Unusual microfacies character of the Pieniny Limestone in the Orava sector of the Pieniny Klippen Belt

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Abstract: The Pieniny Limestone Formation is a significant formation representing the pelagic sedimentation during the Late Jurassic to Early Cretaceous in numerous units of the Pieniny Klippen Belt. On the hills over Revišné, in the Orava sector of the Pieniny Klippen Belt, a distinctive klippe was sampled and biostratigraphically analysed in detail. The klippe consists of the "biancone"-type limestones of Early Tithonian to Late Valanginian age. The age range was determined by calcareous dinoflagellates, radiolarians, and aptychi. The section is remarkable by mostly radiolarian and radiolarian-spiculitic microfacies that prevail through the entire Revišné 1 section; the calpionellid to calpionellid-radiolarian microfacies, which typically occurs in the "biancone" facies of the Oravic successions is surprisingly lacking. The samples contain only very rare calpionellids and no calpionellid zones or subzones could be determined. Moreover, probably due to a tectonic reduction, there is a missing interval encompassing microfossil zones of the Lower Tithonian and Lower Beriassian (the calcareous dinoflagellate zones Tenuis, Fortis, Proxima, Fusca, Waneri and Minuta are absent). Lower Tithonian was determined solely based on dinoflagellate cysts, proving Tithonica and Malmica zones. Younger part of the section, just above the discontinuity, was dated to the Upper Berriasian (Vogleri Zone) by the onset of *Colomisphaera vogleri* and *Stomiosphaera wanneri*. Lower Valanginian (Valanginiana Zone) was determined by the occurrence of *Colomisphaera lucida, Colomisphaera heliosphaera, Carpistomiosphaera valanginiana* and *Stomiosphaera echinata*. Apart from dinoflagellates, the Late Valanginian age of the youngest layers was also proved by lamellaptychi. Predominance of radiolarians (approximately 30-40% in all thin sections), missing calpionellids, and conformable lithology and microfacies suggest that the studied beds sedimented in the deepest parts of the basin with relatively stable conditions. The lack of dinocyst and calpionellid zones in the lower part of the section is interpreted by a tectonic reduction of the sediments, resulting from a younger local tectonic event. The specific character of the described limestones reflects microfacies variability of the Pieniny Limestone Formation in the Oravic successions.

Key words: Pieniny Klippen Belt, Pieniny Limestone Formation, Late Jurassic, Early Cretaceous, microfacies, dinocysts, radiolarians, lamellaptychi

1. INTRODUCTION

Oravic units of the Pieniny Klippen Belt (PKB) represent the border between the Outer Western Carpathians and Central Western Carpathians. They were formed during approximately 135 Ma of sedimentation and multiphase deformation. During the Laramian phase of the Alpine orogeny, southern part of the Penninic Ocean was closing, and sedimentary units were detached from their substratum and thrust over each other. Subsequently, transpression disintegrated the thrust sequences into blocks which resulted in its recent structure, where harder Upper Jurassic to Lower Cretaceous limestone klippen are surrounded by usually younger, less resistant rocks. Due to these tectonic events, most of the successions are preserved in lenses, commonly with incomplete sedimentary records. Their presence in the PKB differs from segment to segment. Oravic units are divided and classified by their position in the accomodation space during sedimentation, from the north represented by Šariš Unit (Grajcarek Unit in Poland), Czorsztyn Unit, transitional Niedzica, Czertezik, Orava and Nižná units and deep water Kysuca (Branisko) and Pieniny units in the south. In the Orava segment, in the field of our study, only Šariš, Kysuca and rarely Czorsztyn successions outcrop. The most widespread lithostratigraphic unit of these Oravic successions in the western Orava part is the Pieniny Limestone Formation. These also called "biancone"-type limestones, deposited in a deep marine trough and they represent the Tithonian to Barremian/Aptian age of several successions from both sides of the paleoridge (Czorsztyn Ridge) (Fig. 1). Character of the Pieniny Limestone Formation differs from succession to succession in its overall thickness, thickness of the beds, and by the presence of cherts. Thickness of these deposits varies widely from 1–6 m in the Šariš and Niedzica successions to 90–190 m in the Pieniny and Branisko successions (Birkenmajer, 1977). Typically, the microfacies of the Upper Tithonian to Berriasian part of the Pieniny Limestone Formation consists of calpionellid, calpionellid-globochaete, and calpionellid-radiolarian microfacies (Birkenmajer, 1977; Michalík et al., 1990, 2009). A klippe with atypical facies in the Pieniny Limestone Formation, with strata ranging from Lower Tithonian to Lower Valanginian, was documented

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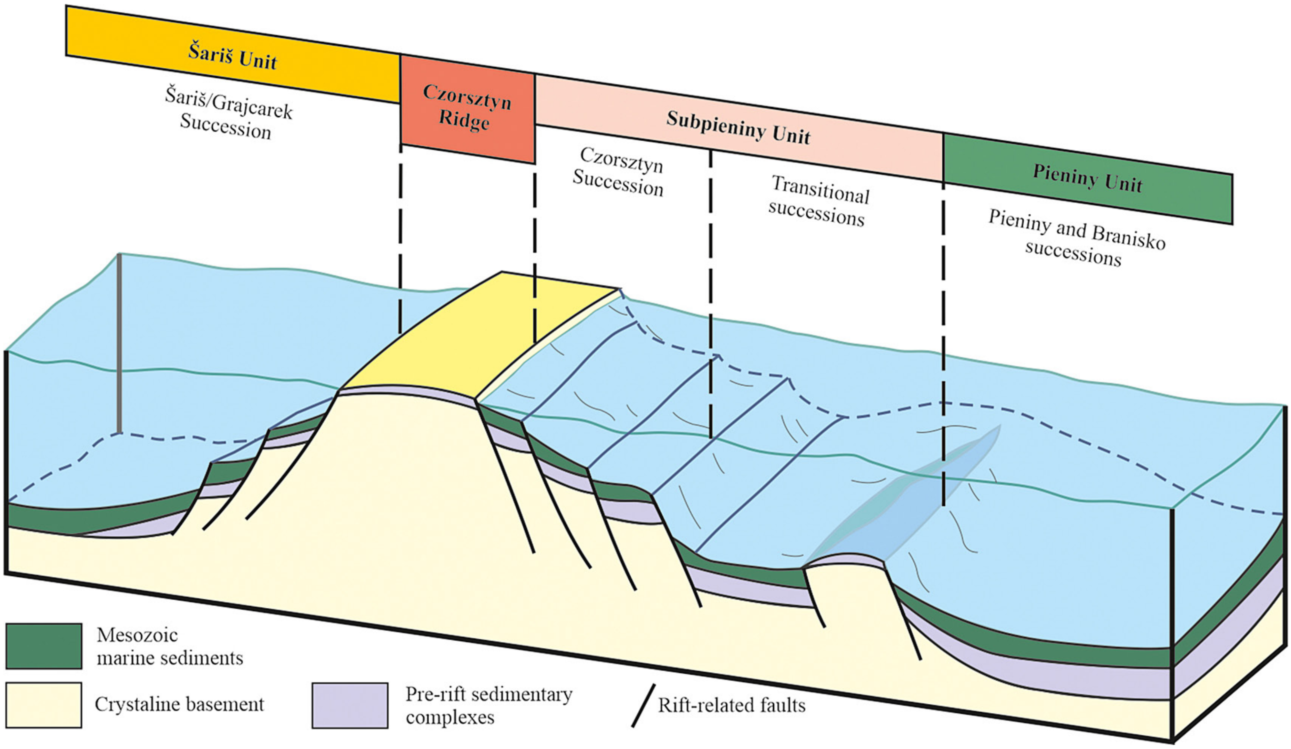

Fig. 1. Palinspastic reconstruction of the Pieniny Klippen Belt and adjoining areas during the Late Jurassic – Early Cretaceous (modified after Birkenmajer, 1977)

near the village of Revišné, belonging to the Kysuca (Pieniny) Unit.

1.1. Regional and geological setting

Klippe with the analysed section is located in the Žilina region, Dolný Kubín district, on the western hills over the village of Revišné (N 49°13.182´; E 19°14.056´) (Fig. 2). For research purposes, the klippe was called Revišné 1 section. The beds of the Pieniny Limestone Formation on the klippe are positioned subvertically with dip orientation of 60° to the NW. Revišné 1 section is situated in the more southern to middle part of the studied area of the PKB. This territory is formed by Kysuca, Czorsztyn and Šariš units.

