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The Jurassic/Cretaceous boundary and high resolution biostratigraphy of the pelagic sequences of the Kurovice section (Outer Western Carpathians, the northern Tethyan margin)

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Abstract: Microfacies and high resolution studies at the Kurovice quarry (Czech Republic, Outer Western Carpathians) on calpionellids, calcareous and non-calcareous dinoflagellate cysts, sporomorphs and calcareous nannofossils, aligned with paleomagnetism, allow construction of a detailed stratigraphy and paleoenvironmental interpretation across the Jurassic/Cretaceous (J/K) boundary. The Kurovice section consists of allodapic and micrite limestones and marlstones. Identified standard microfacies types SMF2, SMF3 and SMF4 indicate that sediments were deposited on a deep shelf margin (FZ3), with a change, later, into distal basin conditions and sediments (FZ1). The sequence spans a stratigraphic range from the Early Tithonian calcareous dinoflagellate Malmica Zone, nannoplankton zone NJT15 and magnetozone M21r to the late Early Berriasian calpionellid Elliptica Subzone of the Calpionella Zone, nannoplankton NK-1 Zone and M17r magnetozone. The J/K boundary is marked by a quantitative increase of small forms of *Calpionella alpina*, the base of the Alpina Subzone (that corresponds to NJT17b and M19n.2n) and by the rare occurrence of *Nannoconus wintereri.* Palynomorphs include Early Berriasian terrestrial elements — non-calcareous dinoflagellate cysts *Achomosphaera neptunii, Prolixosphaeridium* sp. A and *Tehamadinium evittii*. The depositional area for Kurovice was situated at the margin of the NW Tethys. The influence of cold waters from northern latitudes and potential upwellings is highlighted by: 1) the high proportion of radiolarians and sponge spicules, 2) rare calpionellids represented mostly by hyaline forms, 3) the absence of microgranular calpionellids — chitinoidellids, 4) the small percentage of the genera *Nannoconus, Polycostella* and *Conusphaera* in nannofossil assemblages, as compared to other sites in Tethys, 5) scarce *Nannoconus compressus,* which has otherwise been mentioned from the Atlantic area.

Keywords: Tithonian, Berriasian, calcareous and non-calcareous microfossils, calcareous nannofossils, palynomorphs, magnetostratigraphy.

Introduction

Determining the Global Boundary Stratotype Section and Point (GSSP) for the Berriasian Stage in the Tethys has been the objective of elaborate research and discussions of the Berriasian Working Group during the past several years. Tethys was the largest depositional area during Tithonian and Berriasian times that is available for study by diverse stratigraphic methods, namely lithostratigraphy, biostratigraphy (based on calpionellids, nannofossils, dinoflagellates, radiolarians, foraminifers, ammonites and belemnites), as well as by magnetostratigraphy, geochemistry and sequence stratigraphy (Andreini et al. 2007; Houša et al. 2007; Michalík et al. 2009, 2016; Casellato 2010; Lukeneder et al. 2010; Pruner et al. 2010; Grabowski et al. 2010a, b; Grabowski 2011; Michalík & Reháková 2011; Wimbledon et al. 2011, 2013; Petrova et al. 2012; Guzhikov et al. 2012; Lakova & Petrova 2013; López-Martínez et al. 2013, 2015; Schnabl et al. 2015; Svobodová & Košťák 2016; Hoedemaeker et al. 2016; Grabowski et al. 2017; Kietzmann 2017; Lakova et al. 2017; Wimbledon 2017; Elbra et al. 2018a, b, Kowal-Kasprzyk & Reháková 2019).

Much research has been focused on the Jurassic/Cretaceous (J/K) boundary of the Western Carpathians (Grabowski & Pszczółkowski 2006; Grabowski et al. 2010b, 2013; Michalík et al. 2016; Skupien et al. 2016); and the Brodno section in Slovakia was chosen as a regional stratotype (Michalík et al. 1990, 2009; Houša et al. 1996, 1999). Marine strata at the locality of Kurovice were suggested as another possible J/K profile for multidisciplinary research. Reháková (in Eliáš et al. 1996) noted calpionellid zones ranging from the Late Tithonian Crassicollaria Zone to the Late Berriasian

Calpionellopsis Zone. However, the J/K boundary could not then be strictly determined. Recent bed-by-bed study confirmed a similar calpionellid distribution, with a biozonation, and the J/K boundary to be precisely located (Svobodová et al. 2017; Švábenická et al. 2017; Elbra et al. 2018a).

