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Conodonts across the Permian-Triassic boundary in the Bükk Mountains (NE Hungary)

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Abstract: The results of micropaleontological studies, especially of conodonts, across the Permian-Triassic (P-T) boundary interval in the Bálvány-North, Bálvány-East and Gerennavár sections of the Bükk Mountains (NE Hungary) are presented. Conodont zones for the boundary interval have been identified on the basis of biostratigraphic data for conodont taxa (*Hindeodus parvus*, *H. praeparvus*, *Hindeodus* sp., *Isarcicella* cf. *prisca*, *Hindeodus/Isarcicella* sp.) and the FOD of *H. parvus*. The *praeparvus* Zone possibly the Late *praeparvus* Zone (uppermost part of Changhsingian, Late Permian) in the Nagyvisnyó Limestone, inclusive of the 'Boundary Shale Bed', and the *parvus* Zone (earliest Induan, Early Triassic) in the Gerennavár Limestone are discriminated.

Key words: Permian-Triassic boundary interval, Bükk Mountains, NE Hungary, biostratigraphy, conodonts.

Introduction

Geological mapping in the Bükk Mountains of NE Hungary led to the identification of important Permian-Triassic (P-T) boundary sections, targets of intense stratigraphic, paleontological, sedimentological, mineralogical, and geochemical investigations in the last decades (Kozur 1985, 1989; Haas et al. 1988; Fülöp 1994; Hips & Pelikán 2002; Haas et al. 2004; Posenato et al. 2005; Hips & Haas 2006; Haas et al. 2006; Haas et al. 2007). These studies have demonstrated continuity of marine conditions through the boundary sequence with the presence of macro- and microfossils of crucial importance (Haas et al. 2004). A salient negative carbon isotope peak, considered to be the chemostratigraphic marker of the boundary, was found within the 'Boundary Shale Bed' (BSB) (Haas et al. 2006). The classic marine P-T boundary successions in the Dolomites (Italy) and in the Carnic Alps (Austria and Italy) were deposited in shallow inner ramp situations (Farabegoli et al. 2007, with references), whereas the boundary sections in the Bükk Mountains represent a deeper ramp, unique in Europe. This paleogeographic setting provides potential for enhanced comparison of the boundary sections of the Bükk Mountains with those elsewhere in the Tethyan realm where detailed biostratigraphies, vital for precise correlations, have been established. Conodonts are pivotal for this because definition of the P-T boundary is based on the first appearances of conodont taxa. This paper presents the results of micropaleontological studies of the most important boundary sections in the Bükk Mountains, focused primarily on conodonts, and the conodont zonation inferred from these data.

Geologic and stratigraphic settings

The Bükk Mountains are located in northeastern Hungary, south of the Inner Western Carpathians (Fig. 1). Recent paleogeographic reconstructions show that the P-T boundary sections studied in the Bükk area are within the distal part of a carbonate ramp developed on the western Tethys margin (Haas et al. 2007). It was situated near the depositional areas of the Southern Alps, the Southern Karavanke Mountains, and the Sana-Una Unit and the Jadar Block of the present Vardar Zone (Protić et al. 2000; Filipović et al. 2003).

The Bükk Mountains consist of the Bükk Parautochthon Unit tectonically overlain by nappes containing elements of the Neotethys accretionary complex (Csontos 1999). The Bükk Parautochthon Unit consists of Paleozoic–Mesozoic (Carboniferous to Jurassic) formations affected by multi-stage folding and predominantly anchizonal metamorphism (Árkai 1973, 1983; Pelikán et al. 2005). Its structure is characterized by four east-west-striking, southward recumbent anticlines (Csontos 1999; Pelikán et al. 2005). The grade of metamorphism significantly varies within the structural unit from epizonal to the lower temperature part of the anchizone or in some areas to medium-deep diagenesis (Árkai 1983; Fülöp 1994). Metamorphism occurred in two episodes in the Cretaceous, at 120 and 90 Ma, respectively (Árkai et al. 1995). The metamorphosed series are overlain by non-metamorphosed Paleogene–Neogene formations (Pelikán et al. 2005).

The Paleozoic and Early Triassic formations, and consequently the P-T boundary sequences, are known only from the northern part of the mountains, in the North Bükk Anticline. The core of this anticline is formed by a middle Car-

