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Siliciclastics in the Upper Triassic dolomite formations of the Krížna Unit (Malá Fatra Mountains, Western Carpathians): constraints for the Carnian Pluvial Event in the Fatric Basin

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Abstract: The Upper Triassic carbonates of the Krížna Unit in the eastern part of the Krivánska Malá Fatra Mts contain the unique siliciclastic interbeds. They are developed between the Ramsau Dolomite Formation and the Hauptdolomite Formation, and comprise alternating dark grey shales and pale grey dolomites. Such a shaly-dolomite formation is unknown from the Upper Triassic formations of the Krížna Unit, which makes it possible to define a new lithostratigraphic unit (Tržinovo Formation). The Ramsau Dolomites beneath the Tržinovo Formation contain microfauna of Carnian foraminifers. Therefore, the Carnian age has also been constrained for the Tržinovo Formation, which by the reduced carbonate productivity and enhanced terrigenous influx could be related to the Reingraben Event. This event related to the "Carnian Pluvial Episode" is also inferred in the Tržinovo Formation by the presence of lingulide brachiopods (*Lingularia*) and spinicaudatan crustaceans (*Euestheria*). This fauna provides evidence of not fully marine conditions of the Tržinovo Formation, influenced by continental freshwater influx and humid climate.

Key words: Carnian event, Upper Triassic dolomites, Western Carpathians, Krížna Unit, shaly interbeds, lingulids, conchostracans.

Introduction

The Krížna Unit in the eastern part of the Malá Fatra Mts is formed by the Upper Triassic carbonate complexes, which have been studied in the Veľká Lučivná Valley between Zázrivá and Párnica villages (Fig. 1). Dolomite formations in the Veľká Lučivná Valley cropped out along the forest roads, where the dark grey, yellowish-grey and grey-green claystones and dolomitic shales were also uncovered. Dolomite beds and shaly interbeds occur in lens-shaped bodies, which are underlain by the Ramsau Dolomite Formation and overlain by the Hauptdolomite Formation (Fig. 2). The claystones contain the rare fossils, such as lingulid brachiopods and conchostracans, which mean that these sediments represent a unique facies unknown from the Upper Triassic formations of the Krížna Unit up till now. Besides claystones and carbonates the Upper Triassic sediments in the eastern part of the Malá Fatra Mts are also represented by the Lunz Beds, which occur rarely in the form of discontinuous lenslike bodies within the Upper Triassic dolomites. Both sedimentary formations of claystones and sandstones were probably deposited during the Carnian. They represent the intraplatform and periplatform terrigenous facies, which were deposited in response to the demise of carbonate platforms and enhanced siliciclastic input during the Reingraben Event (Schlager & Schöllnberger 1974), Carnian productivity crisis (Hornung et al. 2007a), Carnian Pluvial Event (Simms & Ruffel 1989) and Carnian humid intermezzo (Kozur & Bachmann 2010).

Study area and geological setting

The Triassic sequence of the Krížna Unit in the area studied is represented by limestone, dolomitic, sandy siliciclastic and shaly claystone formations (see lithostratigraphical column in Fig. 2).

The Middle Triassic sequence belongs to the Gutenstein Limestone Formation (Anisian), composed of dark grey bedded limestones with mudstone, wackestone and packstone microfacies, molluscs, echinoids, foraminifers and ostracods. The overlying sequence of the Ramsau Dolomite Formation (Anisian to Lower Carnian see Lexa et al. 2000 for comparison) consists of grey, bedded or massive, fine-grained to crystalline dolomites with rare bivalves, echinoids, peloids and algae. This formation locally contains discontinuous lens-shaped bodies of crinoidal and bioclastic limestones with well-bedded stratification (indicated in Fig. 2). The Fassanian age of these limestones has been determined by the conodonts of *Gondolella acuta* Kozur and *Gondolella trammeri* Kozur (Sýkora 2003).

The Ramsau Dolomite Formation, the uppermost part of which belongs to the Carnian, is overlain by sediments, represented by two different clastic formations. The first is represented by the Lunz Beds, which are composed of fine-grained sandstones (feldspathic graywackes mainly) with thin intercalations of sandy or silty shales. The carbonate-terrigenous facies is recognized herein as the Tržinovo Formation, which is characterized by alteration of shales and dolomites. Both terrigenous formations occur in lens-shaped bodies within the Upper Triassic carbonate formations.

The terrigenous facies of the Lunz Beds and Tržinovo Formation was subsequently replaced by sedimentation of carbonates. The Late Carnian and Norian Hauptdolomit Formation consists of light grey bedded dolomites with very scarce allochems. The overlying Norian Carpathian Keuper Formation is composed of variegated shales, siltstones, quartzose sandstones and fine-grained dolomites (so-called Keuper dolomites).

The uppermost formation of the Triassic sequence is represented by shallow-marine sediments of the Rhaetian Fatra Formation, which consists of bedded limestones with cyclic development of bioclastic, ooidal, oncoidal, peloidal and microbial limestones (lagoonal and patch reefs), interlayered with shaly claystone and occasional dolomite beds.

The information about the presence of the siliciclastic interbeds in the Carnian formation of the Krížna Unit unknown until the paper by Kozur & Mock (1993), who mentioned occurrences and findings of fossils in the claystones from a forest road outcrop in the Lučivná Hill area (see Fig. 1). A similar formation of dolomitic clays and shaly clays has been described from the Krížna Unit in the Ružbachy Horst by Kullmanová & Nemčok (1985), where its Carnian age is proved by lamellibranchs and foraminifers (see below). Increased terrigenous material in the Upper Triassic dolomites underlying the Carpathian Keuper Formation is also recorded in the Krížna Unit in some mountains of the Western Carpathians, like Považský Inovec Mts, Strážovské vrchy Mts, Low Tatra Mts and Tatra Mts (see Mahel' et al. 1967; Mahel' 1986), but their more precise stratigraphic position and lithological descrition remains unknown.

The carbonates and claystones of the Tržinovo Formation have been studied in two sections designated as P–A locality and P–B locality with a distance of about 1.5 km (Fig. 1). The sections show the alternation of claystones and dolomites, which resemble the sediments of the platform and shelf facies of the Raibl Shales in the Norther Calcareous Alps (see e.g. Tollmann 1976), but without the marine fossils typical for the Raibl Shales and especially the Reingraben Shales in the Alpine and Western Carpathian units (Choč Unit). The fossil components of the Tržinovo Formation (P–A locality) comprise only the infaunal brachiopods of the genus *Lingula* together with spinicaudatan crustaceans–conchostracans of the family Euestheridae (Kozur & Mock l993).

The stratigraphic position of the Tržinovo Formation is inferred from foraminifers in dolomitic limestones of the Ramsau Dolomite Formation. In the section studied here it directly underlies the claystones with conchostracan species of *Euestheria minuta* (von Zieten), which according to Kozur & Weems (2010) formed the Late Ladinian zone, but is still present in the entire Cordevolian. The presence of these freshwather to brackich-water conchostrachans in the Tržinovo Formation reflects the Carnian carbonate productivity crisis in the North Tethyan realm, which corresponds to the Reingraben Event during the Early Carnian.

Exposure of the Lunz Beds occurs in the dolomites near the Lučivná elevation point on the left (southern) slope of the Tržinovo Valley. Its verified thickness is just about 10 m, and its observable lenght is a few hundred meters (see Fig. 1). Outcrops and debris derived from the Lunz Beds are situated around 200 m to the NW from the P–A locality. The lithology of the Lunz Beds is different from the shaly-carbonate sedi-

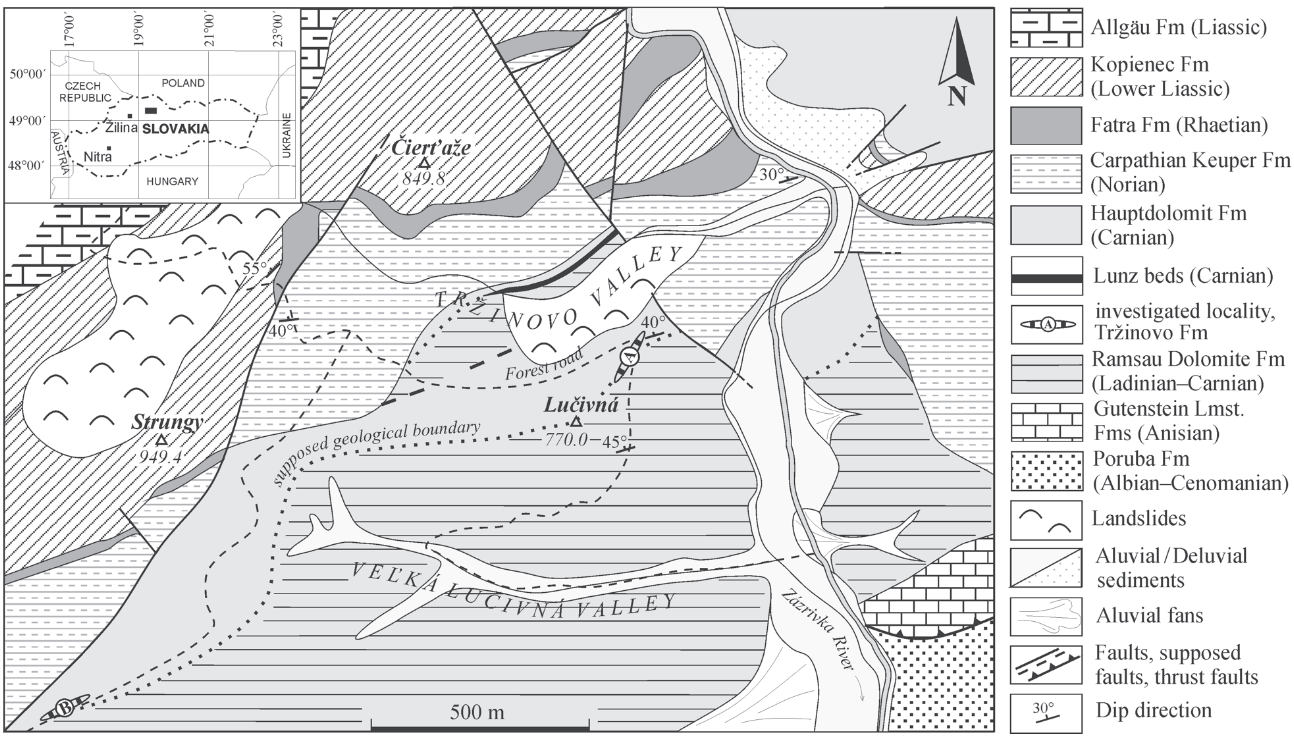

Fig. 1. Location and geological map of the surroundings of the Tržinovo Valley area with localities studied.

