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Middle Jurassic radiolarian assemblages from the sedimentary cover of the Adriatic margin (Zlatar Mountain, SW Serbia)

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Key words. – Jurassic, Radiolarians, Internal Dinarides, Zlatar Mt., SW Serbia.

Abstract. – This paper focuses on the age of radiolarite sequences that are believed to be part of the sedimentary cover of the Adriatic margin; they are found structurally underneath ophiolitic mélange formations forming the base of the obducted western Vardar Ophiolitic Unit. Three sections of radiolarian chert yielded moderate to well preserved radiolarian assemblages. The age range inferred for all the three studied sections spans the Late Bajocian to Early Callovian interval.

Assemblages de radiolaires du Jurassique moyen extraits de la couverture sédimentaire de la marge Adriatique (Mont Zlatar, sud-ouest de la Serbie)

Mots-clés. – Jurassique, Radiolaires, Dinarides Internes, Mont Zlatar, Sud-ouest de la Serbie

Résumé. – Le principal objectif de cet article est de déterminer l'âge des séries radiolaritiques lesquelles sont considérées comme appartenant à la couverture sédimentaire de la marge continentale Adriatique ; elles se trouvent structurellement en-dessous des formations du mélange ophiolitique constituant la base des unités ophiolitiques obductées du Vardar occidental. Trois coupes de ces séries radiolaritiques ont livré des assemblages de radiolaires moyennement bien à bien préservés. L'intervalle d'âge obtenu dans les trois coupes étudiées s'étend du Bajocien supérieur au Callovien inférieur.

INTRODUCTION

Studies of Mesozoic Radiolaria occurring within the territory of Serbia are of key importance for understanding the paleogeography and overall tectonic structure of the Dinarides. During the 80's, radiolarian assemblages were described in several studies and encompass Triassic [Obradović, 1986; Obradović *et al.*, 1986a, 1987/88; Obradović and Goričan, 1988] as well as Jurassic [Obradović *et al.*, 1986b; Obradović and Goričan, 1988] assemblages. During the last decade, investigations of radiolarian cherts from SW Serbia were intensified [Goričan *et al.*, 1999; Djerić *et al.*, 2007; Djerić and Gerzina, 2008; Vishnevskaya and Djerić, 2009; Vishnevskaya *et al.*, 2009; Gawlick *et al.*, 2009; Djerić *et al.*, 2010].

While all the above studies confirmed the importance of radiolarian cherts for solving stratigraphic, paleogeographic, tectonic and paleotectonic problems, knowledge about Mesozoic Radiolaria from Serbia is still insufficient. This paper investigates the age of radiolarite sequences that are found structurally underneath ophiolitic mélange formations at the base of the obducted western Vardar Ophiolitic Unit (fig. 1).

The close spatial association of radiolarites with ophiolites, typical for the internal Dinarides, was noted early on ("Diabas-Hornstein-Formation" of Hammer [1921]) and taken as testimony of initial volcanism in an eugeosyncline. After the advent of plate tectonics, there was a tendency to invariably regard radiolarite deposits as an integral part of the obducted ophiolites and/or underlying ophiolitic mélanges (e.g. "Radiolarite Formation" of Pamić *et al.* [2002]) although such radiolarites are also found as part of the sedimentary cover of the adjacent distal continental margins [Dimitrijević, 1997, 2001].

The investigated localities are located in western Serbia, in a very complex geotectonic setting (fig. 1), where in map view there are two ophiolitic belts separated from each other by the intervening continental Drina-Ivanjica "block". The western and more external belt is known as the Dinaridic Ophiolite belt [Pamić *et al.*, 2002; Karamata, 2006] or the Central Dinaridic Ophiolite belt [Lugović *et al.*, 1991], while the internal belt is known as the Vardar Zone western belt [Karamata, 2006], Inner Dinaridic Ophiolite belt [Lugović *et al.*, 1991], External Vardar Subzone [Dimitrijević, 1997, 2001] or simply the Vardar Zone [Pamić *et al.*, 2002].

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Traditionally, and for the majority of authors, these two ophiolite belts are regarded as the remnants of two distinct oceanic realms in the Dinarides and Hellenides, while the intervening continental units such as the Drina-Ivanjica block and others (e.g. Jadar, Korab, Pelagonian) are considered as continental terranes that separated them [e.g. Dimitrijević and Dimitrijević, 1973; Robertson and Karamata, 1994; Dimitrijević, 2001; Karamata, 2006; Papanikolaou, 2009]. However, according to other authors, these two ophiolite belts are the erosional remnants of just one ophiolitic sheet, referred to as western Vardar Ophiolitic Unit by Schmid *et al.* [2008], obducted onto the Adriatic margin to which the various continental blocks mentioned above belong [Bernoulli and Laubscher, 1972; Pamić, 1998; Pamić *et al.*, 2000; Csontos *et al.*, 2003; Schmid *et al.*, 2008]. The separation into two ophiolite belts occurred as a result of out-of-sequence thrusting during the Cretaceous and Tertiary orogenic phases that postdated the Jurassic obduction of the western Vardar Ophiolitic Unit. Finally, some others are of the opinion that continental elements such as the Drina-Ivanjica "terrane" originated from the European margin and were thrusted onto the previously emplaced Dinaridic ophiolites [Pamić *et al.*, 1998; Pamić and Hrvatović, 2000].

