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Stratigraphy and microfossils (radiolarians and planktonic foraminifers) of the Upper Cretaceous (upper Santonian–lower Campanian) Struganik limestone (Western Serbia)

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Abstract

Radiolarians and planktonic foraminifers were studied from several sections of the Upper Cretaceous lithographic limestones near Struganik Village (Western Serbia). These deposits were formed in a local basin, in a low-energy sedimentary environment surrounded by a shallow-water carbonate platform. The Struganik limestone is represented by alternating micritic limestone with calcarenite, rudite and tuffaceous rocks. The sections of the Struganik limestone have a narrow stratigraphic interval that covers the upper Santonian and probably includes the lower Campanian, with a total thickness reaching 120–150 m. The radiolarian zones *Crucella robusta* and *Afens perapediensis* were traced within the unit. The foraminiferal zone *Dicarinella asymetrica* was tentatively identified.
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Keywords: Santonian; Campanian; Radiolarians; Foraminifers; Biostratigraphy; Serbia

1. Introduction

Western Serbia is characterized by extremely complicated geology with numerous Mesozoic (pre-Cretaceous) structures of the Dinarides including continental blocks (the Jadar-Kopaonik thrust sheet) and ophiolite belts (the Western Vardar ophiolite). These units are overlain unconformably by widespread mid-Cretaceous to Upper Cretaceous sedimentary deposits. The Cretaceous of Western Serbia is represented by various sedimentary units; the most common are carbonate platform deposits, including rudistid limestones overlain by calcarudites and calcarenites of shallow-water origin, and thick flysch deposits that are very common in the uppermost Cretaceous (Filipović et al., 1978; Dimitrijević, 1997).

Another type of Upper Cretaceous deposits herein called the Struganik limestone is developed locally to the east of the town of Valjevo in the area around the village of Struganik (Fig. 1). The Struganik limestone is composed mainly of thin-bedded lithographic limestone with interlayers of chert, thick-bedded limestone and calcarenite. The lithographic limestones are of commercial value and are intensively quarried and well-exposed.

The Cretaceous deposits of this area start with Albian–Cenomanian transgressive clastics (150–200 m) that unconformably overlie older rocks: Triassic limestones, Jurassic ophiolitic mélange (Fig. 1) (Filipović et al., 1978). They are overlain by marlstones, sandy limestones and calcarenites (30–80 m) presumed to be Turonian in age (Filipović et al., 1978; Djerić and Gerzina, 2014). These deposits are in turn overlain by the Struganik limestone (120–150 m) that was dated by various investigators as Senonian (Marković and Anđelković, 1953), Coniacian–Santonian (Djerić et al., 2009), Upper Santonian (Bragina et al., 2014, 2018), Santonian (Djerić and Gerzina, 2014) and Santonian–Campanian (Gajić et al., 2011, 2014). The Struganik limestone is overlain by a Campanian–Maastrichtian flysch succession (400 m) (Filipović et al., 1978; Gajić et al., 2016).

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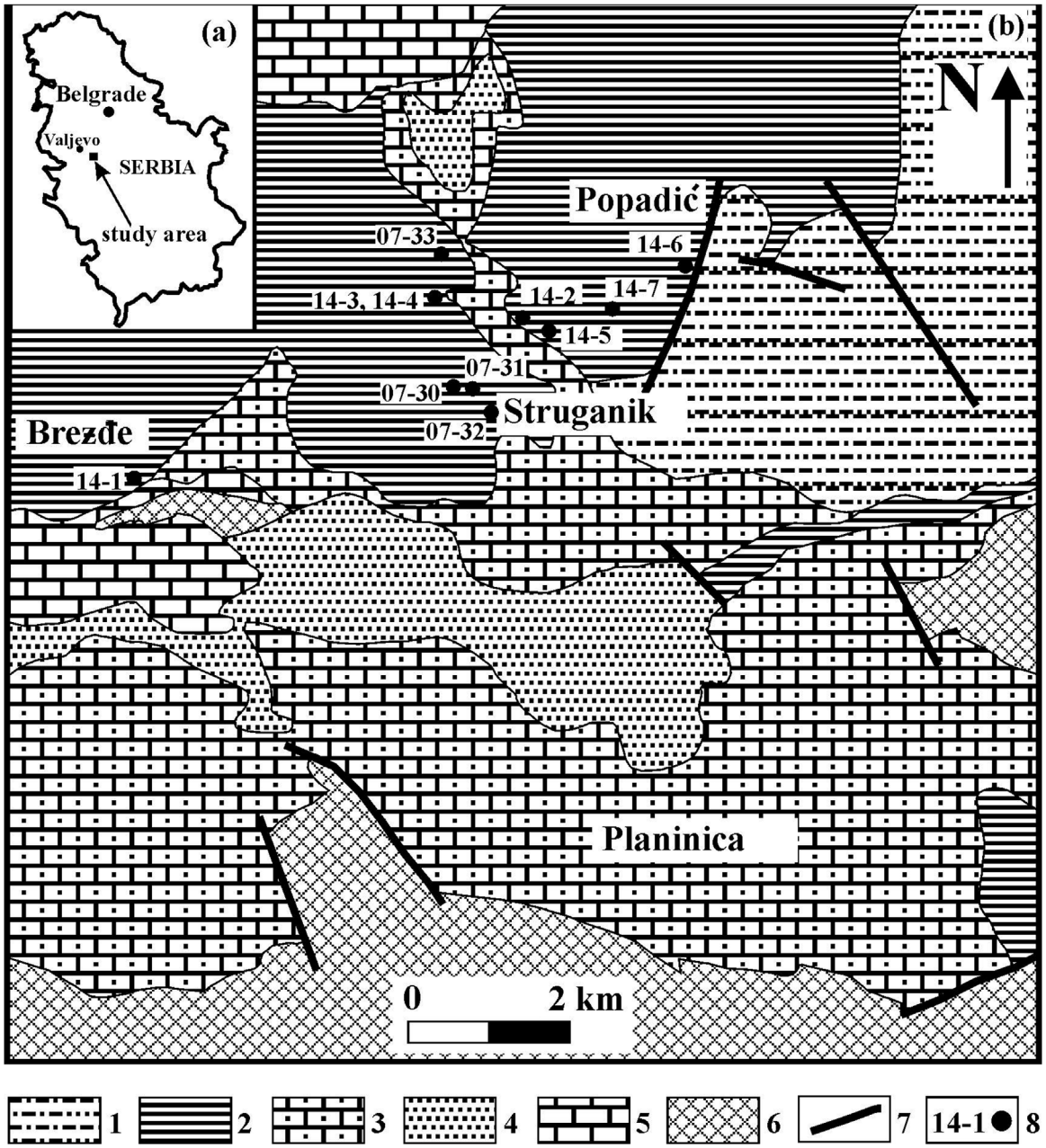

Fig. 1. Simplified geological map of the Struganik Village vicinity (modified after Filipović et al., 1978; Gajić et al., 2011); 1 – clastic flysch, Campanian–Maastrichtian; 2 – platy limestone, marl, calcarenite, Santonian–Campanian; 3 – calcarenite, rudite, limestone conglomerate, sandy limestone, marl, Cenomanian–Coniacian; 4 – conglomerate, calcarenite, Albian–Cenomanian; 5 – limestone, Upper Triassic; 6 – Jurassic ophiolitic mélange; 7 – faults; 8 – localities of main sections of the Struganik limestones and numbers of sections.

It should be noted that there are presently few biostratigraphic data for precise dating of the Struganik limestone. There are age determinations based on inoceramids (Marković and Anđelković, 1953) that need to be re-studied, and planktonic foraminifers, typically useful for biostratigraphy, were studied only in thin sections (Gajić et al., 2011). Radiolarians are the only fossil group that are common. The first radiolarian data from the Struganik limestone were obtained from a distinctive level of bentonitic clay in the State quarry (Fig. 2, sample 07-30-2) (Vasić et al., 2005). The radiolarian assemblage from this level was studied independently by several investigators (Djerić et al., 2009; Vishnevskaya et al., 2009; Bragina et al., 2014), and was interpreted initially as Coniacian–Santonian (Djerić et al., 2009; Vishnevskaya et al., 2009), then as lower Santonian (Bragina et al., 2014). A well diversified radiolarian fauna was recognized, containing *Theocampe urna–Dictyomitra koslovae* (Bragina et al., 2014). These beds were previously interpreted as *Theocampe urna* Zone (lower Santonian) (Bragina et al., 2018).

Another succession was characterized by more diverse radiolarian assemblage (Bragina et al., 2014). Beds with *Afens perapediensis–Clathropyrgus titthium* and with *Alievium gallowayi–Crucella espartoensis* (upper Santonian) were

Fig. 2. Correlation of the investigated sections in this study; 1 – mudstone; 2 – platy limestone; 3 – silty limestone, sandy limestone, calcarenite; 4 – clayey limestone, marl; 5 – tuffaceous mudstone and siltstone; 6 – chert nodules and layers; 7 – levels of fossiliferous samples; 8 – radiolarians; 9 – foraminifers; 10 – boundary between lower and upper units of the Struganik limestone; 11 – supposed boundary between *Crucella robusta* and *Afens perapediensis* Assemblage zones (radiolarians).

described for this part of the section (samples 07-30-5–07-30-9) (Bragina et al., 2014). These preliminary radiolarian biozones need to be modified, and the zones of a recent radiolarian zonal scheme (Bragina, 2016) should be applied to the stratigraphy of the Struganik limestone.

The strata with *Theocampe urna–Dictyomitra koslovae* were revised and divided into *Theocampe urna* Zone and *Crucella robusta* Zone (Bragina, 2016). During previous study (Bragina et al., 2018) the presence of *Theocampe urna* Zone (lower Santonian) was supposed in the lower part of Struganik limestone. During this study the composition of radiolarian assemblage from this level was significantly complemented. We now consider that there is possibly the *Crucella robusta* Zone (middle Santonian–lower part of upper Santonian) (Bragina, 2016) and the *Theocampe urna* Zone is not present in the Struganik sections due to the presence of *Crucella robusta* Bragina and *Clathropyrgus titthium* Riedel et Sanfilippo in the lowermost samples of succession. These species appear only in the *Crucella robusta* Zone (Bragina, 2016).

In a recently proposed zonal scale of radiolarians (Bragina, 2016) layers with *Afens perapediensis–Clathropyrgus titthium* and layers with *Alievium galloway–Crucella espartoensis* are fully included in the *Afens perapediensis* Zone (upper part of the upper Santonian). Therefore two zones of the new zonal scale can be supposed in the Struganik Section: *Crucella robusta* Zone and *Afens perapediensis* Zone.

The study of Brežđe Section gave opportunity to trace *Afens perapediensis* Zone in the upper part of succession (Bragina et al., 2018). We extracted upper Santonian planktonic foraminifers from the same sample with radiolarians. It is important that stratigraphic succession of Brežđe Section was previously dated as Campanian on the base of foraminifers studied in thin sections (Gajić et al., 2011). The joint studies of planktonic foraminifers and radiolarians extracted from same samples are common and are very successful (Korchagin et al., 2012; Bragina et al., 2016; Soycan and Hakyemez, 2018).

During this study we made additional sampling of two previously studied sections (including previously sampled levels) and studied four other sections to obtain more comprehensive data and to refine stratigraphy of Struganik limestones. Moreover, we planned to support radiolarian data by independent results of planktonic foraminifers and to revise the works in 2014 and 2018. Therefore, the aim of this paper is to conduct a combined study of both the planktonic foraminifers and radiolarians extracted from the Struganik limestone, to determine their stratigraphic distribution in sections and to apply the newest zonal schemes based on planktonic foraminifers (Robaszynsky and Caron, 1995; Georgescu, 2017) and radiolarians (Bragina, 2016) to produce more precise biostratigraphic dating and correlation of studied deposits, and to better calibrate the radiolarian zones.

