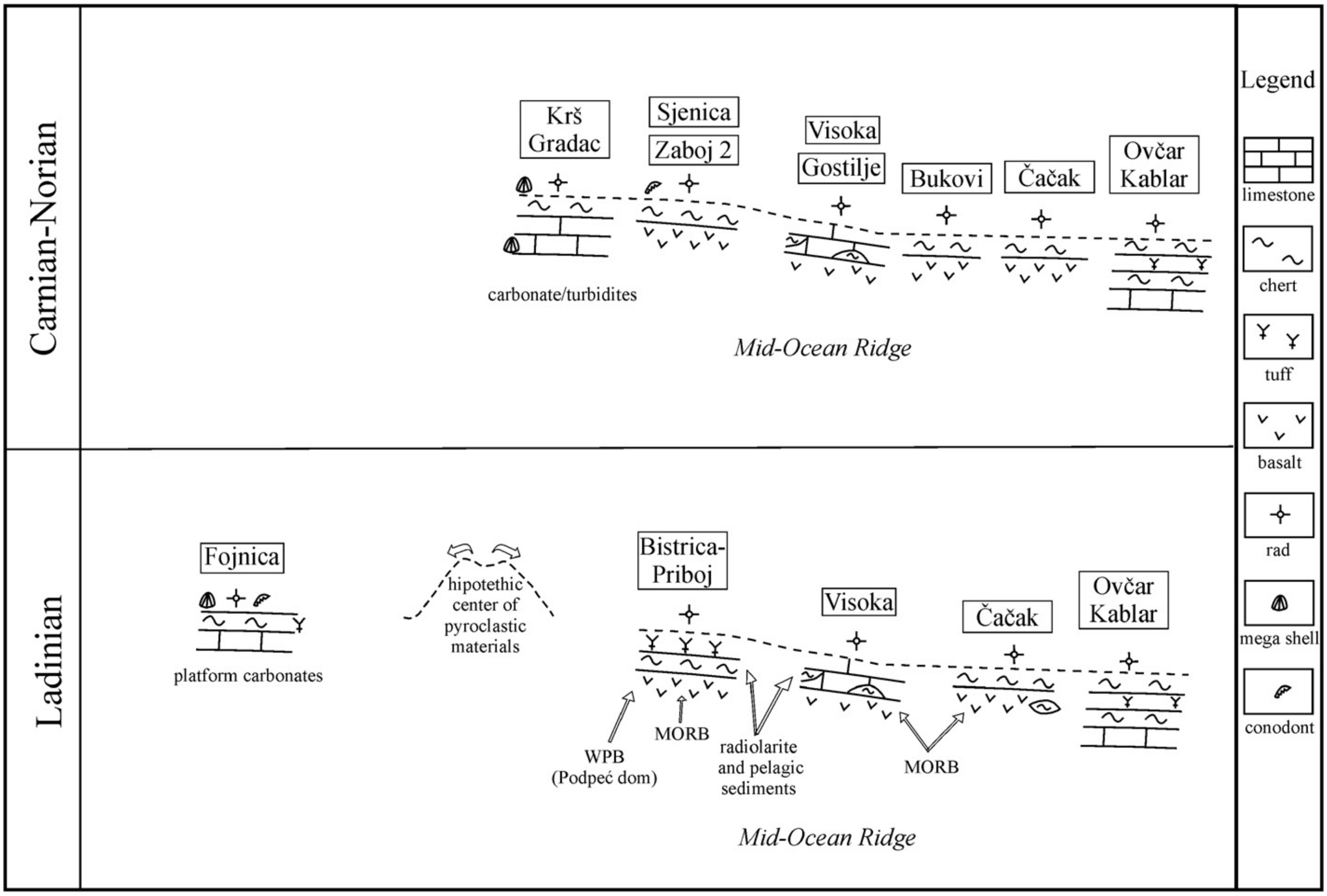


Fig. 16. Reconstruction of the rift paleohistory of the Triassic basalt–radiolarite associations.

