Olenekian (Early Triassic) Fossil Assemblage from Eastern Julian Alps (Slovenia)

Tea Kolar-Jurkovšek, Valery J. Vuk, Dunja Aljinović, Michael Hautmann, Andrzej Kaim & Bogdan Jurkovšek

Abstract: New palaeontological and sedimentological data from the Lower Triassic strata of the eastern Julian Alps in Slovenia are presented. They are unusual for the Early Triassic of the Alps in representing a relatively deeper, unrestricted marine (mid-ramp) setting. There are two basic microfacies types in the section investigated (types A and B), which are organized as couplets with coarse-grained tempestitic deposits (microfacies A), overlain by laminated or bioturbated lime mudstones and/or marls (microfacies B), frequently containing ammonoids. This pattern is interpreted as storm deposition with occasional winnowing of bottom sediments and the formation of coarse-grained skeletal deposits (lags), followed by the slow settling of suspended particles, when the storm waned, in addition to background deposition. Dominantly lime mud deposition and the presence of ammonoids indicate deposition on a more distal, deeper ramp with an unrestricted connection to the open sea. Intense reworking of bottom skeletal-rich sediment and accumulation of storm lags suggest deposition above the storm wave base, possibly in a wide low-energy mid-ramp environment. Faunas from such settings have been reported relatively rarely from the Early Triassic of the Alps. The macrofauna contains ammonoids, bivalves and gastropods, whereas the microfauna is represented by foraminifer tests and conodont elements; rare fish remains also occur. In the foraminifer assemblages, species of Ammodiscus, Hoyenella, Glomospirella dominated, corresponding to the widespread "Glomospira-Glomospirella" foraminifer community, with some miliolids and nodosariids. The conodont fauna is characterized by Triassospathodus hungaricus (Kozur et Mostler), indicating an early Spathian (Olenekian) age. The fossil assemblage highlights the wide distribution of Early Triassic taxa in the Tethys and facilitates its worldwide correlation. Its relatively low diversity by comparison with shallow marine settings is interpreted as an evolutionary proximal-distal trend in the wake of the end-Permian mass extinction. Re-diversification first occurred in nearshore settings and expanded into deeper/distal marine environments through geological time.

Key words: Olenekian, Early Triassic, foraminifers, bivalves, gastropods, conodonts, sedimentology, Julian Alps, Slovenia.

Manuscript received 4 August 2013, accepted 23 December 2013

INTRODUCTION

The end-Permian mass extinction event was pivotal in the Phanerozoic history of marine life, terminating the incumbrancy of the “Palaeozoic Evolutionary Fauna” that had dominated life in the sea for nearly 250 million years (Sepkoski, 1984). In the wake of the extinction event, the ecological structure of the present-day biosphere evolved from the stock of the surviving taxa, shaping the “Modern Evolutionary Fauna” that characterizes marine ecosystems until today (Sepkoski, 1997). The recovery from the end-Permian mass extinction is therefore crucial for understanding
how the present-day biosphere evolved. An indispensable prerequisite in this context is a census of the faunas that lived and evolved during the Early Triassic, i.e., the epoch that followed the crises. Thus, collecting and interpreting new field data from the Early Triassic has been a major research agenda during the past decade (e.g., Brayard and Bucher, 2008; Posenato, 2008; Kumagae and Nakazawa, 2009; Kaim et al., 2010, 2013; Hautmann et al., 2011, 2013; Brühwiler et al., 2012; Wasmer et al., 2012; Hofmann et al., 2013a, b). However, Early Triassic benthic faunas have been described mostly from relatively shallow marine sections, particularly in Europe, where deeper shelf settings are rare. The section investigated is also known as the location, where an isolated temnospondyl bone (Lucas et al., 2008), was found and therefore represents an important site of Slovenian natural heritage. In this study, new sedimentological and palaeontological data are presented from the Spa-thian (late Early Triassic) section in the Julian Alps (Slovenia). They contribute to a better understanding of how diversity and faunal composition changed along depth gradients during re-diversification from the greatest crisis in the history of life.

GEOLOGICAL SETTING

The study area is in the Julian Alps, NW Slovenia (Fig. 1). Structurally they form the easternmost continuation of the Southern Alps, where the South Alpine and the Dinaric structures now overlap (Placer, 1999). The largest overthrust unit in the Slovenian part of the Julian Alps is represented by the Julian Alps Overthrust (Jurkovšek, 1987a, b) or the Julian Nappe, which is composed of successions, ranging from Early Triassic to Cretaceous strata, though a major part of it is made up of Late Triassic carbonates. Early Triassic strata are scattered in narrow disconnected belts or patches in the wider Julian Alps area. They usually occur within smaller tectonic slices (Figs 2, 3).

The area investigated is located in the uppermost tectonic slice of the Julian Alps Overthrust, SE of Triglav Mt. (2863 m), the highest peak in Slovenia. The lower part of these strata is in tectonic contact with the Norian–Rhaetian Dachstein Limestone, whereas upwards they pass continuously into Anisian limestones and dolomites (Jurkovšek, 1987a; Celarc and Kolar-Jurkovšek, 2008).