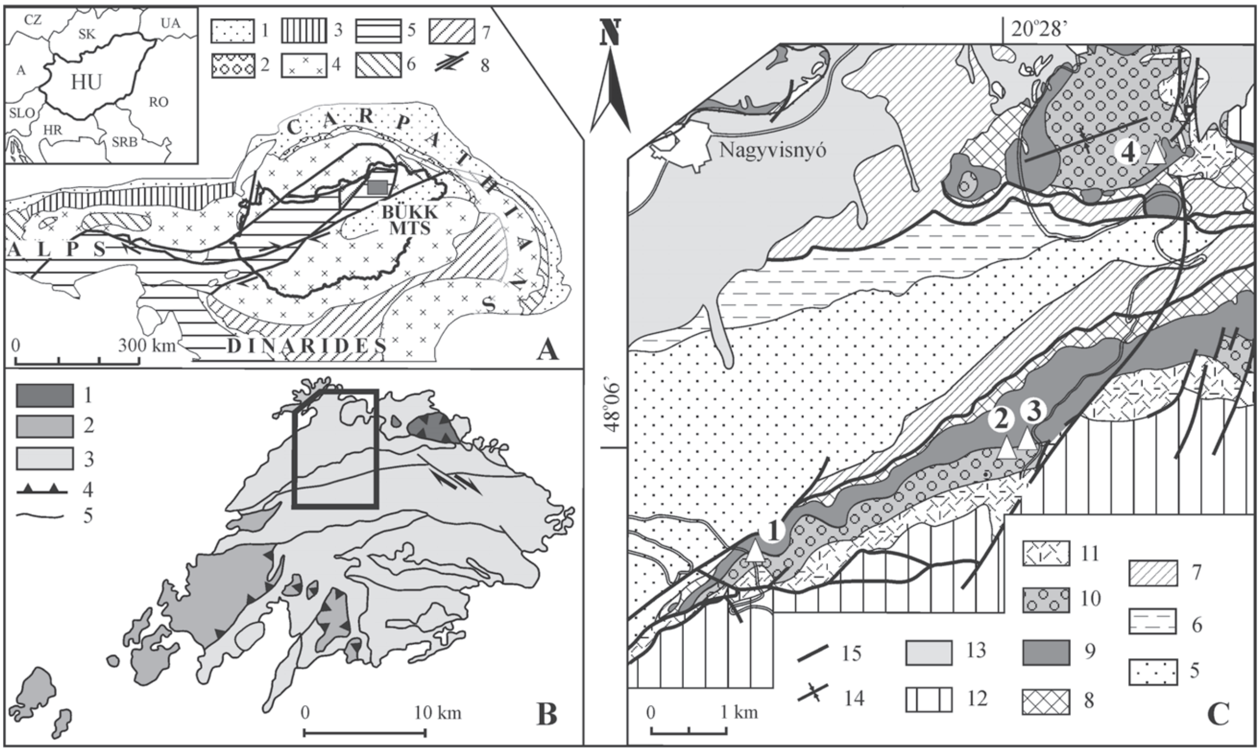

Fig. 1. Geology of the studied area (modified from Hips & Haas 2006). **A** — Schematic terrain map of the Circum-Pannonian region with location of the Bükk Mountains (dark rectangle) (Kovács et al. 2000): 1 — Flysch Belt, 2 — Pieniny Klippen Belt, 3 — Northern Calcareous Alps, 4 — Early Alpine units related to the European continental margin, 5 — Early Alpine shelf sequences related to the Apulian (Southern Alps and Outer Dinarides) continental margin, 6 — Ophiolites of the Penninic Ocean, 7 — Ophiolites of the Vardar Ocean, 8 — Major strike-slip zones. **B** — Simplified geological map of the Bükk Mountains, Cenozoic cover omitted (after Less et al. 2002): 1 — Kisfennsik Nappe, 2 — Szarvaskő-Mónosbél Nappe, 3 — Parautochthon, 4 — Nappe boundary, 5 — Faults. **C** — Geology of the northern part of the mountains (rectangle on B) with locations of the studied sections (after Less et al. 2002); **P-T boundary sections:** 1 — Gerennavár section, 2 — Bálvány-North section, 3 — Bálvány-East section, 4 — Kemesnye Hill section; **Carboniferous formations:** 5 — Szilvásvárad Siltstone, 6 — Zobóhegyese Formation, 7 — Mályinka Formation; **Permian formations:** 8 — Szentélek Formation, 9 — Nagyvisnyó Limestone; **Early Triassic formations:** 10 — Gerennavár Limestone, 11 — Ablakoskovölgy Formation, 12 — Other Triassic formations, 13 — Cenozoic cover, 14 — Synclinal structure, 15 — Major tectonic lineaments.

boniferous distal flysch-type series overlain by a Pennsylvanian molasse-type shallow marine succession. It is followed, after a gap by Middle Permian siliciclastic coastal plain deposits. Carbonate ramp facies typifies the Late Permian extending into the Early Triassic. Among the P-T boundary sections, the Bálvány and Gerennavár ones are located on the southern limb, whereas the Kemesnye section occurs on the northern limb of the North Bükk Anticline (Fig. 1B,C).

The Late Permian is represented by the Nagyvisnyó Limestone, consisting of 250–280 m of black and dark grey, thick-bedded limestone with dolomite in the lower part, and mainly of marl with nodular marl interbeds in the uppermost 60–80 m (Balogh 1964; Fülöp 1994). The Nagyvisnyó Limestone contains a rich microflora as well as a micro- and macrofauna, with calcareous algae, sponges, anthozoans, bivalves, gastropods, nautiloids, ostracods, trilobites, brachiopods, bryozoans, echinoderms, scolecodonts, conodonts, and foraminifers (Schréter 1963, 1974; Balogh 1964; Kozur 1985; Pešić et al. 1988; Fülöp 1994). It is Capitanian to Changhsingian in age (Kozur 1988, 1989).

The Nagyvisnyó Limestone is overlain by nearly 1 m of clayey marl (BSB) overlain in turn by 8.5 m of dark grey, thin-bedded, mostly stromatolitic limestone representing the lowest part of the 110–140 m-thick Gerennavár Limestone (Hips & Haas 2006). The next 17.5 m of this unit consist of thick- to thin-bedded mudstone. Bioclastic grainstone interbeds, gradually increasing in thickness, appear up-section, followed by oolitic limestone that makes up the bulk of the Gerennavár Limestone (Hips & Pelikán 2002). In the layers overlying the stromatolitic interval, the ostracods *Hollinella tingi* and *Langdaia* sp. were found (Kozur in Fülöp 1994). An advanced form of *Hindeodus parvus* was reported by Kozur from 14 m above the 'Boundary Shale Bed' (BSB).

From among several P-T boundary sections identified during geological mapping in the northern part of the Bükk Mountains, the most complete ones were found on the northern slope of Mount Bálvány and referred to as Bálvány-North and Bálvány-East (Haas et al. 2004). The lower part of the 3 m-thick Bálvány-North section (Fig. 1C) is composed predominantly of dark grey, thin-bedded limestone of the Nagyvisnyó Limestone. It is overlain by the BSB that, in turn, is overlain by laminated limestone of the Gerennavár Limestone.

The Bálvány-East section is located about 500 m from the Bálvány-North section (Fig. 1C); it exposes the same interval but is structurally more disturbed. However, it usefully complements the Bálvány-North section as it exposes a thicker section of the overlying stromatolitic beds.

Another important exposure of the P-T boundary interval, the Gerennavár section (Fig. 1C), is located beside the motorway between Szilvásvárad and Jávorkút, 8 km from Szilvásvárad. The boundary is exposed at the foot of a cliff. In this section, the facies succession of the uppermost Nagyvisnyó Limestone is very similar to that of the corresponding interval in the Bálvány-North section, but the argillaceous limestone bed (Bed N 4) is missing. The most significant difference between the Bálvány and the Gerennavár sections is the much reduced thickness of shale bed (BSB) in the latter section, most probably due to tectonic disturbance. Litho- and biofacies characteristics of the platy limestone directly overlying the shale bed are very similar in the Bálvány and the Gerennavár sections.

The 4 m-thick boundary section on the steep southeastern slope of Kemesnye Hill was also studied; it is located in the basal part of a 25 m-high cliff (Fig. 1C). It consists of limestone beds of the Nagyvisnyó Limestone and Gerennavár Limestone, but compared with the other investigated P-T boundary sections, it appears to be less complete; the uppermost half-meter of the Nagyvisnyó Limestone and the shale bed (BSB) are completely missing due to tectonic disturbances (cf. Haas et al. 2004). This section is not suitable for detailed study of end-Permian events and the P-T boundary interval.

Litho- and biofacies of the studied sections

Bálvány-North section

The beds exposed in the lower part of the Bálvány-North section (Beds N 1 to N 6) including the 'Boundary Shale Bed' (Bed N 7) belong to the Nagyvisnyó Limestone, whereas the overlying 0.65 m-thick platy limestone interval, represented by Bed N 8, corresponds to the Gerennavár Limestone (Fig. 2).

The lowest part of this section (Beds N 1–3) consists of dark grey to black limestone of bioclastic wackestone texture (Fig. 2). Crinoid detritus is predominant; fragments of shells and spines of brachiopods, bivalves, gastropods, foraminifers, ostracods, and dasycladacean algae also occur locally in large numbers.

The next bed (Bed N 4) is composed of alternating dark grey limestone (bioclastic wackestone) and layers of purple to reddish-brownish calcareous marl with limestone nodules, 0.5–5 cm in diameter. The bioclasts are usually smaller than in the underlying beds, typically in the medium to fine sand to silt size range.

Bed N 5 is a dark grey limestone of patchy, bioturbated bioclastic wackestone texture. Small gastropods are common, fragments of thin-shelled bivalves, echinoderms, brachiopod spines, ostracods and a few foraminifers also occur; marine acritarchs and bisaccate and striate pollen grains were found in this bed (Haas et al. 2004).

