GEOLOGIJA 58/2, 155-174, Ljubljana 2015

http://dx.doi.org/10.5474/geologija.2015.012

Conodont zonation of Lower Triassic strata in Slovenia

Konodontna conacija spodnjetriasnih plasti Slovenije

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Prejeto / Received 8. 12. 2015; Sprejeto / Accepted 21. 12. 2015; Objavljeno na spletu / Published online 30. 12. 2015

Key words: conodont zonation, Lower Triassic, Southern Alps, Dinarides, Slovenia
Ključne besede: konodontna conacija, spodnji trias, Južne Alpe, Dinaridi, Slovenija

Abstract

The paper presents the results of a conodont study carried out in the Triassic strata in the area of the Slovenian part of the Southern Alps, External Dinarides and the Transition region between the External and Internal Dinarides. The following conodont zones have been distinguished: *Hindeodus praeparvus* Z., *H. parvus* Z., *Isarcicella lobata* Z., *I. staeschei* – *I. isarcica* Z., *H. postparvus* Z., *Hadrodontina aequabilis* Z., *Ha. anceps* Z., *Eurygnathodus costatus* Z., *Neospathodus planus* Z., *N. robustus* Z., *Platyvillosus corniger* Z., *Pl. regularis* Z., *Pachycladina obliqua* Z., *Foliella gardenae* Z., *Triassospathodus hungaricus* Z., *T. symmetricus* Z., *N. robustispinus* - *T. homeri* Z. and *T. triangularis* Z. The introduced conodont zonation spans from the Induan, including the Permian-Triassic boundary interval to the late Olenekian and is valid for the shallow shelf environments of western Tethys.

Izvleček

Predstavljeni so rezultati večletnih raziskav spodnjetriasnih plasti s konodonti na prostoru slovenskega dela Južnih Alp, Zunanjih Dinaridov in prehodnega območja med Zunanjimi in Notranjimi Dinaridi. V raziskanih profilih so bile ugotovljenje naslednje konodontne cone: *Hindeodus praeparvus, H. parvus, Isarcicella lobata, I. staeschei – I. isarcica, H. postparvus, Hadrodontina aequabilis, Ha. anceps, Eurygnathodus costatus, Neospathodus planus, N. robustus, Platyvillosus corniger, Pl. regularis, Pachycladina obliqua, Foliella gardenae, Triassospathodus hungaricus, T. symmetricus, N. robustispinus - T. homeri* in *T. triangularis*. Izdvojene konodontne cone obsegajo čas od spodnjega induana, vključno s permsko triasnim mejnim intervalom, do zgornjega olenekija. Vpeljana je konodontna conacija za okolja plitvega šelfa zahodne Tetide.

Introduction

Conodont research in Slovenia started back in the sixties of the last century, during the time of elaboration of the Basic Geologic Map of Yugoslavia 1 : 100,000. The first analysis of conodont samples were carried out by the Serbian paleontologist Smiljka Pantić who determined the fauna from Lower Triassic strata of the Polhograjsko hribovje Hills (Grad & Ferjančič, 1976). Despite a rapid development of Slovenian conodontology in the following period, Lower Triassic strata were considered for more than two decades being poorly perspective for conodonts. It was only in the eighties of the last century when the fauna of the Smithian *Parachirognathus / Furnishius* conodont zone was collected in a section near Idrija (Kolar-Jurkovšek, 1990). In the following decades an intensive conodont research of the lowermost Lower Triassic succession contributed to definition of the Permian-Triassic boundary (PTB) interval, first in Slovenia, and then in the broader area of the Dinarides of Croatia and Serbia (Kolar-Jurkovšek et al. 2011c, 2012; Aljinović et al., 2014; Sudar, 2007).

After the Permian-Triassic catastrophe, as often named the greatest mass extinction, the global biosphere was greatly impoverished and needed some time to be able to recover to the previous diversity, as at the end of the Permian 70 % of genera of terrestrial vertebrates and 85 to 96 % of marine invertebrate species that lived at the end of the Paleozoic became extinct (Benton, 2005). The first pulse of extinction was already between the Middle and Upper Permian, at about 260 million years ago and the second between the Permian and Triassic, at about 252 million years ago. For the second - the main pulse between the Permian and Triassic a pronounced increase in volcanic activity was especially fatal. In the PTB interval sedimentary rocks is documented a sudden drop in δC^{13} that is today by researchers mostly linked with the release of frozen gas hydrates on the seafloor (Berner, 2002). The climate changes caused a change in ocean currents and change of the pH of sea water that greatly increased aridity in the supercontinent inland. Some studies indicate long-term global deep anoxic event in the PTB interval. The

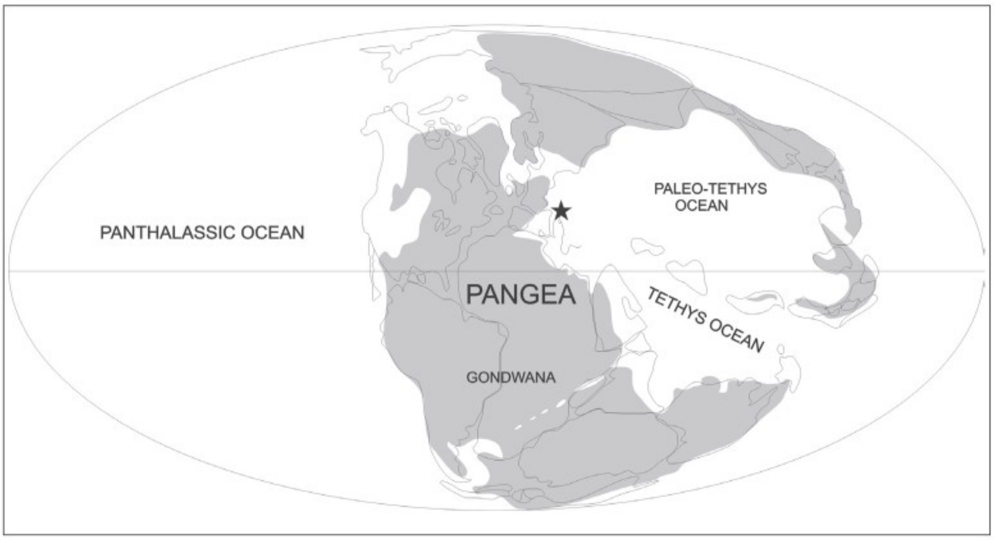


Fig. 1. Paleogeographic sketch of Earth in the Early Triassic. Star indicates the location of Early Triassic beds in Slovenia (modified from Scotese, 2001).

Panthalassa Ocean became fully stratified for almost 20 million years. Beginning, peak and the end of the oceanic stratification corresponds to the global biotic events from the decline in the number of species at the end of the Guadalupian, and extinction at the end of the Permian to the full recovery of life during the Anisian (Isozaki, 1997, 2009). Due to coincidence of timing of different triggers of the Permian-Triassic extinction, the biodiversity in the Mesozoic was significantly reduced for entire 25 million years.

In general, the Triassic Earth's crust was relatively stable until the Late Triassic, when disintegration was intensified caused by continental rifting. The Tethys Ocean, which has already begun to develop in the Permian south of the Paleotethys or south of the lands of Cimmeria, started to incise increasingly to the west during the Triassic and later already in the Jurassic it divided the Pangea into two halves, on Gondwana and Laurasia.

Review of conodont research in Lower Triassic strata in Slovenia

General geological setting

Slovenia is situated in the area of four major geotectonic units: the Dinarides, the Southern Alps, the Eastern Alps and the Pannonian Basin. Today's geological image of Slovenia is largely result of the collision of the Adriatic and European plates and accompanying tectonic processes, which persist even today. Paleozoic and Mesozoic structures are thus largely deformed, blurred or covered with sediments of the Pannonian Basin. All tectonic units of the Slovenian territory belong to the Adriatic lithosphere plate, which was originally connected to the African plate, and from the Mesozoic era onwards existed as a separate plate.