2. CHARACTERISTICS OF THE PIENINY LIMESTONE

The most prevailing lithostratigraphic unit of the Kysuca Unit (Pieniny), Šariš Unit and of the transitional units is the Pieniny Limestone Formation of Late Tithonian to Aptian age, belonging to the "biancone" or "maiolica"-type limestone. Since the formation overlaps the J/K boundary it has been extensively studied (Andrusov, 1945; Michalík et al., 1987; Michalík et al., 1990; Michalík et al., 1995a,b; Michalík et al., 2009; Michalík et al., 2016; Michalík et al., 2019; Michalík et al., 2021; Reháková, 1995; 2000a,b; Reháková et al., 2011; Scheibnerová, 1963).

Generally, the Pieniny Limestone Formation is white to pale-grey and grey in color, consistently bedded, rich in fractures and veins filled by calcite. This compact limestone contains abundant calpionellids, with presence of radiolarians in minority in most of the cases. Andrusov (1945) studied the Pieniny Limestone Formation in the Skalka klippe near Oravský Podzámok, in the Červený Kameň klippe near Podbiel, in the klippe near Rudina north of Žilina and many other places in the Váh Valley. He determined the difference between the Pieniny type series near Dlhá na Orave and other localities (Skalka and Červený Kameň klippen - where the bedding is periodical with layers of 20 cm) in thickness of the beds and in onset of thin intercalations of marls. In the Orava region (Dlhá and Oravou), the limestones contain grey to light blue cherts varying in size, with sphaeroidal shape, positioned in the middle of the beds. In many sections in the Middle Tithonian, Andrusov (1945) described several meters of sediments with the absence of cherts. In the white limestones, sporadic nests of aptychi occur and microscopically there is visible abundance of radiolarians. In the Tithonian of the Pieniny Unit, and also in the transitional units, the content of radiolarians is lower compared to the considerable presence of calpionellids (Andrusov, 1945). The section in the Rudina klippe was also studied by Scheibnerová (1963) and she described the Lower Cretaceous complex (gradually passing from the Tithonian limestones) as 30 m thick suite of limestones of "biancone" -type, light grey in color and rich in calpionellids and lombardias *(Saccocoma).* The limestone is often spotted and contains cherts. In the Lower Berriasian part of the suite, she determined *Calpionella alpina* Lorenz, *Calpionella elliptica* Cadisch, *Calpionella undelloides* Colom, *Tintinnopsella carpathica* (Murgeanu et Filipescu), *Tintinnopsella oblonga* (Cadisch), *Tintinnopsella longa* (Colom), *Tintinnopsella cadischiana* Colom, *Calpionellites darderi* (Colom), *Stenosemellopsis hispanica* (Colom) and rarely *Globochaete alpina* Lombard. There was also frequent presence

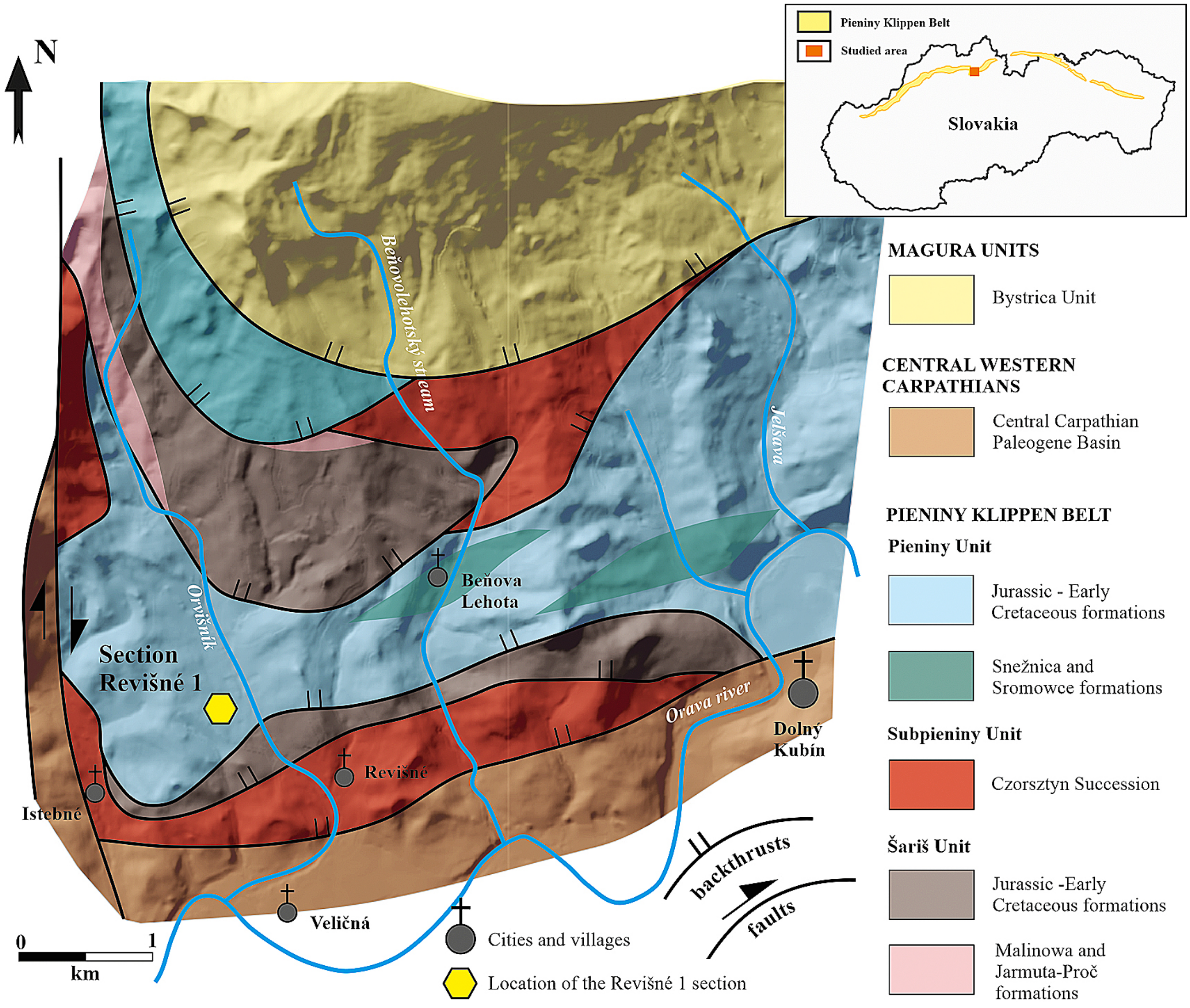

Fig. 2. Tectonic scheme of the area with location of the studied Revišné 1 section.

of *Nannoconus* sp.. In younger beds of the section in the Rudina klippe, there is an increase of marly intercalations in which the Valanginian-Hauterivian microfauna was found. Michalík et al. (1995a) distinguished the character of the Pieniny Limestone Formation based on the position of the sedimentation space in the Western Carpathians (Outer Western Carpathians, Central Western Carpathians). The basinal sedimentation in the Outer Carpathians is, based on their research, typically represented by white-grey or grey, radiolarian-calpionellid and radiolarian-nannoconid micritic wackestones with dark chert nodules and stratiform cherty layers. Both the marly admixture and the frequence of calciturbidite layers in this complex increase upwards with presence of belemnites, aptychi and rarely ammonites. This sedimentation continued up to the Aptian (Birkenmajer, 1977). In the Central Western Carpathians, the Berriasian to Valanginian sedimentation in the basinal area is characterised by hemipelagic limestones of the "biancone" -type consisting of light grey micritic mudstones to biopelmicrites. Macrofauna is scarce and includes poorly preserved aptychi, ammonites and belemnites (Michalík et al., 1995a). The onset of these pelagic limestones was diachronous in different units (Boorová et al., 1993). From the evironmental point of view, the boundary between Jurassic and Cretaceous is marked by crustal stretching that caused gradual subsidence of basins in the West Carpathian area (Mahel', 1979), altering the character of the sedimentation space. The change commenced in the Late Jurassic shifting of the sedimentation from condensed nodular Ammonitico Rosso limestones to well oxygenated higher rate sedimentation of "maiolica"- or "biancone" -type deposits. This environment is not only characterized by deepening but also by changes in current regime and rapid increase in plankton evolution (flourishment of nannosfossil and calpionellid associations) evidenced by the microplanktonic Crassicollaria and Calpionella zones (Michalík et al., 1990). Wieczorek (1988) and Michalík et al. (1995a) associate the mass distribution of the "maiolica" facies with the decrease of CCD level at the beginning of the Cretaceous and related development of calcareous micro- and nanoplankton. During the Valanginian and Hauterivian shallowing occurred, accompanied by new diversification of the sedimentation space (Michalík et al., 1987).

