Upper Tithonian Crassicollaria Zone: new data on the calpionellid distribution and subzonal division of the Pieniny Klippen Belt in Western Carpathians

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Abstract: The study of two selected profiles of the Upper Jurassic to Lower Cretaceous sequences of the Western Carpathians enabled a revision of the calpionellid zonation used so far for this area and it resulted in the proposal of a new division of the Crassicollaria Zone. Biozonation was based on research in detail on carbonate sediments of the Pieniny Klippen Belt from the localities of Čertova skala and Kóta 720 – the ridge between Jarabina and Litmanová. The results were subsequently verified and correlated with the distribution of calpionellids in the Crassicollaria Zone in Brondo, Snežnica and Strapkova profiles. The present proporsal envisages the division of the Crassicollaria Zone into the Remanei, Intermedia and Colomi subzones. Currently, the calpionellids are important biomarkers for dating the Upper Jurassic and Lower Cretaceous pelagic carbonate sequences of the Tethyan area, the central Atlantic and the southeastern edge of the Pacific. Therefore, it is important to continue to refine and improve the calpionellid zonation in the light of new knowledge.

Key words: Calpionellid Zonation, Dinocyst Zonation, Crassicollaria Zone, subzonal division, Biostratigraphy, Microfacies, Late Jurassic, Western Carpathians

1. INTRODUCTION

The calpionellids are planktonic microorganisms with calcite shells (loricae). They represent one of the most important components of the calcareous microplankton in the Tethyan area (Allemann et al., 1971; Remane 1971; Borza 1984; Nagy 1986; Bakalova-Ivanova, 1986; Remane et al., 1986; Pop 1994; Reháková, 1995; Grün & Blau, 1997; Andreini et al., 2007; Lakova & Petrova, 2013; Benzaggagh 2020). They are also known from oceanic areas of the central Atlantic, Caribbean and Gulf of Mexico (Cuba, Mexico) as well as from southeastern edge of the Pacific (Argentina, Chile) as they were documented in the works of López-Martínez et al. (2015, 2017), Kietzmann (2017) and Kietzmann et al. (2021). The calpionellids are abundant in the Upper Jurassic and Lower Cretaceous pelagic limestone facies. They play an important role in their biostratigraphy due to their widespread distribution, rapid evolution, changing variability and diversification, onset and declination of bioevents documented so far in the areas of their occurrence. Calpionellids have not been documented in boreal areas yet (Lakova et al., 1997; Wimbledon et al., 2020a, 2020b). Especially in sediments deposited below the Aragonite Compensation Depth (ACD), the calpionellids, as the only fossils, allow the biostratigraphic zonation almost as detailed as the ammonite zonation (Grün & Blau, 1997).

Remane (1964, 1969) was responsible for the first application of calpionellids in stratigraphy. Allemann et al. (1971) were the first to introduce standard calpionellid zonation which was accepted by other scholars (Remane (1971), Borza (1984), Borza & Michalík (1986), Remane et al. (1986), Pop (1994, 1997), Reháková (1995), Reháková & Michalík (1997a, 1997b), Grün & Blau (1997), Bakalova-Ivanova (1986), Lakova et al. (1997), Andreini et al. (2007), Lakova & Petrova (2013), López-Martínez et al. (2015) and Benzaggagh (2020).

Andrusov & Koutek (1927) were the first to investigate the biostratigraphic potential of calpionellids in the sediments of the Western Carpathians. Other authors, such as Andrusov (1950), Houša et al. (1963), Borza (1969, 1974, 1980) were also dedicated to this aspect. Borza (1984) was the first to develop a parabiostratigraphic scale valid for the Western Carpathians which is based on the distribution of calpionellids and calcareous dinoflagellates. This work was later revised in terms of creation of separate calpionellids and dinocyst zonations (Reháková, 1995, 2000b). Reháková & Michalík (1997b) in addition to the calpionellid zonation still valid for dating the Upper Jurassic and Lower Cretaceous pelagic carbonate deposits of the Western Carpathians, also discussed the evolution of the calpionellids.

The published calpionellid zonations (Fig. 1) count with the possibility of determination of the following chitinoidellid and calpionellid zones and subzones: Chitinoidella Zone (Dobeni and Boneti subzones); Praetintinnopsella Zone, Crassicollaria Zone (Remanei, Intermedia, Brevis and Colomi subzones); Calpionella Zone (Alpina, Ferasini and Elliptica Subzones); Calpionellopsis Zone (Simplex and Oblonga subzones); Calpionellites Zone (Darderi and Major subzones); Tintinopsella Zone (listed chronologically from Upper Tithonian to Upper Valanginian). However, the last occurrence of *Tintinnopsella carpathica* has also been recorded from the Hauterivian deposits (Reháková, 1995). The zonation of the Western Carpathians

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PERIOD	STAGES	Substages	Allemann et al., 1971	Remane (1971)	Remane et al. (1986)	Pop (1994, 1997)	Reháková & Michalík (1997a, 1997b)	Grün a Blau (1997)	Andreini et al. (2007)	Bakalova (1977,1986)	Lakova, Stoykova (1997), Lakova et al. (1997,1999), Lakova a Petrova (2013)	López-Martinez et al. (2015)	Benzaggagh (2020)	This study (2022)
CRETACEOUS	VALANGINIAN	Upper	Calpionellites			Tintinnopsella: carpathica, cadischiana	Tintinnopsella	Tintinnopsella: gr. carpathica, gr. hungarica	Tintinnopsella		Tintinnopsella		Tintinnopsella-Lorenziella	Tintinnopsella
		Lower		E	Calpionellites	Calpionellites: major, darderi	Calpionellites: major, darderi	Calpionellites: major, darderi	Calpionellites: major, darderi	Calpionellites	Calpionellites: major, darderi		Calpionellites: Calpionellites-Tintinnopsella, Calpionellites-Oblonga	Calpionellites: major, darderi
	BERRIASIAN	Upper	Calpionellopsis	D: 3, 2, 1	Calpionellopsis: oblonga, simplex	Calpionellopsis: murgeanui, oblonga, simplex	Calpionellopsis: murgeanui, oblonga, simplex	Calpionellopsis: dadayi, murgeanui, filipescui, oblonga, simplex	Calpionellopsis: oblonga, simplex	Calpionellopsis	Calpionellopsis: murgeanui, oblonga, simplex	Calpionellopsis: oblonga	Calpionellopsis: Oblonga-Praecalpionella, Oblonga-Simplex, Simplex-Remaniella	Calpionellopsis: murgeanui, oblonga, simplex
		Lower	Calpionella	C, B	Calpionella: elliptica, Remaniella, alpina	Calpionella: longa, elliptica, ferasini, alpina	Calpionella: elliptica, ferasini, alpina	Calpionella: cadischiana, elliptica, alpina	Calpionella: cadischiana, elliptica, Remaniella, alpina	Calpionella: elliptica, Remaniella, alpina	Calpionella: elliptica, Remaniella, alpina	Calpionella: elliptica, ferasini, alpina	elliptica: Elliptica -Carpathica, Elliptica-Alpina; alpina: Alpina-Alpelliptica, Alpina-Remaniella, Alpina-Parvula	Calpionella: elliptica, ferasini, alpina
JURASSIC	TITHONIAN	Upper	Crassicollaria	A: 3, 2, 1	Crassicollaria: intermedia, remanei	Crassicollaria: colomi, intermedia, remanei; Praetintinnopsella; Chitinoidella	Crassicollaria: colomi, brevis, remanei; Praetintinnopsella; Chitinoidella: boneti	Crassicollaria: catalanoi, intermedia, remanei; Chitinoidella: andrusovi, bermudezi, boneti	Crassicollaria: intermedia, remanei; Chitinoidella: boneti	Crassicollaria; Chitinoidella	Crassicollaria: massutiniana, remanei; Praetintinnopsella; Chitinoidella: boneti	Crassicollaria: colomi	Crassicollaria: Brevis-Massutiniana, Intermedia-Alpina, Tintinnopsella-Intermedia, chitinoidelliids/ p. calpionellids; chitinoidllids: boneti	Crassicollaria: colomi, intermedia, remanei; Praetintinnopsella; Chitinoidella: boneti
		Lower					dobeni	dobeni	dobeni		dobeni		dobeni	dobeni

Fig. 1. Summary of published and used calpionellid zonations for Tithonian-Valanginian sediments from different regions of the Tehyan area, a correlation with the revised zonation for the Western Carpathians (this work).

(sensu Reháková & Michalík, 1997b) also counts with calpionellid Praecolomiella and Colomiella Zones (Mexicana and Recta subzones) with their time span from Lower Aptian to Lower Albian.

In this paper we propose a revised subzonal framework of the Crassicollaria Zone as it emerged from the study of the Čertova skala and Kóta 720 – the ridge between Jarabina and Litmaná profiles (Ölveczká, 2021), as well as the subsequent correlation with the already published Brodno, Snežnica and Strapkova sections (Michalík et al., 2009, 2016, 2021), in which a partial shift towards a new understanding and division of the Crassicollaria Zone is also visible.

1.2. Crassicollaria Zone – historical overview

Crassicollarians represent an important and diversified group of Late Tithonian pelagic microorganisms. They were among the first to produce pure calcite ("hyaline") loricae. Their ancestors either had a completely preserved microgranular structure in one of the two layers of the wall or it was only partially preserved especially on the loricae collars.

Remane (1963) introduced the Crassicollaria Zone as "A Zone". Later, Remane (1963, 1964, 1971) divided the Crassicollaria Zone based on the composition and increase in the abundance of several taxa into three subzones: basal (basale) aff. Intermedia (A1), middle (médiane) Intermedia-Alpina (A2) and upper (supérieure) Brevis-Massutiniana (A3).

Catalano & Ligouri (1971) established the Crassicollaria intermedia Zone, the lower boundary being determined on the first occurrence of *Crassicollaria intermedia*.

Allemann et al. (1971) defined the Crassicollaria Zone as an "Acme" Zone. They divided the zone into two subzones: Remanei and Massutiniana. The latter is characterized by the dominance of *Crassicollaria* species. The lower boundary is defined by the occurrence of the first calpionellids with hyaline loricae walls and the presence of small form of *Tintinnopsella carpathica*. The upper boundary is determined by the dominance of the medium-sized spherical forms of *Calpionella alpina*.

Pop (1974, 1976) separated two subzones in the Crassicollaria Zone, the lower one with the predominance of *Crassicollaria intermedia* as the Intermedia Subzone, and the upper one as the Crassicollaria brevis-Crassicollaria parvula Subzone with the predominance of *Crassicollaria brevis* and *Crassicollaria parvula*.

Bakalova (1977) and Bakalova-Ivanova (1986) recognized the Crassicollaria Zone without further division.

Remane et al. (1986) distinguished two subzones: Remanei and Intermedia. The Remanei Subzone (equivalent of „A1" Subzone in Remane (1963, 1964) is based on *Crassicollaria intermedia* dominance in the lowest part of the Crassicollaria Zone as the interval between the first calpionellid occurrence with hyaline lorica and the first occurrence of morphologically distinct *Calpionella alpina*. The Intermedia Subzone (corresponding to "A2" and "A3" Subzones in Remane (1963, 1964) is based according to the occurrence of large elongate *Calpionella alpina (Calpionella elliptalpina)* and numerous *Crassicollaria massutiniana*. The Intermedia Subzone is partially equivalent to classification in the sense of Pop (1974, 1976), Altiner & Özkan (1991) and Lakova (1993). The authors characterize this subzone according to the first occurrence of *Calpionella alpina* in its lower part and the abundant increase of a small spherical form of *Calpionella alpina* in its upper part.