2. Stratigraphy of the Struganik limestone

Stratigraphic sections of the Struganik limestone can be observed mainly in quarries and in road cuts in the territory from Brežđe Village to Popadić Village (Figs. 1, 2). We studied here 6 sections, their detailed lithological descriptions are given in Appendix A, while their stratigraphic columns and correlations are shown in Fig. 2.

The lithological correlation of these sections allow to subdivide the Struganik limestone to two units (Fig. 2). The lower unit is composed of platy, rarely massive silty and detritic limestone with abundant layers of red and green marlstone, clay (including bentonite clay), green tuffaceous mudstone and siltstone, pink and red chert (commonly spiculitic) (Fig. 3). Formerly, this part of the succession was interpreted as Turonian in age (Vasić et al., 2005). According to our new data, the lower unit is assigned to the upper Santonian. The thickness of the unit is approximately 40 m.

The upper unit is represented by thin-bedded platy limestone with subordinate calcarenite and rudite (Fig. 4). Common are chert nodules and thin chert beds, usually cherts are grey, dark-grey and yellowish-grey in colour. Rare thin beds of bentonite clay are present throughout the whole succession (Fig. 4g). Thin-bedded platy rocks of this unit are classified as micrite (orthochemical) limestones, whereas other lithologies are classified as allochemical limestones that are represented by alternating very coarse-grained rudite and moderately to fine-grained calcarenite, commonly with cross-bedding features (Folk, 1959; Gajić et al., 2011, 2014; Matović and Ćalić, 2016). The micritic limestone is interpreted as an autochthonous deposit of deep-water carbonate sedimentation. Micritic beds usually have thin horizontal laminations. The allochemical limestones contain various carbonate fragments, including moulds of shallow-water organisms (rudists), moulds of benthic and planktonic microorganisms as well as algal fragments. The rudites and calcarenites are usually cross-bedded with textures characteristic of the turbulent transport and displaying particular intervals of the Bouma Sequence within the layers. Mechanical and biogenic textures are very common on the bedding planes of all types of lithologies within the Struganik limestone (Gajić et al., 2011). The most abundant are trace fossils such as *Chondrites* and *Thalassinoides*. This unit was previously broadly dated as Senonian (Vasić et al., 2005; Gajić et al., 2011). Our results indicate a narrower upper Santonian to lower Campanian interval. The thickness of the unit is approximately 90 m.

Microfossils (radiolarians and planktonic foraminifers) are present in numerous levels of this succession (Fig. 2) and were utilized for biostratigraphic analysis. Results of this analysis are presented herein.

3. Material and methods

During three field seasons (2007, 2014 and 2015), 123 samples were collected, 110 samples were from limestones, mostly cherty, from the contact with chert nodules. Such limestones usually display microfossils on the weathered surface, and these microfossils can be observed with a magnifying glass. The remaining 13 samples were collected from layers of bentonite clay.

Limestone samples were treated with diluted (10%) formic acid (HCOOH) for 12 h. The residue was rinsed with water and then treated with hot water (10 g) containing less than 1 g of sodium pyrophosphate ($Na_4P_2O_7$) for 5 min to remove clay particles and clean the surface of the microfossils. Then residue was again rinsed and dried. Clay samples were rinsed with water, washed and then treated again with hot water containing sodium pyrophosphate, given a final rinse with water, and dried.

Microfossils (radiolarians and planktonic foraminifers) were extracted from numerous samples. Radiolarians were found in 27 samples, while foraminifers were found in 7 samples. 6 samples yielded radiolarians and foraminifers together. It should be noted that the preservation of microfossils extracted from the limestones is mostly moderate. Radiolarian tests are often corroded but their morphological features are usually preserved. Thin platy limestones sometimes yield well-preserved radiolarians (Fig. 5A, B). Cherty limestones associated with chert nodules usually yield abundant but moderately preserved, recrystallized radiolarians (Fig. 5D, H), sometimes entirely or partly replaced by calcite (Fig. 5C). Foraminiferal shells display secondary silicification and corrosion, sometimes preserved only as internal molds (Fig. 10B3), and sometimes crystals appearing at the surface of tests (Fig. 10B1). In some cases the preservation of foraminifers did not allow for distinguishing details including the structure of the aperture, external ornamentation elements, the nature of the wall structure and the porosity, and the features of the keel and the inter-keel space. Despite these problems, the major morphological features of foraminifers can be observed by SEM. However, a significant part of taxa were left in open nomenclature.

Residues were studied by light microscope LOMO-MBS-10, microfossils were collected, mounted, studied in detail and photographed with scanning electron microscopes: TESCAN 2300 in the Geological Institute RAS, Moscow, and TESCAN VEGA-II XMU in the Paleontological Institute RAS, Moscow. Material is stored in the Geological Institute RAS, Moscow.

4. Results

4.1. Radiolarians

The studied sections contain well-preserved radiolarians in many stratigraphic levels (Table 1, Figs. 5–8). Radiolarian assemblages are abundant and diverse; they change significantly in the succession, and allow for the application of the newest radiolarian zonal scheme for the Upper Cretaceous (Bragina, 2016).

Radiolarians were not found in the lowermost part of the Struganik limestone; they first appear in the middle part of the lower unit (samples 14-1-9, 14-3-5, 14-3-10). This interval is characterized by a radiolarian assemblage in which the most important species are: *Alievium gallowayi* (White), *Alievium praegallowayi* Pessagno, *Crucella robusta* Bragina, *Patellula planoconvexa* (Pessagno), *Praeconocaryomma universa* Pessagno, *Pseudoaulophacus floresensis* Pessagno, *Clathropyrgus*

Table 1
Composition of radiolarian assemblages.

Sample	14-1-9	14-1-11	14-1-13	14-3-5	14-3-10	15-33-1	14-4-1	14-4-3	07-30-2	07-30-5	07-30-6	07-30-7	07-30-9	15-26-2	15-25-3	15-25-2	15-25-1	07-32-13	14-2-0	14-2-2	15-27-1 (14-5-3)	14-5-5	15-27-2	15-27-3	15-27-4	14-7-4
Alievium gallowayi (White)	+	+		+		+			+	+	+	+	+	+	+	+	+		+	+	+	+	+	+		+
Alievium praegallowayi Pessagno	+	+	+	+	+	+	+		+	+	+		+								+	+					
Crucella messinae Pessagno				+																						
Crucella robusta Bragina	+	+	+	+	+	+	+		+	+		+	+	+	+	+	+	+	+		+	+	+	+	+	+	
Praeconocaryomma universa Pessagno	+	+		+	+	+	+		+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	
Pseudoaulophacus floresensis Pessagno		+	+	+	+	+	+		+			+	+	+	+	+	+	+	+	+	+		+	+		+	
Dictyomitra formosa Squinabol	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
Dictyomitra koslovae Foreman	+	+	+	+	+		+	+		+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	
Clathropyrgus titthium Riedel et Sanfilippo	+					+	+		+	+		+	+	+	+	+	+	+		+	+	+	+	+	+	+	
Patellula planoconvexa (Pessagno)	+		+			+									+												
Amphipyndax sp. A		+				+	+	+	+	+	+	+	+	+	+		+		+	+	+		+	+		+	
Pseudoalievium inflatum Bragina		+	+			+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
Parvimitrella cretacea Soycan			+			+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
Actinomma (?) sp. aff. *A. belbekense* Bragina																									+		
Crucella espartoensis Pessagno		+	+					+					+	+	+	+	+			+		+	+	+	+		
Afens perapediensis Bragina		+	+				+	+		+		+	+	+	+	+	+	+	+			+	+	+	+	+	
Heliocryptocapsa perapediensis Bragina		+					+			+			+	+			+			+			+	+			
Pseudoeucyrtis belogorskensis Bragina		+					+			+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	
Pseudoeucyrtis cypricus Bragina		+								+				+	+	+											
Tubilustrionella guttaeforma (Bragina)		+								+		+	+		+	+	+	+	+			+	+	+		+	
Eostichomitra magna (Gorka)		+	+				+	+		+	+	+	+	+	+	+	+	+	+	+			+	+	+	+	
Crucella sp. aff. *C. messinae* Pessagno															+		+										

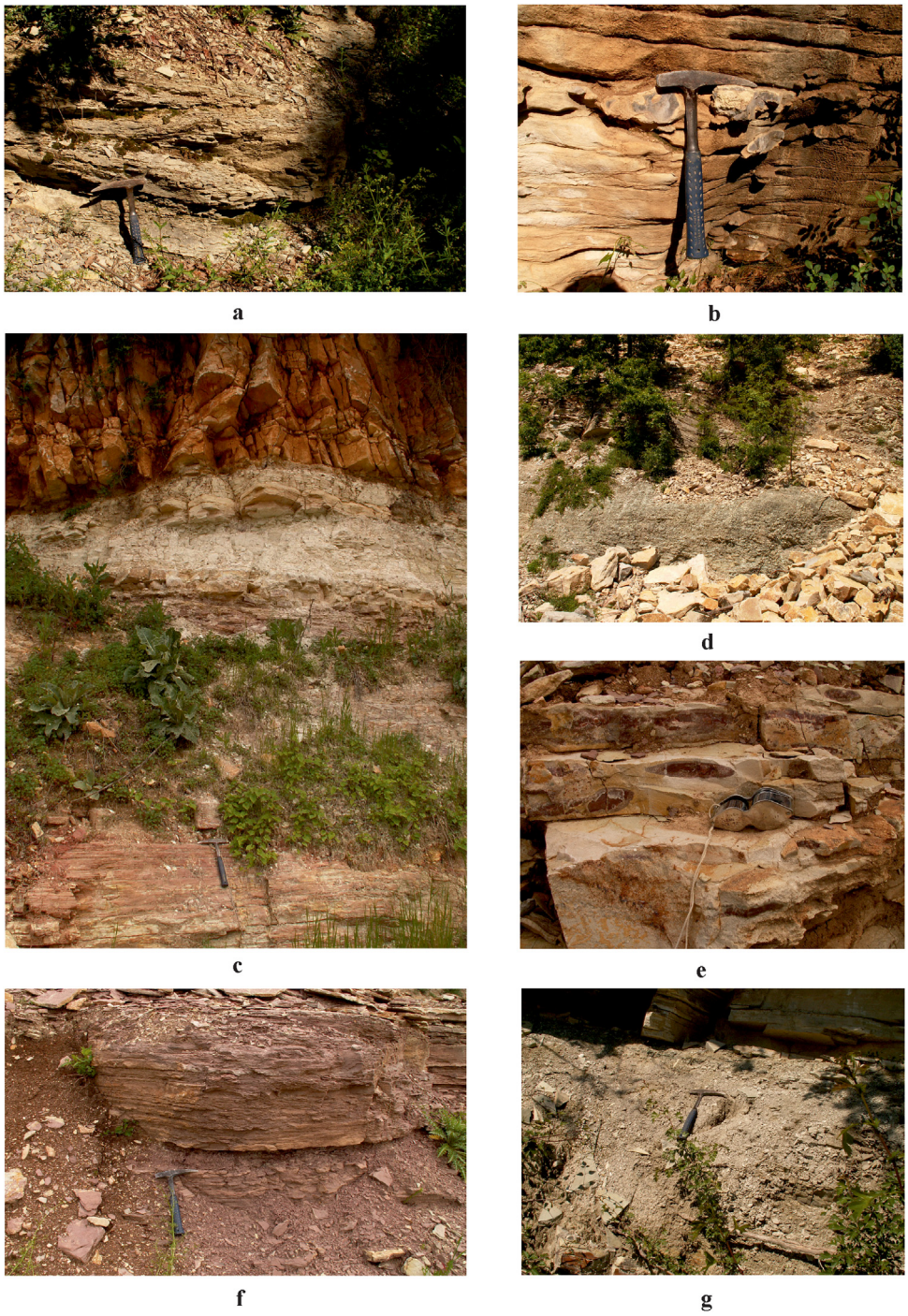

Fig. 3. Lower unit of the Struganik limestones. (a) Grey silty mudstone, roadcut near Brežđe Village, section 14-1, bed 1. (b) Silty platy limestone with chert nodules, roadcut near Brežđe Village, section 14-1, bed 3. (c) Red, bluish-grey and greenish-grey clay and marlstone intercalated with calcarenite, southern slope of Petrovića Brdo, section 14-3, beds 3–7. (d) Light-greenish-grey tuffaceous mudstone, roadcut near Brežđe Village, section 14-1, bed 7. (e) Silty limestones with nodules of red and pink spiculitic chert, southern slope of Petrovića Brdo, section 14-3, bed 2. (f) Reddish marlstone, southern slope of Petrovića Brdo, section 14-3, bed 3. (g) Grey marly clay, roadcut near Brežđe Village, section 14-1, bed 8. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

titthium Riedel et Sanfilippo, *Dictyomitra formosa* Squinabol, and *Dictyomitra koslovae* Foreman and others. The composition of this assemblage suggests the *Crucella robusta* Assemblage Zone, calibrated to the middle Santonian to lower upper Santonian (Bragina, 2016), throughout the section. This zone is known from stratigraphic sections in Southern Cyprus (Bragina, 2016), Bavaria (Ohmert, 2006; Bragina, 2016, p. 159) and probably in Northern Turkey (Soycan and Hakyemez, 2018). The lowermost part of the upper unit (samples 07-30-2, 14-5-3, 15-27-1, 15-33-1) is characterized by the same assemblage of the *Crucella robusta* Assemblage Zone, with the addition of these species: *Pseudoalievium inflatum* Bragina, *Amphipyndax* sp., *Heliocryp-*