During research on numerous sections of the pelagic Pieniny Limestone Formation of the Upper Jurassic to Lower Cretaceous, Michalík et al. (1995b, 1999, 2021) gave detailed description of the change in the ratio of microfauna composition. The authors described (from Brodno, Snežnica and Rochovica sections) the Kimmeridgian and Early Tithonian maximum of calcareous microplankton as dominated by *Saccocoma* and *Globochaete alpina* Lombard. The changes in the Kimmeridgian and Tithonian globochaetes abundance were generally synchronous with the changes in composition of calcareous microplankton. Calpionellid development started during the Late Tithonian and accelerated for the first time in the upper part of the Intermedia Subzone of the Crassicollaria Zone, with the first crisis at the base of the Alpina Subzone of the Calpionella Zone. The second acceleration of calpionellid abundance started since the Ferasini Subzone and culminated in the Oblonga Subzone of the Calpionellopsis Zone, accompanied by short decrease in the abundance during the Elliptica Subzone of the Calpionella Zone. The second calpionellid crisis leading to their extinction was documented after the Calpionellopsis Zone (Reháková, 2019). Since the Late Tithonian, especially during the Calpionellites and Tintinnopsella zones, the calpionellid abundance alternated with the abundance maxima of radiolarians. Nonetheless, in all of their studied sections, calpionellids were present.

3. MATERIALS AND METHODS

Revišné 1 section is an approximately 20 meters long klippe. Macroscopically, layers with samples R0 – R7 (bottom part of section) are formed by pale, slightly nodular limestones of 15 to 50 centimeters of bed thickness. The limestones are strongly affected by tectonic deformation; slickensides and calcite veinlets are common. Layers with samples R8 – R16 are tectonically undisturbed and irregular in thickness (average of 20 centimeters). They contain brown and black cherts. Strong tectonisation (abundant webs of calcite veinlets and small-scale slickensides) of the rock onsets above the layer with sample R17. Here, layers of white, light grey limestones with yellow patina alternate with 5 intercalations of dark grey marls. Studies were focused on biostratigraphical and lithostratigraphical analysis of the layers.

Samples from the Revišné 1 section were collected approximately every 0.5 meter and marked by letter R with the following number of sample (Fig. 3). The sample numbers correspond to stratigraphic distance in meters above the base of the section. Samples were also collected from the marls for washing and possible age dating by foraminifera and nanoplankton. These were taken from positions R8.7, R9.2, R9.8, R13.7 and R14.9. Due to the high content of siliceous radiolarians in the thin sections, further sampling of cherts was carried out from samples R8.1, R9.5, R11.5, R12.5, R13.8 and R15.5. The Revišné 1 section also contains ammonites (Vašíček, oral information, unpublished) and aptychi. 22 lamellaptychi were collected and marked by the limestone sample number, from which, or near which they were found. Only two fragments of aptychi were collected in situ, the rest was found in debris, most probably not far from the layer of origin (the layers are in subvertical position). Because of this, each of the aptychi was labelled after an interval of limestone samples (approx. 1 meter up and down the section, e.g. R12.5-R15).

Altogether 39 thin sections were prepared and consequently studied using the light microscope LEICA DM 2500-P. Microfacies and microfossils were documented by a LEICA DFC 290 HD camera. The thin sections are deposited at the Department of Geology and Paleontology of the Faculty of Natural Sciences in Bratislava. Classification of Dunham (1962) was used for determination of the microfacies. The distribution,

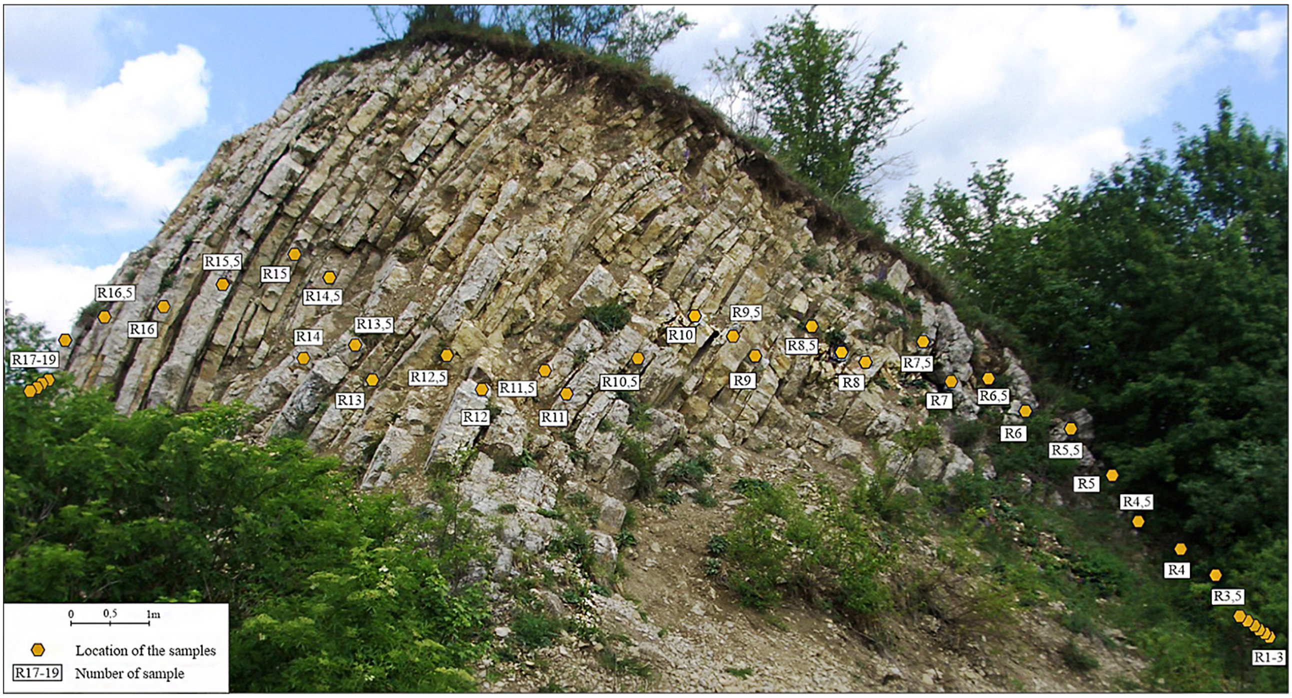

Fig. 3. Overturned succession in the Pieniny Limestone Formation in Revišné 1 section. Position of the samples is indicated.

abundance and diversity of calcareous dinoflagellate cysts was determined using classifications of Ivanova (1994), Kowal-Kasprzyk (2016), Lakova et al. (1999), Olszewska (2005, 2010), Reháková (2000a) and Řehánek & Heliasz (1993). In publications devoted to research in the Western Carpathians, the most used zonation for dinocysts is by Reháková (2000a), who revised the zonation of Borza (1984). However, other works (Nagy, 1966; Nowak, 1968; Olszewska, 2005; Olszewska, 2010; Kowal-Kasprzyk, 2016) and the newest zonation by Ivanova & Kietzmann (2017) show that different taxa of dinocysts vary in age of onset and their disappearance (Fig. 4). The disproportion in the onset and span of individual dinocysts is yet unclear and is open for further research. Classification of rarely occuring calpionellids is according to Borza (1980, 1984) and Reháková (1995).

Quantitative composition analysis was performed on the thin sections of individual samples under an optical microscope. We focused on percentual evaluation of radiolarians, calpionellids, saccocomids and calcareous dinoflagellates relative to all of the microfacies components, using the quantitative evaluation with the optical charts *sensu* Bacelle & Bosellini (1965) (the same method was used in the research by Michalík et al., 1999).

Six chert samples were processed for radiolarians. In order to separate radiolarians, the samples were ground (fragments of size ± 1–2cm^3) and immersed in a solution of 4 % hydrofluoric acid. The dissolution process was interrupted every two hours in order to decant the separated material collected on the bottom of vessels, and to manually lower the concentration of acid by half the vessel volume. After 5–6 days of dissolution all the decanted material from individual samples was boiled for two hours in a solution of hydrogen peroxide to remove the radiolarian shells infilling. Afterward, the samples were sieved at mesh size of 0.250 μm, 0.125 μm and 0.063 μm (DeWever et al., 2001).

5 samples from the intercalations of slightly lithified grey marls were collected for the study of washed material, dissolving the samples in 10 % HCl and sieving them through mesh size of 0.125 μm and 0.063 μm. However, the results from the shaly interalations were insufficient, and no stratigraphically important microfossils species were determined by this analysis.

