GEOLOGIJA 54/2, 193–204, Ljubljana 2011

doi:10.5474/geologija.2011.015

Stratigraphy of Upper Permian and Lower Triassic Strata of the Žiri Area (Slovenia)

Stratigrafija zgornjepermskih in spodnjetriasnih plasti Žirovskega ozemlja

Tea KOLAR-JURKOVŠEK[1], Bogdan JURKOVŠEK[1], Dunja ALJINOVIĆ[2] & Galina P. NESTELL[3]

[1]Geological Survey of Slovenia, Dimičeva ulica 14, SI-1000 Ljubljana, Slovenia; e-mail: tea.kolar@geo-zs.si; bogdan.jurkovsek@geo.zs.si
[2]University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering, Pierottijeva 6, 10 000 Zagreb, Croatia; e-mail: dunja.aljinovic@rgn.hr
[3]Department of Earth and Environmental Sciences, University of Texas at Arlington, Arlington, TX 76019, USA; e-mail: gnestell@uta.edu

Prejeto / Received 9. 11. 2011; Sprejeto / Accepted 21. 11. 2011

Key words: Stratigraphy, P-T boundary, Bellerophon Formation, Lukač Formation, Conodonts, Foraminifera, External Dinarides, Slovenia
Ključne besede: stratigrafija, P-T meja, Bellerophonska formacija, Lukač formacija, konodonti, foraminifere, Zunanji Dinaridi, Slovenija

Abstract

The paper deals with the stratigraphy of Late Permian and Early Triassic strata of the Lukač section in the Žiri area of western Slovenia. This is the only section presently known in the External Dinarides where the Permian-Triassic boundary is defined following international criteria based on the first appearance of the conodont *Hindeodus parvus*. The following lithostratigraphic units have been formalized: the Bellerophon Limestone and Evaporite-dolomite Members of the Bellerophon Formation and the Lukač Formation with the three members, the Transitional Beds, Streaky Limestone and Carbonate-clastic Member. The paper presents the results of micropaleontological study based on foraminifers and conodonts as well as petrographic and sedimentologic research results. The investigation of conodont assemblages enabled the conodont biozonation of the Permian-Triassic interval of the studied Lukač section.

Izvleček

Članek obravnava stratigrafijo zgornjepermskih in spodnjetriasnih plasti v profilu Lukač na žirovskem ozemlju. To je zaenkrat edini profil v Zunanjih Dinaridih, v katerem je določena permsko-triasna meja po mednarodnih kriterijih na osnovi prvega pojava konodontne vrste *Hindeodus parvus*. Formalizirane so naslednje litostratigrafske enote: Bellerophonski apnenec in Evaporitno-dolomitni člen Bellerophonske formacije ter Lukač formacija s tremi členi: Prehodne plasti, Pasnati apnenec in Karbonatno-klastični člen. V članku podajamo tudi rezultate mikropaleontoloških raziskav na osnovi foraminifer in konodontov ter rezultate petrografskih in sedimentoloških raziskav. Analiza konodontnih združb je omogočila uvedbo konodontne bioconacije permsko-triasnega intervala raziskanega profila Lukač.

Introduction

At the end of the Permian Period and the beginning of the Triassic the most severe mass extinction in Phanerozoic life history occurred where up to 96% of all existing biota was lost (Sepkoski, 1984, Hallam & Wignall, 1997). This event has stimulated scientists all over the world to study this phenomenon and many hypotheses have been put forward but the extinction cause remains still unknown. An extraterrestrial impact in the Permian-Triassic boundary (PTB) interval appears unlikely (Isozaki, 2001). Possible causes of this catastrophic event are connected with large scale environmental changes such as volcanic eruptions, enhanced atmospheric carbon dioxide, rapid climate change with gradual warming of the planet, changing ocean chemistry (anoxia, salt content, oxygen, carbon, sulphur, strontium isotopes) and changing sea level as well as fungal virulence (Baud et al., 1989; Wignall & Twichett, 1996; Erwin et al., 2002; Bottjer, 2004; Visscher et al., 2011).

The Permian-Triassic boundary (PTB) interval beds have long been topic of numerous studies globally that intensified after the establishment of the Permian-Triassic Working Group (PTWG) in 1981.

Important records of the PTB extinction event have been established in the Tethyan realm. The section at Meishan in South China was chosen as the Global Stratotype Section and Point (GSSP) of the PTB that was ratified by IUGS in 2001 (Yin et al., 2001). Stratigraphically the most important conodont species across the PTB belong to the genera *Hindeodus* and *Isarcicella*. The first appearance datum (FAD) of the species *Hindeodus parvus* in the middle of Bed 27 (27c) in the Meishan D section in South China marks the base of the Triassic System. The approved proposal clearly separates the event stratigraphic and biostratigraphic boundaries and is of key importance, not only for defining the GSSP of the basal Triassic boundary, but also to study the Permian-Triassic mass extinction and recovery (Wang, 1999). *Hindeodus parvus* is an easily recognizable species with wide geographic distribution and it is the first globally distributed species that appears just above the minimum faunal diversity indicated by a minimum in $\delta^{13}C$ and has no facies restriction (Kozur, 1996; Kozur et al., 1996).

During the last decade, study of the PTB interval has been intensified in the Dinarides and the presence of hindeodids and isarcicellids was documented.

In Croatia, *H. parvus* was reported from the Školski Brijeg section of the Gorski Kotar region (Aljinović et al., 2006), whereas a recovery of *Isarcicella* is documented in the Plavno section of the Knin area (Aljinović et al., 2011). The two faunas are assigned to the Griesbachian *parvus-isarcicella* and *isarcica* zones.

In Serbia, an extensive biostratigraphic study was carried out in the Komirić section of the Jadar Block in the Vardar Zone of NW Serbia where elements of *Hindeodus typicalis* belonging to the Lower *praeparvus* Zone (Changhsingian) were collected (Sudar et al., 2007; Nestell et al., 2009; Crasquin et al., 2010).