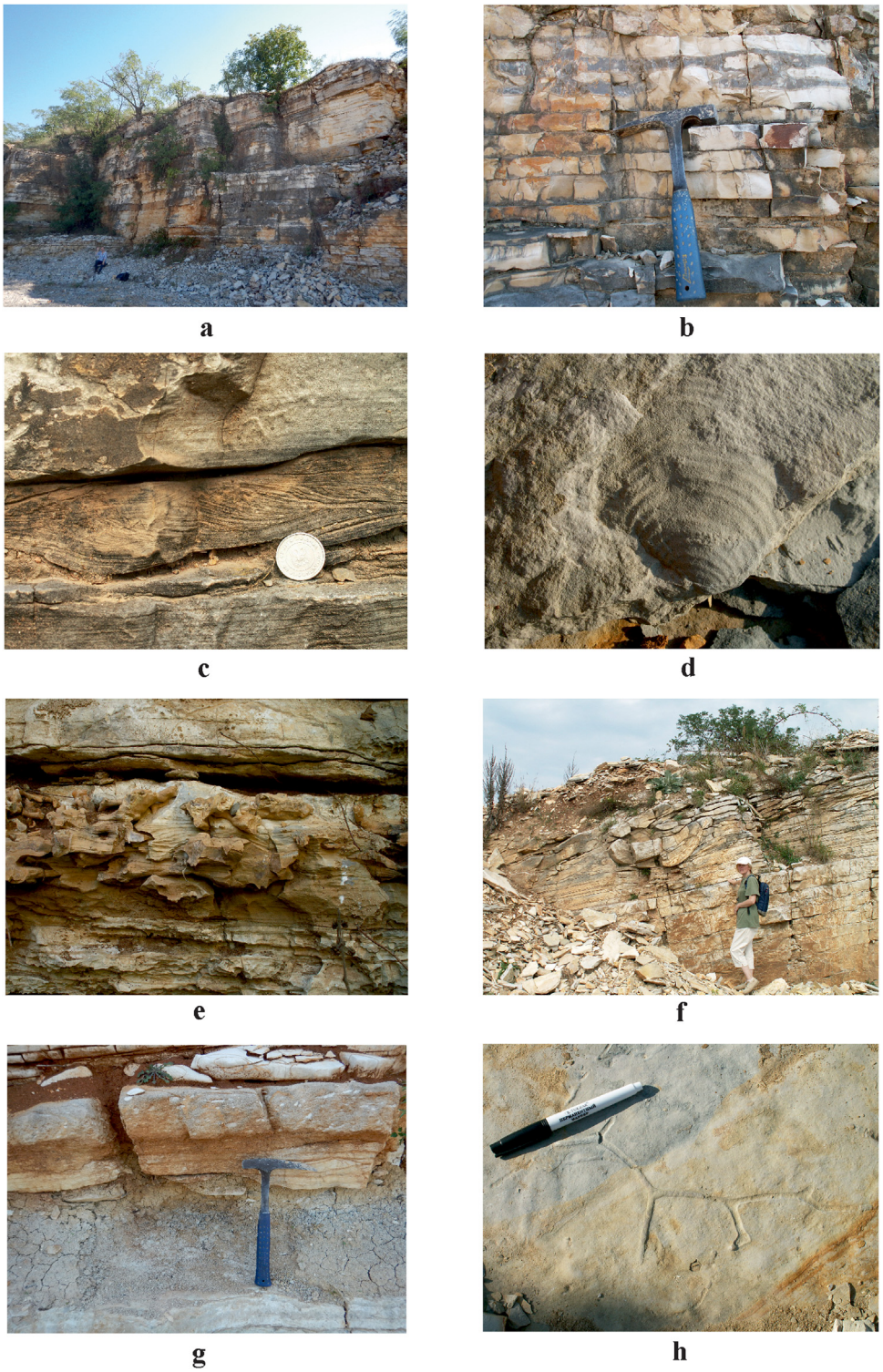

Fig. 4. Upper unit of the Struganik limestone. (a) Thin-bedded micritic limestone intercalated with calcarenite, Struganik Village, section 07-32 (general view). (b) Thin-bedded micritic limestone with chert nodules, Struganik Village, section 07-30, bed 8. (c) Calcarenite with cross-bedding, Struganik Village, section 07-30, bed 9. (d) Inoceramid, Struganik Village, section 07-32, bed 4. (e) Calcarenite with abundant chert nodules, Popadić Village, section 14-6, bed 5. (f) Slump folds in platy micritic limestone, Struganik Village, section 07-30, bed 21. (g) Bed of bentonitic clay, covered by white micrite limestone and grey rudite, Goveđe Brdo, section 14-5, beds 2 and 3. (h) Ichnofossils on the surface of a platy limestone bed, Struganik Village, section 07-32, bed 4. (For interpretation of the references to color in the text, the reader is referred to the web version of this article.)

tocapsa neagui Dumitrica, and *Parvimitrella cretacea* Soycan. It should be noted that the zonal assemblage in the Struganik limestone has relatively low taxonomic diversity and that all taxa of this assemblage continue to be present in the next, *Afens perapediensis* Assemblage Zone. So, there is a possibility that *Afens perapediensis* and other species with first occurrence in

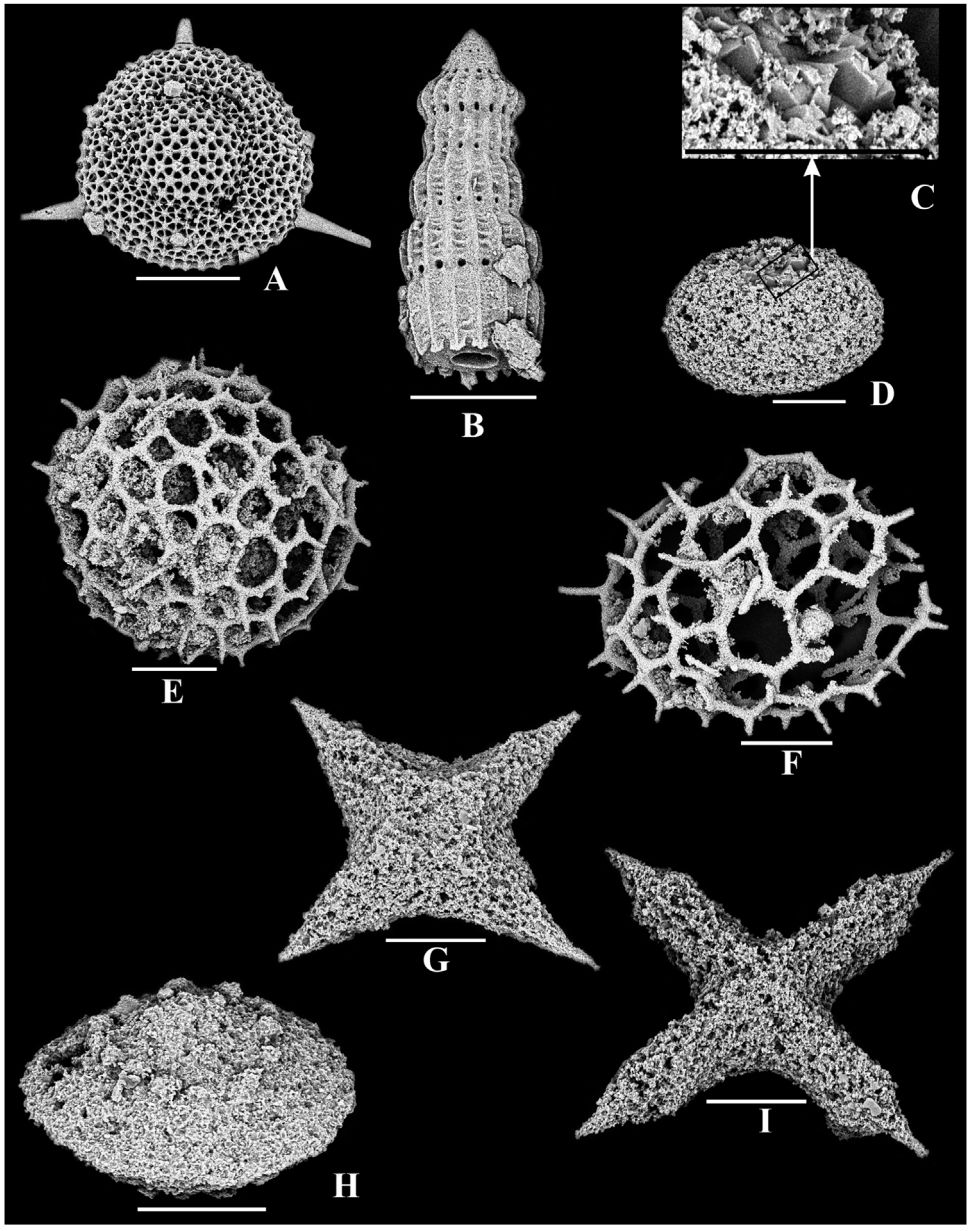

Fig. 5. Scanning Electron Micrographs of late Santonian radiolarians obtained from sample 15-33-1 (B) in the Petrovića Brdo section, and from samples 14-5-5 (A), 15-27-4 (E, F) in the Goveđe Brdo section, and early Campanian radiolarians from sample 15-25-1 (C, D, G, I), and from sample 15-25-3 (H) in the State quarry. Scale bar = 100 μm for (A–D, G–I); scale bar = 200 μm for (E, F). (A) *Pseudoaulophacus circularis* Bragina. (B) *Dictyomitra koslovae* Foreman. (C, D) *Phaseliforma concentrica* (Lipman). (E, F) *Actinomma* (?) sp. aff. *A. belbekense* Bragina. (G) *Crucella cachensis* Pessagno. (H) *Patellula planoconvexa* Pessagno. (I) *Crucella* sp. cf. *C. espartoensis* Pessagno.

the next zone are missing in the lower strata due to ecological factors rather than age difference. Thus, we tentatively consider the occurrence of *Crucella robusta* Assemblage Zone in the Struganik limestone.