3.1. Microfacies analysis and biostratigraphy

Dinoflagellate cysts and calpionellids

Microscopically, every studied thin section was thickly studded by siliceous or calcified radiolarians, sometimes even filled by chalcedony and affected by pyritization, with radiolarians forming about 80 % of the fossil content (percentual estimate relative to all bioclasts, excluding matrix and other components) (Fig. 5). Revišné 1 section starts with biomicrite wackestone with radiolarian microfacies (sample R0). Radiolarians, aptychi, juvenile ammonites, sponge spicules, calcareous dinoflagellate cysts and fragments of agglutinated formanifers, bivalves and *Saccocoma* sp. occur. The Lower Tithonian Tithonica Zone was determined by the dinocyst assemblage: *Carpistomiosphaera tithonica* Nowak, *Carpistomiosphaera borzai* (Nagy) (Fig. 6 A), *Stomiosphaera moluccana* Wanner, *Colomisphaera lapidosa* (Colom) and *Cadosina semiradiata semiradiata* Wanner (Fig. 6 B). The samples R1 – R4 have mostly *Saccocoma-Globochaete*, *Saccocoma*-radiolarian (Fig. 6 C) and radiolarian microfacies with presence of aptychi, juvenile ammonites, "filaments" (cross-sections of thin-shelled bivalves), gastropods, sporadically ostracods and echinoderm fragments. The bioclasts and matrix are often impregnated by Fe-oxides or hydroxides (Fig. 6 D). The limestones are penetrated by abundant calcite veinlets. *Globochaete alpina* (Lombard), *Parastomiosphaera malmica* (Borza) (Fig. 6 E), *Cadosina semiradiata semiradiata* Wanner, *Cadosina semiradiata fusca* (Wanner), *Colomisphaera lapidosa* (Colom), *Colomisphaera carpathica* (Borza) and *Cadosina parvula* Nagy point to the Malmica Zone and indicate the uppermost part of Lower Tithonian. It should be mentioned though, that Olszewska (2005, 2010) indicated presence of *Parastomiosphaera*

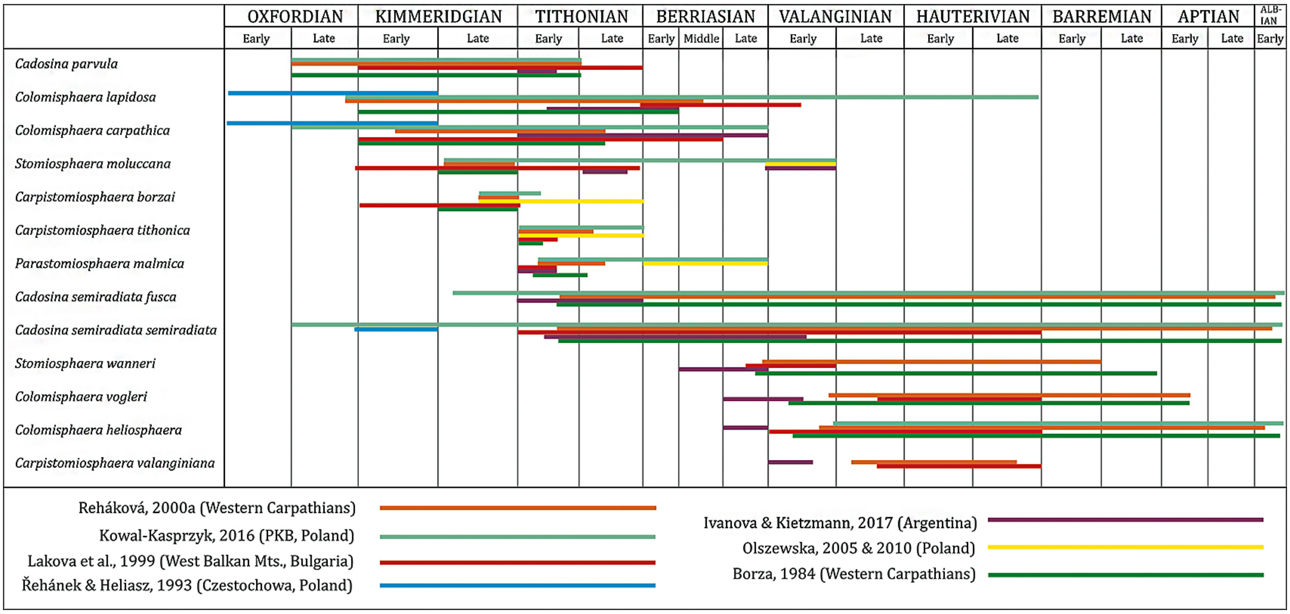

Fig. 4 Comparison of calcareous dinocyst stratigraphic ranges published by different authors.

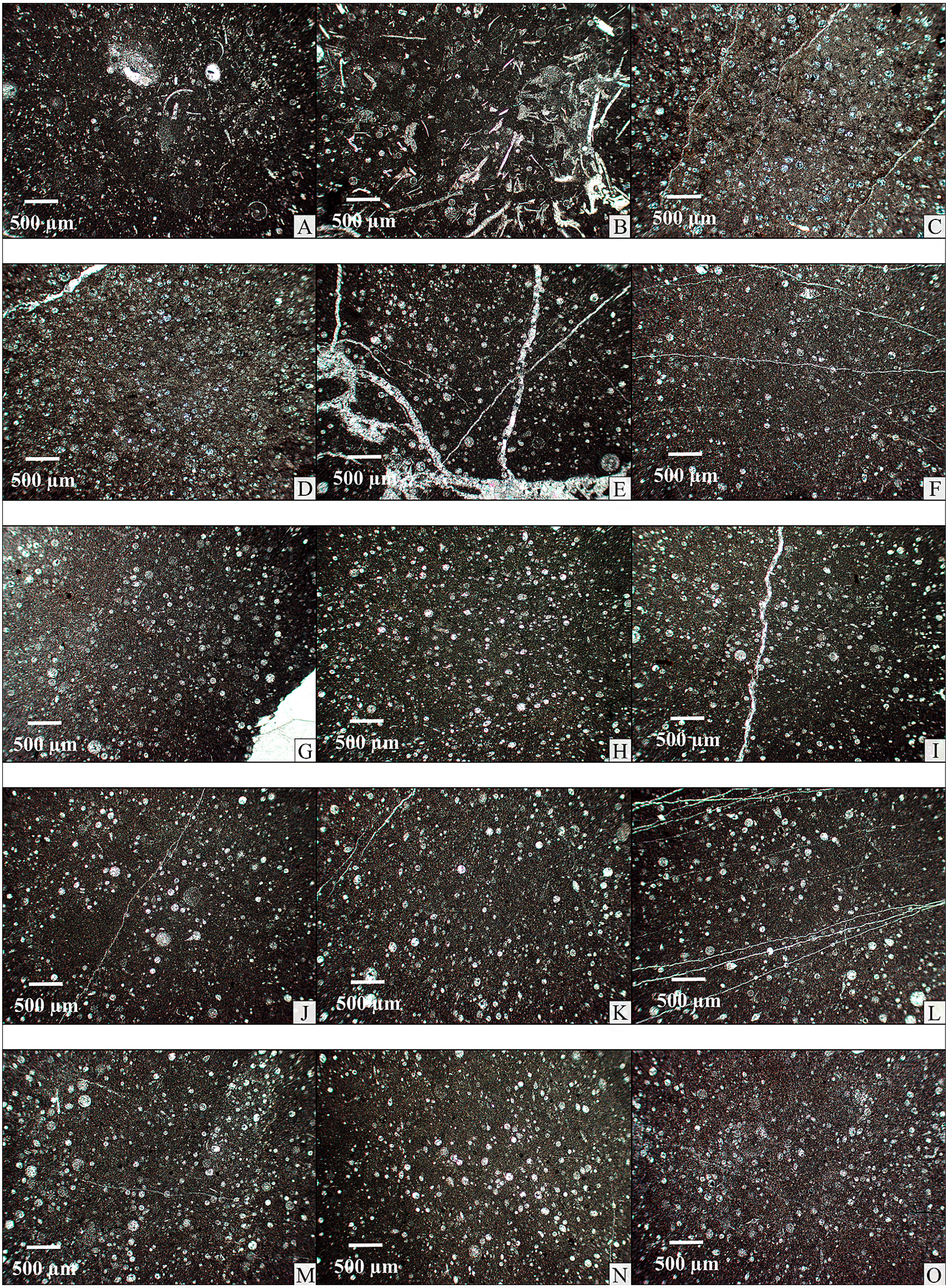

Fig. 5. Microfacies of selected samples: **A** – sample R1; **B** – sample R2; **C** – sample R3.3; **D** sample R4.5; **E** – sample R5.5; **F** – sample R6.5; **G** – sample R7; **H** – sample R9.5; **I** – sample R10; **J** – sample R12; **K** – sample R14; **L** – sample R14.5; **M** – sample R16; **N** – sample R18; **O** – sample R19.