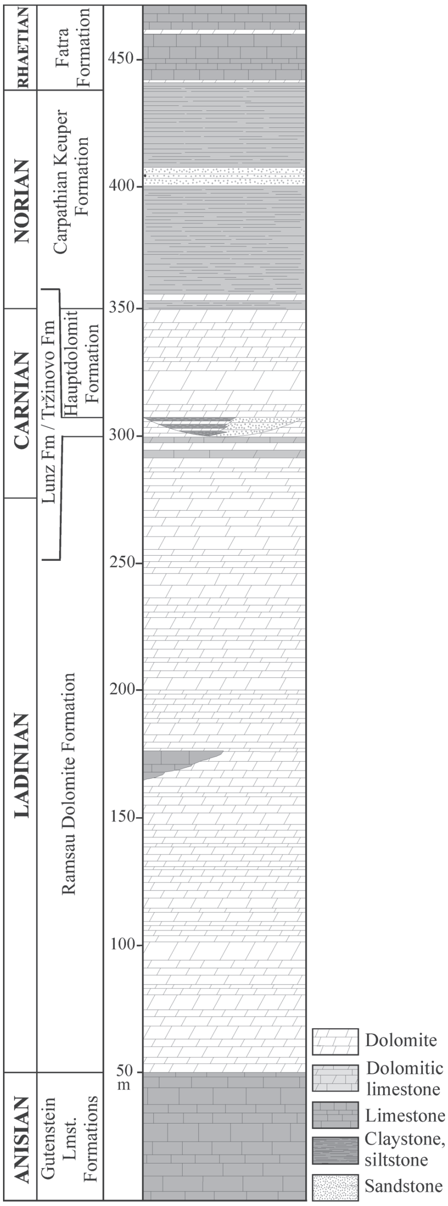

Fig. 2. The lithostratigraphic column of the Triassic sequences of the Krížna Unit in the eastern part of the Malá Fatra Mts, indicating the position of the Tržinovo Formation.

ments at P–A and P–B sections. In the Lunz Beds, the sandstones do not alternate with dolomites, but they are rather homogeneous and do not contain any claystones typical of the sections studied. Thin lenslike bodies of the Lunz Beds *s.l.* are also known from other areas of the Malá Fatra Mts (Haško & Polák 1979; Rakús et al. 1988).

Material and methods

Sedimentary sequences have been logged, analysed and sampled. Selected samples of carbonates were studied by microscopic methods to determine microfacies, petrographic features and microfossils like foraminifers, algae, ostracods, etc. Macrofossils were collected from the claystones, and prepared for paleontological study. The claystone samples from the P–A-section (layers I, II, III see Fig. 3) were macerated and treated with HCl and HF by using of standard palynological processing techniques, but preservation of the extracted palynomorphs was not sufficient for specific determination.

Several samples of the dolomitic limestones were dissolved in 10% acetic acid to extract stratigraphically important microfossils, like conodonts. The carbonate (dolomitic) fraction of the samples from the selected claystones (layers I, II, III, IV) was analysed by manometric methods (Turanová & Turan 1993), and was removed by diluted HCl. The mineralogical composition of the insoluble residue (fraction under 2 μm) was studied by using X-ray powder analysis (PXRD). The analysis was performed on a DRON-3 diffractometer operating at 40 kV and 15 mA, with CoKα radiation at scan speed of 0, 02 °2Θ in range of 4–74 °2Θ. Oriented specimens were prepared by the sedimentation from suspension on a glass slide. The prepared samples were analysed at room temperatures (air-dry) and after treating with ethylenglycol (EG) for 8 hours at a temperature of 60 °C.

Thin sections of the samples are deposited in the Department of Geology and Paleontology of Comenius University Bratislava (M. Sýkora) and in the Geological Institute of the Slovak Academy of Sciences Banská Bystrica (J. Soták). The macrofossils *Lingularia* and *Euestheria* figured in this paper are deposited in the Slovak National Museum in Bratislava.

Microfacies and petrographic analysis of the sections

Section A (P–A)

The sequence of the P–A section can be divided into two parts (see Fig. 3). The lower part of the section represents the uppermost members of the Ramsau Dolomit Formation and consists of dolomites and dolomitic limestones (beds No. 04, 03, 02, 01, 1, 1a, 1b, 2, 2a, 2b, 3, 4, 5b, 5v, 6, 7, 8, 8a). The stratigraphic age of the Ramsau Dolomite Formation in the Krížna Unit corresponds to Anisian up to Carnian–Cordevolian (see Biely et al. 1997; Lexa et al. 2000). The Carnian age is also indicated by the foraminiferal microfauna (see stratigraphical study) from the terminal beds of the Ramsau dolomite (beds No. 0 to 3). The lower part of the section is only partly exposed with an observable thickness of about 6.5 m. Four bedset groups of grey, partly dolomitized limestones, alternating with grey to light grey dolomites can be distinguished here.

In the lower part of the section A (No. 04 to 03) the bedset of dolomitic limestones are represented by packstones and grainstones mainly with intraclasts, peloids and bioclasts. Rounded intraclasts of mudstones, wackestones and peloids are dominant. Foraminiferal components dominated by the uniserial morphotypes, like *Nodosaria* and *Pseudonodosaria*. Ostracods and shell fragments of bivalves are less abundant. Algal fragments (indeterminable thallii of dasyclads) and miliolid foraminifers *Agathammina austroalpina* Kristan-Tollmann & Tollmann are very rare.

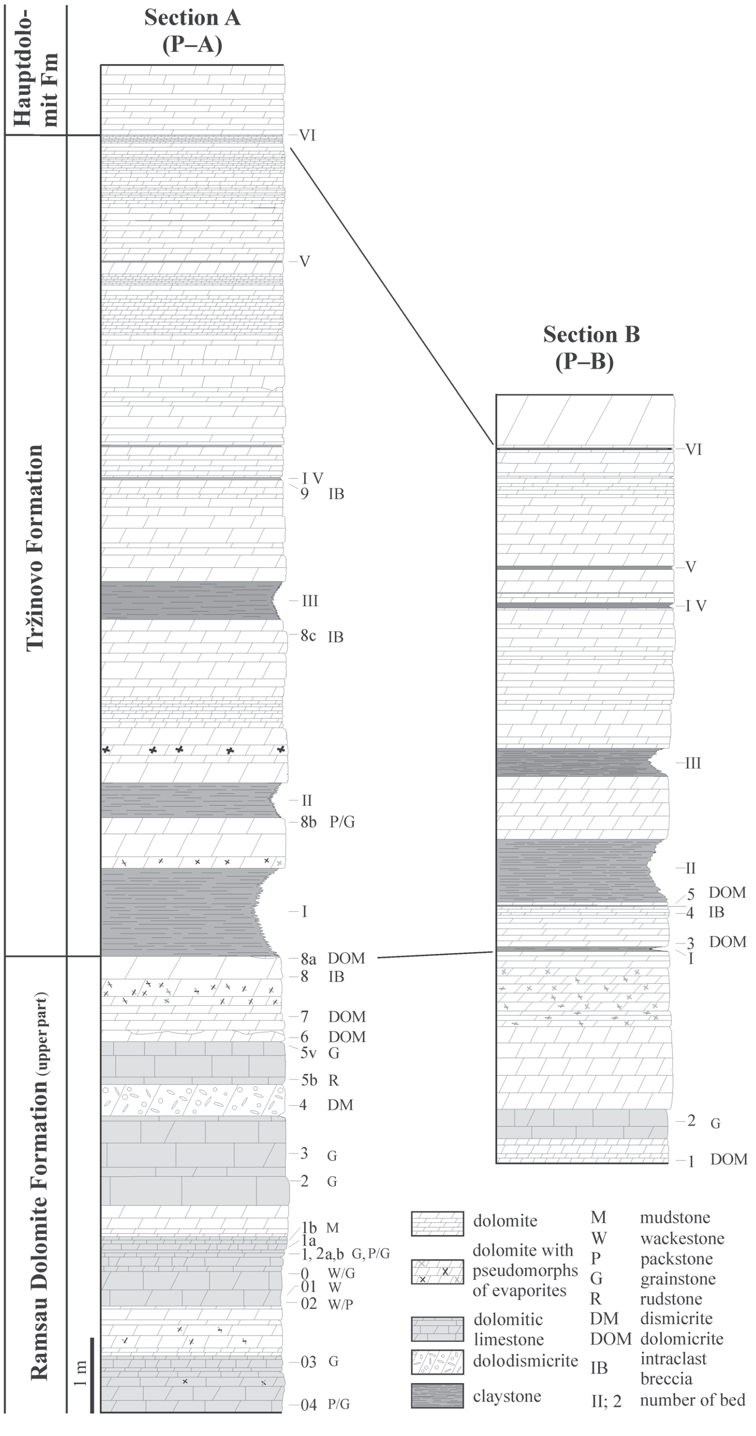

Fig. 3. Lithological sections from the localities studied (Section A, B), extending from the upper part of the Ramsau Dolomite Formation, through the shaly-dolomitic sequence of the Tržinovo Formation to the lower part of "Hauptdolomit" Formation.

In the upper bedsets (No. 02–3) the dolomicritic limestones (mudstones, wackestones and packstones) alternated with grainstones and breccias. The allochems are similar to the dolomitic limestones of the former bedset, apart from those in the grainstone of bed No. 1 (foraminiferal limestones). Beds No. 02, 01, 0 consist of the carbonatic breccias (Fig. 5b), formed by increasing water energy with erosional wash-outs on the basal bed surfaces. The limestones contain flat mudstone lithoclasts with fine parallel laminations and clasts of cryptalgal bindstones with micritic algal biolamination. Peloids and small biodetritic grains are also present.

Bed No. 1 is formed by foraminiferal grainstones with involutinid, ammodiscid, miliolid and rarely duostominid foraminifers (Fig. 6b,c). Dasyclad algae *Halycorine* and echinoderm fragments were rarely found, as well. In this limestone, the specific components are represented by aggregate grains (Fig. 6a,b) forming grapestone to lumpy aggregates (cf. Tucker & Wright 1990), which indicate the shallow marine environments of the subtidal to intertidal zone. Mixing of bioclasts and intraclasts derived from various sources reflects the changes in depositional energy and intensity of bottom erosion (rip-up intraclasts). Disorganization of some tempestite-like beds (Fig. 5b, No. 0, 1) indicates a storm activity, but typical storm-related textures like lags and scour-and-fill structures are not developed.

The layers No. 1a,b, 2, 3 are composed of grainstones, less mudstones, wackestones and packstones. The beds provide the structures of fenestral fabrics, fine lamination, bioturbation and rare desiccation cracks filled by breccias. Low-diversity microfauna is typical of these sediments, revealing an abundance of nodosariid foraminifers in some beds.

The superposed beds No. 4, 5 are formed by dolomitic limestones with textures of mudstones, packstones and grainstones. The special microfacies fabric is recorded in the bed No. 4, which consists of peloidal bioturbated wackestone with irregular vuggs and tubular fenestrae (Fig. 6d). These textures were probably produced from trapping of gases released from the sediment.

The texture of bed No. 5 is heterogeneous. Its basal part bears the lithoclasts of mudstones with small irregular fenestrae (Fig. 5d), micritic intraclasts and frequent peloids. Aggregate grains, intraclasts and fenestral pores occur in the upper part of this bed, associated with rare foraminifers, bivalves and ostracods. Laminoid fenestral fabrics of the LF-BII-type have been observed, too. According to Flügel (2004), such fabrics are typical of modern intertidal and supratidal environmets.

The described bedsets of dolomitic limestones alternate with fine-grained dolomites. They contain relatively frequent pseudomorphs of dolomite after evaporitic minerals, such as sulphates. Fossils (ostracods and uniserial foraminifers) are generally uncommon. In thin sections of dolomites, the admixture of silty and very fine sandy quartz has also been identified in a few cases (beds No. 6, 7, 8a).

