

The Lower Triassic platy limestone in the Jajce area (Bosnia and Herzegovina)

Spodnjetriasni ploščasti apnenec iz okolice Jajca (Bosna in Hercegovina)

Tea KOLAR-JURKOVŠEK¹, Bogdan JURKOVŠEK¹, Valery Ja. VUKS², Hazim HRVATOVIĆ³,
Dunja ALJINOVIC⁴, Čazim ŠARIĆ³ & Ferid SKOPLJAK³

¹Geološki zavod Slovenije, Dimičeva ulica 14, SI-1000 Ljubljana, Slovenia; e-mail: tea.kolar@geo-zs.si,
bogdan.jurkovsek@geo.zs.si

²Federal State Unitary Enterprise "A.P. Karpinsky Russian Geological Research Institute" Sredny pr. 74,
199106 St. Petersburg, Russia; e-mail: Valery_Vuks@vsegei.ru

³Federalni zavod za geologiju, Ilidža, Ustanička 11, 71 210 Sarajevo, Bosnia and Herzegovina; e-mail:
hharish@bih.net.ba; cazim.saric@fzgg.gov.ba; fskopljak@yahoo.com

⁴Rudarsko-geološki naftni fakultet Sveučilišta u Zagrebu, Pierottijeva 6, HR-10000 Zagreb, Croatia;
e-mail: dunja.aljinovic@rgn.hr

Prejeto / Received 17. 9. 2014; Sprejeto / Accepted 14. 11. 2014

Key words: biostratigraphy, microfacies, Lower Triassic, Jajce area, Bosnia and Herzegovina

Ključne besede: biostratigrafija, mikrofacies, spodnji trias, okolica Jajca, Bosna in Hercegovina

Abstract

The study presents palaeontological and sedimentological data of the Lower Triassic strata of the Jajce area in Bosnia and Herzegovina. Four microfacies types were differentiated: coarse grained bioclastic packstones, fine grained bioclastic packstones, laminated mudstone and laminated calcisiltites. Sedimentary characteristics of the depositional environment indicate the distal part of a wide, shallow shelf/ramp, in keeping with some other locations spanning the Dinaride chain. Characteristic ichnofossils and macrofauna are present, including ammonoids, bivalves, and gastropods, dominated by *Natiria costata* (Münster). Conodont elements provide a biostratigraphic framework. The older part of the section is characterized by the conodont *Triassospathodus hungaricus* (Kozur & Mostler) and the foraminiferans *Nodosaria* ex gr. *skyphica* Efimova, *Ammodiscus* ex gr. *minutus* Efimova, *Glomospirella triphonensis* Baud, Zaninetti & Broennimann and *Glomospirella shengi* Ho. A younger fauna yields *T. triangularis* (Bender), *Meandrospira cheni* (Ho) and *M. pusilla* (Ho). The older fauna belongs to the *T. hungaricus* conodont Zone based on presence of Spathian conodont elements, while the younger fauna belongs to the *T. triangularis* conodont Zone.

Izvleček

V članku so prikazani paleontološki in sedimentološki podatki iz spodnjetriasnih plasti pri Jajcu v Bosni in Hercegovini. V profilu so litološko definirani štirje mikrofaciesni tipi: grobozrnati bioklastični packstone, drobnozrnati bioklastični packstone, laminirani mudstone in laminirani karbonatni siltit. Na osnovi raziskanih sedimentoloških značilnosti lahko okolje sedimentacije primerjamo z distalnim delom odprtega in plitvega šelfa/rampe, kot je pogosto interpretiran za ostale lokalnosti vzdolž celotnega področja Dinaridov. Izdvojene litotipe označujejo ichnofosili in prisotnost makrofavne, najpogosteje amonitov, školjk in polžev s prevladujočo vrsto *Natiria costata*. Dobljena mikrofavna vsebuje pomembne konodontne elemente, ki omogočajo veliko biostratigrafsko ločljivost. Starejšo favno označuje konodontna vrsta *Triassospathodus hungaricus* in foraminifere *Nodosaria* ex gr. *skyphica*, *Ammodiscus* ex gr. *minutus*, *Glomospirella triphonensis* in *G. shengi*. Mlajša favna vključuje vrste *T. triangularis*, *Meandrospira cheni* in *M. pusilla*. Na osnovi najdenih konodontnih vrst spathijske starosti je starejša združba v raziskanem profilu uvrščena v *T. hungaricus* konodontno cono, medtem ko mlajša združba pripada *T. triangularis* konodontni coni.

Introduction

The Jajce old town and the well known mills at Pliva River are often paved by Lower Triassic platy limestones, exposed in a narrow valley west of Bravnice village, southeast of Jajce (Fig. 1).

Bravnice is located in the northeastern part of the Ključ-Raduša Nappe, near the town of Jajce (Fig. 2) in the central Dinarides of Bosnia and Herzegovina. The Ključ-Raduša Nappe can be traced along the NW-SE strike for ca. 150 km. Its

frontal parts override the Glamoč-Drežnica-Gacko Nappe, and it is underlain along its northeastern margin by the Bosnia Flysch Nappe. The Ključ-Raduša Nappe is composed largely of Triassic carbonates, subordinate coeval clastic and igneous rocks, and sparse Permian sediments. In its frontal parts, Middle/Late Permian evaporites are exposed which may have lubricated the basal thrust plane. The northern part of the Ključ-Raduša Nappe adjoins the Paleozoic complex of the Mid-Bosnian Schist Mts. tectonic block (HRVATOVIĆ, 2006).

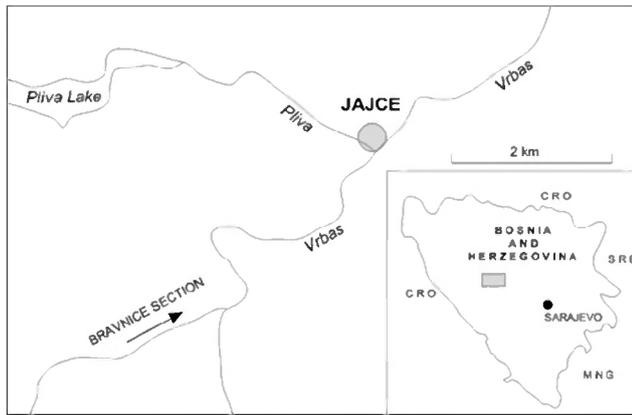


Fig. 1. Location of the Lower Triassic strata of the Bravnice section in Bosnia and Herzegovina.

The Bravnice section lies in the Otomalj-Bukovica-Oborci tectonic unit. This unit is mainly composed of sandstone, siltstone and platy limestone of Early Triassic age. In the southeast part of this unit are sediments of Late Permian and Permian-Triassic age from the edge of the Palaeozoic Mid-Bosnian Schist Mts. (VUJNOVIĆ, 1980, 1981).

The uppermost part of the Early Triassic strata of the Jajce area were discussed in numerous older works (KATZER, 1921; PUZINA et al., 1969; VUJNOVIĆ, 1981), in which the section has been divided into older »Seis« beds and younger »Campil« beds. The upper part of the Lower Triassic limestone (»Campil« beds) can be easily recognized by presence of ammonoids, bivalves, gastropods and ichnofossils. The basic petrographic composition of the samples from the Bravnice section does not differ significantly from the younger part of the Lower Triassic in the Dinarides and the wider Tethys area (Fig. 3), sharing dominance of micritic carbonate, occasional biotrital accumulation of

shells of molluscs, gastropods and echinoderms, as well as rare presence of siliciclastic detritus in thin layers or individual laminae. The aim of this work is to document biota and microfacies of the strata near Jajce, calibrate their age within the Olenekian based on microfossil associations, and determine the environment of deposition.

Material and methods

The material examined for this study was collected in the course of field work carried out in 2011-12 in the Jajce area in central Bosnia and Herzegovina. The Lower Triassic section, 222 m thick, was measured and sampled (Fig. 4). Altogether, 18 samples (BR 1 - 18) were collected for conodont processing. A minimum 2 kg of rock were prepared for conodont study using standard laboratory techniques. One to four thin sections from each level of conodont sampling were prepared to study foraminifera and carbonate petrography. The locations of the collected samples is shown in Fig. 4. The laboratory work was carried out at Geological Survey of Slovenia / Geološki zavod Slovenije where the studied material is stored under catalogue numbers 5079 - 5087, 5113 - 5122 and abbreviated GeoZS. The conodont elements were illustrated using the JEOL JSM 6490LV Scanning Electron Microscope at the Geological Survey of Slovenia. Some macrofossil specimens are stored in the Jajce town museum.