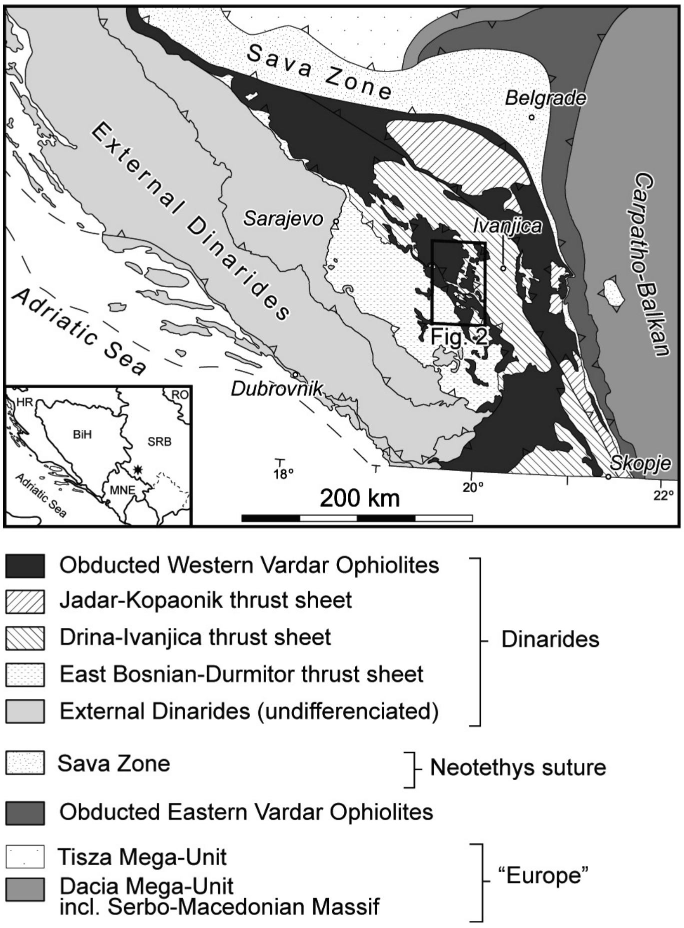


FIG. 1. – Tectonic sketch of the Dinarides [modified from Schmid *et al.*, 2008; Schefer *et al.*, 2010]
FIG. 1. – *Esquisse tectonique des Dinarides (modifié d'après Schmid* et al. *[2008]; Schefer* et al. *[2010]).*

GEOLOGICAL SETTING

In general, radiolarian cherts can be found in 3 different tectonic settings of the internal Dinarides: (1) Jurassic radiolarites belonging to the in-situ preserved stratigraphic cover of ophiolitic sequences, as this is preserved in Albania [e.g. Prela *et al.*, 2000; Chiari *et al.*, 1994]; the ophiolites in Serbia and Bosnia-Herzegovina underwent post-obduction erosion and were unconformably overlain by latest Jurassic to earliest Cretaceous fluvial conglomerate and sandstone (Pogari Formation) and/or platform carbonates [Blanchet *et al.*, 1970; Pamić and Hrvatović, 2000]. (2) Radiolarian chert sequences of either Triassic or Jurassic age [Obradović and Goričan, 1988], which are incorporated into ophiolitic mélange formations underlying the obducted ophiolites in the form of gravitationally emplaced olistoliths or "olistoplaka" [e.g. Dimitrijević, 1997], or alternatively, as tectonically incorporated slivers scraped off the footwall, i.e. the Adriatic margin [Schmid *et al.*, 2008] and, (3) Jurassic-age radiolarian cherts that are an integral part of an in situ passive margin sedimentary sequence preserved in the footwall of the ophiolitic mélange, which is the case in our study area. Most of the radiolarites in setting (2) and all radiolarites in setting (3) were originally deposited onto older carbonate platform sequences of the distal Adriatic margin, following drowning of the carbonate platform below the CCD. Such a drowning typically occurred in two stages: a first one in Triassic times that only affected the most distal parts of the Adriatic margin and a second one in Mid-Jurassic times that is by far more widespread within the more distal continental margin sequences of the internal Dinarides that were adjacent to Neotethys [e.g. Dimitrijević, 1997; 2001].

The localities "Zlatar 2" (Zl2), "Zlatar 3" (Zl3) and "Lokvice" (Zl4) presented here are located between Nova Varoš and Sjenica (fig. 2). They were traditionally considered as parts of the ophiolitic mélange that structurally underlie the ophiolites of the Dinaridic Ophiolite belt [e.g. Karamata *et al.*, 1997; Gawlick *et al.*, 2009]. Consequently, it is a widely accepted opinion among Serbian geologists that the association of siliceous rocks (cherts and radiolarites) that belong to the so-called Zlatar Formation represents the sedimentary cover of oceanic crust.

Although detailed structural investigations still lack in the area, our field work confirms the findings of Rampnoux [1970, 1974]; in his view the Zlatar trough of the Serbian zone ("sillon de Zlatar de la zone Serbe") to which the studied chert sequence belongs, represents a drowned carbonate platform of the Adriatic margin; according to Schmid *et al.* [2008] this is part of the East Bosnian-Durmitor thrust sheet (fig. 2). Very thick Jurassic radiolarite successions, such as those found at the localities described here, are typical for the Zlatar Mountain area. Where exposed, the contact of these radiolarites with the underlying Triassic carbonate sequences is stratigraphic as can be seen in a key outcrop at the Krš Gradac locality (KG locality indicated in fig.2; Vishnevskaya and Djerić [2009]; Vishnevskaya *et al.* [2009]; Radoičić *et al.* [2009], Gawlick *et al.* [2009]). However, it cannot be entirely excluded that such sequences that are typically seen in isolated outcrops may represent blocks that were scraped off the Adriatic margin and were subsequently mechanically incorporated into the ophiolitic mélange during the Jurassic obduction of the ophiolites.

SECTION DESCRIPTION AND BIOSTRATIGRAPHY

The samples taken from the three investigated sections Zlatar 2 (Zl2), Zlatar 3 (Zl3) and Lokvice (Zl4) (figs. 2, 3) were etched with hydrofluoric acid at different concentrations, utilizing the standard methods. In this paper we adopted the radiolarian zonation based on Unitary Association Zones (UAZ) proposed by Baumgartner *et al.* [1995]. The names of genera were corrected according to the new revision by O'Dogherty *et al.* [2009].

Zlatar 2 section (Zl2)

This section is exposed in a quarry that is situated along the road Nova Varoš-Aljinovići-Sjenica (fig. 2), about 5 km southeast of Nova Varoš (43.429°N; 19.828°E). The isolated outcrop exposes a continuous section through some 27 m of red thin-bedded chert with clayey interlayers (fig. 3).