The topmost beds of the Ramsau Formation (No. 8) are composed of wackestone/floatstone limestones with micritic intraclasts up to 7 mm in size (Fig. 5c). The micritic matrix

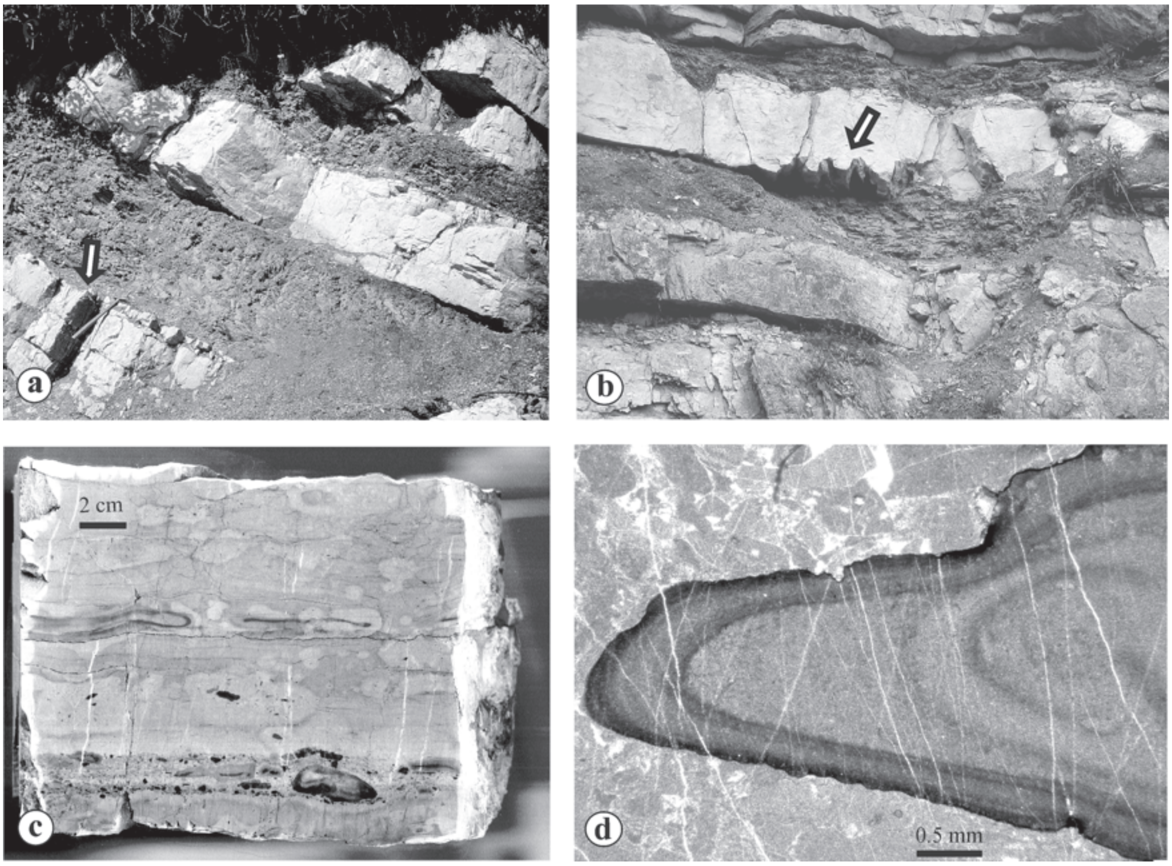

Fig. 4. Sedimentary sequence and internal structures of the Tržinovo Formation. **a** — Lower part of section A (P–A), locus typicus of the Tržinovo Formation, formed by two members: Tržinovo Shales and Tržinovo Dolomites. Outcrop in forest road cut, hammer as a scale with 50 cm length. **b** — Lower part of section B (P–B), parastratotype of the Tržinovo Formation, formed by two members. Dolomite layer exhibits a seismotectonic deformation on the top of the claystone bed-marked by the arrow in the middle of the picture. Forest road cut outcrop, hammer as a scale. **c** — Intraformational carbonate conglomerate deposited probably as a storm lag. Dark lithoclasts in lower part show the liesegang bands. Sample from the Ramsau Dolomite Formation outcrop in the forest road cut near section A. **d** — Lithoclast with liesegang bands from carbonate conglomerate, see previous picture.

also contains fine-sized biodetrital grains (less than 0.1 mm), the orgin of which is uncertain. This type of micritic limestone with well-rounded intraclasts prove evidence of textural inversion, which is typical of the high energy environments of channels. The lithology of the lower part of the section changes above bed No. 8a, where the carbonates are suddenly replaced by dolomitic claystones, exhibiting no visible erosion contact.

Samples of the dolomitic limestones from the beds No. 04 and 1 were dissolved in 10% CH_3COOH, but no stratigraphically important microfossils were found in the insoluble residuum.

The superposed formation in the upper part of section A is formed by dolomitic claystones and claystones (I to VI beds), intercalated by fine-grained, pale grey carbonates in the beds 8b,c, 9. The sequence with alternation of shales and carbonates forms the upper part of the section (11.8 m), providing the various thickness of claystones in the lower bed I (up to 120 cm) and uppermost bed VI (only 2 cm). The colour of the claystones is grey, dark grey, greenish-grey and yelowish.

The carbonates are mostly fine-grained, pale grey dolomites with specific allochems and detritic dolomitized limestones. Bed No. 8b represents moderately to poorly sorted grainstone to packstone with intraclasts, peloids, aggregate grains and fenestrate cavities. Rare bioclasts have their origin in bivalves, foraminifers, ostracods and gastropods. Bed No. 8c is formed by breccias with flat clasts of laminated mudstones or bindstones; the second part of this bed consists of grainstone with mudstone lithoclasts. Bed No. 9 is formed by breccia with fine-grained matrix and poorly-sorted mudstone intraclasts, which reveals the textural inversion. Therefore beds No. 8b,c and 9 are considered to represent channel deposits. Allochems of these carbonates have qualitatively similar composition to the dolomitic limestones in the lower part of section A (beds No. 04–5). Dolomites commonly have parallel lamination and form generally thin-bedded layers.

The claystones are composed of illite and dolomite (XRD and DTA analyses). The dolomite content in claystones in the middle part of shaly beds is as follows: bed I — 34.4 %; II — 7.2 %; III — 0 %; IV — 20.3 %. The shales are pelitic, with the average grain size of 0.007 mm.

The dolomitic claystones in bed No. I are dark grey to grey in colour. This bed contains the brachiopods and spinicaudatans (conchostracans), which was firstly recorded by Kozur &

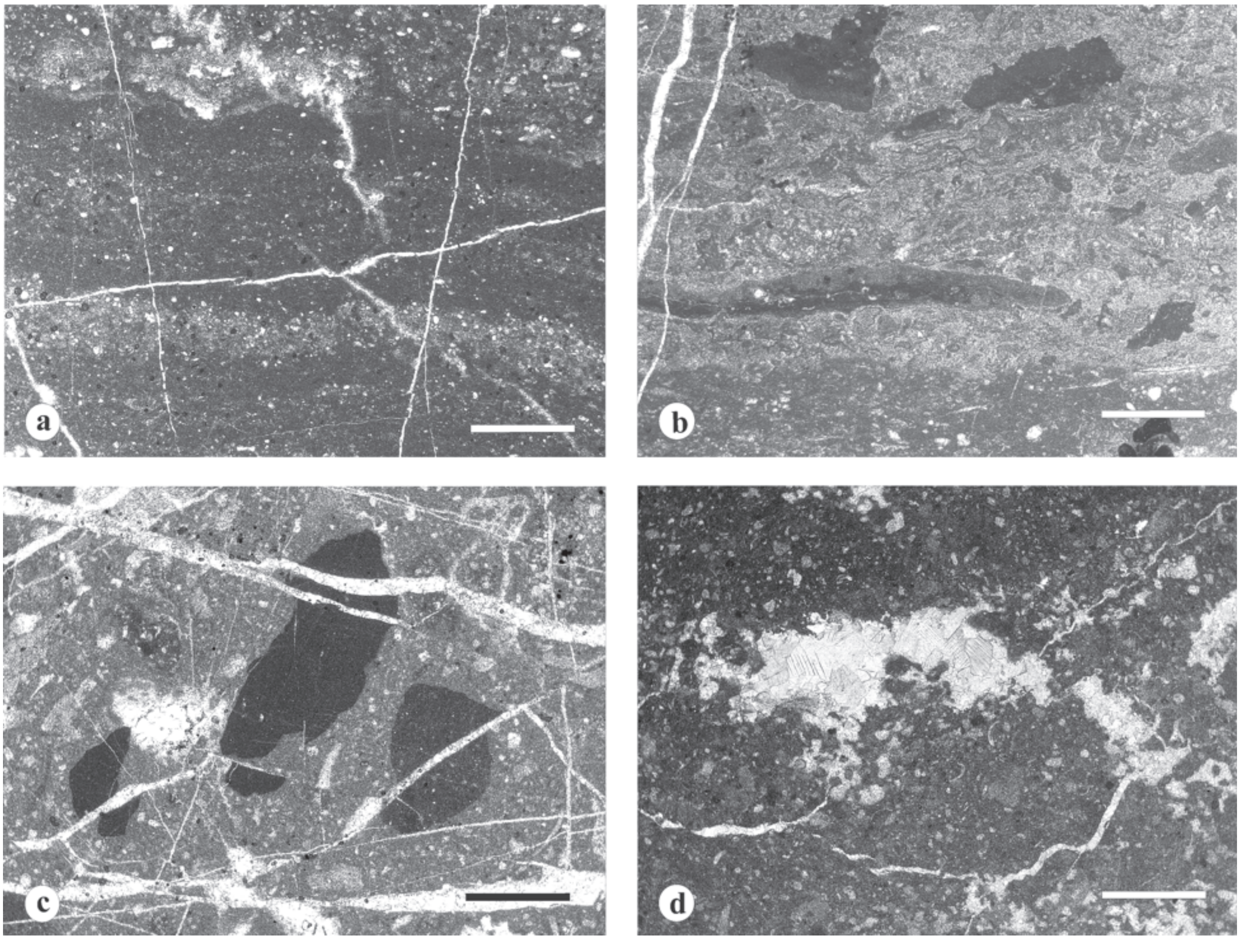

Fig. 5. Microfacial types of the carbonates from the Raumsau Dolomite Formation. **a** — Dolomitic limestone with fine parallel lamination, bed No. 01, thin section 27284, section A, scale 1 mm. Ramsau Dolomite Formation. **b** — Carbonatic microbreccia with mainly angular lithoclasts of fine-grained carbonates. Channel-type sediment, bed No. 0, thin section 27287, Ramsau Dolomite Formation, section A, scale 1 mm. **c** — Intraclasts of micritic carbonates with wackestone to packstone matrix, textural inversion in bed No. 8, thin section 27103, Ramsau Dolomite Formation, section A. Scale bar 1 mm. **d** — Fenestral fabric with irregular voids in carbonates from lower part of bed No. 5, thin section 27282a, Ramsau Dolomite Formation, section A, scale bar 1 mm.

Mock (1993). These fossils are relatively rare, and they occur as isolated valves often with fragmentary preservation. The claystones with lingulids do not show any burrowings and presence of ichnofossils. The lingulids are arranged mostly parallel to bedding, indicating a post-mortem transport of their shells. Brachiopods of *Lingularia* ex gr. *tenuissima* (Bronn) (description in systematic part) occurs much more frequently than conchostracans of *Euestheria minuta* (von Zieten) (determination by Kozur & Weems 2010). Bioclasts were recorded only in bed No. I. Other macrofossils have not been found, apart from very rare small (less than 1 mm) fragments of fish? bones.

Besides fossils, the authigenic pyrite (in small grains below 0.1 mm) and rare oxidized pyrite concretions (max. size 2 cm) were found in the claystones. The claystones occasionally yield a very fine parallel lamination and admixture of silty terrigenous quartz. The inorganic and organic carbon content of the claystones is as follows: Bed No. I (dark grey claystones with fossils) — TC 3.63 %, TOC 0.5 %, TIC 3.13 %; Bed No. II (grey-brownish claystones without fossils) — TC 1.65 %, TOC 0.18 %, TIC 1.47 %; Bed No. III (grey-greenish claystones without fossils) — TC 0.1 %, TOC trace, TIC 0.1 %; Bed No. IV (grey-yellowish dolomitic claystone — 5 cm thin) — TC 2.34 %, TOC 0.32 %, TIC 2.02 %. The clay fractions of below 2 μm were determinated by XRD analysis from the beds No. I, II and III. The dominant clay mineral was illite. Kaolinite was determined only in the bed No. I (up to 5 %). The kaolinite/illite ratio is about 0.05, which indicates humid and warm climate (compare to Simms & Ruffell 1989, 1990). Other clay minerals were not recorded. In the coarser fraction of the claystones (over 2 μm), minerals like dolomite, quartz and feldspar were identified.