In Slovenia, the strata across the PTB interval have been studied in the Idrija-Žiri area and in the southern Karavanke Mts. (Grad & Ogorelec, 1980; Buser et al., 1989; Ramovš, 1986; Dolenec et al., 1999, 2003; Kolar-Jurkovšek & Jurkovšek, 1995, 2007; Mlakar & Placer, 2000). However, the two areas belong to different geotectonic units, namely the Idrija-Žiri area belongs to the External Dinarides whereas the southern Karavanke Mts. to the Southern Alps (Placer, 1999, 2008). In the Idrija-Žiri area, conodonts from the PTB interval were first reported by Kolar-Jurkovšek & Jurkovšek (2007) who documented rich *Hindeodus-Isarcicella* associations in the Lukač section. Based on the presence of conodont species such as *H. parvus, H. typicalis, Hindeodus* sp., *Isarcicella turgida, I. lobata, I. staeschei, I. isarcica, Isarcicella* sp. A, at least three Early Triassic faunas have been recognized (Kolar-Jurkovšek & Jurkovšek, 2007).

In the Idrija-Žiri area, the Upper Permian is represented by the Bellerophon Formation (also named the Žažar Formation in Slovenia) consisting of limestone and dolomite with a thickness of 60m to 350m (Ramovš, 1958; Grad & Ogorelec, 1980; Buser et al., 1989; Mlakar & Placer, 2000; Skaberne & Ogorelec, 2003). The Žažar Formation is an equivalent of the Bellerophon Formation in the Carnic Alps and the Dolomites of Austria and Italy (Farbegolli et al., 1986; Holser & Schöulaub, 1991) and therefore this term is eliminated herein. In the Žiri area, the strata of the lowermost Triassic are known as the "Streaky Limestone Member" of the Werfen Formation with a thickness of up to 40m (Mlakar, 2002). The Permian-Triassic boundary was mostly »hidden« within the dolomitic beds of the Bellerophon Formation (Grad & Ogorelec, 1980; Buser et al., 1989; Mlakar & Placer, 2000). In the sections where the dolomite member is not developed, the PTB was traditionally defined lithologically between the dark gray algal limestone of the Bellerophon Formation and light-medium gray thin bedded limestone that is already of Triassic in age (Buser, 1986). In the Masore section near Idrija, west from Žiri, Dolenec et al., (2004) described the disappearance of skeletal algae below the lithological boundary and above it the appearance of ostracodes, echinoderms, foraminifers of the genus "*Earlandia*", filaments of cyanobacteria and mollusk shells. In the same section, the authors documented a negative shift of organic carbon in an aproximatelly 50 cm thick interval and it coincides more or less with the lithological boundary (Dolenec et al., 2004). An earliest Triassic age of the laminated limestone in the Masore section is based on the appearance of foraminifers *Earlandia tintinniformis* and the annelid *Spirorbis phlyctaena* (Buser, 1986), both of which have been known only from Triassic strata in many regions (Brönnimann & Zaninetti, 1972; Brönnimann et al., 1972). According to the foraminifers, the lower boundary of the Triassic worldwide has been drawn on the basis of the appearance of the species "*Cyclogyra*" (= "*Cornuspira*") *mahajeri* and *Rectocornuspira kalhori*, especially in sections where conodonts could not be found (Brönnimann & Zaninetti, 1972; Brönnimann et al., 1972; Altiner & Zaninetti, 1981; Köylüoglu & Altiner, 1989; Rettori, 1995; Groves et al., 2005, 2007).

Recently, one of the sections of the Permian-Triassic interval in the Žiri area, the Lukač section, was studied biostratigraphically with the documentation of a *Hindeodus-Isarcicella* conodont population through this interval (Kolar-Jurkovšek & Jurkovšek, 2007). The species *Hindeodus parvus* (Kozur and Pjatakova) was found in sample L1 in the Transitional Beds (Kolar-Jurkovšek et al., 2011) permitting an accurate placement of the Permian-Triassic boundary in the Lukač section. Because the precise position of the lower boundary of the Triassic in the Lukač section is established based on conodonts, the distribution of the associated foraminifers around this boundary also was examined in detail (Nestell et al., 2011). In the Lukač section, the species "*Cornuspira*" *mahajeri*, "*Earlandia*" *gracilis* and "*E.*" sp. have been found in the Transitional Beds below the first occurrence of the conodont species *Hindeodus parvus*. These foraminiferal taxa are considered to be ecological species and should not be used as stratigraphic markers (Nestell et al., 2011).

The Permian-Triassic interval of the Lukač section in western Slovenia was studied sedimentologically and micropaleontologically by using conodonts and foraminifers. The following lithostratigraphic units are formalized herein: the Bellerophon Limestone and Evaporite-dolomite Members of the Bellerophon Formation and the Lukač Formation with the Transitional Beds, Streaky Limestone and Carbonate-clastic Members in ascending order.

Materials and methods

The study in the Lukač section started in 2006 and was focused on the PTB interval only (Kolar-Jurkovšek & Jurkovšek, 2007). In the next three years additional sampling of the entire section was carried out. The present study is based on conodont collections recovered from 53 samples that produced conodonts out of the 124 processed carbonate samples. The conodont fauna is assigned to 15 species of several genera (Kolar-Jurkovšek et al., 2011).

The foraminiferal study is based on the examination of 38 samples collected from the uppermost Permian beds, Permian-Triassic Transitional Beds and lowermost Triassic strata. Foraminifers were found in twenty one samples from which thin sections were made. A few recrystallized free specimens were obtained in the conodont residues. For studying the internal morphology, some thin sections were made from free specimens and the tiny specimens were studied with Cargille Meltmount (Nestell et al., 2011).

For the petrographic purposes 117 samples have been studied. They were stained with K-fericyanid and Alizarin Red S aiming to determine dolomite and the dedolomitization processes.

The sampled horizons are shown in Figs. 2, 3.

Geological setting

The Lukač section is situated in the Žiri area of the north-western part of Slovenia that belongs to the External Dinarides geotectonic unit (Fig. 1). A wider area is composed of Carboniferous, Permian and Triassic rocks. The Carboniferous is represented by clastic rocks with prevailing black shale, sandstone and conglomerate. These strata are discordantly overlain by Middle Permian beds developed in the continental depositional environments of the Gröden Formation (Val Gardena Formation) in which shale prevails, but sandstone and locally also conglomerate and breccia are present. The Upper Permian and Lower Triassic strata of the External Dinarides in Slovenia were formed on an extensive Slovenian Carbonate Platform which became established during the Late Permian, and it remained stable until Middle Triassic time (late Anisian) when it

Fig. 1. Sketch of geotectonic units in Slovenia: A – Eastern Alps, B – Southern Alps, C – External Dinarides, D – Adriatic-Apulia foreland, E – Pannonian basin (modified after Placer, 1999) and the map with geographic position of the Lukač section (star) (after Kolar-Jurkovšek et al., 2011).

was split by the Slovenian Basin into the Julian Carbonate Platform in the north, and the Dinaric Carbonate Platform in the south (Buser, 1989, 2003; Buser et al., 2007, 2008).