Sample NĐ 331 was taken about 1 m above the bottom of the section from red laminated chert that contains poorly preserved radiolarians. The assemblage (pl. I, figs. 1-6) can be assigned to UAZs 6 and 7 spanning the middle Bathonian to early Callovian, based on the range of *Striatojaponocapsa conexa* (last appearance in UAZ 7), *Protunuma turbo* (last appearance in UAZ 7) and *Paronaella mulleri* (first appearance in UAZ 6) [Baumgartner *et al.*, 1995].

Sample NĐ 240 is taken from about 9 m from the bottom of the section in red, thin-bedded chert. The radiolarian fauna is moderately-well preserved, but relatively diverse (pl. I, figs. 7-26). The presence of *Unuma gordus* Hull (4-7; Suzuki *et al.* [2001]) suggests that this assemblage is not younger than Callovian. However, *Zhamoidellum ovum*, supposed to be restricted to UAZs 9-11 [Baumgartner *et al.*, 1995], was also found. Suzuki *et al.* [2001] suggested that the proposed range of this species should be extended down to the Middle Jurassic, with a first appearance in UAZ 7. Therefore, the most probable age of this sample is between the late Bathonian and the early Callovian (UAZ 7).

The radiolarian association also contains *Williriedellum tetragonum* (Matsuoka) that according to Baumgartner *et al.* [1995] is known only from UAZ 5 (latest Bajocian to early Bathonian). However, Suzuki and Gawlick [2003] found this species also in an association with younger radiolarians in several samples.

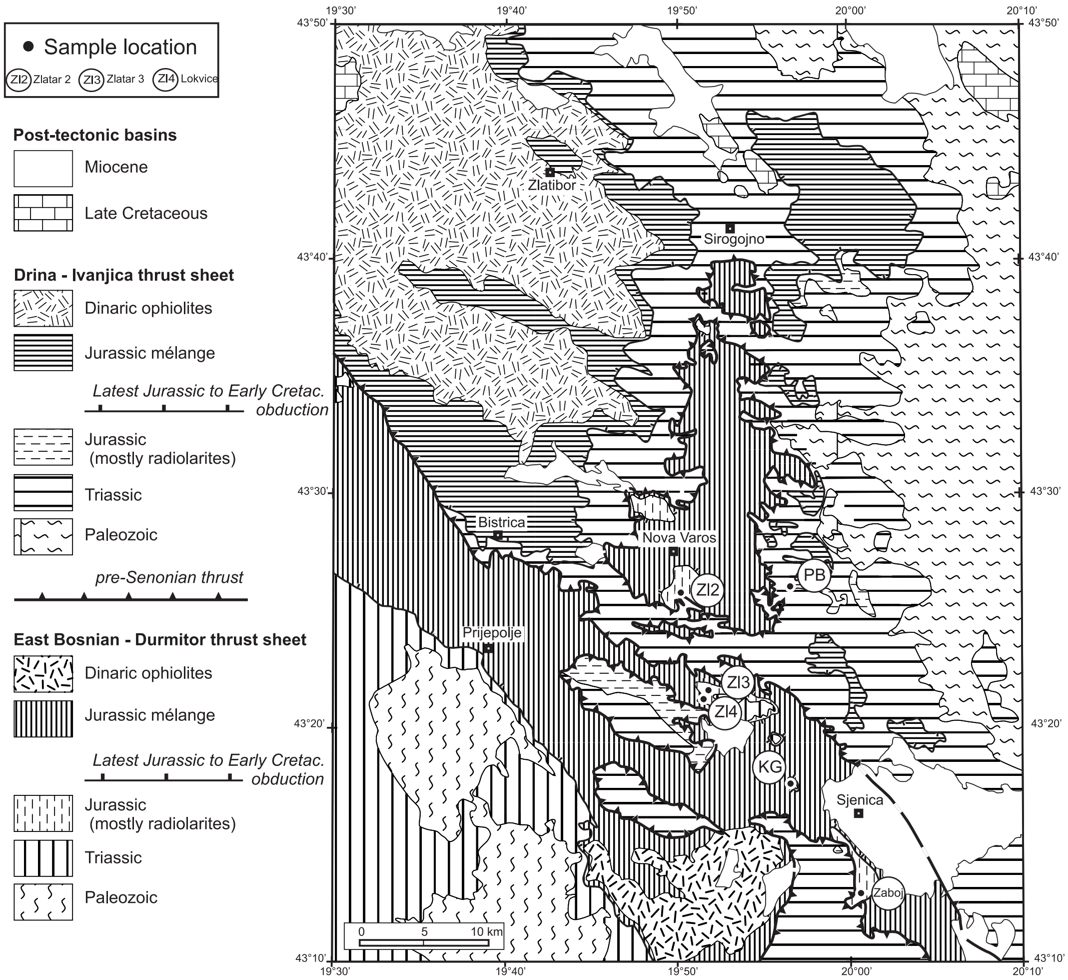


Fig. 2. – Map of western Serbia with localities for the three sections described in this paper: Zlatar 2 (Zl2), Zlatar 3 (Zl3) and Lokvice (Zl4), plus three other outcrops mentioned in the text: Krš Gradac (KG), Zaboj (Zaboj) and Pavlovića Brod (PB).
Fig. 2. – *Carte géologique de la Serbie occidentale avec la localisation des trois coupes décrites dans cet article : Zlatar 2 (Zl2), Zlatar 3 (Zl3) et Lokvice (Zl4), plus trois autres affleurements mentionnés dans le texte : Krš Gradac(KG), Zaboj (Zaboj) et Pavlovića Brod (PB).*