Altiner & Özkan (1991) reported identical division of the Crassicollaria Zone ("A1" – "A3") as Remane (1963, 1964, 1971, 1985). The former authors characterized the "A1" Subzone according to the first occurrence of calpionellid forms with hyaline loricae. They also identified representatives of the genera *Tintinnopsella, Praetintinnopsella* and forms resembling the genus *Crassicollaria* in the subzone. Intermedia Subzone ("A2") has been designated as Massutiniana Subzone. The lower boundary of "A2" Subzone was defined on the basis of the first occurrence of the large form of *Calpionella alpina*. In this subzone *Crassicollaria intermedia* predominates, as well as a small form of *Tintinnopsella carpathica*. "A3" Subzone is defined by the dominance of *Crassicollaria brevis* over *Crassicollaria intermedia*, while *Tintinnopsella carpathica* is very rare.

Lakova (1993) introduced the Massutiniana Subzone which is equivalent to the Intermedia (according to Remane et al., 1968) and identical to the "A2" and "A3" Subzone in terms of Remane (1963, 1964) and Altiner & Özkan (1991); it also partially coincides with the Brevis-Parvula Subzone according to Pop (1974, 1976) and Reháková (1995).

Pop (1994) distinguished three subzones within the Crassicollaria Zone: Remanei, Intermedia and Colomi. He described the highest part of the Crassicollaria Zone, the Colomi Subzone, based on the first occurrence of the species *Crassicollaria colomi*. Subsequently, Pop (1997) updated the subdivision in three subzones: Parvula, Intermedia and Colomi. The first occurrence of calpionellid forms of the Parvula Subzone represents a continuous development from chitinoidellids to calpionellids. Remanei Subzone was renamed to Parvula Subzone by the author because, according to the author, the forms described as *Tintinnopsella remanei* belong to the genus *Lorenziella*. The lower boundary of Intermedia Subzone is defined on the first occurrence of the large *Calpionella alpina* and elongated *Calpionella alpina*. The first occurrence of *Crassicollaria colomi* defines the onset of the Colomi Subzone.

Reháková (1995) distinguished three subzones: Intermedia, Brevis and Colomi, where the Brevis and Colomi subzones correspond to the Intermedia Subzone in the sense of Remane et al. (1986). Intermedia Subzone was allocated according to the last occurrence of *Praetintinnopsella andrusovi* and first occurrence of *Crassicollaria intermedia*. The author separated the Brevis Subzone based on the first occurrence of *Crassicollaria brevis* and last occurrence of *Crassicollaria intermedia*. Colomi Subzone is characterized by the first occurrence of *Crassciollaria colomi* and the last occurrence of *Crassicollaria brevis*. At the end of the Colomi Subzone, the author stated the dominance of the spherical form of *Calpionella alpina*.

Grün & Blau (1997) identified three subzones within the Crassicollaria Zone: Remanei, Intermedia and Catalanoi. The lower boundary of the Remanei Subzone was defined based on the first occurrence of calpionellid forms. *Tintinnopsella remanei* is mentioned as the index-species of the subzone. Intermedia Subzone was separated according to the first occurrence of the large form of *Calpionella alpina (Calpionella grandalpina)*. The index marker of the subzone is *Crassicollaria intermedi*a. The Catalanoi Subzone was characterized by the first occurrence of species of the genus *Remaniella*.

Lakova et al. (1997) identified two subzones: Remanei based on the first occurrence of *Tintinnopsella carpathica* and Massutiniana based on the first occurrence of *Calpionella grandalpina*.

Reháková & Michalík (1997b) divide the Crassicollaria zone in three subzones: Remanei (the occurrence of crassicollarians where *Crassicollaria intermedia* is dominant), Brevis (diversified association where numerous *Crasscicollaria massutiniana* predominate over the large elongate form of *Calpionella grandalpina*) and Colomi (based on the occurrence of *Crassicollaria colomi*) according to Reháková (1995). The lower boundary of the zone was identified based on the appearance of the first crassicollarians and *Tintinnopsella remanei*.

Andreini et al. (2007) identified two subzones: Remanei and Intermedia. The Remanei subzone is based on the first occurrence of hyaline calpionellid forms. The subzone is characterized by the rare presence of *Praetintinnopsella andrusovi* and the presence of less diversified species of the genus *Crassicollaria*, small *Calpionella alpina* and *Tintinnopsella carpathica*, the occurrence of which has not been clearly documented. The Intermedia Subzone was separated according to the first occurrence of the large form of *Calpionella alpina*, small spherical *Calpionella alpina* and *Calpionella* sp. In the Intermedia Subzone, they observed diversification of *Crassicollaria* species. The occurrence of the crassicollarians is fluctuating. While in the lower part of the subzones, they are common, in the upper part they are rare. Rarely, *Tintinnopsella carpathica* can be found.

Lakova & Petrova (2013) defined two subzones: Remanei and Massutiniana. The remanei Subzone was allocated based on the first occurrence of *Tintinnopsella remanei* in the lower part and *Calpionella grandalpina* in the upper part of the subzone. *Crassicollaria intermedia* appeared higher. The Massutiniana Subzone was defined by the first occurrence of *Calpionella grandalpina* in the lower part and the last occurrence of *Calpionella elliptalpina* in the upper part of the subzone. Petrova et al. (2019) also mentioned the Colomi Subzone of the Yavorets profile in Western Balkan Mts.

López-Martínez et al. (2015) did not divided the Crassicollaria Zone due to radiolarian-rich facies and the sporadic presence of calpionellids. The calpionellid associations documented by authors included species such as *Crassicollaria intermedia, Crassicollaria parvula, Crassicollaria colomi, Crassicollaria brevis, Tintinnopsella remanei, Calpionella grandalpina, Calpionella alpina* and *Tintinnopsella carpathica*.

Kowal-Kasprzyk (2018) identified two subzones: Remanei and Intermedia. In the Remanei Subzone, *Tintinnopsella remanei, Tintinnopsella carpathica, Crassicollaria intermedia, Crassicollaria massutiniana, Crassicollaria parvula* and the rare occurrence of *Praetintinnopsella andrusovi* were observed. *Crassicollaria intermedia, Crassicollaria parvula, Crassicollaria massutiniana, Calpionella alpina, Calpionella elliptalpina, Calpionella grandalpina and Tintinnopsella carpathica* were present in the Intermedia Subzone, but *Crassicollaria brevis* and *Crassicollaria colomi* were absent.

Benzaggagh (2020) identified four subzones in the Crassicollaria Zone: chitinoidellids/primitive calpionellids, Tintinnopsella-Intermedia, Intermedia-Alpina, Brevis-Massutiniana. According to the author, the latter subzone extends to the Lower Berriasian. The Remanei Subzone is replaced by the chitinoidellids/primitive calpionellids and Tintinnopsella-Intermedia subzones, where *Praetintinnopsella* and *Tintinnopsella remanei* also occasionally appear. The Intermedia-Alpina Subzone is equivalent to the Intermedia Subzones of Remane et al. (1986), Pop (1994) and Brevis Subzone sensu Reháková & Michalík (1997b). Within the Brevis/Massutiniana Subzone, he has allocated the Brevis/Massutiniana and Parvula/Elliptalpina interval horizons.

The Crassicollaria Subzone has so far been described in the following areas: France (Remane, 1963, 1971; Le Hėgarat & Remane, 1968; Cecca et al., 1989, Wimbledon et al., 2013, 2020a, 2020b; Benzaggagh et al., 2020), Italy (Catalano & Liguori, 1971; Channell & Grandesso, 1987; Grün & Blau, 1997; Andreini et al., 2007; Houša et al., 2004), Spain (Allemann et al., 1975; Pruner et al., 2010; Hoedemaeker et al., 2016), Slovakia (Borza, 1984; Borza & Michalík, 1986; Reháková, 1995; Reháková & Michalík, 1997a, 1997b; Houša et al., 1999a, 1999b; Michalík et al., 2009; Grabowski et al., 2010b), Czech Republic (Svobodová et al., 2019; Košťák et al., 2018; Elbra et al., 2018), Poland (Wierzbowski & Remane, 1992; Pszczółkowski, 1996; Pszczółkowski & Myczyński, 2004; Grabowski & Pszczółkowski, 2006), Ukraine (Reháková et al., 2011; Bakhmutov et al., 2018; Grabowski et al., 2019), Romania (Pop, 1974, 1986a, 1986b, 1994, 1997; Barbu & Melinte-Dobrinescu, 2008), Hungary (Grabowski et al., 2010a), Austria (Reháková & Michalík, 1996; Lukeneder et al., 2010), Greece (Skourtsis-Coroneou & Solakius, 1999), Turkey (Altiner & Özkan, 1991), Iran (Azimi et al., 2008), Tunisia (Boughdiri et al., 2006, 2009 – similar to the described "A Zone" by Remane (1963) in Tunisia (Ben Abdesselam-Mahdaoui et al., 2010)), Morocco (Benzaggagh & Atrops, 1995; Benzaggagh et al., 2010), Cuba (Pop, 1976; Pszczółkowski et al., 2005; Pszczółkowski & Myczyński, 2010; López-Martínez et al., 2013a), Mexico (Trejo, 1980; Adatte et al., 1994, López-Martínez et al., 2013b, 2015), Bulgaria (Bakalova, 1977; Lakova, 1993; Lakova et al., 1999; Ivanova, 1997; Ivanova et al., 2002; Lakova & Petrova, 2013; Petrova et al., 2019), Serbia (Lakova et al., 2009, Petrova et al., 2012), Slovenia (Reháková & Rožič, 2019), Argentina (Lopéz-Martínez et al., 2017; Kietzmann et al., 2021).

2. STUDIED AREA

The studied sections are located in the Prešov region, northeastern part of Slovakia (Fig. 2). From a geological point of view, it is part of the Pieniny Klippen Belt. The localities Čertova skala and Kóta 720 – the ridge between Jarabina and Litmanová were selected for the purpose of this study. The study was focused on the microfacies analysis of their Upper Jurassic and Lower Cretaceous sediments. According to Plašienka & Mikuš (2010), the studied localities belong to the Subpieniny Unit of the Oravicum.

