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LOWER CRETACEOUS SECTION OF THE TERNBERG NAPPE (NORTHERN CALCAREOUS ALPS, UPPER AUSTRIA): FACIES-CHANGES, BIOSTRATIGRAPHY AND PALEOECOLOGY

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Abstract: Lithological, sedimentological and paleoecological studies of the Lower Cretaceous (KB1-A section, Ternberg Nappe, Northern Calcareous Alps, Upper Austria) uncovered rich spectra of Early Berriasian to Late Valanginian macro- and microfaunal elements in addition to microfloral members. The evaluation of the thin sections indicates a change from a calpionellid facies to an echinoid facies within the Steinmühl Formation whereas the Schrambach Formation consists of mudstones with rare microfossils. Several compositional changes in calcareous dinoflagellate and calpionellid assemblages (bio-events) are detected at the Austrian KB1-A section. They correspond to eustatic sea-level fluctuations observed in Lower Cretaceous sections of the Western Carpathians and correlate with the Nozdrovice Breccia (Nozdrovice Event) at the end of the Late Berriasian (*Calpionellopsis* Zone) and with the Oravice Turbidite Event at the Early Valanginian (*Calpionellites* Zone). The surface of the topmost bed of the Steinmühl Formation (latest Early Valanginian) is characterized by an accumulation of pygopids, partly eroded ammonoids with crinoidal epifaunas, and belemnites with *Acrothoracica* burrows. Additionally, a probably small biostratigraphic gap in the calpionellid subzonation between the Steinmühl- and the Schrambach Formations show a sedimentation stop (omission) during the pygopid accumulation.

Key words: Early Cretaceous, Austria, Ternberg Nappe, paleoenvironment, sea-level fluctuations, microfossils, ammonoids.

Introduction

As noted by many authors (Vašíček & Michalík 1999; Stampfli & Mosar 1999), the area investigated (Ternberg Nappe, Northern Calcareous Alps) was situated on the eastern border of the Alpine-Carpathian block during the Early Cretaceous. This was located between the Penninic Ocean (Alpine Tethys) in the North and the Vardar Ocean (Meliata Ocean) in the South-East.

Lower Cretaceous pelagic sediments are well known to form a major element of the northernmost tectonic units of the Northern Calcareous Alps (e.g. Ternberg, Reichraming, Frankenfels, and Lunz Nappes). In the Ternberg Nappe of the Northern Calcareous Alps, Lower Cretaceous cephalopod-bearing deposits are recorded in four different facies, the Steinmühl, the Schrambach, the Tannheim and the Losenstein Formations.

A general overview of the Austrian Lower Cretaceous sediments (Northern Calcareous Alps) and its ammonoid fauna was given by Immel (1987). The most recent publications (Faupl et al. 1994; Reháková et al. 1996; Vašíček et al. 1999) deal with the microfacial analysis and biostratigraphy of the Lower Cretaceous synclines in the Reichraming, Frankenfels and Lunz Nappes. The Lower Cretaceous of the Lunz Nappe was investigated, and the Kaltenleutgeben section described by Richarz (1905) and Schwinghammer (1975).

During the last decade, a rich fauna of cephalopds was collected from Lower Cretaceous sediments from the Reichraming Nappe, situated to the south of the presented section (Vašíček & Faupl 1996; Vašíček & Faupl 1998, 1999; Vašíček et al. 1999).

Publications dealing with different fossil-groups (e.g. ammonoids, belemnites, *Rhynchoteuthis*, *Pygope*, *Acrothoracica*, calpionellids) of the presented section and the sourounding area were done by Lukeneder (1997, 1998, 1999, 2000, 2001, 2002), Lukeneder & Harzhauser (2002) and Lukeneder & Tanabe (2002).

Locality and geological setting

The investigated Lower Cretaceous section KB1-A (Klausriegler-Bach 1; Fig. 1) is situated near the Enns River, approximately 1 km southwest, in the Ternberg Nappe (N 47°54'32'', E 14°21'10''). This region is part of the northernmost Northern Calcareous Alps. The Losenstein Syncline is situated in the southernmost part of the Ternberg Nappe (Fig. 1). This syncline is the last syncline to the north filled by Lower Cretaceous sediments. The investigated fossiliferous section is located on the left, nearly vertical (dipping 040/85), step-like wall of the gorge, exposed on a length of 10 m and a height of 5 m.

At the area around Ternberg, the Lower Cretaceous sequence is presented by two different formations from bottom to top (Fig. 2):