Lithology

Four microfacies were differentiated in the Bravnice section (Fig. 5), as follows:

- 1) Laminated mudstones
- 2) Laminated calcisiltites
- 3) Fine grained bioclastic packstones
- 4) Coarse grained bioclastic packstones

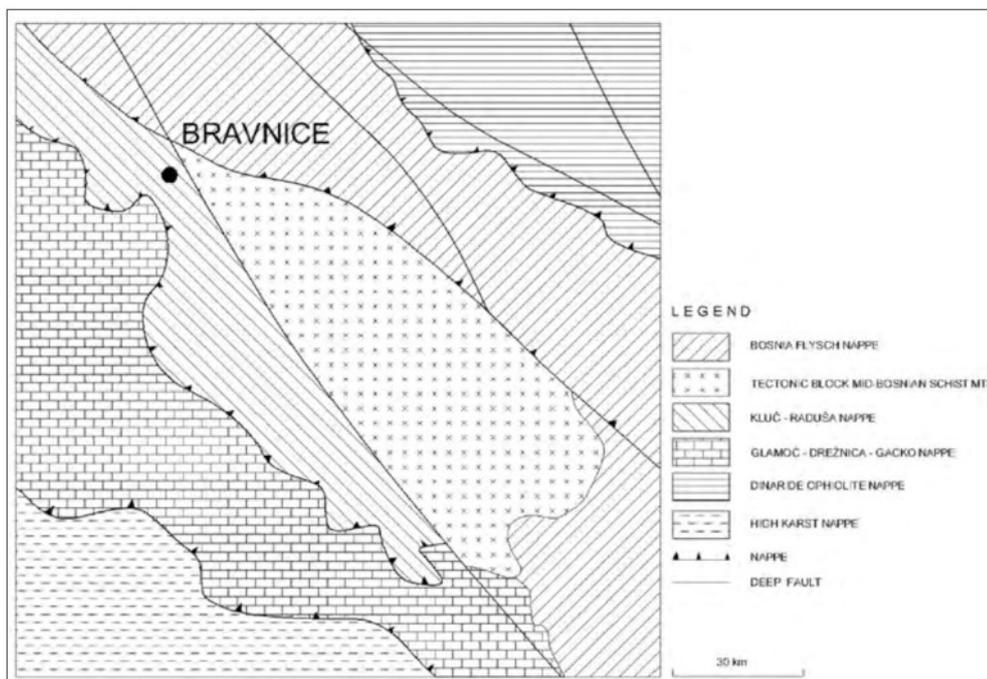


Fig. 2. Section from the geotectonic map of Bosnia and Herzegovina with the Bravnice section marked, modified from Hrvatović (2006).

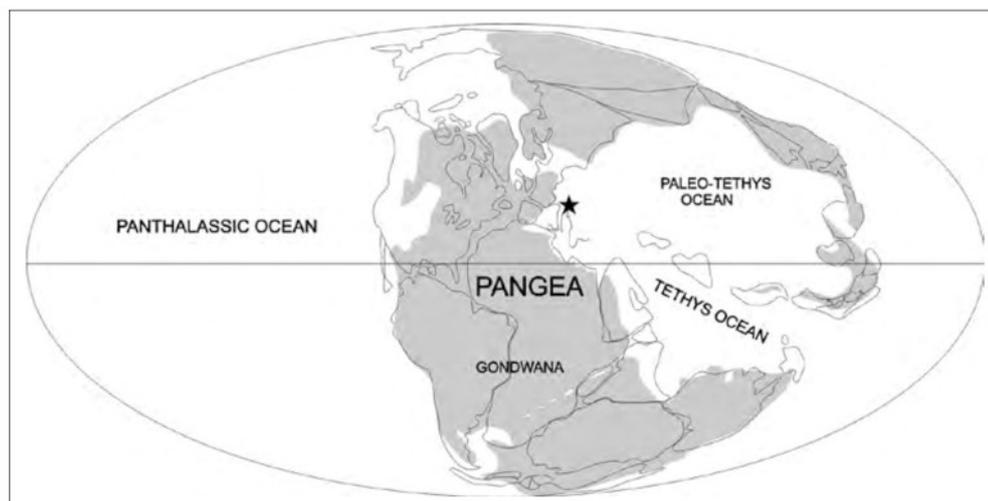


Fig. 3. Palaeogeographic map for the Early Triassic with position of the Bravnice section marked (star), modified from SCOTSE (2001).

Some samples represent transitional variations between coarse- and fine grained bioclastic packstones (biomicrites) (BR 13) or between laminated micritic mudstones and calcareous siltstones (BR 18).

- 1) Laminated mudstones (micrites) - samples: BR 4, BR 8, BR 11, BR 12B, BR 16/1, BR 16/2, BR 17.

This microfacies type is characterized by laminated carbonate mud (Fig. 5A), mostly calcitic apart from sample BR 17 which is partly dolomitized. Extremely fine lamination is due to alternation of silty siliciclast-rich and carbonate mud-rich laminae. Siliciclastic component grains are mostly quartz and partly feldspar grains. Sometimes pyrite crystals accumulate along laminae. Sample BR 12B is an exception, where the carbonate mud is not laminated, but has been disintegrated in irregular fragments due to bioturbation. Rare crinoidal elements are present. With increase in siliciclastic detritus, a graded transition occurs to laminated calcisiltites.

- 2) Laminated calcisiltites - samples: BR 12A, BR 15 (Fig. 5B).

In this microfacies type, thin siliciclast-rich laminae or thin beds rich in quartz and feldspar alternate with laminae of carbonate mud or silt-sized bioclasts. Siliciclastic particles are poorly rounded, irregular or long and prismatic. Some laminae are extremely rich in pyrite, or in finely preserved foraminifera tests (*Glomospirella*, *Meandrospira*).

- 3) Fine-grained bioclastic packstones (biomicrites) - samples: BR 6, BR 7, BR 14.

This microfacies type consists dominantly of fine-grained biotritus in a micritic matrix. Alternation of bioclastic- with matrix- rich laminae can be observed in some samples, while in others, reworking by organisms results in a chaotic distribution of fossils and carbonate mud. Among the bioclastic debris, well sorted plates of echinoderms prevail (Fig. 5C). Fairly well preserved foraminifera tests (*Glomospirella*, *Meandrospira*) are rare. Some sporadic laminae with well sorted peloids or fine grained siliciclastic

detritus are present. Sample BR 13 shows lamination due to alternation of coarse- and fine-grained biotritus.

- 4) Coarse-grained bioclastic packstones (biomicrites) - samples: BR 1, BR 3, BR 5, BR 15.

The lithotype consists of coarse-grained bioclasts consisting of bivalves, gastropods, echinoderms and ostracods within dense micrite (Fig. 5D). Molluscan fragments exceed 2 mm in size and are usually preferentially oriented parallel to bedding. Plates of echinoids and ostracod carapaces are smaller than 2 mm. Size grading from coarser bioclastic detritus to carbonate mud can be observed in sample BR 1. Bioturbation was observed in sample BR 3. Bioclasts are occasionally silicified. Euhedral pyrite crystals are often present.

Depositional environment

A common characteristic of Early Triassic sedimentary facies in the Dinarides is dominance of carbonate mud with sporadic accumulation of coarser bioclastic detritus (bivalves, gastropods and echinoderms), and rarely, thin bedded calcisiltites. The composition and petrographic features of the Bravnice section do not differ significantly from this pattern (ALJINOVIĆ, 1995, KOLAR-JURKOVŠEK et al., 2013).

The data may be explained as a background deposition of fine carbonate mud in a low energy environment (laminated mudstone facies) signifies slow deposition in where the vast quantities of finest carbonate particles can be accumulated. Pyrite indicates partly anaerobic or disaerobic episodes within the low energy environment. Settling of carbonate mud of the laminated limestone facies in a quiet-water environment alternates with sporadic influx of terrigenous quartz or feldspar grains transported by traction currents. The evidence implies deposition in deeper/distal parts of a ramp, sometimes poorly aerated, and is in line with other late Early Triassic deposits elsewhere in the Dinarides (e.g. KOLAR-JURKOVŠEK et al., 2013).