The investigated section is located 4 km northwest from Žiri (x=5,102,525, y=5,428,000), in a ravine between Mrzli vrh (862 m) and Ledinski grič (893 m) (Fig. 1). In the period of 2006-2009, the section was part of a detailed biostratigraphic study based on conodonts that enabled the definition of the Permian-Triassic boundary according to internationally accepted criteria (Kolar-Jurkovšek et al., 2011). The base of the Lukač section is formed by the reddish-brown clastic rocks of the Gröden Formation that are in a tectonic contact with the Upper Permian and Lower Triassic rocks. The strata of the section are in overturned position and they dip from 60° to 75° north–northeast. The lowermost part of the section starts with the Bellerophon Limestone Member that continuously passes into the Evaporite-dolomite Member of the Bellerophon Formation. Then follows the Lukač Formation with the Permian-Triassic Transitional Beds in its lowermost part, and these are overlain by the Streaky Limestone Member and Carbonate-clastic Member. The thickness of the entire section is 283 m (Figs. 2, 3).

Six conodont biozones have been established in the section that can be compared with the biozonation of various sections in the Southern Alps and the Meishan section in China, as well

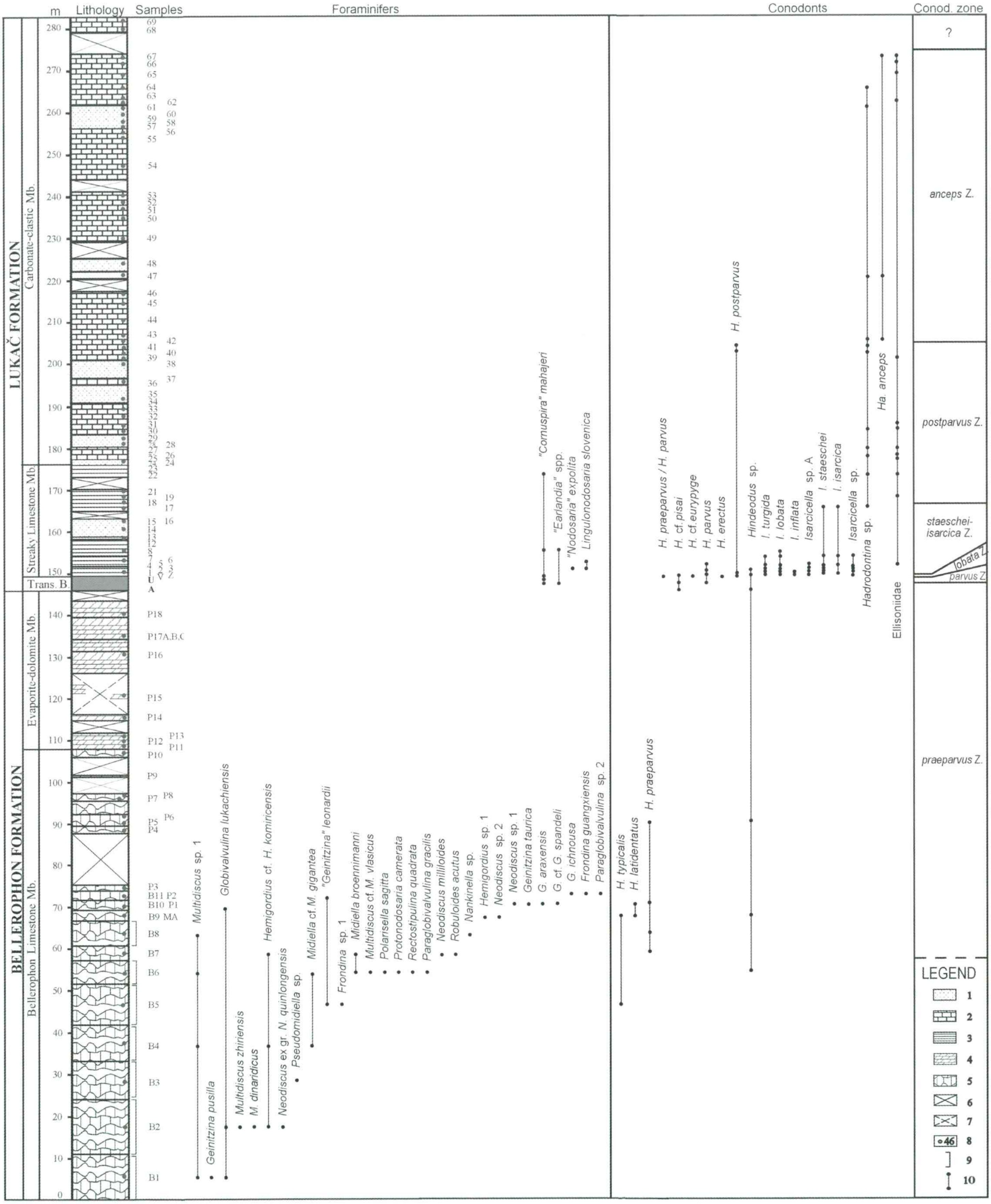
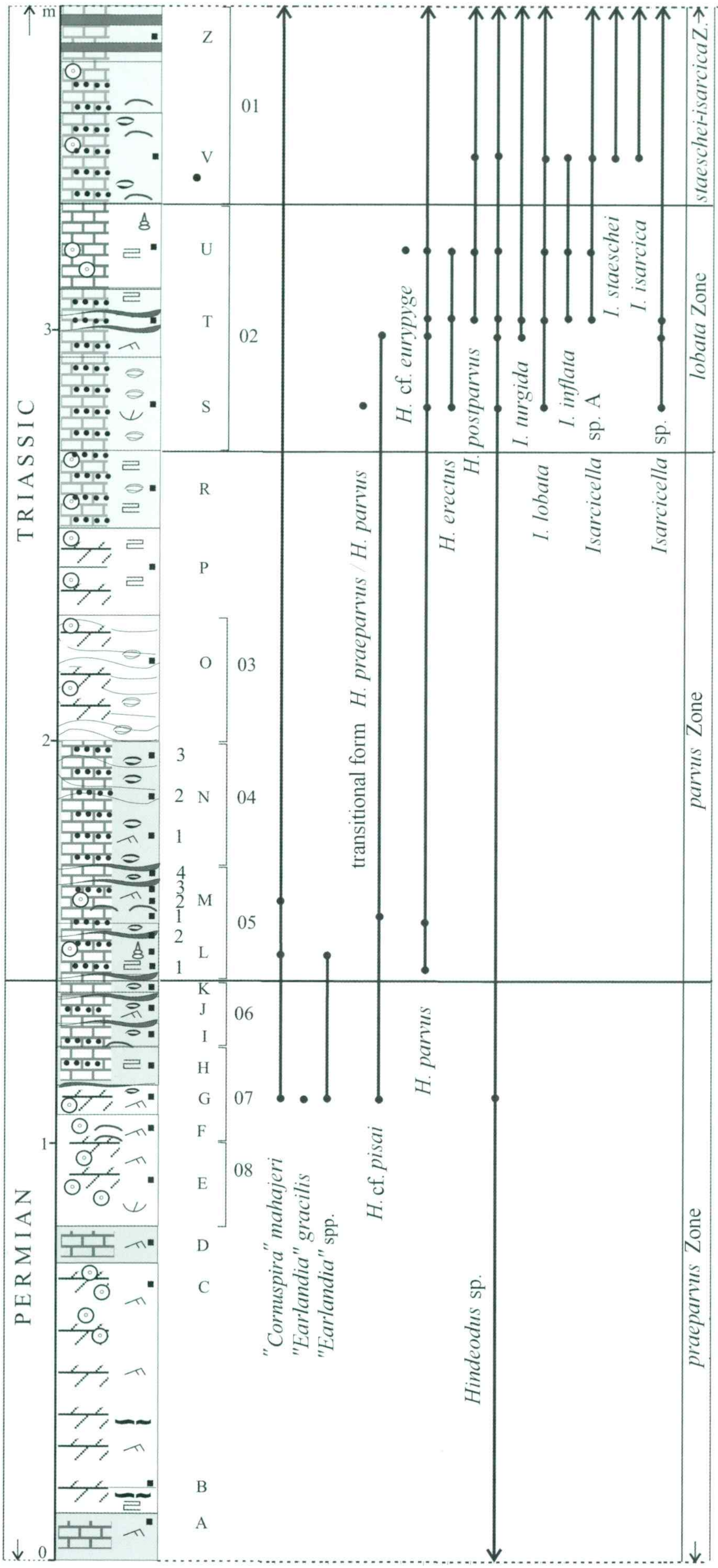