Maslovare–Teslić and Nova Varoš sections (Fig. 17). The presence of MOR-type basalt in the Nova Varoš area, in association with Jurassic radiolarites is evidently explicable by the sea-floor spreading process. Part of the Kozara paleo-oceanic succession is apparently of late Jurassic age according to the evidence of a Sm–Nd mineral isochron (158 ± 8 Ma) for cumulate olivine gabbro in the southern part of the Complex (Ustaszewski et al., 2006, 2009-this volume).

The absence of interbedded carbonates in the Bajocian–Callovian and Oxfordian–Kimmeridgian radiolarian chert (= radiolarites) of the Dinaride Ophiolite Belt suggests deposition beneath the CCD (Fig. 17).

During Tithonian–Berriasian time (perhaps locally to Valanginian–Hauterivian) when chert–carbonaceous sedimentation dominated, accumulation took place above the CCD. The presence of abundant radiolarians, planktonic foraminifers and ostracodes indicates a stable pelagic marine environment within the Dinaride Ophiolite Belt and the Vardar Zone Western Belt. N-MOR-type basalt of approximately late Tithonian–Berriasian age occurs at only one location, the Mileševa Section (Fig. 17). This is suggestive of ongoing rifting at the rim of the ocean basin. Monaxone sponge spicules and calpionellids are very common in the Tithonian–Berriasian sediments of many sections. The increase in sponge spicules and limestones with marls upwards in the Uzlomac–Lipnje area is indicative of sedimentation above the CCD, perhaps related to shallowing of the basin or marine regression.

Radiolarite sedimentation ceased at the end of the Valanginian. During latest early Cretaceous–earliest Late Cretaceous subduction process gave rise to a new back-arc rifting with the accumulation radiolarian muds or sediments, accompanied by IA-type volcanism in the Vardar Zone Western Belt.