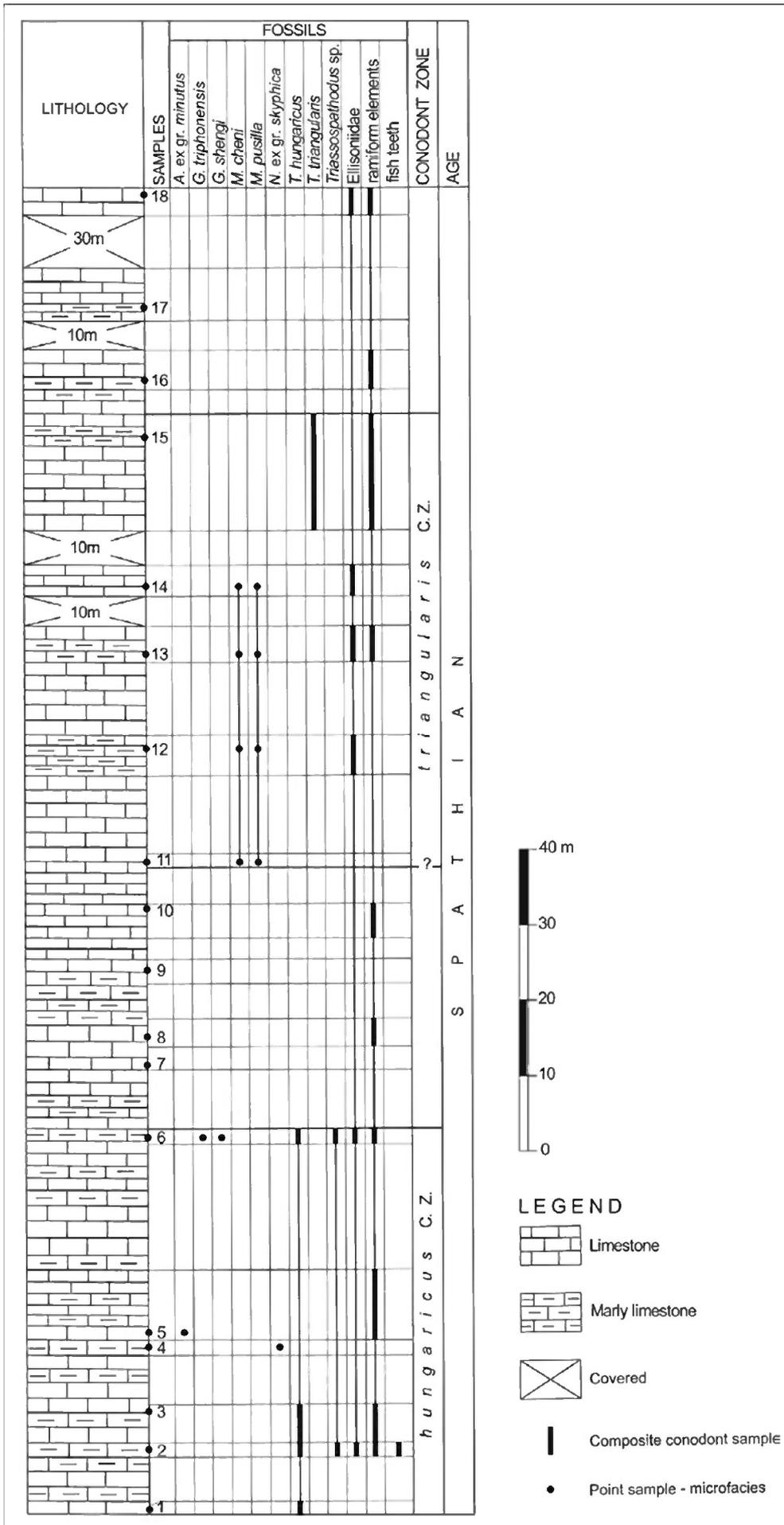
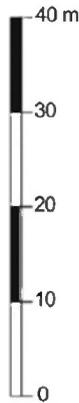


Fig. 4. Stratigraphic column of the Lower Triassic strata at Bravnice.

Abbreviations :

- A. - *Ammodiscus*,
- G. - *Glomospirella*,
- M. - *Meandrospira*,
- T. - *Triassopathodus*.



LEGEND

- Limestone
- Marly limestone
- Covered
- Composite conodont sample
- Point sample - microfacies

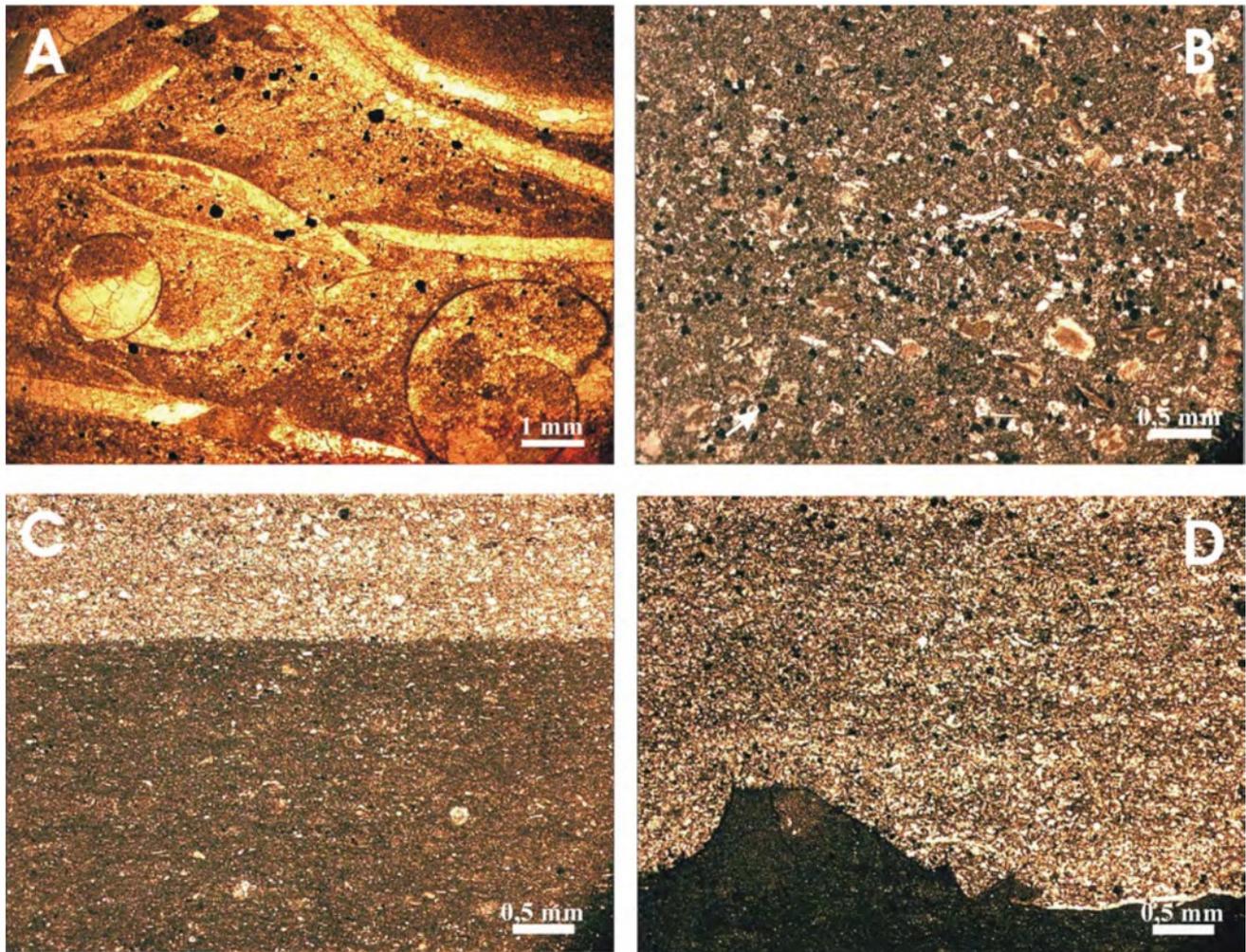


Fig. 5. Microfacies types of the Early Triassic Bravnice section.

- | | |
|---|--|
| A | Laminated mudstone (sample BR 11). |
| B | Laminated calcisiltites (sample BR 12A). |
| C | Fine grained bioclastic packstones (sample BR 14). |
| D | Coarse grained bioclastic packstones (sample BR 15). |

The laminated calcisiltite microfacies formed by transport of siliciclastic or fine-grained bioclastic material to the distal parts of a ramp by weak currents. Such resedimentation of terrigenous material from the shallow ramp into the laminated mudstones may be attributed to distal storm-induced currents. Infaunal bioturbation took place in the undisturbed intervals between stormy periods (sample BR 12 B).

Storm activity also explains the finer- or coarser-grained bioclastic detritus. Fine-grained bioclastic packstones with faint lamination and foraminifera tests along laminae were formed by distal transport by weak currents of molluscan bioclasts, echinoid plates and foraminifera from the shallower part of ramp. Storm transport is supported by the high degree of sorting of bioclastic material and by presence of foraminifera that usually inhabit the shallow proximal ramp. The coarse-grained bioclastic packstones (biomicrites) represent stronger influence of short-term storm events into the outer ramp where carbonate mud was deposited from suspension. Peak storm currents caused bottom-

shear conditions that concentrated shells of living and dead organisms on the sea floor, by exhuming buried shells, ripping up weakly consolidated sediments forming lags, and followed by burial by the influx of storm suspended particles. In this way coarse grained bioclastic detritus including large fragments and sometimes unbroken fossils were preferentially preserved by storm burial, protecting them from normal destructive processes. Preferential orientation of valves parallel to bedding plane also suggests deposition under short-term high energy conditions such as storms. Grading of bioclasts as observed in sample BR 1 takes place in the course of slow settling of the sediment storm cloud. Presence of pyrite indicates low-energy and partly anaerobic/disaerobic conditions in between storms.