Fig. 2. Geological column of the Upper Permian and Lower Triassic sediments of the Lukač section in western Slovenia. 1 – calcareous siltstone, 2 – limestone (oolitic grainstone and laminated silty micrite/biomicrite), 3 – thin bedded streaky limestone, 4 – evaporitic dolomite (partly rauchwacke type deposits), 5 – black nodular Bellerophon limestone, 6 – covered interval, 7 – partly covered interval, 8 – petrographic and spot conodont samples, 9 – composite sample for conodont analysis, 10 – range of conodont and foraminifer taxa.



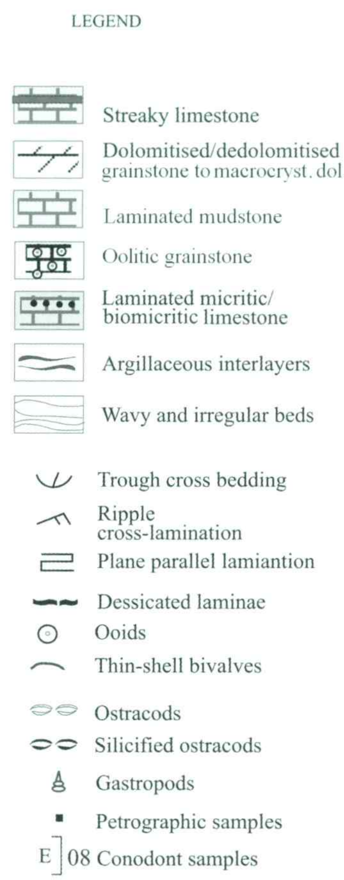


Fig. 3.
Geological column of the Permian-Triassic interval beds in the Lukač section.

as other sections in the world (Kolar-Jurkovšek et al., 2011). The following zones have been recognized: the latest Changhsingian (uppermost Permian) *praeparvus* Zone, and the Griesbachian (lowermost Triassic) *parvus*, *lobata*, *staeschei-isarcica*, *postparvus* and *anceps* Zones. The first appearance of *Hindeodus parvus* in the sample L1 in the Transitional Beds marks the systemic boundary between the Permian and Triassic and the boundary between the Paleozoic and Mesozoic erathems (Kolar-Jurkovšek et al., 2011).

Lithostratigraphic units of the Lukač section

Bellerophon Formation

The **Bellerophon Limestone Member** is represented by black nodular or faintly bedded limestone (Fig. 4) that predominantly consists of arenite or rudite size fossil detritus (algae, corals, echinoderms, foraminifers, gastropods, bivalves and brachiopods) included in the micritic matrix. Carbonate detritus is commonly tightly packed with the small amount of matrix forming dense packstone, only rarely wackestone.

Fig. 4. Black nodular Bellerophon Limestone Member at the Lukač section.

The predominantly, micritic microfacies imply deposition under low energy conditions, possibly lagoon or back reef.

Well bedded, intensively recrystallized biomicrites are present at the top of the Bellerophon Limestone Member. They pass continuously into a 30 m thick **evaporite unit** named as **Evaporite-dolomite Member** (Fig. 5). It is represented by tabular, 0.5-3 m thick dolomite beds with dissolved cm-sized molds of primary evaporitic minerals. The dolomite has a unimodal macrocrystalline planar e- or s-structure with stair-step or rounded molds (Fig. 6).

Dolomite and the stair-step molds present in the **Evaporate-dolomite Member** suggest deposition under hypersaline conditions where evaporites were possibly deposited as primary minerals which have been removed by dissolution, possibly in supratidal conditions.