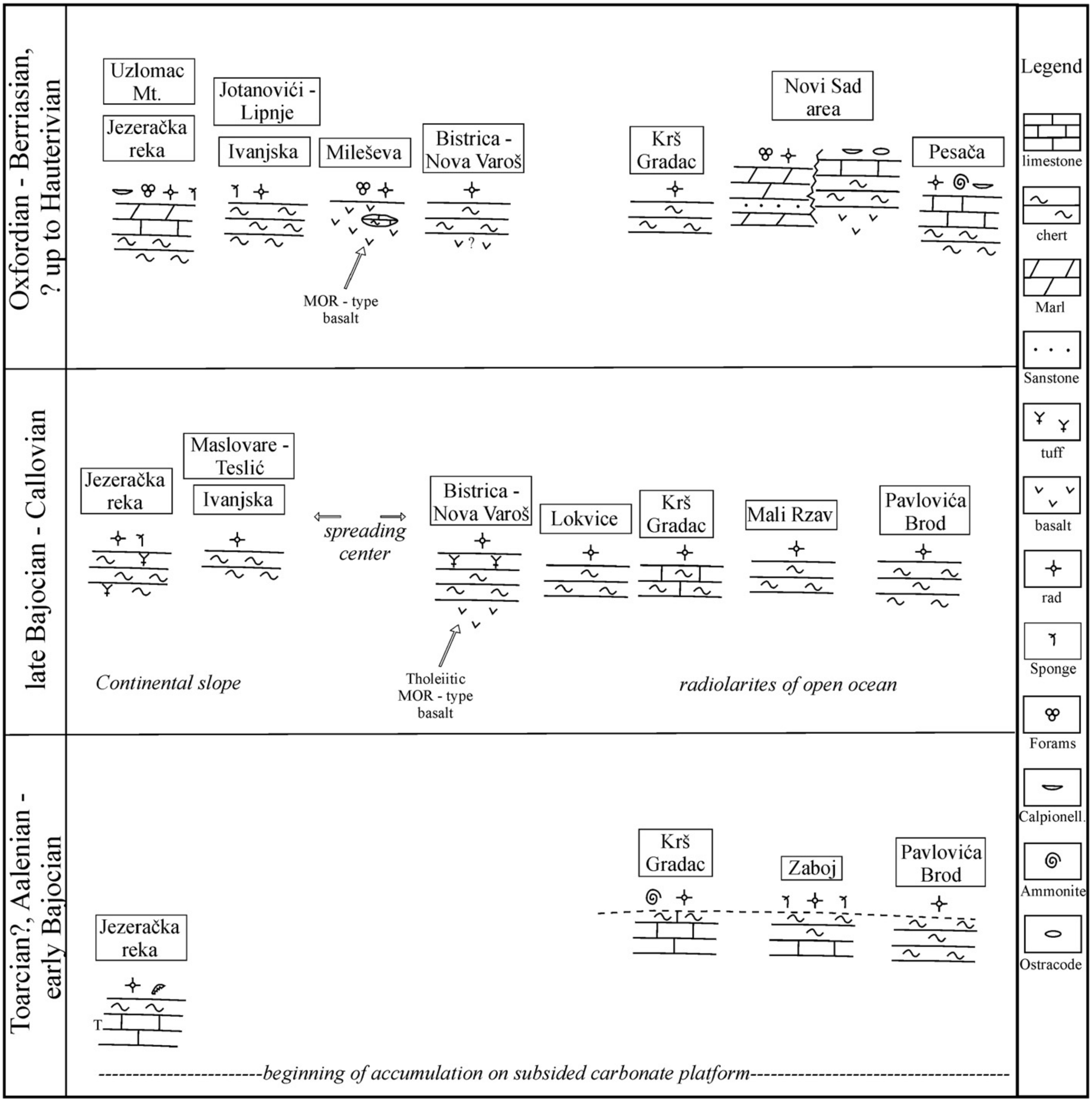


Fig. 17. Reconstruction of the paleogeographic position of the Jurassic–earliest Cretaceous radiolarites and associated sediments.