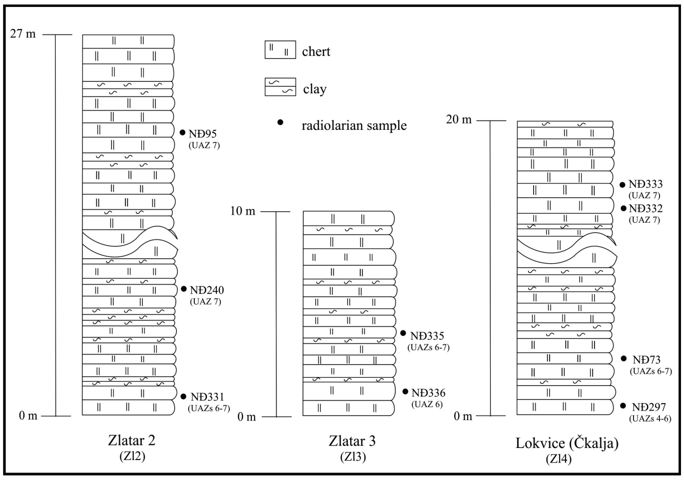


FIG. 3. – Lithostratigraphic columns of the examined sections and position of studied samples.
FIG. 3. – *Colonnes stratigraphiques des coupes examinées et position des échantillons étudiés.*

Sample NĐ 95 is a chert collected 20 m above the bottom of the section (fig. 3). The diversity of the poorly preserved radiolarians is very low (pl. I, figs. 27-31). The assemblage is compatible with UAZs 4 to 7, covering the time span from late Bajocian to early Callovian, as indicated by the presence of *Semihsuum amabile* (AITA) [Baumgartner *et al*., 1995]. Considering the position of the sample in the stratigraphic column, we assume that the chert of sample NĐ 95 formed during a time corresponding to UAZ 7.

In summary, the maximum possible time interval contained in this section is middle Bathonian to early Callovian (UAZs 6-7).

Zlatar 3 section (Zl3)

This section is also exposed along the Nova Varoš-Aljinovići-Sjenica road (fig. 2), about 14 km southeast of Nova Varoš (43.358°N; 19.856°E). It exposes dark red, thin-bedded and locally platy chert with clayey interlayers. The section is approximately 10 m thick (fig. 3).

Sample NĐ 336 is a chert collected 1.2 m from the bottom of the section (fig. 3). Radiorlarians are abundant and diverse, but poorly preserved (pl. II, figs. 1-16). A middle Bathonian age (UAZ 6) is indicated by the coexistence of two species *Unuma echinatus* ICHIKAWA & YAO (LAD in UAZ 6; Baumgartner *et al.* [1995]) and *Pseudoristola* sp. cf. *P. tsunoensis* (AITA) (FAD in UAZ 6; Baumgartner *et al.* [1995]).

Sample NĐ 335 is from about 4.5 m above the bottom of the section and taken from red, thin-bedded chert (fig. 3). Radiolarians are abundant, relatively diverse, but poorly preserved (pl. II, figs. 17-29). The sample is certainly not younger than early Callovian as evidenced by *Praewilliriedellum robustum* (MATSUOKA), *Protunuma turbo* MATSUOKA and *Dictyomitrella* sp. cf. *D. kamoensis* MIZUTANI & KIDO (LADs in UAZ 7; Baumgartner *et al.* [1995]).

In summary, the inferred maximum age range for the Zlatar 3 section is Middle Bathonian to Early Callovian (UAZs 6-7).

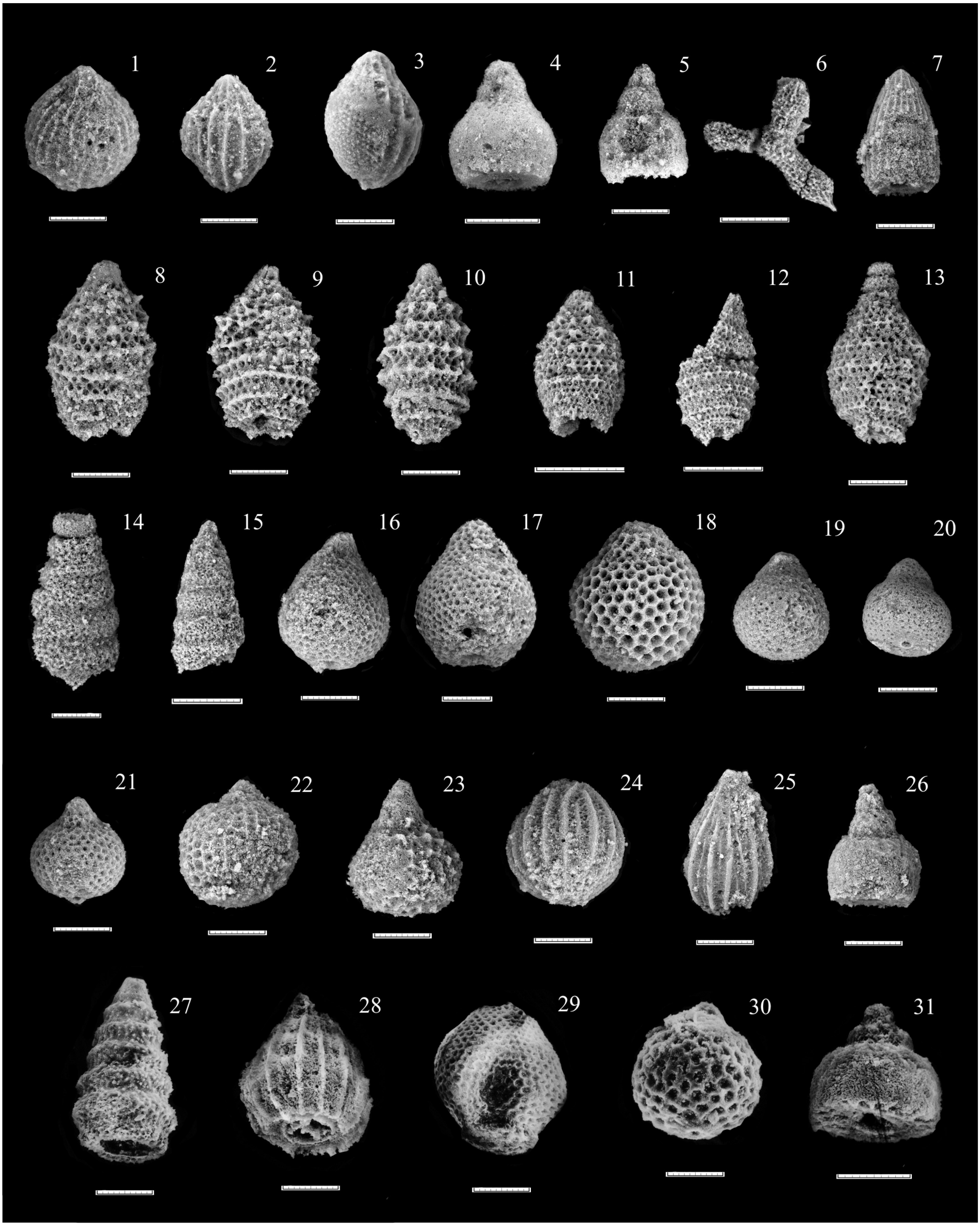
Lokvice section (also known as Čkalja section) (Zl4)