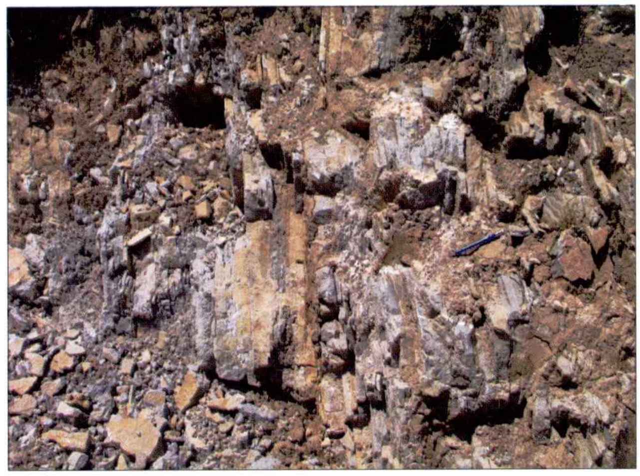


Fig. 5. Evaporite-dolomite Member of the Lukač section is composed of well bedded crystalline dolomite.

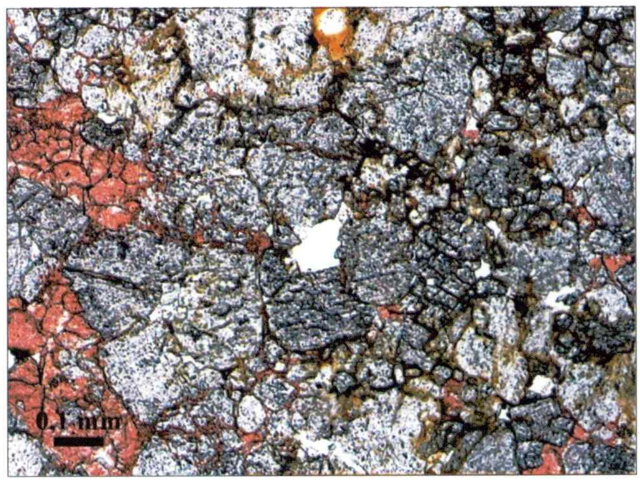


Fig. 6. Macrocrystalline planar -e or -s dolomite structure in the Evaporite-dolomite Member. Dissolution cavities with the stair-steps walls (centre) suggest dissolving of evaporate minerals.

Lukač Formation

Evaporite-type dolomite continuously passes to the **Transitional Beds** that consist of light yellow to red colored carbonate beds that vary in thickness from 0.03 – to 0.62 m (Fig. 7). The base of the 3.3 m thick transitional interval consists

Fig. 7. Transitional Beds of the Lukač Formation at the Lukač section.

of **laminated mudstone, laminated micritic/biomicritic limestone and plane parallel or trough ripple cross-laminated grainstone**. The laminated mudstone consists dominantly of limy lamina that alternate with the lamina composed of limy mud, clay and/or 5-7% of siliciclastic terrigenous coarse-silt component (Fig. 8). The **laminated micritic/biomicritic** limestone type consists of prevailingly micritic laminae that alternate with prevailingly bioclastic laminae (very often containing ostracodes) (Fig. 9). The grainstone consists of ooid and bioclastic detritus and sparry-calcitic cement (Fig. 10).

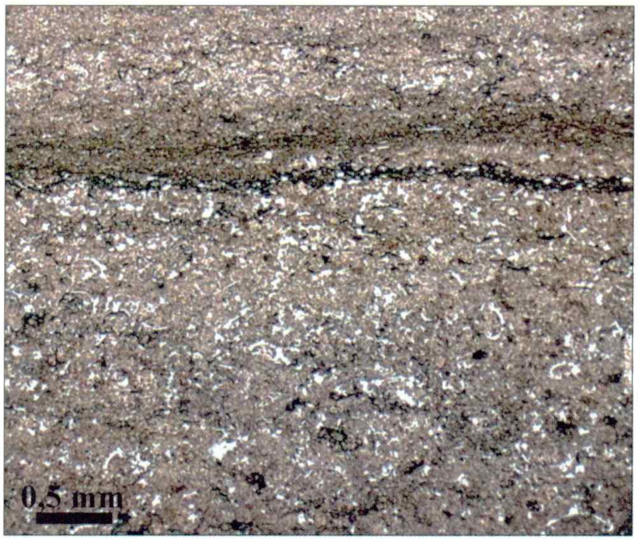


Fig. 8. In the Transitional Beds laminated mudstone occurs consisting of calcareous lamina and lamina with mixture of limy mud, clay and siliciclastic silty detritus (microphotograph of sample Lukač A).

Fig. 9. The laminated micritic/biomicritic limestone of the Transitional Beds is composed of dominantly micritic or dominantly bioclastic lamina. Bioclastic detritus consist often of ostracod carapaces (microphotograph of sample Lukač S).

Grey and pail-red **dolomite** and less **dedolomite** occur also in the **Transitional Beds**. They have homogenous micro- to macrocrystalline structure and occasionally very often preserved ooid ghosts (Fig. 11).

The **Transitional Beds** were deposited in shallow marine conditions. The presence of micrite rich microfacies types imply more restricted conditions with the predominance of suspension settling of fines. Trough and ripple cross-lamination found in the grainstone suggests migration of ooid detritus due to oscillatory and/or tidal currents.

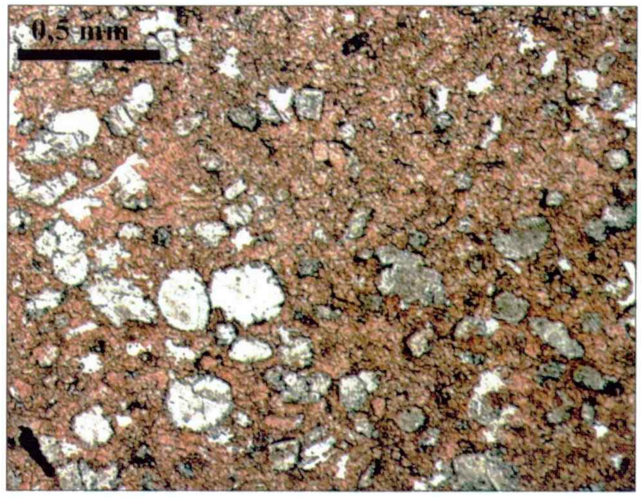


Fig. 10. Oolitic grainstone of the Transitional Beds is composed of poorly preserved primary ooid structure due to dolomitisation (microphotograph of sample Lukač L).