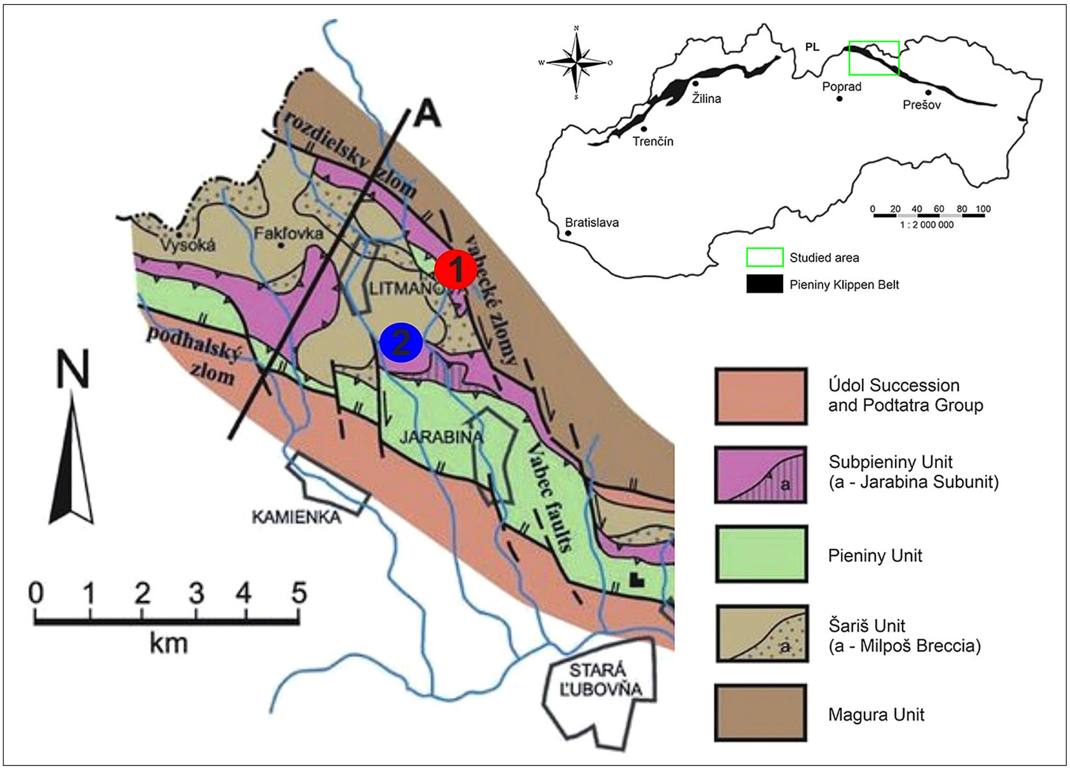

Fig. 2. Localization of Čertova skala (red, 1) and Kóta 720 (blue, 2) sections in the Pieniny sector of the Pieniny Klippen Belt in the eastern Slovakia; localities situated in the frame of tectonic units as were proposed in Pieniny and Šariš sector of the Pieniny Klippen Belt by Plašienka & Mikuš (2010).

3. METHODS

From the Čertova skala profile 27 samples were taken (ČS-1 to ČS-22) and from the Kóta 720 profile were taken 22 samples (Kóta 720-1 to Kóta 720-15.7). The samples were used to prepare thin-sections for microfacies analysis and micropaleontology. They were studied under a Leica DM 2500 transmission light microscope. The microfacies and microfossils were documented with an Axiocam ERc 5s camera and processed by the ZEISS ZEN software program. Lithofacies types of deposits were assigned to the formations as introduced by Birkenmajer (1977). The biostratigraphy of the studied sediments was based on calpionellid zonation according to Reháková & Michalík (1997b) and calcareous dinoflagellate cyst zonation according to Reháková (2000a). The microfacies were interpreted according to Dunham (1962). The standard microfacies (SMFs) and facies zones (FZs) were defined according to Wilson (1975) and modified after Flügel (2004). CorelDRAW® Graphics Suite X5 was used for graphic visualization of the studied data. The samples and thin-sections are stored at the Faculty of Science of Comenius University in the archive of the Department of Geology and Paleontology.

4. DESCRIPTION OF PROFILES

4.1. Čertova skala profile

Čertova skala profile is situated in the Jarabinské tiesňavy north of the breakthrough Jarabina. The outcrop lies between the villages Litmanová and Jarabina (N: 49°21' 28.0"; E: 20°39' 08.1") (Fig. 2). According to Plašienka & Mikuš (2010), the profile is formed by sediments of the Czorsztyn succession (Fig. 2).

The klippe (Fig. 3) with a length of 21 m is formed by massive pinkish bench-like nodular limestone of the Czorsztyn Formation (samples 0 to 7). Higher up the lithology changes. Pale

Fig. 3. View of the Čertova skala klippe.

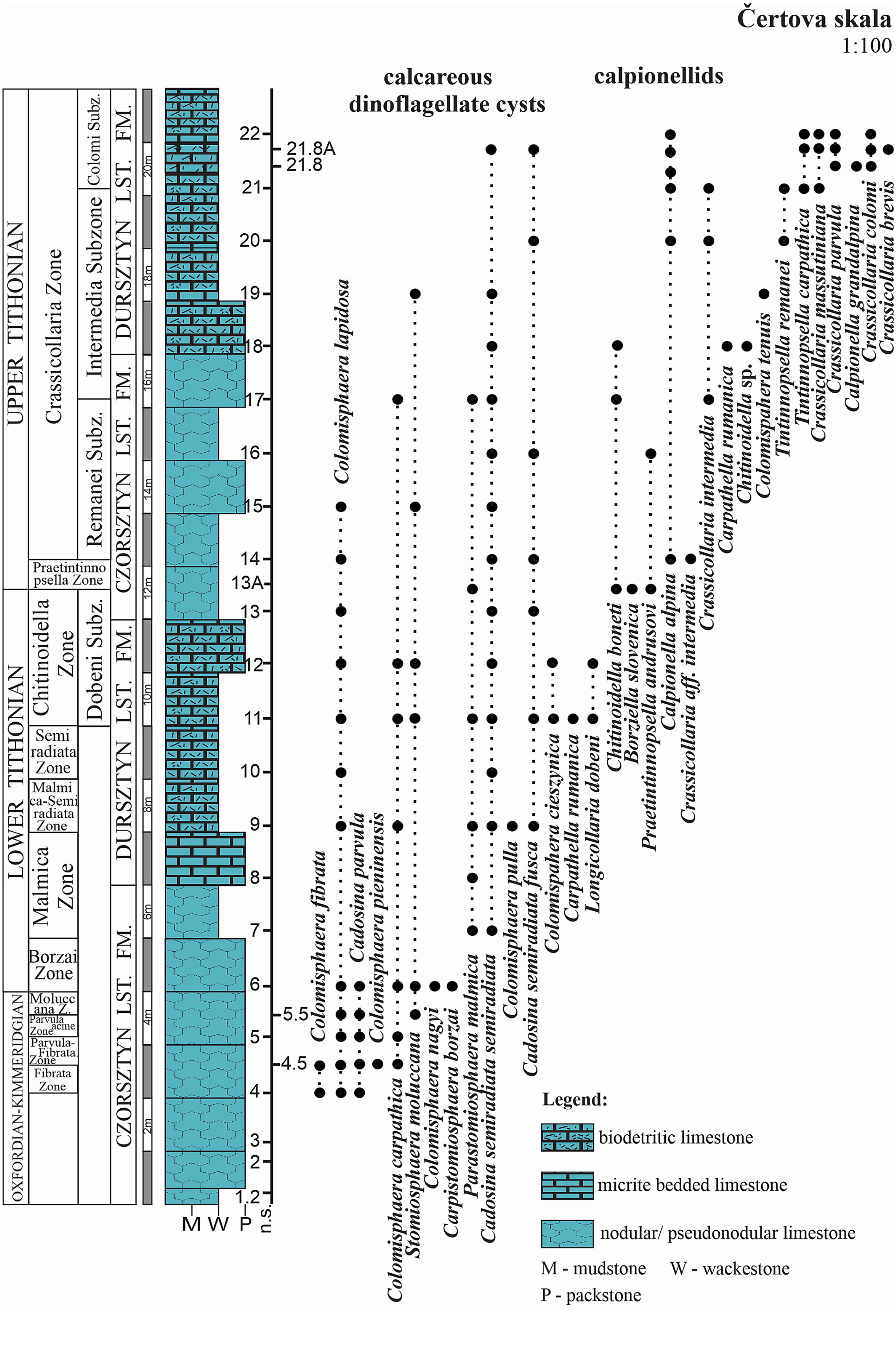

Fig. 4. Lithology and distribution of calcareous dinoflagellates and calpionellids in Čertova skala section with calpionellid and dinoflagellate cyst biozonation.

micrite bedded limestone of the Dursztyn Limestone Formation (sample 8) appear, passing up-section into more biodetritic limestone variety of the same formation (samples 9 to 12). The nodular limestone of the Czorsztyn Formation (samples 13 to 17) and the biodetritic limestone of the Durstzyn Limestone Formation (samples 18 to 22) are higher above. The sampling interval was 1 m, the sampling was concentrated locally (Fig. 4).

4.2. Microfacies analysis and biostratigraphy

The sequence of Upper Oxfordian to Upper Tithonian deposits was confirmed on the klippe (from the calcareous dinocyst Fibrata Zone to calpionellid Colomi Subzone of standard Crassicollaria Zone). The dinocyst Tithonica Zone and calpionellid Boneti Subzone of Chitinoidella Zone were not detected in the studied sequence.

ČS-1.2; ČS-2; ČS-3

Biomicrite limestone with *Protoglobuligerina* (Fig. 5-1), *Globochaete-Protoglobuligerina* microfacies (wackestone to packstone, SMF 2, 3). They contain crinoid fragments, juvenile ammonites, ostracods, ophiuroids, globochaetes, bivalves, aptychi, foraminifera – *Spirilina* sp., *Nodosaria* sp., *Protomarssonella* sp., *Frondicularia* sp., echinoids, rhyncholits. The Oxfordian age of sediments is considered on the basis of their superposition.

ČS-4

Pelbiomicrosparite limestone with *Protoglobuligerina* microfacies (packstone) with transition to finely laminated biomicrite limestone of crinoid-foraminifera microfacies (wackestone, SMF 2) with planktonic foraminifera Protoglobuligerina sp., benthic foraminifera – *Spirilina* sp., *Nodosaria* sp., *Lenticulina* sp., crinoid fragments, juvenile ammonites, echinoids, globochaetids, ostracods, bivalves, aptychi, rhyncholits, ophiurds, fragments of foraminifera – *Protomarssonella* sp., *Frondicularia* sp. and dinocysts *Colomisphaera fibrata* (Fig. 6-1), *Colomisphaera lapidosa* and *Cadosina parvula*. **Fibrata Zone, Upper Oxfordian**.

ČS-4.5

Pelbiomicrosparite limestone of filamentous-*Protoglobuligerina* microfacies (wackestone to packstone, SMF 2, 3). It contains filaments, crinoid fragments, juvenile ammonites, ostracods, thick-walled bivalves, aptychi, foraminifera – *Protoglobuligerina* sp., *Lenticulina* sp., *Spirilina* sp., *Nodosaria* sp., *Protomarssonella* sp., echinoids, ophiuroids, globochaetes, *Saccocoma* sp. (Fig. 5-7). The frequent dinocysts of *Colomisphaera fibrate* and *Cadosina parvula* (Fig. 6-2) dominates over *Colomisphaera lapidosa*, *Colomisphaera pieninensis* (Fig. 6-3) and *Colomisphaera carpathica*. **Transition between Fibrata and Parvula Zone, Upper Oxfordian**.