This work follows the Elbra et al. (2018a) paper, which presented the magnetostratigraphy of the Kurovice sequence, beds 1–148, compared to concise biostratigraphic data. The aim of this study is to provide detailed documentation of the biota in an extended succession (beds −29 to 148) and to compare the distribution of calpionellids, calcareous dinoflagellates, palynomorphs and calcareous nannofossils, with a focus on the biostratigraphic and paleoenvironmental interpretations. In addition, the work also includes the magnetostratigraphy of the lower part of the sequence (beds −1 to −29), which was not mentioned by Elbra et al. (2018a).

Geological setting

The Kurovice Quarry (49°16'25.0" N, 17°31'19.0" E; 260–269 m a.s.l.) is located in the south-eastern part of the Czech Republic, 9 km NW from Zlín (Fig. 1). It is situated in the front of the Magura Group of nappes (Fig. 2) that represent a significant regional unit of the Outer Western Carpathians (Švábenická et al. 1997; Pícha et al. 2006). In Tithonian and Berriasian times, this depositional area was situated on the northern margin of Tethys and was confined to the south by the Czorsztyn Ridge and the Silesian Cordillera (Golonka et al. 2006).

Limestone quarrying started in Kurovice during the first half of the 18th century, and continued until 1997. In 1999, the area of the abandoned quarry was declared as a nature reserve due to its geological and paleontological significance, and for the protection of rare biota. The geological age of the quarry's rocks described as the Kurovice Limestone (Glöckner 1841) has always been a subject of discussion. On the basis of finds of aptychi, a Jurassic age was assigned. Andrusov (1933, 1945) documented both a Jurassic and a Lower Cretaceous age for the deposits.

The Kurovice Limestone is a sequence consisting of centimetre- to decimetre-scale micrite limestones alternating with whitish-grey allodapic limestones, silty limestones and marlstones, deposited on a deep shelf margin passing into deposition in distal basinal conditions (Vašíček & Reháková 1994). The formation's thickness is estimated to be approximately 120–150 m.

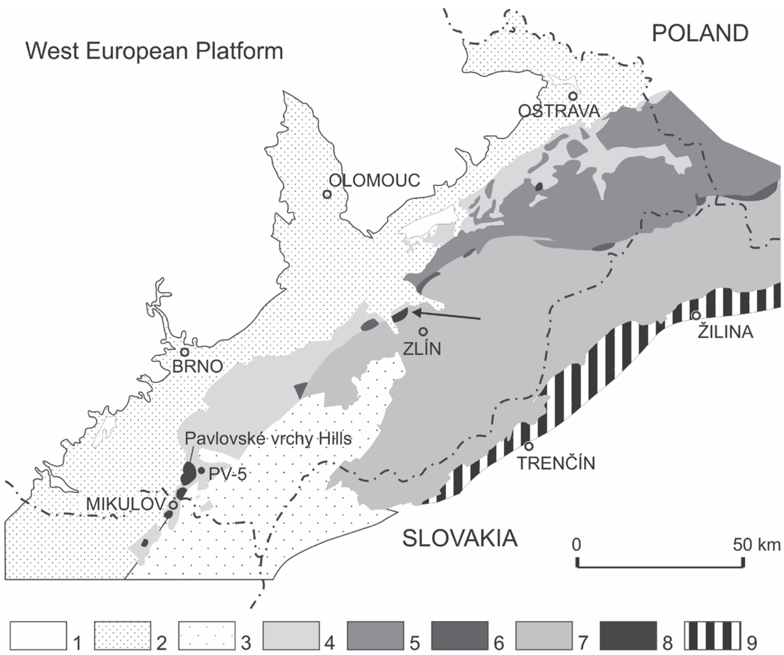

Fig. 1. Simplified geological map of the Outer Western Carpathians. The Kurovice section is marked with an arrow. 1 — Bohemian Massif, 2 — Carpathian Foredeep, 3 — Vienna Basin, 4 — Žďánice-Subsilesian Unit, 5 — Silesian Unit, 6 — Foremagura Unit, 7 — Magura Group of Nappes, 8 — Outer Klippen Belt, 9 — Inner Klippen Belt. Simplified after Švábenická (2012).