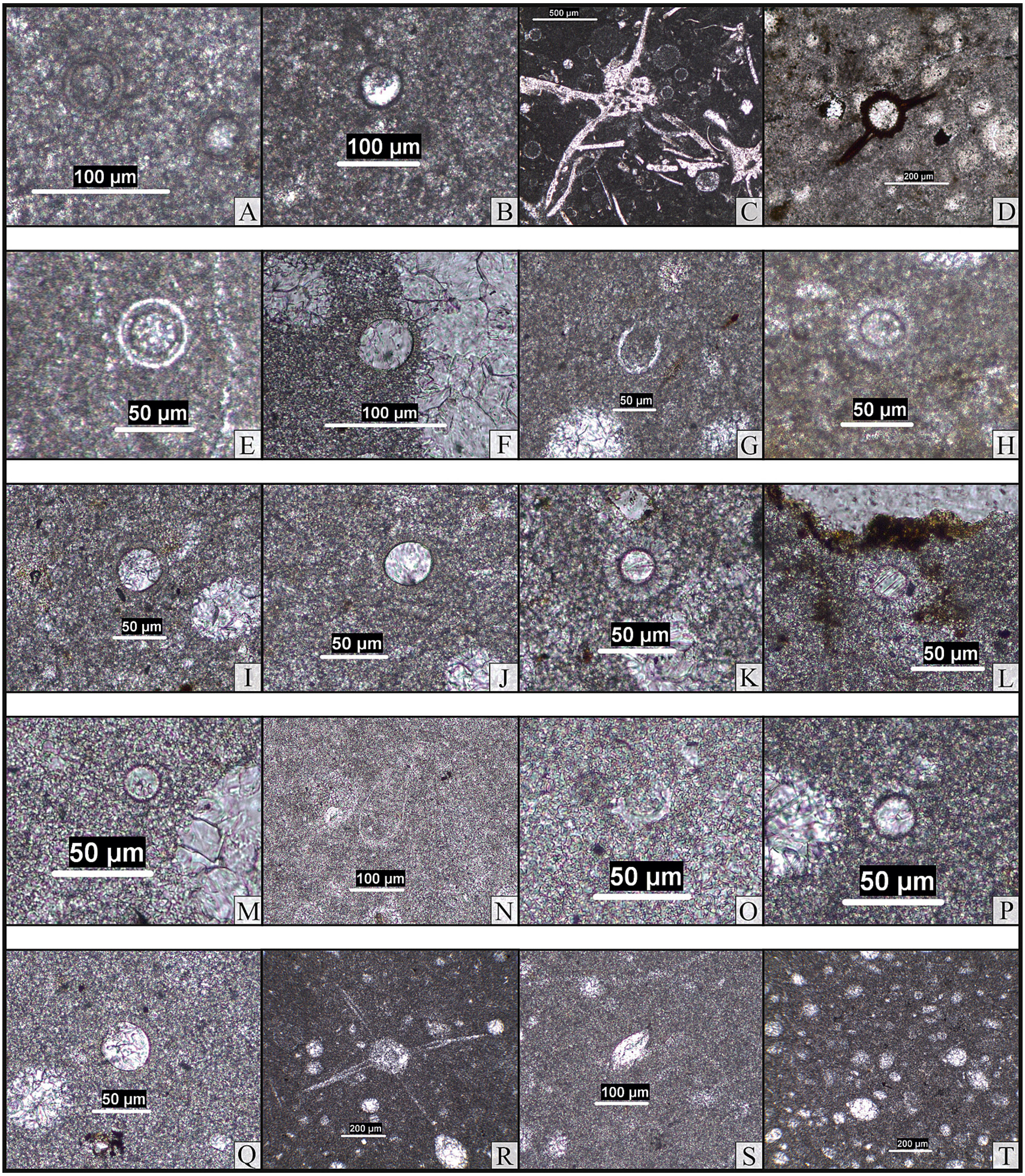

Fig. 6. Calcareous dinocysts, calpionellids and radiolarians from the Revišné 1 section: **A** – *Carpistomiosphaera borzai* (Nagy), R0; **B** – *Cadosina semiradiata semiradiata* (Wanner), R0; **C** – *Saccocoma* – radiolarian microfacies, R3; **D** – Pyritized radiolaria, R3.3; **E** – *Parastomiosphaera malmica* (Borza), R2; **F** – *Colomisphaera vogleri* (Borza), R7.5; **G** – *Calpionella alpina* (Lorenz), R8.5; **H** – *Colomisphaera carpathica* (Borza), R9; **I** – *Colomisphaera vogleri* (Borza), R9; **J** – *Colomisphaera lucida* (Borza), R10; **K** – *Colomisphaera heliosphaera* (Vogler), R10; **L** – *Colomisphaera heliosphaera* (Vogler), R12; **M** – *Stomiosphaera wanneri* (Borza), R13; **N** – *Tintinnopsella carpathica* (Murgeanu et Filipescu), R13; **O** – *Stomiosphaera echinata* (Nowak), R13; **P** – *Colomisphaera lapidosa* (Colom), R14; **Q** – *Carpistomiosphaera valanginiana* (Borza), R18; **R** – Nicely preserved radiolaria, R18; **S** – *Pithonella* sp., R18; **T** – Radiolarian microfacies, R19.

malmica (Borza) only in the Berriasian. Reháková (in Svobodová et al., 2019) documented *Parastomiosphaera malmica* (Borza) in the Middle Berriasian Elliptica Subzone of the Calpionella Zone in the Kurovice Limestone Formation. The last mentioned author explained the presence of several Lower Tithonian cysts as a consequence of resedimentation. Sample R5 is a radiolarian wackestone with occurence of *Colomisphaera lapidosa* (Colom) and first appearance of *Stomiosphaera wanneri*

Borza and *Colomisphaera vogleri* (Borza) (Fig. 6 F). These layers belong already to Berriasian based on the newest classification by Ivanova & Kieztmann (2017). Regardless of the hiatus between the samples R4 and R5, the abundance of radiolarians persits. The samples R6–R9 promote in radiolarian wackestone. The samples R9–R12 are radiolarian wackestones to packstones, all containing radiolarians, *Saccocoma*, foraminifers, rarely ostracods, and bivalves, which are occasionally phosphatised. The samples R9–R12 are marked by the onset of *Carpistomiosphaera valanginiana* Borza, *Colomisphaera lucida* Borza, *Colomisphaera heliosphaera* (Vogler) and *Stomiosphaera echinata* Nowak. Based on Ivanova & Kietzmann (2017) *Carpistomiosphaera valanginiana* Borza appears in the Lower Valanginian. Stratigraphical range of *Colomisphaera lucida* Borza was not included in the zonation by Ivanova & Kietzmann (2017) but based on the zonation by Reháková (2000b) it also starts in the Lower Valanginian. In addition, Early Valanginian age is supported by the first occurrence of *Colomisphaera heliosphaera* (Vogler) with stratigraphical range determined by Ivanova & Kietzmann (2017) as Upper Berriasian-Lower Valanginian and by Reháková (2000b) as starting in Lower Valanginian. These layers are interpreted as belonging to the Valanginiana Zone (Ivanova & Kietzmann, 2017). In the sample R8.5, one specimen of *Calpionella alpina* (Lorenz) (Fig. 6 G) was distinguished.

In the sample R9.5 the presence of two calpionellid specimens was evidenced: *Tintinopsella carpathica* (Murgeanu et Filipescu) and *Tintinopsella longa* (Colom). Above the sample R12, the limestone beds contain *Colomisphaera carpathica* (Borza) (Fig. 6 H), *Colomisphaera vogleri* (Borza) (Fig. 6 I), *Colomisphaera lucida* Borza (Fig. 6 J), *Colomisphaera heliosphaera* (Vogler) (Fig. 6 K, L), *Stomiosphaera wanneri* Borza (Fig. 6 M), *Stomiosphaera echinata* Nowak (Fig. 6 O), *Colomisphaera lapidosa* (Colom) (Fig. 6 P), *Carpistomiosphaera valanginiana* Borza (Fig. 6 Q) and *Cadosina semiradiata fusca* (Wanner). The dinocysts are accompanied by occassional presence of *Pithonella* sp. (Fig. 6 S) and foraminifers *Frondicularia* sp., *Spirillina* sp. and *Involutina* sp.. In the sample R13, one more specimen of *Tintinopsella carpathica* (Murgeanu et Filipescu) (Fig. 6 N) was determined. The dinoflagellate cysts association here is almost the same as in the previous interval, however already representing the Upper Valanginian, based on the aptychi association (see following chapter). The limestone samples R13 up to R19 show radiolarian microfacies (Fig. 6 R, T) with sponge spicules, thin-shelled bivalves, ostracods, foraminifers and rare echinoderm fragments. Framboidal pyrite and calcite veinlets are common. Texture of the limestones is mostly wackestone, seldom passing to packstone, and in the sample R17.5 even to mudstone texture. Layers contain also *Globochaete alpina* Lombard and foraminifera *Involutina* sp. and *Dentalina* sp..