ČS-5

Biodetritic limestone of filamentous microfacies (packstone, SMF 2) with numerous filaments, less abundant *Protoglobuligerina* sp., aptychi, crinoid fragments, juvenile ammonites, ostracods, thick-walled bivalves, saccocoma elements are increasing, present are also foraminifera – *Lenticulina* sp., *Nodosaria* sp., *Gaudryina* sp.; among dinocysts *Cadosina parvula* is abundant, less abundant are *Colomisphaera carpathica* (Fig. 6-4) and Colomisphaera lapidosa. **Acme Parvula Zone, Lower Kimmeridgian**.

ČS-5.5

Pelbiomicrite limestone of *Saccocoma*-filamentous microfacies (packstone, SMF 2).

It contains crinoid fragments, bivalves, sporadic protoglobuligerinids, aptychi, *Laevaptychus* sp., juvenile ammonites, ostracods, very rare globochaetes, calcified radiolarians, echinoids, foraminifera – *Spirilina* sp., *Lenticulina* sp., *Protomarssonella* sp., dinocysts of *Stomiosphaera moluccana* (Fig. 6-5), *Cadosina parvula* and *Colomisphaera lapidosa*. The sediment is bioturbated, fragments of bivalves and aptychi bear traces of boring and are significantly recrystallized. **Moluccana Zone, Lower Kimmeridgian**.

ČS-6

Biomicrite limestone of *Saccocoma-Globochaete* microfacies (packstone with transitions to wackestone, SMF 2, 3). It contains crinoid fragments, bivalves, protoglobuligerinid foraminifera, aptychi, juvenile ammonites, ostracods, globochaetes, ophiuroids, foraminifera – *Spirilina* sp., *Lenticulina* sp., *Protomarssonella* sp., *Involutina* sp. (Fig. 5-8), dinocysts of *Carpistomiosphaera borzai* (Fig. 6-6), *Colomisphaera lapidosa, Stomiosphaera moluccana, Cadosina parvula, Colomisphaera nagyi* (Fig. 6-7), *Colomisphaera carpathica*. **Borzai Zone, Upper Kimmeridgian**.

ČS-7; ČS-8

Biomicrite limestone of *Saccocoma-Globochaete, Globochaete-Saccocoma microfacies* (wackestone with transitions to packstone, SMF 2, 3). It contains crinoid fragments, bivalves, aptychi, juvenile ammonites, ostracods, globochaetes, ophiuroids, echinoids, foraminifera – *Spirilina* sp., *Lenticulina* sp., *Protomarssonella* sp., dinocysts represented by abundant *Parastomiosphaera malmica* (Fig. 6-8) dominated over less frequent *Cadosina semiradiata semiradiata*. **Malmica Zone, upper part of Lower Tithonian**.

ČS-9

Biomicrite limestone with *Globochaete-Saccocoma* microfacies (wackestone, SMF 3). Limestone contains juvenile ammonites, crinoid fragments, bivalves, aptychi, ostracods, *Saccocoma* sp., globochaetes, foraminifera – *Nubecularia* sp. Dinocysts of *Colomisphaera pulla* are common (Fig. 6-9), less frequent are *Cadosina semiradiata semiradiata, Cadosina semiradiata fusca, Parastomiosphaera malmica, Colomisphaera carpathica and Colomisphaera lapidosa*. **Transition interval between Malmica and Semiradiata zones, upper part of Lower Tithonian**.

ČS-10

Biomicrite limestone of *Globochaete-Saccocoma* microfacies (wackestone SMF 3).

It contains planktonic crinoids, *Saccocoma* sp., algae spores of *Globochaete alpina*, juvenile ammonites, crinoid fragments, bivalves, aptychi, ostracods, rhyncholits, ophiuroids, foraminifera – *Spirilina* sp., *Lenticulina* sp., dinocysts of *Colomisphaera* *lapidosa, Cadosina semiradiata semiradiata*. **Semiradiata Zone, upper part of Lower Tithonian.**

ČS-11; ČS-12; ČS-13

Biomicrite limestone of *Saccocoma-Globochaete* (Fig. 5-2) and *Globochaete-Saccocoma* microfacies (wackestone with transitions to packstone, SMF 2, 3). It contains *Saccocoma* sp., globochaetes, juvenile ammonites, crinoid fragments, bivalves, aptychi, ostracods, calcifed radiolarians, rhyncholits (Fig. 5-5), ophiuroids, foraminifera – *Spirilina* sp., *Lenticulina* sp., *Nodosaria* sp., *Gaudryina* sp. (Fig. 5-11), *Scherochorella* sp. (Fig. 5-2), *Eomarssonella* sp. (Fig. 5-11). Calpionellids are represented by *Longicollaria dobeni* (Fig. 6-16), *Carpathella rumanica* (Fig. 6-15). Dinoysts of *Cadosina semiradiata fusca* (Fig. 6-12), *Cadosina semiradiata semiradiata, Colomisphaera lapidosa* (Fig. 6-11), *Colomisphaera carpathica, Parastomiosphaera malmica, Colomisphaera cieszynica* (Fig. 6-10) and *Stomiosphaera moluccana* were observed. **Chitinoidella Zone, Dobeni Subzone, upper-most part of Lower Tithonian.**

ČS-13A

Biomicrite limestone of *Globochaete-Saccocoma* microfacies (wackestone to packstone, SMF 2, 3). It contains *Saccocoma* sp., globochaetes, crinoid fragments, juvenile ammonites, bivalves, aptychi, ostracods, echinoids, occasional calcified radiolarians, foraminifera – *Pseudomarssonella* sp., calpionellids – *Praetintinnopsella andrusovi, Chitinoidella boneti, Borziella slovenica,* dinocysts of *Parastomiosphaera malmica*. **Praetintinnopsella Zone, lower part of Upper Tithonian.**

ČS-14; ČS-15; ČS-16

Biomicrite limestone with clasts (nodules) of *Saccocoma-Globochaete, Saccocoma*-radiolarian and radiolarian-*Saccocoma* microfacies (wackestone to packstone, SMF, 2) in which followed microfossils were documented: *Saccocoma* sp., globochaetes, juvenile ammonites, crinoid, and bivalves fragments, aptychi, ostracods, calcified radiolarians, ophiuroids, foraminifera – *Spirilina* sp., *Lenticulina* sp., *Nodosaria* sp., *Gaudryina* sp., *Pseudomarssonella* sp., miliolid foraminifera, dinocysts – *Cadosina semiradiata fusca, Cadosina semiradiata semiradiata* (Fig. 6-13), *Colomisphaera lapidosa, Stomiosphaera moluccana*, calpionellids – *Praetintinnopsella andrusovi* (Fig. 6-17), *Calpionella alpina* and *Crassicollaria* aff. *intermedia*. The age is detected on the base of superposition as **Crassicollaria Zone, Remanei Subzone, Upper Tithonian**.

ČS-17; ČS-18; ČS-19; ČS-20; ČS-21

Biomicrite limestone of *Saccocoma, Saccocoma*-radiolarian (Fig. 5-3) and calpionellid-*Saccocoma-Globochaete* microfacies (wackestone passing to packstone). Limestone contains crinoid, and bivalve fragments, aptychi, ostracods, globochaetes, juvenile ammonites, calcified radiolarians, gastropods, echinoids, foraminifera – *Spirilina* sp., *Lenticulina* sp. (Fig. 5-10), *Frondicularia* sp., *Nodosaria* sp., *Paleogaudryina* sp. (Fig. 5-9), miliolid foraminifera, dinocysts of *Colomisphaera carpathica, Cadosina semiradiata semiradiata, Cadosina semiradiata fusca, Parastomiosphaera malmica, Colomisphaera tenuis* (Fig. 6-14) and *Stomiosphaera moluccana*. In calpionellid association dominated by *Crassicollaria intermedia* (Fig. 6-19), *Crassicollaria massutiniana, Calpionella alpina* over *Tintinnopsella carpathica* and *Tintinnopsella remanei* (Fig. 6-20), *Chitinoidella boneti* (Fig. 6-18), *Carpathella rumanica* were rarely observed. **Crassicollaria Zone, Intermedia Subzone, Upper Tithonian.**

ČS-21.8; ČS-21.8A; ČS-22

Biodetritic limestone with calpionellid, calpionellid-radiolarian-*Globochaete*, calpionellid-*Globochaete* microfacies (wackestone, SMF 2, 3). Small forms of *Calpionella alpina* dominated (Fig. 6-25) over *Crassicollaria parvula* (Fig. 6-22) and rare *Crassicollaria brevis* (Fig. 6-24), *Crassicollaria colomi* (Fig. 6-23), *Crassicollaria massutiniana* (Fig. 6-21) and small forms of *Tintinnopsella carpathica*. Calpionellids are accompanied with bivalves, aptychi and crinoid fragments, calcified radiolarians, globochaetes, juvenile ammonites, echinoids, rhyncholits, saccocomas, foraminifera – *Lenticulina* sp., *Spirilina* sp., *Pseudovalvulina* sp., *Paleogaudryina* sp. (Fig. 5-6) and dinocysts *Cadosina semiradiata fusca, Cadosina semiradiata semiradiata*. In the sample ČS-21,8, a microdyke filled with pelbioclastic sediment was observed (Fig. 5-4). **Crassicollaria Zone, Colomi Subzone, Upper Tithonian.**

4.3. Kóta 720 – ridge between Jarabina and Litmanová profile

The klippe Kóta 720 is situated between the villages Litmanová and Jarabina (N: 49°21’10.0”; E: 20°38’18.8”) (Fig. 2). The profile documented measures approximately 14 m. Samples were taken at 1 m interval, sampling was locally concentrated at half meter intervals. According to Plašienka & Mikuš (2010), deposits studied belong to the Czorsztyn succession (Fig. 2).

The profile (Fig. 7) begins with 10 cm brown-pink massive nodular to pseudonodular limestone of the Czorsztyn Formation (samples 1 to 2), which about 4 m above pass into fine-grained nodular limestones of the same formation (samples 3 to 5). The overlying bed (sample 6) is composed of limestone with partially pseudonodular texture passing into biodetritic limestone. The character of the lithology does not change higher, in some places the fine-grained biodetritic limestones of the Dursztyn Limestone Formation contain more abundant crinoid fragments (sample 7 to 8). Higher up (sample 9), the inclination of layers changes and the profile is interrupted at an interval of 1 m (sample 10). The bedded biomicrite limestone of the Dursztyn Limestone Formation continues till the top of the section (samples 11 to 15,7) (Fig. 8).

4.4. Microfacies analysis and biostratigraphy

In the studied profile, the sequence of Upper Tithonian to Lower Valanginian deposits was confirmed (from the Remanei Subzone of the standard Crassicollaria Zone to the Darderi Subzone of the Calpionellites Zone).