The next layer (N 6.1) is relatively coarse-grained grey, platy, argillaceous limestone and calcareous marl of bioclastic wackestone–packstone texture. Fragments of molluscs and brachiopods predominate; echinoderm detritus and ostracods are common. The key biofacies feature of this layer is the abundance of the foraminifer *Hemigordius*.

The amount of biogenic components decreases considerably in the next two thin layers (N 6.2 and N 6.3), although no striking lithological change is apparent. These gray argillaceous and silty limestone layers contain only a small amount of fine sand- to silt-sized bioclasts: fragments of echinoderms, ostracods, and the foraminifer *Hemigordius*.

A carbonate mudstone layer (Bed N 6.3) is directly overlain by 94 cm of brownish-grey silty marl (BSB — Bed N 7).

Well-preserved bivalves (*Bakevellia* cf. *ceratophaga*, *Eumorphotis lorigae, Entolium piriformis*, *Pernopecten latangulatus*) and brachiopods (*Orthothetina ladina*, *Ombonia tirolensis*, *Orbicoelia tschernyschewi*) were found in the BSB (Beds N 7.1, N 7.2) (Posenato et al. 2005). In thin section it contains quartz-mica siltstone laminae and relatively few bioclasts: fragments of echinoderms predominate with a few ostracods and brachiopod fragments. Pyrite is abundant in stripes, patches, and mold-fillings.

A 2 cm-thick light grey, argillaceous–silty limestone interlayer containing a 4 mm-thick graded crinoid coquina microlayer (N 7.2) occurs within the BSB. It is overlain by grey marly silt, becoming more limy and silty up-section (N 7.3). In the lower part of this interval, bioclasts including fine echinoderm detritus, fragments of foraminifers, molluscs and ostracods still occur, but in much reduced numbers. The last determinable bivalves and brachiopods were collected from the lower part of this interval.

Alternating calcareous marl and siltstone laminae occur in the next thin interval, almost without bioclasts (N 7.4). Only a few small echinoderm fragments occur, along with calcispheres, ostracods, and fragments of foraminifers.

A 4 cm-thick light grey, sandy marl layer occurs in the upper part of the BSB (N 7.5). It is overlain by 2 cm of marly silt (N 7.6) forming the uppermost part of the BSB. Numerous small cavate spores were found in a sample from the uppermost 30 cm of Bed N 7 (Haas et al. 2004).

The BSB is overlain by 0.65 m of platy limestone (individual plate thickness is 1–3 cm) with very thin (0.5 cm) shale interbeds (N 8.1) of the Gerennavár Limestone. The limestone layers are made up of micrite with small amounts of bioclasts and silt-sized siliciclasts (quartz and mica). Fragments of brachiopod spines are relatively common; ostracods, calcispheres, and foraminifers (nodosariids and *Earlandia*) also occur. A horizon rich in fine sand-sized siliciclasts (quartz and mica) was found 25 cm above the base of the bed.

Bálvány-East section

In the basal part of the Bálvány-East section, the uppermost 2.40 m of limestone of the Nagyvisnyó Limestone and the BSB are exposed (Fig. 3).

The BSB is overlain by limestone of the Gerennavár Limestone. The basal 0.5 m (Bed E 4) of this formation consists of grey platy limestone corresponding to Bed N 8.1 in the Bálvány-North section. It consists of an alternation of 0.5 cm silty limestone layers with a few mm thick marly silt inter-

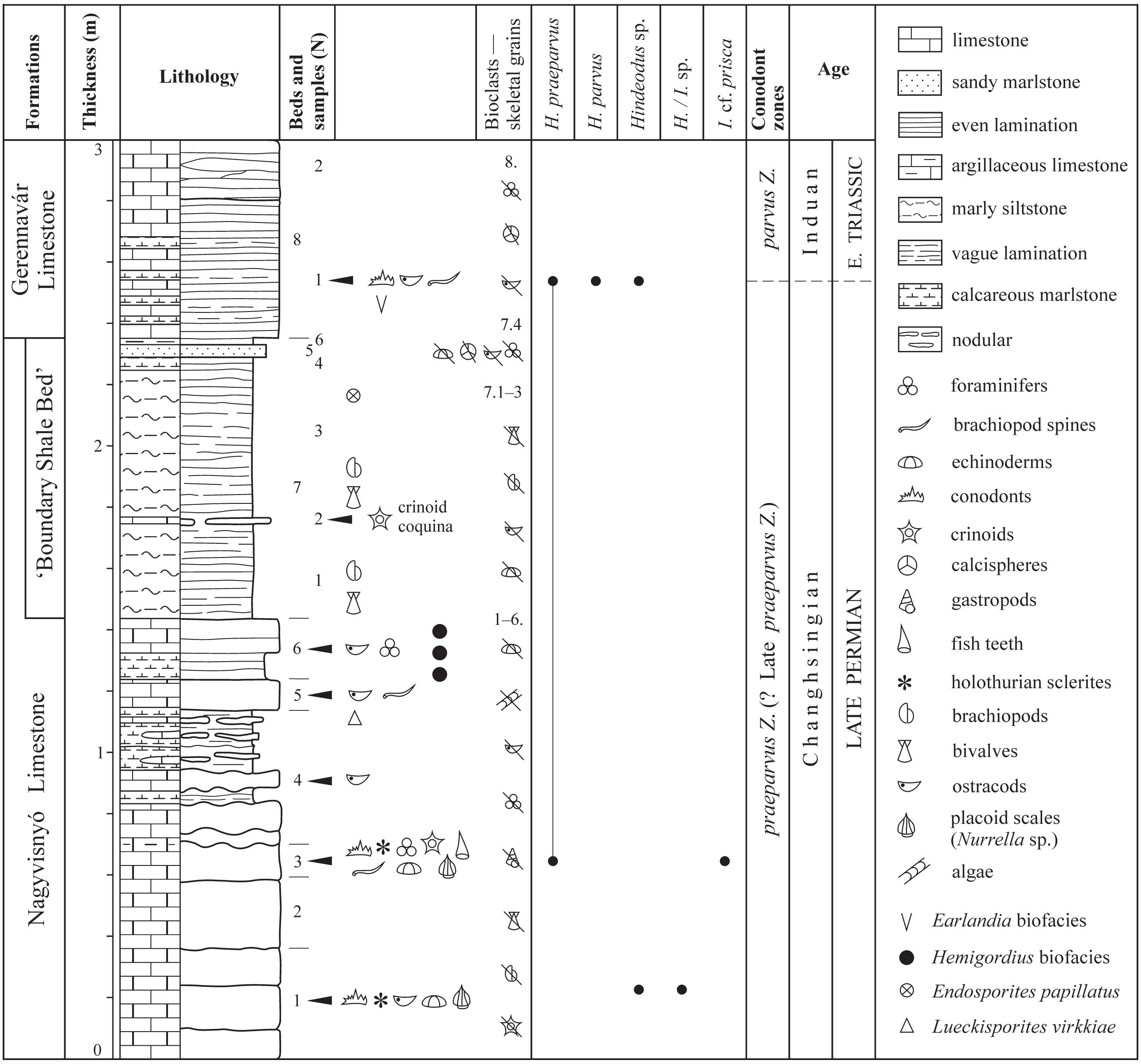

Fig. 2. Geological column of the Permian-Triassic boundary interval of the Bálvány-North section, Bükk Mountains, NE Hungary.

beds. The limestone layers are characterized by bioturbated mudstone texture with a few ostracods and foraminifers.