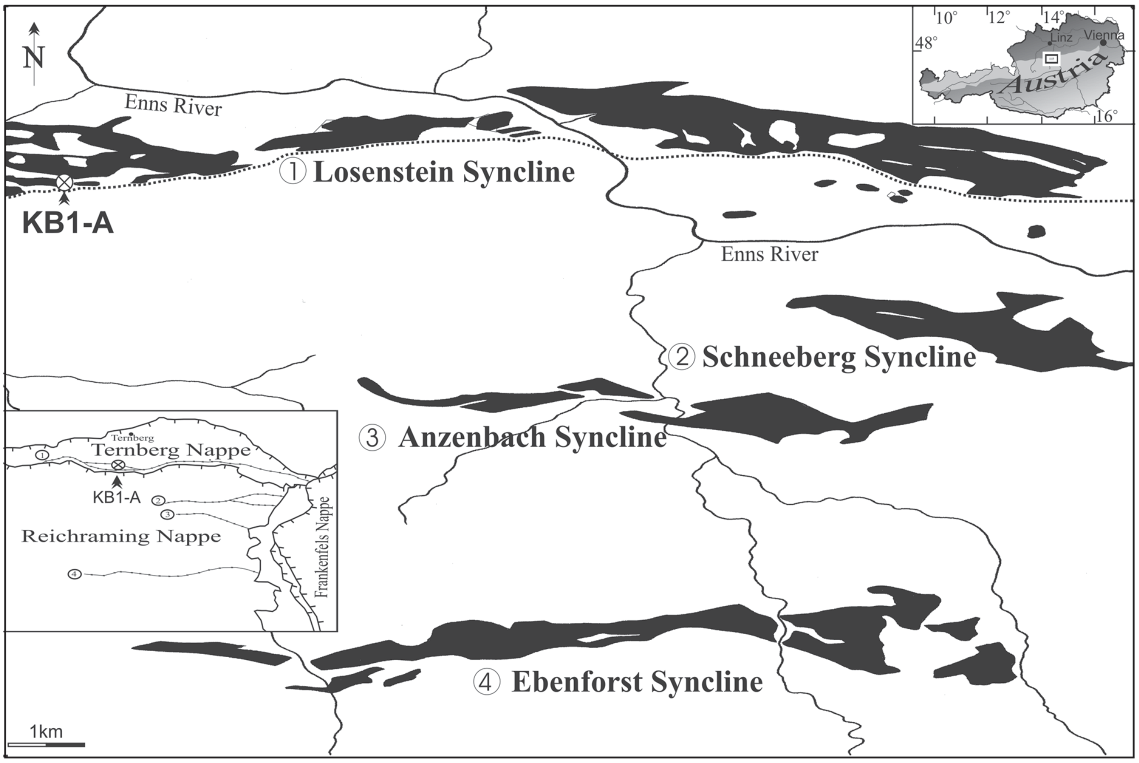

Fig. 1. Position of the section investigated, KB1-A along a stream outcrop. Inset map shows the geological setting and the geographical position of the study area. Indicating (on left margin) the synclines of the area: **1** — Losenstein Syncline, **2** — Schneeberg Syncline, **3** — Anzenbach Syncline, **4** — Ebenforst Syncline. (Black — Early Cretaceous sediments; dotted line — boundary between Ternberg and Reichraming Nappes.)

Steinmühl Formation (approx. 15 m): Early Berriasian to late Early Valanginian in age, its lower part consisting of red ("Ammonitico rosso" type) and its upper part of grey ("Maiolica" type) condensed pelagic limestones with a few ammonoids, but abundant calpionellids and calcareous dinoflagellates enabling precise biostratigraphic correlations. The brachiopod *Pygope cattuloi* is abundant in the topmost bed (Lukeneder 2002).

Schrambach Formation (approx. 150 m): Late Valanginian to Late Barremian in age, consisting of pale grey, even bedded limestones intercalated with grey to black calcareous marlstones (laminated "black shales"), and marls. The beds are intensively bioturbated, and the trace fossils *Zoophycos*, *Chondrites* and *Planolites* occur throughout (Lukeneder 2001).

The wavy boundary between the Steinmühl and the Schrambach Formation is marked by a primary hardground characterized by fragmented, encrusted, and partly eroded ammonoids and several bored cephalopods (e.g. belemnites; Lukeneder 1999).

The evolution of marine biota on the southern European shelf was influenced by continuing disintegration of carbonate platforms during the Early Cretaceous. Their pelagic influence also became more pronounced in former reef and shallow areas. The morphological highs (elevations) in the pelagic environments were characterized by condensed sedimentation of the "Ammonitico rosso" facies (Cecca et al. 1993, 1994).

Only elevated, firmer parts of the bottom were typically inhabited by benthic micro-organisms at that time. Reorganization of the Mediterranean Tethys paleogeography correlated with a change in current patterns resulted in a new Berriasian-Valanginian "bloom" in plankton development (Vašíček et al. 1983; Michalík & Vašíček 1989). Nannoconid biomicrites prevailed both in the hemipelagic and pelagic environments over the extensive sea floor, formerly (during the Late Jurassic) characterized by diversified sedimentation. Pelagic marine environments were characterized by a uniformly soft unconsolidated muddy bottom. Nannoconids persisted in dominance during the Valanginian and Hauterivian, while the calpionellid share in the microplankton association decreased (Reháková 2000b).

Material and methods

The lithological composition and biofacies were analysed in thin sections from level 15m to 31 (50 samples; see Figs. 2 and 3). Washed residues were obtained from limestones and marls by dissolution using formic acid and acetic acid, and later washing with desogen and sieves of 500 μm to 63 μm mesh. In some cases, ultrasonic treatment was necessary to clean aggregated or encrusted specimens.

The total sulphur content (wt. %) of samples from the KB1-A section was analysed using X-ray fluorescence and wet methods. Calcium carbonate content ($CaCO_3$) was determined using the carbonate bomb technique. Total carbon content was determined using a LECO WR-12 analyser. Total organic car-