Paleozoic rocks of today's Slovenia were formed in the northern part of the former southern supercontinent Gondwana, mainly on its epicontinental shelf. More clearly their origin is

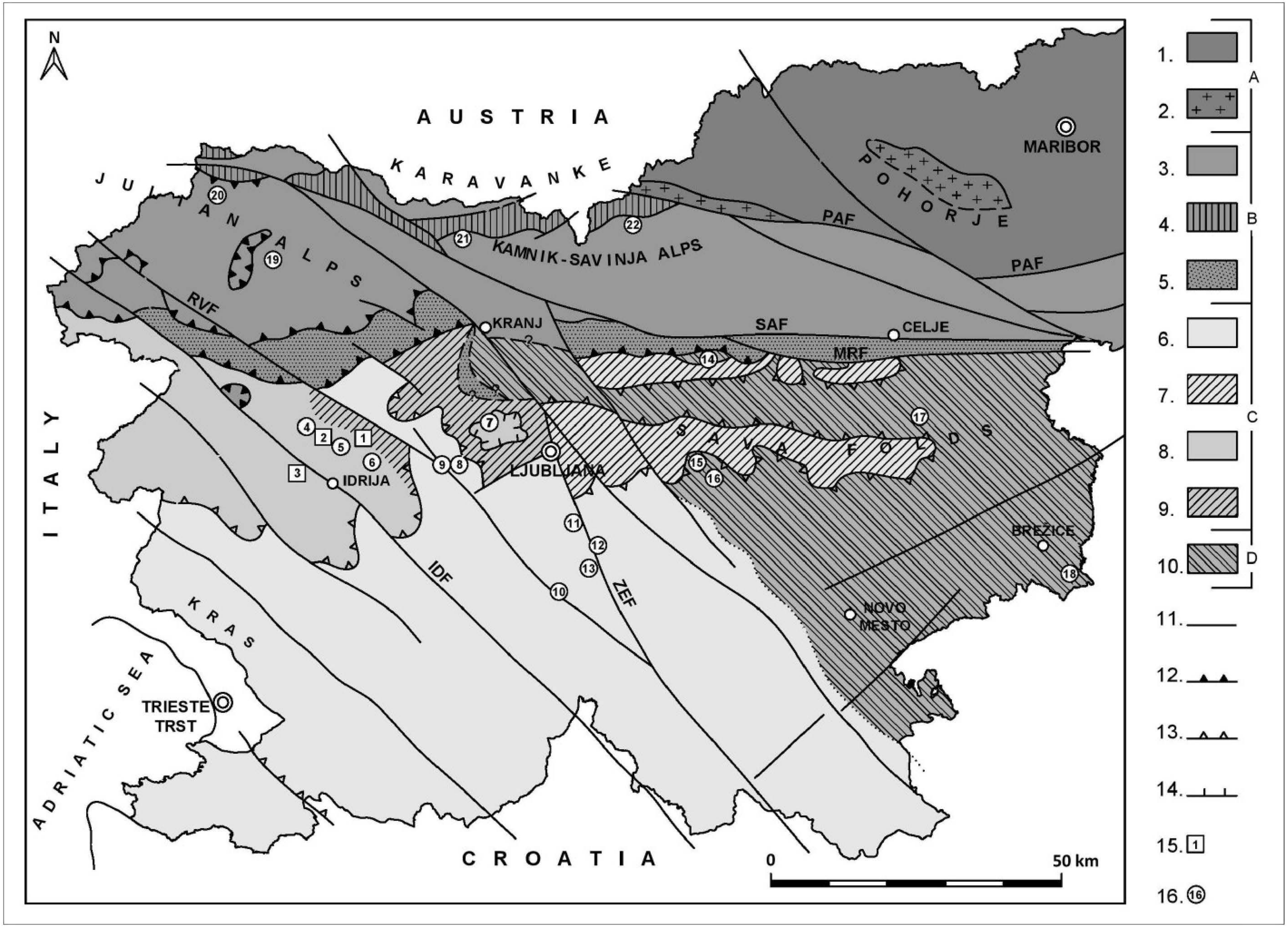
Fig. 2. Sketch of macrotectonic subdivision of the border region between the Southern Alps and External Dinarides in Slovenia showing Early Triassic sections with conodonts (modified and supplemented after Placer, 2008).

A – Eastern Alps: 1 – in general, 2 – Pluton of tonalite/granodiorite (Pohorje) and Periadriatic intrusive; **B – Southern Alps**: 3 – in general, 4 – Paleozoic, 5 – Slovenian Basin sediments; **C – External Dinarides**: 6 – in general, 7 – Paleozoic, 8 – Trnovo nappe, 9 – Paleozoic; **D – Transition area between External and Internal Dinarides**: 10 – in general; 11 – **Faults**: **PAL** – Periadriatic lineament, **IDF** – Idrija fault, **RVF** – Ravne and Sovodenj fault, **SAF** – Sava fault, **MRF** – Marija Reka fault; 12 – thrust and overthrust faults in Southern Alps; 13 – thrust and overthrust faults in Dinarides; 14 – tectonic slice; 15 – Induan conodonts; 16 – Olenekian conodonts.

Note: Tertiary and Quaternary, mainly molasse sediments of the Pannonian Basin, are not shown on the map.

Sections:

1 – Lukač near Žiri, Javorjev Dol
2 – Masore, Idrijca
3 –Vojsko
4 – Želin –Vrlejca
5 – Žiri surroundings
6 – Golob, Krkoč near Spodnja Idrija
7 – Tehovec near Medvode
8 – Horjul surroundings
9 – Šentjošt, Samotorca, Prevalc
10 – Iška
11 – Draga near Ig, Skopačnik near Želimlje
12 – Borštnik near Turjak
13 – Četež near Turjak
14 – Trojane
15 – Grmače near Šmartno
16 – Leskovica, Bogenšperk - Temnica
17 – Mišnica near Jurklošter
18 – Mokrice
19 – Studorski preval – Julian Alps
20 – Špica v sedlcih – Julian Alps
21 – Tržiška Bistrica
22 – Solčava surroundings


N
AUSTRIA
ITALY
CROATIA
ADRIATIC SEA
JULIAN ALPS
KARAVANKE
KAMNIK-SAVINJA ALPS
POHORJE
SAVA FOLDS
KRAS
MARIBOR
KRANJ
CELJE
LJUBLJANA
IDRIJA
BREŽICE
NOVO MESTO
TRIESTE
TRST
PAF
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recognized in the late Paleozoic, when most of the Earth's land masses were united in a supercontinent Pangea. From the east the Paleotethys Ocean incised in it, and at its southern end, however, the Tethys Ocean began to open (Fig. 1). Then an intensive intraoceanic carbonate platform gradually began to form in an autonomous Adriatic lithosphere plate. During the Permian and Lower Triassic there was still a unified sedimentation area, and its smaller part in Slovenia is called the Slovenian Carbonate Platform (Buser, 1989). During the Anisian and Ladinian the Slovenian Carbonate Platform began to disintegrate as a result of extensional tectonics on the edge of Eurasia, where the Meliata Ocean began to originate (Vrabec et al., 2009). All the activities were accompanied by strong volcanism. Until that time a uniform Slovenian Carbonate Platform disintegrated in the Adriatic-Dinaric Carbonate Platform in the south, and the Julian Carbonate Platform in the north, with an intermediate Slovenian Basin (Buser, 1989; Buser et al., 2007, 2008).

In today's geotectonic structure of Slovenia (Placer, 1999; Poljak, 2000) to the Southern Alps belong the sedimentary rocks that built large part of the Southern Karavanke, Julian Alps and the Kamnik-Savinja Alps. To the Transitional area between the External and Internal Dinarides belongs the area which extends from central Slovenia across the Sava Folds to the east and south-east to the Dolenjska and Gorjanci regions and continue further to Croatia. To the External Dinarides corresponds a greater part of southern and south-western Slovenia. To the Eastern Alps in Slovenia is ranked a territory of the Northern Karavanke situated north of the Periadriatic Lineament (Fig. 2).

Overview of the Early Triassic sections with conodonts

Lower Triassic marine sedimentary rocks in the area of the Southern and Eastern Alps, the External Dinarides and the Transitional area between the External and Internal Dinarides were sampled for conodont research. In all units the lithostratigraphic development of the Lower Triassic strata is more or less similar. Their lowest part containing conodonts of the PTB interval gave positive results only in the Idrija-Žiri area belonging to the External Dinarides. In the other units Olenekian conodonts were identified, whereas the conodont research of Lower Triassic strata in the Slovenian part of the Eastern Alps were negative.

Base of the Lower Triassic strata in all these geotectonic units is formed of limestone and dolomite of the Bellerophon Formation as a result of general marine transgression in a shallow shelf of west Paleotethys in the Late Pemian. For convenience, it is necessary to clarify the names of the Late Permian lithostratigraphic units, that were used in Slovenia. The first is the Karavanke Formation of the Southern Alps (Buser et al., 1989), which is represented mainly by dolomite development, and in its upper part there occur limestone and dolomite with characteristic Late Permian fossil association of the Bellerophon Formation (Skaberne et al., 2009). The second is the Žažar Formation of the External Dinarides, which was named by Ramovš (1958 a, b) and he distinguished twelve limestone levels with a brachiopod fauna of the Caucasus-Indoarmenian type. The name of the Žažar Formation was later taken up by some researchers (Grad & Ferjančič, 1976; Buser et al., 1989; Dolenec et al., 2004; Mlakar & Čar, 2009), although it is the lithological and biostratigraphic equivalent of the Bellerophon Formation of the Carnic Alps and the Dolomites in Austria and Italy (Farabegolli et al., 1986; Holser & Schönlaub, 1991).

Following a decision of the International Commission of the IUGS (Yin et al., 2001) to define the PTB based on the first appearance datum (FAD) of a globally spread conodont species *Hindeodus parvus* (Kozur & Pjatakova), there was also in Slovenia greatly increased interest to study the PTB interval. Researchers were particularly interested in the Idrija Žiri area in the western Alpine foothills. The geological structure of the area is relatively well known due to elaboration of the Basic Geological Map SFRY 1: 100,000, sheet Tolmin and Udine (Buser, 1986, 1987) and also due to extensive geological research of the Idrija mercury mine area (Mlakar, 1969; Placer, 1973, 1981; Mlakar & Čar, 2009; Čar, 2010). In sections in which the PTB is located entirely in the dolomite-evaporite strata, paleontological research did not reveal any results. However, in the sections in a limestone development, the boundary was often placed on the upper lithological boundary of the Bellerophon Formation (Grad & Ogorelec, 1980; Buser et al., 1989; Mlakar & Placer, 2000; Mlakar & Čar, 2009; Čar, 2010). There are two particularly interesting well-exposed sections in the limestone development near Idrija town (Masore and Idrijca sections), in which the PTB was defined on the basis of geochemical - isotopic studies (Dolenec & Ramovš, 1998; Dolenec & Ogorelec, 2001; Dolenec et al., 1999 a, 1999 b, 2001, 2004). The goal of an ongoing study of the two sections is to define the PTB based on biostratigraphic evidence.