Biostratigraphy

Macrofauna (Fig. 6)

The rich gastropod, bivalve (Fig. 6. 3-4), and ammonoid molluscan fauna of the Bravnice section, as well as (Fig. 6. 2) numerous ichnofossils

(Fig. 6. 1, 5-6) can be seen on bedding planes of the limestone pavements of the Old Jajce town, as well as at the Pliva mills. The gastropod species *Natiria costata* (Fig. 6. 3) is most common, whereas genus *Turbo* appears rarely. Poor preservation of ammonoids and bivalves does not permit their

determination. Some well-preserved specimens from the Bravnice section are housed in the Jajce town museum / Zavičajni etno muzej u Jajcu. *Natiria costata* is the most typical gastropod of the Early Triassic Werfen Formation in Europe, suggesting equivalence of the outcrops with

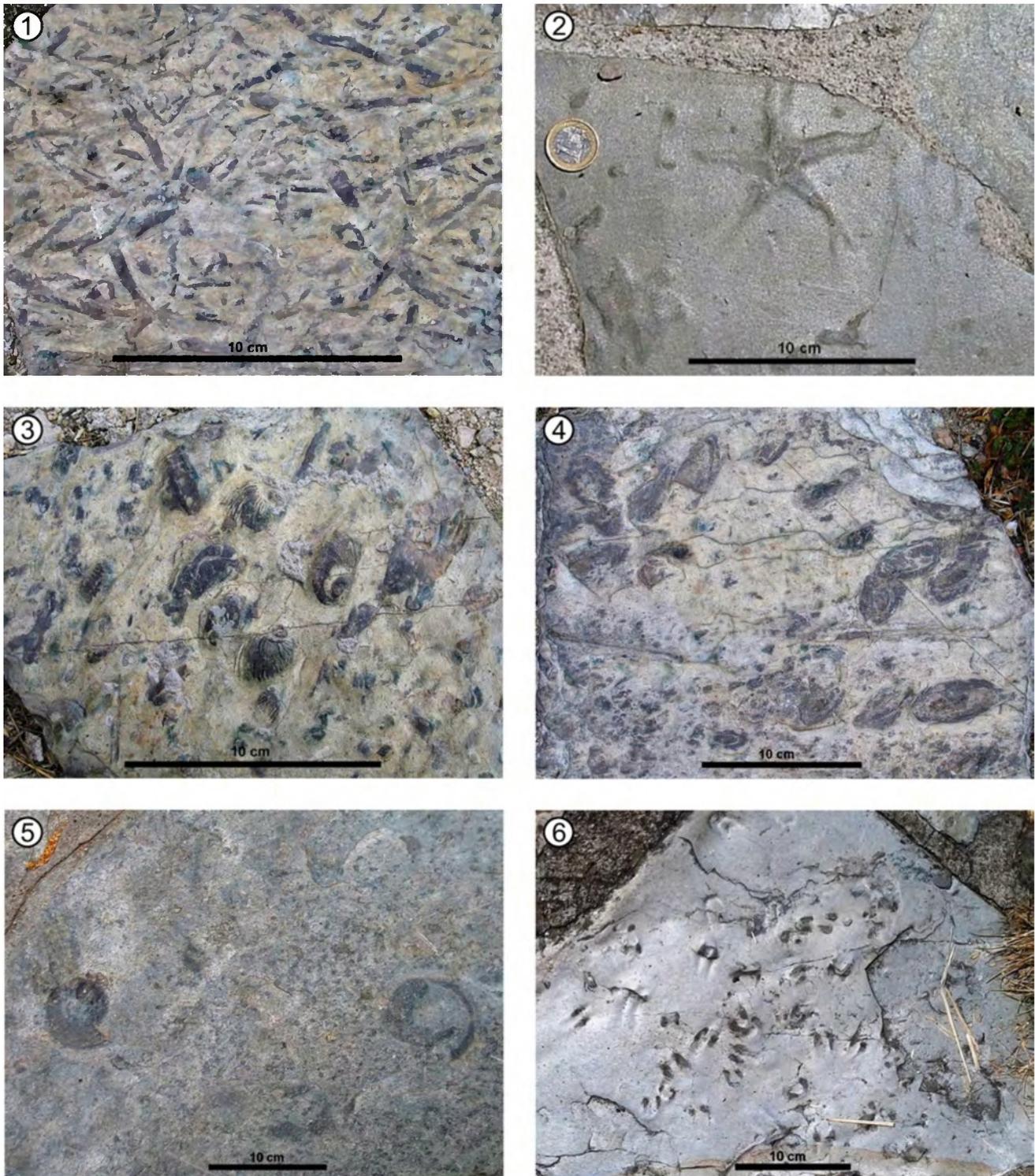


Fig. 6. Ichnofossils and macrofossils from the Early Triassic strata in the Jajce area.

- 1 Asteroid imprint (plate in a pavement to the entrance of the Jajce fortress).
- 2 Ammonoids (plate in a stairway to the tower in Jajce old town).
- 3 *Natiria costata* (Münster) and *Turbo* sp. (Museum of Jajce town / Zavičajni etno muzej u Jajcu).
- 4 Poorly preserved bivalves (plate in a pavement of Jajce old town).
- 5 Bioturbated limestone (plate in a pavement of Jajce old town).
- 6 Ichnofossil (plate in a pavement of the mill at Pliva River).

that formation (KOLAR-JURKOVŠEK et al., 2013). Recently, poorly preserved *Natiria* cf. *costata* has also been reported from Spathian of Utah, USA (HOFMANN et al., 2013) and Slovenia (KOLAR-JURKOVŠEK et al., 2013). This gastropod is present also in the equivalent strata near Muć (Dalmatia, Croatia), that has been proposed as a candidate for the European stratotype section of the late Early Triassic (HERAK et al., 1983; PRLJ-ŠIMIĆ, 2006).

Microfauna

The microfossil material recovered from the Bravnice section includes foraminifera and conodonts, with occurrence and abundance of taxa summarized in Fig. 7. The Conodont Colour Alteration index CAI value sensu REJEBIAN et al. (1987) is 5.5.

Foraminifera faunas

The genera *Glomospirella* and *Meandrospira* dominate the taxonomic composition of the foraminifera assemblages (Fig. 8) from the Bravnice locality. The foraminifera are very small and their preservation is not very good. Two assemblages can be distinguished:

- The lower part of the Bravnice section (samples BR 4 - 6) yields *Nodosaria* ex gr. *skyphica*, *Ammodiscus* ex gr. *minutus*, *Glomospirella triphonensis* and *G. shengi*. Among these taxa, *Glomospirella* is most abundant.
- The assemblages from the upper part of the section (samples BR 11 - 14) are marked by abundant of *Meandrospira cheni* and *M. pusilla*.

TAXA	SAMPLE	BR 1	BR 2	BR 3	BR 4	BR 5	BR 6	BR 7	BR 8	BR 9	BR 10	BR 11	BR 12	BR 13	BR 14	BR 15	BR 16	BR 17	BR 18	BR 19	
<i>Ammodiscus</i> ex gr. <i>minutus</i>						x															
<i>Glomospirella triphonensis</i>							x														
<i>Glomospirella shengi</i>							x														
<i>Meandrospira cheni</i>												x	x	x	x						
<i>Meandrospira pusilla</i>												x	x	x	x						
<i>Nodosaria</i> ex gr. <i>skyphica</i>					x																
<i>Triassospathodus triangularis</i>												1				1					
<i>Triassospathodus hungaricus</i>		4	2	6			1														
<i>Triassospathodus</i> sp.			1				1														
Ellisoniidae			16				7						12	9	30					1	1
ramiform elements			4	5		5	25		6		1			17		15	3			1	1
fish teeth			4																		

Fig. 7. Distribution of microfossils in the Bravnice section. Vr – very rare (1 specimen), r – rare (2 – 4 specimens), a – abundant (5–10 specimens), va – very abundant (more than 11 specimens).

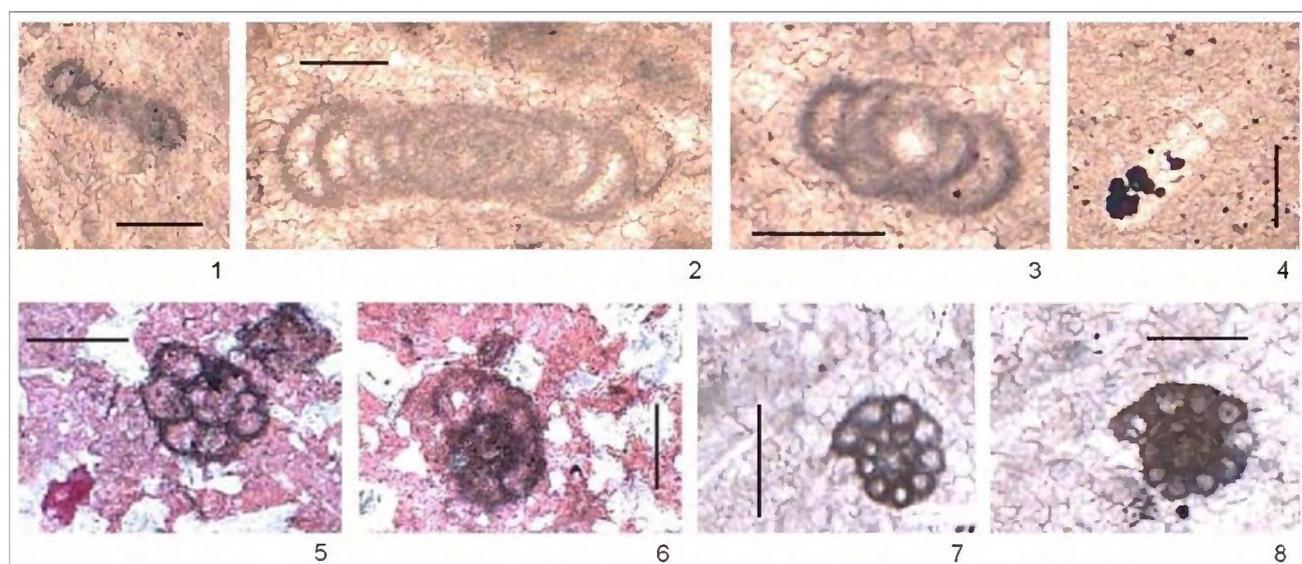


Fig. 8. Foraminifera of the Early Triassic Bravnice section, Bosnia and Herzegovina. 1–4 *hungaricus* Zone, 5–8 *triangularis* Zone. Scale bar 100 microns.