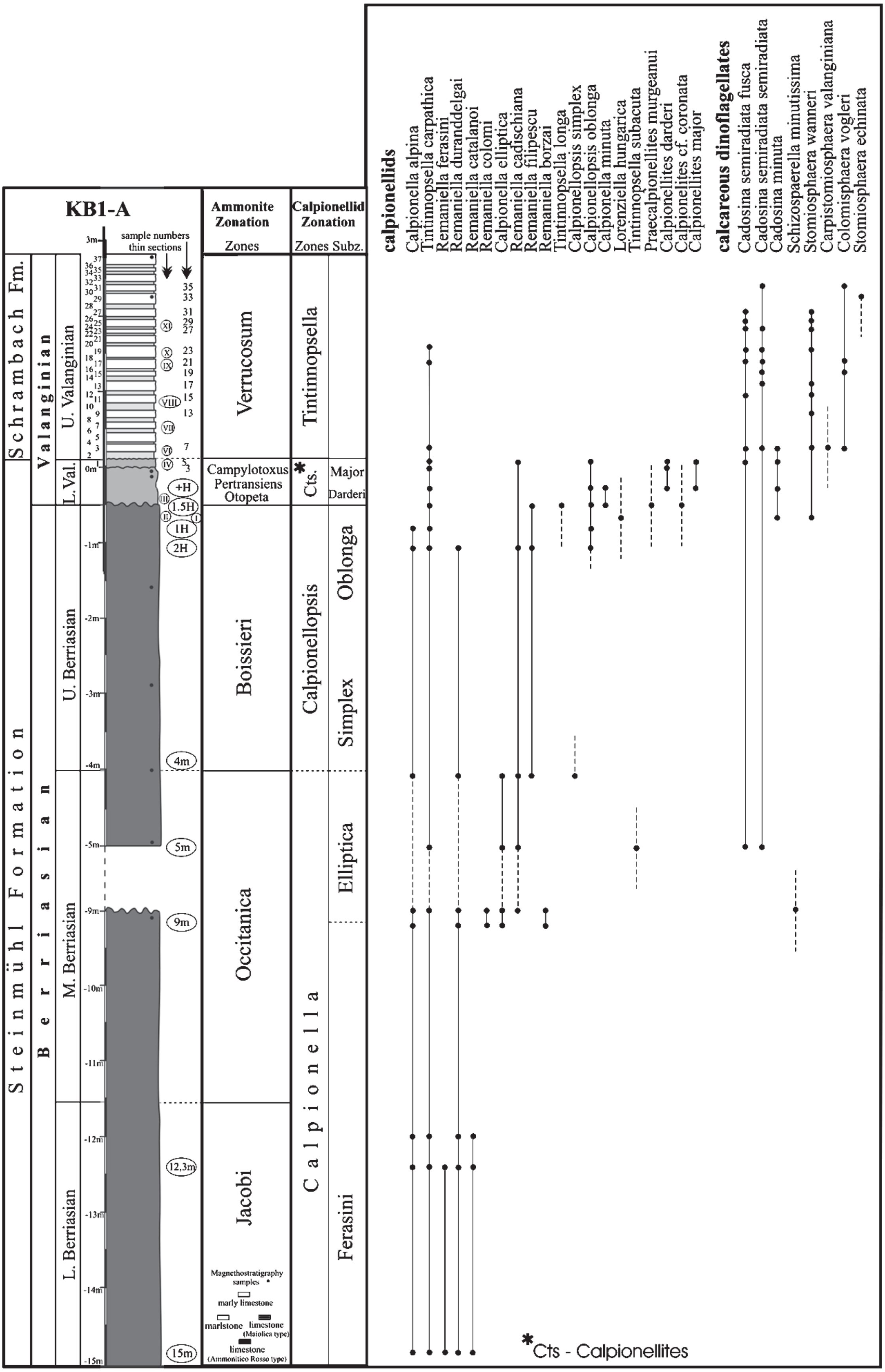

Fig. 2. Stratigraphic distribution of calpionellids and calcareous dinoflagellates and their correlation with the ammonoid zonation of the KB1-A section.

bon (TOC) content was calculated as the difference between total carbon and carbonate carbon, assuming that all carbonate is pure calcite. All the chemical analyses were carried out in the laboratory of the Institute of Forest Ecology at the University of Vienna.

The material (Figs. 2, 4–5) originates from the Upper Austrian Lower Cretaceous section KB1-A.

Conventions: NHMW Museum of Natural History Vienna. DPV Department of Paleontology Vienna. The authors follow the classification of the Cretaceous Ammonoidea by Wright et al. (1996). All specimens are stored at the Museum of Natural History Vienna.

Ammonoids represent almost the totality of the macrofauna (94 %). The ammonoids are poorly preserved and appear as steinkerns without shell.

The ammonoid fauna from the Berriasian (red limestone) of the Steinmühl Formation comprises in most cases material from rock samples because of the very steep terrain. 46 ammonoid specimens were observed.

The Lower Valanginian macrofauna consists of ammonoids and comprises lytoceratids and phylloceratids, which are accompanied by brachiopods (e.g. pygopids). 21 ammonoids from the Early Valanginian (uppermost meter of the Steinmühl Formation) were collected.

The very abundant but generally poorly preserved Late Valanginian assemblages consist of 9 genera: *Phylloceras*, *Lytoceras, Leptotetragonites*, *Protetragonites*, *Olcostephanus*, *Neocomites*, *Neohoploceras*, *Rodighieroites*, *Bochianites*. About 250 ammonoids (mainly *Olcostephanus guebhardi*) between 10 and 102 mm in diameter were collected and investigated.

Results

Lithology

The calcium carbonate contents ($CaCO_3$ equivalents calculated from total inorganic carbon) vary from 54 to 88 % within the Schrambach Formation (bed 2 to 37) and from 88 to 96 % within the Steinmühl Formation (beds 15m to 1) (Fig. 3). As expected, the carbonate content decreased from the lowermost Schrambach Formation upwards. Samples for geochemical analysis were taken at the important facies changes. The weight % TOC values vary between 0.2 and 7.3 % within the Schrambach Formation and between 0.1 % and 10.2 % within the Steinmühl Formation. The total sulphur content shows a positive correlation to the TOC values. The

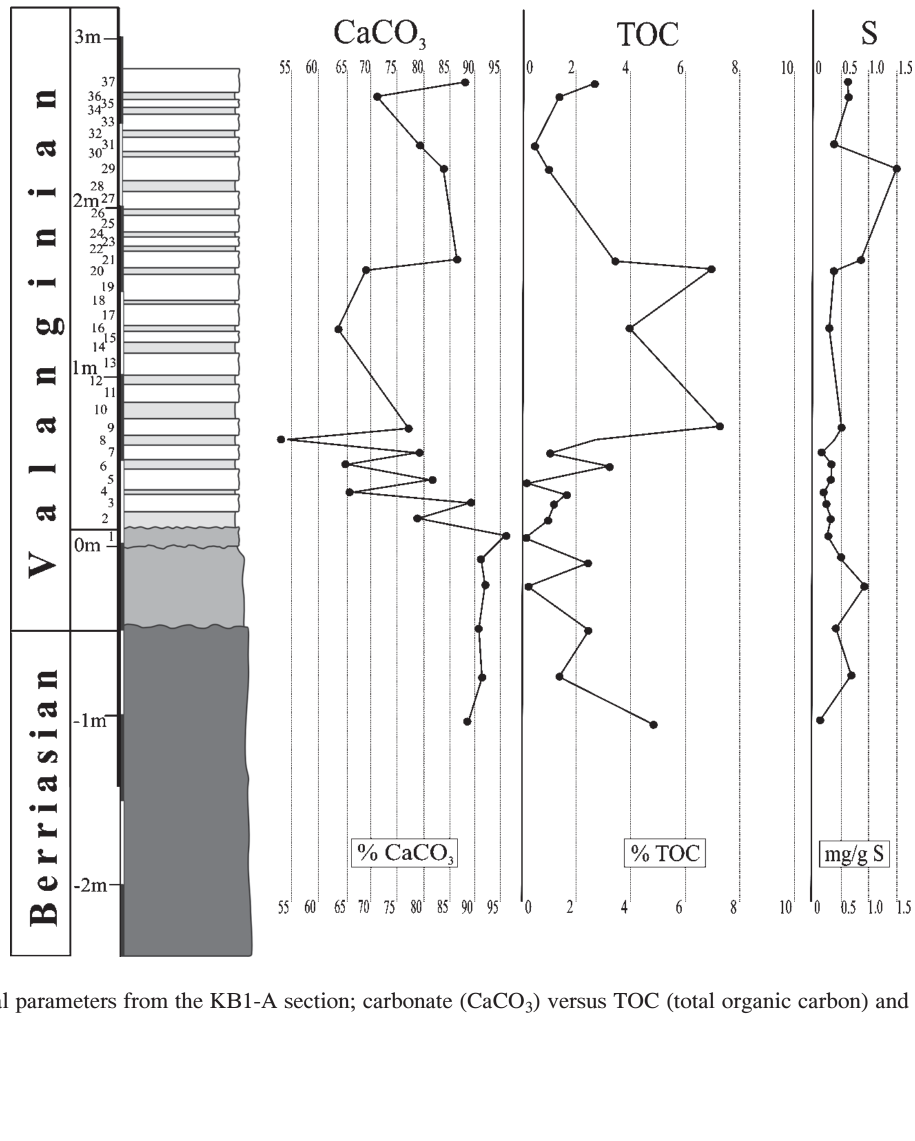

Fig. 3. Geochemical parameters from the KB1-A section; carbonate ($CaCO_3$) versus TOC (total organic carbon) and S (sulphur).