In the Lukač section near Žiri in the External Dinarides, the PTB was for the first time defined in Slovenia according to an international criterion based on the finding of the conodont species *H. parvus* (Kolar-Jurkovšek & Jurkovšek, 2007). The section is similar to most other studied Permian-Lower Triassic sections in the Idrija-Žiri area of the Trnovo nappe, which is the highest thrust unit of the External Dinarides in this area. The obtained conodont faunas of the Lukač section enabled very fine biozonation due to rapid evolution of the genera *Hindeodus* and *Isarcicella* and for this reason the Lukač section represents a key section to define PTB interval strata in Slovenia that is taken also as a standard for conodont zonation for the whole Dinaric area (Kolar-Jurkovšek et al., 2011a, 2011b, 2012). The Late Permian Bellerophon Formation is divided into two members, the lower Bellerophon Limestone and the Evaporite-dolomite Member of the rauchwacke type at the top of the formation (Kolar-Jurkovšek et al., 2011 b). On the dolomite there concordantly rest The transitional Beds of the Lukač Formation. A 3.3 m thick, shallow-water transitional interval consists of laminated mudstone, laminated micrite/biomicritne limestone and grainstone with parallel and cross-lamination. From the Transitional Beds a new species of foraminiferal species *Lingulonodosaria slovenica* Nestell et al. has been described (Nestell et al., 2011).

Above the Transitional Beds concordantly rest a 30 m of the Lower Triassic Streaky Limestone, which is composed of very thin strata of bioclastic limestone with minor siliciclastic component. Darker intermediate laminae give a »streaky« appearance to the limestone (Mlakar, 2002; Kolar-Jurkovšek & Jurkovšek, 2007), consisting mainly siliciclastic-clayey material that was reworked by organisms. Wavy and hummocky structure of the Streaky Limestone indicates a shallow subtidal environment with oscillations and storms.

In the upper part of the Lukač Formation than follows a 80 m strata of the Carbonate-clastic Member consisting of ooid grainstone, laminated silty micrite/biomicrite and calcareous siltstone. Deposition of the calcareous siltstone implies intensive terrigenous input in a very shallow depositional environment.

In the Lukač section six conodont zones have been identified, which can be well compared with biozonation of different sections in the Southern Alps, Meishan in China and some other sections in the world (Kolar-Jurkovšek et al., 2011 a). The upper Changhsingian (Late Permian) *Hindeodus praeparvus* Zone and the Induan (Early Triassic) *H. parvus, lsarcicella lobata, I. staeschei – I. isarcica, H. postparvus* and *Hadrodontina anceps* Zones have been distinguished. The first appearance datum of the species *Hindeodus parvus* in the Transitional Beds indicates systemic boundary between the Permian and Triassic (Kolar-Jurkovšek et al., 2006, 2011a, b).

Late Permian–Early Triassic succession of the Lukač section continues to the northwest and in a similar form it is exposed in a road cut of the Javorjev Dol area. Grad and Ogorelec (1980) set the the PTB in a dolomite, which corresponds to the Evaporite-dolomite Member of the Bellerophon Formation. Conodont fauna collected in the limestone of the Bellerophon Formation below the dolomite yields *H. praeparvus* Kozur and *H. latidentatus* (Kozur, Mostler & Rahimi-Yazd). However, the actual boundary with the Lower Triassic strata that outcrop along the road about 30 m in a direction to Sovodenj is covered and tectonized. In the Lower Triassic oolitic limestone strata *I. isarcica* (Huckriede) was collected.

In the Idrija-Žiri area three sections with the PTB are currently studied: the Masore, Idrijca and Vojsko sections. Conodont faunas were recovered from all three sections.

In the Masore section the limestone of the Bellerophon Formation attains a thickness of about 250 m. Its upper part is characterized by the fauna of the *H. praeparvus* Zone that has relatively wide range. The Bellerophon Limestone passes then through thin bedded, predominately microbialite limestone with stylolites into the Lower Triassic bedded limestone containing typical Induan conodont association with *I. isarcica*.

The same strata of the Permian-Triassic boundary as in the Masore section, occur 2 km laterally in the valley of the river Idrijca. There is visible only the highest part of the limestone of the Bellerophon Formation and the lowest microbialite part of the Lower Triassic strata (Kolar-Jurkovšek et al. 2015a; Aljinović et al. 2015). Also here were identified conodonts of the *H. praeparvus* Zone in the highest part of the Permian portion of the section, and the *I. isarcica - I. staeschei* Zone in the Lower Triassic microbialite part of the section.

The Vojsko section is situated on the eastern slope of the Vojsko plateau at an altitude of 770 m. According to Placer (1981) it belongs to the Kanomlja thrust slice, which lies directly below the Trnovo nappe, and the rocks are in the inverse position. Unlike the Masore section, where over 250 m thick succession of the Bellerophon Formation is exposed, in the section Vojsko only around 30 m of thickness is visible (Mlakar & Čar, 2009; Čar, 2010). In the highest part of the formation, about 2 m below the lithological boundary with light gray stromatolitic dolomite, there occur very rare and small sponge buildups (Sremac et al., submitted). The conodont fauna of this part is assigned to the *H. praeparvus* Zone.

Above the Bellerophon Formation lies medium gray thin bedded stromatolitic dolomite with clear lamination and stylolites that passes up to the medium bedded and slightly recrystallized dolomite and dolomitized limestone in which a conodont fauna of the *I. staeschei - I. isarcica* Zone was found. In the stratigraphically younger parts an increased content of limestone and clastic components is observed, initially in the form of olive green marl, then reddish brown calcarenite, siltstone and shale with lenses of oolitic limestone, followed by more than 100 m grained dolomite. The Lower Triassic sequence is ended by bedded dark gray limestone containing marl sheets, above which concordantly lies Anisian dolomite (Čar, 2010).

In addition to the study in a context of the previously described sections Lukač, Masore, Idrijca and Vojsko that include the PTB interval, interesting results of conodont study were obtained also in some other Lower Triassic sections in the Idrija- Žiri area. It should be noted that the names of most Lower Triassic lithostratigraphic units in the External Dinarides have been traditionally based on the subdivision in the Dolomites and the Northern Calcareous Alps. Therefore also Slovenian geologists often divided the so-called Werfen Formation into lower »Seis Beds« (Seiser Schichten) and the upper »Campil Beds« (Campiler Schichten). Biostratigraphy of Lower Triassic strata was based mainly on macrofossills: ammonites, bivalves and gastropods, rarely on foraminifers, but conodont study was implemented only in a recent two decades. Precise litho-, bio- and chemostratigraphic study have demonstrated the lateral and vertical differences and similarities in litho- and biofacies of adjacent areas. Therefore, the »Seis« and »Campil« beds in the Slovenian part of the External Dinarides can no longer be regarded as chronostratigraphic equivalent of the facies of the Southern Alps (Aljinović et al., 2013 a, b). Distribution of Lower Triassic sediments in the External Dinarides clearly demonstrates temporal and lateral change of carbonate and siliciclastic sediments depending on various transgression-regression cycles on the extensive epeiric carbonate platform of west Tethys. Despite lithological variations between different Lower Triassic sedimentary areas in the External Dinarides in almost all sections their threefold division can be recognized into: the oldest part consisting of carbonates, the middle siliciclastic or mixed siliciclastic-carbonate part, and the third or the highest carbonate part (Buser 1969, 1974a; Aljinović et al., 2013a, b).

Already the first conodont study of the Lower Triassic strata of the Idrija-Žiri area in the nineties of the last century demonstrated that the greater part of the reddish »Seis« shales, siltstones and sandstones that contain also layers of oolitic limestone are not of the Induan but Olenekian in age. In the Želin-Vrlejca section a characteristic Smithian fauna with the following taxa: *Furnishius triserratus* Clark, *Hadrodontina* sp., *Pachycladina obliqua* Staesche and *Parachirognathus ethingtoni* Clark was documented and ranged to the *Parachirognathus/Furnishius* Zone (Kolar-Jurkovšek, 1990).

The greater part of the Lower Triassic represented an extended recovery event following the Permian-Triassic mass extinction, as well as being marked by three minor crises (Stanley, 2009), which were reflected particularly in ammonites and conodonts during the late Griesbachian, late Smithian and late Spathian. The Smithian-Spathian boundary is indicated by a global warming (Galfetti et al., 2007; Sun et al., 2012), which is also indicated by a positive shift of $\delta^{13}C_{carb}$ (Richoz, 2006) as well as conodont size reduction (Chen et al., 2013).