Section B (P–B)

The thickness of the outcropping strata is about 11 m, the sedimentary sequence is very similar to the formation described from section A (see Fig. 4b). The lower part of the section is built up by the Ramsau Dolomite Formation, formed by grey, fine-grained dolomites and less frequently by dolomitic limestones, just like those in section A. Bed No. 2 is com-

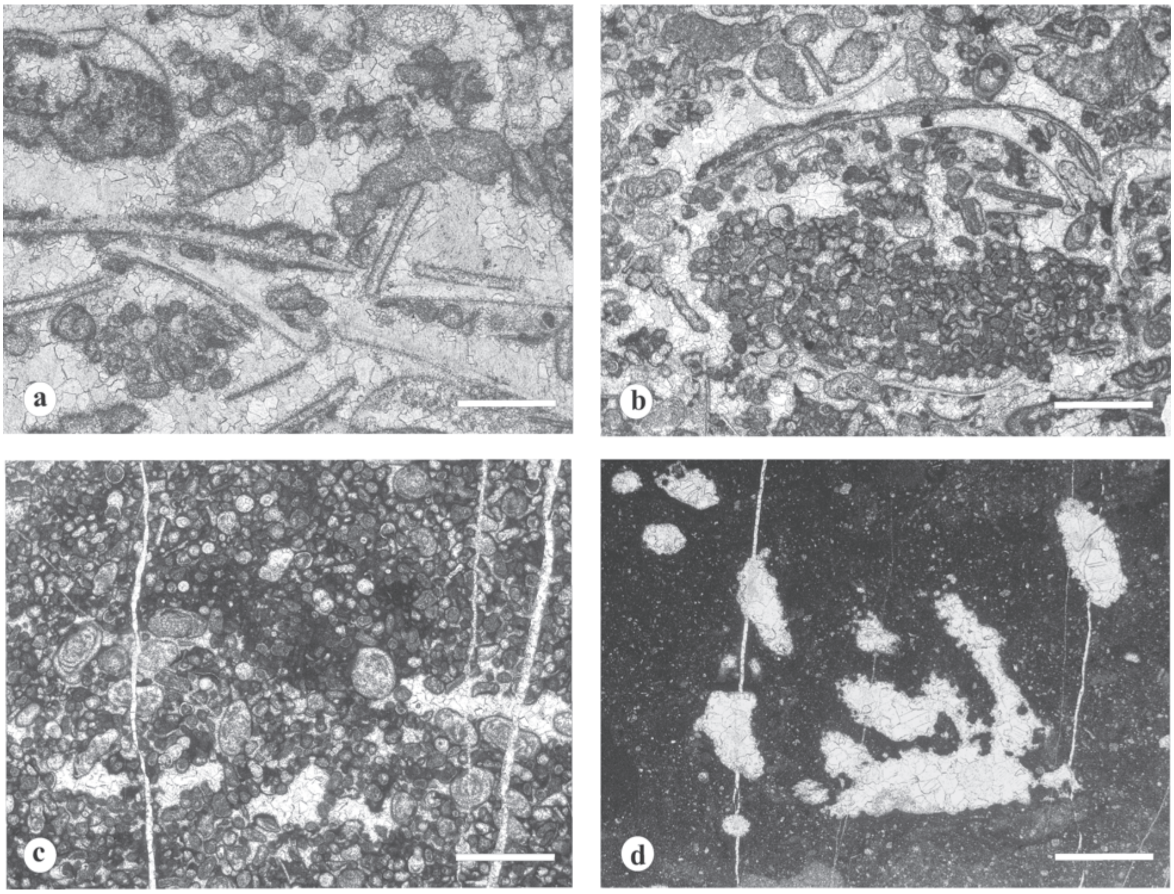

Fig. 6. Microfacial types of the carbonates from the Ramsau Dolomite Formation. **a** — Bioclastic grainstone with allochems (foraminifers and fragments of lamellibranchiate shells), peloids and aggregate grains of grapestone from the bed No. 1. Mixed grains and bioclasts implies a poorly sorted tempestite. Scale 1 mm, thin section 27287b, section A. Ramsau Dolomite Formation, scale 0.5 mm. **b** — Bioclastic grainstone with lamellibranchiate shells coated by sesile foraminifers and lumps of aggregate grains from bed No. 1. Scale is 1 mm, thin section 27287a, section A, Ramsau Dolomite Formation. **c** — Peloidal packstone, locally grainstone with foraminifers and laminoid fenestral fabrics, bed No. 2a, thin section 27290, Ramsau Dolomite Formation, section A, scale 1 mm. **d** — Fenestral fabric with tubular fenestrae in wackestone-type carbonates wackestone. The fenestral cavities were probably formed by degasation and escape of gas bubbles from soft sediment. Bed No. 4, thin section 27281, section A, Ramsau Dolomite Formation, scale 1 mm.

posed of grainstones with very similar microfacies and foraminiferal assemblage to those described from bed No. 1 in section A. The dolomites occasionally contain pseudomorphs after evaporites, cryptalgal fabrics and indistinctive parallel lamination. Allochems are rare and occur mainly as bioclasts. The texture and components of the limestones are very similar to those of the lower part of section A.

The overlying claystones and dolomitic claystones correspond to the claystones in the A-section by their composition and colour. Similarly, they form 6 layers with various thicknesses, from 2 to 100 cm. The upper bedding plane of the claystone bed I is dissected by short faults (see Fig. 4b marked by arrow), which do not cut the superposed dolomite layer. Overlying carbonate infill irregularities caused by the synsedimentary faulting are probably due to seismic activity. Therefore, it is supposed that these deformations were syn- or slightly post-sedimentary. In the section A, the bedding plane above the claystone I does not exhibit any deformation structures. Neither macrofauna nor microfossils were found in the claystones from section B.

Sedimentary environments

The Ramsau Dolomite Formation in the lower part of the sections (A — 6 m, B — 2.8 m) represents peritidal carbonates. The beds are grouped into four bedsets of dolomitic limestones and dolomites (Fig. 3), representing high-frequency cycles (thickness 1.4–1.7). Peritidal carbonates provide a shallowing-upward trend with appearance of parallel lamination and fenestral fabrics (Figs. 5a,d, 6c,d). Intraclasts are also frequent in the beds, especially in the lower and middle part of cycles. They form rounded to angular clasts with various sizes (Fig. 5b,c), consisting of mudstones, wackestones and packstones with laminae of fine biodetrital grains (below 0.1 mm). Supratidal conditions are reflected by the presence of pseudomorphs of dolomite (after gypsum/anhydrite) and peloids. Besides allochems, the grainstone type limestones also contain aggregate grains–grapestones (Fig. 6a,b,c). Some beds indicate the changes in depositional energy, by which various sized grains were periodically mixed and packed in micritic matrix.

Microfossils are represented mainly by foraminiferal associations from different shallow-water environments (No. 02–1b and 2–2b in section A, No. 2 in section B). Aulotortid- and involutinid-rich foraminiferal associations are atypical for the Triassic carbonates of the Krížna Unit, where they were found only for the second time. This type of foraminiferal microfauna is known almost exclusively from the Hronic and Silicic Units.

Organic content and faunal diversity is low in general. Ostracods, fragments of bivalve shells, gastropods and green algae are recorded in the thin sections. Some of the mollusc shells are coated by thin micritic envelopes, due to activity of epilithic organisms (see Kobluk & Risk 1977), cyanobacteria and endolithic microborings. Epiplanktonic zoospores (*Globochaete*) and shells of juvenile bivalves ("filaments") were identified very rarely. On the contrary, the coated grains, grapestones, thick-walled foraminifers and fragments of dasyclad algae were derived from shallow subtidal zone with high and low energy lagoonal environments. Intraclasts of mudstones without allochems and mudstones with fine parallel laminations (<1 mm) originated mainly in the shallow subtidal to supratidal area. Co-occurrence of these components in the layers indicate redeposition of storm-eroded and transported material. Poor sorting of the allochems with great differences in their size, mixing of redeposited components of varied origin in fine-grained matrix is common.

Carbonate formation in both sections also provided field evidence of lenslike shape, as well as sudden lateral changes of microfacies in the beds. All of these observations allow us to interpret the described carbonates as the sediments of channels or depressions in the rugged relief of the peritidal area.

The claystones of the superposed formation above the Ramsau Dolomite Formation are well-sorted sediments with rare internal textures. The boundary claystones on the base of the Tržinovo Formation reveals the very fine parallel lamination, where the laminae are sometimes enriched by epigenetic pyrite grains and rare pyrite concretions, which indicate variations in the redox potential during the sedimentation. The content of carbonate changes in the beds. Presence of the conchostracans and absence of a typical marine biota indicate brackish up to freshwater conditions. The claystone sediments could be deposited from mud suspensions, which overflow the barrier from the channelized area filled by sandstone-rich sediments of the Lunz Beds. Like the Carnian terrestrial systems of Europe, these channels were flooded in monsoonal episodes, then abandoned as pools with standing water and colonized by *Euestheria* (cf. Simms & Ruffell 1990). Therefore, in less humid phases the terrigenous claystones could alternate again with peritidal carbonates.

The sedimentary area of the carbonate claystone deposition in the Tržinovo Formation was separated from the terrigenous clastic systems. The shales were deposited in shallow depressions behind barriers which inhibited input of coarser material. The lens-shaped beds of the Tržinovo Formation represent channels and depressions, which subsided due to tectonic differentiation of the carbonate platform. Initial subsidence is already recorded in the underlying carbonates, which differ from the surrounding dolomites by accumulation of lithoclasts and bioclasts from different shallow-water environments. The Lunz Beds close to A section do not exhibit cyclic organization. It is supposed, that the unique development of the Carnian sediments in the Tržinovo Valley, reflects the specific local conditions.

Dolomites of the Ramsau Formation cropped out in places from below the bed No. 04 in road-cut section A. They are bright grey in colour and locally contain beds of dolomitic breccias to conglomerates (see Fig. 4c). Some of the lithoclasts in these dolorudites exhibit the Liesegang bands (rusty-red on weathered surfaces), which were formed before their deposition in breccia beds (see Fig. 4d). Their origin is explained by redox gradients, when oxidizing and reducing fluids met in an iron-enriched zone, that formed soon after sediment deposition (e.g. Breit 2001). Genesis of the lithoclasts with Liesegang bands is connected with phreatic environments. The carbonate rudites have predominantly micritic matrix, only with local cements. The individual lithoclasts have subangular to well rounded shapes, frequently deformed by stylolites, and between 0.07 to 20 mm in size. Breccias exhibit squeezed and packed clast fabrics. We suppose that the individual lithoclasts were derived from intertidal and supratidal environments, whereas the clasts with Liesegang bands come from the freshwater environments. Because of imperfect size-sorting, mixing of lithoclasts of various origin and erosional contact with the underlying bed the described rudites seem to represent the storm lags (see Demicco & Hardie 1994 for comparison). In the second explanation, the breccias could represent the basal high-energy infill of channel incision, formed in an erosive drainage system at the top of a subaerially exposed platform during drops of relative sea level (see Grélaud et al. 2010 for comparison).