The following succession within the upper unit of the Struganik limestone (samples 07-30-5–07-30-9, 07-30-15, 07-32-13, 14-1-11, 14-1-13, 14-2-0, 14-2-2, 14-4-1, 14-4-3, 14-5-5, 14-7-4, 15-25-1, 15-25-2, 15-25-3, 15-26-2, 15-27-2, 15-27-3, 15-27-4) yield an abundant and diverse radiolarian assemblage containing *Afens perapediensis* Bragina, *Heliocryptocapsa perapediensis* Bragina, *Pseudoeucyrtis belogorskensis* Bragina, *Pseudoeucyrtis cypricus* Bragina, *Tubilustrionella guttaeforma* (Bragina), *Eostichomitra magna* (Gorka) and others, including many taxa from the assemblage found within the *Crucella robusta* Assemblage Zone (Bragina et al., 2014, 2018). This assemblage indicates the presence of the *Afens perapediensis* Assemblage Zone, originally assigned to the upper part of the upper Santonian (Bragina, 2016), but considered later as ranging from upper part of the upper Santonian to the lower Campanian (Bragina et al., 2016). This zone is known in Cyprus (Bragina, 2016), Crimea (Bragina, 2016; Bragina et al., 2016) and in the Northern Atlantic (Thurow, 1988; Bragina, 2016, p. 160). The lower boundary of the zone is recognized by the appearance of the nominal taxon and several of the aforementioned accompa-

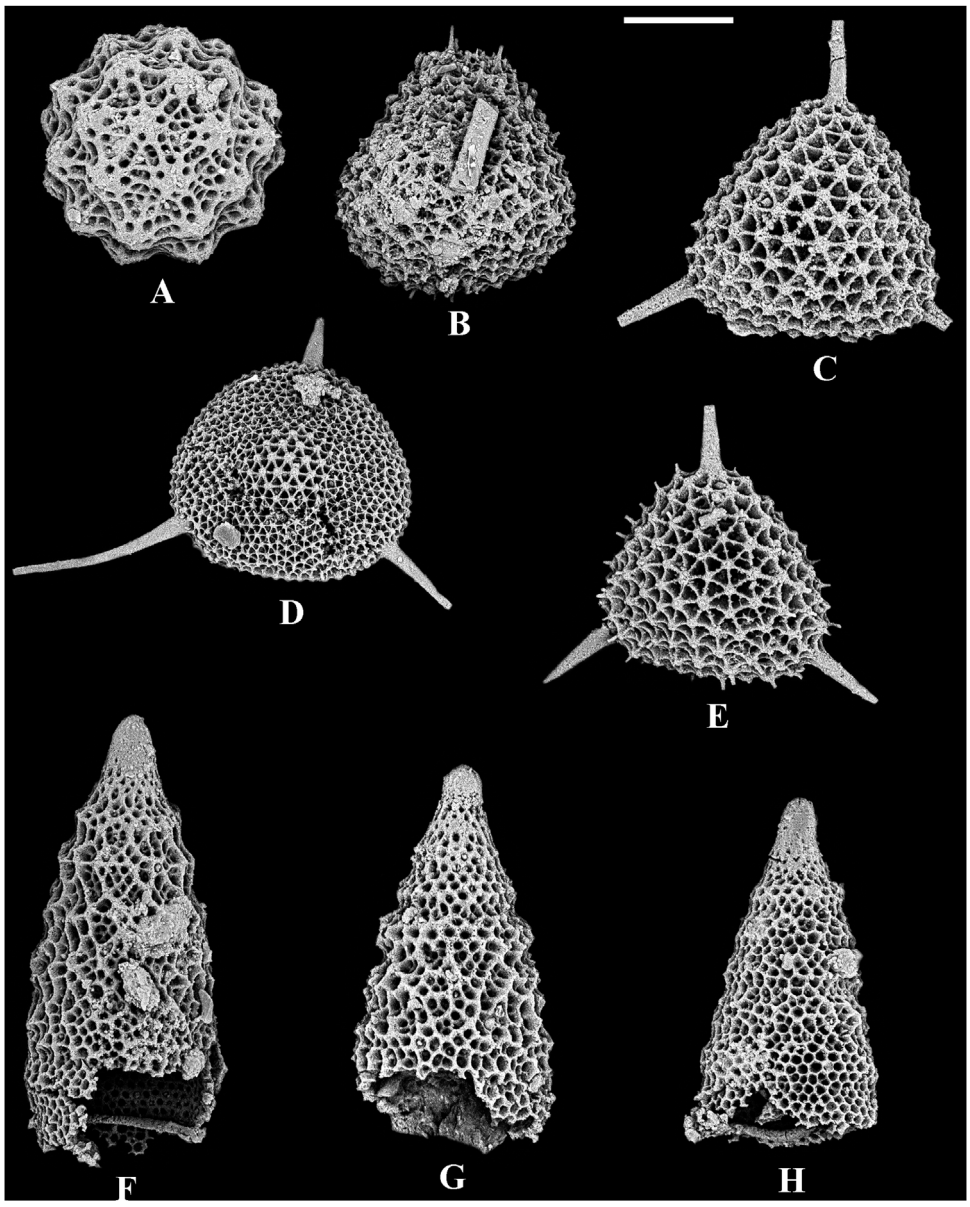

Fig. 6. Scanning Electron Micrographs of late Santonian radiolarians from sample 15-33-1 in the Petrovića Brdo section. Scale bar = 100 μm. (A) *Praeconocaryomma universa* Pessagno. (B) *Pseudoalievium inflatum* Bragina. (C) *Alievium gallowayi* (White). (D) *Pseudoaulophacus floresensis* Pessagno. (E) *Alievium mangaleniense* Bragina. (F–H) *Amphipyndax* sp. A (the morphology of these specimens can be interpreted as intermediate between *Amphipyndax stocki* (Campbell et Clark) and *Amphipyndax pseudoconulus* (Pessagno), this morphotype can be the ancestor of *A. pseudoconulus* (Pessagno)).

nying species. It should be noted that the composition of the radiolarian assemblages did not display any significant change throughout the interval assigned to the *Afens perapediensis* Zone (Table 1).

From the study of the distribution of radiolarians, both the *Crucella robusta* Zone (middle Santonian to lower part of upper Santonian) and the *Afens perapediensis* Zone (uppermost Santonian–lower Campanian) were successfully correlated amongst the sections studied (Fig. 2).

4.2. Foraminifers

The studied sections are characterized by abundant poorly to moderately preserved planktonic foraminifers at several stratigraphic levels (Figs. 2, 9–11). The middle part of the lower unit of Struganik limestone (sample 14-3-5) is characterized by the presence of *Globotruncanita stuartiformis* (Dalbiez), which ranges from the upper Santonian to the Maastrichtian (Robaszynsky et al., 1984; Georgescu, 2015). A higher stratigraphic level (Fig. 2, sample 14-1-9) yields a more diverse foraminiferal assemblage containing *Marginotruncana pseudolinneiana* Pessagno and *Dicarinella primitiva* (Dalbiez) that make their last appearance in the upper Santonian, and *Globotruncana arca* (Cushman) known from the upper Santonian to the Maastrichtian (Georgescu, 2015). Additionally, abundant *Ventilabrella* sp. cf. *V. glabrata* Cushman were found in this level. Since the species *Ventilabrella glabrata* Cushman is known from the upper Santonian to lower Campanian

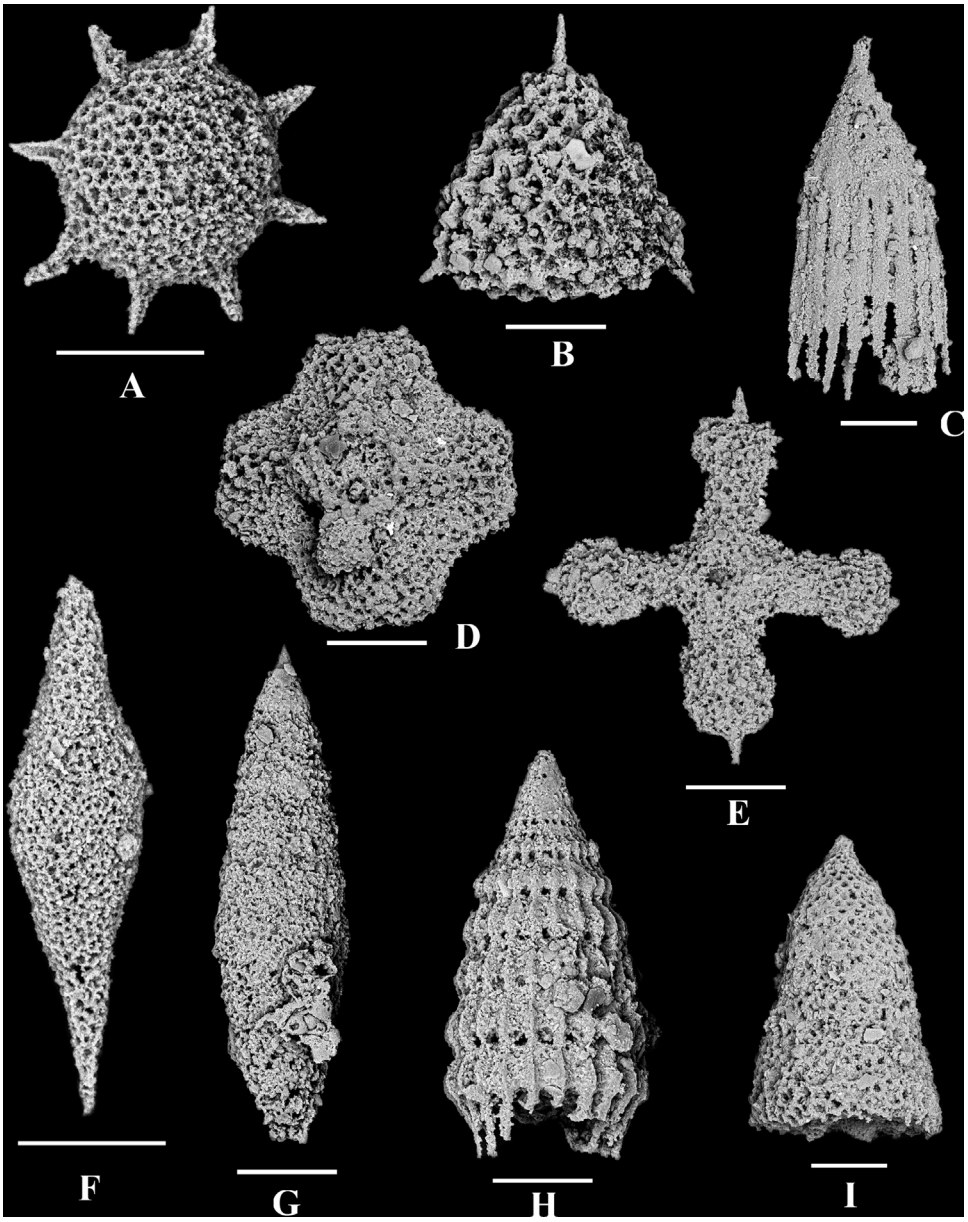

Fig. 7. Scanning Electron Micrographs of late Santonian radiolarians obtained from sample 14-1-11 (B–E, G, H) in the Brezđe section and from samples 07-30-5 (A, I) and 07-30-9 (F) in the State quarry. Scale bar = 100 μm. (A) *Heliocryptocapsa perapediensis* Bragina. (B) *Alievium gallowayi* (White). (C) *Afens perapediensis* Bragina. (D) *Crucella robusta* Bragina. (E) *Crucella espartoensis* Pessagno. (F) *Pseudoeucyrtis belogorskensis* Bragina. (G) *Pseudoeucyrtis cypricus* Bragina. (H) *Dictyomitra formosa* Squinabol. (I) *Parvimitrella cretacea* Soycan.

(Georgescu, 2015), we conclude that the lower part of the Struganik limestone (Fig. 2, samples 14-1-9 and 14-3-5) should be placed within the upper Santonian.