Fig. 4. Typical Leiostraca (e.g. Lytoceratina and Phylloceratina) and Trychyostraca (e.g. Ammonitina and Ancyloceratina) from the Steinmühl Formation (Early Berriasian–Early Valanginian) and the Schrambach Formation (Late Valanginian). White arrows indicate last sutureline. **1** — *Lytoceras* sp., Steimühl Formation, "Ammonitico rosso" type, 2002z0043/0005. **2** — *Phylloceras* sp., Steinmühl Formation, "Ammonitico rosso" type, 2002z0043/0001. **3** — Perisphinctid (indet.), Steinmühl Formation, "Ammonitico rosso" type, 2002z0043/0007. **4** — *Phylloceras* sp., Steinmühl Formation, "Maiolica" type, bed 1, 2002z0043/0002. **5** — *Lytoceras* sp., Steinmühl Formation, 'Maiolica' type, bed 1, 2002z0043/0006. **6** — *Phylloceras thetys* (d'Orbigny), Schrambach Formation, bed 4, 2002z0043/0003. **7** — *Lytoceras* sp., Schrambach Formation, bed 7, 2002z0043/0004. **8** — *Neocomites (Neocomites) teschenensis* (Uhlig), Schrambach Formation, bed 16, 2002z0043/0008. **9** — *Olcostephanus guebhardi* (Kilian) morph. type *querolensis* Bulot, Schrambach Formation, bed 10, 2002z0043/0009. **10** — *Leptotetragonites honnoratianus* (d'Orbigny), Schrambach Formation, bed 4, 2002z0043/0010. Scale bar: figures 1–2, 4, 7 = 4 cm; figures 3, 5, 9, 10 = 2 cm; figure 6 = 1 cm.