Material and methods

Samples from the Kurovice section were taken in 2016 and 2017. An almost 77 m thick sequence was recorded, numbered from −29 to 148 and sampled for paleomagnetic and geochemical research (Fig. 3). The paleomagnetic methods employed here have already been described in Elbra et al. (2018a).

Calcareous nannofossils

Calcareous nannofossils have been analyzed in 114 smear slides. These came from the size fraction of 1–30 μm, separated by a process of decantation using 7 % solution of H_2O_2 (e.g., Švábenická 2012). In order to obtain the relative nannofossil abundances and semiquantitative data, 500 specimens were counted on each slide. Some samples did not provide many specimens, so the number of all nannofossils found on such slides was used as the basis for interpretation. Slides were observed under an Olympus BX51 and Nikon Microphot-FXA transmitting light microscopes with immersion objectives of ×100 magnifications. The identifications of species follow Bralower et al. (1989), Bown & Cooper (1989, 1998), Bown et al. (1998), Casellato (2010), and Nannotax website (Young et al. 2013); and biostratigraphic data were interpreted with reference to the nannofossil zonation of Casellato (2010). The smear slides are stored at the Institute of Geology of the Czech Academy of Sciences, v.v.i. (Department of Paleobiology and Paleoecology) and at the Czech Geological Survey in Prague.

Microfacies, calcareous dinoflagellates and calpionellids

Microfacies and calcareous microfossils — calpionellids and calcareous dinoflagellates were studied in 220 thin sections under a Leica DM 2500 transmitting light microscope and documented by the Axiocam ERc 5s camera in the Department of Geology and Paleontology, Comenius University in Bratislava. The standard calpionellid zones of Remane et al. (1986) and Reháková & Michalík (1997) and calcareous dinoflagellate succession of Nowak (1968) and Reháková (2000) were applied. Carbonate rocks were classified according to the Folk (1959) and Dunham (1962) schemes. Standard microfacies types (SMFs) and facies zones (FZs) were determined following Wilson (1975) and Flügel (2004).

Palynomorphs

A total of 24 samples were processed to concentrate the resistant palynological component using standard maceration techniques, including treatment with hydrochloric (HCl) and hydrofluoric (HF) acids to remove carbonates and silicates. The remaining inorganic fraction was removed by acetolysis and HNO_3. Due to the rare appearance of palynomorphs, sieving was not used. The palynofacies analysis and photo-documentation were carried out using Leica DM 2500 optical microscope (software Leica IM 50) with magnifications of 200–1000× (MS), and by Olympus BX60 optical microscope, SW NIS-Elements 3.1. The formalized non-calcareous dinoflagellate taxa are fully referenced in Fensome & Williams (2004) and Fensome et al. (2009). The palynological slides are stored in the Department of Paleobiology and Paleoecology of the Institute of Geology of the Czech Academy of Sciences, and Institute of Geological Engineering VŠB — Technical University Ostrava.