The Studorski preval section is strongly tectonized (coordinates: N46°21′14.46″, E13°52′55.80″; WGS 84). Thick lime mudstones and marls and thin beds enriched in coarse-grained bioclastic material, predominate. The fauna is characterized by Early Triassic mollusks, dominated by bivalves and gastropods. The microfauna is diversified, but consists mainly of foraminifer assemblages in association with rare conodont elements and fish remains.

Lithology

The Studorski preval section mainly consists of thick mudstones (Fig. 4A) and marls (Fig. 4B), and thin beds, enriched in coarse-grained bioclastic material. These lithologies form units, in which coarse-grained bioclastic material...
is concentrated at the base and gradually passes upward into mudstones/marls. Thus, the microfacies in the Studorski previal section correspond to two microfacies types: microfacies type A, fossiliferous floatstone/packstones, and microfacies type B, dense or laminated lime mudstones that may pass gradually into marls.

Centimetre- to decimetre-thick fossiliferous floatstone/packstone beds (A) have distinctive sharp lower erosional boundaries. The floatstone/packstone interbeds gradationally change upward to much thicker mudstone/marl intervals, which locally were intensively reworked by organisms (Fig. 4C).

Floatstones/packstones of microfacies type A consist of coarse (usually > 2 mm) well preserved skeletal detritus (Fig. 4F). Among the skeletal fragments bivalves, gastropod, and ammonoid detritus predominate. Echinoderm ossicles and foraminiferal tests are rare. In the floatstone/packstone a bimodal sorted biofabric is found, which consists of large bioclasts and micritic matrix. Very frequently, the matrix is non-homogenous and contains a high proportion of peloidal particles and some micrite (Fig. 4E). Whole valves are dominantly oriented parallel to the bedding surface, very often in a convex-up position. Completely preserved bivalve or gastropod shells are geopetally infilled with sparry calcite. Some shelter pores, at the concave side of bivalve shells, are also infilled by sparite.

Microfacies type B consists of dense, laminated or bioturbated mudstones and/or marls. Sparse, well preserved fossils can be dispersed in the mudstones (Fig. 4D). The mudstones consist of homogenous micritic mud or micrite-rich laminae. Disturbance of the lamination is due to reworking by infaunal organisms. Lime mud is slightly recrystallized. In both microfacies types euhedral pyrite crystals and large celestite crystals (determined by EDS analysis) are present.

**MATERIAL AND METHODS**

The present study is based on field work, carried out in 2011 at Studorski previal in the Julian Alps. Approximately 10 m of the Lower Triassic strata was sampled just below the contact with the Anisian dolomite. Nine samples (SP 1–9) were collected for examination from the Lower Triassic strata; sample SP 1 is the lowest and the sample SP 9 is the highest. Rock samples with an average weight of 4 kg were processed for conodont study, using standard laboratory techniques. Several thin sections were made for the study of foraminifers as well as for petrographic purposes. Laboratory preparation was carried out at the Geological Survey of Slovenia (Geološki zavod Slovenije) where all of the micropaleontological material is stored and inventoried under repository numbers 4429, 4548–4555, 4901–4904 and abbreviated GeoZS. The collection of macrofossil specimens: Jurkovšek Paleontological Collection, Kamnica 27, Dol pri Ljubljani, Slovenia, has been registered with the Natural History Museum of Slovenia, Ljubljana and abbreviated as BJ. The determinations of conodont elements presented here and the SEM/EDS analyses were carried out, using the JEOL JSM 6490LV Scanning Electron Microscope at the Geological Survey of Slovenia.

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**Fig. 2.** Generalized stratigraphic section of Triassic strata in Julian Alps. Thick dark bar indicates section studied in tectonic slice at Studorski previal

**Fig. 3.** Palaeogeographic map for Early Triassic with position of the Julian Alps marked (star), modified from Scotese (2001)
Fig. 4. Microfacies types from Early Triassic of Studorski preval, Slovenia. Hammer length 26.5 cm (A) and 29 cm (B, C). 

A. Laminated, thin-bedded mudstones.  
B. Homogenous marl interval.  
C. Bioturbated lime mudstone.  
D. Rare skeletal fragments in dominantly muddy sediment – microfacies type B.  
E. Floatstone (microfacies type A) with coarse skeletal detritus and inhomogeneous matrix containing high proportion of pellooidal particles and some micrite.  
F. Floatstone of microfacies type A consists predominantly of bivalves and gastropod detritus. Note convex-up position of most valves.
PALAEOENVIRONMENT