Tržinovo Formation — new lithostratigraphic unit

On the basis of field works, lithological, microfacial, sedimentological and paleontological research we suggest defining the Tržinovo Formation as a new lithostratigraphic unit. Its name is derived from the Tržinovo Valley on the right (western) site of the valley between Zázrivá and Párnica villages at the eastern tip of the Malá Fatra Mts. The new formation oucrops in two localities. The stratotype and locus typicus of the Tržinovo Formation occur in the forrest road cut section with GPS coordinates N 49°13′16″ and E 19°09′24″ (A-section see Fig. 1).

The lithological composition of the new formation markedly differs from the presumably isochronous clastic sediments of the Lunz Beds and other sediments of the Carnian formations of the Krížna Unit. The new formation consists of two members: the Tržinovo Claystone with six layers of shales (No. I–VI), and the Tržinovo Dolomite with interbeds of dolomites and dolomitic limestones (see Fig. 3).

The Tržinovo Claystone is represented by grey, dark grey, grey-yellowish, grey-greenish dolomitic claystones with shaly desintegration and variable content of terrigenous clay fraction (65.6 up to almost 100 %). In this fraction, illite strongly predominates over kaolinite. The lowermost layer of claystone (No. I) contains rare macrofossils including the brachiopods *Lingularia* ex gr. *tenuissima* (Bronn) and conchostracans

Euestheria minuta (von Zieten), presented by Kozur & Weems (2010). Both fossil groups were found in the lower part of bed No. I. Brachiopods are more common than conchostracans, but their stratigraphical importance is low. Silt quartz admixture of epigenetic pyrite grains was found very scarcely in this basal finely laminated claystone.

The Tržinovo Dolomite Member is represented by pale grey bedded dolomites and sporadic dolomitic limestones. These carbonates are micritic, with rare allochems including peloids, intraclasts (pelsparites, intramicrites) and finely-laminated bindstones. Some beds have fenestral fabrics.

The lower boundary of the Tržinovo Formation is marked by the lower bedding plane of bed No. I. This plane overlies the dolomite bed No. 8a, belonging to the topmost bed of the Ramsau Dolomite Formation, and that without any marks of erosion. The upper boundary of the Tržinovo Formation corresponds to the upper bedding plane of the claystone layer No. VI. This boundary claystone divided the Tržinovo Formation from the Hauptdolomit Formation. Thickness of the Tržinovo Formation is approximately 12.3 m (see Fig. 3). The parastratotype of this formation is only known in the B-section at N 49°12′36″ and E 19°08′05″ (Fig. 1). The new formation has a lens-shaped prolongation, and is known only from two above mentioned localities in the Malá Fatra Mts, up to now.

A very similar formation of Lower Carnian sediments in the Krížna Unit was detected in the Ružbachy Horst in Eastern Slovakia by Kullmanová & Nemčok (1985). They described small outcrop of a formation of dolomites and dolomitic claystones about 1.5 m thick. The dolomites are similar in the composition of the Carnian foraminifers to the association from the Malá Fatra Mts. The dolomitic claystones near Ružbachy also contain marine bivalves *Costatoria*/*Costatoria*/cf. *goldfussi* (Alberti in Zieten) and brachiopods of the genus *Lingula* in the claystones (Kochanová in Kullmanová 1974). On the basis of the bivalves Kullmanová & Nemčok *l.c.* assigned this formation to the Cordevolian, whereas Polák in Janočko et al. (2000) preferred its stratigraphic attribution to the Julian and Tuvalian. Recently, the Ružbachy sections are not uncovered for study.

Stratigraphic attribution of the Tržinovo Formation also depends on the definition of the Carnian Stage. Recent debate makes problematic the lower boundary of the Carnian Stage, when the traditional base of the Cordevolian (=base of the A on Zone *sensu* Krystyn 1978) have been questioned due to asynchronous FOs of *Trachyceras* species (Mietto & Manfrin 1999). Therefore, Broglio Loriga et al. (1998) proposed to shift the base of the Cordevolian to the base of *Daxatina canadensis* Zone, which was the cosmopolitan ammonoid species. Nevertheless, some Late Ladinian species like *Frankites* are still present in the Cordevolian, which led to assignment of the *Daxatina canadensis* Zone to the Ladinian (see Mietto et al. 2007 and Kozur & Bachman 2010 for summary). Consequently, the Carnian stratigraphy has been improved by a two-stage subdivision into the Julian and Tuvalian (e.g. Lucas 2010, etc.).

The age of the Tržinovo Formation can be approximated on the basis of conchostracan species *Euestheria minuta* (von Zieten), which is known from the Longobardian, but is also still present in the entire Cordevolian = Julian 1/I (Kozur & Bachmann 2010). This age is also supported by the Carnian foraminifers from topmost carbonate beds of the Ramsau Dolomite Formation, which is directly overlain by the Tržinovo Formation (see below). Age control in deposion of the Tržinovo Formation is related to the Carnian Pluvial Event, which took place in the latest Julian 1/IIc or at the Julian/Tuvalian boundary (Hornung et al. 2007a,b; Simms & Ruffell 1989; Rostási et al. 2010, etc.).

Paleontology and biostratigraphy

Upper Triassic sediments contain lingulide brachiopods and conchostracans in the Tržinovo Formation and foraminifers in the Ramsau Dolomite Formation. These fossils were studied from the viewpoints of systematic description, ecology and taphonomy and biostratigraphic importance.

Brachiopods

Order: **Lingulida** Waagen, 1885
Superfamily: **Linguloidea** Menke, 1828
Family: **Lingulidae** Menke, 1828
Lingularia Biernat & Emig, 1993

Lingularia ex gr. *tenuissima* (Bronn, 1837)
(Fig. 7a–e)

1830 *Lingula* Bronn — p. 128
1830 *Lingula tenuissima* n.s. Bronn — p. 230 (nomen nudum)
1837 *Lingula tenuissima* Bronn — p. 158, pl. 13, fig. 6b
1920 *Lingula tenuissima* Bronn — Diener, p. 16 (cum syn.)
1927 *Lingula tenuissima* Bronn — Ogilvie Gordon, p. 31, pl. 3, fig. 40
1934 *Lingula tenuissima* Bronn — Kirchner, p. 90, pl. 2, fig. 1
1935 *Lingula tenuissima* Bronn — Leonardi, p. 31, pl. 1, fig. 3–4
1958 *Lingula tenuisima* Bronn (sic) — Virgili, p. 534, fig. 62/4
?1960 *Lingula* cf. *tenuissima* Bronn — Šuf, pl. 14, fig. 7
1968 *Lingula tenuissima* Bronn — Nagy, pl. 2, fig. 3
1968 *Lingula tenuissima* Bronn — Broglio Loriga, p. 201, pl. 1, fig. 1–6
1972 *Lingula tenuissima* Bronn — Encheva, p. 19, pl. 9, fig. 1–6, pl. 10, fig. 7–8
1985 *Lingula tenuissima* Bronn — Senkowiczowa, p. 24, p. 24, pl. 1, fig. 2–3
1988 *Lingula tenuissima* Bronn — Siblík, p. 9 (cum syn.).
1991 *Lingula tenuissima* Bronn — Biely & Rakús, p. 6, pl. 1, fig. 4,7
1997 *Lingula tenuissima* Bronn, 1851 — Calzada & Magrans, p. 45, fig. 1
1999 *Lingula tenuissima* Bronn — Sulser, p. 45, text-fig. 1
(synonymy includes the references with figured specimens only)

Material: 300 more or less fragmentary separated valves, bed I, section A, Tržinovo Valley.

Description: Elongate oval, slightly convex or nearly flat separate valves with up to 18.5 mm in length and 9.5 mm in width. Lateral margins slightly convex, anterior margin rounded. Maximum width at the mid-length. Posterior margin rounded but majority of valves with damaged umbonal parts. Ornamentation consists of growth lines — concentric fila of variable prominence and spacing. Due to damaged posterior parts of most specimens, the distinguishing of pedicle and bra-

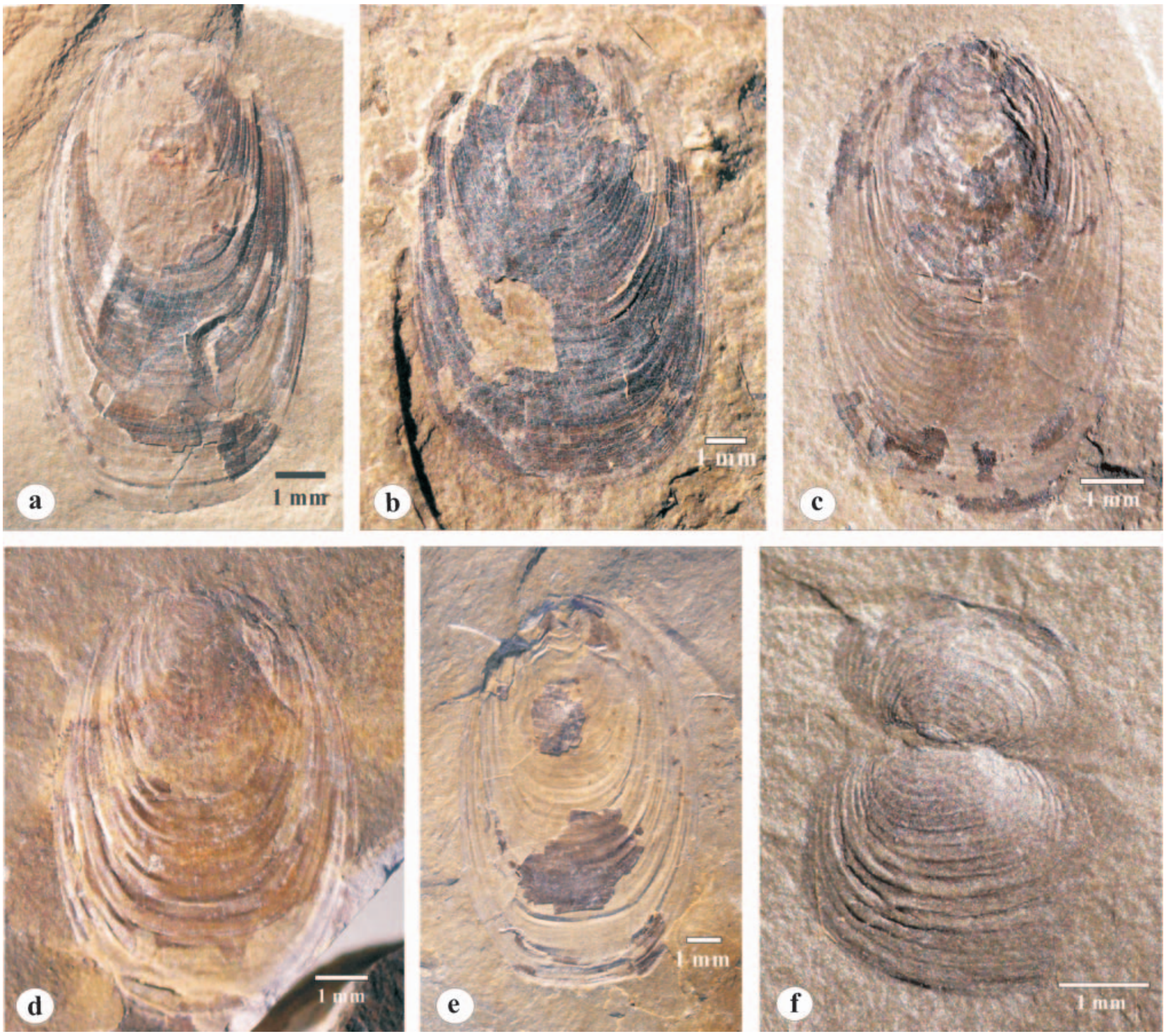

Fig. 7. Lingulid brachiopods and conchostracans from the Tržinovo Formation. **a–e** — *Lingularia* ex gr. *tenuissima* (Bronn); **f** — *Euestheria minuta* (von Alberti) from bed I, section A. Tržinovo Formation. Fossils are deposited in the Slovak National Museum Bratislava under numbers Z 24741–Z 24745 (a–e) and Z 24746 (f).

chial valves of our specimens was practically unfeasible. Internal characters are not well visible. The interior of one pedicle valve only showed narrowly V-shaped grooves joining near the posterior adductor.