Kóta 720-1

Biomicrite limestone *Protoglobuligerina*-filamentous microfacies (Fig. 9-1) (packstone, SMF 2) with abundant dinocysts of *Cadosina parvula* (Fig. 10-5). The limestone contains fragments

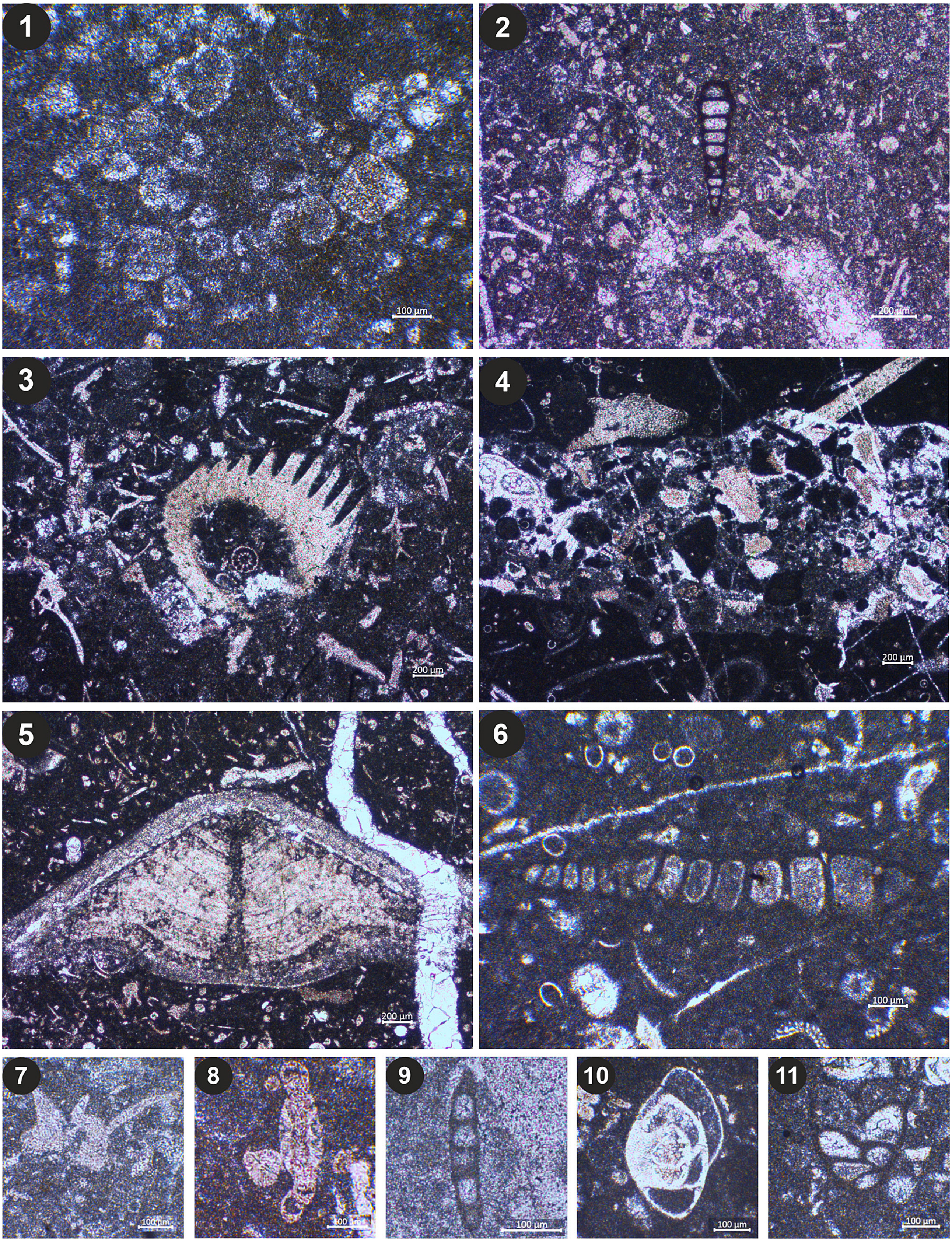

Fig. 5. Microfacies of Čertova skala: 1 – *Protoglobuligerina* microfacies, sample ČS-1.2. 2 – *Saccocoma-Globochaete* microfacies, agglutinated foraminifera *Scherochorella* sp., sample ČS-11. 3 – *Saccocoma*-radiolarian microfacies, aptychus, sample ČS-19. 4 – microdyke with pelbioclastic sediment, sample ČS-21.8. 5 – rhyncholit, sample ČS-11. 6 – *Paleogaudryina* sp., sample ČS-22. 7 – *Saccocoma* sp., sample ČS-4.5. 8 – *Involutina* sp., sample ČS-6. 9 – *Paleogaudryina* sp., sample ČS-19. 10 – *Lenticulina* sp., sample ČS-21. 11 – *Eomarssonella* sp., sample ČS-13. Light microscope Leica DM 2500 with Axiocam ERc 5s digital camera.

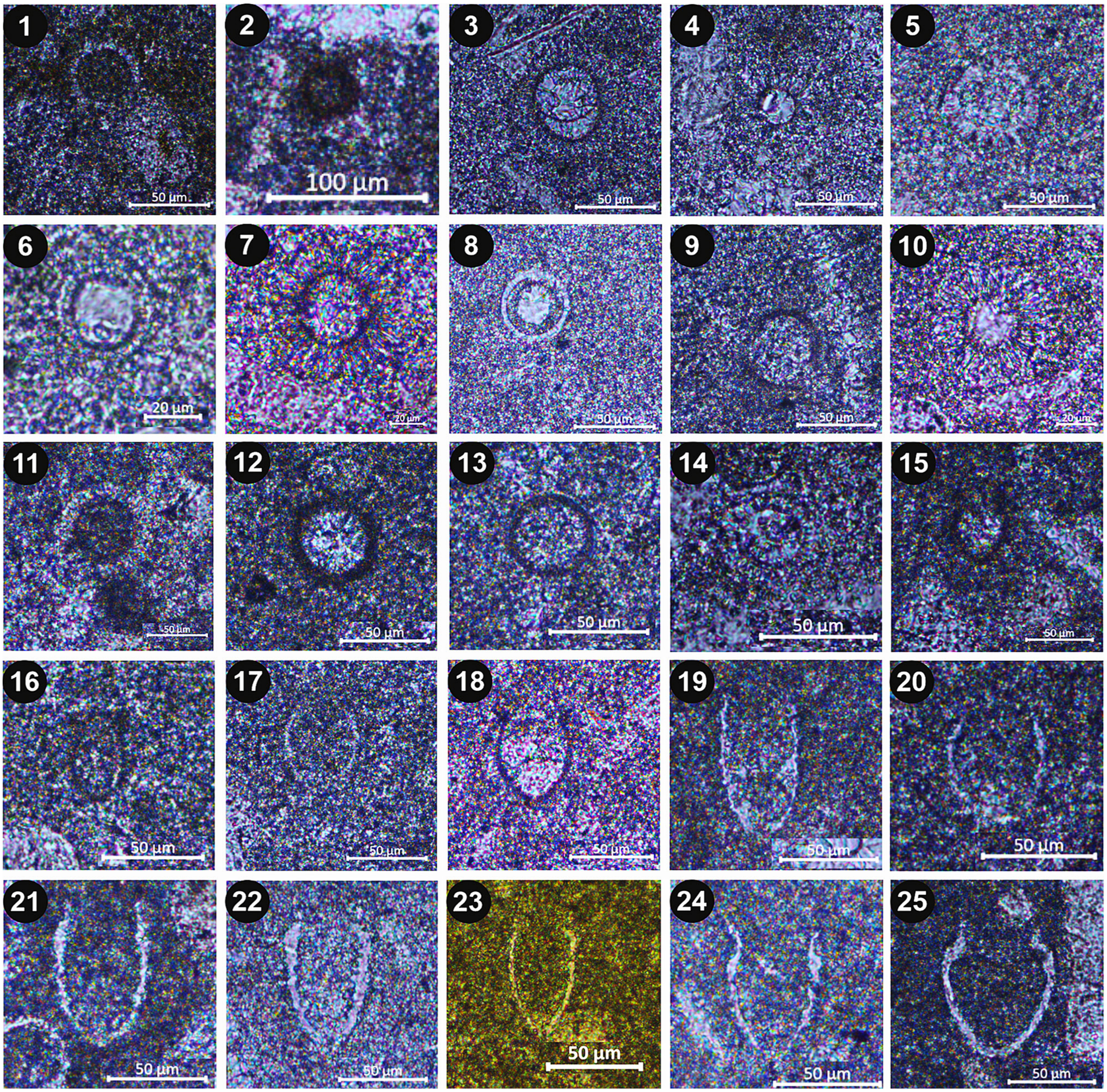

Fig. 6. Calcareous dinoflagellate cysts and calpionellids of Čertova skala: 1 – *Colomisphaera fibrata* (Nagy), sample ČS-4. 2 – *Cadosina parvula* (Nagy), sample ČS-4.5. 3 – *Colomisphaera pieninensis* (Borza), sample ČS-4.5. 4 – *Colomisphaera carpathica* (Borza), sample ČS-5. 5 – *Stomiosphaera moluccana* (Wanner), sample ČS-5.5. 6 – *Carpistomiosphaera borzai* (Nagy), sample ČS-6. 7 – *Colomisphaera nagyi* (Borza), sample ČS-6. 8 – *Parastomiosphaera malmica* (Borza), sample ČS-7. 9 – *Colomisphaera pulla* (Borza), sample ČS-9. 10 – *Colomisphaera cieszynica* (Nowak), sample ČS-11. 11 – *Colomisphaera lapidosa* (Vogler), sample ČS-11. 12 – *Cadosina semiradiata fusca* (Wanner), sample ČS-13. 13 – *Cadosina semiradiata semiradiata* (Wanner), sample ČS-16. 14 – *Colomisphaera tenuis* (Nagy), sample ČS-19. 15 – *Carpathella rumanica* Pop, sample ČS-11. 16 – *Longicollaria dobeni* (Borza), sample ČS-11. 17 – *Praetintinnopsella andrusovi* (Borza), sample ČS-16. 18 – *Chitinoidella boneti* (Doben), sample ČS-18. 19 – *Crassicollaria intermedia* (Durand-Delga), sample ČS-20. 20 – *Tintinnopsella remanei* (Borza), sample ČS-20. 21 – *Crassicollaria massutiniana* (Colom), sample ČS-21.8A. 22 – *Crassicollaria parvula* (Nagy), sample ČS-21.8A. 23 – *Crassicollaria colomi* (Doben), sample ČS-21.8A. 24 – *Crassicollaria brevis* Remane, sample ČS-21.8A. 25 – *Calpionella alpina* (Lorenz), sample ČS-22. Light microscope Leica DM 2500 with Axiocam ERc 5s digital camera.

of bivalves and crinoids, ostracods, aptychi, calcified radiolarians, juvenile ammonites, spores of *Globochaete alpina*, foraminifera – *Spirilina* sp., dinocysts *Colomisphaera lapidosa, Colomisphaera carpathica* and *Colomisphaera fibrata*.

Kóta 720-2; Kóta 720-2,5

Biomicrite limestone calpionellid-*Globochaete* microfacies (packstone, SMF 3) accompanied by *Saccocoma* sp., juvenile ammonites, aptychi, crinoids, calcified radiolarians, foraminifera – *Lenticulina* sp., calpionellids *Tintinnopsella remanei, Calpionella alpina, Crassicollaria intermedia* (Fig. 10-10), *Crassicollaria massutiniana*. From dinocysts *Colomisphaera minutissima* and *Colomisphaera carpathica* are present. **Crassicollaria Zone, Remanei Subzone, Upper Tithonian.**

No clear discordance is visible in the layered sequence between the limestones of this microfacies and the above-mentioned *Protoglobuligerina*-filamentous microfacies. It can be hidden, which is quite common in the klippen zone. However, if we consider the sequence to be continuous, the sediment represented by the sample Kóta 720-1 can be interpreted as redeposited.