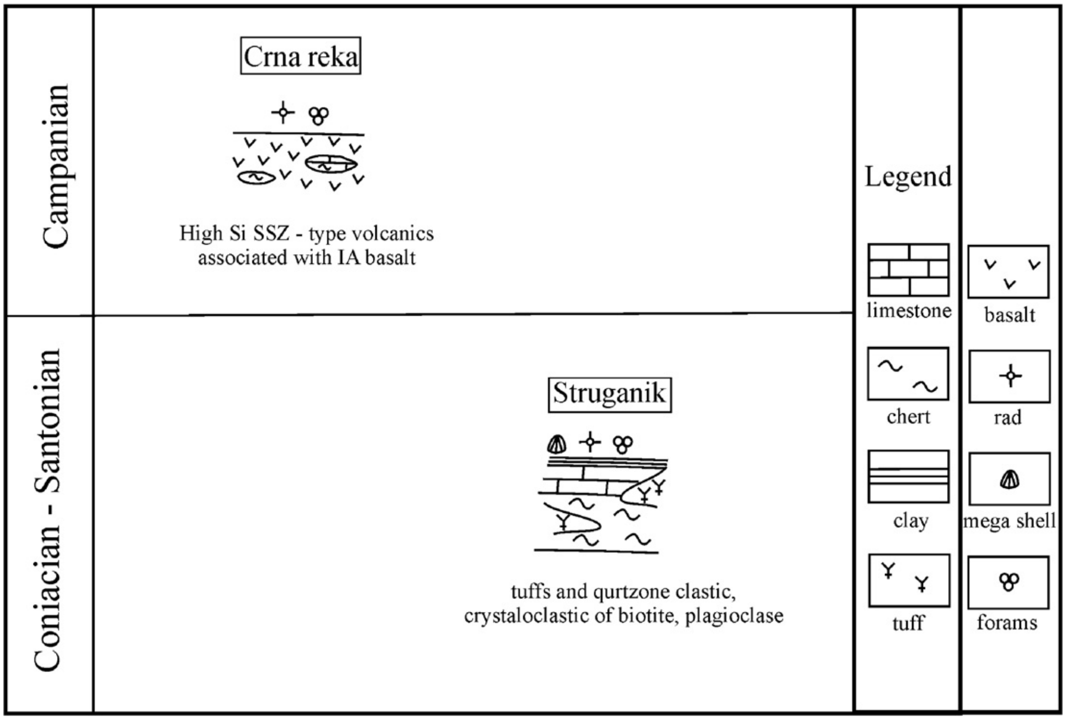


Fig. 18. Reconstruction of the possible sedimentary basin of the Cretaceous E-MOR and IA basalt and associated radiolarite.

In summary, radiolarite formation in the Dinaride Ophiolite Belt occurred during the Jurassic–earliest Cretaceous, but not the Triassic–Jurassic, contrary to a previous suggestion (Karamata et al., 2004b). In addition, the radiolarite–basalt formation of both the Dinaride Ophiolite Belt and the Vardar Zone Western Belt is of mid-late Triassic age (Figs. 16, 17). Local radiolarite sedimentation took place in Coniacian (Fig. 18) or Coniacian–Santonian times (Struganik Section). This is represented by violet tuffaceous chert and clay chert, alternating with light marl and limestone containing the relatively shallow-water bivalve, *Inoceramus*.

The latest radiolarite–basalt association is of Campanian age and contains E-MOR-type and IA-type basalts associated with high-silica SSZ-type volcanic rocks (trachytes, rhyolites). Occasional red limestone lenses in basalt between pillows) contain planktonic foraminifera alternating with cherty limestone enriched in radiolarians (Fig. 18).

8. Conclusions

Well-preserved and abundant radiolarians provide precise biostratigraphic age information concerning the opening and closing of oceanic realms and constrain the timing of eruption of ophiolitic basalts associated with radiolarites.

Jurassic to early Cretaceous radiolarians has been identified in the Dinaride marginal sea and the Vardar Ocean. Late Cretaceous radiolarians have also been discovered in the Vardar Ocean at two locations. The first near Kozara Mt. (Crna reka) contains the Campanian zonal species *Amphipyndax enessefi*, while the second in the non-ophiolite-related marly–limestone sequences of Struganik contains Coniacian–Santonian species.

The ages of radiolarian assemblages obtained for the central part of the Balkan Peninsula are as follows:

1. Visoka: Ladinian–Carnian;
2. Sjenica: Norian;
3. Zaboj 2: latest Carnian–early Norian;
4. Ovčar-Kablar gorge: late Carnian–early Norian;
5. Čačak: early–middle Norian;
6. Jezeračka reka section: latest Bajocian–early Bathonian to Tithonian;
7. Maslovare–Teslić section: late Bathonian–early Callovian;
8. Ivanjska quarry: Bajocian to Kimmeridgian–early Tithonian;
9. Zaboj: Aalenian;
10. Krš Gradac: late Bathonian–early Callovian to middle Oxfordian–early Tithonian;
11. Mali Rzav River: latest Bajocian to early Bathonian;
12. Uzlomac Mt. section: latest Tithonian–late Berriasian/earliest Valanginian;
13. Jotanovići–Lipnje section: late Tithonian–Berriasian to Valanginian–earliest Hauterivian to late Barremian–early Aptian?
14. Struganik: Coniacian–Santonian;
15. Crna reka: Campanian.

The radiolarian assemblage of early Cretaceous (probably Neocomian) age represents the first discovery of radiolarians of this age range in the central Balkan Peninsula. The first finding of late Cretaceous radiolarians in Serbia was indicated by the presence of Coniacian–Santonian inoceramids (Vasić et al., 2005). In addition, Oxfordian to Tithonian Serbian radiolarian fauna is currently being studied from the Pesača–Boljetin road section.