Lamellaptychi

In the interval between the samples R12 and R15, following aptychi were determined: *Mortilletilamellaptychus mortilleti* (Pictet et Loriol), *Mortilletilamellaptychus mendrisiensis mendrisiensis* (Renz et Habicht), *Mortilletilamellaptychus oceanicus* (Renz) and *Mortilletilamellaptychus beyrichodidayi* (Trauth). Other found aptychi belong to the layers with sample numbers R17.5-and higher. Late Valanginian age is proved by presence of *Mortilletilamellaptychus bicurvatus* (Renz et Habicht), *Thorolamellaptychus aplanatus retroflexus* (Trauth). Other specimens, with thick and sparse ribs, like *Didayilamellaptychus seranonis* (Coquand), *Didayilamellaptychus didayi* (Coquand) and *Didayilamellaptychus angulodidayi* Trauth were found too. Their stratigraphic occurences range from upper Lower Valanginian to Lower Hauterivian (Měchová et al., 2010).

Radiolarians

Relatively poorly preserved, often fragmented, and indeterminable radiolarians were separated from all six samples. Extremely poor associations (4–6 species per association) were collected from three samples. Samples R8.1, R9.5 and R11.5 offered limited number of radiolarians, which were not solidly determinable. Altogether we collected 13 radiolarian forms belonging to order Polycystina, which includes all its three presently recognised suborders – Entactinaria (one form), Nassellaria (five forms) and Spumellaria (seven forms). From the sample R12.5, association consists of species *Crococapsa* cf. *zweilii* (Jud) (Fig. 7 H), *Crucella* (?) sp., *Dicerosaturnalis dicranacanthos* (Squinabol) (Fig. 7 N), *Pantanellium squinaboli* (Tan) (Fig. 7 A, B) and *Zhamoidellum* cf. *ovum* Dumitrică (Fig. 7 J, K). The age of this sample is determined based on the first and the last occurrence of *Crococapsa* cf. *zweilii* (Jud) (UA zones 13–19; Upper Tithonian to lower Middle Hauterivian). However, the sample R12.5 also contains *Zhamoidellum* cf. *ovum* Dumitrică (Middle Oxfordian – Lower Tithonian) indicating older age of the sample than the Late Valanginian, determined by other microfossils. Four determinable and few poorly preserved (Pantanelliidae (Fig. 7 E)) species were separated from chert in the sample R13.8 (*Archaeospongoprunum* sp., *Crucella* (?) sp., *Pantanellium squinaboli* (Tan) (Fig. 7 C) and *Zhamoidellum* sp.). This sample represents relatively wide stratigraphic range. The first occurence of *Pantanellium squinaboli* (Tan) and the last occurence of *Zhamoidellum* sp. set the age to Late Kimmeridgian – latest Barremian (UA Zone 11 and lower part of UA Zone 22). The last chert sample was taken from the sample R15.5. Radiolarian association in this sample consists of *Crucella* (?) sp. (Fig. 7 F, G), *Hiscocapsa* cf. *kaminogoensis* (Aita) (Fig. 7 I), *Pantanellium* (?) sp. (Fig. 7 D), *Triactoma* (?) sp. (Fig. 7 M) and *Zhamoidellum* sp. (Fig. 7 L). The first and the last occurence of *Hiscocapsa* cf. *kaminogoensis* (Aita) indicate this association is Early Tithonian to Early Barremian in age (UA Zone 12 – UA Zone 21), which is not in contradiction to the age results from dinoflagellate cyst and aptychi biostratigraphy, however it does not provide a more precise age.

4. DISCUSSION

The Revišné 1 section is composed of the Pieniny Limestone Formation with determined age range from Early Tithonian to Late Valanginian (Fig. 8). Lithology and microfacies show, that the paleoenvironment during sedimentation in the Late Jurassic was deep sea, with exclusively pelagic fauna, rare terrigenous elements and with relatively slow sedimentation. The environment was probably stable, without considerable facies change. Generally, the onset of the typical "maiolica" or "biancone" -type facies is in the Pieniny Unit known from the Upper Tithonian (Michalík et al., 2009). Typical pale limestones in the documented section start in Early Tithonian. Further in the succession, the Upper Tithonian Crassicollaria Zone, Lower Berriasian Calpionella Zone, Upper Berriasian-Lower Valanginian Calpionellopsis Zone and Valanginian Calpionellites Zone and their subzones with usual abundance of calpionellids could not be documented partly due to the absence of calpionellids and partly due to a tectonic reduction of the section. In fact, the dinoflagellate cyst zones Tenuis, Fortis, Proxima, Fusca, Waneri and Minuta are absent, and only 4 calpionellid specimens were documented among radiolarian packstones or wackestones in all thin sections. Instead of calpionellid microfacies, the radiolarian microfacies with abundant calcareous dinoflagellates prevail troughout the studied succession. Radiolarians form approximately 30–40 % of the whole microfacies content in every thin section, occasionally the estimated volume is even up to 55 % (Fig. 9). Even though radiolarians were continuously present in the layers, their preservation was extremely poor. Reháková & Michalík (1994) quantified the abundance of siliceous and calcareous microplankton in thin sections, and they suggest that the degree of abundance of radiolarians is inversely related to that of calpionellids.