The next stratigraphic level (sample 14-1-11) is characterized by several taxa with their last occurrence in the upper Santonian: *Marginotruncana sigali* (Reichel), *M. sinuosa* Porthault, *M. undulata* (Lehmann) and *Heterohelix sphenoides* Masters (Spezzaferri and Spiegler, 2005; Coccioni and Premoli Silva, 2015; Georgescu, 2015; Bragina et al., 2018). Additionally, the presence of benthic foraminifers *Gaudryina rugosa* (d'Orbigny) and *Pullenia dampelae* Dain (Bragina et al., 2018) indicates a late Santonian age. Therefore, we can constrain the interval spanning from the middle part of the lower unit to the lowermost beds of the upper unit of the Struganik limestone as upper Santonian. This interval is equivalent to the upper part of the *Dicarinella asymetrica* Zone (Robaszynsky and Caron, 1995; Coccioni and Premoli Silva, 2015). For a more detailed dating and the application of the newest planktonic foraminiferal zonal scheme for the Upper Cretaceous (Georgescu, 2017), we would need additional material due to relatively low taxonomic diversity of obtained assemblages.

Foraminifers become rare in the upper unit of the Struganik limestone. They appear only in some levels and are usually poorly to moderately preserved. Sample 07-30-5

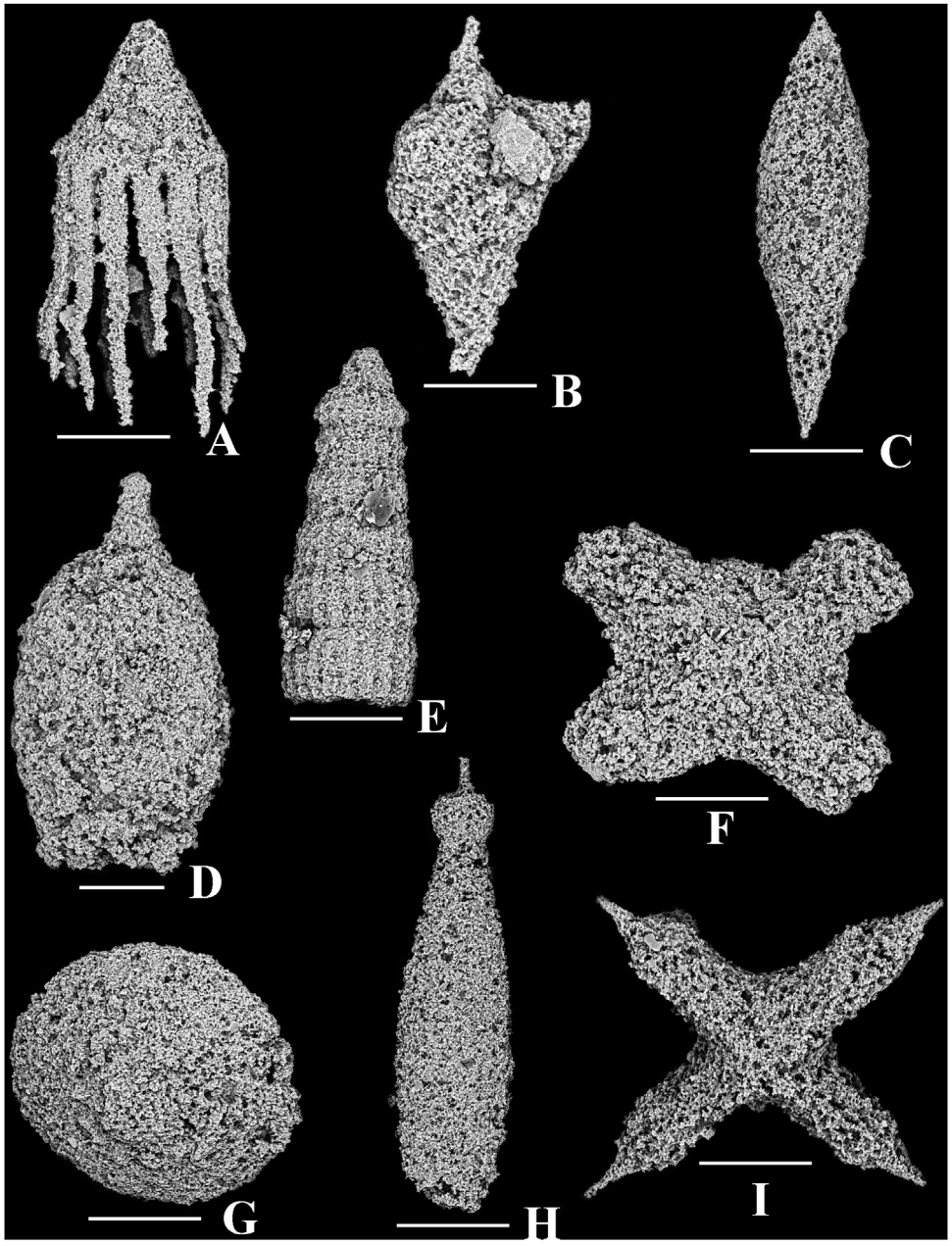

Fig. 8. Scanning Electron Micrographs of late Santonian to early Campanian radiolarian assemblages obtained from samples 15-25-3 (D–G) and 15-25-1 (A–C, H, I) in the State quarry. Scale bar = 100 μm. (A) *Afens perapediensis* Bragina. (B) *Clathropyrgus titthium* Riedel et Sanfilippo. (C) *Pseudoeucyrtis belogorskensis* Bragina. (D) *Tubilustrionella guttaeforma* (Bragina). (E) *Dictyomitra koslovae* Foreman. (F) *Crucella robusta* Bragina. (G) *Patellula planoconvexa* (Pessagno). (H) *Eostichomitra magna* (Gorka). (I) *Crucella* sp. ex gr. *C. messinae* Pessagno.

yields *Globotruncanita* sp. cf. *G. elevata* (Brotzen). Almost all representatives of the genus *Marginotruncana*, except *Marginotruncana coronata* (Bolli) (Table 2), are absent in this sample. The last representatives of *M. coronata* occur in the lower part of the *Globotruncanita elevata* Zone.

The first well-preserved *Globotruncanita elevata* (Brotzen) occurs in the upper part of the upper unit of the Struganik limestone (sample 15-25-3). This species is known from the upper Santonian and lower Campanian (Georgescu, 2015) and is an index-species of the *Globotruncanita elevata* Zone (lower Campanian; Robaszynsky and Caron, 1995; Coccioni and Premoli Silva, 2015, p. 61). Only *Marginotruncana coronata* is still present here. The interval from sample 15-25-3 to sample 15-25-1 is characterized by relatively rare foraminifers, including *Globotruncanita* sp. cf. *G. elevata* (Brotzen), *Globotruncana* sp. cf. *G. arca* (Cushman), *Globotruncana* sp. cf. *bulloides* Vogler), which does not allow for more precise dating. Based on these poor foraminiferal data, we conclude that the upper unit of the Struganik limestone can be dated broadly — from the upper Santonian to the lower Campanian without tracing of any foraminiferal zone.

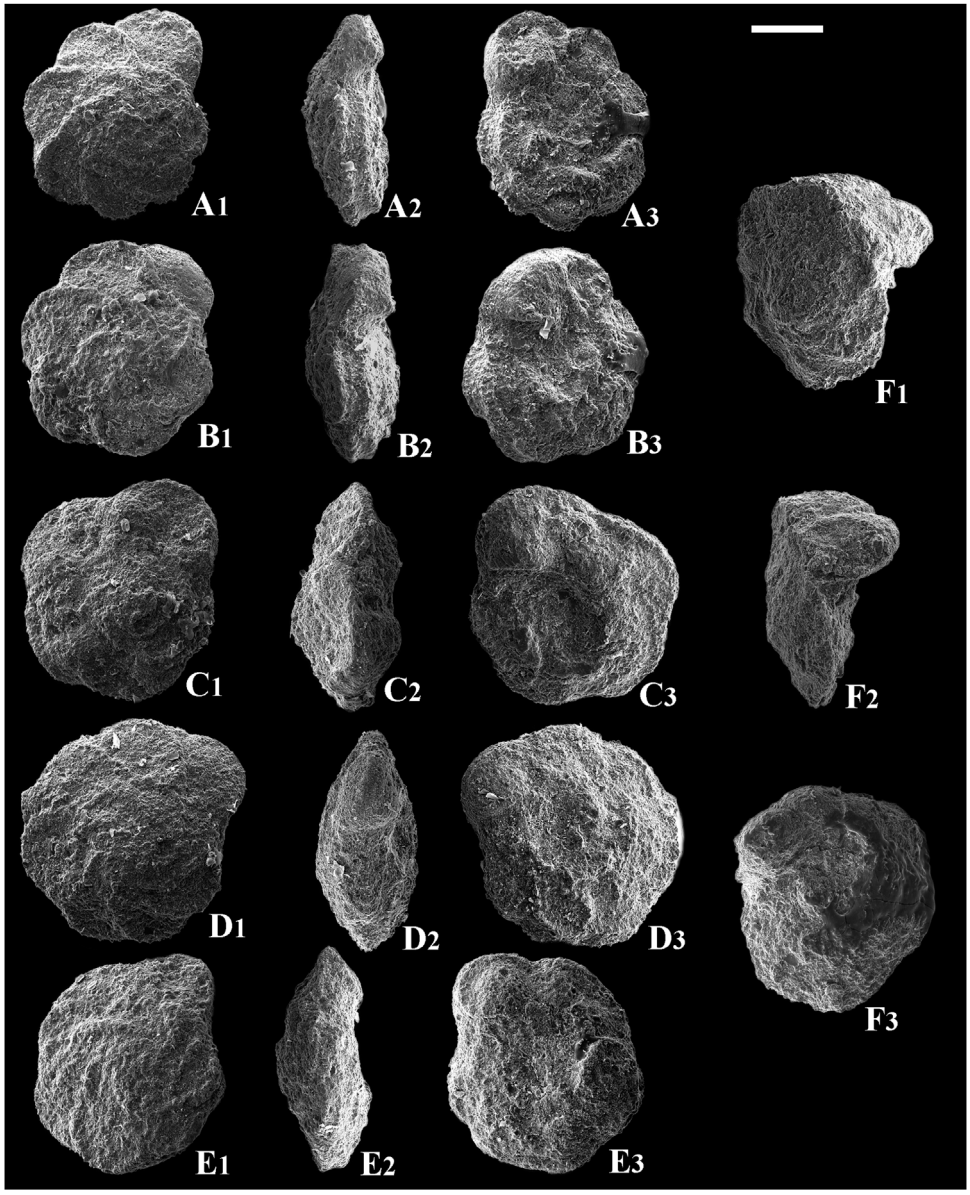

Fig. 9. Scanning Electron Micrographs of late Santonian planktonic foraminifers assemblages obtained from sample 14-1-9 (A–E) in the Brezđe section and sample 14-3-5 (F) in the Petrovića Brdo section. Scale bar = 200 μm; 1 – view from spiral side showing all chambers; 2 – view from umbilical side showing last turnover of the test and aperture; 3 – lateral view showing keel and character of convexity of test. (A1–A3) *Marginotruncana coronata* (Bolli). (B1–B3) *Marginotruncana pseudolinneiana* Pessagno. (C1–C3) *Dicarinella primitiva* (Dalbiez). (D1–D3) *Marginotruncana coronata* (Bolli). (E1–E3) *Marginotruncana pseudolinneiana* Pessagno. (F1–F3) *Globotruncanita stuartiformis* (Dalbiez).

5. Discussion

5.1. Correlation between foraminiferal and radiolarian zones

Precise calibration of radiolarian zones is the most important concern of Mesozoic radiolarian studies (Goričan et al., 2018). Recently, Bragina (2016) proposed a radiolarian zonal scheme for the Cretaceous (upper Albian–Santonian), and two upper zones of this scheme are recognized in the Struganik limestone. The Upper Cretaceous sections of the Struganik limestone are characterized by radiolarians together with planktonic foraminifers. Therefore, they represent good opportunity for further detailed calibration of radiolarian biostratigraphy.

The planktonic foraminifers allow for the recognition of an upper Santonian interval (samples 14-3-5–14-1-11, and 07-30-15) based on the equivalent of the *Dicarinella asymetrica* Zone, and the upper Santonian to lower Campanian interval with poor foraminiferal assemblage (samples 07-30-15, 15-25-1, 15-25-2, 15-25-3) is also recognized here.