The Studorski prevail section can be compared to the Werfen Formation of the Southern Alps that represents deposition on a storm-influenced ramp (Brandner et al., 2012). Sedimentation of the dominantly fine-grained microfacies type B can be interpreted as slow deposition in a deeper marine environment below the fair-weather wave base, which corresponds to the distal part of a ramp. The presence of ammonoid shells indicates a good connection with the open unrestricted sea and also implies deposition in a deeper-ramp environment. Nevertheless, the interlaying with limestone of microfacies type A suggests that slow deposition of fine-grained sediments (microfacies type B) was periodically interrupted by the deposition of coarse skeletal detritus during high-energy events (microfacies type A). The sharp and erosive lower boundaries of microfacies type A beds imply the abrupt commencement of sedimentation. The well-preserved skeletal detritus in the floatstones/packstones and the upward-increasing proportion of matrix indicate deposition during storms, in a zone above the storm-weather wave base. As the beds of microfacies type A are overlain by laminated or bioturbated calcareous mudstones and/or marls (microfacies type B), their deposition reflects short storm events in a deeper low-energy ramp environment, where the deposition of lime mud prevails. The intense bottom-shear conditions during the storm peak concentrated shells of living and dead organisms from the sea bottom, either by burying them under a sudden influx of storm-suspended particles or by exhuming previously buried shells by ripping up the underlying weakly consolidated sediments and forming skeletal concentrations (lag deposits). Therefore, well-preserved fossils within a fine micritic/peloidal matrix of microfacies type A are interpreted as the result of storm events, which preserve whole fossils by burying and protecting them from normal destructive processes. The presence of foraminifera indicates detritus derived by storms from the shallow proximal ramp. Valves oriented parallel to the bedding plane in a convex-up position also indicate deposition under short-term high-energy conditions. Furthermore, winnowing and suspension of fine sediment resulted in the deposition of the upward-finishing units above coarse lag deposits. As the storm waned, more mud was deposited from suspended material, resulting in fining-upward grading. Intense colonization by organisms and bioturbation could reflect the cessation of the storm and a return to normal low-energy ramp sedimentation below the fair-weather wave base. The presence of pyrite also indicates low-energy, and possibly partly anaerobic conditions, whereas the genesis of celestite is considered diagenetic in deep-sea sediments, as explained by Baker and Bloomer (1988) although it also has been described from shallow marine settings (Hattman, 1997). Storms are frequently recorded both in the inner and outer shelf/ramp in the Induan/Olenekian sediments of the wider Dinaric region (Aljinović, 1995; Aljinović et al., 2006, 2011), while this investigation points to deposition in wide mid-ramp zone (the zone between the fair- and storm-weather wave bases), as defined by Burchette and Wright (1992).

There are only a few outcrops of Lower Triassic strata in the Julian Alps and they occur in small tectonically con-

fined areas (e.g., Mavrin, Lipanca). There is some similarity in their development and macrofossil content (Natiria costata and badly-preserved ammonoids). Conodont and other micropalaeontologic analyses were negative and therefore a detailed geological comparison of these strata had not been possible.

PALAEONTOLOGY

Microfauna

The microfossil material recovered from nine conodont samples (SP 1–9) was examined in the present study. The associations consisted of conodont elements, rare fish remains, as well as some recrystallized free specimens of foraminifera from two samples (SP 1 and SP 5). In addition, several thin sections were prepared from each sample for foraminifera study. The conodonts recovered are white with CAI = 1 (Epstein et al., 1977).

The list of microfossils determined is presented in Table 1.

Foraminifera

The foraminifer classifications of Loeblich and Tappan (1988) and Mkhalevich (2000) are combined and used here. The foraminifer descriptions are short, because these foraminifers are mainly well-known and the preservation of these forms is not particularly good.

Genus Ammodiscus Reuss, 1862

Type species: Ammodiscus infimus Bornemann, 1874

Ammodiscus? parapriscus Ho, 1959

Fig. 5A–D

*1959 Ammodiscus parapriscus n. sp. – Ho: p. 408, pl. 2, figs 3–6.

Table 1

<table>
<thead>
<tr>
<th>Ge nus</th>
<th>Type species</th>
<th>Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammodiscus?</td>
<td>parapriscus</td>
<td>Ho, 1959</td>
</tr>
<tr>
<td>Glomospirella</td>
<td>facilis</td>
<td>Ho</td>
</tr>
<tr>
<td>Glomospirella</td>
<td>shengi</td>
<td>Ho</td>
</tr>
<tr>
<td>Glomospirella</td>
<td>sp.</td>
<td></td>
</tr>
<tr>
<td>Pilaminina?</td>
<td>cf. praedensa</td>
<td></td>
</tr>
<tr>
<td>Urosević</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arenovidalina?</td>
<td>sp.</td>
<td></td>
</tr>
<tr>
<td>Meandrospira?</td>
<td>sp.</td>
<td></td>
</tr>
<tr>
<td>Agathaminina?</td>
<td>sp.</td>
<td></td>
</tr>
<tr>
<td>Hoyenella</td>
<td>sinensis (Ho)</td>
<td></td>
</tr>
<tr>
<td>Dentalina</td>
<td>splendida</td>
<td>Schleifer</td>
</tr>
<tr>
<td>Nodosaria?</td>
<td>spp.</td>
<td></td>
</tr>
<tr>
<td>Triassospathodus</td>
<td>hungaricus</td>
<td>(Kozur &amp; Mostler)</td>
</tr>
<tr>
<td>fish teeth</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Vr – very rare (1 specimen), r – rare (2–4 specimens), a – abundant (5–10 specimens), va – very abundant (more than 11 specimens)
Glomospirella facilis was first described from the Lower and Middle Triassic of China (Ho, 1959). Later this species was reported from the Lower and Middle Triassic (Anisian) of the Alps, Dinarides, Albania, Hungary, Bulgaria, Caucasus, Iran (Zaninetti, 1976; Pantić-Prodanović and Radošević, 1977b; Pisa et al., 1979; Oravecz-Scheffer, 1987; Pidreni, 1988; Efimova, 1991; Trifonova, 1992; Rettori, 1995) and in the Upper Triassic of the West Carpathians (Salaj et al., 1983).