Preservation: Most specimens are preserved as more or less fragmentary and depressed internal moulds of separate valves and have thin black organophosphatic shell preserved only in fragments. They are lying scattered, parallel to the bedding. The character of preservation has not enabled information on character states of interior soft parts. No size-sorting of valves was ascertained.

Remarks: Findings of Triassic lingulid brachiopods are relatively rare and their preservation not very favourable. However, the specimens may occur in great numbers ("*Lingula* – Beds"). Mass occurrences of lingulids are reported from several localities in the Italian Lower Triassic ("Scythian") by Broglio Loriga et al. (1980). Those brachiopods were determined as *Lingula tenuissima* in former publications (e.g. Broglio Loriga 1968) or *Lingula* sp. in the subsequent ones. These authors (1980) also summarized lingulid findings in the Lower Triassic from all over the world. On the other hand, mass occurrences in the Iberian Range in Spain were ascertained in the Uppermost Muschelkalk (Cordevolian) by Márquez-Aliaga et al. (1999), and more recently by Márquez-Aliaga et al. (2007). The identification of their respective specific appurtenances is difficult. As there is a very limited number of available external features, and the general outlines and external features of the shell are variable and not sufficient for the specific identification, the determinations remain in many cases doubtful. The shape was certainly influenced by environmental conditions and later by fossilization, which could change shell convexity (thickness of valves).

Most of the past Triassic lingulid finds were assigned to *Lingula tenuissima* Bronn, which was described from the Germanic Triassic. However, due to frequent bad preservation, some identifications remain questionable. Very similar lingulids, also described from the Germanic Triassic *Lingula keuperea* Zenker, 1834, *Lingula calcaria* Zenker, 1834 and *Lingula zenkeri* v. Alberti, 1864 were synonymized by some authors. The names of the first two of them could have priority in the case of identity with *L. tenuissima*. However, *Lingula keuperea* as figured by Zenker, 1834 shows in comparison to *L. tenuissima* relatively larger, subtrigonal outline with maximum width in the anterior third of the shell. *Lingula calcaria* seems to be a juvenile of *L. keuperea*. The Alpine species *Lingula christomani* Skuphos, 1893 from the "Partnachschichten" and *Lingula fischeri* Suess, 1854 from the Hallstatt Limestone were extremely rare when established, and have not been ascertained since their description. They both would deserve a revision.

In 1977 Pajaud assigned "*tenuissima*" to *Glottidia* Dall, 1870 on the basis of the presence of divergent laminae in pedicle valve. This was adopted later also by Siblík (1983). However, *Glottidia* occurs in ?Cretaceous, Tertiary–Holocene (Holmer & Popov 2000). This genus was quite recently confirmed in the Eocene in Antarctica (by Emig & Bittner 2005). The usual generic assignment of the Triassic lingulids to *Lingula* Bruguière, 1797 was called in question recently by Biernat & Emig (1993). They documented that Mesozoic lingulid brachiopods differ significantly from their Recent relatives, and established a new genus *Lingularia*, which occurs in Carboniferous–Cretaceous and ?Tertiary formations. One of their 3 new species, *Lingularia siberica* comes from the Middle Anisian of Siberia. According to the above mentioned authors, the genera of the living lingulids probably arose in the Early Cenozoic. The genus *Lingula* itself occurs within the ?Cretaceous, Tertiary and Holocene only (Holmer & Popov 2000, p. 36), its type species *L. anatina* Lamarck in the Holocene. A detailed summary of the taxonomy and organization of the Recent species of *Lingula* was given by Emig (1982, 2002). The external characters are important, but mainly features of the shell interior are necessary for the differentiation between *Lingula* and *Lingularia*, especially impression of the pedicle nerve, shape of umbonal muscle scar etc. However, the internal characters are ascertainable only rarely in the Triassic fossil finds. According to Biernat & Emig (1993), the shell of *Lingularia* externally differs from *Lingula* in its less acute posterior margin and beak, and in its broadly rounded anterior margin.

Most specimens from the Veľká Lučivná Valley show a more ovate outline in comparison to Bronn's figure (1837), which is very general, however. Their shell morphology, even if fragmentary, is wholly consistent with the attribution to *Lingularia*. Clearly comparable to them is the specimen of *Lingula tenuissima*, figured by Calzada & Magrans (1997) from the Upper Ladinian. The main synonymies of *L. tenuissima* are presented here to show the large specific variability and distribution. The possibility to verify the respective determinations is in most cases unfeasible due to universal, short original descriptions or insufficient illustrations. Also unclear muscle imprints can be easily misinterpreted in some cases. With regard to the above mentioned uncertainties, the determination of our material as *Lingularia* ex gr. *tenuissima* is considered reasonable. It is quite possible, however, that so-called "*tenuissima*" itself is not consistent and corresponds to several species.

Distribution: *Lingularia tenuissima* (Bronn) provides a low biostratigraphic importance. This species was described originally from the Buntsandstein and the Wellenkalk in the Germanic Triassic (Bronn 1835–7). It occurs in the Lower to Upper Triassic (Carnian) of the Germanic and Alpine domains, and is reported from Germany, Spain, France (Vosges), Switzerland, Netherland, Austria, Italy, Slovakia (SE Slovakia: e.g. Nandráž W of Jelšava, Rožňava, Muráň Plateau E of Šumiac — all Early Triassic), Hungary, Bulgaria, Bosnia, Greece, Israel, Algeria, Tunisia and China.

Ecology and taphonomy: Lingulids are marine endobionts, living mainly on offshore, shoreface and intertidal, deltas and estuarine settings — soft substrates of finely grained sand or clayey sand. They are tolerant of reduced salinity — e.g. Robertson (1989) etc., of oxygen deficient settings — e.g. Wignall & Hallam (1992), Schubert & Bottjer (1995), and their short dwelling in fresh or brackish water is possible. Kowalewski (1996) confirmed that recent lingulid brachiopods have very low fossilization potential, and that longer transport of their shells before fossilization is highly improbable. After death they can undergo rapid mechanical damage, and then disappear within weeks or months. Their preservation in the fossil record may be enabled by a high rate of sedimentation only or by catastrophy. On the basis of the literature, Kowalewski *l.c.* concludes that the fossilization potential in Paleozoic lingulids is higher than that in post-Paleozoic ones. It seems that the claystones in section A have not represented the normal substrate of lingulids (no presence of the lingulid — derived trace fossils were found) but on the contrary, they are responsible for their burial. An outline of environmental, biological and taphonomic controls on lingulid distribution was given in Zonnenveld et al. (2007).

Conchostracans

Conchostraca Sars, 1867

Material: A number of shells in bed I, section A, Tržinovo Valley.

Description: Conchostracans belong to the clam shrimps, the systematic classification of which remains uncertain (see Kozur & Weems 2010). Triassic conchostracans are assigned to the suborder Spinicaudata Linder, 1945. Conchostracan shells from the Tržinovo Formation reach sizes of around 3 mm, they display expressive growth bands and chitinous composition (Fig. 7f).

Stratigraphic importance: The conchostracans from bed No. I were originally determined as *Euestheria* cf. *minuta* (von Zieten) by Kozur & Mock (1993). Their systematic attribution to the species of *Euestheria minuta* (von Zieten) has been improved by Kozur & Weems (2010). In the conchostracan zonation of Kozur & Weems (*l.c.*), this taxon is the nominative species of the *Euestheria minuta* Zone, which has been established in the Longobardian. The associations of this con-

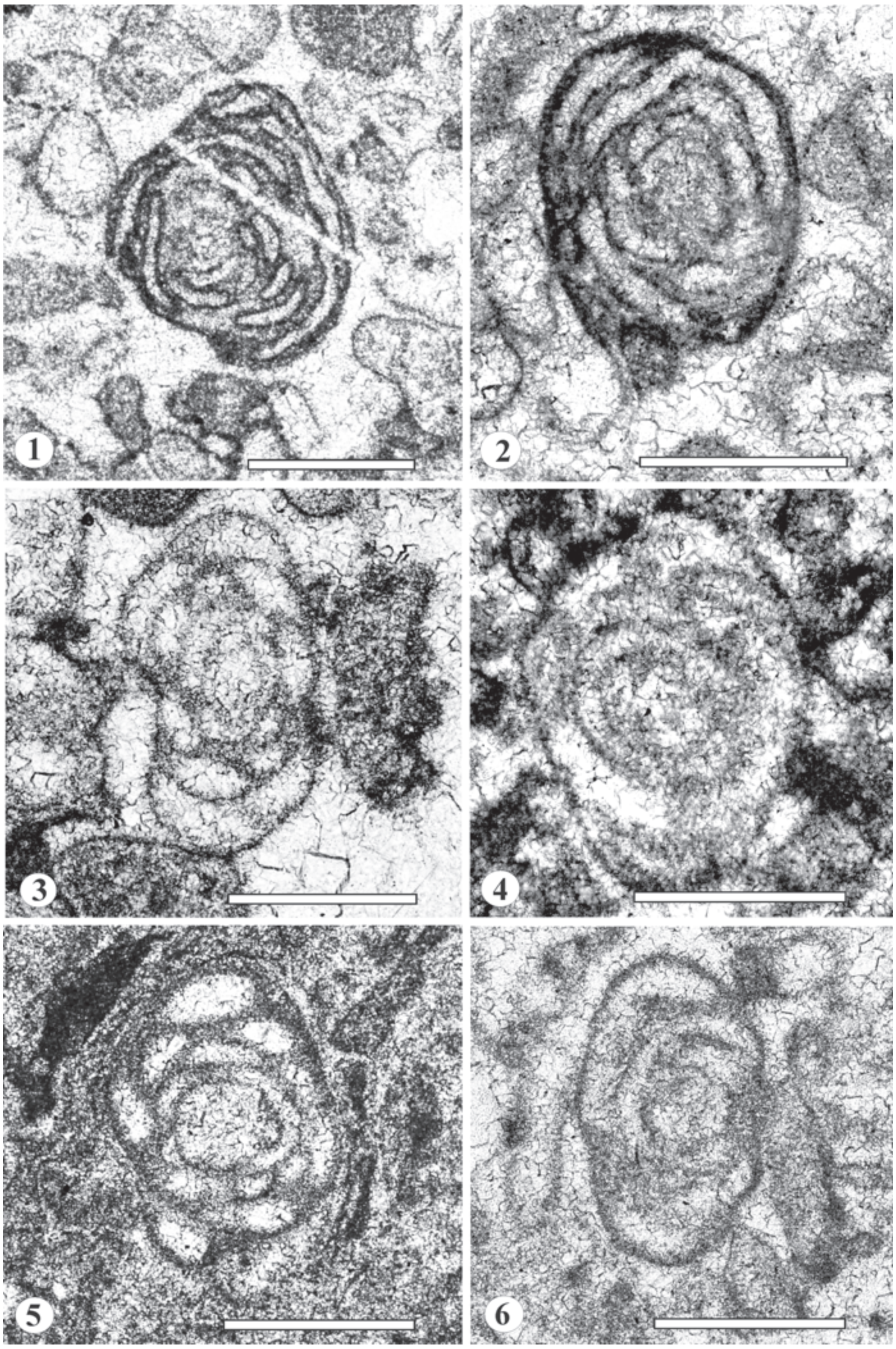

Fig. 8. Foraminiferal microfauna from terminal beds of the Ramsau Dolomite Formation. **1–4** — *Pilamminella kuthani* Salaj, index species of the Carnian foraminiferal biozone. 1–3 — sample bed. 0, section A; 4 — sample bed 2, section A, thin section No. 27290. **5–6** — *Pilamminella* cf. *gemerica* Salaj; 5 — sample bed 0. section A; 6 — sample bed 2, section B. Scale bar 200 μm.

chostracan zone are rather monospecific, different from those found below in the *Xiangxiella bicostata* Zone and above in the *Laxitexella multireticulata* Zone (Kozur & Weems, *l.c.*). Nevertheless, the Late Ladinian conchostracan species of *Euestheria minuta* was still presented in the entire Cordevolian (Kozur & Bachmann 2010).