The *Crucella robusta* Zone (middle Santonian to the lower part of the upper Santonian) and the *Afens perapediensis* Zone (uppermost Santonian–lower Campanian) are radiolarian assemblage zones that can be correlated with the foraminiferal data (Fig. 2). The boundary between the *Crucella robusta* Zone

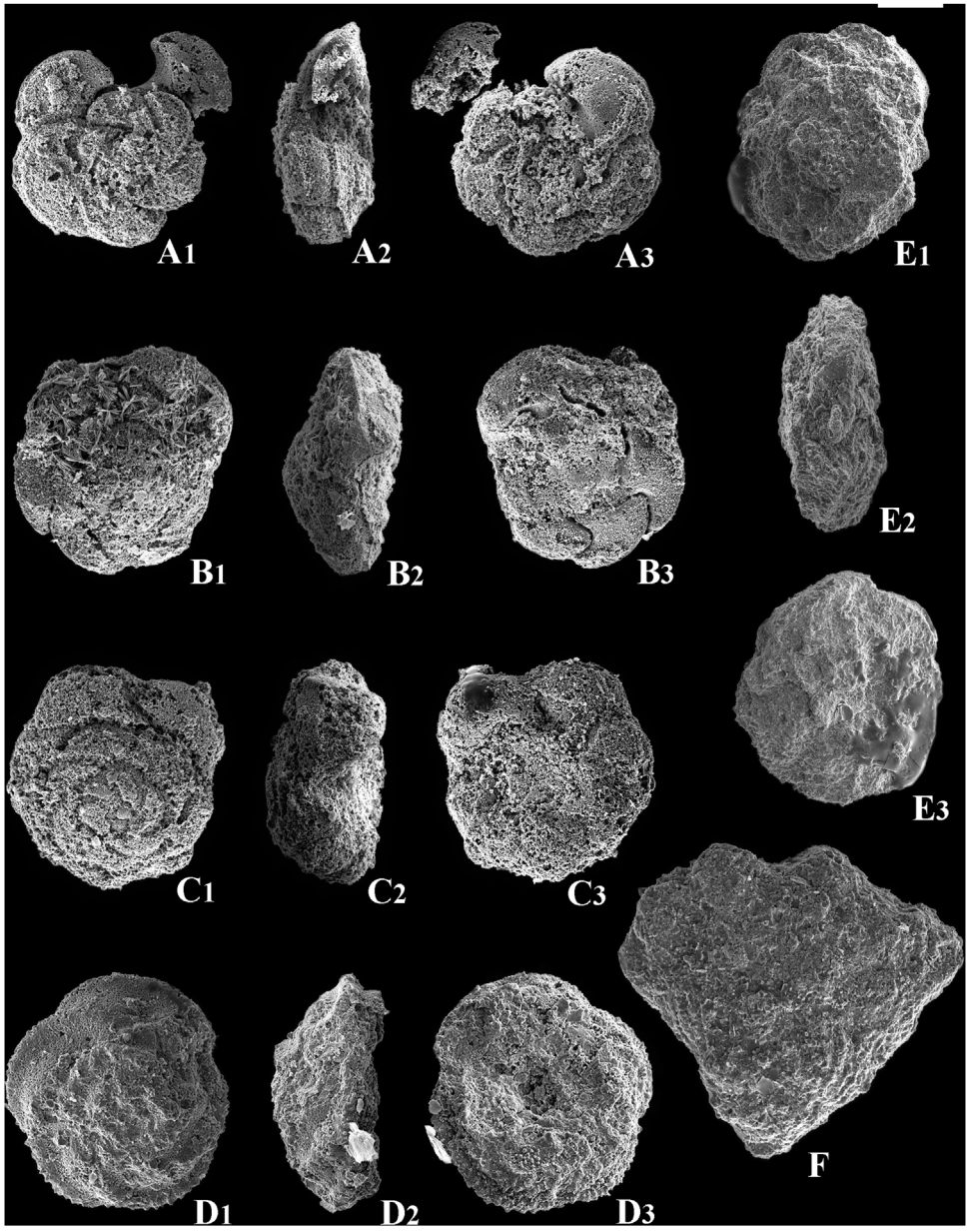

Fig. 10. Scanning Electron Micrographs of late Santonian–early Campanian planktonic foraminifers assemblages obtained from samples 07-30-15 (D) and 15-25-1 (A–C) in the State quarry, sample 14-3-5 (E) in the Petrovića Brdo section, and sample 14-1-9 (F) in the Brezđe section. Scale bar = 200 μm; 1 – view from spiral side showing all chambers; 2 – view from umbilical side showing last turnover of the test and aperture; 3 – lateral view showing keel and character of convexity of test. (A1–A3) *Globotruncana* sp. cf. *G. bulloides* Vogler. (B1–B3) *Globotruncana* sp. cf. *G. arca* (Cushman). (C1–C3) *Globotruncana arca* (Cushman). (D1–D3) *Contusotruncana fornicata* (Plummer). (E1–E3) *Marginotruncana* sp. cf. *M. lapparenti* Brotzen. (F) *Ventlabrella* sp. cf. *V. glabrata* Cushman.

and the *Afens perapediensis* Zone can be traced between samples 07-30-2, 14-5-3, 15-27-1, 15-33-1 and samples 14-4-1, 14-5-5 — just above a characteristic bed composed of bentonitic clay and pyroclastic material, that was described in Struganik (Vasić et al., 2005) and traced in Goveđe Brdo in this study (14-5, Fig. 4g).

Locally, the *Crucella robusta* Zone can be dated here as upper Santonian, however, its lower boundary was not observed in the Struganik limestone and probably just the upper part of this zone is present. Therefore the stratigraphic interval of the *Afens perapediensis* Zone is equal to the upper part of the upper Santonian and may cover the lower Campanian, supporting previous conclusions on the calibration of this radiolarian zonal scheme (Bragina et al., 2016).

5.2. Problem of Santonian–Campanian boundary

The Struganik limestone was previously dated as Senonian (Marković and Anđelković, 1953), and subsequently as Santonian–Campanian (Gajić et al., 2011). The presence of Campanian strata was commonly supposed here and supported by findings of *Inoceramus balticus* Bohm (Marković and Anđelković, 1953; Filipović et al., 1978). Inoceramids are common in the uppermost part of the Struganik limestone, between

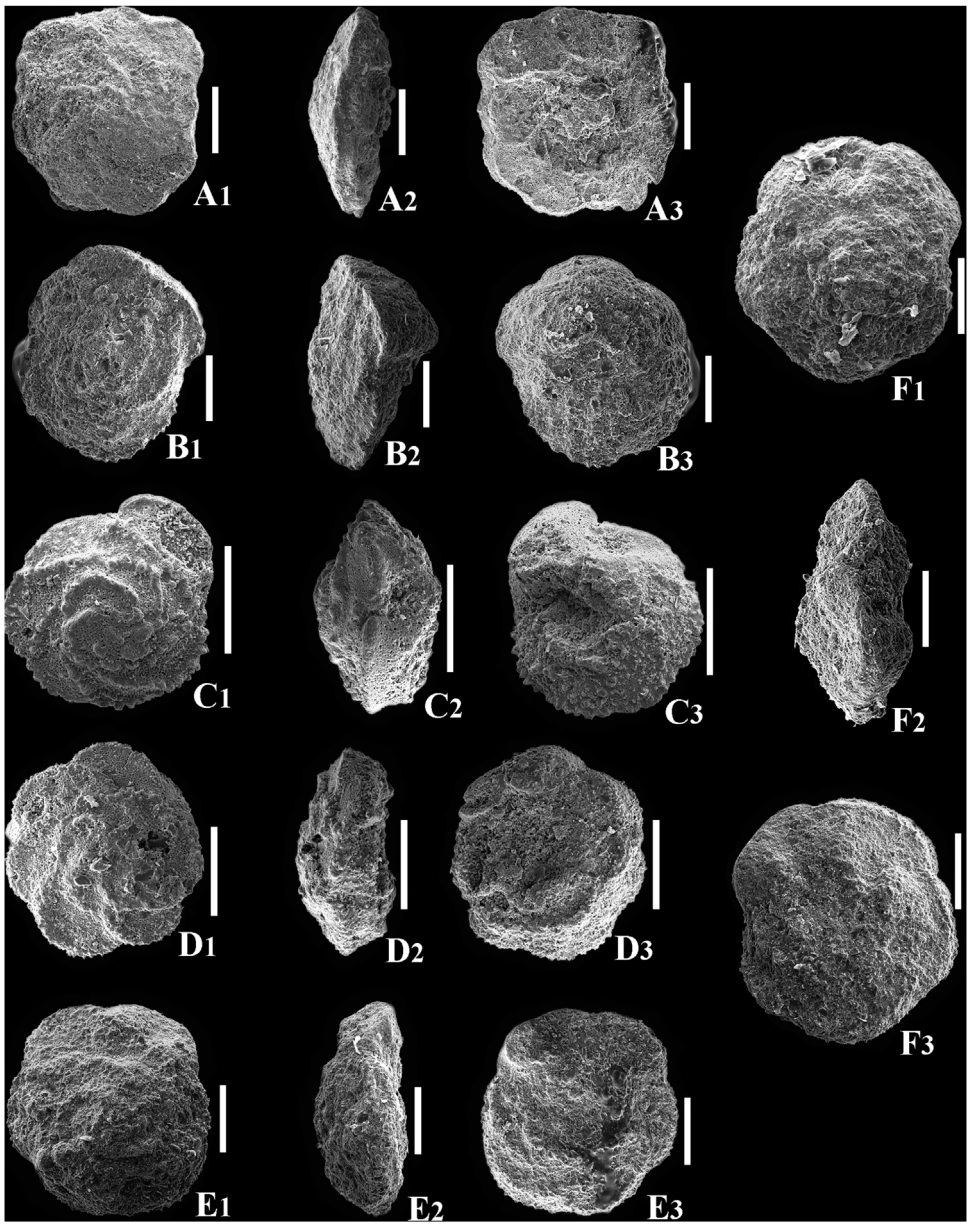

Fig. 11. Scanning Electron Micrographs of late Santonian–early Campanian planktonic foraminifers assemblages obtained from samples 15-25-3 (A, B), 07-30-15 (C, D) in the State quarry and sample 14-1-9 (E, F) in the Brezđe section. Scale bar = 200 μm; 1 – view from spiral side showing all chambers; 2 – view from umbilical side showing last turnover of the test and aperture; 3 – lateral view showing keel and character of convexity of test. (A1–A3) *Marginotruncana coronata* (Bolli). (B1–B3) *Globotruncanita elevata* (Brotzen). (C1–C3) *Globotruncanita* sp. cf. *G. elevata* (Brotzen). (D1–D3) *Globotruncana linneiana* (d'Orbigny). (E1–E3) *Globotruncana* sp. cf. *G. arca* (Cushman). (F1–F3) *Marginotruncana pseudolinneiana* Pessagno.

samples 15-25-3 and 07-32-13 (Fig. 4d). This part of the succession contains the poor foraminiferal assemblage, broadly indicating upper Santonian to lower Campanian.

The boundary between Santonian and Campanian strata is characterized by the major extinction of *Marginotruncana* and *Concavatotruncana*, and by a rapid evolution of *Globotruncana* and *Globotruncanita* that make their first appearance in the Santonian (Georgescu, 2015, 2017). The beginning of the Campanian is marked by the extinction of *Concavatotruncana concavata* (Brotzen) and *Dicarinella asymetrica* (Sigal), whereas *Globotruncanita elevata* Brotzen and *Globotruncana arca* (Cushman) are present here (Bragina et al., 2016). The Santonian–Campanian boundary can be placed between these biotic events in the sections of the Struganik limestone.