**Genus Glomospirella** Plummer, 1945

**Type species:** *Glomospira umbilicata* Cushman & Waters, 1927

*Glomospirella facilis* Ho, 1959

Fig. 5E, F

*1959* *Glomospirella facilis* n. sp. – Ho: p. 414, pl. 6, figs 8–12.

1976 *Glomospirella facilis* Ho – Zaninetti, p. 95, pl. 2, fig. 18.

partim 1983 *Glomospirella facilis* Ho – Salaj et al., p. 63, pl. 2, figs 9–12, figs 14–15, *?non* figs 13, 16.

1992 *Glomospirella facilis* Ho – Trifonova, p. 18, pl. 2, figs 13, 15–16, pl. 6, figs 13–14, 26.

**Material:** 21 sections in the samples SP 1, 3, 4, 5, 6, and 43 free specimens from the samples SP 1 and 5.

**Description:** The test is small, equatorial section oval, axial section mainly plain or convex on the both sides. The spherical proloculus is followed by a streptospirally enrolled undivided tubular second chamber and the last 2–3 whorls become planispirally coiled and gradually increasing in diameter. The streptospiral stage of coiling is wider in the axial section than the last whorl. The wall is agglutinated, thin, and smooth. The aperture is at the end of the tube.

**Remarks:** The characteristic features of this species are the oval form in the equatorial section and the convex or plain form in the axial section, the streptospiral stage of coiling is wider in the axial section than the last whorl. The above mentioned features of *Glomospirella shengi* are different from those of *Glomospirella facilis*. The preservation of the wall of the specimens is not good, owing to recrystallization or pyritization.

**Stratigraphic and geographic occurrence:** This species was first found in the Lower and Middle Triassic of China (Ho, 1959). Later the species was described from Lower and Middle Triassic (Anisian) of the Alps, Dinarides, Albania, Hungary, Bulgaria, Caucasus, Iran (Zaninetti, 1976; Pantić-Prodanović and Radošević, 1977b; Dager, 1978; Oravecz-Scheffer, 1987; Pidreni, 1988; Efimova, 1991; Trifonova, 1992; Rettori, 1995) and from the Rhaetian of the West Carpathians (Salaj et al., 1983).
ally the preservation of the wall of this species is not good and there is no confidence that this species belongs to *Pilammina* and this is true for the studied specimen too.

**Stratigraphic and geographic occurrence:** Species *Pilammina praedensa* was first described from the Lower Triassic of the Dinarides (Urošević, 1988) and after it was found in the upper part of Olenekian of Greece and the Lower Triassic of China (Rettori, 1995).

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**Genus Hoyenella Rettori, 1994**

**Type species:** *Glomospira sinensis* Ho, 1959

*Hoyenella sinensis* (Ho, 1959)

*Fig. 5M–O*

*1959*  
*Glomospira sinensis* n. sp. – Ho, p. 410, pl. 3, figs 16–34.

*1959*  
*Glomospira sinensis* var. *rara*, n. sp. n. var. – Ho, p.
410, pl. 4, figs 1–2.

1972 *Glomospirella elbursorum* n. sp. – Brönnimann, Zaninetti, Bozorgnia and Huber, p. 9, pl. 3, figs 1–10.

partim 1974 *Glomospirella elbursorum* Brönnimann, Zaninetti, Bozorgnia and Huber – Baud et al., pl. 30, figs 4–6, 8–11, non figs 7, 12, pl. 31, figs 1–6, 8–10, non fig. 7.

partim 1975 *Glomospirella* sp. – Zaninetti and Brönnimann, pl. 36, figs 1, 3–6, 10–12, non fig. 9.


partim 1995 *Hoyenella*. Krainer – Baud et al., p. 126, pl. 24, figs 1–15, pl. 25, figs 1–3, 5, 8, non figs 4, 6–7, 9, pl. 26, figs 1–3, 6–8, 10–12, 14, non 4–5, 9, 13, 15–17, pl. 27, figs 5–7, 10, non 1–4, 8–9, 11.

Material: 29 sections in the samples SP 1–6, 9 and 10 free specimens from the samples SP 1 and SP 5.

Description: The test is free and small, mainly ellipsoidal in shape, the spherical proloculus is followed by an undivided tubular second chamber, gradually increasing in diameter. In coiling, early whorls are miliolid-like, later ones are short with 1–2 planispiral whorls. The wall is dark and compact in transmitted light. The aperture is simple, terminal.