This is overlain by thin-bedded and evenly laminated stromatolite (Fig. 3). Thick-bedded stromatolite with crinkle lamination occurs in the higher part of the exposed interval (Hips & Haas 2006) but due to tectonic disturbances establishment of the exact stratigraphic succession of this part of the section is ambiguous.

Gerennavár section

An approximately 1.7 m-thick interval of Nagyvisnyó Limestone is exposed in the lowermost part of the section (Beds Ge 140–Ge 134). The beds consist of dark grey or black limestone (Fig. 4) typically bioclastic wackestone in texture. Fragments of crinoids, bivalves, gastropods, brachiopods, calcareous algae, ostracods and foraminifers occur in various proportions. The microfacies of these beds resembles the lowermost bed of the Bálvány-North section, but the coarse bioclast fraction is more pronounced here.

Indications of a bedding-parallel thrust were encountered on top of the uppermost bed (Bed Ge 133) of the Nagyvisnyó Limestone. It consists of four dark grey to black limestone layers, 10 to 15 cm in thickness. The typical texture of the lower three layers is bioclastic wackestone. There is no significant change in composition of the biota, but the size of the bioclasts is smaller than in the lower beds. The microfacies characteristics of these layers are akin to those of Bed N 2 in the Bálvány-North section. There is no fundamental change in texture of the topmost layer (Ge 133.1), but a large number of

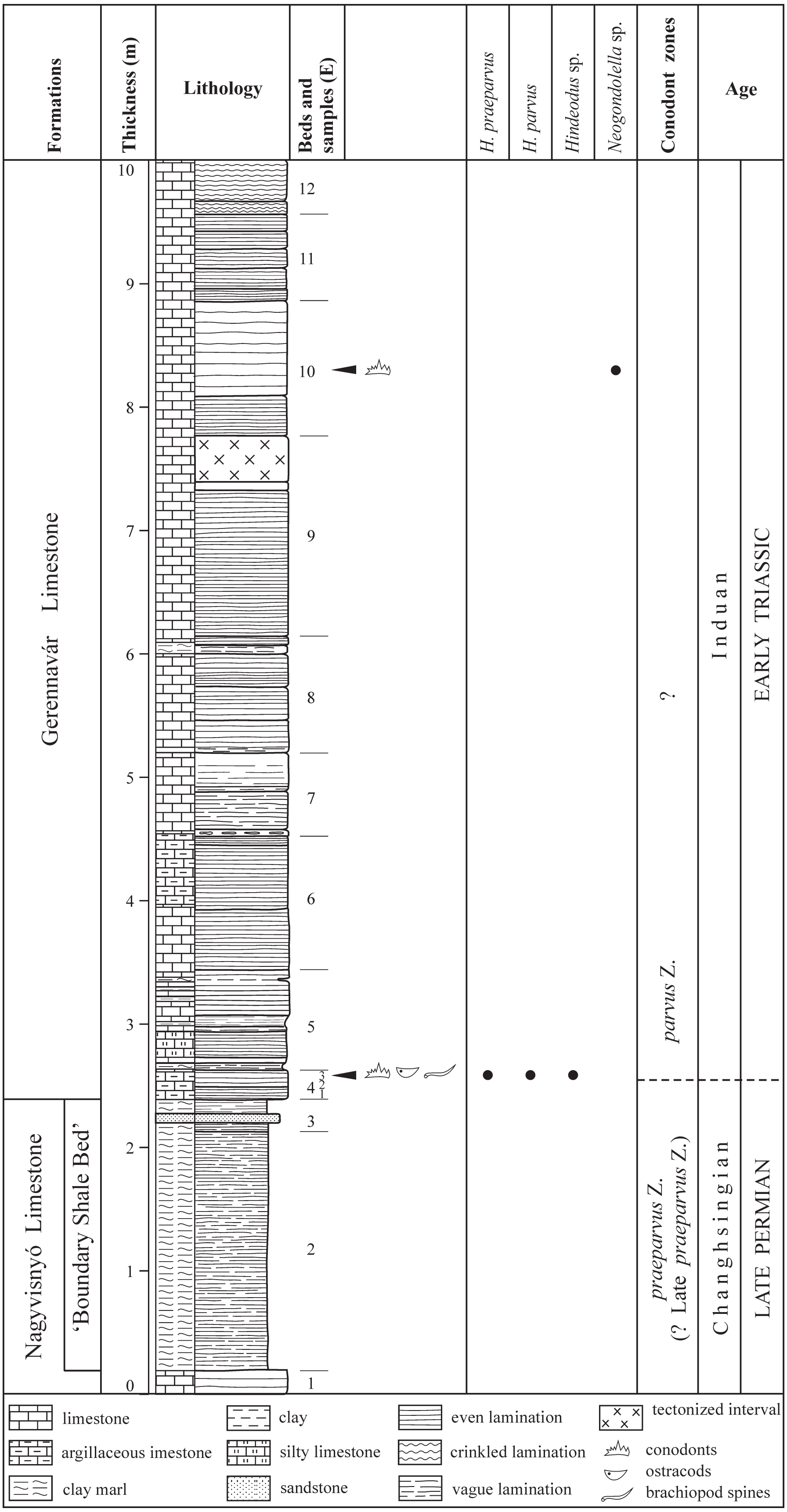

Fig. 3. Geological column of the Permian-Triassic boundary interval of the Bálvány-East section, Bükk Mountains, NE Hungary.

Hemigordius were encountered. A similar biofacies was found in layer N 6.1 in the Bálvány-North section, below the base of the shale bed.

A 6 cm-thick, dark grey, silty calcareous marl layer overlain by 5 cm of dark grey clay occurs above the limestone beds. Under the microscope, 1–3 mm siltstone clasts were noted in the calcareous marl-interpreted as a result of bedding-parallel thrusting. These two beds correspond to the BSB at the top of the Nagyvisnyó Limestone.

The thin clayey horizon is overlain by the Gerennavár Limestone. Medium grey, slightly wavy, platy limestone punctuated by millimeter-thick calcareous marl laminae characterizes the basal part of this succession (Fig. 4 displays only this part of the formation). In the thicker microsparite stripes a few silt-sized bioclasts occur: *Earlandia*, ostracods, and calcispheres.

The overlying 4.5 m-thick succession is made up of stromatolite punctuated by thin-bedded massive mudstone containing thin wackestone or crinoidal grainstone intercalations. Crinkle lamination is ubiquitous and typical of the upper stromatolite level. Ostracods, calcispheres, echinoderm fragments, and foraminifers occur rarely.

The stromatolite beds are overlain by a 16.5 m-thick mudstone interval, very poor in fossils; only rare ostracods were encountered. It is overlain by oolitic grainstone beds of the Gerennavár Limestone.