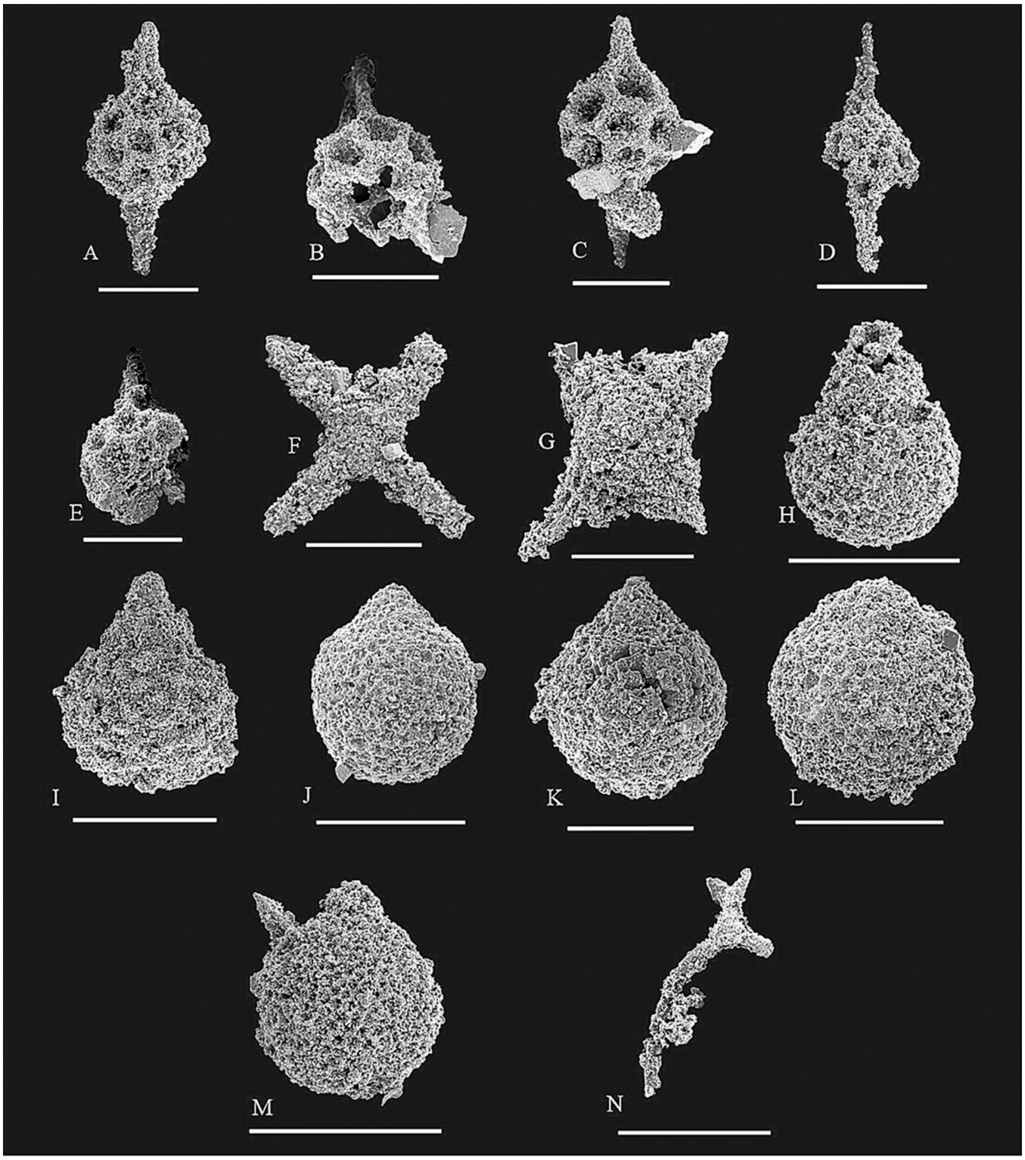

Fig. 7. Radiolarians from the Revišné 1 section (scale bar 100 μm): **A** – *Pantanellium squinaboli* (Tan), R12,5; **B** – *Pantanellium* ex. gr. *squinaboli* (Tan), R12,5; **C** – *Pantanellium squinaboli* (Tan), R13,8; **D** – *Pantanellium* (?) sp., R15,5; **E** – *Pantanelliidae indet.*, R13,8; **F, G** – *Crucella* (?) sp., R15,5; **H** – *Crococapsa* cf. *zweilii* (Jud), R12,5; **I** – *Hiscocapsa* cf. *kaminogoensis* (Aita), R15,5; **J** – *Zhamoidellum* cf. *ovum* (Dumitrică) R11,5; **K** – *Zhamoidellum* cf. *ovum* (Dumitrică), R12,5; **L** – *Zhamoidellum* sp., R15,5; **M** – *Triactoma* (?) sp., R15,5; **N** – *Dicerosaturnalis dicranacanthos* (Squinabol), R12,5.

Previous studies correlated the fluctuations in abundance of nanoplankton and microplankton with Milankovitch orbital cycles (Erba et al., 1992; Hubberten et al., 1993), with changes in water temperature (Reháková & Michalík, 1993), as the result of orbitally induced transgressions, accompanied by climate changes (Erbacher & Thurrow, 1993) or connected with intensive upwelling, influenced by global climatic factors (Reháková & Michalík, 1994). Interpretation of the areal distribution is essential. Based on the research of various sections in the Subpieniny and Pieniny units and of sections from the Zliechov Basin by Michalík et al. (2021), the abundance and size of calpionellids decreased towards open marine environments and were less common in deep basins. However, precise comparison of the Revišné 1 section with older publications on the Pieniny Limestone Formation (Michalík et al., 1999, 2021; Vašíček et al., 1994) is difficult (Fig. 9), as these studies mostly cover Tithonian-Berriasian age which is missing in our section (Brodno, Snežnica, newest publication on the Rochovica section) and in those sections which record

Tithonian-Valanginian age, as determined at the Revišné 1 section, the published data about microfacies, radiolarian/calpionellid ratio, microfossil zones are insufficient (e.g. older publication on the Rochovica section; Vašíček et al., 1994). Nevertheless, calpionellids were at least commonly present in all of their studied sections.

The preservation of siliceous tests of the radiolarians compared to calcareous tests is more probable when close to the CCD depth. Moreover, changes of oligotrophy to more nutritional conditions have been associated with the calpionellid crisis (Weissert & Erba, 2004; Michalík et al., 2021). Michalík et al. (1995b) suspected, that radiolarians required more nutrients than calpionellids. They suggest that maximum development of calpionellids may represent a warm period, while maximum development of radiolarians and dinoflagellates may indicate a period with an increased intensity of upwelling. In general, sites of upwelling currents are characterised by an enormous production of siliceous plankton which can even modify the type of

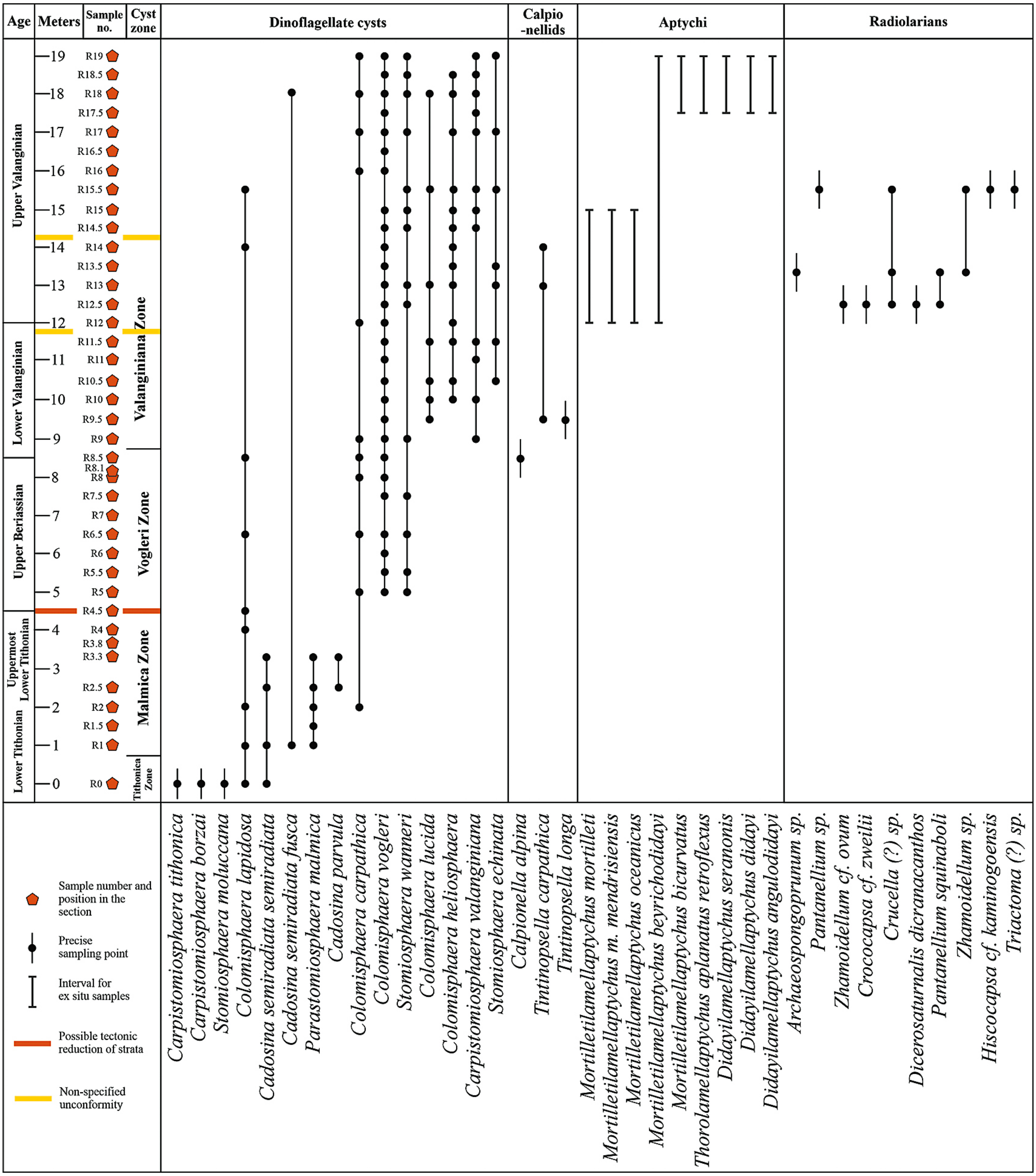

Fig. 8 Distribution of dinocysts, calpionellids, aptychi and radiolarians in the Revišné 1 section.

sediment – this can explain the maximum of radiolarian occurrence (Tremolada et al., 2006). Another fact/question needs to be taken into consideration. Is it possible, that a lack of nutrition forced radiolarians to feed on calpionellids? Even though these two planktonic groups are both protozoans, studies of recent radiolarians and tintinids show that in some cases such behaviour occurs (Capriulo, 1990; De Wever et al., 1994). Recently, bigger radiolarian genera grazing on plankton, that was in size comparable to calpionellids (Matsuoka, 2007), were observed.