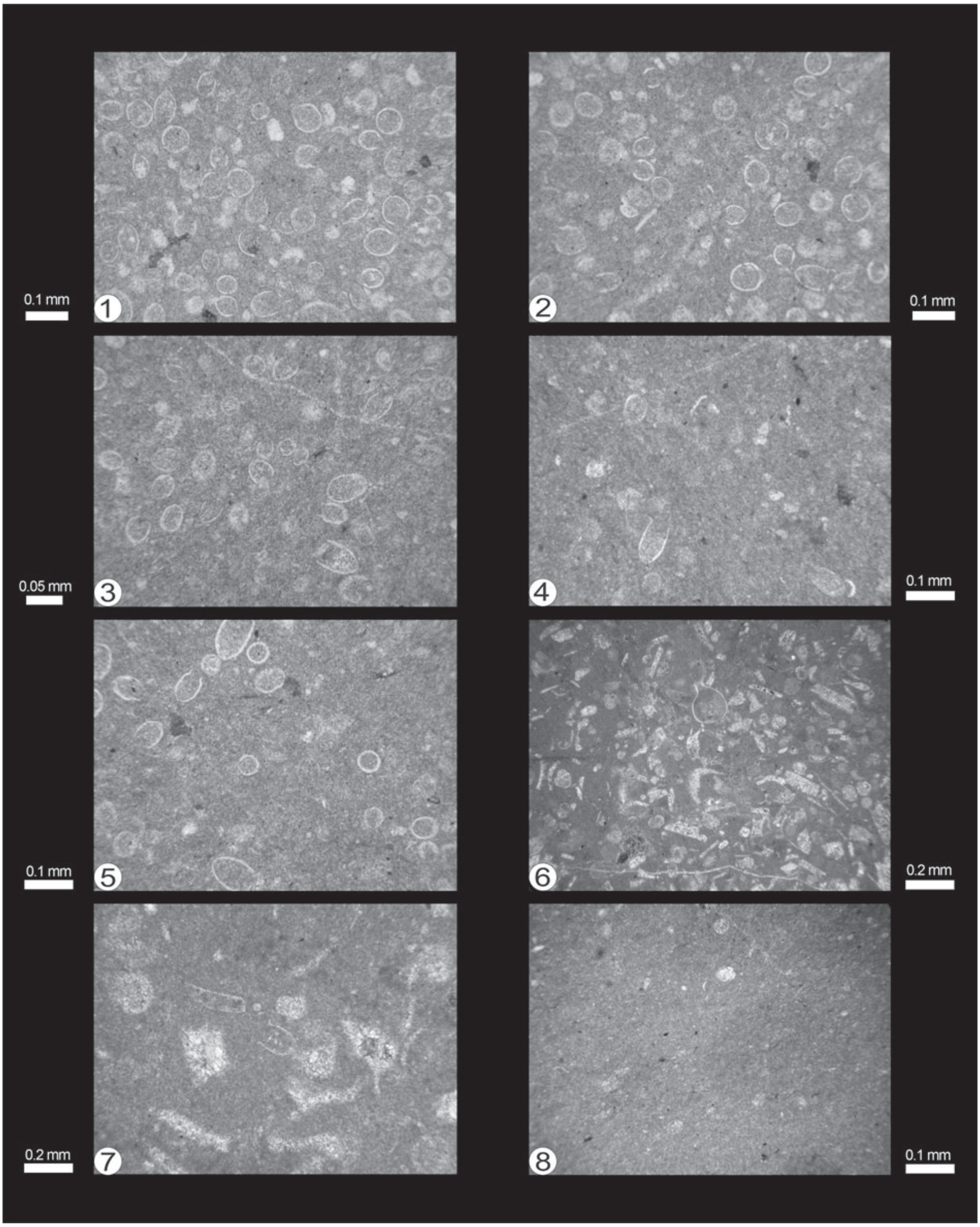

Fig. 5. Microfacies of the Steinmühl Formation (Early Berriasian–Early Valanginian) and the Schrambach Formation (Late Valanginian). **1** — Calpionellid wackestone to packstone, *Calpionella alpina* Lorenz is dominated in calpionellid association of the *ferasini* Subzone (latest Early Berriasian). Sample No. 15, 2002z0043/0011. **2** — *Remaniella duranddelgai* Pop in calpionellid wackestone of the *ferasini* Subzone. Sample No. 15, 2002z0043/0012. **3** — *Remaniella borzai* Pop, *Calpionella alpina* Lorenz, *Calpionella elliptica* Cadisch and *Schizosphaerella minutissima* (Colom) in calpionellid wackestone of the *elliptica* Subzone (latest Middle Berriasian). Sample No. 9, 2002z0043/0013. **4** — *Tintinnopsella longa* (Colom) and *Calpionella elliptica* Cadisch (right corner) in the calpionellid mudstone from the topmost part of the *elliptica* Subzone of the *Calpionella* Zone. Sample 5A, 2002z0043/0014. **5** — Calpionellid association of the Late Berriasian *Calpionellopsis* Zone (the index species *Calpionellopsis simplex* (Colom) is out of the picture). Sample 4, 2002z0043/0015. **6** — Bioclastic packstone rich in echinoderms, bivalves, benthic lenticulinids, ostracods. Planktonic foraminifers and calpionellids of the Early Valanginian *Calpionellites* Zone is less abundant. Sample 3, 2002z0043/0016. **7** — *Tintinnopsella carpathica* (Murgeanu et Filipescu) in bioclastic limestone. Sample 3, 2002z0043/0017. **8** — Nannoconid mudstone of the *Tintinnopsella* Zone (Late Valanginian) with sporadic small fragments of crinoids, aptychi and ostracods. Sample 13, 2002z0043/0018.

maximum amount of 1.5 mg/g sulphur corresponds to a marl bed (bed 30) within the Schrambach Formation, whereas the sulphur values within the Steinmühl Formation vary between 0.1 and 1.0 mg/g sulphur.

Microfossils and microfacial analysis

The evaluation of the thin sections indicates a change from a calpionellid facies (15m to 2H, calpionellid wackestones) to an echinoid facies (1.5H to 3, bioclactic wackestones). The Schrambach Formation (samples 7 to 35) consists of mudstones with rare microfossils (e.g. echinids and foraminifers). The data concerning microfossil fauna of the investigated outcrop was also published by Lukeneder (1997, 2000). For sample numbers see Fig. 2.

Calpionellid wackestones (samples 15; 12.3; 12) contain the fragments of echinoderms, ostracods, aptychi, foraminifers (*Lenticulina* sp., *Spirillina* sp.) and also calpionellids dominated by spherical forms of *Calpionella alpina* Lorenz over *Tintinnopsella carpathica* (Murgeanu et Filipescu), *Remaniella ferasini* (Catalano), *Remaniella duranddelgai* Pop, *Remaniella catalanoi* Pop. The rock is locally rich in stylolites. Stylolite solution zones are filled by iron minerals.

Overlying interval (samples from 9.2; 9A; 9B; 6.5; 5A; 5B) consists of calpionellid, radiolarian-calpionellid wackestones rarely also biopelloidal or pelloidal wackestone containing calpionellids: *Remaniella colomi* (Colom), *Remaniella duranddelgai* Pop, *Remaniella borzai* Pop, *Remaniella cadischiana* Pop, *Remaniella filipescui* Pop, *Tintinnopsella carpathica* (Murgeanu et Filipescu), *Tintinnopsella longa* (Colom), *Tintinnopsella subacuta* (Colom), *Calpionella alpina* Lorenz, *Calpionella elliptica* Cadisch, calcareous dinoflagellates: *Schizosphaerella minutissima* (Colom), *Cadosina semiradiata fusca* (Wanner), *Cadosina semiradiata semiradiata* Wanner, and also rhynchoteuthid fragment, crinoids, ostracods, aptychi, and *Lenticulina* sp. Locally, matrix contains lenses and nests enriched in biodetritus (bioturbation or slight transport).

The calpionellid wackestone of sample 4 shows *Calpionellopsis simplex* (Colom), *Tintinnopsella carpathica* (Murgeanu et Filipescu), *Remaniella cadischiana* Pop, *Remaniella duranddelgai* Pop, *Remaniella filipescui* Pop, *Calpionella alpina* Lorenz and *Calpionella elliptica* Cadisch.

The overlying intervals (samples + 1H; 1.5H + 5; + 1.5H) also contain *Calpionellopsis oblonga* (Cadisch), index marker of the *Calpionellopsis* Zone, the *oblonga* Subzone. Calpionellid and pelloidal bioclastic wackestones comprise calcified radiolarians, ostracods, echinoderms, cephalopod shells, foraminiferal fragments (*Lenticulina* sp., *Dentalina* sp., *Patellina* sp., *Glomospirella* sp.), calpionellids — *Remaniella cadischiana* Pop, *Remaniella filipescui* Pop, *Calpionellopsis oblonga* (Cadisch), *Tintinnopsella carpathica* (Murgeanu et Filipescu), *Tintinnopsella longa* (Colom), *Calpionella alpina* Lorenz, *Calpionella minuta* Houša, *Lorenziella hungarica* Knauer. The matrix is rich in pyrite. Pelloidal bioclastic wackestone bears the marks of geopetal sediment infillings. Geopetal filled bivalve shale also contains calcite pseudomorphs after gypsum or anhydrite, plus rare glauconite. The interval studied can be correlated with the Nozdrovice Event sensu Reháková (2000b). Its age is early Late and Late Berriasian.

Strata H — green A; + H — green B; 3; are represent by bioclastic limestones (grainstones) with huge amounts of crinoid, bivalve, brachiopod, aptychi fragments, benthic foraminifers (*Lenticulina* sp., *Dentalina* sp., *Textularia* sp., *Ophtalmidium* sp., *Gaudryina* sp.), planktonic foraminifers (*Favusella hoterivica* (Subbotina), *Conoglobuligerina gulekhensis* (Gorbachik et Poroshina)), fragments of calcareous algae — *Pseudocymopolia jurassica* (Dragastan), rare sections of *Praecalpionellites murgeanui* Pop, *Calpionellites darderi* (Colom), *Calpionellites major* (Colom), *Calpionellites* cf. *coronata*, *Tintinnopsella longa* (Colom), common *Calpionellopsis oblonga* (Cadisch), *Tintinnopsella carpathica* (Murgeanu et Filipescu), *Calpionella minuta* Houša, *Cadosina minuta* Borza. Organic fragments are often penetrated by pyrite, rare grains of spinel were identified in matrix.