Conodont fauna and biostratigraphy

Only eight of 120 limestone samples, acid-leached for conodonts, proved productive: three in the Bálvány-North section, three in the Bálvány-East section and two in the Gerennavár section (Figs. 2–4, Table 1). Four other samples yielded ostracods, crinoids, holothurian sclerites, foraminifers, fish teeth, placoid scales and fragments of brachiopod spines. No conodonts were obtained from samples from the Kemesnye Hill section.

Table 1: Numerical distribution of conodonts from the P-T sections in the Bükk Mountains, NE Hungary.

Conodont taxa / Sections and samples	Bálvány-North			Bálvány-East		Gerennavár		
	N 1	N 3	N 8.1	E 4.3	E 10	Ge 136	Ge 133	Ge 132.1
H. praeparvus		5	2	2		8	3	
H. parvus			5	4				2
Hindeodus sp.	1		6	8		10	2	
H. / I. sp.	1							
Isarcicella cf. *prisca*		1				1		
Neogondolella sp.					1			
Ramiform elements	5	3	5	4	1	2		

SEM photographs were prepared at the Faculty of Biology, University of Novi Sad, Serbia. The figured and other conodont specimens are housed in the collections of the Department of Paleontology, Faculty of Mining and Geology, University of Belgrade, Belgrade, Serbia, under sample numbers N 1, N 3, N 8.1, E 4.3, E 10, Ge 136, Ge 133 and Ge 132.1.

Conodont dating, biostratigraphy and Colour Alteration Indices (CAI) of the studied sections

The conodont faunas from the Bükk Mountains have similar associations of representatives to the *Hindeodus–Isarcicella* populations (Figs. 5, 6); gondolellids are absent, with the exception of a fragment from 6 m above the base of the Gerennavár Limestone in the Bálvány-East section (Fig. 3).

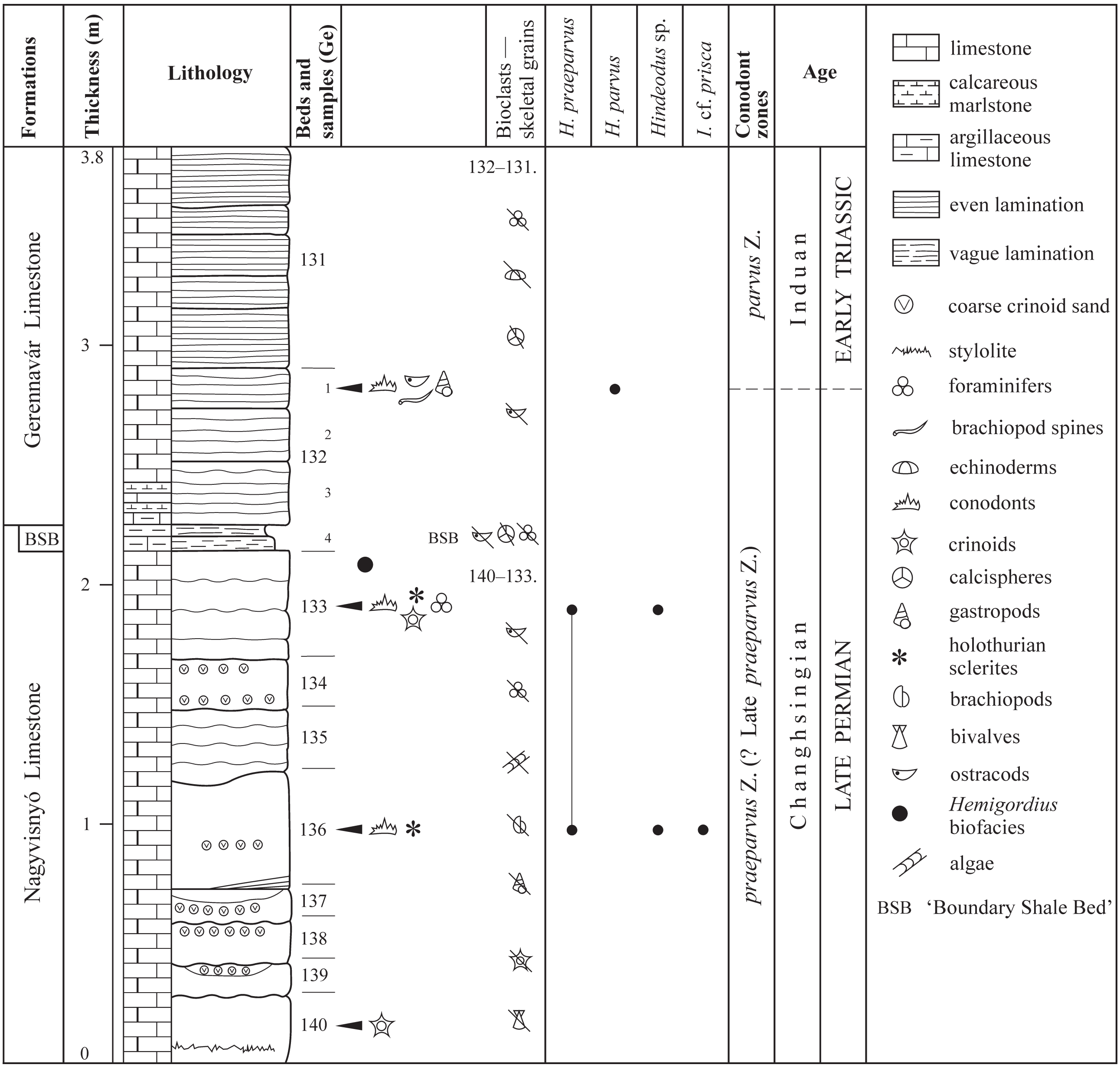

Fig. 4. Geological column of the Permian–Triassic boundary interval of the Gerennavár section, Bükk Mountains, NE Hungary.

Such faunas across the Permian-Triassic boundary interval characterize restricted marine environments (Perri et al. 2004) and have proved to be of great importance for the biostratigraphy of the latest Permian and earliest Triassic. In the present paper the ranges of identified conodont taxa and the inferred conodont zonation of the Late Permian and Early Triassic were established according to the biostratigraphic data of the Southern Alps (Italy) presented by Perri & Farabegoli (2003) for the Tesero section and most importantly for the Bulla section considered by Farabegoli et al. (2007) as the P-T boundary parastratotype for the shallow marine environments of western Tethys. This high-resolution biozonation is the result of intensive study of conodonts across the P-T boundary interval into the Early Triassic of the Southern Alps; it resulted in the discrimination of eight conodont biozones. Comparison was also made with conodont data from P-T boundary intervals from elsewhere in Europe and from Pakistan, Kashmir, Iran, Tibet, China and western North America. The elaboration of the sedimentary and biotic evolution of the 190 m of shallow marine and lagoonal facies in the Bellerophon and Werfen Formations at Bulla in the Southern Alps has permitted comparison between western and eastern Tethys, including comparison of the conodont biozonation based on data from Bulla with the conodont sequence as presently known from the Meishan D stratotype (Farabegoli et al. 2007).