Nevertheless, we do not have enough data to prove the exact position of the lower boundary of the Campanian, because foraminiferal data are still too scarce and sometimes controversial. Sample 07-30-15 yielded *Globotruncanita* sp. cf. *G. elevata* (Brotzen) together with *Contusotruncana fornicata* (Plummer), but the stratigraphic range of *C. fornicata* is disputable: from strictly Campanian–Maastrichtian (Georgescu, 2015) to more broadly Turonian–Maastrichtian. Another important feature at the beginning of the *Globotruncanita elevata* Zone (Brotzen) is the extinction of *Dicarinella asymetrica* (Coccioni

Table 2
Composition of foraminiferal assemblages.

Sample							
Foraminiferal species	14-1-9	14-1-11	14-3-5	07-30-15	15-25-3	15-25-2	15-25-1
Globotruncanita stuartiformis (Dalbiez)			+				
Marginotruncana sp. cf. *M. lapparenti* Brotzen			+				
Marginotruncana pseudolinneiana Pessagno	+	+					
Marginotruncana coronata (Bolli)	+			+	+		
Ventlabrella sp. cf. *V. glabrata* Cushman	+						
Dicarinella primitiva (Dalbiez)	+						
Globotruncana arca (Cushman)	+						+
Dicarinella sp. aff. *D. concavata* (Brotzen)		+					
Marginotruncana sp. cf. *M. coronata* (Bolli)		+					
Marginotruncana sp. cf. *M. pseudolinneiana* Pessagno		+					
M. sigali (Reichel)		+					
M. sinuosa Porthault		+					
M. undulata (Lehmann)		+					
Heterohelix sphenoides Masters		+					
Planoheterohelix globulosa (Ehrenberg)		+					
P. reussi (Cushman)		+					
Globotruncana bulloides Vogler		+					
G. linneiana (d'Orbigny)		+		+			
Contusotruncana fornicata (Plummer)				+			
Globotruncanita sp. cf. *G. elevata* (Brotzen)				+		+	
Globotruncanita elevata (Brotzen)					+		
Globotruncana sp. cf. *G. bulloides* Vogler							+
Globotruncana sp. cf. *G. arca* (Cushman)							+

and Premoli Silva, 2015; Soycan and Hakyemez, 2018). Unfortunately, the species *Dicarinella asymetrica* is rare worldwide, and it is absent in the Struganik limestone. So, the position of the Santonian–Campanian boundary can be determined only in rare cases, most likely in the uppermost part of the Struganik limestone, in the middle of the *Afens perapediensis* radiolarian zone.

5.3. Taxonomic and morphological features of radiolarian and foraminiferal assemblages

The radiolarian assemblages of the supposed *Crucella robusta* Zone are characterized by relatively low taxonomic diversity. They differ from typical assemblages of this zone in Cyprus (Bragina, 2012, 2016). Hagiastridae and Patulibracchiidae, as well as Neosciadiocapsidae (nassellarians) are almost absent in the lower unit and in the lowermost strata of the upper unit of the Struganik limestone (samples 14-1-9, 14-3-5, 14-3-10, 15-33-1). Such features cannot be explained by selective preservation, because even assemblages with good and excellent preservation have such composition (especially sample 15-33-1). This phenomenon is, therefore, likely due to paleoecological factors as is indicated by distinct lithological differences between lower and upper units of the Struganik limestone.

On the other hand, assemblages of the overlying *Afens perapediensis* Zone are almost the same as coeval assemblages in Crimea (Korchagin et al., 2012; Bragina et al., 2016), and are only slightly less diverse than coeval assemblages of Cyprus (Bragina, 2012, 2016). Peculiar features of the assemblages from Cyprus can be explained by their excellent preservation. The paleoecological conditions of the Struganik basin were probably very favorable for radiolarians during time of the *Afens perapediensis* assemblage.

Recovered assemblages of planktonic foraminifera are characterized by relatively low taxonomic diversity. Morphotypes with planispiral and serial tests are present only in certain samples from the lower unit of the Struganik limestone (only abundant *Ventilabrella* in sample 14-1-9). Non-keeled trochospiral morphotypes such as *Archaeoglobigerina* Pessagno, and *Rugoglobigerina* Brönnimann, are absent, while the first appearance of *Rugoglobigerina* represents an important biostratigraphic datum for the Santonian–Campanian boundary (Maslakova, 1978; Robaszynsky et al., 1984; Caron, 1985; Loeblich and Tappan, 1987, 1988; Robaszynsky and Caron, 1995; Coccioni and Premoli Silva, 2015; Kopaevich and Vishnevskaya, 2016).

The low taxonomic diversity of foraminiferal assemblages can be interpreted as the result of selective preservation. For example, morphotypes with thin wall could be dissolved during diagenesis or completely damaged during replacement of calcium carbonate by silica. Because the basin of deposition of the Struganik limestone was surrounded by shallow-water areas of carbonate platform and was isolated in certain sense, there developed two stratigraphically important planktonic groups — foraminifers and radiolarians.

6. Conclusions

1. Microfossils (radiolarians and planktonic foraminifers) studied in several sections of the Upper Cretaceous carbonate deposits (lithographic limestones) near the village of Struganik (Western Serbia) revealed two biozones, the *Crucella*

robusta (middle Santonian–lower part of upper Santonian) and the *Afens perapediensis* (upper part of upper Santonian–lower Campanian) zones that can be traced amongst the sections in the region. One foraminiferal biozone has been identified and traced amongst the sections: the *Dicarinella asymetrica* Zone (middle–upper Santonian). The upper unit of Struganik limestone is characterized by poor foraminiferal assemblage dated as the late Santonian–early Campanian.
2. The integration between radiolarian and planktonic foraminiferal biostratigraphic zones supports the previous conclusions of stratigraphic ranges and position of boundaries of radiolarian zones in the Upper Cretaceous. Boundaries of radiolarian and foraminiferal zones are not coincidental: the lower boundary of the *Afens perapediensis* Zone (upper Santonian) is located within the *Dicarinella asymetrica* Zone.
3. The assemblages of radiolarians and planktonic foraminifers display peculiar features of their taxonomic composition, such as absence or rarity of certain taxa. These are likely caused by selective preservation or by some paleoecological or paleogeographical factors. However, both microfossil groups were successfully used in the stratigraphy of the Struganik limestone.
4. According to the obtained results, the stratigraphic range of the Struganik limestone is constrained to the upper Santonian–lower Campanian.

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Appendix A. Lithological descriptions of the sections of Struganik limestone.

1. Brežđe Section

The most western section is located near Brežđe Village in the roadcut along the road Brežđe–Mionica. The lowermost part of Struganik limestones (Fig. 1, 14-1) can be seen here starting from the coordinates N44°10′45.7″, E20°04′03.4″ (Fig. 2, 14-1):

1. Grey silty mudstone with plant detritus. 5 m.
2. Grey mudstone interbedded with greenish-grey clayey platy limestone. 5 m.
3. Light yellowish-grey and greenish-grey silty platy limestone with nodules of light-brown and grey chert. Nodules become abundant in the middle part of the unit. The upper part is characterized by the presence of greenish-grey tuffaceous siltstones. A horizon of red chert nodules is present in the upper part of the unit. 16 m.
4. Pinkish-grey to brick-red marlstone with interbeds of greenish-grey to yellowish-grey marlstone, pinkish-grey clayey limestone and red clay. Sample 14-1-9 (2.5 m above base of unit 4) is characterized by a radiolarian assemblage that can be tentatively assigned to the *Crucella robusta* Zone (upper part of middle Santonian–upper Santonian) (Table 1). 6 m.
5. Light-grey to yellowish-grey platy limestone with interbeds of yellowish-grey massive calcarenite with layers of chert. 6 m.
6. Light-grey platy limestone interbedded with bluish-grey thin-layered marlstone and rare layers of calcarenite with chert nodules. Sample 14-1-11 (2.8 m above base of unit 6) is characterized by planktonic foraminifers of the *Dicarinella asymetrica* Zone and by radiolarians of the *Afens perapediensis* Zone (Bragina et al., 2018). 5 m.
7. Light-greenish-grey and light-bluish-grey thin-layered tuffaceous mudstone. 8 m.
8. Light-yellowish-grey platy limestone interbedded with yellowish-grey thin-layered marlstone. A layer of grey marly clay (0.6 m) is present in the upper part of unit. Sample 14-1-13 (0.7 m below the top of unit 8) is characterized by radiolarians of the *Afens perapediensis* Zone (Table 1). 6 m.
9. Light-yellowish-grey platy limestones with abundant layers of yellowish-grey silty limestone and rare layers of pinkish-grey calcarenite. Observed thickness 10 m.

The end of the section is at the coordinates N44°10′57.1″, E20°04′14.2″. The main part of the Struganik limestone is present in a steep cliff above the roadcut but it cannot be studied.

2. Petrovića Brdo Section

A similar section can be observed in the southern slope of Petrovića Brdo. A small quarry located at N44°11′53.6″, E20°05′56.2″ (Fig. 1, 14-3) represents the following succession (Fig. 2, 14-3):

1. Greenish-grey, yellowish-grey and pinkish-grey silty platy limestone with nodules of red and pink chert and layers of greenish-grey marly siltstones. 0.5 m.
2. Yellowish-grey and greenish-grey silty to clayey platy limestone. Horizons of red spongolitic chert are present in the lower part. 1 m.
3. Reddish-brown, bluish-grey and greenish-grey thin-bedded marlstone with a layer of crimson-red marly clay (0.5 m above the base of unit 3). Thin interlayers of yellowish-grey silty limestone are present in the upper part of the unit. Sample 14-3-5 (1 m above the base of unit 3) is characterized by foraminifers of analogous to the *Dicarinella asymetrica* Zone (Table 2). 2 m.

4. Crimson-red and greenish-grey marly clay with interlayers of grey silty limestone. 0.5 m.
5. Grey massive calcarenite with chert nodules. 0.5 m.
6. Bluish-grey and greenish-grey clay with interlayers of greenish-grey cherty tuff. Sample 14-3-10 (0.5 m above the base of unit 6) is characterized by radiolarian assemblage that can be tentatively assigned to the *Crucella robusta* Zone (Table 1). 0.6 m.
7. Grey and yellowish-grey massive calcarenite. 2 m.

Another small quarry located on the southern slope of Petrovića Brdo above 14-3 at the coordinates N44°11′53.3″, E20°05′57.6″ (Fig. 1, 14-4) represents a higher part of the stratigraphic succession (Fig. 2, 14-4):

1. Light-grey and yellowish-grey silty and clayey platy limestone. Sample 15-33-1 (0.8 m above the base of unit 1) is characterized by radiolarian assemblage that can be tentatively assigned to the *Crucella robusta* Zone, and sample 14-4-1 (2.2 m above bottom) is characterized by radiolarians of the *Afens perapediensis* Zone (Table 1). 12 m.
2. Light-grey and white platy limestone with interlayers of dark-grey chert. Sample 14-4-3 (4.1 m above the base of unit 2) is characterized by radiolarians of the *Afens perapediensis* Zone (Table 1). 6 m.

The continuation of the succession can be observed in a large quarry in the upper part of northern slope of Petrovića Brdo (Fig. 1, 07-33), at the coordinates N44°12′08.3″, E20°05′56.9″ (Fig. 2, 07-33):

1. Light-grey and white, rarely dark-grey platy limestone with common interlayers of dark-grey chert and with thin layers of yellowish-grey and greenish-grey marlstone. 7 m.
2. Grey massive calcarenite. 1.2 m.
3. Light-grey and white platy limestone with layers of grey chert. 4 m.
4. Grey and pinkish-grey calcarenites with interlayers of light-grey limestone and pinkish-grey to greenish-grey chert. 12 m.
5. Grey massive calcarenite. 0.5 m.
6. Light-grey platy limestone with interlayers of grey chert. 2 m.