Ecology and taphonomy: The occurrence and distribution of the conchostracans are limited by conditions and climate (especially temperature, salinity and acidity). Webb (1979), Kozur & Mock (1993) and Shen et al. (2002) mentioned that the ecological tolerance of the spinicaudatan crustaceans in Paleozoic was wider than that known from the recent taxa. According to Kozur & Mock (*l.c.*), the conchostracans are restricted to freshwater to brackish environments with salt concentration of about 10 ‰. They survived in pliohaline environment with limiting salinity of 16.5 ‰. In recent environments of Australia, the conchostracans do not withstand salinity above 5 ‰ (De Decker 1988). The conchostracans proliferated in environments such as ponds mostly as meiobenthic fauna. The chitinous shells of conchostracans are very fragile and very sensitive to transportation. Therefore, the shells are mostly found in sediments (mainly claystones) at the places of their primary deposition in stagnant environments. Conchostracans are one-season animals. Their growthrate and frequency depends on temperature and nutrient availability (see Webb 1979; Frank 1988, etc.). In conchostra-

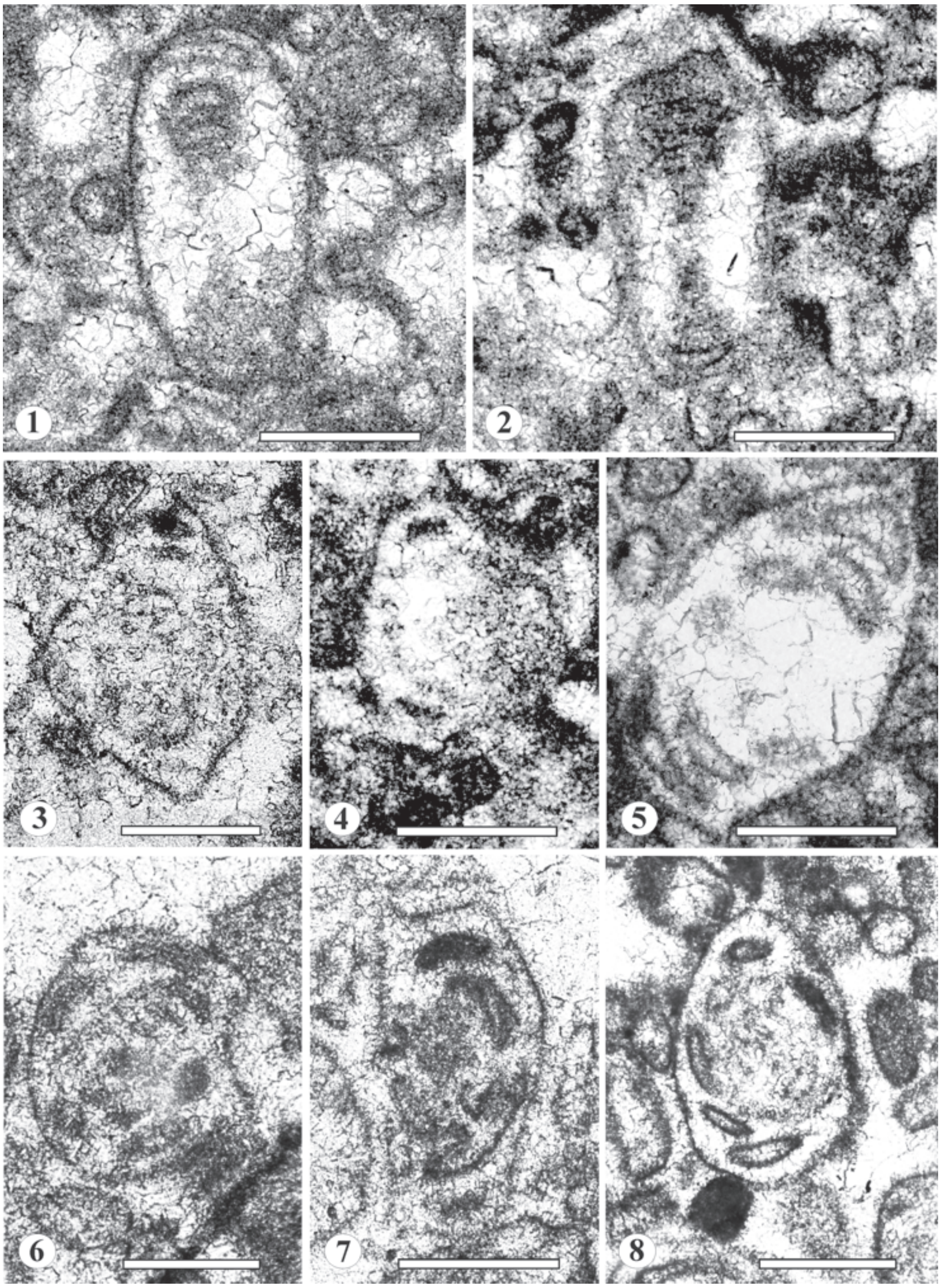

Fig. 9. Foraminiferal microfauna from terminal beds of the Ramsau Dolomite Formation. **1–4** — *Triadodiscus eomesozoicus* (Oberhauser), type species of the Carnian involutinids. 1 — sample bed 2, section B; 2 — sample bed 2, section A, thin section No. 27290; 3 — sample base bed 1b, section A. **5** — *Aulotortus sinuosus* Weynschenk, sample bed 2, section A, thin section No. 27291. **6–8** — *Aulotortus praegaschei* (Koehn-Zaninetti). 6, 7 — sample bed 1, section A, thin section No. 27287b; 8 — sample bed 2, section A, thin section No. 27291. Scale bar 200 μm.

can-bearing bed No. I (section A), the shells of *Euestheria* occur together with valves of *Lingularia*, in which the lingulids dominated. However, the total number of both species is quite low, reflecting relatively unfavourable life conditions during deposition. Therefore we suppose that these fossils represent oryctocoenosis generated by postmortem transport of conchostracans and lingulids in suspension, by low-energy flows over short distances. This flow regime is recorded by fine lamination of fossil-bearing claystones. Similar thanatocoenoses of lingulids and conchostracans are known as in the so-called "Estherienschichten" (= "Estherienschiefer") in the Germanic Keuper, or in "Obererer Muschelkalk" (see Heller 1952; Merki 1961 for summary). They are often reported as *Lingula tenuissima* Bronn and *Euestheria minuta* (Goldfuss). In the latest correlation of the Germanic Triassic with the international scale by Kozur & Bachmann (2005, Fig. 7), the Upper Grabfeld Formation ("Estherienschichten") is assigned to the Cordevolian.

Foraminifers

Material: Foraminiferal microfauna from the limestones in the upper part of the Ramsau Dolomite Formation (Beds 1, 1a, 2, 2a — section A; 2 — section B). See distribution of foraminifers in Table 1.

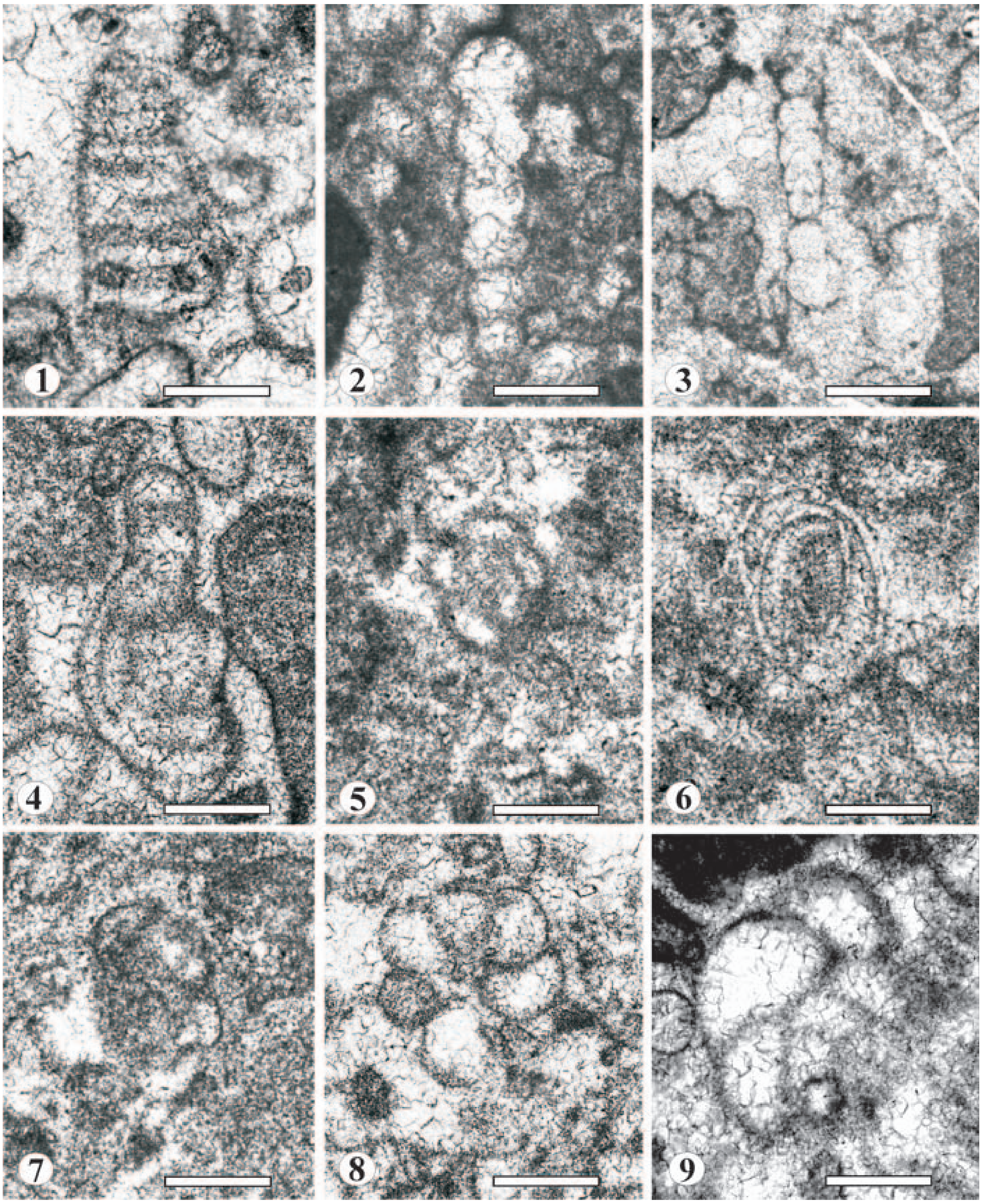

Fig. 10. Foraminiferal microfauna from terminal beds of the Ramsau Dolomite Formation. **1** — *Lamelliconus turris* (Frentzen), sample bed 1, section A, thin section No. 27287b; **2** — *Multiseptida elongata* Salaj, sample bed 2, section A; **3** — *Nodosaria ordinata* Trifonova, sample bed 1, section A, thin section No. 27287b; **4** — *Rectoglomospira* (*Rectopilammina*) *senecta* Trifonova, sample bed 1, section A, thin section No. 27287b; **5** — *Meandrospira* sp., sample bed 1, section A, thin section No. 27287; **6** — *Ophthalmidium exiguum* Koehn-Zaninetti, sample bed 1, section A; **7** — *Endothyra gruenbachensis* Salaj, sample bed 0, section A, thin section No. 27287; **8** — *Oberhauserella mesotriassica* (Oberhauser), sample bed 2, section A; **9** — *Duostomina* cf. *alta* Kristan-Tollmann, sample bed 2, section A, thin section No. 2729. Scale bar 100 μm.