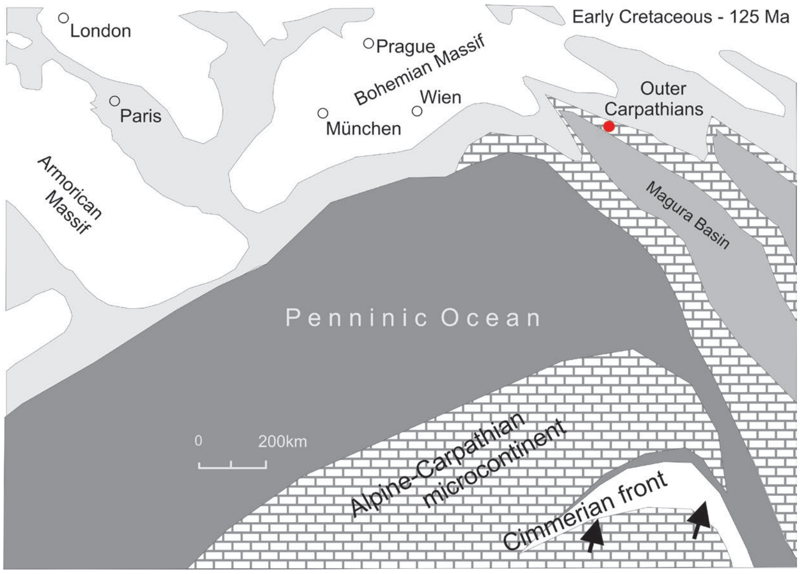

Fig. 2. Probable paleogeographic position of the depositional area (Kurovice section marked by the red dot). After Michalík 2011, modified. Legend: white — dry land; light gray — epicontinental sea; gray — marine basins; bricks — carbonate platforms and basins; dark gray — oceanic bottom).

Results

Calcareous nannofossils

In samples from Kurovice, calcareous nannofossils are usually poorly preserved. Overgrowth and etching are extensive, making identification of some specimens difficult. Generally, nannofossil assemblages are characterized by the dominance of ellipsagelosphaerids, making up more than 90 % of specimens. The genera *Conusphaera*, *Nannoconus* and *Polycostella* are found in small numbers (Fig. 4). Other nannoliths and placoiths are rare, fragmented and often cannot be identified.

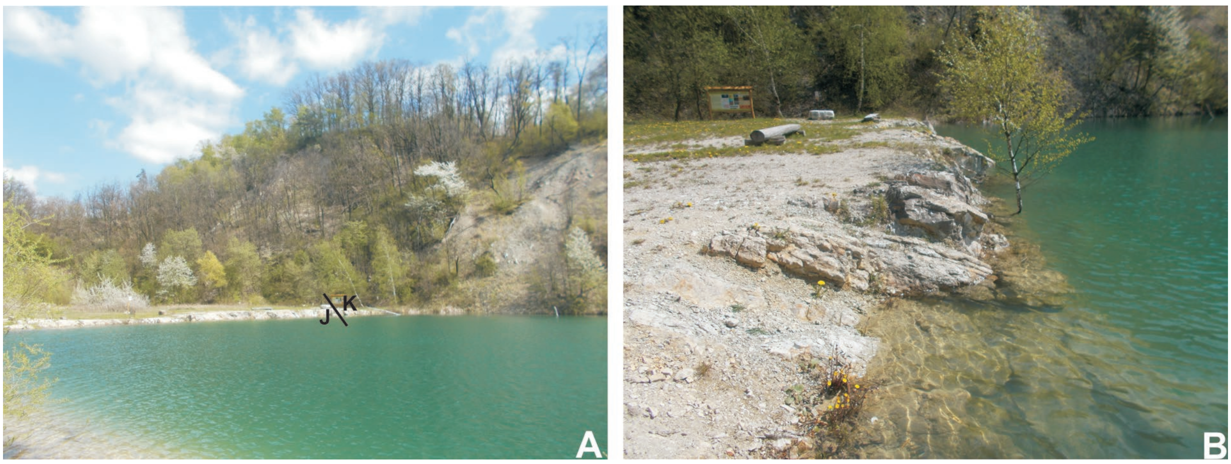

Fig. 3. The profile in the Kurovice quarry. **A** — location of the J–K boundary marked with black line. **B** — a detailed view of the middle part of the section.