- Ammodiscus* ex gr. *minutus* Efimova, 1974. Sample BR 5, subaxial section.
- Glomospirella triphonensis* Baud, Zaninetti & Broennimann. Sample BR 6, subequatorial section.
- Glomospirella shengi* Ho, 1959. Sample BR 6, subequatorial section.
- Nodosaria* ex gr. *skyphica* Efimova, 1974. Sample BR 4, sublongitudinal section.
- Meandrospira cheni* (Ho), 1959. 5 – sample BR 12A/2, 6 – sample BR 12A/3, subequatorial sections.
- Meandrospira pusilla* (Ho), 1959. Sample BR 14/1, subequatorial sections.

Taxonomic remarks

Meandrospira cheni (Ho) and *M. pusilla* (Ho) are very similar, and ZANINETTI (1976) combined these two taxa in *M. pusilla* (Ho). On the other hand, later studies (SALAJ et al., 1983; TRIFONOVA, 1993; RETTORI, 1995) considered the two forms as separate species. Both of these species can be distinguished in the Bravnice section.

Occurrence

G. shengi was first found in the Lower Triassic of China (Ho, 1959). Later this species was described from the Lower and Middle Triassic (Anisian) of the Dinarides, Hungary, East Carpathians, Bulgaria, Turkey, Caucasus (ZANINETTI, 1976; PANTIĆ, 1970; UROŠEVIĆ & JELIČIĆ, 1973-1974; DRAGASTAN, & GRĀDINARU, 1975; DAGER, 1978; ORAVECZ-SCHEFFER, 1987; EFIMOVA, 1991; TRIFONOVA, 1992; RETTORI, 1995; KOLAR-JURKOVŠEK et al., 2013) and from the Rhaetian of the West Carpathians (SALAJ et al., 1983).

G. triphonensis was first described in the Upper Anisian of the Switzerland (BAUD et al., 1971). It is known from the Lower and Middle Triassic (Anisian) of the of the Alps, North-Sudetic Basin, Dinarides, Carpathians, Hungary, Bulgaria, Hellenides, Turkey, Israel, Caucasus, Iran (PANTIĆ & RAMPNOUX, 1972; ZANINETTI, 1976; PANTIĆ & RADOŠEVIĆ, 1977a; DAGER, 1978; SALAJ et al., 1983; ORAVECZ-SCHEFFER, 1987; SALAJ et al., 1988; EFIMOVA, 1991; TRIFONOVA, 1992; RETTORI, 1995; BUCUR et al., 1997; CHRZĄSTEK, 2002).

M. cheni was first found in the Lower Triassic of China (Ho, 1959). Later this species was described from the Lower Triassic of the Dinarides, Carpathians, Bulgaria, Hellenides, Israel, United Arab Emirates (SALAJ et al., 1983, 1988; TRIFONOVA, 1993; RETTORI, 1995; MAURER et al., 2008; KORNGREEN et al., 2013).

M. pusilla was first described in the Lower Triassic of China (Ho, 1959). It is known from the Lower and Middle Triassic (Anisian) of the of the Alps, Apennines, Dinarides, Carpathians, Hungary, Bulgaria, Hellenides, Turkey, Israel, Crimea, Caucasus, Iran, Pakistan, Thailand, Malaysia; British Columbia (ĐURĐANOVIĆ, 1967; PANTIĆ, 1970; UROŠEVIĆ, 1971; PANTIĆ & RAMPNOUX, 1972; RAMOVŠ, 1972; ZANINETTI, 1976; PANTIĆ & RADOŠEVIĆ, 1977a, b; DAGER, 1978; SALAJ et al., 1983; ORAVECZ-SCHEFFER, 1987; SALAJ et al., 1988; EFIMOVA, 1991; TRIFONOVA, 1993; RETTORI, 1995; BUCUR et al., 1997; POPESCU & POPESCU, 2005; VUKS, 2007; KRÄINER & VACHARD, 2011; SANO et al., 2012).

N. skyphica was first found in the Olenekian of the Eastern Precaucasus and Western Caucasus (EFIMOVA, 1974). Later this species was described from upper Olenekian and Middle Triassic (Anisian) of Bulgaria, Anisian of Hellenides and

Carpathians (EFIMOVA, 1991; TRIFONOVA, 1994; BUCUR et al., 1997).

A. minutus was first described in the Lower Olenekian of the Western Caucasus; EFIMOVA (1974) wrote that some *Ammodiscus incertus* d'Orbigny identified by some micropalaeontologists from the Lower Triassic of the Western Europe were in her opinion *A. minutus*.

All species from the Bravnice section are known from the Lower Triassic and Anisian, except *M. cheni*, which is typical for the Lower Triassic only.

Comparison

The generic composition of the foraminiferan assemblages from the Bravnice is similar to Early Triassic assemblages from different parts of the Tethys, from the Alps to China. There are some species in common with foraminiferan assemblages from the Lower Triassic of China (Ho, 1959; HE, 1993), the Olenekian of the Caucasus area (EFIMOVA, 1991), the Lower Triassic of Bulgaria (TRIFONOVA, 1992; 1993), Hungary (ORAVECZ-SCHEFFER, 1987), Alps (ZANINETTI, 1976; BROGLIO LORIGA et al., 1990; RETTORI, 1995), British Columbia (SANO et al., 2012).

Foraminiferan assemblages with similar taxonomical composition are mainly known in the Lower Triassic and Anisian of the several areas of Dinarides (ĐURĐANOVIĆ, 1967; DIMITRIJEVIĆ et al., 1968; PANTIĆ & RAMPNOUX, 1972; RAMOVŠ, 1972; PANTIĆ-PRODANOVIĆ & RADOŠEVIĆ, 1977a, b). The joined findings of the mentioned species of *Meandrospira* are possible in the Spathian (SALAJ et al., 1983; TRIFONOVA, 1993) or in the Spathian without lowermost part (RETTORI, 1995). Therefore it is reasonable to conclude that both foraminiferan assemblages from the Bravnice section in Bosnia and Herzegovina is within the Olenekian.

Conodont faunas (Fig. 9)

Conodont faunas of Bravnice section are predominantly ramiform elements and some can be attributed to Ellisoniidae. The fragmentation of conodont elements does not permit apparatus reconstruction. All collected P elements belong to *Triassospathodus* Kozur. In a contrast to *Neospathodus* Mosher (MOSHER, 1968), elements of *Triassospathodus* can be easily distinguished due to downcurved posterior end of the lower margin of the basal cavity (KOZUR et al., 1998).

The segminate P₁ elements from the lower part of the section (samples BR 1-3, 6) are short and high. They bear three to five denticles, and the expanded basal cavity is symmetrical. Such elements are attributed to *T. hungaricus* (Fig. 9. 1-8) and thus the lower part of the Bravnice section is placed in the *hungaricus* conodont Zone.