In order to establish the main biostratigraphic conclusions for P-T boundary sections in the Bükk Mountains, special attention was focused on the following:

- first occurrence datum (FOD) of *H. parvus*, the diagnostic species and globally recognized marker defining the base of the Triassic System (Yin 1993; Yin et al. 1996, 2001);
- determining the vertical distributions of taxa of the *Hindeodus–Isarcicella* fauna for discriminating zones in the investigated P-T boundary interval.

Since the main focus of the present conodont investigations in the Bükk area was to biostratigraphically constrain determination of the P-T boundary, only conodont zones immediately below and above the boundary (*praeparvus* and *parvus* Zones) were taken into account.

Bálvány-North section

Samples N 1 and N 3 from the lowest part of the Nagyvisnyó Limestone in the Bálvány-North section yielded the conodonts *H. praeparvus*, *Hindeodus* sp., *Hindeodus/Isarcicella* sp. and *Isarcicella* cf. *prisca* (Fig. 2, Table 1). No conodonts were found in samples (N 4–N 7) from the upper part of the formation (including the BSB). The determined conodont taxa and absence of *H. parvus* indicate that the uppermost part of the Nagyvisnyó Limestone with the BSB of this section possibly belongs to the Late *praeparvus* Zone (Late Permian, uppermost Changhsingian).

The first occurrence of *H. parvus*, 20 cm above the base of the Gerennavár Limestone in sample N 8.1, in association with *H. praeparvus* and *Hindeodus* sp. in the first 65 cm of microbialitic platy limestone of this formation (Fig. 2, Table 1), defines the base of the Triassic and of the *parvus* Zone (Early Triassic, earliest part of the Induan).

Posenato et al. (2005) identified bivalves and brachiopods from the shale interval they regarded as the 'basal beds' of the Gerennavár Limestone from the Bálvány-North section, in order to determine their vertical distributions. Their 'basal bed' are here referred to as 'Boundary Shale Beds' (BSB), the uppermost interval of the Nagyvisnyó Limestone (Figs. 2–4). Aviculopectinids and Entolidae show strong affinities with those from the Lower Tesero Member of the Werfen Formation in the Southern Alps. Brachiopods *Orthothetina ladina* (Stache) and *Ombonia tirolensis* (Stache), characterizing the 'basal beds' (i.e. BSB), end their ranges in the upper third of the unit, below the FOD of *H. parvus.* The bioevents seem comparable with those in the Southern Alps where *Ombonia* and *Orthothetina* underwent extinction below the first occurrence of *H. parvus* during the second extinction event E2 of Farabegoli et al. (2007, Fig. 7), in the Lower Tesero Member of the Werfen Formation. In Pakistan too, the *Ombonia* and *Orthothetina* association occur only up to the latest Changhsingian in the Lower Kathwai Member (Wignall et al. 1996). In the BSB, extinctions of palynomorphs in the upper 30 cm (Haas et al. 2004) and a sharp decrease of $\delta^{13}C$ values in the upper third of these beds (Haas et al. 2006, 2007) have been recorded. These events would possibly fall in the second extinction event E2 of Farabegoli et al. (2007). In addition to the Late Permian bivalves and brachiopods, Pelikán & Csontos-Kiss (1990), reported the occurrence of dasycladacean algae (*Gymnocodium* sp.) from the basal part of the Gerennavár Limestone. In the Southern Alps gymnocodiacean algae were the last group to undergo extinction within the Triassic layers; *Gymnocodium* sp. disappears above the first occurrence of *H. parvus* at the third extinction event E3 of Farabegoli et al. (2007).

In the Bálvány-North section the sequence of bioevents across the P-T boundary can be summarized by the presence of *H. praeparvus* and possibly of *I. prisca* in the upper part of the Nagyvisnyó Limestone, the extinction of *Ombonia* and *Orthothetina* in the BSB followed by the first occurrence of *H. parvus* at 20 cm above the base of the Gerennavár Limestone in a microbialitic interval with gymnocodiacean algae. The sequence of bioevents seems comparable with that of the Southern Alps where a more detailed conodont biostratigraphic analysis was possible, the presence of richer conodont faunas allowing identification of the P-T boundary. Despite the scarcity of conodont-bearing layers in the Bálvány-North section, the occurrence of *H. parvus*, the only formally accepted marker for the base of the Triassic (Yin et al. 2001), at sample N 8.1 should identify or closely approximate the FOD of *H. parvus* in the section and possibly in the region — discriminating the P-T boundary.

Bálvány-East section

The conodonts *H. parvus, H. praeparvus* and *Hindeodus* sp. were encountered in sample E 4.3 from 20 cm above the base of the Gerennavár Limestone (Fig. 3, Table 1); it could possibly be aligned with the level of sample N 8.1 in the Bálvány-North section. Level of sample E 4.3 is assigned to the base of the *parvus* Zone.

Sample E 10 from 5.80 m above the base of the Gerennavár Limestone, and so above the tectonically disturbed in-