This is the third section exposed along the road Nova Varoš-Aljinovići-Sjenica (fig. 2). Approximately 14 m of dark red to black chert (fig. 3) crop out in a small quarry located about 16 km southeast of the Nova Varoš (43.354°N; 19.854E). Stratification is only poorly preserved in the heavily fractured upper parts of the quarry, while 3-5 cm thick layers are visible in its lower part. Dark-red to dark-grey layered chert (about 10-15 cm thick), situated stratigraphically above the cherts in the quarry, is exposed about 30 m after the abandoned quarry further along the road towards Sjenica. This younger part of the section is only some 6 m thick.

Sample NĐ 297 was taken about 0.5 m from the bottom of the quarry section within dark grey, thin-bedded chert (fig. 3). The sample is characterized by a poor and badly preserved radiolarian association (pl. II, figs. 1-5). On the basis of the presence of *Unuma gordus* HULL a maximum age range between late Bajocian and middle Bathonian (UAZs 4 to 6) is inferred.

Sample NĐ 73 is from about 3.5 m from the bottom of the quarry section and found within dark red, laminated chert (fig. 3). Radiolarians are poorly preserved and their diversity is very low (pl. III, figs. 6-9). A maximum age

PLATE 1. – Middle Jurassic radiolarians from samples of the Zlatar 2 section (Zl2).
Scale bars: = 50 µm (figs. 1-5, 7-10, 13, 14, 16-32); = 100 µm (figs. 6, 11, 12, 15)
PL. I. – *Radiolaires du Jurassique moyen des échantillons de la coupe de Zlatar 2 (Zl2).*
Barres d'échelle : = 50 µm (figs. 1-5, 7-10, 13, 14, 16-32) ; = 100 µm (figs. 6, 11, 12, 15).
Figs. 1-6. – Sample NĐ 331; middle Bathonian to late Bathonian-early Callovian (UAZs 6-7) / *Échantillon NĐ 331; Bathonien moyen au Bathonien supérieur-Callovien inférieur (UAZ 6-7).*
1. *Striatojaponocapsa conexa* (MATSUOKA); 2. *Protunuma turbo* MATSUOKA; 3. *Protunuma* sp.; 4. *Eucyrtidiellum* sp. cf. *E.* ? *circumperforatum* CHIARI, MARCUCCI & PRELA; 5. *Eucyrtidiellum* sp.; 6. *Paronaella mulleri* PESSAGNO
Figs. 7-26. – Sample NĐ 240; late Bathonian-early Callovian (UAZ 7) / *Échantillon NĐ 240; Bathonien supérieur-Callovien inférieur (UAZ 7)*
7. *Archaeodictyomitra* sp.; 8-13. *Eoxitus hungaricus* KOZUR; 14. *Cinguloturris* sp. cf. *C. getsensis* O'DOGHERTY, GORIČAN & DUMITRICA; 15. *Cinguloturris* sp.; 16. *Praewilliriedellum* sp. cf. *P. convexa* (YAO); 17. *Praewilliriedellum* sp.; 18. *Zhamoidellum* sp. cf. *Z. ovum* DUMITRICA; 19, 20. *Praewilliriedellum* sp.; 21. *Williriedellum marcucciae* CORTESE; 22. *Williriedellum tetragonum* (MATSUOKA); 23. *Hiscocapsa kodrai (*CHIARI, MARCUCCI & PRELA*)*; 24. *Unuma gordus* HULL; 25. *Semihsuum* sp.; 26. *Eucyrtidiellum* sp.
Figs. 27-31. – Sample NĐ 95; late Bathonian-early Callovian (UAZ 7) / *Échantillon NĐ 95; Bathonien supérieur-Callovien inférieur (UAZ 7)*
27. *Cinguloturris* sp.; 28. *Semihsuum amabile* (AITA); 29. *Praewilliriedellum* sp.; 30. *Williriedellum* sp.; 31. *Eucyrtidiellum* sp.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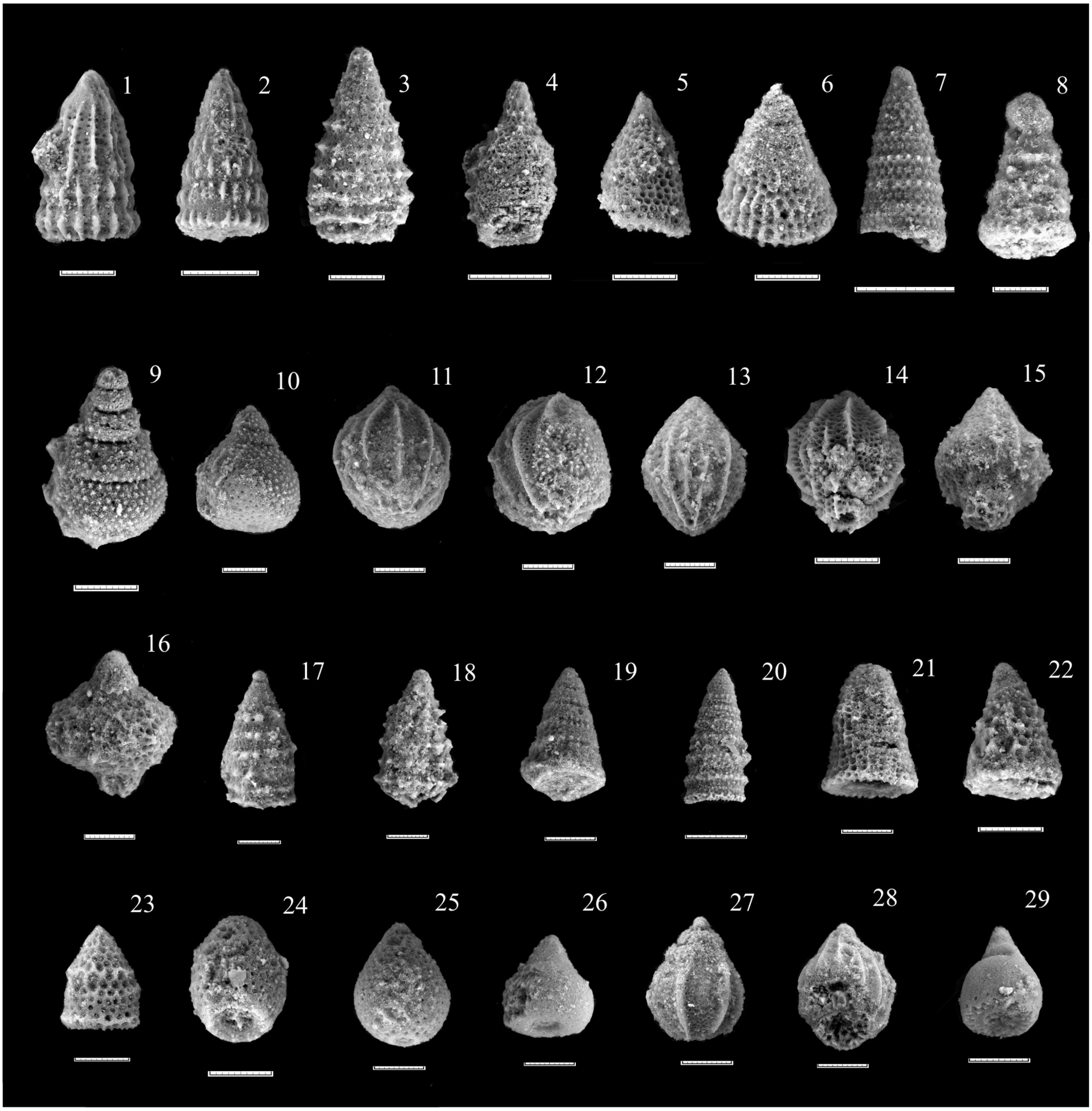