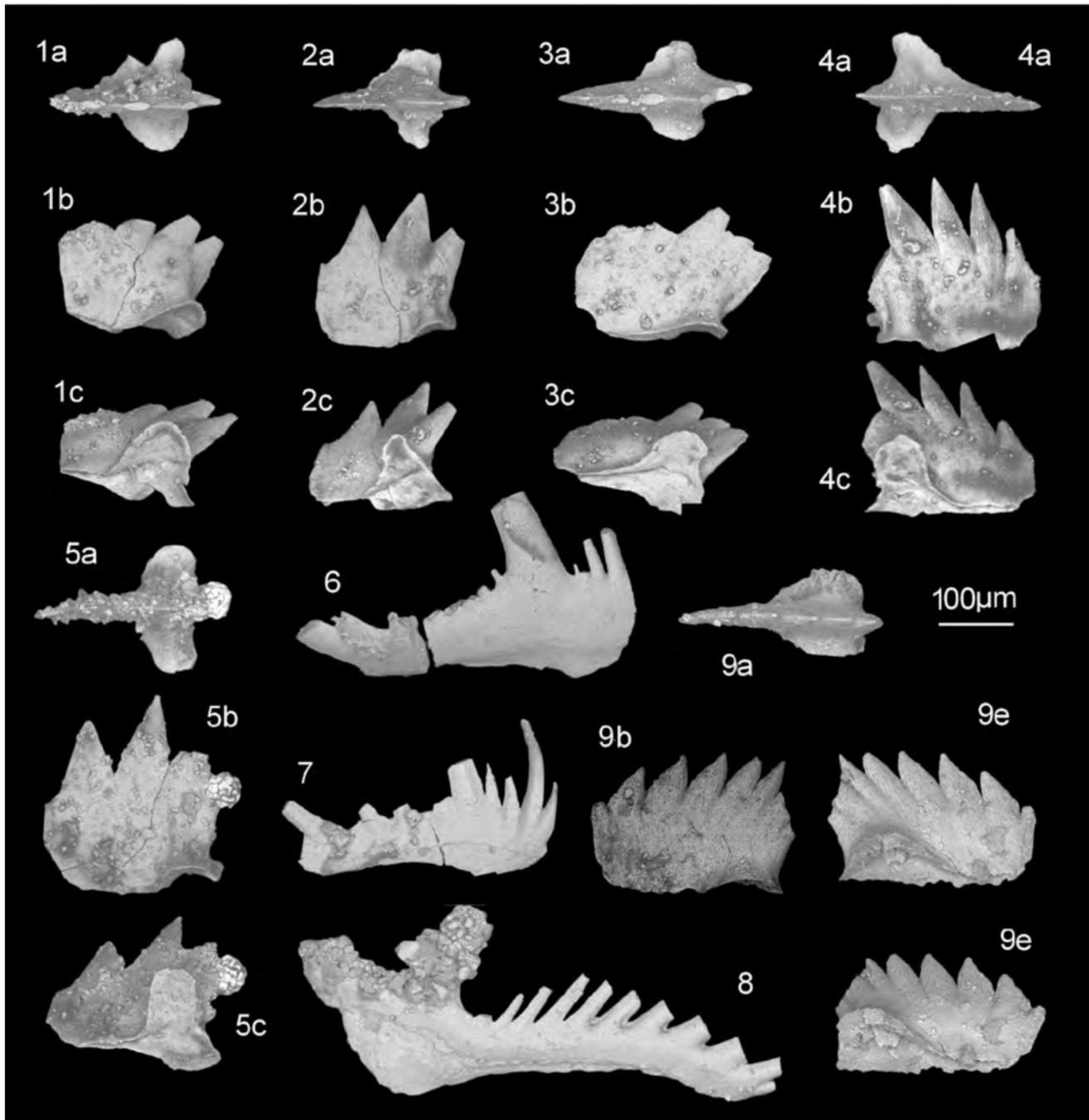


Fig. 9. Conodonts of the Early Triassic Bravnice section, Bosnia and Herzegovina. 1–8 *hungaricus* Zone, 9 *triangularis* Zone. Scale bar 100 microns.

1–8 *Triassospathodus hungaricus* (Kozur & Mostler). 1–5 P-elements: 1–4 sample BR 1 (GeoZS 5113), 5 sample BR 3 (GeoZS 5114); 6–8 ramiform elements (S3 or S4): 6–7 sample BR 2 (GeoZS 5079), 8 sample BR 3 (GeoZS 5114).

9 *Triassospathodus triangularis* (Bender). Sample BR 15 (GeoZS 5120).
a – upper, b – lateral, c – oblique lower views.

The samples BR 11 and 15 yield rare segminate elements that are relatively short with subtriangular basal cavity developed in the posterior half. Denticles, eight or nine in number are slightly increasing in height and reveal posterior inclination. One smaller denticle is developed behind the cusp. This specimens are attributed to *T. triangularis* and some forms probably represent an intermediate stage (Fig. 9. 9). This portion of the section is placed into the *T. triangularis* conodont Zone.

Taxonomic remarks

The classification of the Early Triassic segminate pectiniform elements is still uncertain. Several views on their relationships have been put forward. According to ORCHARD (1995) *Neospathodus* species may belong to any of several Lower Triassic groups depending on their basal profile, development of cusp, or inclination of denticles. In his opinion there exist also some unrelated homeomorphs. This genus evolved from *Neogondolella* in the Induan as demonstrated by

similarities in composition of their apparatuses (ORCHARD, 2010). On the other hand, KOZUR et al. (1998) placed most Spathian segminate elements in the genus *Triassospathodus*, and this view is adopted in this paper.

Occurrence

T. hungaricus was first described from the *Tirolites* beds of Felsőörs in Hungary (KOZUR & MOSTLER, 1970). The species has been known in Slovenia so far from the Spathian of the Idrija-Žiri and Krško areas (KOLAR-JURKOVŠEK, unpublished data) and Julian Alps (KOLAR-JURKOVŠEK et al., 2013). Some similar specimens collected in the Thaynes Group of Elko County in Nevada were illustrated and determined as »*Neospathodus*« cf. *hungaricus* (LUCAS & ORCHARD, 2007). The full stratigraphic range of the lowermost Spathian species *T. hungaricus* is not yet known and its occurrence above the *T. hungaricus* Zone has not yet been reported.

T. triangularis was first described from the Marmarotrapeza Formation at Chios by BENDER (1970). The latest Spathian spathodid faunas that include *T. triangularis* were hitherto reported from the central Slovenia (DOZET & KOLAR-JURKOVŠEK, 2007) and the Idrija-Žiri area (KOLAR-JURKOVŠEK, unpublished data). In the southeastern continuation of the Dinarides, the species was collected also from the Muć section in Croatia that was proposed as a standard section for the European Upper Scythian (HERAK et al., 1983). The fauna with co-occurring elements of *T. homeri* and *T. triangularis* was also reported from the Spathian of Krivi potok in NW Serbia (SUDAR, 1986a, b).

Discussion

The biostratigraphic scheme of KOZUR (2003) of the Late Olenekian is largely based on *Triassospathodus* (Fig. 10), and the stratigraphic importance of this genus for the Spathian strata was pointed out by KOZUR et al. (1998). There are six conodont zones in the Spathian, and *T. hungaricus* is the nominal index species of the basal Spathian, that is equivalent to the *Tirolites cassianus* ammonoid zone. *T. triangularis* is the marker of the fourth zone (KOZUR, 2003). In the shallow western Tethys, the *T. hungaricus* fauna lies within the lower Spathian, in the absence of the *Icriospathodus collinsoni* (Solien) fauna (H. KOZUR - pers. comm., 2012).

Comparison of conodont faunas:

The genera *Triassospathodus* and *Spathicuspus* are dominant in the Olenekian, whereas the long-ranging late Olenekian species assigned to žN.' *triangularis* is an uncommon conodont taxon, that ranges up to the Olenekian/Anisian boundary in the Guandao section (ORCHARD et al., 2007b).

In the Deşli Caira section the LAD of characteristic conodont species determined as žN.' *triangularis* was recorded in the sample GR7 representing a major faunal change of the succession (Datum 3) that involves also the FADs of *Chiosella timorensis* Nogami and *Chiosella* n. sp. A (ORCHARD et al., 2007a).

According to ORCHARD et al. (2007b) species of the *T. ex gr. homeri* that includes *T. symmetricus* (Orchard), *T. brochus* (Orchard), *T. sosioensis* (Kozur, Krainer & Mostler) are most common and ubiquitous elements of late Spathian faunas in Eurasia and North America. The assemblage of the *T. homeri* group indicates late Smithian-Spathian interval in the Cache Creek Terrane succession of British Columbia (SANO et al., 2012).

T. triangularis is a widespread late Spathian taxon, present in Deşli Caira in Romania and Guandao in China (ORCHARD et al., 2007a, b). It is part of the Fauna 3 that is equivalent to the *Prohungarites/Subcolumbites* beds within the context of North American ammonoid succession (ORCHARD, 2010).

Conclusions

This study presents new sedimentological and palaeontological documentation of the remarkable Lower Triassic limestone of the Jajce area (Bosnia and Herzegovina), a candidate for the UNESCO World Heritage Site. The bio- and litho- stratigraphy of the Bravnice section near Jajce has been investigated. The material is rich in ichnofossils and molluscan macrofauna dominated by *Natiria costata*, a widely distributed and characteristic species for the Early Triassic. The strata yield significant Spathian (Olenekian) faunas based on a *Triassospathodus* dominated conodont assemblage. The older fauna is marked by *Triassospathodus hungaricus* and the foraminifera *Nodosaria ex gr. skyphica*, *Ammodiscus ex gr.*

Stage/ Substage	Ammonoid Zone	Conodont Zone
Late Olenekian (Spathian)	<i>Neopopanoceras haugi</i>	<i>Chiosella gondolelloides</i>
	<i>Prohungarites-Subcolumbites</i>	<i>Triassospathodus sosioensis</i>
	<i>Procolumbites</i>	<i>Triassospathodus triangularis</i>
	<i>Columbites parisianus</i>	<i>Triassospathodus homeri</i>
	<i>Tirolites cassianus</i>	<i>Icriospathodus collinsoni</i>
		<i>Triassospathodus hungaricus</i>

Fig. 10. Correlation of Late Olenekian (Spathian) ammonoid and conodont zonations after KOZUR (2003).

minutus, *Glomospirella triphonensis* and *G. shengi*, that can be attributed to the lower Spathian *T. hungaricus* conodont Zone. A younger fauna marked by presence of *T. triangularis* in association with *Meandrospira cheni* and *M. pusilla* is placed into the *T. triangularis* conodont Zone.