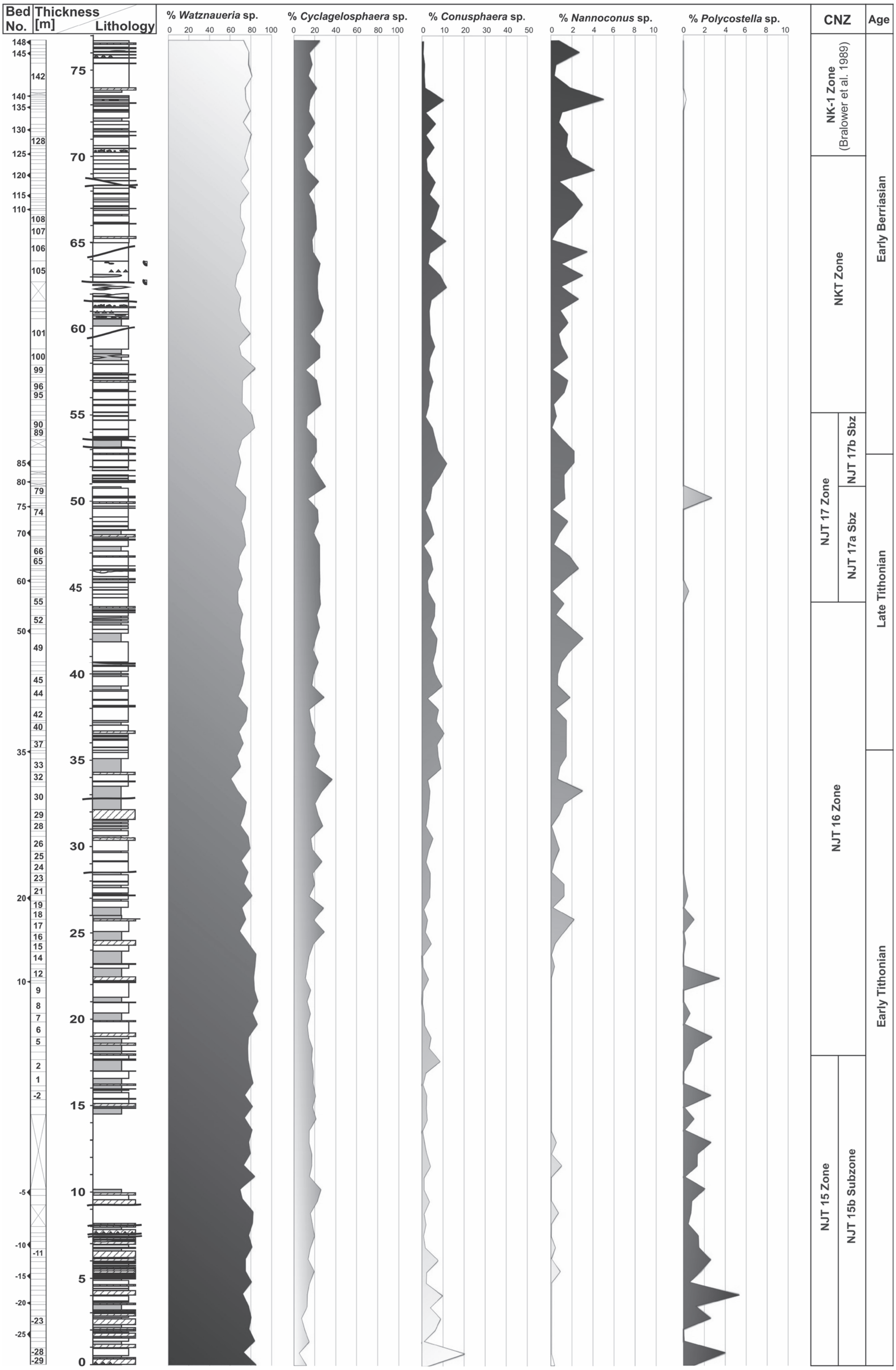

Fig. 4. Percentage share of selected nannofossil genera in the assemblages across the Kurovice section. Lithology after M. Bubík in Košťák et al. (2018), nannofossil zones (CNZ) by Casellato (2010).