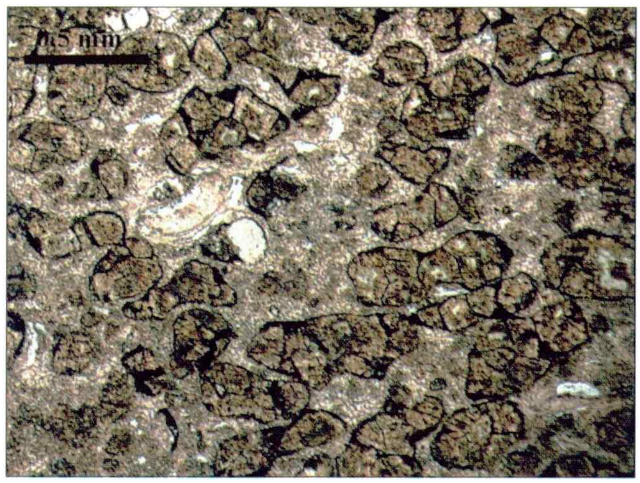


Fig. 11. Intensive dolomitisation and dedolomitisation of oolitic grainstone (Transitional Beds, microphotograph of sample Lukač G).

The **Transitional Beds** with the **Permian-Triassic boundary** are conformably overlain by the ca 30 m thick **Streaky Limestone Member** (samples V to 25). This unit consists of a repetitive alternation of very thin bedded light grey or yellow and dark gray bed couplets (Fig. 12). The beds are planar, wavy or irregularly shaped. Parallel and wavy-cross lamination can be seen. Siliciclastic sandy, silty and clayey detritus is present in greater amounts then before. Within the streaky limestone, light colored interbeds consist dominantly of siliciclastic or bioclastic material whereas dark interbeds are dominantly of carbonate mud components (Fig. 13). Bioclastic detritus are represented by silicified ostracodes and are rarely of recrystallized ooids. In each bed couplet, the uppermost laminae are usually destroyed due to the activity of organisms. Within the thin bedded streaky alternation some 0.3 m thick recrystallized ooid rich beds occasionally occur. A wavy structure observed in the streaky

Fig. 12. The Streaky Limestone Member of the Lukač Formation.

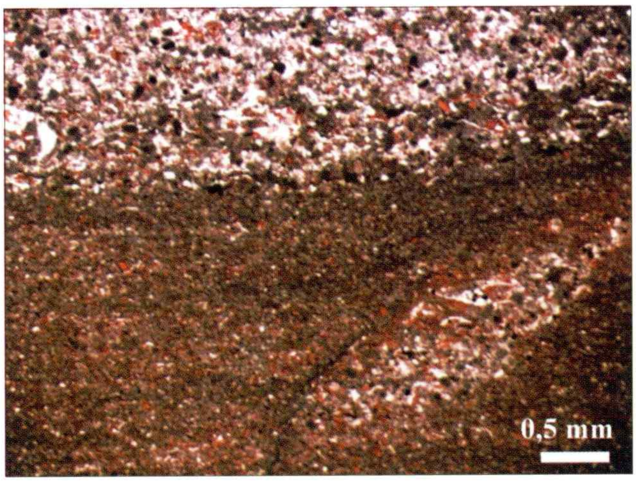


Fig. 13. Microphotograph of the sample T-18 (Streaky Limestone Member) shows a more siliciclastic bed at the top and a calcareous (micritic) bed beneath.

limestone suggests deposition in a shallow subtidal environment and deposition by oscillatory currents. Irregularly shaped beds were formed due to intensive bioturbation. Predominantly subtidal deposition implies deepening of the environment associated with increased terrigenous influx during Early Triassic time.

In the upper part of the section until its very end there is the approximately 80 m thick **Carbonate-clastic Member** of the Lukač Formation that consists of: a) **ooid-grainstone**, b) **laminated silty micrite/biomicrite** and of c) **calcareous siltstone**. Rarely ooid rich **biocalcarenite** occurs. In the uppermost 30 m of the succession, ooid grainstone beds disappear and the limy mudstone occurs more often with a nodular appearance. In the upper part of the succession micrite rich limestone containing reworked ooids is also present.

Wave ripple cross lamination was found in the ooid grainstone as well as in the calcareous siltstone. Plane parallel lamination can be seen only in the calcareous siltstone. Reworking by organisms is often present and can be seen as mottling of the siliciclastic and carbonate material.

a) The **ooid grainstone** consists of poorly to fairly sorted fine to medium sand sized ooid detritus. Exceptionally very coarse grained varieties (diameter 1.6 mm) occur. The ooid grainstone can be intensively dolomitized or dedolomitized. Mollusk and gastropod fragments are common in the ooid grainstone (Fig. 14).

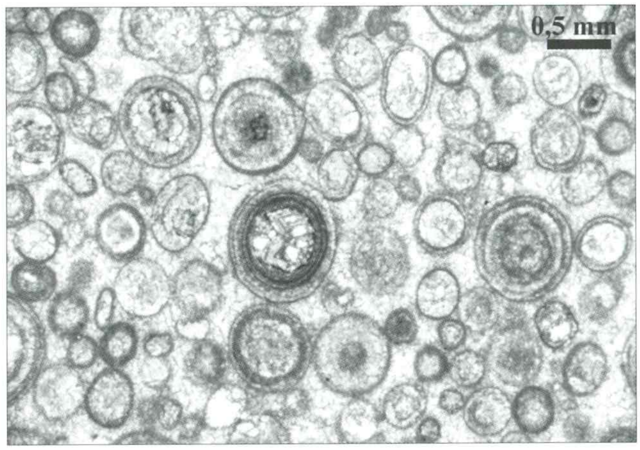


Fig. 14. Microphotograph of sample Lukač 69 shows oosparitic fabric of oolitic grainstone from the Carbonate-clastic Member. Ooids are fairly preserved and consist of core and several concentric envelopes.

b) The **laminated silty micrite/biomicrite** layers consist of an alternation of laminae containing silty siliciclastic detritus and micritic/ biomicritic material. The total amount of the silty component is less than 50%. A small amount of clayey component is present as well. Biomicritic lamina consists of ostracod biodetritus and some mollusk and gastropod fragments. The lamination in the silty micrite/biomicrite is mostly of wave origin. Reworking by organisms is common.

c) The **calcareous siltstone** is composed of more than 50% of silty siliciclastic material and calcareous (usually bioclastic) detritus. The cement is calcitic and/or dolomitic. Biodetritus is represented mainly by ostracodes and subordinarily by mollusk fragments.