3. State quarry Section

Nearly the whole succession of the Struganik limestone is present in the series of large quarries directly west from the center of the village of Struganik. The section at State quarry (Fig. 1, 07-30) starts at coordinates N44°11′25.3″, E20°06′09.5″ (Fig. 2, 07-30):

1. Light-grey platy limestone with interlayers of dark-grey chert. 0.2 m.
2. White, light-grey, and brownish-grey bentonitic clay. Sample 07-30-2 (0.1 m above the base of unit 2, Table 1) is characterized by radiolarian assemblage that can be tentatively assigned to the *Crucella robusta* Zone (previously beds with *Theocampe urna–Dictyomitra koslovae*) (Bragina et al., 2014). 0.2 m.
3. Light-grey and white platy limestone. 1 m.
4. Yellowish-grey calcarenite. 0.3 m.
5. Light-grey massive and thick-bedded limestone with nodules of light-grey to yellowish-grey chert. 0.4 m.
6. Light-grey and white platy limestone and marlstone. 1 m.
7. Grey massive calcarenite. 0.7 m.
8. Light-grey and white platy limestone and marlstone with nodules of dark-grey and yellowish-grey chert. Sample 07-30-5 (1.3 m above the base of unit 8) and sample 07-30-6 (3.8 m above the base of unit 8) are characterized by radiolarians of the *Afens perapediensis* Zone (previously beds with *Afens perapediensis–Clathropyrgus titthium*) (Table 1) (Bragina et al., 2014). 4 m.
9. Grey massive calcarenite. 0.5 m.
10. Light-grey and white platy limestone and marlstone with interlayers of dark-grey chert. Sample 07-30-7 (1.3 m above the base of unit 10) is characterized by radiolarians of the *Afens perapediensis* Zone (previously beds with *Afens perapediensis–Clathropyrgus titthium*) (Table 1) (Bragina et al., 2014). 1.5 m.
11. Grey massive calcarenite. 0.5 m.
12. Light-grey and white massive limestone with nodules of grey chert. 1.2 m.
13. Light-grey and white platy limestone with thin layer of yellowish-grey chert. 0.5 m.
14. Grey massive calcarenite. 0.5 m.
15. White and yellowish-grey limestone with layer of yellowish-grey chert. Sample 07-30-9 (0.5 m above the base of unit 15) is characterized by radiolarians of the *Afens perapediensis* Zone (previously beds with *Alievium gallowayi–Crucella espartoensis*) (Table 1) (Bragina et al., 2014). 1 m.
16. Light-grey and white platy limestone with thin interlayers of yellowish-grey marlstone and with nodules of grey and yellowish-grey chert. 2.5 m.
17. Yellowish-grey and pinkish-grey calcarenite with chert nodules. 1.2 m.
18. Light-grey and white platy limestone with interlayers of dark-grey chert. 3.5 m.
19. Grey massive calcarenite with chert nodules. 1.5 m.
20. Light-grey and white platy limestone with abundant nodules of grey and yellowish-grey chert. 1.5 m.
21. Light-grey platy limestone with chert nodules. This unit displays strong slump folding. 3.5 m.
22. Yellowish-grey and greenish-grey marlstone. 0.2 m.
23. Yellowish-grey and greenish-grey clay. 0.1 m.
24. Light-grey and yellowish-grey limestone with nodules of grey chert. Sample 07-30-15 (1 m above the base of unit 24) is characterized by late Santonian to early Campanian planktonic foraminifers (Table 2). 1.2 m.
25. Yellowish-grey and greenish-grey clay. 0.1 m.
26. Light-grey and white platy limestone with layers of grey chert. 2.3 m.
27. Grey massive calcarenite. 1 m.

28. Light-grey and white platy limestone with layers and nodules of grey chert. 2.3 m.

This section ends at the coordinates N44°11′25.2″, E20°06′11.5″. The continuation of the succession is observed in the next quarry (Fig. 1, 07-31) and starts at coordinates N44°11′25.2″, E20°06′18.0″ (Fig. 2, 07-31):

1. Light-grey and white thick-plated limestone with rare layers of grey chert. 2.5 m.
2. Light-grey and white limestone and marlstone with layers of dark-grey chert and thin layers of greenish-grey clay. Sample 15-26-2 (0.7 m above the base of unit 2) is characterized by radiolarians of the *Afens perapediensis* Zone (Table 1). 4 m.
3. Grey and pinkish-grey massive calcarenite. 0.8 m.
4. Light-grey and white thick-plated limestone with rare small nodules of yellowish-grey chert. 2 m.
5. Grey and pinkish-grey rudite changing upwards to grey calcarenite. 4 m.
6. Light-grey and white platy limestone with layers of grey chert. 4 m.
7. Grey massive rudite. 1 m.

The uppermost part of the Struganik limestone is observed in next quarry (Fig. 1, 07-32), directly in the village of Struganik starting at coordinates N44°11′17.9″, E20°06′27.1″ (Fig. 2, 07-32 with additional samples collected in 2015 with numbers 15-25):

1. Grey massive rudite. 0.5 m.
2. Light-grey platy limestone. 0.2 m.
3. Grey massive rudite. 0.6 m.
4. Light-grey and white platy limestone with interlayers of yellowish-grey chert. Sample 15-25-3 (base of unit 4) is characterized by radiolarians of the *Afens perapediensis* Zone and late Santonian to early Campanian foraminifers (Tables 1, 2). 1 m.
5. Light-grey and white platy limestone with interlayers of dark-grey to brownish-grey chert and greenish-grey marlstone. 0.3 m.
6. Light-grey, greenish-grey and yellowish-grey thin-laminated clay. 0.1 m.
7. Light-grey platy limestone. 0.6 m.
8. Grey massive rudite. 0.25 m.
9. Light-grey and white platy limestone with interlayers of grey chert. 1 m.
10. Grey massive calcarenite. 0.6 m.
11. Dark-grey and grey thin-bedded limestone. 0.2 m.
12. Light-grey thick-bedded limestone with interlayers of grey chert. 1.5 m.
13. Light-grey and white platy limestone with interlayers of grey chert. Sample 15-25-2 (0.5 m above the base of unit 13) is characterized by radiolarians of the *Afens perapediensis* Zone and late Santonian to early Campanian foraminifers (Tables 1, 2). 1.5 m.
14. Grey massive calcarenite. 0.5 m.
15. Light-grey and white thick-bedded limestone with nodules of grey and yellowish-grey chert. 1.5 m.
16. Grey massive calcarenite. 0.6 m.
17. Light-grey and white thick-bedded limestone with rare layers of yellowish-grey chert. 1.3 m.
18. Grey massive calcarenite. 0.6 m.
19. Light-grey thick-bedded limestone. 0.3 m.
20. Light-grey and white platy limestone with layers of grey chert. 1.3 m.
21. Grey massive rudite. 1.5 m.
22. Light-grey and white thick-bedded limestone. 1 m.
23. Light-grey platy limestone with interlayers of grey calcarenite and yellowish-grey chert. Sample 15-25-1 (1.7 m above the base of unit 23) is characterized by radiolarians of the *Afens perapediensis* Zone and late Santonian to early Campanian foraminifers (Tables 1, 2). Sample 07-32-13 is characterized by radiolarians of the *Afens perapediensis* Zone (Tables 1, 2). 6 m.

4. Small quarry Section

The uppermost part of the Struganik limestone can be seen directly east of the village of Struganik (Fig. 1, 14-2), in the small quarry at coordinates N44°11′46.9″, E20°06′34.7″ (Fig. 2, 14-2):

1. Light-grey to yellowish-grey platy limestone with abundant interlayers of dark-bluish-grey chert. Sample 14-2-0 (0.6 m above the base of unit 1) and sample 14-2-2 (3.7 m above the base of unit 1) are characterized by radiolarians of the *Afens perapediensis* Zone (Table 1). 4 m.
2. Yellowish-grey calcarenite with chert nodules. 1.2 m.
3. Light-grey platy limestone with interlayers of grey chert and rare beds of grey calcarenite. 7 m.

5. Goveđe Brdo Section

The next section of the Struganik limestone is located on the western slope of Goveđe Brdo (Fig. 1, 14-5), east of the village of Struganik, starting at coordinates N44°11′46.5″, E20°06′47.6″ (Fig. 2, 14-5):

1. Light-grey and light-bluish-grey platy limestone with interlayers of dark-grey translucent chert. 1 m.
2. Light-bluish-grey and yellowish-brown clay. Samples 14-5-3 and 15-27-1 (0.2 m above the base of unit 2) are characterized by radiolarians of the *Crucella robusta* Zone. 0.4 m.
3. Light-grey platy limestone with interlayers of chert and with interlayers of yellowish-grey rudite in the lower part of the unit. Sample 14-5-5 (1.6 m above the base of unit 3) is characterized by radiolarians of the *Afens perapediensis* Zone (Table 1). 2 m.
4. Grey and yellowish-grey calcarenite. 2.5 m.
5. Light-grey and white platy limestone with interbeds of dark-grey chert. 5 m.
6. Grey massive calcarenite. 0.3 m.

7. Light-grey, yellowish-grey and bluish-grey platy limestone with interbeds and nodules of dark-grey chert. 2 m.
8. Grey massive calcarenite. 0.5 m.
9. Grey and yellowish-grey thick-bedded limestone with interlayers and nodules of dark-grey chert. Sample 15-27-2 (1.7 m above the base of unit 9) is characterized by radiolarians of the *Afens perapediensis* Zone (Table 1). 2 m.
10. Grey massive calcarenite. 0.5 m.

Covered interval 2 m.

11. Light-grey, bluish-grey and yellowish-grey platy clayey limestone with abundant interlayers of dark-grey chert. 2 m.
12. Grey platy limestone with interlayers of grey calcarenite and rudite. 2 m.
13. Grey and bluish-grey platy limestone with abundant interlayers and nodules of dark-grey chert. Sample 15-27-3 (3.1 m above the base of unit 13) is characterized by radiolarians of the *Afens perapediensis* Zone. 5 m.
14. Grey massive calcarenite. 1.5 m.
15. Light-grey and white platy limestone with abundant interlayers and nodules of dark-grey and yellowish-grey chert. 7 m.
16. Grey massive calcarenite. 0.5 m.

Covered interval 6 m.

17. Grey thick-bedded clayey limestone with abundant nodules of dark-grey chert. 1.5 m.
18. Grey platy chert with abundant thin interlayers of dark-grey calcarenite and rare nodules of grey chert. Sample 15-27-4 (1.9 m above the base of unit 18) is characterized by radiolarians of the *Afens perapediensis* Zone and late Santonian to early Campanian foraminifers (Tables 1, 2). 6 m.

6. Popadić Section

Finally, in the eastern part of the study area, near the village of Popadić (Fig. 1, 14-6), the following section can be observed in the quarry starting at coordinates N44°12′10.3″, E20°07′51.2″ (Fig. 2, 14-6):

1. Crimson-red and greenish-grey marlstone. 2 m.
2. Greenish-grey and bluish-grey tuffaceous mudstone. 2 m.
3. Grey massive and thick-bedded calcarenite. 7 m.
4. Grey and yellowish-grey platy limestone with abundant interlayers of grey and yellowish-grey chert. 5 m.
5. Grey platy limestone with interlayers of grey calcarenite and dark-grey chert. 4 m.
6. Grey massive calcarenite. 2 m.

The upper part of the Struganik limestone can be observed in the next quarry (Fig. 1, 14-7), starting at coordinates N44°11′55.7″, E20°07′13.7″ (Fig. 2, 14-7):

1. Light-grey and white platy limestone with interlayers of dark-grey chert. 2.5 m.
2. Grey and yellowish-grey calcarenite. 1 m.
3. Grey and light-grey thick-bedded limestone with nodules of grey and yellowish-grey chert. 1 m.

Covered interval 2 m.

4 Grey and bluish-grey platy limestone with abundant interlayers of dark-grey chert. Sample 14-7-4 (2.2 m above the base of unit 4) is characterized by radiolarians of the *Afens perapediensis* Zone (Table 1). 8 m.
5. Grey massive calcarenite. 1 m.
6. Light-grey and white thick-bedded limestone. 2 m.

Covered interval 3 m.

7. Grey and yellowish-grey platy limestone with interlayers of grey calcarenite and rare nodules of yellowish-grey chert. 3 m.

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