PLATE II. – Middle Jurassic radiolarians from samples of the Zlatar 3 section (Zl3). Scale bars: = 50 µm (figs. 1, 3, 5, 6, 8-19, 21-29); = 100 µm (figs. 2, 4, 7, 20)

PLANCHE II. – *Radiolaires du Jurassique moyen des échantillons de la coupe de Zlatar 3 (Zl3). Barres d'échelle : = 50 µm (figs. 1, 3, 5, 6, 8-19, 21-29); = 100 µm (figs. 2, 4, 7, 20).*

Figs. 1-16. – Sample NĐ 336; middle Bathonian (UAZ 6) / *Échantillon NĐ 336; Bathonien moyen (UAZ 6).*

1. *Transhsuum* sp.; 2. *Transhsuum brevicostatum* gr. (OZVOLDOVA); 3. *Eoxitus dhimenaensis dhimenaensis* (BAUMGARTNER); 4. *Eoxitus* sp.; 5. *Pseudodictyomitrella* sp. cf. *P. renevieri* O'DOGHERTY, GORIČAN & DUMITRICA; 6. *Parahsuum* sp.; 7. *Dictyomitrella* sp.; 8. *Stichomitra* (?) *takanoensis* gr. AITA; 9. *Pseudoristola* sp. cf. *P. tsunoensis* (AITA); 10. *Williriedellum* sp. cf. *W. buekkense* (KOZUR); 11., 12. *Protunuma* (?) sp.; 13. *Protunuma fusiformis* ICHIKAWA & YAO; 14. *Unuma echinatus* ICHIKAWA & YAO; 15. *Unuma* sp. aff. *U. latusicostatus* (AITA); 16. *Williriedellum* sp.

Figs. 17-29. – Sample NĐ 335; middle Bathonian to late Bathonian-early Callovian (UAZs 6-7) / *Échantillon NĐ 335; Bathonien moyen au Bathonien supérieur-Callovien inférieur (UAZ 6-7).*

17. *Eoxitus sp. cf. E. spinifer* (TAKEMURA); 18. *Eoxitus hungaricus* KOZUR; 19. *Dictyomitrella* sp. cf. *D. kamoensis* MIZUTANI & KIDO; 20. *Dictyomitrella* sp.; 21. *Parahsuum* (?) sp.; 22. *Pseudodictyomitrella* (?) sp.; 23. *Pseudodictyomitrella* sp.; 24. *Nassellaria* gen. et sp. indet.; 25. *Praewilliriedellum robustum* (MATSUOKA); 26. *Eucyrtidiellum* sp.; 27. *Unuma* sp.; 28. *Protunuma turbo* MATSUOKA; 29. *Eucyrtidiellum unumaense* s.l. (YAO)