A systematic sampling of five Lower Triassic sections in the Idrija-Žiri area of the Trnovo nappe has yielded the best Early Triassic conodont sequence in central and southern Europe. The recovered conodont faunas enabled us to distinguish nine conodont biozones spaning from the late Induan (Dienerian) to the Olenekian (Spathian) (Chen et al., 2015 a). In the five studied sections following conodont zones were determined: *Eurygnathodus costatus* Z., *Eurygnathodus hamadai* Z., *Foliella gardenae-Pachycladina obliqua* A.Z., *Neospathodus robustus* Z., *Platyvillosus corniger* Z., *Platyvillosus regularis* Z., *Triassospathodus hungaricus* Z., *Triassospathodus symmetricus* Z., and *Neospathodus robustispinus* Zones. The succession of the Lower Triassic zones is of particular value for stratigraphic correlation in central and southern Europe and it enables better correlation studies between the western and middle-eastern Tethys.

The sections in vicinity of Spodnja Idrija and Žiri could be regarding their position above the »Seis« beds traditionally compared with the »Campil« beds of the Dolomites, that in the highest part often contain Olenekian fauna with the ammonites of the genera *Tirolites* and *Dinarites*, gastropods *Natiria* and *Turbo* and foraminifera *Meandrospira pusilla* (Ho). Since the development of Olenekian strata of the Žiri area significantly differs from the typical Campil Beds, the local beds are ranged to the new informal lithostratigraphical unit, the "Žiri Beds".

In the western part of the Alpine foothills the conodont study was directed to the Polhograjsko hribovje hills, which are situated west of Ljubljana between the Ljubljana moor in the south, Podlipščica to the west and to the north it is separated from the Škofja Loka hills by the Poljanska Sora River. All studies from different sections and outcrops have confirmed only the Olenekian age, whereas Induan strata have not been identified in this area.

In the Tehovec section, southwest of Medvode, a slightly marly biomicrite limestone lies on a thick bedded dark gray dolomite and with thin marlstone intercalations. In several beds also oolites are encountered. Among fossil molluscs there are represented *Natiria costata* (Münster) and *Costatoria costata* (Zenker) as well as rare badly preserved ammonites. Among the microfossils in the greater part of a 47 m section foraminifera *M. pusilla* occurs and the conodonts are represented by typical Lower Triassic shallow water elements *P. obliqua* and genera *Hadrodontina* and *Ellisonia* (Jurkovšek et al., 1999). Similar Lower Triassic successions are known from many other localities in the Polhograjsko hribovje Hills (Grad & Ogorelec, 1980; Ramovš, 1958b). These strata produced conodonts in the Horjul surroundings (Koreno, Samotorca, Prevalc and Šentjošt).

In the External Dinarides, Lower Triassic strata with conodonts were also found in several places of Notranjska and Dolenjska regions. Detail investigations have been done in the sections on the southern and eastern outskirts of the Krimsko-mokrško hribovje hills. Buser (1969, 1974) roughly divided Early Triassic strata into three superposition packages. Below is bedded gray dolomite with claystone and siltstone intercallations, in the middle part is reddish shale and sandstone with intercalations of oolitic limestone, and in the upper part there is light gray dolomite with marl beds. In all sections conodonts were recovered only from the samples of the middle superposition package. The carbonate beds (sparitic limestone, calcarenite and oolite limestone), which are deposited between the reddish claystones, siltstones and fine grained sandstone in the Iška River gorge yield conodonts *Ellisonia* sp., *Foliella gardenae* (Staesche) *Hadrodontina* sp., *P. obliqua* and *P. ethingtoni*. The fauna is dominated by the elements of the conodont apparatus *P. obliqua* at different ontogenetic stages (Kolar-Jurkovšek & Jurkovšek, 1996). Similar conodont fauna was also found in Lower Triassic strata at Draga near Ig (Kolar-Jurkovšek & Jurkovšek, 1996), Četež near Turjak and Borštnik. The recovered conodont elements of these localities are comparable with the obtained Smithian faunas from the Želin-Vrlejca sections of the Idrija-Žiri area and near Tržič (Kolar-Jurkovšek, 1990, Kolar-Jurkovšek & Jurkovšek, 1995). From the middle superposition package of a variegated clastites containing oolitic limestone beds at Skopačnik near Želimlje (Dozet & Kolar-Jurkovšek, 2007) a Smithian species *F. gardenae* and *P. obliqua* are determined, whereas in the overlying dolomite strata which correspond to the upper carbonate superposition package the Spathian elements *T. homeri* (Bender) and *T.* ex gr. *triangularis* (Bender) were determined.

Similar lithological developments of Lower Triassic strata with conodonts as in the External Dinarides are also represented in the Transitional area between the External and Internal Dinarides, which extend from central Slovenia to the east on the territory of Croatia. The greater part of the Transitional area belongs to the Sava Folds, where in all of the investigated Lower Triassic strata conodonts were collected only in the middle mixed siliciclastic-carbonate part, which includes also oolitic limestone beds. Northwest of Trojane in the limestone between the reddish and olive grey clastites conodont species *Hadrodontina anceps* Staesche and *P. obliqua* have been found, in the Grmače section south of Litija *P. obliqua*, at Leskovica south of Bogenšperk and along the road between Bogenšperk and Temnica *P. obliqua* and *F. gardenae*. In the eastern Kozjansko region in the valley Mišnica north of Jurklošter the species *P. obliqua* was collected. All reported conodont elements indicate to a Smithian age of the sampled strata. A poorly preserved Early Triassic conodonts of the genera *Hadrodontina* and *Pachycladina* and some other non-identifiable fragments yield also some other test samples from the Sava Folds (Dobovica south of Podkum, Čebine north of Zagorje, etc.).

To the Transition region between the External and Internal Dinarides belongs also the Dolinski potok near Mokrice, which is located in the easternmost part of the Gorjanci - Žumberak Mt. near the Slovenian-Croatian border and it includes sedimentary rocks of the Smithian-Spathian interval (Kolar-Jurkovšek et al., submitted). The investigated part of the section is dominated by a thin bedded limestone with marl intercalations. Two limestone lithothypes are mainly represented: biomicrite/packstone and micritic limestone (mudstone). The following conodont zones have been distinguished: *Ha. aequabilis* Zone, *Platyvillosus corniger* Zone, *Pl. regularis* Zone and *Triassospathodus hungaricus* Zone. The same conodont zones were also discriminated in Lower Triassic sections of the Idrija-Žiri area (Kolar-Jurkovšek et al., 2015b; Chen et al., 2015 a) and they are particularly relevant for correlation of the equivalent strata of the adjacent as well as broader areas with significant sections of Asia and North America. The conodont material from this section has enabled the reconstruction of two conodont multielements: *T. hungaricus* (Kozur & Mostler) and *Pl. regularis* (Budurov & Pantić).

The conodont research in the Lower Triassic of the Slovenian part of the Southern Alps was carried out in the eastern part of the Julian Alps, the Southern Karavanke and Kamnik-Savinja Alps. For the Julian Alps, which comprise a large part of north-western Slovenia, is characterized by an overthrust structure. The largest is the Julian nappe (Placer, 2008) or the Julian Alps overthrust (Jurkovšek, 1987 a, b) which is formed of strata ranging from the Lower Triassic through the Cretaceous; its greater part is presented by the Upper Triassic shallow marine carbonates. Lower Triassic strata most frequently occur in discrete narrow bands or within smaller tectonic slices. Their footwall in this part of the Julian Alps is not visible, and in some places they are concordantly overlain by Anisian carbonate rocks.

At Studorski preval (Studor Pass), situated 4.5 km southeast of the peak of Mount Triglav (2864 m), the Lower Triassic strata are predominantly tectonized. In a tectonically undisturbed parts of the section microfacially two basic types occur: coarse tempestite sediment (microfacies A) and laminated or bioturbated calcareous mudstone and / or marl (microfacies B), pointing to a more distal parts of the ramp with storm influence. A similar formation also applies to the depositional environment of the Werfen Formation of the Southern Alps (Brandner et al., 2012). The Lower Triassic strata of Studorski preval are characterized by common gastropods *Natiria costata*, bivalves of the genera *Bakevellia, Avichlamys* and *Eumorphotis,* foraminifer fauna with the genera *Ammodiscus, Hoyenella* and *Glomospirella* corresponding the global »*Glomospira-Glomospirella*« foraminifer association. Ammonites in the microfacies B show that a connection to the open sea was unimpeded. The conodont fauna with *T. hungaricus* is typical of the lower Spathian

(Kolar-Jurkovšek et al., 2013). From Lower Triassic strata of the Studorski preval the first discovery of a fossil amphibian in Slovenia (Temnospondyl) was found, which most probably belongs to the group Capitosauridae (Lucas et al., 2008).

Similar Lower Triassic strata with gastropods *Natiria costata*, bivalves and very rare ammonites are tectonically squeezed in the area of Špica v Sedlcih located about 2 km northeast of the Vršič pass (Jurkovšek, 1987 a, b). In the limestone that corresponds to the microfacies B of Studorski preval some unidentifiable fragments of conodonts were found.