It is probable that the sedimentation space of the studied Pieniny Limestone Formation from the Revišné 1 section was deeper then of the typical "biancone" facies, due to the fact that already during the Early Tithonian, and later during the latest Berriasian-Late Valanginian, there is constant presence of radiolarians and lack of calpionellids. Thus, this part of the formation could belong to a deeper stable part of the basin, which is also indicated by absence of fluctuation and markable change in microfacies. Deeper sea environment, local sites of upwelling, increased radiolarian preservation potential with increasing sedimentation rate or interaction between the plankton species may explain the lack of calpionellids and the prevalence of radiolarians. Since radiolarians were not sufficiently preserved in the limestones, additional sampling was done from cherts. Low diversity of separated radiolarian assemblages, and their wide stratigraphic ranges do not provide a sufficient base for solid dating. In addition, the sample R12.5 contains species *Zhamoidellum* cf. *ovum* Dumitrică with known stratigraphic range from Middle Oxfordian to Lower Tithonian, which is in contradiction to the Late Valanginian based on dinoflagellate cysts and aptychi. This can be explained by redeposition of radiolarians by periodical currents or contourites from older yet unconsolidated deposits. Disregarding the problematic dating of most of the chert samples, the determined stratigraphic range of the sample R13.8 (Upper Kimmeridigian - uppermost Barremian) and the sample R15.5 (Lower Tithonian - Lower Barremian) encompass the Valanginian age indicated by other stratigraphically important groups. Analysis of cherts did not bring expected refining of the age, neither did it cover the missing stratigraphical interval. Moreover, unpublished data of ammonites, and noncalcareous dinoflagelates from the uppermost part of the Revišné 1 section point to Late Valanginian age (Vašíček, Skupien, oral information).

There are three interpretations that may explain the missing layers of the Late Tithonian to Early Berriasian age. One

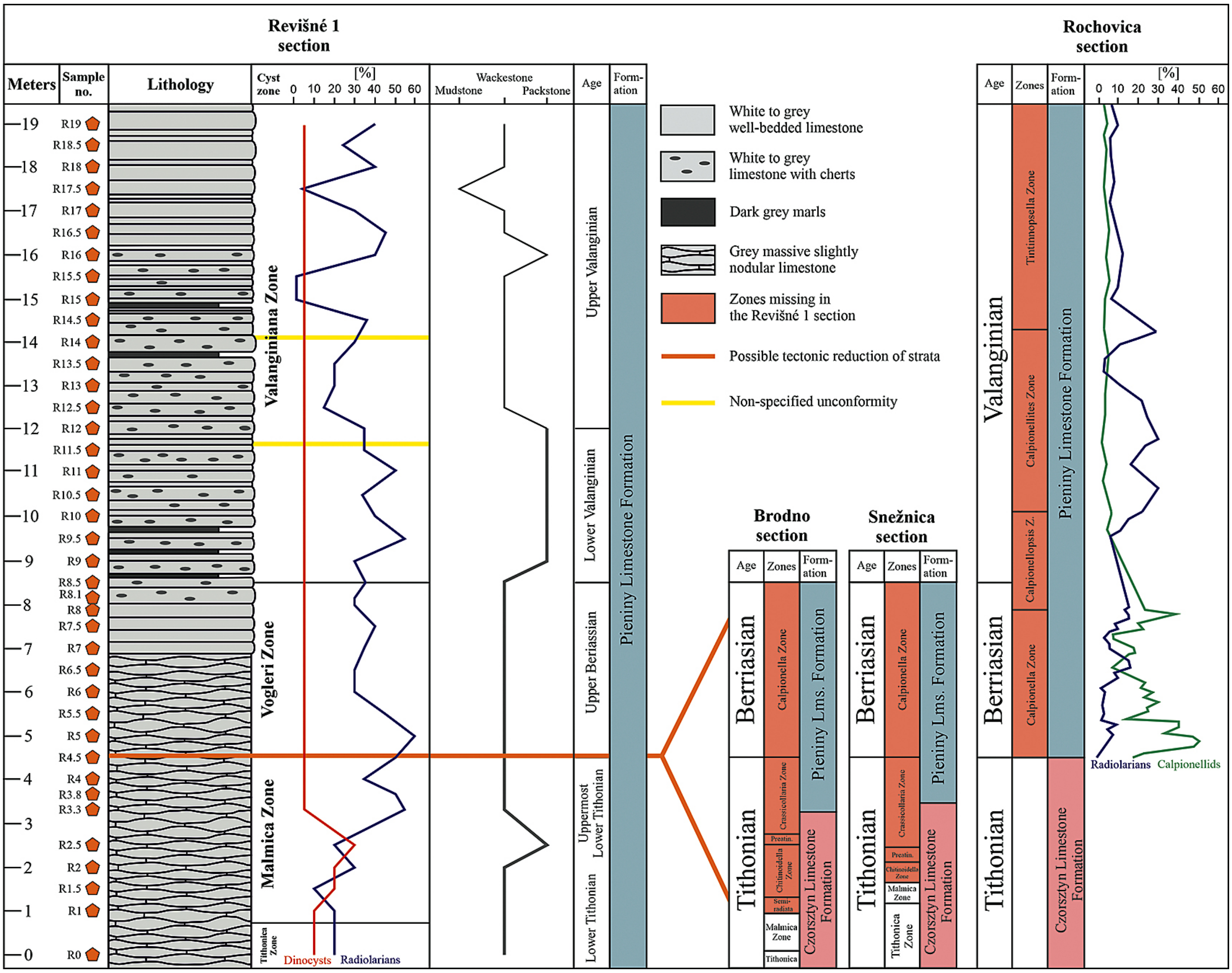

Fig. 9 Lithostratigraphic column of the Revišné 1 section (with vertical change in microfacies and quantitative distribution of dinocysts and radiolarians) compared to the Brodno, Snežnica (Michalík et al., 1999, 2021) and Rochovica sections (Michalík et al., 1995b; Vašíček et al., 1994).

explanation could be a stratigraphic hiatus (an interruption of sedimentation). Similar sedimentary hiatuses are known from other successions in the PKB, Central Western Carpathians and Peri-klippen Zone (Obermajer, 1986; Michalík et al., 2012; Michalík et al., 2021 and many others). The latter interpretation has its downside as the stratigraphic hiatus should be present also in other occurrences of the Pieniny Limestone Formation in the surrounding area. However, this was not proven. The second explanation is an erosion of sedimented, maybe also partially litified layers. However, no slumping or synsedimentary breccia were observed on the klippe. The third interpretation, and most probable, is that the lack of certain zones is a result of tectonic reduction. Nearby at Istebné, a klippe belonging to the Kysuca Succession, contains Tithonian to Valanginian Pieniny Limestone Formation (white micritic limestones with cherts) preserved only as clasts in turbiditic layers of Hauterivian age. This resedimentation might have been induced by local restricted faulting which uncovered underlying formations, not older than the Oxfordian (Aubrecht, 1994). Extensive presence of slickensides, calcite veinlets and cracks frequently leave the formation with poor preservation of tectonically unaffected limestones and could indicate a local tectonic event. Probable discordancies at sample positions R11.5-R12 and R14-R14.5, and slight change the sample in the orientation of layers is visible on the klippe but it is not related to the documented gap.

5. CONCLUSIONS

The Revišné 1 section is composed of the Pieniny Limestone Formation with determined stratigraphical range from Lower Tithonian to Upper Valanginian. Layers of the Pieniny Limestone Formation are represented by characteristic "biancone" -type limestones, suprisingly with radiolarian, *Saccocoma*-radiolarian and radiolarian-spiculitic microfacies; typical calpionellid microfacies is missing. Biostratigraphy is based on calcareous dinoflagellates, few specimens of calpionellids, radiolarians and aptychi. Lower Tithonian Tithonica and Malmica zones were determined on the base of dinoflagellate cysts. Upper Berriasian Vogleri Zone was indicated on the base of presence of *Colomisphaera vogleri* and *Stomiosphaera wanneri*, passing to the Valanginiana Zone of Early Valanginian age. This part of the section is determined by the onset of *Colomisphaera lucida, Colomisphaera heliosphaera, Carpistomiosphaera valanginiana* and *Stomiosphaera echinata* together with 4 specimens of big loricated tintinnopsellid species *Tintinnopsella carpathica and Tintinnopsella longa.* Determined sparse radiolarians represent relatively wide stratigraphic range and do not bring any expected results. The aptychi from the upper part of the section indicate Late Valanginian age. Based on the microfacies and predominance of radiolarians in the thin sections we interpret the depositional environment as deep marine with stable conditions starting already in the Early Tithonian. The studied succession could represent the deepest part of the Pieniny Basin, with possible upwelling that benefited radiolarians. The lack of certain microplankton zones could be interpreted as caused by depositional hiatus, synsedimentary slumping, or submarine erosion, but the most probable cause looks to be the tectonic reduction of the succession due to a later local tectonic event.

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