Remarks: *Glomospirella elbursorum* Brönnimann, Zaninetti, Bozorgnia and Huber (1972) could be placed into synonymy with the species studied, because of the very similar structure of the test and in this point, the decision of Rettori (1994) is followed. *Glomospirella* sp. (Zaninetti and Brönnimann, 1975) is placed into synonymy with the species studied, according to the morphological features of this species. The preservation of the wall of the specimens studied is not good owing to recrystallization or pyritic features of this species. The preservation of the proloculus and other chambers are oval and elongated. The holotype is broken, without a proloculus. The preservation of the specimens is not good, because they are mainly recrystallized, but there is proloculus present in all specimens.

Stratigraphic and geographic occurrence: The species *Dentalina splendida* was first described from the lower part of the Olenekian of the North Siberia (Gerke, 1961). Later this species was found in the Olenekian of the North Caucasus and Precaucasus (Efimova, 1991), and in the upper part of the Lower Triassic in the Lower Triassic and in the lower part of the Anisian of Bulgaria (Trifinova, 1994).


The main feature of the taxonomic composition of this foraminifer assemblage from the Studorski previal locality in the Julian Alps of western Slovenia is the dominance of primitive agglutinated foraminifers (*Ammodiscus* and *Glomospirella*) and some miliolids and nodosariids. The foraminifers are very small and not well-preserved. The generic composition of this foraminifer assemblage is mainly similar to the composition of the Early Triassic and Anisian assemblages from different parts of the Tethys, from the Alps to China. Several authors have indicated that there are “*Glomospira-Glomospirella*” foraminifer communities at different levels of the Lower Triassic and the lower Anisian in the Tethyan Realm (Zaninetti, 1976; Salaj et al., 1983; Trifonova, 1992; Vuk, 2007). The foraminifer assemblage from the Studorski previal locality has some species common with the foraminifer assemblages from the Lower Triassic of China (He, 1993), the Olenekian of the Caucasus area (Efimova, 1991), the Lower Triassic and Anisian of Bulgaria (Trifonova, 1992) and Hungary (Oračev-Schleifer, 1987), and it can be correlated with foraminifer assemblages from these areas. In the Alps and the Dinarides the “*Glomospira-Glomospirella*” foraminifer communities with some miliolids and nodosariids are known mainly from the Lower Triassic (*Dimitrijević et al., 1968; Pantić-Prodanović and Radošević, 1977, b; Dager, 1978; Pisa et al., 1979; Kristan-Tollmann, 1984; Oračev-Schleifer, 1987; Piderini, 1988; Salaj et al., 1988; Efimova, 1991; Trifonova, 1992; Rettori, 1995) and in the Upper Triassic of the West Carpathians and Bulgaria (Salaj et al., 1983; Trifonova, 1992).

Genus *Dentalina* Risso, 1826

Type species: *Nodosaria* (*Dentaline*) *cuvieri* (d’Orbigny, 1826)

*Dentalina splendida* Schleifer, 1961 in Gerke (1961)

Fig. 5P, R

*1961 Dentalina splendida* n. sp. – Schleifer in Gerke: p. 233, pl. 29, figs 5–6.

1991 *Dentalina splendida* Schleifer – Efimova, pl. 1, fig. 7.

1994 *Dentalina splendida* Schleifer – Trifonova, p. 37, pl. 4, figs 7, 11–12, 18.

Material: Four sections in the samples SP 1, SP 2, SP 3 and SP 8.

Description: The small test is almost rectilinearly or slightly curved. The proloculus is usually oval. The number of elongated oval chambers is from 4 to 8. They usually increase very gradually in size and are, comparatively loosely joined in all chambers. The sutures are depressed. The wall is very thin. The aperture is simple, terminal.

Remarks: The typical feature of this species is usually the oval proloculus and other chambers are oval and elongated. The holo...
Triassospathodus hungaricus (Kozur and Mostler, 1970)

Fig. 6A–G

*1970 Spathognathodus hungaricus n. sp. – Kozur and Mostler: p. 453, pl 4, figs 8–11.

Material: Five P-elements and eleven ramiform elements (samples SP 1, 3, 5) of moderate preservation.

Description: The spathodid P-elements examined are similar in length and bear three denticles. The basal cavity is wide and open. However, part of the posterior margin in the illustrated specimen is broken in the aboral view (Fig. 6D). It is obvious that the elements have an expanded basal cavity.

The ramiform elements are mostly fragmented and they do not permit reconstruction. Some of them are determined as ?M, ?S1 and S3 elements.

Remarks: Triassospathodus can be easily distinguished from Neospathodus Mosher, 1968, which has a terminally upward-directed lower margin of the basal cavity (Mosher, 1968). On the other hand, there exists a morphologic similarity in the P elements of Triassospathodus Kozur, 1998 (in Kozur et al., 1998) and Novispathodus Orchard, 2005 (Orchard, 2005); the latter has a shorter and more widened basal cavity and it has also a different apparatus composition (Heinz Kozur, pers. comm., 2012).

From the Spithian strata of the Thaynes Group in Nevada, Lucas and Orchard (2007) reported elements that are morphologically close or identical with “Neospathodus” cf. hungaricus.