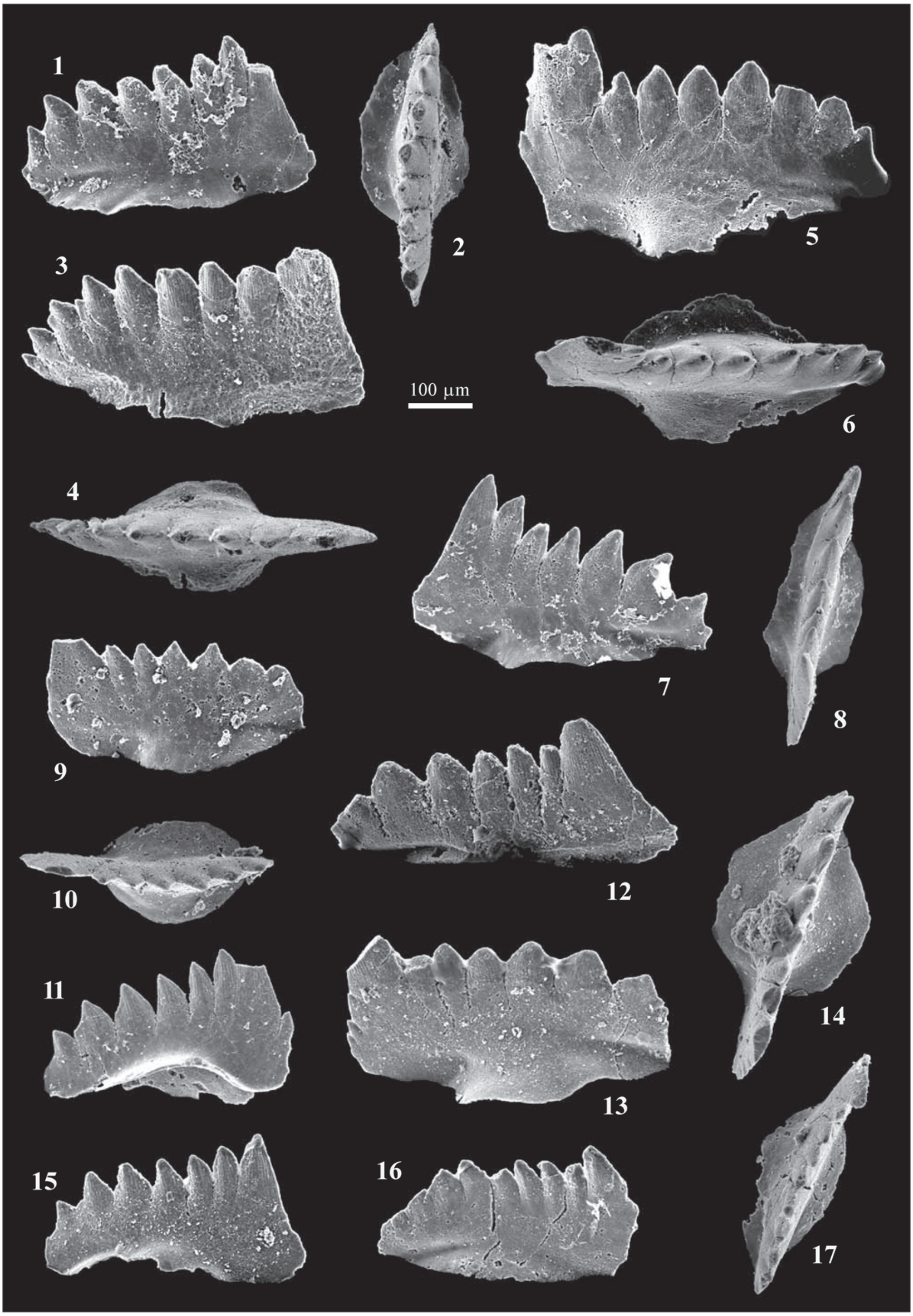

Fig. 5. Conodonts of the Permian-Triassic boundary interval in the Bükk Mountains, NE Hungary. **1–17** — *Hindeodus praeparvus* Kozur. Figs. 1–15 — Latest part of the Late Permian, Changhsingian, *praeparvus* Zone (? Late *praeparvus* Zone), Nagyvisnyó Limestone; 1–11 — Gerennavár section, sample Ge 136; 12 — Sample Ge 133; 13–15 — Bálvány-North section, sample N 3. Figs. 16, 17 — Earliest part of the Early Triassic, Induan, *parvus* Zone, Gerennavár Limestone, Bálvány-North section, sample N 8.1. All magnifications are 100×.

terval, yielded one fragment of *Neogondolella* sp. (Fig. 3, Table 1).

Gerennavár section

The conodonts *H. praeparvus*, *Hindeodus* sp., and *I.* cf. *prisca* were found in sample Ge 136 from the upper part of the Nagyvisnyó Limestone, 1.10 m below the top of the formation. Sample Ge 133 from the uppermost bed of this formation yielded *H. praeparvus* and *Hindeodus* sp. (Fig. 4, Table 1). No conodont was found in the 11 cm thick BSB. The presence of the determinated conodonts possibly defines the Late *praeparvus* Zone in the uppermost Nagyvisnyó Limestone (Late Permian, latest Changhsingian).

Only *H. parvus* was found in sample Ge 132.1 taken from 70 cm above the base of the overlying Gerennavár Limestone (Fig. 4, Table 1). The discovery of this species indicates the base of the Triassic and the *parvus* Zone (basal Induan of the Early Triassic) in the lowermost part of the Gerennavár Limestone.

Conodont Alteration Indices

The Colour Alteration Index (CAI values *sensu* Epstein et al. 1977) of the conodonts from the Bálvány-North and the Gerennavár sections is 3, and from the Bálvány-East section 3.5; these indicate the diagenetic zone (cf. Kovács & Árkai 1987). This deviation from the CAI values in the bulk of the Bükk Mountains, which are anchi- to epimetamorphosed (Árkai 1983; Árkai et al. 1995) and contain Late Triassic conodonts with CAI values of 5–7 (Sudar & Kovács 2006) indicates that the northern part of the Bükk Mountains with Late Paleozoic and Early Triassic formations did not reach the lower boundary of metamorphism (cf. Árkai op. cit. and in Fülöp 1994).

Comparison with conodont faunas of other areas

Latest Permian–Early Triassic shallow-water sequences lacking ammonoids are widely distributed in many regions of the world. They contain conodont associations with *Hindeodus–Isarcicella* faunas. Gondolellids may be present or absent in such populations. Conodont faunas with gondolellids, thought to reflect deeper or at least more open marine environments, are present in many localities: in Pakistan (Salt Range, Trans-Indus Range), Kashmir, Malaysia, Armenia, Iran, Tibet, and China (see citations in Perri et al. 2004, p. 470). Other associations, lacking gondolellids and reflecting shallow-water with restricted marine conditions, occur in the Southern Alps (Carnic Alps to Dolomites), Pakistan (Chitral), China (Jiangxi Province) and elsewhere (Perri 1991; Perri & Farabegoli 2003; Perri et al. 2004; Farabegoli et al. 2007).

In the uppermost Bellerophon Formation and the lower Werfen Formation (Tesero and Mazzin Members) in the Bulla and Tesero sections (Dolomites, Italy) and in many other P-T boundary sections in the Southern Alps (Carnic Alps to Dolomites), conodont associations composed mainly of hindeodids and isarcicellids have been found (Perri & Farabegoli 2003; Farabegoli et al. 2007). The absence of gondolellids is ecologically noteworthy. The biostratigraphic study of these conodont faunas, following intensive taxonomic revision, highlighted morphological trends among *Hindeodus* and *Isarcicella* and allowed the recognition of the Early and Late *praeparvus* Zones (Late Permian) and succeeding zones in the earliest Early Triassic: *parvus*, *lobata*, *staeschei* and *isarcica* Zones. These data and inferences are pivotal for correlation of the P-T boundary sections in the Bükk Mountains studied on the basis of conodont biostratigraphy.

For the P-T boundary interval of the Southern Alps, the paper of Schönlaub (1991) on a very rich conodont fauna, collected from the Werfen Formation in the Carnic Alps in the Gartnerkofel-1 core and in the parallel outcrop section, has to be mentioned. Five distinct Early Triassic assemblages were discriminated on the basis of the presence of *H. parvus*, *H. turgidus* and *I. isarcica*.

The evolution of the Jadar Block (Vardar Zone, NW Serbia) was remarkably similar to the Variscan–early Alpine evolution of the Bükk Mountains (Protić et al. 2000; Filipović et al. 2003). There are many studies of the Early Triassic strata of this block but conodonts have been obtained mostly from its higher, Olenekian, part (e.g. Sudar 1986). Conodonts of the *H. typicalis* group of the *Hindeodus–Isarcicella* populations were found only in the P-T boundary interval of the Komirić section (Sudar et al. 2007); they indicate the Early *praeparvus* Zone (Changhsingian, Late Permian).