Well bedded Spathian limestones of the type exploited by local inhabitants for construction and paving in the old Jajce town, have been investigated from east from the Bravnice village. Four microfacies types were differentiated: 1) laminated mudstone – micrite, 2) laminated calcareous siltstone, 3) fine-grained bioclastic packstone – biomicrite and 4) coarse-grained bioclastic packstone – biomicrite. The depositional environment is characteristic of the outer part of a wide shallow shelf/ramp, but subject to distal storm events. Between storms, bioturbated sediments are formed, but may be interrupted by episodes of poor aeration and anoxia. These features have similarly been suggested also for other locations along entire Dinaride area.

The Bravnice section represents an important reference section for the Olenekian of Bosnia and Herzegovina based on Spathian (Olenekian) conodont faunas and the accompanied fossil association. The recovered faunas consist of important correlative elements for comparison with co-eval faunas elsewhere in the Dinaride area, and for the Early Triassic Tethys worldwide.

These Lower Triassic limestones of Bravnice are of great importance for the restoration of old buildings in this area, and particularly for reconstruction of the Jajce town, a candidate for the UNESCO World Heritage List. They can also be used for new architectural projects that should conform to the local style. Such source materials should play a much more significant role in reconstruction, and are much preferred to non-autochthonous magmatic and metamorphic rocks that have unfortunately been used in the past.

Acknowledgments

Field work for this study was carried out in the framework of scientific research cooperation between the republics of Slovenia and Bosnia and Herzegovina (2012–2013). Elaboration of this work was supported financially by the Research Agency of Slovenia (program P1-0011) and University of Zagreb (SP project 202652). Communication with the late Heinz Kozur on conodont fauna is appreciated. The authors thank Milan Sudar (Belgrade) and Yanlong Chen (Graz) for constructive review and Chaim Benjamini (Jerusalem) for correcting the English. This is a contribution to international project IGCP 630 »Permian-Triassic climatic and environmental extremes and biotic responses«.

References

- ALJINOVIĆ, D. 1995: Storm influenced shelf sedimentation - An example from the Lower Triassic (Scythian) siliciclastic and carbonate succession near Knin (Southern Croatia and Western Bosnia and Herzegovina). *Geologia Croatica*, 48/1: 17–32.
- ALJINOVIĆ, D., KOLAR-JURKOVŠEK, T., JURKOVŠEK, B., HRVATOVIĆ, H. 2011: Conodont dating of the Lower Triassic sedimentary rocks in the External Dinarides (Croatia and Bosnia and Herzegovina). *Rivista italiana di paleontologia e stratigrafia*, 117/1: 135–148.
- BENDER, H. 1970: Der Nachweis von Unter- Anis (Hydasp) auf der Insel Chios. *Ann. Geol. Pays Helleniques*, 19: 412–464.
- BROGLIO LORIGA, C., GOCZAN, F., HAAS, J., LENNER, K., NERI, C., ORAVECZ-SCHEFFER, A., POSENATO, R., SZABO, I. & MAKK, A.T. 1990: The Lower Triassic sequences of the Dolomites (Italy) and Transdanubian Mid-Mountains (Hungary) and their correlation. *Memorie di Scienze Geologiche, Università di Padova*, 42: 41–103.
- BUCUR, I.I., STRUTINSKI, C. & PAICA, M. 1997: A new occurrence of Triassic deposits NE of Oravita (Southern Carpathians, Rumania) and its paleotectonic significance. *Geologica Carpathica*, 48/1: 39–48.
- CHRZĄSTEK, A. 2002: Stratigraphy and sedimentation conditions of Roet and Lower Muschelkalk of the North Sudetic Basin. *Acta Universitatis Wratislaviensis No 2383, Prace Geologiczne – Mineralogiczne*, 73: 1–112. (In Polish with English summary)
- DAGER, Z. 1978: Les Foraminifères du Trias de la Péninsule de Kocaeli – Turquie. *Notes du Laboratoire de Paleontologie de l'Université de Geneve*, 3/4: 23–69.
- DIMITRIJEVIĆ, M., PANTIĆ, S., RADOIČIĆ, R. & STEFANOVSKA, D. 1968: Lithostratigraphic and biostratigraphic Mesozoic columns in the Gacko-Sutjaska-Drina region. *Bulletin Institut de Recherches Geologiques et Geophysiques, Series A*, 26: 35–114.
- DOZET, S. & KOLAR-JURKOVŠEK, T. 2007: Spodnjetriasne plasti na južnovzhodnem obrobju Ljubljanske kotline, osrednja Slovenija. *RMZ - Materials and Geoenvironment*, 54/3: 361–386.
- DRAGASTAN, O., & GRĂDINARU, E. 1975: Asupra unor alge, foraminifere, sphinctozoare și microproblematice din Triasicul din Carpații Orientali și Dobrogea de Nord. *St. cerc. geol. geofiz. geogr., Geol.*, 20/2: 247–254.
- ĐURĐANOVIĆ, Ž. 1967: The Lower Triassic of the Gorski Kotar region. *Geološki vjesnik*, 20: 107–110.
- EFIMOVA, N.A. 1974: Triassic foraminifers of the North-West Caucasus and Precaucasus. *Questions of Micropaleontology*, 17: 54–83. (in Russian)
- EFIMOVA, N.A. 1991: Triassic system. In: AZBEL, A.Y. & GRIGELIS, A.A. (eds.): *Practical Manual on Microfauna of the USSR 5. Mesozoic Foraminifers*. Nedra, Leningrad: 16–25. (in Russian)
- HE, Y. 1993: Triassic foraminifera from northeast Sichuan and south Shaanxi, China. *Acta Paleontologica Sinica*, 32/2: 170–187. (in Chinese, with English abstract)