In a wider area of the Southern Karavanke on the dolomite of the Late Permian Bellerophon Formation there rest Lower Triassic strata that pass upward to the Anisian dolomite (Buser, 1980; Buser & Cajhen, 1978). Lower Triassic strata in the valley Tržiška Bistrica near Tržič belong to the South Karavanke overthrust that is in the south limited with the Sava fault, and in the north by the Košuta overthrust of the Southern Karavanke. The lower and upper boundaries of the investigated sequences are not exposed, but the strata can be roughly divided into two parts (Dolenec et al, 1981). For the lower part of the sequence are characterized numerous strata and lenses of reddish oolitic limestone that are interbedded with the shale sheets and limestone beds with detritic admixture. In the upper part there is interbedded darker limestone, sandstone, marlstone and dolomite. A total thickness of the Lower Triassic strata in the section is about 200 m, of which the two parts of the section of approximately the same thickness. Conodonts were collected in the oolitic and sparitic limestone of the lower part of the section (Kolar-Jurkovšek & Jurkovšek, 1995). The recovered conodonts *F. gardenae, Ha. anceps, P. obliqua* and *Pa. ethingtoni* suggest a Smithian age.

Lower Triassic strata of the South Karavanke overthrust built a great part of the Kamnik-Savinja Alps in the upper part of Savinja valley. In the area between the Logarska dolina, Solčava, Robanov kot and the northern slopes of Raduha these strata attain thickness up to 1000 m (Mioč, 1983; Mioč & Žnidarčič, 1983; Celarc, 2002, 2004; Žalohar & Celarc, 2010), but due to folding their thickness is only apparant. In the lowest part of the Lower Triassic strata there rests dolomite, which passes upwards into a carbonate-clastic succession of marlstone, siltstones, sandstone and marly limestone. Preliminary sampling of the limestones in the upper part of the stratigraphic sequences at several localities confirmed the presence of the Smithian conodont taxa *P. obliqua* and *Parachirognathus* sp., and the Spathian species *T. hungaricus*.

Conodont zonation

Altogether seventeen conodont zones can be distinguished in Lower Triassic strata of Slovenia (Fig. 3, 4). In this section these zones are described in ascending order, and in the beginning also a description of the latest Permian conodont Zone is added.

Hindeodus praeparvus Zone
(latest Changhsingian)

Lower limit: defined by the first occurrence (FO) of *Hindeodus praeparvus* Kozur. Upper limit: first appearance datum (FAD) of *H. parvus* (Kozur & Pjatakova). Associated taxa: *H. typicalis* Sweet, *H. latidentatus* (Kozur, Mostler & Rahimi-Yazd), *Hindeodus* sp., and *H.* cf. *pisai* Perri & Farabegoli.

Occurrence: Lukač (the upper part of the latest Permian Bellerophon Limestone Member of the Bellerophon Formation through the lowermost Transitional Beds - latest Permian); Javorjev Dol, Masore, Idrijca, Vojsko (latest Permian; Bellerophon Formation).

Remarks. In the Masore section the elements of *H. praeparvus* and *H. latidentatus* co-occur in the uppermost part of the Bellerophon Formation. Both taxa range also in the lowermost Triassic and based on their occurrence in absence of *H. parvus* these strata are attributed to the *H. praeparvus* Zone (Late Permian, latest Changhsingian). *H. praeparvus* was reported to range in the lowermost Triassic in the Dolomites (Perri & Farabegoli, 2003). Very rare elements of *Isarcicella* with a widely opened and thickened basal cavity are also present, of which some specimens are designated to *Isarcicella* cf. *prisca* Kozur, in the uppermost strata of the Bellerophon Formation. According to Perri (Perri & Farbegoli, 2003) the genus *Isarcicella* made its first appearance in the latest Permian and is marker to distinguish the Upper from the Lower *H. praeparvus* Zone in the Southern Alps. Thus the presence of isarcicellids in the upper part of the *H. praeparvus* Zone in the Masore section enables to divide this zone in the lower and upper part.

Hindeodus parvus Zone

Lower limit: first appearance datum of *H. parvus*. Upper limit: first appearance datum of *Isarcicella lobata* Perri & Farabegoli. Associated taxa: *H.* cf. *pisai* and *Hindeodus* sp.

Occurrence: Lukač (earliest Griesbachian; Transitional Beds of the Lukač Formation). Remarks: *H. parvus* first appearance datum is documented in the L1 sample of the Transitional Beds of the Lukač Formation, and its last appearance datum is in the *I. staeschei – I. isarcica* Zone (Streaky Limestone Member of the Lukač Formation). This conodont zone is characterized by scarce fauna of exclusive representation of hindeodids.

Isarcicella lobata Zone

Lower limit: first appearance datum of *I. lobata* Perri & Farabegoli. Upper limit: first appearance datum of *I. staeschei* Dai & Zhang and *I. isarcica* (Huckriede). Associated taxa: transitional form *H. praeparvus / H. parvus*, *H.* cf. *pisai, H.* cf. *eurypyge* Nicoll et al., *H. parvus, H. erectus* Kozur, *H. postparvus* (Kozur), *Hindeodus* sp., *I. turgida* (Kozur et al.), *I. lobata, I. inflata* Perri & Farabegoli, and *Isarcicella* sp.

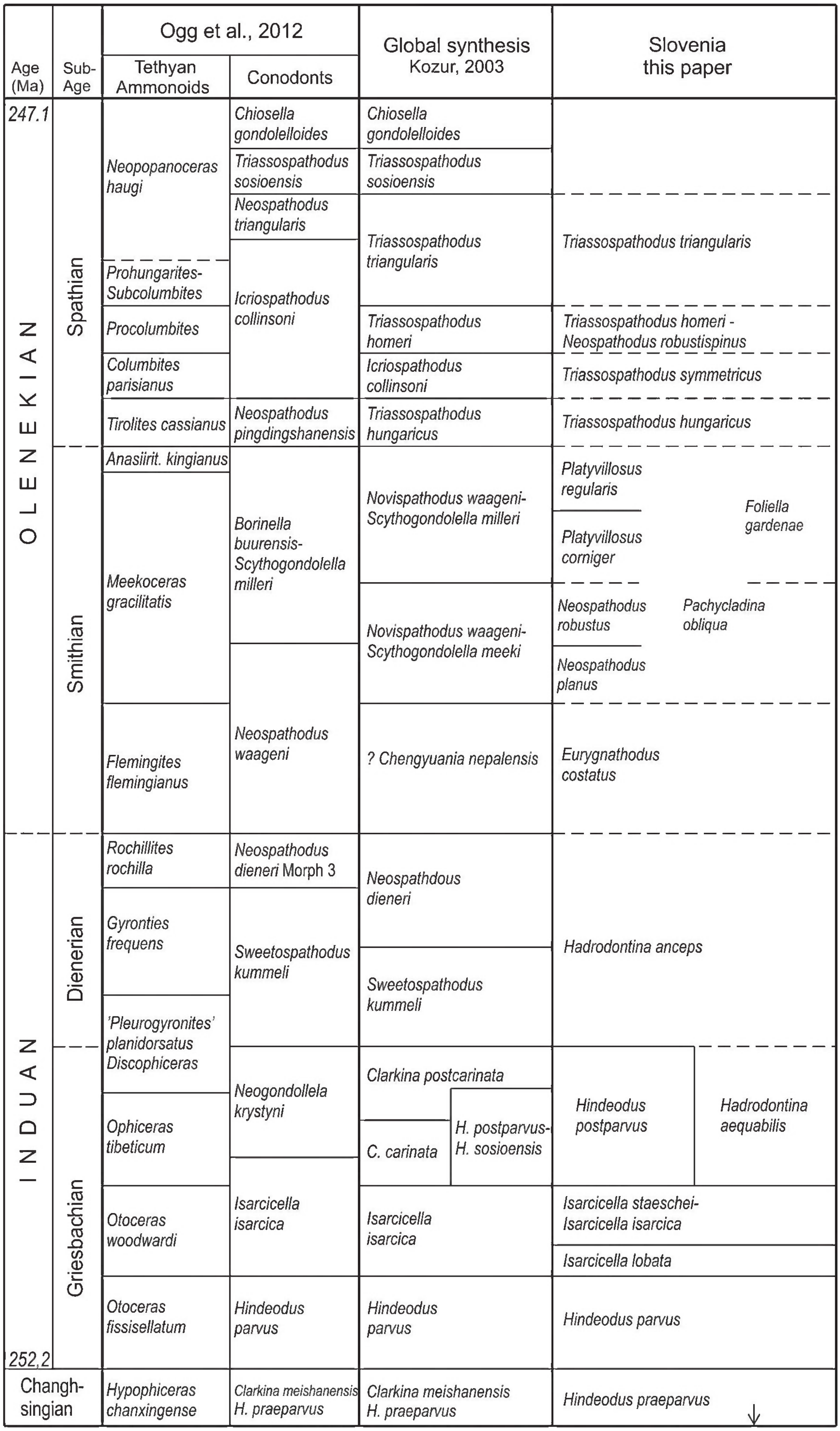

Fig. 3. Correlation of the Lower Triassic zones. Abbreviations: *C.* – *Clarkina*, *H.* – *Hindeodus*.

Occurence: Lukač (early Griesbachian; Transitional Beds of the Lukač Formation).

Remarks: *I. lobata* first appears in the Transitional Beds of the Lukač Formation. This zone is marked by the entry of several other taxa and it represents a recovery event. The entire stratigraphic range of the species *H. erectus* lies within this zone. Three other taxa (*H. postparvus, I. turgida, I. inflata)* have their entry (FAD) in this zone, whereas *H.* cf. *eurypyge* appears only in this zone.