Stratigraphic and geographic occurrence: Species T. hungaricus was first described from the Tirolites beds of Felsőrs in Hungary (Kozur and Mostler, 1970). Triassospathodus is an important Lower Triassic genus that comprises the majority of Upper Olenekian (Spithian) index species (Kozur et al., 1998).

In an integrated ammonoid and conodont zonation of the Triassic, Kozur (2003) presented T. hungaricus as the marker taxon for the basal Spithian equivalent to the Tirolites cassianus ammonoid Zone. According to H. Kozur (pers. comm., 2012), in the shallow western Tethys the T. hungaricus fauna lies within the lower Spithian, where the fauna with Icriospathodus collinsoni is missing.

There are several records of Early Triassic conodonts from Slovenia, but most of them are older than Spithian (see Kolar-Jurkovič et al., 2011). Recovery of the spathodid Spithian fauna has been documented only from the borderland of the Ljubljana depression in central Slovenia (Dozet and Kolar-Jurkovič, 2007). In Slovenia, a conodont fauna, high in spathodid elements and with few denticles, is abundant in the Spithian of Slovenia (Idrija-Žiri and Krško areas; unpublished data). From the External Dinarides, the Muč section in Croatia was proposed as a standard section for the European Upper Scythian. This section is well-known for its rich macrofauna and also contains Triassospathodus triangularis (Herak et al., 1983).

Macrofauna

The macrofauna collected contains bivalves and gastropods, as well as a few badly preserved specimens of ammonoids of the genus Tirolites that indicate an Early Spithian age.

Bivalves

Genus Bakevellia King, 1848

Type species: Avicula antiqua Graf zu Münster in Goldfuss, 1836 [non A. antiqua Defrance] = Avicula binneyi Brown, 1841, by original designation

Bakevellia cf. incurvata (Lepsius, 1878)

Fig. 7A–C

*1878 Gervillia incurvata sp. n. – Lepsius: p. 353, pl. 1, figs 3a–b.

1908 Gervillia incurvata Lepsius – Wittenburg, p. 31, pl. 4, fig. 7.

1923 Gervillia incurvata Lepsius – Diener, p. 91 (cum syn.).

Material: One well-preserved specimen with conjoined valves
Description: Relatively slender, posteriorly elongated *Bakevellia*, with left and right valve more or less equally convex. Beaks pointed, projecting above hinge margin in both valves.

Remarks: This species is unusual for its genus in having more or less equally convex left and right valves. On this basis, the material is tentatively assigned to *Bakevellia incurvata*, although there are slight differences in the outline by comparison with the single right valve, figured by Lepsius (1878, pl 1, figs 3a, b). Lepsius (1878, p. 353) indicated that the beak of the right valve did not project above the hinge line, whereas in the material described, it does. Another difference to the description by Lepsius (1878) is...
the apparent lack of a shell sulcus at the ventral margin, but the intraspecific variability of this feature is unclear.

A peculiarity of the present material is an unusual orientation of specimens that have both valves conjoined. Frequently, these specimens have their valves opened up to 30° and rest on the ventral valve margins, i.e. the hinge margin lies in a dorsal position, more or less parallel to the substrate. It is unlikely that this was the life position of the animal, because constructional morphology (elongated shape, long hinge axis, similar convexity of valves) indicates life as an endobystate mud sticker with the hinge axis oriented more or less vertically to the sediment surface (Seilacher, 1984, text-fig. 7; Muster, 1995, p. 98). Because the fauna occurs at the top of a tempestitic bed, as indicated by hummocky cross-stratification, a possible explanation is that the animals were excavated and displaced by storm waves and then smothered by the resettling silt-clay suspension. The observed orientation in the Studorski preval material might thus be an unnatural dying position of this species.

Genus *Eumorphotis* Bittner, 1901

**Type species:** *Pseudomonotis telleri* Bittner, 1898 by subsequent designation (Cossmann, 1902)

*Eumorphotis* cf. *gronensis* (Wittenburg, 1908)  
*Fig. 7E*

*1908 Mysidoptera gronensis* sp. n. – Wittenburg: p. 31, pl. 4, fig. 4.

**Material:** One left valve with a partly preserved external shell layer (BJ 2766), questionable three abraded left valves (BJ 2701).

**Description:** Very large *Eumorphotis* with about 70 radial ribs near the shell margin. Ribs nodose, increasing in number by intercalation during ontogeny. Outline of shell typical of the genus, but posterior wing relatively elongated.

**Remarks:** The largest specimen is about 8 cm long and more than 8 cm high. This is to the knowledge of the authors the largest *Eumorphotis* specimen, reported so far from the Early Triassic.

Although the type material of *E. gronensis* (Wittenburg, 1908) is incomplete, the specimen in the present study is tentatively assigned to that species on the basis of the similar ornamentation. The shell exterior of the specimen is dorsally eroded, but an increase in the number of ribs by intercalation of additional ribs is observed on the posterior wing. Therefore, it is assumed that the higher number of ribs in this specimen (ca. 70) by comparison with the holotype of *E. gronensis* (28) could be related to its larger size.