- HERAK, M., ŠČAVNIČAR, B., ŠUŠNJARA, A., ĐURDANOVIĆ, Ž., KRYSŤYN, L. & GRUBER, B. 1983: The Lower Triassic of Muć – Proposal for a standard section of the European Upper Scythian. *Schriftenreihe der Erdwissenschaftlichen Kommissionen, Österreichische Akademie der Wissenschaften*, 5: 93–106.
- HO, Y. 1959: Triassic foraminifera from the Chialingkiang Limestone of South Szechuan. *Acta Paleontologica Sinica*, 7/5: 387–418. (in Chinese, with English abstract)
- HOFMANN, R., HAUTMANN, M., WASMER, M. & BUCHER, H. 2013: Palaeoecology of the Virgin Formation (Utah, USA) and its implications for the Early Triassic recovery. *Acta Palaeontologica Polonica*, 58/1: 149–173.
- HERAK, M., ŠČAVNIČAR, B., ŠUŠNJARA, A., ĐURDANOVIĆ, Ž., KRYSŤYN, L. & GRUBER, B. 1983: The Lower Triassic of Muć – Proposal for a standard section of the European Upper Scythian. *Schriftenreihe der Erdwissenschaftlichen Kommissionen, Österreichische Akademie der Wissenschaften*, 5: 93–106.
- HRVATOVIĆ, H. 2006: Geological guidebook through Bosnia and Herzegovina. *Geološki Glasnik*, 28: 1–172.
- KATZER, F. 1921: Pregledna geološka karta Bosne i Hercegovine, list Banja Luka 1:200.000, Sarajevo.
- KOLAR-JURKOVŠEK, T., VUKS JA.V., ALJINOVIĆ, D., HAUTMANN M., KAIM, A. & JURKOVŠEK, B. 2013: Olenekian (Early Triassic) fossil assemblage from Eastern Julian Alps (Slovenia). *Annales Societatis Geologorum Poloniae*, 83: 213–227.
- KOZUR, H. 2003: Integrated ammonoid-, conodont and radiolarian zonation of the Triassic. *Hallesches Jahrb. Geowiss.*, 25: 49–79.
- KOZUR, H. & MOSTLER, H. 1970: Neue Conodonten aus der Trias. *Berichte Natur-Medizin Vereins Innsbruck*, 58: 429–464.
- KOZUR, H., MOSTLER, H., & KRÄINER, K. 1998: *Sweetospathodus* n. gen. and *Triassospathodus* n. gen., two important Lower Triassic conodont genera. *Geologia Croatica*, 51/1: 1–5.
- KORNGREEN, D., ORLOV-LABKOVSKY, O., BIALIK, O., & BENJAMINI, C. 2013: The Permian–Triassic transition in the central coastal plain of Israel (North Arabian plate margin), David 1 borehole. *Palaios*, 28/8: 491–508, doi:10.2110/palo.2012.p12-042r.
- KRÄINER, K., & VACHARD, D. 2011: The Lower Triassic Werfen Formation of the Karawanken Mountains (Southern Austria) and its disaster survivor microfossils, with emphasis on *Postcladella* n. gen. (Foraminifera, Miliolata, Cornuspirida). *Revue de Micropaléontologie*, 54/2: 59–85, doi:10.1016/j.revmic.2008.11.001.
- LUCAS, S.G. & ORCHARD, M.J. 2007: Triassic lithostratigraphy and biostratigraphy north of Currie, Elko County, Nevada. In: LUCAS S.G. & SPIELMANN J.A. (eds.): *The Global Triassic*. New Mexico Museum of Natural History and Science Bulletin, 40: 119–126.
- MAURER, F., RETTORI, R. & MARTINI, R. 2008: Triassic stratigraphy, facies and evolution of the Arabian shelf in the northern United Arab Emirates. *International Journal of Earth Sciences (Geologische Rundschau)*, 97: 765–784.
- MOSHER, L.C. 1968: Triassic conodonts from western North America and Europe and their correlation. *Journal of Paleontology*, 42/4: 895–946.
- ORAVECZ-SCHNEFFER, A. 1987: Triassic foraminifera of the Transdanubian Central Range. *Geologica Hungarica, Series Palaeontologica*, 50: 1–134.
- ORCHARD, M.J. 1995: Taxonomy and correlation of Lower Triassic (Spathian) segminate conodonts from Oman and revision of some species of *Neospathodus*. *Journal of Paleontology*, 69/1: 110–122.
- ORCHARD, M.J. 2010: Triassic conodonts and their role in stage boundary definition. In: LUCAS, S.G. (ed.): *The Triassic Timescale: an Introduction*. Geological Society, London, Special Publications, 334: 139–161.
- ORCHARD, M.J., GRÄDINARU, E. & NICORA, A. 2007a: A summary of the conodont succession around the Olenekian–Anisian boundary at Deșli Caira, north Dobrogea, Romania. In: LUCAS, S.G. & SPIELMANN, J.A. (eds.): *The Global Triassic*. New Mexico Museum of Natural History and Science Bulletin, 41: 341–346.
- ORCHARD, M.J., LEHRMANN, D.J., JIALONG, W., HONMEI, W. & TAYLOR, H.J. 2007b: Conodonts from the Olenekian–Anisian boundary beds, Guandao, Guizhou Province, China. In: LUCAS, S.G. & SPIELMANN, J.A. (eds.): *The Global Triassic*. New Mexico Museum of Natural History and Science Bulletin, 41: 347–354.
- PANTIĆ, S. 1970: Caractéristiques micropaléontologiques de la colonne triasique de l'anticlinal de Zdrelo (Serbie orientale). *Bulletin Institut de Recherches Géologiques et Géophysiques, Series A*, 28: 377–385.
- PANTIĆ, S. & RAMPINOUX, J.P. 1972: Concerning the Triassic in the Yugoslavian Inner Dinarides (Southern Serbia, Eastern Montenegro): microfacies, microfauna, an attempt to give a paleogeographic reconstitution. *Mitteilungen der Gesellschaft der Geologie- und Bergbaustudenten*, 21: 311–326.
- PANTIĆ-PRODANOVIĆ, S., & RADOŠEVIĆ, B. 1977a: The lithostratigraphic characteristics of Triassic sediments on Tara mountain Inner Dinarides, Yugoslavia. In: KALLERGIS, G., (ed.): *Proceedings of the VI Colloquium on the Geology of the Aegean Region*, Athens: 1159–1167.
- PANTIĆ-PRODANOVIĆ, S. & RADOŠEVIĆ, B. 1977b: Geological section of Scythian and Anisian stages in the Jelovica River valley (southeastern Serbia). *Bulletin du Museum d'histoire naturelle de Belgrade, Series A*, 32: 75–93.

- POPESCU, D.A., & POPESCU, L.G. 2005: The Olenekian carbonates of the Bucovinian nappe (the central sector of the Hăgismaş syncline, Eastern Carpathians): lithology and microfacies. *Studia Universitatis Babeş-Bolyai, Geologia*, 50/1-2: 53-62.
- PRLJ-ŠIMIĆ, N. 2006: Stratotip. Hrvatski prirodoslovni muzej, Zagreb: 47 p.
- PUZINA, D., VASILJEVIĆ, R. & KUČUKOVIĆ, A. 1969: Novi rezultati geoloških istraživanja područja sjeverno od Jajca. *Geološki vjesnik*, 22: 247-268.
- RAMOVŠ, A. 1972: Mikrofauna der alpinen und voralpinen Trias Sloweniens. *Mitteilungen der Österreichischen Geologischen Gesellschaft*, 21: 413-426.
- REJEBIAN, V.A., HARRIS, A.G. & HUEBNER, J.S. 1987: Conodont color alteration and textural alteration: An index to regional metamorphism, contact metamorphism and hydrothermal alteration. *Geol. Soc. Am. Bull.*, 99: 471-497.
- RETTORI, R. 1995: Foraminiferi del Trias Inferiore e Medio della Tetide: revisione tassonomica, stratigrafia ed interpretazione filogenetica. *Université de Genève, Département de Géologie Paléontologie*, 18: 1-150.
- SALAJ, J., BORZA, K. & SAMUEL, O. 1983: Triassic foraminifers of the West Carpathians. *Geologický Ústav Dionýza Stura, Bratislava*: 213 p.
- SALAJ, J., TRIFONOVA, E., GHEORGHIAN, D. & CORONEOU, V. 1988: The Triassic foraminifera microbiostratigraphy of the Carpathian-Balkan and Hellenic realm. *Mineralia Slovaca*, 20/5: 387-415.
- SANO, H., ONOUE, T., ORCHARD, M.J. & MARTINI, R. 2012: Early Triassic peritidal carbonate sedimentation on a Panthalassan seamount: the Jesmond succession, Cache Creek Terrane, British Columbia, Canada. *Facies*, 58/1: 113-130.
- SCOTESE, C.R. 2001: Atlas of Earth History. Volume 1, Paleogeography, PALEOMAP Project, Arlington, Texas: 52 p.
- SUDAR, M. 1986a: Mikrofosili i biostratigrafija trijasa unutrašnjih Dinarida Jugoslavije između Gučeva i Ljubišnje / Triassic microfossils and biostratigraphy of the Inner Dinarides between Gučevo and Ljubišnja Mts., Yugoslavia. *Geološki anali Balkanskoga poluostrva*, 50: 151-394 (in Serbian, English summary).
- SUDAR, M. 1986b: Značaj konodonata za biostratigrafiju trijasa unutrašnjih Dinarida Jugoslavije = The importance of conodonts for Triassic biostratigraphy of the Inner Dinarides of Yugoslavia). XI Kongres geologa Jugoslavije, Tara, 30. IX - 2. X 1986, knj. 2, Stratigrafija, paleontologija i regionalna geologija: 113-124. (in Serbian, English summary)
- TRIFONOVA, E. 1992: Taxonomy of Bulgarian Triassic foraminifera. I. Families Psammosphaeridae to Nodosinellidae. *Geologica Balcanica*, 22/1: 3-50.
- TRIFONOVA, E. 1993: Taxonomy of Bulgarian Triassic foraminifera. II. Families Endothyriidae to Ophthalmidiidae. *Geologica Balcanica*, 23/2: 19-66.
- TRIFONOVA, E. 1994: Taxonomy of Bulgarian Triassic foraminifera. III. Families Spiroloculiniidae to Oberhausereliidae. *Geologica Balcanica*, 24/2: 21-70.
- UROŠEVIĆ, D., 1971: A survey of Triassic fauna and flora of Stara Planina Mt (Carpatho-Balkan Region). *Annales Geologiques de la Peninsule Balkanique*. 36: 95-104.
- UROŠEVIĆ, D. & JELIČIĆ, L. 1973-1974: Conodonts and foraminifers from Hanbulog limestone of Serbia, Bosnia, Herzegovina and Montenegro. *Bulletin Institut de Recherches Geologiques et Geophysiques, Ser. A*, 31-32: 251-263.
- VUJNOVIĆ, L. 1980: Geologija područja između Jajca-Donjeg Vakufa i Kupresa (Geology of the area Jajce-Donji Vakuf-Kupres). Posebno izdanje *Geološkog glasnika*, 16: 1-104.
- VUJNOVIĆ L. 1981: Tumač za list Bugojno L33-143. Osnovna geološka karta SFRJ 1:100.000. Savezni geološki zavod, 58 p., Beograd.
- VUKS, V.J. 2007: Olenekian (Early Triassic) foraminifers of the Gorny Mangyshlak, Eastern Precaucasus and Western Caucasus. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 252: 82-92.
- ZANINETTI, L. 1976: Les Foraminifères du Trias. Essai de synthèse et corrélation entre les domaines mésogéens européen et asiatique. *Rivista italiana di paleontologia e stratigrafia*, 82/1: 1-258.