***Isarcicella staeschei* –*Isarcicella isarcica* Zone**

Lower limit: first appearance datum of two isarcicellid taxa, *I. staeschei* and *I. isarcica*. Upper limit: last appearance datum of two isarcicellid taxa, *I. staeschei* and *I. isarcica* and the first appearance of *Hadrodontina* sp. *(Ha.* ex gr. *aequabilis)*. Associated taxa: *H. parvus, H. postparvus, Hindeodus* sp., *I. turgida, I. lobata, I. inflata,* and *Isarcicella* sp.

Occurrence: Lukač (Streaky Limestone Member of the Lukač Formation); Javorjev Dol, Masore, Idrijca, Vojsko ("Werfen Formation"); Griesbachian.

Remarks: This zone is marked by the entire stratigraphic range and co-occurrence of *I. staeschei* and *I. isarcica*. Five taxa (*H. postparvus, I. turgida, I. lobata, I. inflata,* and *Isarcicella* sp.) that appeared already in the previous zone continue with their presence in this zone. All associated taxa have the LAD within this zone, except *H. postparvus*. For the presence of numerous taxa the fauna of this zone is still part of the recovery event.

In the Lukač section the LAD of *I. staeschei* and *I. isarcica* coincides with the first occurrence of the genus *Hadrodontina* of which some elements can be identified as *Ha.* ex gr. *aequabilis*. In the Dolomites a successive appearance of some isarcicellid taxa is documented, i.e. *I. lobata* - *I. staeschei* – *I. isarcica* and moreover, the species *Ha. aequabilis* has a synchronous entry together with *I. staeschei*.

***Hindeodus postparvus* Zone**

Lower limit: first appearance datum of *H. postparvus* (Kozur) without the presence of *I. isarcica* and *I. staeschei*. Upper limit: last appearance datum of *H. postparvus*. Associated taxa: *Hadrodontina* sp., Ellisoniidae.

Occurrence: Lukač (latest Griesbachian; uppermost Streaky Limestone Member through the lowermost Carbonate-clastic Member of the Lukač section).

Remarks: This conodont zone in the Lukač section is marked by the highest portion of the stratigraphic range of *H. postparvus* without the presence of *I. isarcica* and *I. staeschei*. The discriminated *H. postparvus* Zone in the Lukač section is partly correlated with the *H. postparvus* – *H. sosioensis* Zone (Kozur, 2003).

***Hadrodontina aequabilis* Zone**

Lower limit: the first occurrence of *Hadrodontina aequabilis* Staesche. Upper limit: the first appearance datum of *Ha. anceps* Staesche. Associated taxa: *Hadrodontina* sp., Ellisoniidae.

Occurrence: Mokrice (late Griesbachian; "Werfen Formation").

Remarks: *Ha. aequabilis* was first described from the Dolomites (Staesche, 1964) and its multielement reconstruction was provided by Perri (1991). In the Mokrice section the *Ha. aequabilis* Zone has been distinguished where the marker taxon is present as a single species (Kolar-Jurkovšek et al., submitted). In the Dolomites, the *I. isarcica* Zone is succeeded by the succession of the zones based on euryhaline shallow water species: *Ha. aequabilis* Zone (latest Griesbachian - Dienerian), *Ha. anceps* Zone and *P. obliqua* Zone (Perri, 1991; Farbegoli & Perri, 2012).

Based on comparison with the Dolomites and regarding long range of *Ha. aequabilis* it is reasonable to conclude that the stratigraphic range of *H. postparvus* overlaps with the lower portion of the stratigraphic range of *Ha. aequabilis*. The later species has been reported also from Japan (Igo, 1996) and South Primorye in Russian Far East (Bondarenko et al., 2015).

***Hadrodontina anceps* Zone**

Lower limit: first occurrence of *Ha. anceps* Staesche. Upper limit: first occurrence of *P. obliqua*. Associated taxa: *Hadrodontina* sp., Ellisoniidae.

Occurrence: Lukač (Dienerian; middle and upper part of the Carbonate-clastic Member of the Lukač Formation).

Remarks: *Ha. anceps* was first described from the Dolomites (Staesche, 1964). The *Ha. anceps* multielement was first reconstructed by Perri & Andraghetti (1987). This zone is well correlated with the *Ha. anceps* Zone of the Dolomites where it is based on the position between the *Ha. aequabilis* Zone and followed by *P. obliqua* Zone (Perri,1991).

***Eurygnathodus costatus* Zone**

Lower limit: the first occurrence of *Eurygnathodus costatus* Staesche. Upper limit: the last occurrence of *E. costatus*. Associated taxon: *Eurygnathodus hamadai* (Koike).

Occurence: Golob (latest Dienerian and early Smithian; "Werfen Formation").

Remarks: *E. costatus* has been first described from the Dolomites, Italy (Staesche, 1964). In the Dinaric area and it has been later reported to occur in western Serbia (Budurov & Pantić, 1973), Croatia (Aljinović et al., 2006) and in Bosnia and Herzegovina. The species has been well documented from many sections in Asia (Chen et al., 2015a).

The GSSP of the Olenekian Stage has not been defined yet, but two proposals based on the FO of *Novispathodus waageni* have been put forward (Krystyn et al., 2007; Zhao et al., 2008). Both candidate sections, the Spiti of India and Chaohu in Anhui Province in China, are characterized by presence of *E. costatus* that has short stratigraphic range. *E. costatus* has been reported to occur already in the latest Induan in some sections in Asia (Zhang, 1990; Igo, 2009, Chen et al. 2015b).

It is worthy to mention here that *Nv. waageni* has not been collected in the European sections and therefore *E. costatus* it is currently taken as an important marker around this boundary. The hitherto obtained data from Slovenia and other locations in the Dinarides unabled us to document its entire stratigraphic range and to define its precise stratigraphic position. The preliminary C-isotope data suggests, that the Induan-Olenekian boundary probably lies within the Golob section (Chen et al., 2015a) that means within the range of this taxon. Therefore in the Figure 3 the boundaries of this zone are presented with dashed lines.

Pachycladina obliqua Zone

Lower limit: the first occurrence of *P. obliqua*. Upper limit: the last occurrence of *P. obliqua*. Associated taxa: *Ha. anceps, Hadrodontina* sp., *Ellisonia* sp.

Occurence: Tehovec, Horjul and Žiri surroundings, Trojane, Grmače, Mišnica, Dobovica, Čebine (Smithian; "Werfen Formation").

Remarks: *P. obliqua* was first reported from the Dolomites, Italy by Staesche (1964) and also its multielement was first reconstructed from there (Perri & Andraghetti, 1987). The value for stratigraphy of *P. obliqua* in the Dolomites was first emphasized and was later confirmed also for the Dinarides (Perri, 1991; Kolar-Jurkovšek & Jurkovšek, 1995, 1996; Jelaska et al., 2003; Aljinović et al., 2011).

P. obliqua is the most frequent Early Triassic element reported from the entire Dinaric area, including Slovenia (Jurkovšek et al., 1999, Kolar-Jurkovšek & Jurkovšek, 2001; Dozet & Kolar-Jurkovšek, 2007), Croatia (Jelaska et al., 2003; Aljinović et al., 2006), Bosnia and Herzegovina (Aljinović et al., 2011), Serbia (Sudar, 1987). The exact stratigraphic range of *P. obliqua* in Slovenia has not yet been defined, but in the Dolomites it ranges from the Smithian to the lower Spathian (Perri & Andraghetti, 1987).

The fauna with dominating species *P. obliqua* and joined by *Hadrodontina* was assigned to the Smithian *P. obliqua* Zone and correlated to the *P. obliqua* Zone in the Dolomites as well as to the Lower Smithian Zone 7 (*Parachirognathus-Furnishius* Zone) of Sweet et al. (1971).

This species has been reported also from South China (Wang & Cao, 1981; Yang et al., 1986; Yan et al., 2013) and North America (Beyers & Orchard, 1991).

Foliella gardenae Zone

Lower limit: the first occurrence of *F. gardenae* (Staesche). Upper limit: the last occurence of *F. gardenae*. Associated taxa: *Ellisonia* sp., *Hadrodontina* sp., *P. obliqua, Furnishius triserratus* Clark, *Parachirognathus ethingtoni* Clark.

Occurrence: Iška, Draga, Skopačnik, Četež, Borštnik, Leskovica, Bogenšperk – Temnica, Želin-Vrlejca, Žiri and Solčava surroundings, Tržič, (late Smithian and earliest Spathian; "Werfen Formation").

Remarks: *F. gardenae* was originally reported from north Italy where it co-occurs with *P. obliqua,* however, in the upper portion of its stratigraphic range only (Staesche, 1964). This species has been later reported from the Dinaric area: Serbia (Budurov & Pantić, 1973; Sudar et al. 2014), Slovenia (Kolar-Jurkovšek, 1990 a; Kolar-Jurkovšek & Jurkovšek, 1995), Croatia (Aljinović et al., 2006). A limited geographic distribution of this species suggests it was ecologically restricted. It is possible that its occurrence is confined to the environment of the epeiric ramp conditions (Aljinović et al., 2013 a).

In western Serbia, the *F. gardenae* Zone is distinguished above the *E. costatus* Zone (Budurov & Pantić, 1974). It is worthwhile to mention that the two taxa have short stratigraphic ranges and according to the presented data, there is an intermediate interval without any evidence of conodont occurrences. Similar distribution revealing occurrence of *E. costatus* in the older strata and *F. gardenae* in the younger strata are supported by the situation in the Dolomites (Staesche, 1964).