Calcarenites contain extremely poor nannofossil associations (Fig. 5A). Scarce nannofossil fragments (1–3 specimens per 10 fields of view of the microscope, FOM) are represented almost exclusively by ellipsagelosphaerids. *Watznaueria* div. spec. may total up to 80 % and *Cyclagelosphaera margerelii* up to 11 % of nannofossil assemblage. Micrite limestones contain poorly preserved nannofossils with abundance ±1 up to 10 specimens per 1 FOM (Fig. 5B). The associations comprise numerous specimens of the genera *Watznaueria* (Fig. 6S–AB) and *Cyclagelosphaera* (Fig. 6AC–AH) accompanied by rare specimens of *Conusphaera* (*C. mexicana mexicana*, *C. mexicana minor, Conusphaera* sp. 1), *Polycostella beckmannii, Nannoconus* spp., *Zeugrhabdotus* (*Z. embergeri*, *Z. cooperi*), and fragments of outer rims of the genera *Retecapsa* and *Helenea*. Specimens of *W. barnesiae* may comprise 70 % and *C. margerelii* up to 13 %. Marlstone interbeds contain highly abundant (10–20 up to ±50 specimens per FOM and more) diversified nannofossil assemblages (Fig. 5C). Although ellipsagelosphaerids still predominate quantitatively, abundances of *Watznaueria* species (*W. manivitiae*, *W. fossacincta*, *W. britannica*, *W. communis*, *W. cynthae*, *W. ovata*) and *Cyclagelosphaera* (*C. deflandrei*, *C. argoensis*) increase. Specimens of genera *Conusphaera* (Fig. 7I–P), *Nannoconus* (Fig. 7S–AJ), *Polycostella* (Fig. 7Q,R), *Retecapsa* (Fig. 6O,P), *Helenea* (Fig. 6A–D), *Diazomatolithus* (Fig. 7B), *Zeugrhabdotus* (Fig. 6I–L), *Hexalithus* (Fig. 7E,F) are present in higher quantities than in calcarenites and micrite limestones. Generally, the composition of calcareous nannofossil assemblage in the studied material corresponds to the Tithonian and Early Berriasian age, compared with the previous studies (e.g., Michalík et al. 2009; Casellato 2010; Lukeneder et al. 2010; Svobodová & Košťák 2016). Selected calcareous nannofossil taxa are presented in Figs. 6 and 7. The distribution of all nannofossil species is shown in Table 1, and a list of calcareous nannofossil taxa is given in Appendix.

Microfacies, calcareous dinoflagellates and calpionellids

The deposits contain selected bioclasts and allochems, such as calpionellids, radiolarians, globochaetes, saccocomids, filaments, fragments of benthic organisms, quartz and lithoclasts. Calpionellids are generally rare and hyaline forms dominate. Calpionellids are not well preserved. Gradually in the overlying beds, they exhibit loricae with thinned walls, which are often damaged or have poorly preserved collars. Through the section, calcified radiolarians and sponge spicules determine the prevailing type of spiculite-radiolarian and radiolarian–spiculite microfacies. In the lowermost part of the section, cysts of dinoflagellates and crinoid fragments are locally a significant part of fossil assemblages. Microgranular chitinoidellid loricae were not found. On the basis of microfacies, calcareous dinoflagellate and calpionellid development, the Kurovice succession is divided into several intervals (from the bottom to the top):

Beds −29 to −7 (~0–7.7 m): Marly and slightly laminated, locally bioturbated limestones (mudstones), in some places