The radiolarite–basalt formation (N-MORB-type and locally WPB-type) is of Mid-Late Triassic age, while the Radiolarite formation is Jurassic–earliest Cretaceous in age, rather than Triassic–Jurassic (cf. Pamić, 2002; Karamata et al., 2004b). The basalt–radiolarite formation (E-MORB-type and IA-type) is of Late Cretaceous (Campanian) age. Local tuffaceous–clay–radiolarite sedimentation took place in the Coniacian, or Coniacian–Santonian (Struganik Section). There is little information on radiolarian deposition and basaltic volcanism during the post-Norian–pre-Toarcian, and also the post-Valanginian in the Dinaride Ophiolite Belt. The same applies to the post-Norian–pre-Bathonian and the post-Valanginian–pre-Coniacian time intervals in Vardar Zone Western Belt. This absence of deposition may represent phases of deformation, or ocean basin consumption within both of the oceanic areas.

The investigations of the rich Triassic and Jurassic, to early Cretaceous, radiolarian associations in Serbia and Bosnia provide information to reconstruct the paleogeography of the Dinaride marginal sea and the Vardar Ocean. On the basis of the different Jurassic, and Jurassic to Early Cretaceous radiolarian assemblages and sponge spicules it is possible to distinguish two different depositional areas in the region:

1. A marginal sea-type setting in the Dinaride Ophiolite Belt during Bajocian–latest Tithonian/earliest Berriasian times (e.g. Jezerečka Reka and Maslovare–Teslić); during Aalenian-to probably the beginning of the Bajocian (Zaboj of Sjenica area), and also during the latest Tithonian–Valanginian–Hauterivian (Jotanovići–Lipnje section, Uzlomac Mt.). A marginal sea setting also existed in the Vardar Zone Western Belt during the Tithonian–Valanginian (Novi Sad and Banat areas).
2. Abyssal oceanic settings are recorded in the Vardar Zone Western Belt during late Bajocian to early Bathonian, and in the Dinaride Ophiolite Belt during late Bajocian–Kimmeridgian to earliest Tithonian (Ivanjska quarry), and also during late Oxfordian–Kimmeridgian to earliest Tithonian (Krš Gradac). All of the radiolarian associations from the Ivanjska quarry are typical of an open oceanic environment, where all groups of cyrtoidal, prunoidal, discoidal and spherical radiolarians flourished.

Based on chemical data for the volcanic paleo-oceanic series the Dinaride Ophiolite Belt is interpreted as a sutured marginal basin (Middle Triassic–Late Jurassic) and the Vardar Zone Western Belt as an accretionary complex that formed after destruction of a wide system of immature arcs and back-arc basins (Late Triassic–Late Cretaceous; Campanian–Maastrichtian).

Finally, the detailed investigation of radiolarites not directly related to ophiolite complexes in Serbia provides additional evidence of the regional palaeogeography.

Acknowledgements

We are grateful to Academician Stefan Karamata for coordination of the scientific research and the fieldtrips, to Dr. Boris Bazilev (Russian Academy of Sciences) for participation in the collecting and preparation of radiolarian samples, to Prof. Milan Sudar and Saša Popević for collecting the samples from the Zaboj area, and to Vladimir Bernard (Geological Institute, Russian Academy of Sciences) for the production of high-quality electron microphotographs. We are deeply grateful to Dr Marco Chiari for his hard work and suggestions for improving our manuscript and to Dr Kagan Tekin for helpful comments and advice. We wish to express our thanks to Alastair Robertson for his critical comments and suggestions, as well as English editing. The new data on Mesozoic radiolarians in Bosnia were obtained as a result of joint Russian–Serbian research (2000–2007). The work was supported by Serbian Ministry of Science and Technological Development (Project No. 146009). This study was also supported by the Russian Foundation for Basic Research (Projects 06-05-64859 and 08-05-00-503).

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