Kóta 720-3

Bioclastic limestone (wackestone, SMF 3) *Calpionella-Globochaete* microfacies (Fig. 9-2) with abundant bioclast fragments – juvenile ammonites, crinoids, aptychi, foraminifera *Spirilina* sp., bivalves, abundant calpionellids *Crassicollaria pravula* (Fig. 10-9), *Crassicollaria intermedia, Calpionella alpina, Calpionella grandalpina* and *Crassicollaria massutiniana*. **Crassicollaria Zone, Intermedia Subzone, Upper Tithonian.**

Kóta 720-4; Kóta 720-4.5

Bioclastic limestones of calpionellid-*Globochaete* microfacies (wackestone, SMF 3) with fragments of crinoids, aptychi, foraminifera – *Spirilina* sp., *Lenticulina* sp., bivalves, juvenile ammonites, calcified radiolarians; very sporadic saccocomas can also be observed. The small form of *Calpionella alpina* (Fig. 10-12) predominates over *Crassicollaria pravula*, sporadic *Crassicollaria brevis* (Fig. 10-11), *Crassicollaria colomi* (Fig. 10-13), *Tintinopsella carpathica* and dinocysts of *Colomisphaera lapidosa* and *Colomisphaera minutissima*. **Crassicollaria Zone, Colomi Subzone, Upper Tithonian.**

Fig. 7. View of the Kóta 720.

Kóta 720-5; Kóta 720-5.0

Bioclastic limestones of calpionellid-*Globochaete* microfacies (wackestone, SMF 3). They contain more abundant spores of *Globochaete alpina* accompanied by crinoid fragments, juvenile ammonites, ostracods, aptychi, *Laevaptychus* sp., foraminiferas with calcite shells – *Spirillina* sp., *Lenticulina* sp., *Frondicularia* sp. and calcified radiolarians. *Calpionella alpina* dominates over *Crassicollaria parvula, Tintinnopsella carpathica*. Quite rare *Calpionella elliptalpina, Calpionella grandalpina, Crassicollaria brevis, Crassicollaria intermedia* and *Crassicollaria massutiniana* can be attributed to their redeposition. **Calpionella Zone, Alpina Subzone, Lower Berriasian.**

Kóta 720-6

Bioclastic limestones of calpionellid-*Globochaete* microfacies (Fig. 9-3) (wackestone, SMF 3). They contain crinoid fragments, juvenile ammonites, ostracods, bivalves (Fig. 9-3), calcified radiolarians, echinoids, aptychi, ophiuroids, probably resedimented fragments of *Saccocoma* sp., foraminifera *Pseudomarssonella* sp., *Dentalina* sp., *Spirilina* sp., *Lenticulina* sp., *Gaudryina* sp. In association of calpionellids *Calpionella alpina* dominates over sporadic *Calpionella grandalpina* (Fig. 10-14), *Calpionella alpelliptica, Crassicollaria intermedia, Crassicollaria massutiniana, Crassicollaria pravula, Remaniella catalanoi*

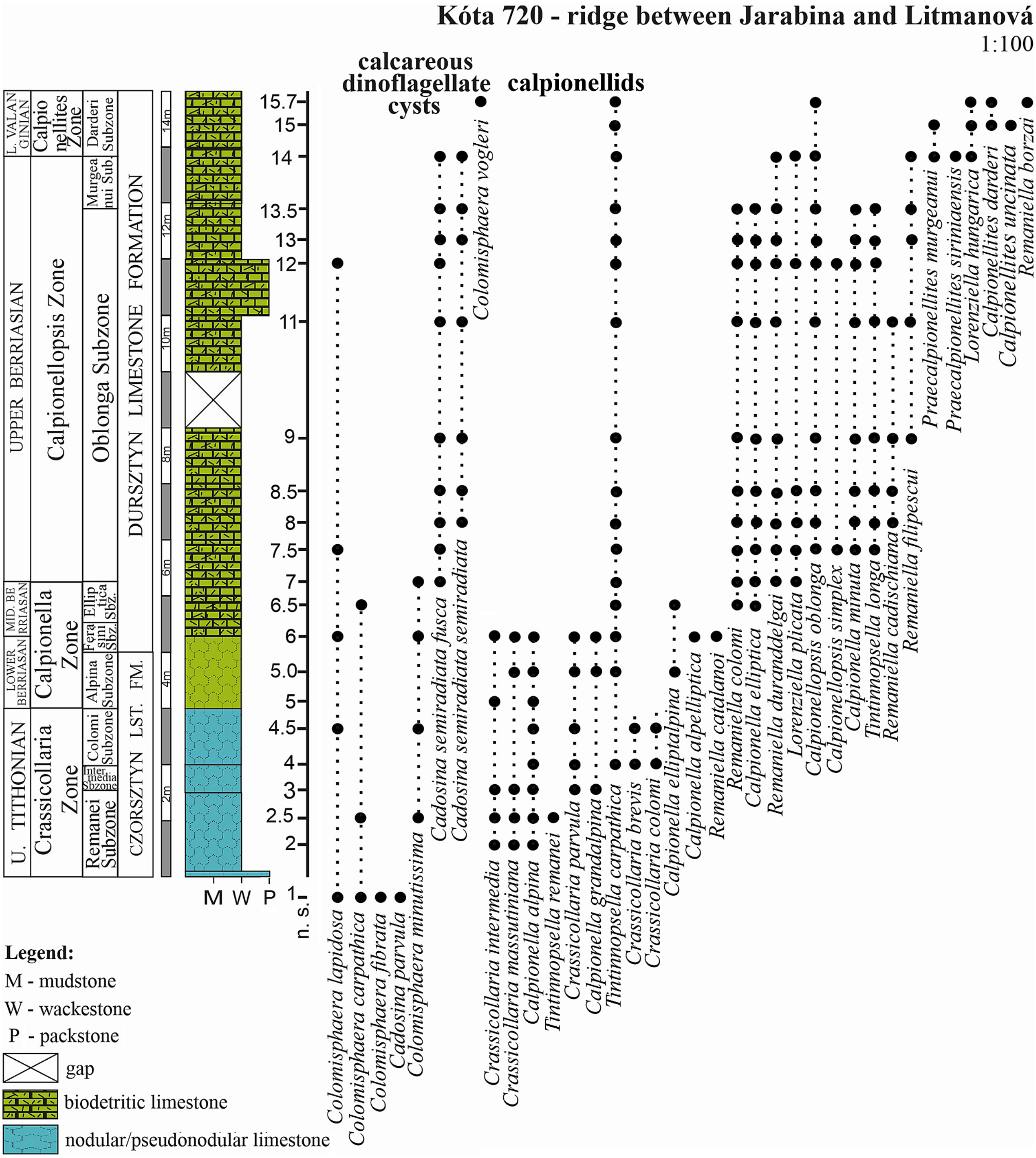

Fig. 8. Distribution of calcareous dinoflagellates and calpionellids in Kóta 720 section with calpionellid and dinoflagellate cysts biozonation.

(Fig. 10-15), *Tintinnopsella carpathica*. Dinocysts of *Colomisphaera minutissima* (Fig. 10-6) and *Colomisphaera lapidosa* were documented. **Calpionella Zone, Ferassini Subzone, Berriasian.**

Kóta 720-6.5; Kóta 720-7

Bioclastic limestones of calpionellid-*Globochaete* and calpionellid-radiolarians microfacies (wackestone to packstone, SMF 3). Crinoid fragments, juvenile ammonites, ostracods, bivalves, calcified radiolarian, echinoids, aptychi, ophiuroids, sponge spicules, benthic foraminifera – *Dentalina* sp., *Spirilina* sp., *Lenticulina* sp., *Nodosaria* sp., planktonic foraminifera of *Favusella* sp. have been observed. There were also documented *Calpionella elliptica, Calpionella alpelliptica* (Fig. 10-18), *Calpionella elliptalpina* (redeposited) (Fig. 10-16), *Lorenziella plicata* (Fig. 10-19), *Remaniella colomi* (Fig. 10-17), *Remaniella duranddelgai* (Fig. 10-20), *Tintinnopsella carpathica*, dinocysts of *Colomisphaera carpathica, Cadosina semiradiata fusca* and *Colomisphaera minutissima* documented. **Calpionella Zone, Elliptica Subzone, Middle Berriasian.**