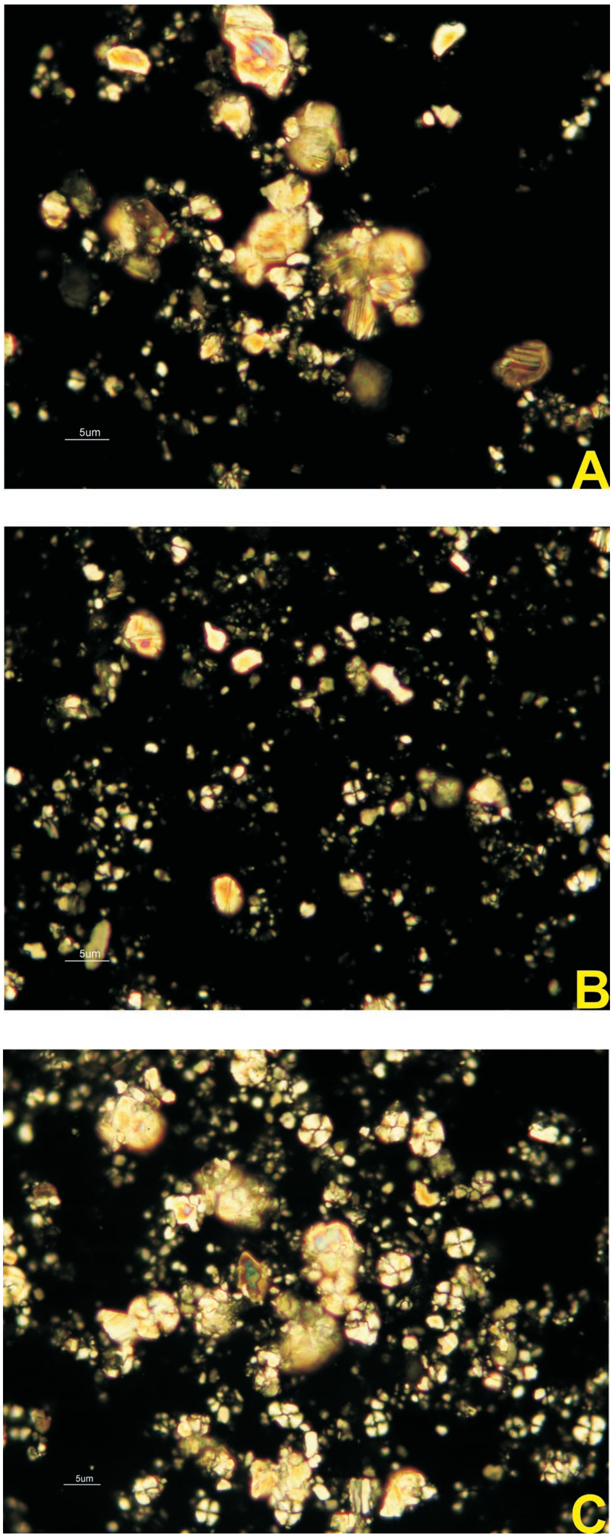

Fig. 5. Kurovice section, abundance of nannofossils in the particular types of rock. Fields of views in the microscope. **A** — calcarenite; **B** — micrite limestone; **C** — marlstone.

with thin layers and laminae rich in a silt admixture and silt-sized fragments of litho- and bioclasts, locally also siltstones. Further, biomicritic slightly bioturbated limestone of