Neospathodus planus Zone

Lower limit: the first occurrence of *Neospathodus planus*. Upper limit: the first occurrence of *N. robustus* Koike. Associated taxon: *Neospathodus* sp.

Occurrence: Žiri surroundings (Smithian; "Žiri Beds").

Remarks: This zone is distinguished based on a new species defined from Slovenia (Chen et al., 2015 a). The specimens of the namebearer of this zone are associated with other neospathodid elements determined as *Neospathodus* sp.

This zone can be roughly correlated to the lower protion of the *P. obliqua* Zone. It can be also correlated with the *Novispathodus waageni waageni* and *Discretella discreta* Zones which are reported from South China (Chen et al., 2013, 2015 b; Yan et al., 2013).

Neospathodus robustus Zone

Lower limit: the first occurrence of *N. robustus*. upper limit: the last occurrence of *N. robustus*. Associated taxon: *Neospathodus* sp.

Occurrence: Žiri surroundings (Smithian; "Žiri Beds").

Remarks: *N. robustus* was first reported from western Malaysia, and the first entry of this species is documented approximately 10 m higher (*ca.* 10m) than the LOs of *E. costatus* and *Nv.* cf. *waageni* (Koike, 1982). The reports on occurence of *N. robustus* are very rare.

In the Žiri area the lower *N. planus* and the succeeding *N. robustus* Zones are followed by the level with the *Platvyllosus* elements. Based on obtained data from Slovenia we may conclude that the *N. planus* and the *N. robustus* Zones can be correlated to the *P. obliqua* Zone.

Platyvillosus corniger Zone

Lower limit: the first occurence of *Platyvillosus corniger*. Upper limit: the first occurrence *Pl. regularis* (Budurov & Pantić).

Occurrence: Žiri surroundings ("Žiri Beds"), Mokrice ("Werfen Formation"); Smithian.

Remarks: This zone is marked by the occurrence of a single species, the zonal namebearer. The *P. corniger* Zone can be together with the following *Pl. regularis* Zone roughly correlated with the *F. gardenae* Zone (see the remarks of the following zone).

Platyvillosus regularis Zone

Lower limit: the first occurrence of *Pl. regularis*. Upper limit: the first occurrence *Triassospathodus hungaricus* (Kozur & Mostler).

Occurrence: Žiri surroundings ("Žiri Beds"), Mokrice ("Werfen Formation"); Smithian.

Remarks: This zone is marked by the occurrence of a single species, the zonal namebearer. The *Pl. regularis* has been reported from Serbia for the first time (Budurov & Pantić, 1973) and was assigned to the Ladinian genus *Pseudofurnishius* (e.g., Budurov & Pantić 1973). However taxonomic revision and new discoveries indicate that it should be assigned to genus *Platyvillosus* (Chen et al., 2015a, c).

Both *Platyvillosus* taxa have been collected in two sections in Slovenia, Žiri and Mokrice sections. The older strata in both sections are marked with the fauna of *Pl. corniger* that are followed by the strata with the fauna of *Pl. regularis*. Also in the first description of *Pl. regularis* there is no information about the composition of the fauna that enables us to speculate that the species in the type locality was collected as a monofauna. The absence of any accompaning fauna suggests to stressful conditions controlled by ecollogical factors that renders their comparison difficult.

In both Slovenian sections the *Pl. corniger* and the *Pl. regularis* Zones lie below the *T. hungaricus* Zone, similar as the *F. gardenae* Zone. Therefore it is reasonable to conclude that the faunas with *Platyvillosus* and *Foliella* are contemporaneous in Slovenia.

Triassospathodus hungaricus Zone

Lower limit: the first occurrence of *T. hungaricus*. Upper limit: the first occurrence of *T. symmetricus* Orchard.

Occurrence: Studorski preval (Werfen Formation), Žiri surroundings ("Žiri Beds"), Mokrice, Solčava surroundings ("Werfen Formation"); Spathian.

Remarks: *T. hungaricus* was originally reported from Hungary from the strata with the ammonoid *Tirolites* (Kozur & Mostler, 1970).

In the Dinarides *T. hungaricus* has been just recently collected from Slovenia, as well as from Bosnia and Herzegovina (Kolar-Jurkovšek et al., 2013, 2014). The species has been also reported from the Sichuan Province, China (Tian et al., 1983). Some specimens determined as "*N.*" cf. *hungaricus* have been collected in Nevada (North America) (Lucas & Orchard, 2007).

Tirolites is widely accepted by stratigraphers as a marker for the Smithian-Spathian boundary (e.g., Kozur, 2003). According to Kozur (2003) the *T. hungaricus* Zone is presented as the first conodont zone of the Spathian. In the shallow western Tethys, *T. hungaricus* Zone lies in the lower Spathian, where *Icriospathodus collinsoni* (Solien) is missing (Kolar-Jurkovšek et al., 2013). The present zone can be roughly correlated with the lowermost Spathian *Pl. asperatus* Zone of the Great Basin, USA (Clark et al., 1979).

In the Mokrice section *T. hungaricus* occurs as the only species of this zone and it ranges up to the lowermost portion of the following zone characterized by the presence of *Neostrachanognathus tahoensis* Koike (Kolar-Jurkovšek et al., submitted).

Triassospathodus symmetricus Zone

Lower limit: the first occurrence of *T. symmetricus*. Upper limit: the first occurrence of *Neospathodus robustispinus* Zhao & Orchard. Occurrence: Žiri surroundings (Spathian, "Žiri Beds").

Remarks: *T. symmetricus* was first reported from Oman and North America and it is accompanied by *Ic. collinsoni* and *T. homeri* (Mosher, 1968; Orchard, 1995). In the Slovenian section no accomapanied species were collected. *T. symmetricus* has also been reported from Italy (Perri, 1986), Greece (Dürkoop et al., 1986), North America (Mosher, 1973) and many sections in Asia (see Chen et al., 2015a, b).

This zone can be correlated with the *T. symmetricus* Zone of North Vietnam and the *Ic. collinsoni* zone of Jiarong, South China, as both zones lie immediately above the *Nv. pingdingshanensis* Zone (Chen et al., 2013, 2015b; Maekawa & Komatsu, 2014).

Neospathodus robustispinus – Triassospathodus homeri Zone

Lower limit: the FO of *N. robustispinus* and/or the FAD of *T. homeri* (Bender). Upper limit: the LO of *N. robustispinus* and/or LAD *T. homeri*. Accompanied taxa: *T. symmetricus, N.* ex gr. *robustispinus*.

Occurrence: Žiri surroundings ("Žiri Beds"), Skopačnik (Werfen Formation); Spathian.

Remarks: *N. robustispinus* was first reported from Chaohu, Anhui province (South China), and it occurs in the lower Spathian ammonoid *Columbites-Tirolites* Zone (Zhao et al., 2008). *T. homeri* (Bender) was first described from Greece (Bender, 1970) and a worldwide distribution of the species is well documented (Orchard, 1995).

In the Slovenian section *N. robustispinus* is documented higher than the FO of *T. symmetricus*. The stratigraphic position of this zone can be roughly correlated to *T. homeri* Zone that is just below the *T. triangularis* Zone according to (Kozur, 2003). The *N. robustispinus - T. homeri* Zone in Slovenia probably correlates with the *T. homeri* Zone in South China (Chen et al., 2013, 2015b).