Description: The limestones contain an abundant microfauna of ammodiscid, involutinid and various elongated and multilocular foraminifers. The most typical ammodiscid foraminifers belong to the species *Pilamminella kuthani* Salaj (Fig. 8.1–4), which represents the index species of the Carnian biozone (Salaj 1969; Salaj et al. 1983). Some club-shaped foraminifers are closer to another Carnian species *Pilamminella* cf. *gemerica* Salaj (Fig. 8.5–6) and *Rectopilammina* (*Rectoglomospira*) *senecta* Trifonova. Involutinid foraminifers are more diversified, including the species of *Triadodiscus eomesozoicus* (Oberhauser), *Aulotortus praegaschei* (Koehn-Zaninetti), *Prorakusia salaji* Di Bari & Laghi, *Aulotortus broennimanni* Salaj and *Aulotortus sinuosus* Weynschenk (Fig. 9). Trochospiral involutinids and nodosariids, rich asso-

Table 1: Distribution of foraminifers.

	Bed numbers — Section A											Sec. B
Foraminiferal species	03	0	1 27287a	1 27287b	1	1b base bed	1b middle part of bed	2	2 27403	2a 27290	2b 27289F	2
Microfacial type	W/G	W/P/G	G	G	P/G	P	P	P/G	BM	P/G	P/G	P/G
Pilamminella kuthani	R	C	R	F	F	C	C	R	–	C	C	R
Pilamminella gemerica	–	C	–	R	R	R	–	–	–	R	R	–
Rectopilammina senecta	–	R	–	R	–	–	–	–	–	–	–	–
Triadodiscus eomesozoicus	C	C	R	R	–	R	R	C	R	R	R	F
Aulotortus praegaschei	–	R	C	R	C	C	F	R	–	C	C	R
Aulotortus sinuosus	R	C	F	C	F	R	F	C	R	R	R	R
Aulotortus broennimanni	–	–	C	–	C	R	C	–	–	R	R	R
Lamelliconus turris	R	–	R	–	–	–	C	R	–	–	–	R
Nodosaria ordinata	C	C	R	C	C	R	R	F	F	F	R	F
Multiseptida elongata	R	C	R	F	C	–	–	F	C	C	R	C
Oberhauserella mesotriassica	R	R	–	–	–	–	–	R	–	–	–	–
Duostomina alta	R	R	–	–	–	–	–	R	–	–	–	–
Endothyra gruenbachensis	R	C	–	–	–	–	–	–	–	–	–	–
Meandrospira sp.	–	R	R	R	–	–	R	R	–	–	–	–
Ophthalmidium exiguum	C	–	R	R	R	–	–	R	R	R	C	R
Glomospirella sp.	R	R	C	C	C	C	C	C	R	C	R	C
Aulotortus sp.	C	C	F	C	C	R	C	R	R	C	C	C
Semiinvolutina sp.	R	R	C	–	–	–	R	–	–	–	R	–
Prorakusia sp.	R	R	C	–	R	R	R	R	–	C	C	R

Explanation: R — rare, C — common, F — frequent, W — wackestone, P — packstone, G — grainstone.

ciations of which occur in the Late Ladinian–Carnian limestones, are represented by *Lamelliconus turris* (Frentzen), *Nodosaria ordinata* Trifonova and *Multiseptida elongata* Salaj, Borza & Samuel (Fig. 10). The so-called Triassic "globigeriniids" are represented by the species of *Oberhauserella mesotriassica* (Oberhauser) and *Duostomina* cf. *alta* Kristan-Tollmann. The foraminiferal association is completed by the species of *Endothyra gruenbachensis* Oberhauser, *Abriolina* cf. *mediterranea* Luperto, *Meandrospira* sp., *Ophthalmidium exiguum* Koehn-Zaninetti, etc.

Stratigraphic importance: The association of the listed species allows us to determine the Carnian age of the limestones. This age is indicated by three important species — *Pilamminella kuthani* Salaj, *Triadodiscus eomesozoicus* (Oberhauser) and *Lamelliconus turris* (Frentzen). The association of these species is indicative for the Carnian formations (cf. Ciarapica & Zaninetti 1983, 1984a,b; Peybernes et al. 1991; Fréchengues & Peybernes 1991; Fréchengues et al. 1993; Di Bari & Laghi 1994; Kolar-Jurkovšek et al. 2005, etc.). The Carnian age is also supported by the species *Aulotortus praegaschei* (Koehn-Zaninetti), *Abriolina* cf. *mediterranea* Luperto, *Multiseptida arcata* Salaj, Borza & Samuel, *Rectoglomospira (Rectopilammina) senecta* Trifonova and *Endothyra gruenbachensis* Salaj.

Ecologic implications: Foraminiferal microfauna allows us to propose certain characteristics of the paleoecological conditions. Involutinid genera, like *Triadodiscus*, *Aulotortus*, *Lamelliconus*, etc., belong to the lamellar aragonitic foraminifers, which are characteristic of high-energy and shallow-water conditions. On the contrary, the agglutinated benthic foraminifers, like *Pilamminella*, *Rectoglomospira*, *Meandrospira*, etc., indicate the restricted low-energy environments. The low-energy facies of micritic limestones reveals an abundance of elongated morphotypes like *Nodosaria*, *Pseudonodosaria*, *Frondicularia*, etc., which could indicate dysoxic conditions (cf. Ciarapica et al. 1987; Maurer & Rettori 2002). Under a stress life condition, some nodosariids lost the calcareous hyaline walls, exhibiting a preference for agglutination (*Multiseptida*). These limestones are also enriched in some epiplanktonic forms like the zoospores *Globochaete* and juvenile lamellibranchians ("filaments").

Discussion and conclusions

The Upper Triassic development of the Germanic and North Tethyan shelf basins was significantly influenced by overall siliciclastic input, which suffocated a carbonate factory and led to the so-called "Carnian Crisis" (Hornung et al. 2007a), Reingraben or Raibl Turnover (Schlager & Schöllnberger 1974), Carnian Pluvial Event (Simms & Ruffell 1989), Middle Carnian wet intermezzo (Kozur & Bachmann 2010) and other related events. These Carnian terrigenous inputs reflected climatic warming, increased humidity, monsoonal precipitation, enhanced weathering, extreme seasonality and development of large fluvial systems (Simms & Ruffell 1990; Krystyn 1991; Vissher et al. 1994; Mutti & Wissert 1995; Hornung 2007; Hornung et al. 2007a,b; Roghi et al. 2010; Kozur & Bachmann 2010, etc.). During the Carnian, these Tethys-wide changes resulted in the demise of carbonate platforms, enhanced input of siliciclastics, freshwater influx and brackishing of shallow-marine basins, anoxic conditions, decrease of faunal diversity, biotic extinctions, etc. (later cit.). The Carnian Crisis is documented between the uppermost *Aonoides* Zone and uppermost *Austriacum* Zone, which correspond to its duration between Julian 1/IIc and Julian 2/II (Hornung & Brandner 2005; Hornung et al. 2007b). Subsequent deposition of the Lunz Beds (*s.s.*) took place during Julian 2/IIa–2IIb, estimated at about 1 Myr duration. As the same time as in the Northern Calcareous Alps, the Carnian Crisis is also recorded in the Western Carpathians. Nevertheless, the decreased rate of terrigenous input in the Western Carpathians implies their more distant position from clastic sources than the Northern Calcareous Alps.

Sedimentary changes in the Upper Triassic carbonate platform of the Western Carpathians are manifested mainly from the Carnian (Maheľ et al. 1968; Andrusov & Samuel (Eds.) 1985). Manifestations of the most conspicuous changes are known from the Hronic and Silicic Zones (Choč Unit, Jablonica Unit), where the Carnian siliciclastic inputs are recorded by the Reingraben Shales and Lunz Beds. Their thick formation was described, for example, from the Dobrá Voda DV-1 and Kuklov 3 boreholes (Michalík et al. 1992; Masaryk & Lintnerová 1997), where the black shales with halobiids are equivalent to the Reingraben (= Halobia) Shales, and to the Lower Carnian event in full-marine environment and sabkha-type environment (Opponitz Formation). An enhanced input of siliciclastics is also recorded in the intraplatform basins of the Hronic Zone, where the Reifling limestones were replaced by the Aonian Beds (Svarín Beds) and higher by the thick sequence of the Lunz Beds (Marschalko & Pulec 1967; Michalík 1988; Masaryk et al. 1993; Havrila 1993). These changes, which correspond to the Julian, were dated by the occurrence of *Trachyceras aonoides* Mojsisovics, *Monophyllites simoyi* Hauer, *Carnites floridus* (Wulfen) and others ammonoids from the transition beds between the Reifling Limestones and Lunz Beds (Andrusov et al. 1973; Bystrický in Andrusov & Samuel 1985). Palynological study provided the Carnian spore-pollen patterns of the Lunz Beds (Planderová 1972). The Lunz Beds also occur in the Fatric Zone, where they are developed as a thinner formation with sandstone-dominated facies. The thickness of the Lunz Beds with "Aon Schiefer" in the NCA is about 500 m (Behrens 1972) and in the Choč Unit about 300 m (Marschalko & Pulec 1967). Their thickness in the Krížna Unit is reduced perhaps to 50–80 m, and in the Malá Fatra Mts about 10 m. In the Tatricum, the Carnian siliciclastic sediments are infrequent, known up to now only from the Veľká Fatra Mts, from where Planderová & Polák (1976) described the dark grey shales and marly claystones with abundant pollen/spore assemblages.

The Tržinovo Formation newly described from the Malá Fatra Mts also represents the siliciclastic systems of the Fatric basin, but those from shallow-lagoonal up to not fully marine environments. The presence of pliohaline and euryhaline fauna like conchostracans and lingulids point to brackish water environments of the Tržinovo Formation. The claystone sediments of this formation could be deposited from mud suspensions overspilled from submarine channels filled by the coarser terrigenous sediments of the Lunz Beds. The Flood basins of the Tržinovo Formation were rather shallow intraplatform depressions with restricted extent (1.5 km between two border sections A–B). Similar flood basins with siliciclastics within the shalow-marine platform environments were formed during the Carnian Pluvial Event also in the Dolomites (Breda et al. 2009). Like the Carnian terrestrial systems of Europe, these inundation basins were flooded in monsoonal episodes, and than abandoned as pools with standing water and colonized by *Euestheria* (cf. Simms & Ruffell 1990). Therefore, in less humid phases the terrigenous claystone deposition was suppressed, which led to the recovery of full-marine conditions and precipitation of carbonates. Alteration of such conditions during the Carnian Pluvial Episode is recorded by the mixed siliciclastic-carbonatic sequence of the Tržinovo Formation, and related similar sediments of the Krížna Units (e.g. dolomitic claystones with *Costatoria* cf. *goldfussi* in the Ružbachy Horst, Eastern Slovakia — Kullmanová & Nemčok 1985).

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