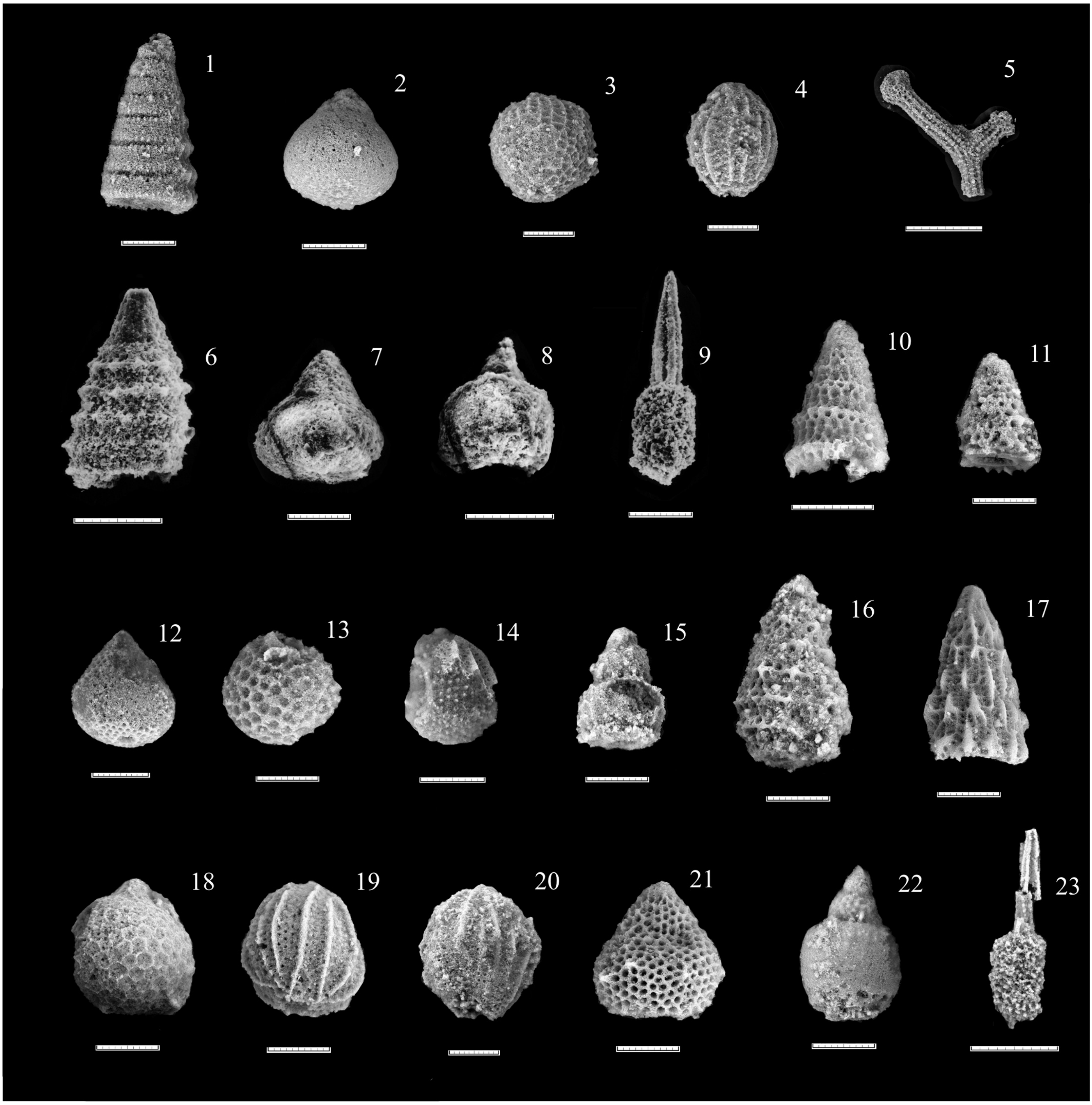

PLATE III. – Middle Jurassic radiolarians from samples of the Lokvice section (Zl4).
Scale bars: = 50 µm (figs. 1-22); = 100 µm (fig. 23)
PL. III. – *Radiolaires du Jurassique moyen des échantillons de la coupe de Lokvice (Zl4).*
Barres d'échelle : = 50 µm (figs. 1-22) ; = 100 µm (fig. 23).
Figs. 1-5. – Sample NĐ 297; late Bajocian to middle Bathonian (UAZs 4-6) / *Échantillon NĐ 297; Bajocien supérieur au Bathonien moyen (UAZ 4-6).*
1. *Transhsuum* sp.; 2. *Williriedellum buekkense* (KOZUR); 3. *Williriedellum* sp. cf. *W. tetragonum* (MATSUOKA); 4. *Unuma gordus* HULL; 5. *Homoeoparonaella ? pseudoewingi* BAUMGARTNER
Figs. 6-9. – Sample NĐ 73; middle Bathonian to late Bathonian-early Callovian (UAZs 6-7) / *Échantillon NĐ 73 ; Bathonien moyen au Bathonien supérieur-Callovien inférieur (UAZ 6-7).*
6. *Eoxitus hungaricus* KOZUR; 7. *Williriedellum buekkense* (KOZUR); 8. *Eucyrtidiellum* (?) sp.; 9. *Archaeospongoprunum* sp. cf. *A. macrostylum* PESSAGNO.
Figs. 10-15. – Sample NĐ 332; late Bathonian to early Callovian (UAZ 7) / *Échantillon NĐ 332; Bathonien supérieur-Callovien inférieur (UAZ 7)*
10. *Dictyomitrella kamoensis* MIZUTANI & KIDO; 11. *Pseudodictyomitrella* sp. cf. *P. ulivii* (CHIARI, CORTESE & MARCUCCI); 12. *Praewilliriedellum* sp.; 13. *Cryptamphorella* (?) sp.; 14. *Unuma* sp.; 15. *Eucyrtidiellum* sp.;
Figs. 16-23. – Sample NĐ 333; late Bathonian to early Callovian (UAZ 7) / *Échantillon NĐ 333; Bathonien supérieur-Callovien inférieur (UAZ 7)*
16. *Eoxitus* sp.; 17. *Transhsuum maxwelli* gr. (PESSAGNO); 18. *Gongylothorax* sp. aff. *G. favosus* DUMITRICA sensu Baumgartner *et al.* (1995); 19. *Unuma* sp.; 20. *Unuma gordus* HULL; 21. *Quarticella magnipora* CHIARI, MARCUCCI & PRELA; 22. *Eucyrtidiellum unumaense* s.l. (YAO); 23. *Archaeospongoprunum* sp.

range between early Bajocian and early Oxfordian age (UAZs 3 to 8) can be inferred from *Eoxitus hungaricus* KOZUR. Considering the stratigraphic position of sample NĐ 73 within the entire section (see fig. 3) and the age of sample NĐ 332 discussed below, the age of this sample ranges between the middle Bathonian and early Callovian (UAZs 6-7).