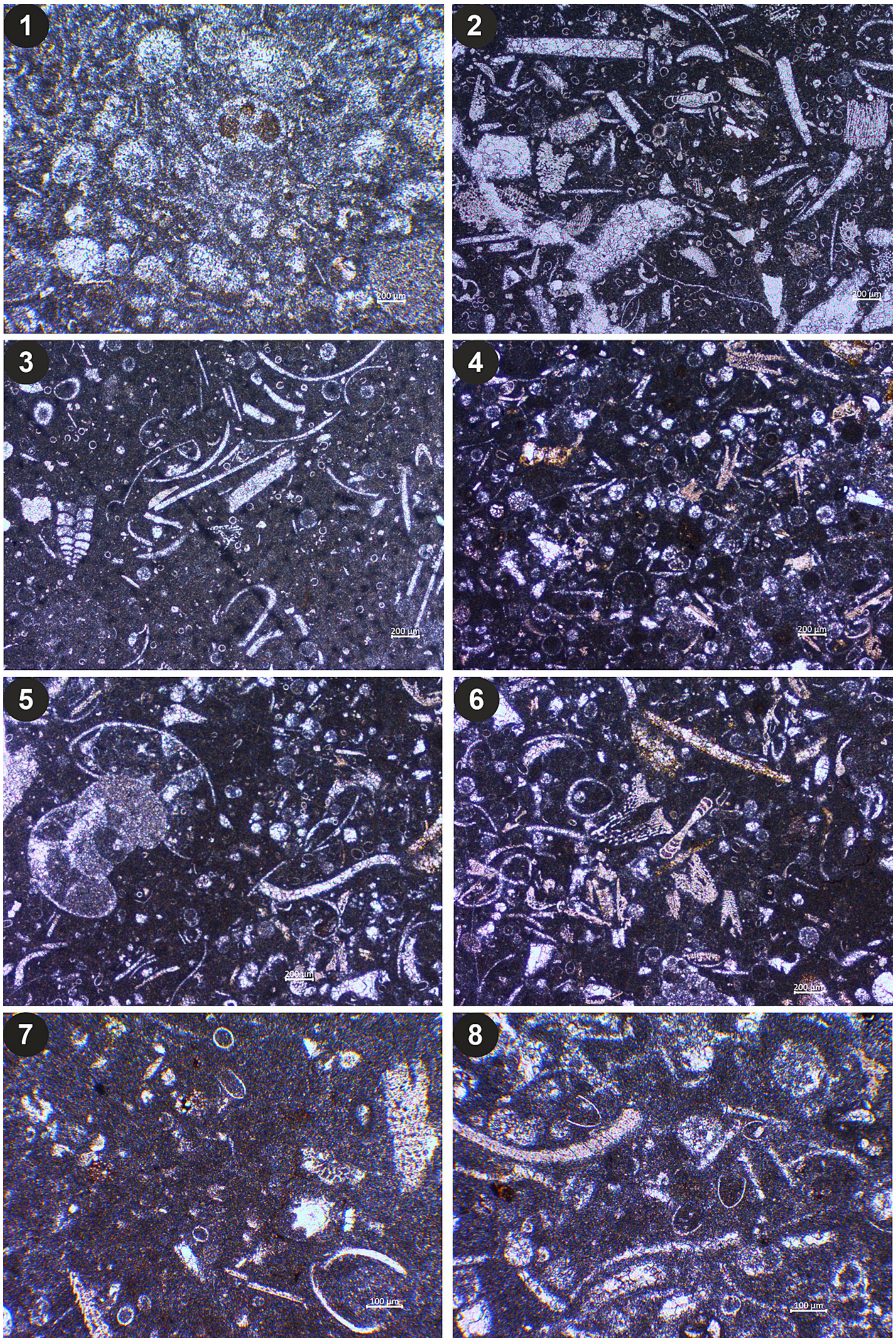

Fig. 9. Microfacies of Kóta 720: 1 – *Protoglobuligerina*-filamentous microfacies, sample Kóta 720-1. 2 – calpionellid-*Globochaete* mikrofacies, crinoids, *Involutina* sp., sample Kóta 720-3. 3 – calpionellid-*Globochaete* microfacies, foraminifera, bivalves, sample Kóta 720-6. 4 – radiolarian microfacies, crinoids, sample Kóta 720-8. 5 – calpionellid-radiolarian mikrofacies, juvenile ammonites, sample Kóta 720-12. 6 – calpionellid-radiolarian mikrofacies, crinoids, *Spirillina* sp., sample Kóta 720-12. 7 – bioclastic limestone with *Calpionellopsis oblonga* Cadisch and crinoids, sample Kóta 720-8.5. 8 – bioclastic limestone with *Calpionellites* sp., sample Kóta 720-15. Light microscope Leica DM 2500 with Axiocam ERc 5s digital camera.

Kóta 720-7.5; Kóta 720-8; Kóta 720-8.5; Kóta 720-9; Kóta 720-11; Kóta 720-12; Kóta 720-13; Kóta 720-13.5

Bioclastic limestones calpionellid-radiolarian microfacies (Fig. 9-4, 9-6) (wackestone, SMF 3). Crinoid fragments, common juvenile ammonites (Fig. 9-5), bivalve fragments, aptychi, ostracods, fragments of resedimented saccocomas, calcified radiolarians, sponge spicules, echinoids, foramiferans *Spirilina* sp. (Fig. 9-6), *Lenticulina* sp., *Nodosaria* sp., *Gaudryina* sp., *Textularia* sp., *Patellina subcretacea* (Fig. 10-1), *Pseudomarssonella* sp., *Ophthalmidium* sp., planktonic foraminifera *Favusella* sp. (Fig. 10-2) were documented. In association of calpionellids *Calpionellopsis oblonga* (Fig. 9-7, 10-21), *Calpionellopsis simplex, Calpionella elliptica, Calpionella alpelliptica, Calpionella minuta, Lorenziella plicata, Remaniella cadischiana, Remaniella colomi, Remaniella duranddelgai, Remaniella filipescui* (Fig. 10-24), *Tintinnopsella carpathica* (Fig. 10-23), *Tintinnopsella longa* (Fig. 10-22) were observed. The spectra of dinocysts are represented by frequent *Cadosina semiradiata fusca* (Fig. 10-7), *Cadosina semiradiata semiradiata* and *Colomisphaera lapidosa*. **Calpionellopsis Zone, Oblonga Subzone, Upper Berriasian.**

Kóta 720-14

Bioclastic limestone (wackestone, SMF 3) with less abundant calpionellids – *Calpionellopsis oblonga, Lorenziella hungarica, Lorenziella plicata, Praecalpionellites murgeanui* (Fig. 10-25), *Praecalpionellites siriniaensis* (Fig. 10-26), *Remaniella duranddelgai, Remaniella filipescui, Tintinnopsella carpathica, Tintinnopsella longa*, crinoid fragments, ophiuroids, ostracods, bivalves, brachiopods, aptychi, foraminifera – *Spirilina* sp., *Lenticulina* sp., *Nodosaria* sp., *Patellina subcretacea, Gaudryina* sp., *Pseudomarssonella* sp., *Textularia* sp., dinocysts – *Cadosina semiradiata fusca* and *Cadosina semiradiata semiradiata*. **Calpionellopsis Zone, Murgeanui Subzone, Upper Berriasian.**

Kóta 720-15; Kóta 720-15.7

Bioclastic limestones (wackestone, SMF 3) (Fig. 9-8) with calcified radiolarians, crinoid fragments, ophiuroids, echinoids, ostracods, bivalves, brachiopods, aptychi, foraminifera – *Spirilina* sp., *Lenticulina* sp., *Nodosaria* sp., *Gaudryina* sp., *Pseudomarssonella* sp. (Fig. 10-4), *Textularia* sp., planktonic foraminifera – *Favusella* sp., *Favusella hoterivica* (Fig. 10-3), calpionellids – *Calpionellites darderi* (Fig. 10-27), *Calpionellites uncinata* (Fig. 10-28), *Calpionellopsis oblonga, Lorenziella hungarica, Praecalpionellites*

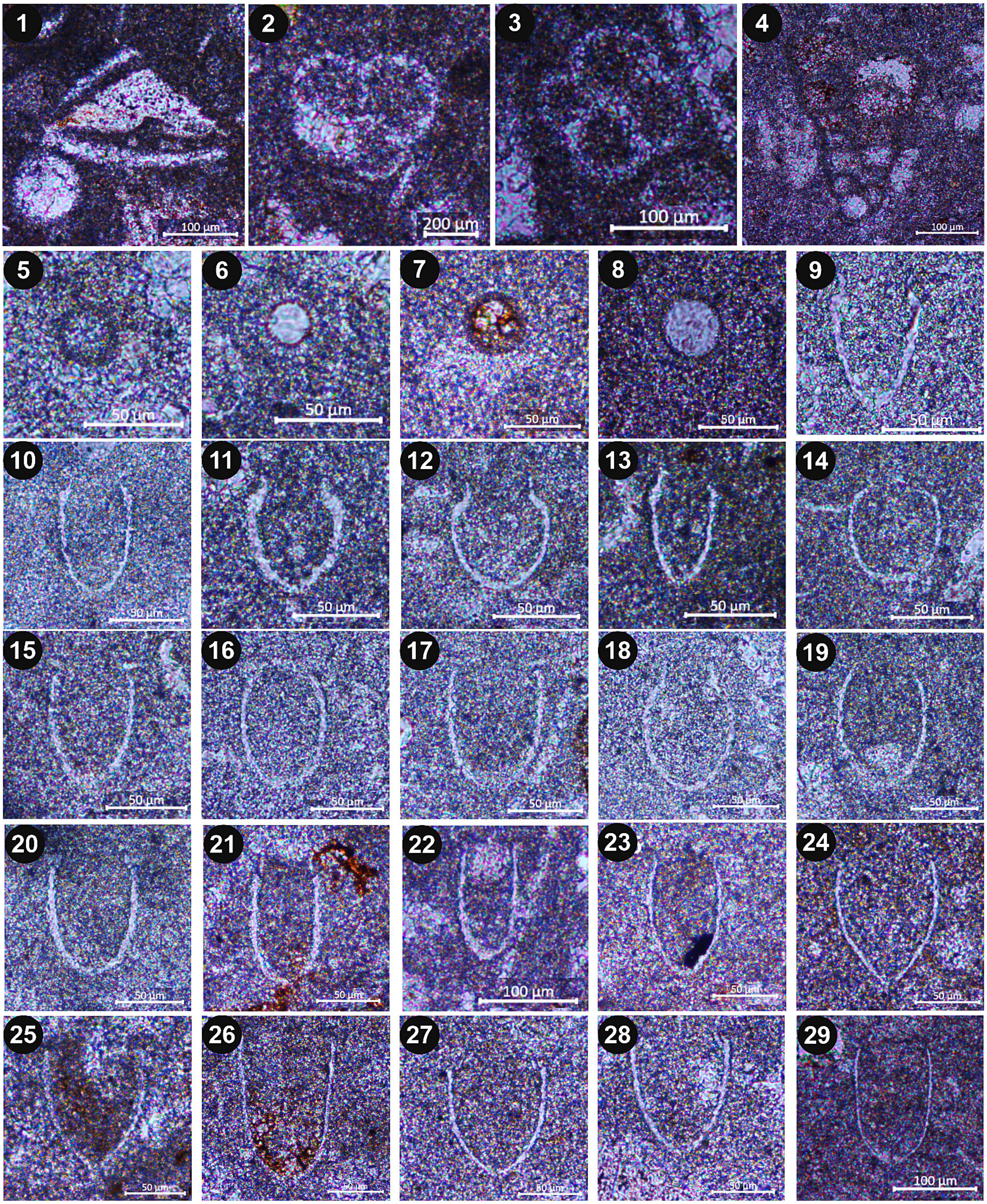

Fig. 10. Planktonic foraminifera, calcareous dinoflagellate cyst and calpionellids: 1 – *Patelina subcretacea* Cushman, Alexander, sample Kóta 720-9. 2 – *Favusella* sp., sample Kóta 720-12. 3 – *Favusella hoterivica* (Subbotina), sample Kóta 720-15. 4 – *Pseudomarsonella* sp., sample Kóta 720-15.7. 5 – *Cadosina parvula* (Nagy), sample Kóta 720-1. 6 – *Colomisphaera minutissima* (Nowak), sample Kóta 720-6. 7 – *Cadosina semiradiata fusca* (Wanner), sample Kóta 720-9. 8 – *Colomisphaera vogleri* (Borza), sample Kóta 720-15.7. 9 – *Crassicollaria parvula* (Nagy), sample Kóta 720-3. 10 – *Crassicollaria* intermedia (Durand-Delga), sample Kóta 720-2. 11 – *Crassicolaria brevis* Remane, sample Kóta 720-4. 12 – *Calpionella alpina* (Lorenz), sample Kóta 720-4.5. 13 – *Crassicollaria colomi* (Doben), sample Kóta 720-4.5. 14 – *Calpionella grandalpina* (Nagy), sample Kóta 720-6. 15 – *Remaniella catalanoi* (Pop), sample Kóta 720-6. 16 – *Calpionella elliptalpina* (Nagy), sample Kóta 720-6.5. 17 – *Remaniella colomi* (Pop), sample Kóta 720-7. 18 – *Calpionella alpelliptica* (Nagy), sample Kóta 720-7. 19 – *Lorenziella plicata* (Remane), sample Kóta 720-7. 20 – *Remaniella duranddelgai* (Pop), sample Kóta 720-7. 21 – *Calpionellopsis oblonga* (Cadisch), sample Kóta 720-7.5. 22 – *Tintinnopsella longa* (Colom), sample Kóta 720-8.5. 23 – *Tintinnopsella carpathica* (Murgeanu et Filipescu), sample Kóta 720-11. 24 – *Remaniella filipescui* (Pop), sample Kóta 720-13. 25 – *Praecalpionellites murgeanui* (Pop), sample Kóta 720-14. 26 – *Praecalpionellites siriniaensis* (Pop), sample Kóta 720-14. 27 – *Calpionellites darderi* (Colom), sample Kóta 720-15. 28 – *Calpionellites uncinata* Cité et Pasquaré, sample Kóta 720-15. 29 – *Remaniella borzai* (Pop), sample Kóta 720-15.7. Light microscope Leica DM 2500 with Axiocam ERc 5s digital camera.

murgeanui, *Remaniella borzai* (Fig. 10-29), *Tintinnopsella carpathica* and cysts *Colomisphaera vogleri* (Fig. 10-8). **Calpionellites Zone, Darderi Subzone, Lower Valanginian.**

The above-indicated standard microfacies (SMFs 2, 3 sensu Flügel, 2004) are typical of facies zones (FZs) 2 and 3 in the sense of Wilson (1975), indicating the environment of the slope edge of the deeper shelf. Similar facies are reported from the Pieniny Klippen Belt by Reháková & Wierzbowski (2005), Reháková et al. (2011), Michalík et al. (2009, 2016), Grabowski et al. (2019), Fekete et al. (2019).