There are several investigations proving erosion of stratigraphicaly older strata. The matrix inside brachiopod shells contains calpionellids of the *oblonga*, *darderi* and *major* Subzones of the standard *Calpionellopsis* and *Calpionellites* Zones. This interval resembles the Early Valanginian Oravice Turbidite Event (Reháková 2000b).

Predominantly marly limestone strata of the Schrambach Formation (sample 7–35) consist of locally bioturbated echinoderm wackestone to mudstone containing crinoids, bryozoans, globochaetes, ostracods, juvenile aptychi, fragments of rhyncholites, algae fragments, calcareous dinoflagellates: *Cadosina semiradiata semiradiata* Wanner, *Cadosina semiradiata fusca* Wanner, *Colomisphaera vogleri* (Borza), *Stomiosphaera wanneri* Borza, *Stomiosphaera echinata* Nowak, *Carpistomiosphaera valanginiana* Borza, foraminiferal fragments — *Reophax* sp., *Dentalina* sp., *Ophtalmidium* sp., *Ammobaculites* sp., *Bolivinopsis* sp., *Lenticulina* (*Lenticulina*) *espitalei* Dieni et Massari, *Lenticulina* sp., *Spirillina italica* Dieni et Massari, *Spirillina* sp., *Patellina* sp.; hardly determined calpionellid sections dominated by *Tintinnopsella carpathica* (Murgeanu et Filipescu). In several layers, bio-fragments decrease in abundance, mudstone intervals are rich in nannoplankton. Thin siliclastics layers/or lenses occur in the section; sporadically also grains of spinels, glauconite and authigenic pyrite are visible in the matrix. Locally, matrix is penetrated by multiple fractures (filled by spary calcite).

Macrofauna

The Lower Cretaceous KB1-A section shows percentages of pelagic Lytoceratina and Phylloceratina (= Leiostraca; smooth-shelled ammonoids) reaching approximately 35 % in the lower "Ammonitico rosso" type limestone part of the Steinmühl Formation, and up to 80 % in the upper "Maiolica" type part, whereas they reach an average of 5–10 %, respectively, in the overlying Schrambach Formation.

The ammonoid fauna from the red limestone of the Steinmühl Formation comprises in most cases material from rock samples because of the very steep terrain. The bad preservation of the ammonoids hinders identification to species level. The following ammonoids were observed: *Phylloceras* sp., *Lytoceras* sp., ?*Oppelia* sp., and numerous perisphinctids. In most of the phylloceratids and lytoceratids, body chambers are missing. They reach a maximum size of about 30 centimeters (in lytoceratids and phylloceratids; see Fig. 4). Several specimens of *Lamellaptychus* and pygopids complete the macrofaunal assemblage.

The overlying "Maiolica" complex comprises a diverse macrofauna with ammonoids, belemnites, echinoids, and brachiopods. The uppermost meter of the Steinmühl Formation is of decimeter bedded grey Maiolica-like limestone and contains the following ammonoids (see Fig. 4): *Phylloceras* sp., *Lytoceras* sp., and *Leptotetragonites* sp. The maximum size of the cephalopods reaches approx. 10 centimeters. The specimens often show encrustation (e.g. crinoids) and borings (e.g. *Acrothoracica*; Lukeneder 1999). In few cases only body chambers are preserved. Lukeneder (2002) reported a characteristic faunal element of this uppermost layer on a comparable small square of about 30 cm^2, formed by the abundant double-valved brachiopod *Pygope catulloi* Pictet (7 specimens).

The lowermost 3 m of the Schrambach Formation yielded an extraordinarily rich and diverse invertebrate fauna consisting mainly of ammonoids, aptychi and belemnites. The ammonoids are often badly preserved, occurring as crushed internal moulds affected by bioturbation. Sexual dimorphism is observed in *Olcostephanus* (Lukeneder 2004). Many of the investigated specimens show fragmentation. Juvenile stages and the ventral area can be observed in just a few specimens. No suture lines are visible on the steinkerns. The abundant cephalopods are: *Phylloceras tethys* (d'Orbigny), *Phylloceras* sp., *Lytoceras subfimbriatum* (d'Orbigny), *Lytoceras* sp., *Leptotetragonites honnoratianus* (d'Orbigny), *Protetragonites quadrisulcatus* (d'Orbigny), *Olcostephanus (Olcostephanus) guebhardi* (Kilian) morph. type *querolensis* Bulot, *Neocomites (Neocomites) teschenensis* (Uhlig), *Neocomites (Neocomites)* cf. *neocomiensis* (d'Orbigny), *Neocomites (Teschenites)* cf. *neocomiensiformis* (Uhlig), *Bochianites neocomiensis* (d'Orbigny), *Neohoploceras* sp., *Rodighieroites* sp., *Pseudobelus bipartitus* (Blainville), *Lamellaptychus* cf. *retroflexus* (Trauth), *Lamellaptychus* cf. *symphysocostatus* (Trauth).

Additionally, ophiurids, echinoids, phyllocrinids, bryozoans, brachiopods (*Pygope catulloi* Pictet), ostracods, serpulids, and bivalves (inoceramids) occur. The fauna was described by Lukeneder & Harzhauser (2002). Moreover, rare vertebrate remains such as unidentified fish debris, scales, teeth and 1 shark tooth of *Sphenodus* sp. are recorded. Amongst the trace fossils, *Chondrites* and *Zoophycos* are the most abundant.

Biostratigraphy

The stratigraphy of the sequence studied was supported by the scale of calpionellid and calcareous dinoflagellate distribution (Reháková & Michalík 1997; Reháková 2000a) as well as by the ammonoid zonation scale proposed by Hoedemaeker & Rawson (2000). Calpionellids and calcareous dinoflagellates indicate Early Berriasian to Late Berriasian age (based on the standard *Calpionella* and *Calpionellopsis* Zones) of the lower part of the Steinmühl Formation (Lukeneder 2000) (Figs. 2 and 3).