The nodular mudstone varieties consist of dense micrite containing some silty siliciclastic grains. The mudstone is dolomitized, silicified and contains iron oxide.

Ripple cross-lamination in the ooid grainstone as well as in laminated siltstone exhibits characteristics of oscillatory/storm currents related to waves. Plane parallel lamination can be seen only in the calcareous siltstone and is probably due to suspension settling. Reworking by organisms is often present and can be seen as mottling of siliciclastic and carbonate material. All of these characteristics imply deposition in a marine, shallow environment, possibly between fair and storm weather wave base and an intensive terrigenous input.

Biostratigraphy

The importance of the Lukač section for the definition of the Permian-Triassic Boundary in Slovenia is the recovery of conodonts in the boundary interval beds. This section is the first found in Slovenia from which conodonts are recorded from the Permian-Triassic interval. The conodont fauna is characterized by a *Hindeodus–Isarcicella* population that provides a good basis for a very fine biozonation (Kolar-Jurkovšek & Jurkovšek, 2007; Kolar-Jurkovšek et al., 2011) The succession enables the definition of the PTB based on the first appearance of *Hindeodus parvus*, the diagnostic species and globally recognized marker defining the systemic boundary (Yin, 1993, 1996; Yin et al., 2001).

Conodont faunas are characterized by shallow water elements with prevailing *Hindeodus* and *Isarcicella* that are in the higher part of the section accompanied by representatives of *Hadrodontina* and ellisonids. The absence of gondolellids is obvious. The identified conodont elements are assigned to 15 species of 3 genera. The following conodont biozones have been recognized based on very detail collecting:

- the latest Changhsingian (uppermost Permian) *praeparvus* Zone,
- and the Griesbachian (lowermost Triassic) *parvus, lobata, staeschei-isarcica, postparvus* and *anceps* Zones.

The recovered conodont faunas can be well correlated with the Global Stratotype Section and Point (GSSP) at the Meishan section (Yin et al., 2001) and the Southern Alps (Fig. 15), as well as with other coeval sections of the adjacent areas in neighbouring areas of Austria, Hungary and Croatia.

A study of the foraminiferal fauna was also undertaken and identifications of the faunal elements were based on examination of thin sections and isolated forms. Four new species of foraminifers were described from the Lukač section: *Multidiscus zhiriensis*, *M. dinaridicus,* and *Globivalvulina lukachiensis* from the Upper Permian and *Lingulonodosaria slovenica* from the lowermost Triassic (Nestell et al., 2011).

Late Permian foraminifers were obtained from the lower and middle part of the Bellerophon Formation as its uppermost part in the Lukač section is represented by dolomite and does not contain foraminifers. The assemblage is represented by 43 species of 22 genera, including 2 genera of fusulinaceans: *Reichelina* and *Nankinella*. Foraminifers were recognized in the samples from B1 through B11. It should be noted that two forms were determined as *Hemigordius* cf. *H. komiricensis* as well as *Multidiscus* cf. *M. vlasicus* that were just recently introduced from the Komirić section in the Internal Dinarides (Nestell et al., 2009). The Late Permian foraminiferal assemblage of the Lukač section consists of species characteristic for the Changhsingian of many regions in the Tethys: northwestern Caucasus, Transcaucasia, Turkey, northern Italy, northwestern Serbia, northeastern Hungary, and South China (Nestell et al., 2011 with references).

Younger foraminifers also co-occur with conodonts and were recovered from the Permian-Triassic boundary interval represented by carbonate Transitional Beds deposited in shallow restricted marine conditions. The assemblage of Early Triassic foraminifers is very poor and it is represented by seven species of four genera. Among them is important the recognition of the species "*Cornuspira*" *mahajeri* and "*Earlandia*" spp., marking the lower boundary of the Triassic worldwide based on foraminifers. These species are found below the first appearance of the conodont species *Hindeodus parvus* which officially marks the lower boundary of the Triassic, and they are considered to be ecological species and their appearance coincides with a stressful shallow water environment. The first interval with nodosariid foraminifers appear 2m above the Permian-Triassic boundary and second one is approximately 5 m above the boundary. Both intervals are in the range of the last appearance of the conodont species *H. parvus* and within *I. staeschei – I. isarcica* conodont Range Zone (Kolar-Jurkovšek et al., 2011; Nestell et al., 2011).

Conclusions

The Permian-Triassic interval of the Lukač section in western Slovenia was studied sedimentologically and micropaleontologically by using conodonts and foraminifers. The analyzed section is composed of the Bellerophon Formation (Bellerophon Limestone and Evaporite-dolomite Members) and the Lukač Formation (Transitional Beds, Streaky Limestone Member and Carbonate-clastic Member). All described lithostratigraphic units, but the Bellerophon Formation, are here formalized.

The overall sedimentary characteristics reflect shallow marine conditions that began with the Permian Bellerophon Limestone Member where micritic microfacies prevail. A deposition of micrites/biomicrites (Bellerophon Limestone Member) in a lagoonal, possibly back reef conditions, continuously change to hypersaline very shallow conditions depicted as Evaporite-dolomite Member. The conformable boundary with the Transitional Beds suggests maintaining of a shallow marine condition during the depositon of the Transitional Beds. Laminated mudstone and laminated micritic/biomicritic limestone suggest deposition in a restricted marine condition, but the presence of grainstone implies periodically established higher energy condition and deposition of oolitic detritus by oscillatory and/or tidal currents.

A wavy and/or hummocky structure observed in the Streaky Limestone Member that overly Transitional Beds suggests deposition in strictly subtidal conditions by oscillatory currents in a shallow sea. Irregularly shaped beds were formed due to intensive reworking by organisms.

Sedimentary rocks of the Carbonate-clastic Member show characteristics of shallow marine deposition of ooid or bioclastic detritus by oscillatory/storm currents. A prevailing deposition of carbonate was periodically punctuated by terrigenous input of silty siliciclastic material. The deposition reflects predominantly subtidal conditions.

A deposition in the Lukač Formation implies a general deepening of the environment associated with the increased terrigenous influx during Early Triassic time.

The studied PTB interval beds are characterized by a diverse microfauna. The entire section is characterized by a *Hindeodus-Isarcicella* association and only the highest part of the section is marked by the presence of ellisoniids, predominantly *Hadrodontina*. The absence of gondolellids is noteworthy. Six conodont zones have been recognized in ascending order, the latest Changhsingian (uppermost Permian) *praeparvus* Zone, and the Griesbachian (lowermost Triassic) *parvus, lobata, staeschei-isarcica, postparvus* and *anceps* zones.