Microfacies analysis of the sediments of both studied profiles confirmed the conclusions presented by Plašienka & Mikuš (2010; Fig. 2) that studied sediments represent the sequences of the Czorsztyn succession.

5. DISCUSSION

Based on the results obtained by studying the above-mentioned localities as well as new findings from the Snežnica locality and the revision of the Crassicollaria Zone from the Brodno and Strapkova localities (Michalík et al., 2009, 2016, 2021), it is possible to revise the previous division of this zone in Reháková (1995) and to confirm the validity of Crassicollaria Zone division into Remanei, Intermedia and Colomi subzones.

5.1. Remanei Subzone

In terms of new knowledge, we define the Remanei Subzone as the interval of appearance of the first fully hyaline calpionellid loricae. Their abundance is low, ranging in the order of several of loricae to one standard thin-section. The loricae are smaller in size, often having reduced collars which greatly affects their species taxonomic identification. *Tintinnopsella remanei* is the first to appear in the subzone together eith first smaller forms of crassicollarias – *Crassicollaria* aff. *intermedia*, followed higher by sporadic *Crassicollaria intermedia* and *Calpionella alpina*. Reháková (1995) designed the Remanei Subzone as the Intermedia Suzone precisely because of the appearance of *Crassicollaria intermedia* already in this subzone. Reháková & Michalík (1997b) proposed the designation Remanei, although the subzone was defined by the *Crassicollaria intermedia* range. It can be said that the new understanding of this subzone is a return to its original use in the sense of Remane et al. (1986).

5.2. Intermedia Subzone

The Intermedia Subzone is characterized here as the interval of high number of calpionellids and high species diversity of calpionellid associations. The base of the subzone is easy to recognize because of the changes. Numerous variable forms of crassicollarians appear – *Crassicollaria intermedia, Crassicollaria massutiniana, Crassicollaria parvula*, and later *Crassicollaria brevis* (actually first rare specimens of these crassicollarians occur down in the Remanei Subzone). Against small form of *Calpionella alpina* larger species appear – *Calpionella grandalpina*, and elongate forms – *Calpionella elliptalpina* as well as the small species of *Tintinnopsella carpathica*. Reháková (1995) proposed to rename the Intermedia Subzone according to Remane et al. (1986) as the Brevis Subzone based on the first occurrence of the index species *Crassicollaria brevis*. More detailed studies of the Brodno, Strapkova and Snežnica profiles (Michalík et al., 2009, 2016, 2021), and the profiles studied by us shown that *Crassicollaria brevis* is not a stable marker. We understand the Intermedia Subzone as an interval of high abundance and high species diversity of calpionellids. It is one of the most prominent, easily distinguishable global Upper Jurassic calpionellid event observed in all published works devoted to distribution and successive calpionellid events. Reháková (1998, 2000b) correlated the maxima of species variability and diversity of calpionellids (K strategists) with a stable water regime during periods of sea level culmination.

5.3. Colomi Subzone

The Colomi Subzone is characterized by an event that could be described as the onset of at crisis in the development of calpionellids, which culminated in the onset of the Alpina Subzone of the Lower Berriassian standard Calpionella Zone also known as *Calpionella alpina* ecoevent (Kowal-Kasprzyk & Reháková, 2019). The onset of this event at the interface of the calpionellid Crassicollaria and Calpionella zones was selected by the Berriassian working group as one of the determining markers for defining the J/C boundary (Wimbledon et al., 2020a, 2020b). In the Colomi Subzone, large forms of crassicollarians and large species of the genus *Calpionella* gradually begin to decline from the record. The small loricae of *Calpionella alpina* and *Crassicollaria parvula* dominate. The abundance of the latter towards the onset of the Alpina Subzone also decline significantly. Rarely, *Crassicollaria colomi* and the small form of *Tintinnopsella carpathica* are present. The quite sporadic presence of large crassicollarians as well as large and elongated loricae of *Calpionella* species can be explained rather as a consequence of environmental dynamics, erosion and resedimentation of the underlying frequently bioturbed and partially unconsolidated sediments. Resediments from the Intermedia Subzone appear regularly in the frame of the Colomi Subzone creating thin layers and laminae, locally showing gradation of bioclasts and abiotic components, often depending on the situation and dynamics of the sedimentation environment, they also contain accumulations of bioclasts derived from the edge of carbonate platforms (Svobodová et al., 2019; Vaňková et al., 2019; Bubík et al., 2020; Michalík et al., 2021). The local chaos of the component arrangement can also be explained of storm activity. We assume that the high dynamics of the environment affecting the character of sediments is also reflected in the latest proposal for calpionellid zonation, which was submitted by Benzaggagh (2020). Therefore, we do not agree with its division of the Crassicollaria Zone and the possibility to use this division on a more global scale, as also based on our observations, the Colomi Subzone represents a decline interval of calpionellid diversity and abundance, ending in a reduced monoassociation formed mainly by a small spherical form of *Calpionella alpina* as a consequence of the maximum eustatic sea-level drop and thus of climate change (Reháková, 2000b; Kowal-Kasprzyk & Reháková, 2019). Within existing calpionellid zonations (Fig. 1) the Grün & Blau (1997) zonation shows the most differences in the division of the Crassicollaria Zone. It's necessary to note that so far, the presence of remaniellids has not been demonstrated in the upper-most part of Tithonian in any other area of the Thetyan area. We assumed, the above-mentioned authors studied the distribution of calpionellids in profile with a reduced layered sequence, which were already pointed out by Reháková (1998). Similar observations have been documented in Michalík et al. (2012), Michalík at al. (2021) and Granier et al. (2020). The absence of the upper part of Tithonian Colomi Subzone and the Lower Berriasian Alpina Subzone was also observed by us (not yet published) on the profile of the klippe of Šarišské Jastrabie from the area of the Pieniny Klippen Belt of the Western Carpathians.

In the Colomi Subzone, deformed (aberrant) loricae of crassicollarians were documented in the works of Reháková et al. (2016), Svobodová et al. (2019), Grabowski et al. (2019). The causes of deformations in loricae would need to be examined in more detail in the future. In the Colomi Subzone, smaller loricae morphologically resembling *Calpionella alpina* appear, in which the aboral part of the shell is markedly thickened and the shell is closed in the collar part by a convexly oriented arched aperture (in Řehánek, 1987; Pl. 2, Fig. 16). Řehánek (1987) considered these microfossils described above to be cysts of *Stomiosphaera* sp. We suppose that these shells could belong to dinocysts, but in analogy to recent tintinnids, they could also be interpreted as calpionellid cysts. These may have been produced by the preceding large and elongated forms of the genus *Calpionella* due to stressful environmental conditions. This issue will also need further study.

6. CONCLUSION

A systematic study of the distribution of calpionellids from the profiles of the Western Carpathians led to a revision of the Crassicollaria Zone. In terms of new knowledge, we divide this into three subzones:

1) Remanei Subzone is characterized by the onset of the first few abundant to sporadic hyaline loricae with reduced collars which represent the species *Tintinnopsella remanei, Crassicollaria* aff. *intermedia*, later also *Crassicollaria intermedia, Calpionella alpina*.

2) Intermedia Subzone is characterized by diversification, species variability and large abundance of calpionellids, in the range of *Crassicollaria intermedia, Crassicollaria massutiniana, Crassicollaria parvula, Crassicollaria brevis, Calpionella alpina, Calpionella grandalpina, Calpionella elliptalpina* and small forms of *Tintinnopsella carpathica*.

3) Colomi Subzone is the interval of decline of diversity and abundance of calpionellids in which large forms of crassicollarians and large forms of the *Calpionella* genus disappeared. Dominant small loricae of *Calpionella alpina* are accompanied by frequent *Crassicollaria parvula*. The abundance of the latter species gradually decline. Rare are *Crassicollaria colomi* and small form of *Tintinnopsella carpathica*. In the Colomi Subzone, the occurrence of deformed (? aberrant) predominantly crassicollarians loricae can be observed, as well as small closed loricae-like shells which could probably belong to cysts of receding large and elongated forms of the genus *Calpionella*.

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APPENDIX

List of microfosill species

Foraminifera:

Favusella hoterivica (Subbotina)
Patellina subcretacea Cushman, Alexander

Chitinoidellids:

Borzeilla slovenica (Borza)
Carpathella rumanica Pop
Chitinoidella boneti Doben
Longicollaria dobeni (Borza)
Praetintinnopsella andrusovi Borza

Calpionellids:

Crassicollaria intermedia (Durand-Delga)
Crassicollaria brevis Remane
Crassicollaria massutiniana (Colom)
Crassicollaria parvula Remane
Crassicollaria colomi Doben
Calpionella alpina Lorenz
Calpionella elliptica Cadisch
Calpionella alpelliptica Nagy
Calpionella elliptalpina Nagy
Calpionella grandalpina Nagy
Calpionella minuta Houša
Tintinnopsella carpathica (Murgeanu & Filipescu)
Tintinnopsella remanei Borza
Tintinnopsella longa (Colom)
Lorenziella hungarica Knauer & Nagy
Lorenziella plicata Remane
Calpionellopsis simplex (Colom)
Calpionellopsis oblonga (Cadisch)
Remaniella cadischiana (Colom)
Remaniella borzai Pop
Remaniella catalanoi Pop
Remaniella colomi Pop
Remaniella duranddelgai Pop
Remaniella filipescui Pop
Praecalpionellites murgeanui (Pop)
Praecalpionellites siriniaensis Pop
Calpionellites darderi (Colom)
Calpionellites uncinata Cita et Pasquaré

Calcareous dinoflagellate cysts:

Colomisphaera fibrata (Nagy)
Colomisphaera lapidosa (Vogler)
Colomisphaera fibrata (Nagy)
Colomisphaera vogleri (Borza)
Colomisphaera pieninensis (Borza)
Colomisphaera carpathica (Borza)
Colomisphaera nagyi (Borza)
Colomisphaera minutissima Nowak
Colomisphaera cieszynica Nowak
Colomisphaera tenuis (Nagy)
Colomisphaera pulla (Borza)
Cadosina parvula Nagy
Cadosina semiradiata fusca Vogler
Cadosina semiradiata semiradiata (Wanner)
Stomiosphaera moluccana Wanner
Parastomiosphaera malmica (Borza)
Carpistomiosphaera borzai (Nagy)