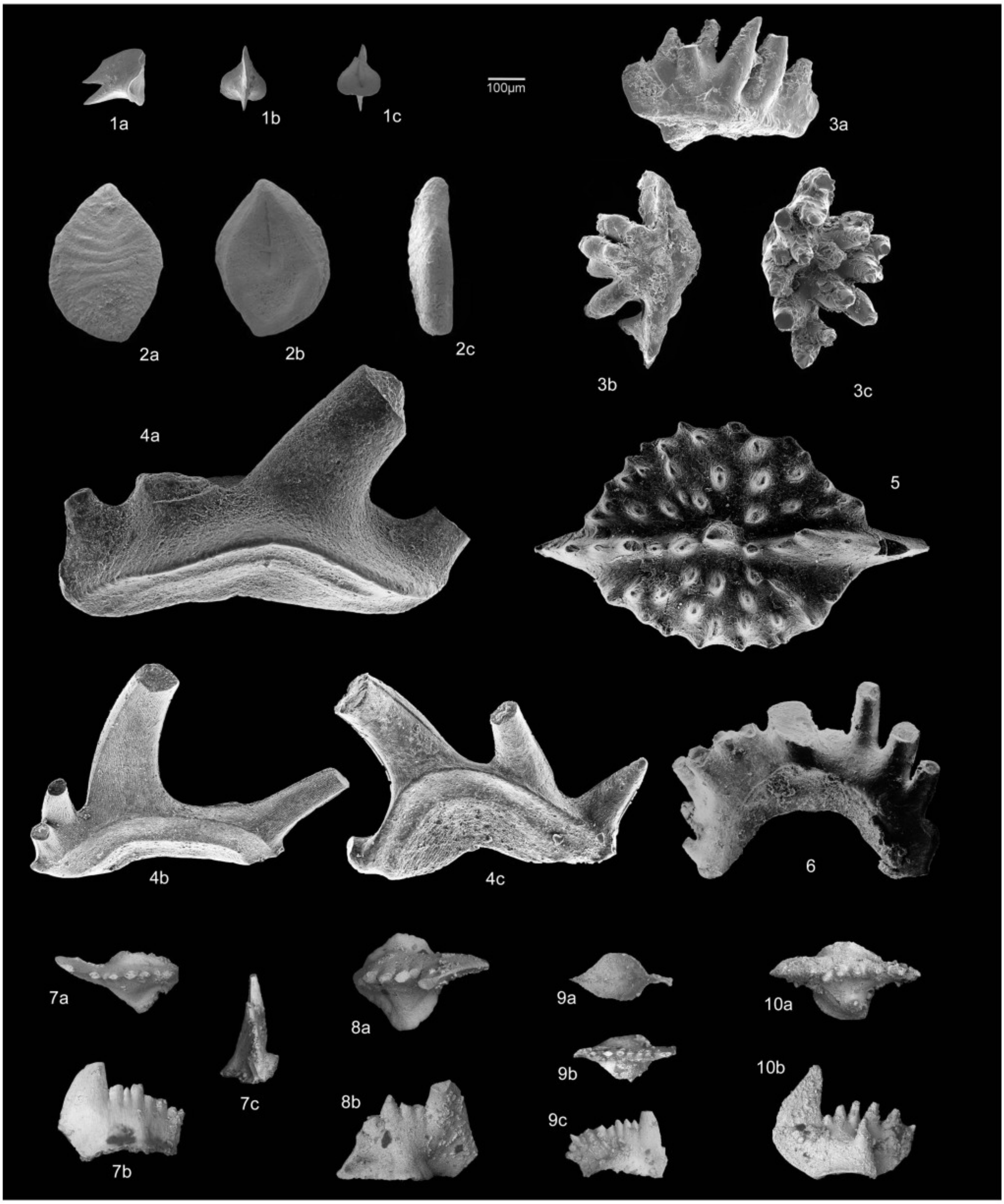

Fig. 4. Conodonts from the Lower Triassic of Slovenia.
1 a-c *Triassospathodus hungaricus* (Kozur & Mostler). Spathian, *Triassospathodus hungaricus* Zone. Mokrice, sample R1/3.
2 a-c *Eurygnathodus costatus* Staesche. Latest Dienerian – early Smithian, *Eurygnathodus costatus* Zone. Golob, sample 44/8.
3 a- c *Platyvillosus regularis* (Budurov & Pantić). Smithian, *Platyvillosus regularis* Zone. Žiri surroundings, sample 28/17.
4 a -c *Pachycladina obliqua* Staesche. Late Smithian – earliest Spathian, *Foliella gardenae* Zone. Iška, samples IŠ1, IŠ2.
5 – *Foliella gardenae* (Staesche). Late Smithian – earliest Spathian, *Foliella gardenae* Zone. Tržič, sample 66.
6 – *Hadrodontina anceps* Staesche. Late Smithian – earliest Spathian, *Foliella gardenae* Zone. Tržič, sample 59.
7 a -c *Hindeodus parvus* (Kozur & Pjatakova). Griesbachian, *Hindeodus parvus* Zone. Lukač, sample L1.
8 a- b *Isarcicella lobata* Perri & Farabegoli. Griesbachian, *Isarcicella lobata* Zone. Lukač, sample T.
9 a-c *Hindeodus postparvus* Kozur. Griesbachian, *Hindeodus postparvus* Zone. Lukač, sample 41.
10 a – b *Isarcicella staeschei* Dai & Zhang. Griesbachian, *Isarcicella isarcia* – *Isarcicella staeschei* Zone. Lukač, sample V.
All species are presented by the Pa element, except fig. 4 – *P. obliqua* is presented by the Pa, Sc, M elements in ascending order.

Triassospathodus triangularis Zone

Lower limit: the FAD of *T. triangularis* (Bender).
Upper limit: the LAD of *T. triangularis*.

Accompanied taxa: *T.* ex gr. *triangularis*.
Occurrence: Skopačnik (Werfen Formation); Spathian.

Remarks: *T. triangularis* was first reported from Greece by Bender (1970) and it has been documented also from the Dolomites (Staesche, 1964; Perri & Andraghetti, 1987). The species has widespread distribution and has been extensively reported from many sections of the world (see Orchard, 1995; Chen et al., 2013, 2015b).

The marker taxon of the zone was collected also in a few sections south of Ljubljana, however, its entire range has not been well defined. Nevertheles, this zone can be compared to the *T. triangularis* Zone (Kozur, 2003).

Discussion and conclusions

The PTB interval in Slovenia is characterized by the genera *Hindeodus* and *Isarcicella* and the absence of gondolellids is obvious. Therefore, a conodont zonation for shallow facies of the Meishan section in China introduced by Wang (1996) and later refined for the Dolomites in Italy (Perri & Farabegoli, 2003) was applied. The Lukač section represents a key section to define the PTB interval strata in Slovenia as well as in the wider Dinarid area (Kolar-Jurkovšek et al., 2011a, 2012).

Certain levels of the Lower Triassic succession in Slovenia are marked by shallow water and euryhaline genera. Due to the absence of worldwide biozonal markers, a stratigraphic use of some taxa (i.e. *Hadrodontina aequabilis, Ha. anceps, Pachycladina obliqua*) was first recognized in the Dolomites, Italy (Perri, 1991) and was later applied also in the Dinarides (Jelaska et al., 2003). Therefore the use of euryhaline genera is important regional biostratigraphic tool in western Tethys.

Certain Olenekian faunas in Slovenia show very low diversity and many collected faunas are characterized by the presence of a single species, for example *Eurygnathodus costatus, E. hamadai, Platyvillosus corniger*, *Pl. regularis* and *Triassospathodus hungaricus*. The two *Platyvillosus* taxa have been hitherto reported only from the Dinarides. Stratigraphically important taxa for example: *Neospathodus dieneri, Novispathodus waageni*, *Icriospathodus collinsoni*, *Nv. pingdingshanensis* have not been documented to occur in Slovenia or the Dinarides.

For some time it was believed that the genus *Eurygnathodus* Staesche is a junior synonym of *Platyvillosus* Clark, Sincavage & Stone (e.g., Kozur & Mostler, 1973). Therefore there was certain misunderstanding in recognition of some Olenekian genera. In the Treatise of Invertebrate Paleontology (Clark et al., 1981), in the volume of the genus *Platyvillosus* as a synonym is regarded *Eurygnathodus* as well as ? *Foliella* Budurov & Pantić. The three genera have markedly different morphology and they are regarded as separate genera (e.g., Orchard, 2007; Chen et al., 2015a). The genus *Platyvillosus* was first described from North America and the type species is *Pl. asperatus* Clark, Sincavage & Stone. The relationship among all known occurrences of *Platyvillosus* representatives from Europe and North America is not clear.

In Slovenia, *Eurygnathodus* and *Platyvillosus* do not co-occur and this is in accordance with the data from Serbia (Budurov & Pantić, 1974). However, their relation is not yet solved. The P_1 element of *Platyvillosus* is demonstrated by the transitional forms from a neospathodid type ancestor as already suggested by Orchard (2007) and Chen et al. (2015a).

In Slovenia, the genera *Foliella* and *Platyvillosus* also do not co-occur and the recovered material does not reveal their relationship. *Foliella gardenae* has been documented only in Europe, however, the accompanied *Pachycladina* with an extensive geographical distribution enables worldwide comparison of the fauna.

Platyvillosus taxa have also limited geographic occurrence outside Slovenia. Of the two recognized species, only *Pl. regularis* has been known to occur in Serbia (Budurov & Pantić, 1973). Their occurrence outside the Dinarides has not yet been reported.

The two neospathodid taxa, *Neospathodus planus* and *N. robustus* occur in a level with obvious absence of *Novispathodus waageni*.

Certain recovered conodont faunas from Slovenia markedly differ from the contemporaneous conodont faunas of North America and Asia. A limited geographic distribution of some genera confined to the European sections suggests they were ecologically restricted and probably adapted to shallow water environments.

Triassospathodus hungaricus has been lately reported from few sections in the Dinarides where it occurs as single conodont species. Outside the area this species has been reported to occur in the Sichuan Province of South China (Tian et al., 1983) and moreover, Lucas & Orchard (2007) reported elements morphologically close or identical to "*Neospathodus*" cf. *hungaricus* from Nevada.

Representatives of the *T. symmetricus-homeri-triangularis* lineage are well documented and quite common worldwide.

Acknowledgements

The authors wish to thank to Milan N. Sudar (Belgrade, Serbia) for communications on the conodont part. Constructive and thoughtful review by Chen Yanlong (Graz Austria) is acknowledged. We are indebted to Galina P. Nestell and Merlynd Nestell (Arlington, Texas) for editing the manuscript. Facilities and technical staff of the Geological Survey of Slovenia are gratefully acknowledged. The investigation was financially supported by the Slovenian Research Agency (programme number P1-0011and project number J1-6665). This is a contribution to the IGCP 572 »Recovery of ecosystems after the Permian-Triassic mass extinction« and IGCP 630 »Permian-Triassic climatic and environmental extremes and biotic response«.

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