Sample NĐ 332 was taken from the lowermost part of the second section exposed further along the road, about 1 m from the bottom of this second section. There, dark red chert is characterized by a scarce and poorly preserved radiolarian association (pl. III, figs. 10-15). The inferred age range spans the early Bajocian to early Callovian (UAZs 3 to 7) by the presence of *Dictyomitrella* (?) *kamoensis* MIZUTANI & KIDO. The radiolarian association also includes *Pseudodictyomitrella* sp. cf. *P. ulivii* (CHIARI, CORTESE & MARCUCCI), which is restricted to UAZs 7 to 10 [Chiari *et al.*, 1997]. Hence it seems that the assemblage probably corresponds to UAZ 7 (late Bathonian-early Callovian).

Sample NĐ 333 is from about 1.7 m above the bottom of this second section and taken from within dark red, well-bedded chert. A poor radiolarian fauna is moderately well preserved (pl. III, figs. 16-23). Also for this assemblage a late Bathonian to early Callovian age (UAZ 7) is indicated by the first appearance of *Gongylothorax* sp. aff. *G. favosum* DUMITRICA sensu Baumgartner *et al.* [1995] (UAZs 7-8) and the last occurrence of *Unuma gordus* HULL (UAZs 4-7+; Suzuki *et al.* [2001]) and *Quarticella magnipora* (CHIARI, MARCUCCI & PRELA) (UAZs 4-7; Chiari *et al.* [2002]).

In summary, the inferred maximum age range for this section is late Bajocian to early Callovian (UAZs 4-7).

DISCUSSION AND CONCLUSION

The age range inferred for all the three sections investigated in this work spans between the late Bajocian and the early Callovian. Radiolarians from the Jurassic cover of the East-Bosnian-Durmitor thrust sheet that stratigraphically overlies Triassic sediments were previously described by Vishnevskaya *et al.* [2009]. These were found at two nearby localities, for which the locations are indicated in figure 2, namely localities Zaboj (Zaboj) and Krš Gradac (KG). Both of these localities are important because, in contrast to the three localities investigated in this study, they directly expose the contact between radiolarites and underlying Triassic and early Liassic carbonates; hence they constrain the timing of the onset of drowning of the carbonate platform below the CCD.

The radiolarian assemblage found in the Zaboj section constrains the age of drowning of the carbonate platform to the earliest Middle Jurassic, i.e. the Aalenian [Vishnevskaya *et al.*, 2008]. At the Krš Gradac locality, also described by Rampnoux [1974], Radoičić *et al.* [2009] and Gawlick *et al.* [2009] the oldest radiolarian assemblages are of Late Bathonian age [Vishnevskaya *et al.*, 2008]. They directly overlie an undated hardground that can be found just above a condensed layer of red Ammonitico Rosso-type limestone of post-middle Toarcian age [Radoičić *et al.*, 2009; Gawlick *et al.*, 2009]. At this key locality, the radiolarite sequence is assigned to the middle Oxfordian – early Tithonian (UAZs 9-11) [Vishnevskaya *et al.*, 2009], perhaps extending into the lowermost Cretaceous [Radoičić *et al.*, 2009], and is in turn seen to be tectonically overlain by the ophiolitic mélange formation.

Drowning of the carbonate platform and subsequent deposition of radiolarites is also observed in a more internal tectonic unit, the Drina-Ivanjica thrust sheet. At the Pavlovića Brod locality (PB) (fig. 2) radiolarite deposition starts in the Aalenian, as is the case in the Zaboj section, and continues into the early Callovian [Djerić *et al.*, 2007]. Since the base of the radiolarite is not exposed at the localities Zlatar 2 (Zl2), Zlatar 3 (Zl3) and Lokvice (Zl4) and since the exact age of the hardground is not known at the Krš Gradac locality it is suggested that the drowning occurred probably during the Aalenian over a wider area of the former Adriatic margin.

Various causes could be responsible for the drowning of the distal Adriatic margin of the Dinarides at the beginning of the Middle Jurassic, the most important being: (1) subsidence, (2) sea level rise, and (3) environmental factors such as decreases in carbonate productivity [e.g. Morettini *et al.*, 2002]. The fact that radiolarite deposition was followed soon afterwards by obduction of the western Vardar ophiolites suggests that a tectonic signal and hence subsidence, may be the predominant cause. In the case of the Adriatic passive margin, it is unlikely that crustal thinning caused such subsidence, since passive margin formation and the opening of Neotethys occurred in Triassic times and hence significantly pre-dates the Mid-Jurassic [Gawlick *et al.*, 2009; Schefer *et al.*, 2010]. However, flexural bending of the Adriatic margin due to plate convergence, such as proposed for the Hellenides [Scherreiks *et al.*, 2010] is a viable alternative. The timing of intraoceanic subduction within Neotethys is well constrained in the case of the Dinarides; it occurred during the Aalenian to Oxfordian times, as inferred from radiometric dating of various metamorphic soles (174-157 Ma, see Schmid *et al.* [2008] for discussion and references). Obduction of the ophiolites and underlying mélanges onto the passive margin occurred much later, only after the accumulation of the youngest radiolarites, which is after the early Callovian as demonstrated in this study.

The radiolarite sequences from the Zlatar area are typically very thick and in this sense they very much resemble the equally thick late Middle Jurassic to earliest Cretaceous [Vishnevskaya *et al.*, 2009] "Radiolarite Formation" described in the Bosna Valley section [Pamić, 2000], located much further to the NW in Bosnia-Herzegovina. This Bosnian radiolarite section is also a part of the East Bosnian-Durmitor thrust sheet according to the compilation of Schmid *et al.* [2008] and was deposited prior to the latest Jurassic to Early Cretaceous obduction of the western Vardar Ophiolitic Unit that tectonically overlies this "Radiolarite Formation" [Schmid *et al.*, 2008]. Thus it appears that the younger parts of the Middle to Late Jurassic radiolarites were deposited in a kind of foredeep developed within the Adriatic margin that predated the final arrival of the obducted West Vardar Ophiolite Unit.

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