From the Croatian and Slovenian parts of the Dinarides which may have been located paleogeographically close to the Bükk area, similar P-T conodont associations were reported. In the former area, representatives of *Hindeodus* (*H. parvus* and *Hindeodus* sp. from the *parvus–isarcica* Zones) were described from the Školski Brijeg section (Gorski Kotar region, Croatia) from the lower part of the basal, dolomitized, oolitic bar facies (F-1) of the lowermost Early Triassic shallow marine succession (Aljinović et al. 2006). In the Žiri area of western Slovenia, the P-T interval has been identified by a rich *Hindeodus–Isarcicella* fauna dominated by isarcicellids but, strikingly, lacking gondolellids. The following taxa were determined: *H. parvus*, *H. typicalis*, *Hindeodus* sp., *I. isarcica*, *I. lobata*, *I. staeschei*, *I. turgida* and *Isarcicella* sp. A., allowing establishment of Faunas 1, 2 and, 3 respectively, on the basis of their ranges. The base of the Triassic was identified by the first occurrence of *H. parvus* in the lowermost "Streaky Limestone Member" of the Werfen Formation (Kolar-Jurkovšek & Jurkovšek 2007).

Conclusions

The lithostratigraphic boundary between the Nagyvisnyó Limestone (with the BSB) and the Gerennavár Limestone was documented in several sections in the Bükk Mountains, Northern Hungary (Haas et al. 2004; Hips & Haas 2006; Haas et al. 2006; Haas et al. 2007, etc.). The best sections across the P-T boundary (Bálvány-North, Bálvány-East and Gerennavár) were selected for detailed biostratigraphic studies. These continuous marine sections represent a deeper ramp setting developed at the margin of the western Tethys.

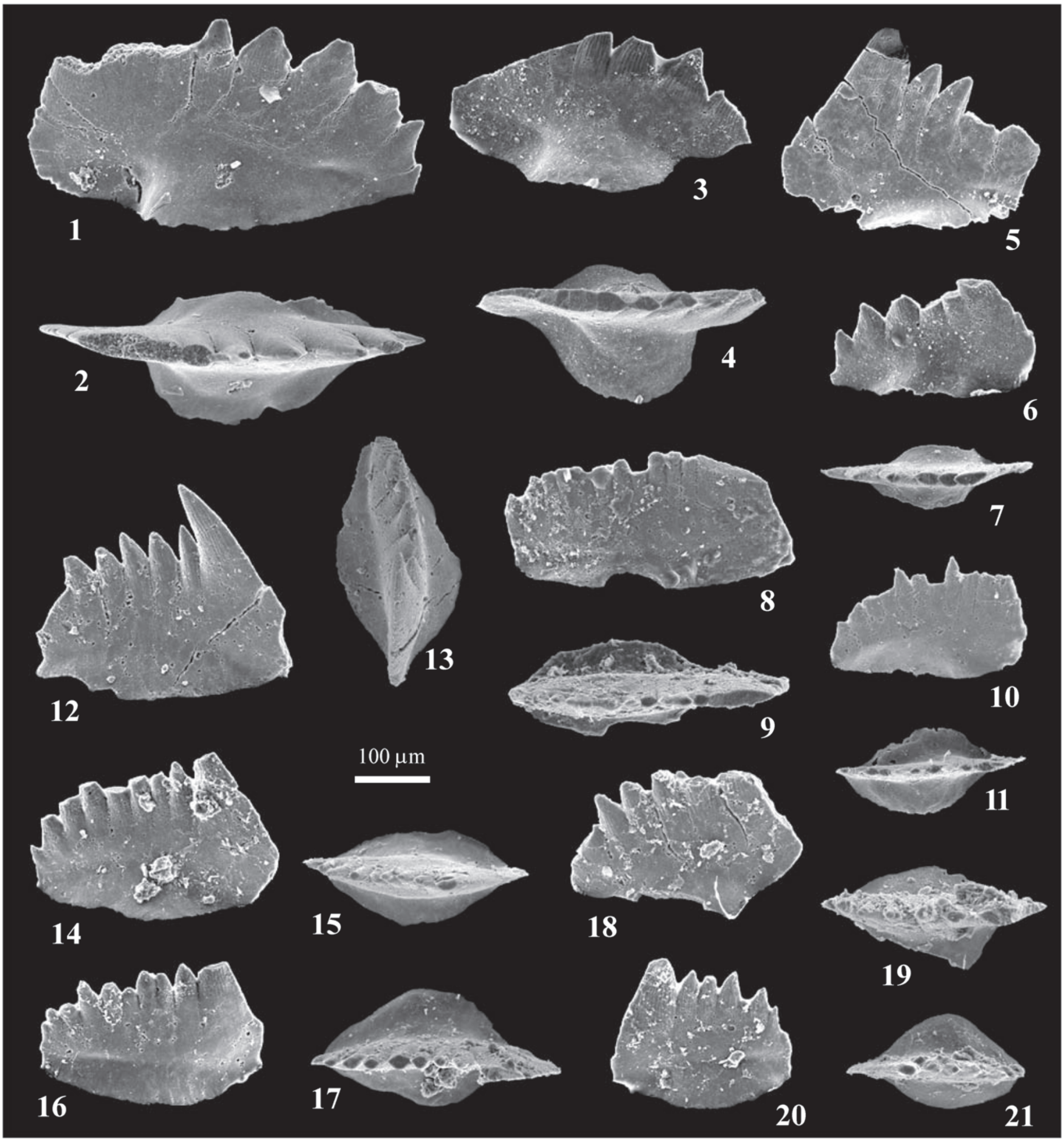

Fig. 6. Conodonts of the Permian-Triassic boundary interval in the Bükk Mountains, NE Hungary. **1–4** — *Isarcicella* cf. *prisca* Kozur, latest part of the Late Permian, Changhsingian, *praeparvus* Zone (? Late *praeparvus* Zone), Nagyvisnyó Limestone; 1, 2 — Gerennavár section, sample Ge 136; 3, 4 — Bálvány-North section, sample N 3. **5–7, 10–21** — *Hindeodus parvus* (Kozur & Pjatakova), earliest part of the Early Triassic, Induan, *parvus* Zone, Gerennavár Limestone; 5 — Gerennavár section, sample Ge 132.1; 6–7, 10–11 — Bálvány-North section, sample N 8.1; 12–21 — Bálvány-East section, sample E 4.3. **8, 9** — *Hindeodus* sp., earliest part of the Early Triassic, Induan, *parvus* Zone, Gerennavár Limestone, Bálvány-North section, sample N 8.1. All magnifications are 100×.

The study of conodonts from these boundary successions resulted in the determination of taxa of the *Hindeodus–Isarcicella* association, without gondolellids. Conodont taxa identified are *H. parvus*, *H. praeparvus*, *Hindeodus* sp., *Hindeodus/Isarcicella* sp. and *Isarcicella* cf. *prisca*.

Biostratigraphic characteristics of the conodont assemblages enable establishment of the base of the Triassic at or below 20 cm (Bálvány-North, Bálvány-East) and at or below 70 cm (Gerennavár), respectively, above the base of the Gerennavár Limestone. The *praeparvus* Zone or possibly Late *praeparvus* Zone (Changhsingian, latest Permian) was recognized in the uppermost part of the Nagyvisnyó Limestone (including the BSB), and the *parvus* Zone (Induan, earliest Triassic) in the lowermost part of the Gerennavár Limestone.

The studies performed allow us to add the Bükk Mountains to the list of well-known and important localities of P-T boundary conodonts; the results may contribute to improving the precision of the Tethys-wide and even worldwide correlation of the boundary events.

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