The first occurrence of *H. parvus* in sample L1 in the Transitional Beds marks the systemic boundary between the Permian and Triassic. A rapid entry of several conodont taxa is observed in the highest level of the Transitional Beds, in the *lobata* Zone and in the succeeding *staeschei-isarcica* Zone in the lowermost part of the Streaky Limestone Member, and both probably represent a recovery event.

The introduced conodont biozonation for the Lukač section is the first proposed for the PTB interval in Slovenia as well as in the entire Dinaride region. The recognized conodont fauna of the Lukač section enables correlation with the similar age sequences in the Southern Alps in Italy, and with the GSSP Meishan D section in South China (Fig. 15).

Foraminifers are found together with conodonts in the Permian Bellerophon Limestone Member of the Bellerophon Formation, Permian-Triassic Transitional Beds and in the lower part of the Streaky Limestone Member of the Lukač Formation of the lowermost Triassic. Foraminifers of the Bellerophon Limestone Member are characteristic for the Changhsingian of various regions of the Tethyan realm. In the Permian-Triassic Transitional Beds, the species "*Cornuspira*" *mahajeri* , and "*Earlandia*" spp. marking the lower boundary of the Triassic worldwide based on foraminifers appear below the first appearance of *Hindeodus parvus* and are considered to be an ecological species as two of determined species are also found above the Permian-Triassic boundary. The appearance of the species "*C.*" *mahajeri* and "*E.*" spp. coincides probably with a shallow restricted environment, and thus, they cannot be used for biostratigraphic purposes as stratigraphic markers of the lower boundary of the Triassic. The first nodosariids appear at the base of the Streaky Limestone Member, approximately 2 m above the PTB and are represented by the one recently described new species, *Lingulonodosaria slovenica* not found anywhere else yet.

Acknowledgements

The authors are indebted to Merlynd Nestell (Arlington, Texas) for editing the manuscript and wish to extend our thanks to Heinz Kozur (Budapest, Hungary), Milan Sudar (Belgrade, Serbia) for helpful suggestions and communications during this study. Bojan Ogorelec (Ljubljana, Slovenia) and Milan Sudar (Belgrade, Serbia) provided constructive reviews of the manuscript. Facilities and technical staff of the Geological Survey

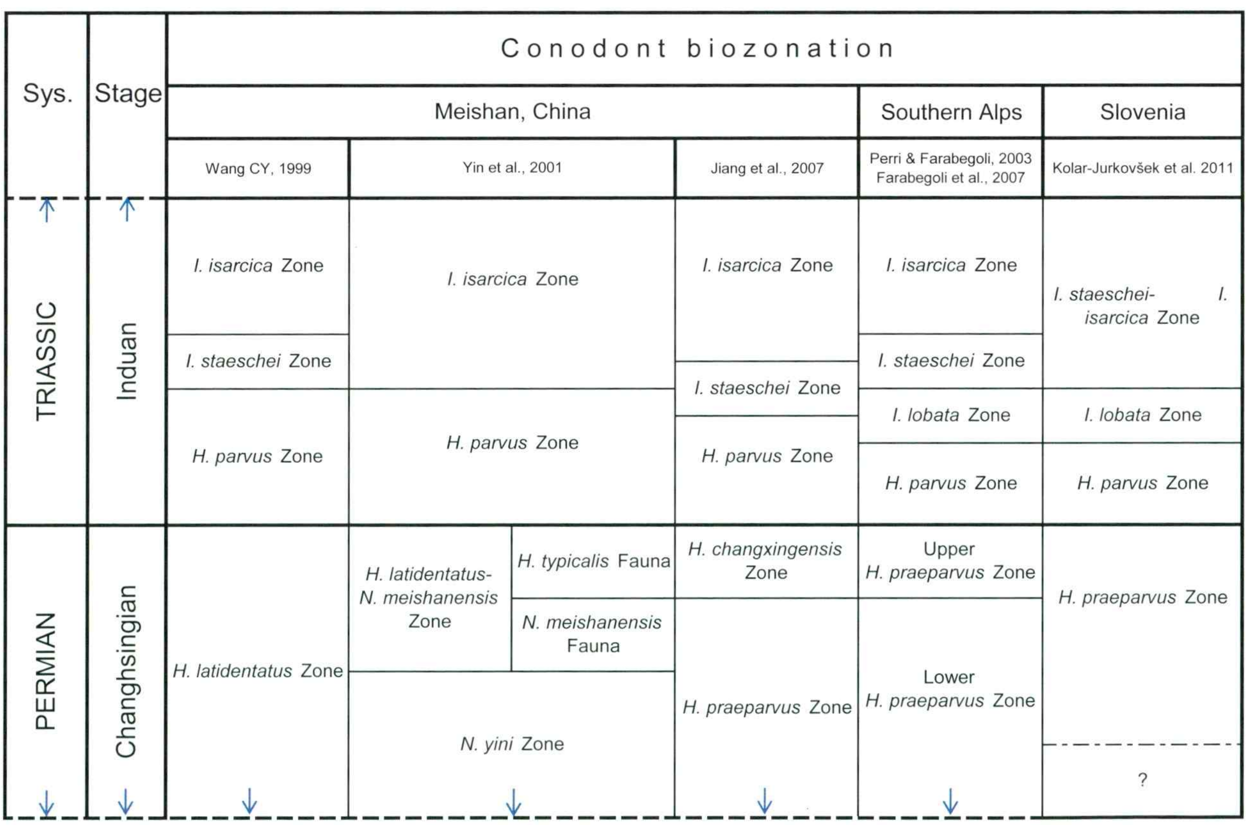


Fig. 15. Correlation chart of shallow water conodont biozones across the Permian-Triassic boundary interval of the studied Slovenian section at Lukač with Meishan, China and the Southern Alps.

of Slovenia are gratefully acknowledged. The investigation was partly supported by the Slovenian Research Agency (program number P1-0011 and project number J1-6665), Croatian Ministry of Science (project number 195-0000000-3202) and through the program of bilateral cooperation in science and technology Slovenia-Croatia (2009–2010). This is a contribution to the IGCP-Project 572 (»Recovery of ecosystems after the Permian-Triassic mass extinction«).

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