Species *E. kittlii* Bittner, 1901 differs from *E. gronensis* chiefly in its stronger development of the ten to twelve most posterior radial ribs, which cover the posterior wing and the adjacent part of the disc. Although the present authors currently treat both species separately, they wish to note that the difference in ornamentation might turn out to be a preservation effect or as lying within the range of intraspecific variation. In this case, *E. kittlii* would have priority over *E. gronensis* and species assignment of the specimen would change accordingly (see also Broglio Loriga and Mirabella, 1986).

Genus *Aviclamys* Allasinaz, 1972

**Type species:** *Pecten cspakensis* Frech, 1905 by original designation

*Aviclamys?* sp.  
*Fig. 7D*

**Material:** One complete left valve and two incomplete valves (BJ 2765).

![Fig. 8. Neritimorph gastropod *Natiria costata* (Münster, 1841) from Early Triassic of Studorski preval, Slovenia, BJ 2480.](image)

A. General view of rock fragment with numerous poorly preserved individuals. B. Close-up of the specimen arrowed on A, showing mode of preservation

**Description:** Disc nearly circular, covered with about ten strong first-order radial ribs plus the same number of intercalated weaker second-order ribs. The posterior auricle is without a sinus.

**Remarks:** The state of preservation does not allow specific determination of this taxon. However, the circular disk, truncated posterior auricle and style of ornament are typical of *Avichlamys. Pecten vajolettensis* Wittenburg, 1908, subsequently referred to *Avichlamys* by Allasinaz (1972, p. 225), has a similar ornament. However, the presence of an elongated anterior auricle, as figured by Wittenburg (1908, pl. 1, fig. 9), cannot be verified in the material described.

**Gastropods**

Genus *Natiria* de Koninck, 1881

**Type species:** *Natiria lyrata* Phillips, 1836 by monotypy (de Koninck, 1881, p. 5)

*?Natiria costata* (Münster, 1841)  
*Fig. 8A, B*

*1841 Naticella costata* sp. n. – Münster: p. 101, pl. 10, fig. 14.  
1897 *Naticella costata* Münster – Leonardi, pl. 20, figs 15–16.  
1985 *Natiria costata* (Münster) – Neri and Posenato, p. 91.  
2002 *Natiria costata* (Münster) – Hips and Pelikán, p. 356, fig. 8A.  
2005 *Natiria costata* (Münster) – Nützel, p. 440, fig. 6.

**Type locality:** Most likely Gruneshof, South Tirol, Italy; Werfen Formation, Olenekian, Early Triassic (compare Kitt, 1892: 67).

**Material:** Single rock piece, composed of gastropod coquina from Studorski preval. The association is monospecific, the shells are recrystallized and mostly weathered out from the visible surfaces. Sample BJ 2480.

**Remarks:** In spite of the mass occurrences of this gastropod in the Werfen Formation, its taxonomic – both generic and specific – status remains unclear. The type species of *Natiria* was described from the Visean (Lower Carboniferous) of Yorkshire (Phillips, 1836), while the species *Natiria costata* was defined by Münster (1841) in a monograph on gastropods from the Carnian (Upper
Triassic) St. Cassian Formation. It seems, however, that the type series of *N. costata* came from a locality of the Werfen Formation, rather than of the Cassian Fm. Kitzl (1892, p. 67) suggested that the material of Münter (1841) could have come from an outcrop of the Werfen Fm at Groneshof, where it occurs abundantly. Taking into account approximately 100 million years and the P-T extinction event between the occurrences of *N. lyra* and *N. costata*, it is doubtful that both forms are congenic (see also discussion in Yin and Yochelson, 1983, p. 523). Unfortunately, despite the ubiquity of the material from the Lower Triassic, no protococon of *N. costata* has been discovered yet.

The material recovered at Studorski preval is poorly preserved and does not contribute any new morphological information to the existing descriptions. In fact the identification itself is poorly constuted and only conditional, on the basis of gross shell morphology. Nevertheless, no other gastropod of this morphology and size is known from the Werfen Formation and therefore the identification seems to be plausible and it is yet another piece of data, confirming the wide distribution of this gastropod in the Early Triassic Tethys.

**Stratigraphic and geographic occurrence:** *Natria costata* along with *Werfenella rectecostata* are the most typical gastropods of the Early Triassic Werfen Formation (e.g. Nützel, 2005). These two species occur in Europe, coinciding roughly with outcrops of the upper Werfen Formation or its equivalents. Occurrences include in Italy (e.g., Leonardi, 1967; Neri and Posenato, 1985, Nützel, 2005), Hungary (Broglio Loriga, 1990; Hipps and Pelikán, 2002), Austria (Dienzer, 1926; Kutassy, 1940), Croatia (Prlj-Šimić, 2006), and Slovenia (Pavič, 2003; this paper). Recently, poorly preserved *Natria* cf. *costata* has also been reported from the Spathian of Utah, USA (Hofmann et al., 2013a, b).