Within the upper part of the Steinmühl Formation well preserved calpionellids (mainly the association of the standard *Calpionellites* Zone) and dinoflagellates enabled a detailed stratigraphical correlation, and therefore this part is dated as Early Valanginian. A small biostratigraphic gap in the calpionellid subzonation between the Steinmühl- and the Schrambach Formations show a condensation (omission) after the accumulation of the topmost bed of the "Maiolica" type limestone.

The lowermost part of the Schrambach Formation contains ammonoids of the *verrucosum* Zone, the lowermost of three known Late Valanginian ammonoid zones (duration 3.5 Ma, after Gradstein et al. 1999). This part was dated by Lukeneder (1999, 2001) as Late Valanginian (stratigraphy according to Hoedemaeker & Rawson 2000). New data allow an even better biostratigraphic resolution. The diverse cephalopod fauna clearly indicates the *verrucosum* Zone in the early Late Valanginian. The association indicates the *pronecostatum* Subzone and/or the *peregrinus* Subzone. The biostratigraphically indicative cephalopods are described in Lukeneder (2001) and Lukeneder & Harzhauser (2002). The calpionellids give evidence to the Late Valanginian age (*Tintinnopsella* Zone).

Interpretation of paleoenvironmental conditions

According to Caracuel et al. (1997), the deposition of nodular-marly (lower energy), nodular-calcareous and pseudonodular-calcareous-massive (higher energy) Ammonitico-rosso facies was controlled by a combination of productivity and hydrodynamics, related to fluctuations in relative sea level (see also Cecca 1992; Cecca et al. 1993, 1994; Krobicki 1993). It is assumed that the Steinmühl Formation was deposited on a distal pelagic-swell system or epioceanic "plateau". The overlying Schrambach Formation marks a change in pelagic sedimentation above the more energetic and probably somewhat shallower red limestone facies.

Pure calpionellid wackestone passes to pelloidal bioclastic (e.g. crinoids, foraminifers, ostracods, juvenile ammonoids, bivalves, calpionellids) limestone. Wackestone of *Calpionellopsis* Zone (*oblonga* Subzone) situated at the base of the Maiolica-like limestone, bears irregular fenestrae and geopetal filled bivalve shell with calcite pseudomorphs (replacing ?anhydrite). The matrix contains also glauconite (not very frequent). Features mentioned reflect erosional and current activities and may be linked with the sea-level falling. Reháková (2000b) correlated a distinct breccia accumulation, known as the Nozdrovice Breccia (Borza et al. 1980), with a significant rapid third-order sea-level fall (= type 1 sequence boundary B7) (Haq et al. 1988) at the end of the Late Berriasian *Calpionellopsis* Zone and called it the Nozdrovice Event.

The accumulation of abundant brachiopod shells (dominated by *Pygope cattuloi*; Lukeneder 2000) observed in the light grey bioclastic limestones at the topmost part of the Steinmühl Formation, just below the boundary to the Schrambach Formation, may reflect a further Early Valanginian phase of sea level lowering.

The sudden appearance of siliclastic inputs in Lower Valanginian basinal deposits Reháková (2000b) correlated with a rapid third-order sea-level fall (= type 1 sequence boundary Va4) and called it the "Oravice Event". The latter author stated that this abrupt change in environmental conditions wiped out the calpionellids almost throughout the Tethyan region ("calpionellid crisis").

According to Kázmér (1990, 1993, 1998) the pygopid forms of *catulloi/diphya* pair are more successful in deep-water bathyal environment. Predominantly packstones to grainstones are rich in crinoids, common bivalves, aptychi, and brachiopod fragments. The macrofauna of the Maiolica-like limestone (sample number 1.5H to 3) is dominated by brachiopods (n = 7, with shell preservation), by sculpture-moulds of rare ammonoids (n = 21) and belemnites (with *Acrothoracica* burrows; Lukeneder 1999). Benthic settlement of the maiolica sea bottom was not prevented by a soft bottom, but instead, by a stratified water column above it (Hay 2002). Therefore, oxygenated waters could reach the surface of the bottom after (partial) removal of a warm hypersaline water layer sinking from shelves into deep water level.

The matrix inside of the brachiopod shells contains calpionellids of standard *Calpionellopsis* and *Calpionellites* Zones (*oblonga*, *darderi* and *major* Subzones), which hints at a presumed reflection of either condensation or erosion (?coevent of Oravice Event sensu Reháková 2000b). The rich microfauna consisting of numerous elements of ophiurids, echinoids and crinoids is unexpectedly well-preserved. Furthermore, a large number of ostracods contributes to the autochthonous fauna, while radiolarians and planktonic favusellid foraminifers (suggest open marine conditions). Partly eroded ammonites with encrusting crinoids on their outer shell surface indicate quiet depositional conditions and low sedimentation rates (Lukeneder 2001). This favoured the building of a firm- to hardground, which allowed the pygopids and other epifaunal elements to settle on the sea-floor (Lukeneder 2002).

The macrofauna of the lowermost Schrambach Formation (*Olcostephanus*-Level, approx. 3 m) is predominated by sculpture-moulds of cephalopods, rare belemnites and scattered echinoderms. For a detailed interpretation of the Schrambach Formation see Lukeneder (2001) and Lukeneder & Harzhauser (2002). Due to new investigations the latter authors interpreted the fauna of the Late Valanginian section as a mixed assemblage, comprising transported elements from the shallower shelf and autochthonous benthic and parautochthonous pelagic elements from the open sea (Lukeneder 2004; Lukeneder & Harzhauser 2002, 2003).

Thin sections and microfossil material from the KB1 sequence clearly show that the different lithologies around the marked lithological change from the Early Berriasian to the Late Valanginian are consequences of changes in the paleoceanography: they reflect sea-level fluctuations during the Berriasian and Valanginian ages (Fig. 6).

As noted by Reháková (2000b), calpionellids and calcareous dinoflagellates are apparently sensitive to a whole complex of environmental changes such as climate perturbations, sea-level fluctuations and nutrient distribution. Changes of environmental conditions are clearly reflected in relative abundances of species, in wall structure and thickness, as well as in species diversity (Reháková 2000b).