**DISCUSSION AND CONCLUSIONS**

This paper presents detailed documentation and interpretation of sedimentological data on a remarkable Early Triassic fossil site in the Julian Alps of Slovenia. The report on the palaeontological material, collected at Studorski preval, confirms the wide distribution of mollusk and foraminifer taxa in the Early Triassic Tethys. The recovery of the earliest Spathian conodont fauna with *Triassospathodus hungaricus* indicates an Olenekian age of the fauna and is an important correlative element for comparison with coeval faunas in the Dinarid area and worldwide.

The sedimentological data presented here indicate that the strata of Studorski preval in the Julian Alps of western Slovenia were deposited in a more distal, storm-influenced ramp. A ramp setting was also mentioned for the deposition of the Werfen Formation in the Southern Alps (Brandner et al., 2012). Two types of beds were recognized, designated here as microfacies types A and B. These alternate vertically and form a sedimentary architecture that consists of coarse-grained skeletal lag deposits of microfacies A, overlain by the laminated or bioturbated mudstones and/or marls of microfacies B. Units with such organization imply the occasional winnowing of bottom sediments during storm peaks and the deposition of coarse-grained skeletal material as the storms waned, followed by the slow settling out of fine-grained material during intervals without storms. Ammonoids encountered in microfacies B imply a barrier-free connection of the depositional environment with the open sea, i.e. deposition in a more distal, deeper-ramp setting.

Numerous trace fossils in the mudstones and marls of microfacies B type beds suggest deposition in a low-energy deeper part of the ramp. A low-energy, poorly aerated environment is also indicated by the presence of pyrite and celestite. Periodic reworking of the bottom skeletal-rich sedimentation and the sedimentation of storm beds suggest deposition in a zone above the storm wave base, possibly in a wide low-energy mid-ramp environment.

Foraminifer assemblages mainly consist of the primitive agglutinated foraminifers, typical for the Lower Triassic and the Anisian. The foraminifer assemblage is represented by *Ammodiscus? parapariscus* Ho, *Glomospirella facilis* Ho, *Gl. shengi* Ho, *Gl. sp.*, *Pilammina?* cf. *praedens* Urosević, *Arenovidalina?* sp., *Meandrospira?* sp., *Agathamina?* sp., *Hoyenella sinensis* (Ho), *Dentalinia splendida* Schleifer and *Nodosaria?* spp. The main feature of the taxonomic composition of this foraminifer assemblage is the dominance of primitive agglutinated foraminifers (*Ammodiscus, Glomospirella, Hoyenella*), associated with some miliolids and nodosariids. It can be assigned to the time range from Early Triassic to Anisian "Glomospira-Glomospirella" foraminifer community. An Early Triassic age is more plausible.

The mollusk fauna includes taxa comparable to those of the *Tirrollites* beds of the (Upper) Werfen Fm. Gastropods form monospecific coquinas that are most likely of the shells of *Natria costata*, a typical faunistic element of the Tethyan Early Triassic. The bivalve fauna includes three genera that differ in stratigraphical range and geographical distribution. *Bakevellia* is a long-lived genus, known worldwide from the Permian up to the Cretaceous. *Eumorphophis* was cosmopolitan in the Early Triassic and reached its acme in the Olenekian, although the genus might have persisted locally into the Middle Triassic. In contrast, *Avichlamys* was restricted to the Olenekian and is currently known only from the western Tethys. The bivalve species include *Bakevellia* cf. *incurvata, Eumorphophis* cf. *gromensis* and *Avichlamys* sp. One of the specimens of *Eumorphophis* displays unusually large dimensions, seemingly constituting a record for the largest size of this genus, so far reported from the Early Triassic. The unusual position of articulated *Bakevellia* specimens is in accordance with storm-event deposition, inferred from sedimentological observations. By comparison with other recently described bivalve faunas from the Spathian (Neri and Posenato, 1985; Wasmer et al., 2012; Hautmann et al., 2013) and even from the Griesbachian (Kumage and Nakazawa, 2009; Hautmann et al., 2011), the bivalve diversity is low in the Studorski preval section, and no infaunal taxa are present. However, the normal to large growth sizes of the specimens indicate that this low diversity is not related to environmental stress. Rather, it may be related to the relatively greater water depth, provided that the specimens have not been transported over very large distances, which is unlikely given the low level of fragmentation. Miller (1988) demonstrated an evolutionary onshore-offshore trend in the Palaeozoic history of bivalves, in which taxa mainly evolved in shallow marine settings and expanded later into deeper/distal settings. This onshore-offshore or proximal-distal trend can be easily applied to the weakly inclined ramp situation, as depicted for
the site investigated. The low bivalve diversity in the relatively deeper distal setting described here may thus reflect an evolutionary delay of re-diversification in distal settings, compared to the more diverse faunas in shallower settings of the same age (e.g., Neri and Posenato, 1985; Hautmann et al., 2013). The data indicate a general evolutionary trend that is onshore-offshore (see also Jablonski et al., 1983), seldom considered in analyses of the timing of biotic recovery after mass extinctions.

Acknowledgements

The authors thank the Triglav National Park (Triglavski narodni park) for permission to collect samples at Studorski preval (no. 35607-1/2011-2 dated 9th June 2011). Communication with Heinz dni park) for permission to collect samples at Studorski preval (no. Aljinoviæ, 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: 17–32.