A series of diversification and extinction events recorded by calpionellids and calcareous dinoflagellates reflect the major environmental changes. Mass abundances of these microfossils were closely connected to elevated zones and shallow intrashelf basins opened to nutrient-bringing currents. If the changes in abundance and diversity of the latter microfossil groups are compared with eustatic fluctuations (Haq et al. 1988), then it seems likely that these bio-events were controlled by such pulses. While transgressions were favourable for the development of planktonic organisms, their acmes were controlled by sea-level highstands. On the other hand,

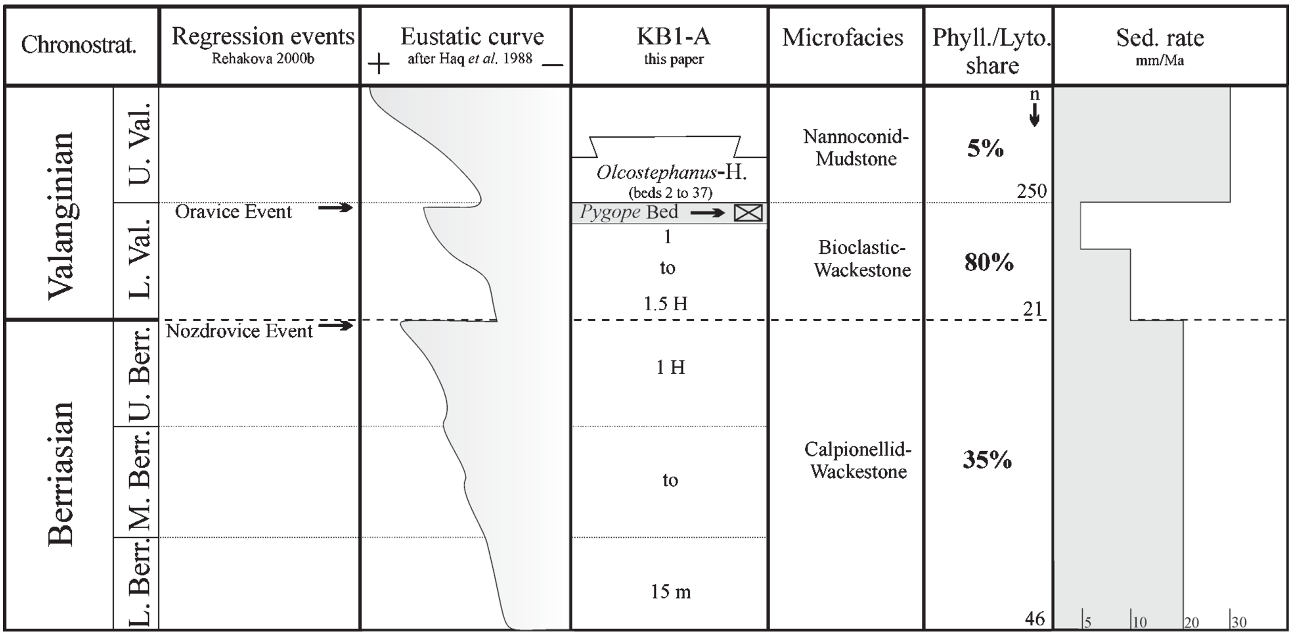

Fig. 6. Comparison of regional events described from the Western Carpathians (after Reháková 2000b) with the section of KB1-A (eustatic curves, microfacies, phylloceratid/lytoceratid share and sedimentation rate).

during regressions, several distinct diversity-reduction events were recorded within the microplanktonic groups studied (Reháková 2000b). Additionally, it has to be noted, that the abundance can also be controlled by the sedimentation rate and the dilution of carbonate mud exported from platforms, as it was evoked for nannofossils (Mattioli & Pittet 2002).

Reháková (2001) also showed that the oblique-wall-type calcareous dinoflagellates dominated during transgressive and highstand intervals, whereas tangential or radial-wall-type calcareous dinoflagellates were dominant during regressions; the latter in addition suffered several distinct reductions in diversity. According to the author mentioned above, these ecological calcidinocyst events, caused by the blooming of a single species (predominance of forms with an oblique wall structure), might be related to intervals with warm climate.

Conclusions

Several compositional changes in dinoflagellate and calpionellid assemblages (bio-events), which are explained by eustatic sea-level fluctuations in the Western Carpathians (Early Cretaceous; Late Berriasian and Early Valanginian), can be observed in the Austrian KB1-A (Northern Calcareous Alps) section.

The two events, the Nozdrovice Event (Nozdrovice Breccia) at the end of the Late Berriasian *Calpionellopsis* Zone explained by a regressive phase and the Oravice Event (Early Valanginian), also explained by a rapid sea-level lowering. Both phases manifested in the Nozdrovice and Oravice Events, at the approximate end of the Late Berriasian and the end of the Early Valanginian, are evident in the KB1 section.

The first one situated at the base of the Maiolica-like limestone is represented by pelloidal bioclastic wackestones of *Calpionellopsis* Zone (*oblonga* Subzone) bearing marks of geopetal infillings, pseudomorphs after ?anhydrite and also containing glauconite spreading in matrix. Its occurrence coincides with the Nozdrovice Event.

The second one, at the top of the Maiolica-like, consisting of light grey bioclastic limestones at the topmost Steinmühl Formation, contains abundant *Pygope catulloi* (Fig. 6). This interval is not a transition, but in fact an independent step and is most probably joined with a distinct Early Valanginian sea-level fall (Oravice Event). The last one was followed by a huge sea level rise, manifested in the Late Valanginian (*verrucosum* Zone) succession of the lowermost Schrambach Formation; it is formed by light grey spotted limestones with marly intercalations, which are very fossiliferous in micro- and macrofossils.

The evaluation of the thin section indicates a change from the calpionellid facies (lower part of the "Ammonitico rosso" type limestone), to an echinoid facies (upper part of the Steinmühl Formation) up to nannoconic facies (the Schrambach Formation) with rare echinids and foraminifers.

The beds with abundant brachiopod *Pygope catulloi* (*Pygope*-Bed) reflect a phase of rapid sea-level fall. The *Pygope* accumulation, partly eroded ammonoids with crinoidal epifaunas, belemnites with *Acrothoracica* burrows, as well as the probably small biostratigraphic gap in the calpionellid subzonation between the Steinmühl and Schrambach Formations show a sedimentation stop (omission) during the pygopid accumulation. This favoured the building of a firm- to hardground, which allowed the pygopids and other epifaunal elements to settle on the sea-floor. The associated calpionellid fauna indicates an Early Valanginian (*Calpionellites* Zone; *major* Subzone) age of the *Pygope catulloi*-bearing bed. Thus, the occurrence of abundant pygopids and the additional analysis of the micro- and macrofauna support the interpretation of a hardground paleoenvironment on a swell of the outer shelf.

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