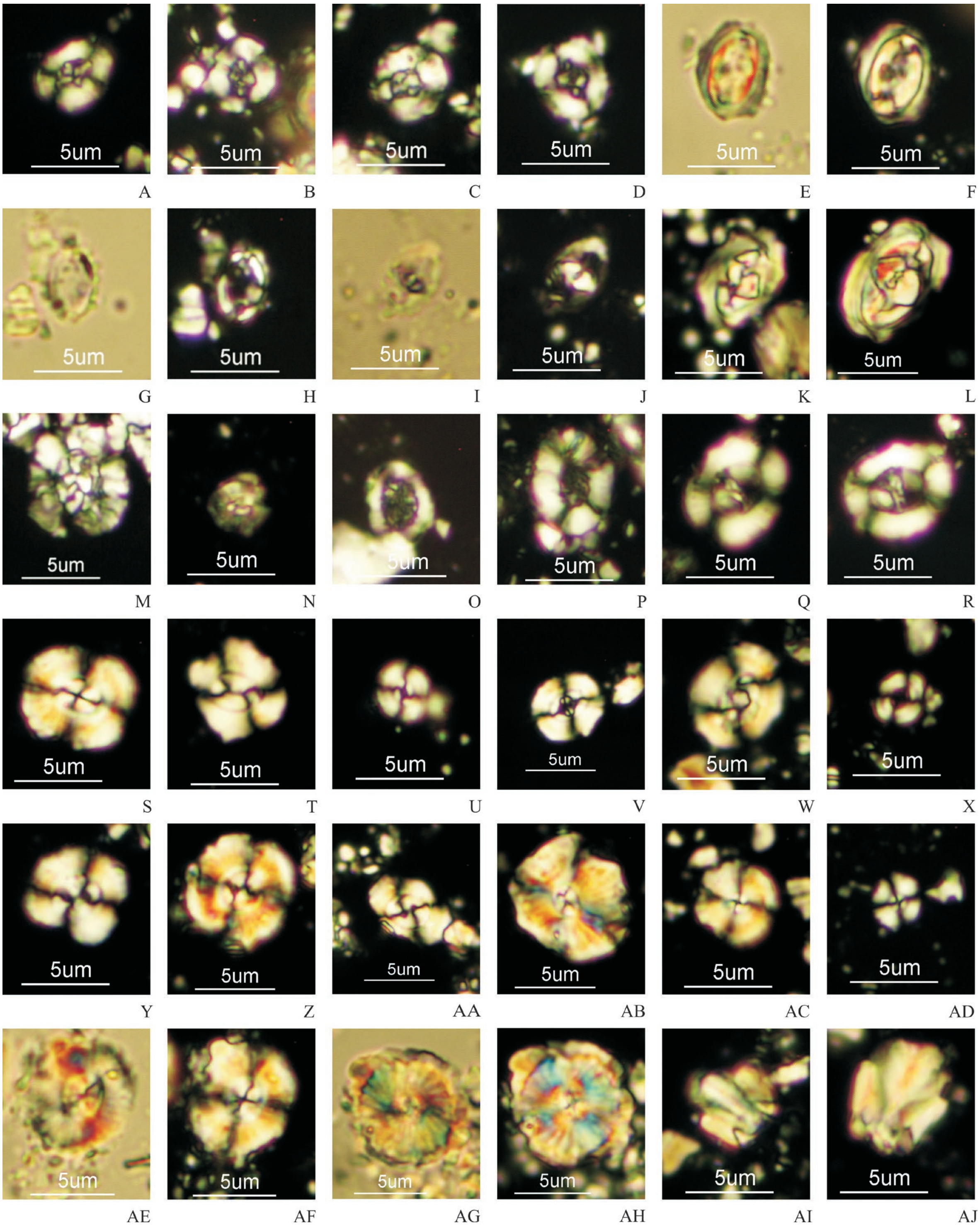

Fig. 6. Kurovice section, calcareous nannofossils, Heterococcoliths. Photographs in cross polarized light, figures E, G, AE and AG in plane polarized light. **A, B** — *Helenea staurolithina*: A — sample 1t, B — sample 5b; **C, D** — *Helenea chiastia*, C — sample 142s, D — sample 107; **E, F** — *Rhagodiscus nebulosus*, sample 145; **G, H** — *Umbria granulosa minor* (fragment), sample 100 marlstone; **I, J** – *Zeugrhabdotus fluxus*, sample −6; **K** — *Zeugrhabdotus cooperi*, sample 1t; **L** — *Zeugrhabdotus embergerii*, sample 142s; **M** — *Pickelhaube furtiva*, sample 8/9; **N** — *Biscutum ellipticum*, sample 133/134; **O** — *Retacapsa surirella*, sample 132; **P** — *Retacapsa* cf. *octofenestrata,* sample 133/134; **Q, R** — *Speetonia colligata* (specimen in 0^{o} and 30^{o}), sample 133/134; **S** — *Watznaueria barnesiae*, sample 1t; **T** — *Watznaueria communis*, sample 94; **U** — *Watznaueria fossacincta*, sample 105b; **V, W** — *Watznaueria britannica*: V — sample 1t, W — sample 144s; **X** — *Watznaueria ovata*, sample 111/112; **Y** — *Watznaueria biporta*, sample 30; **Z, AA** — *Watznaueria cynthae*: Z — sample 46, AA — sample 142s; **AB** — *Watznaueria manivitiae*, sample 132; **AC, AD** — *Cyclagelosphaera margerelii*: AC — sample 9, AD — sample 1t, small specimen; **AE, AF** — *Cyclagelosphaera deflandrei,* sample 9; **AG, AH** — *Cyclagelosphaera argoensis,* sample 1t; **AI** — *Parhabdolithus* cf. *robustus*, sample 5b, reworked specimen from the older Jurassic strata; **AJ** — *Parhabdolithus marthae,* sample 89, reworked specimen from the older Jurassic strata.

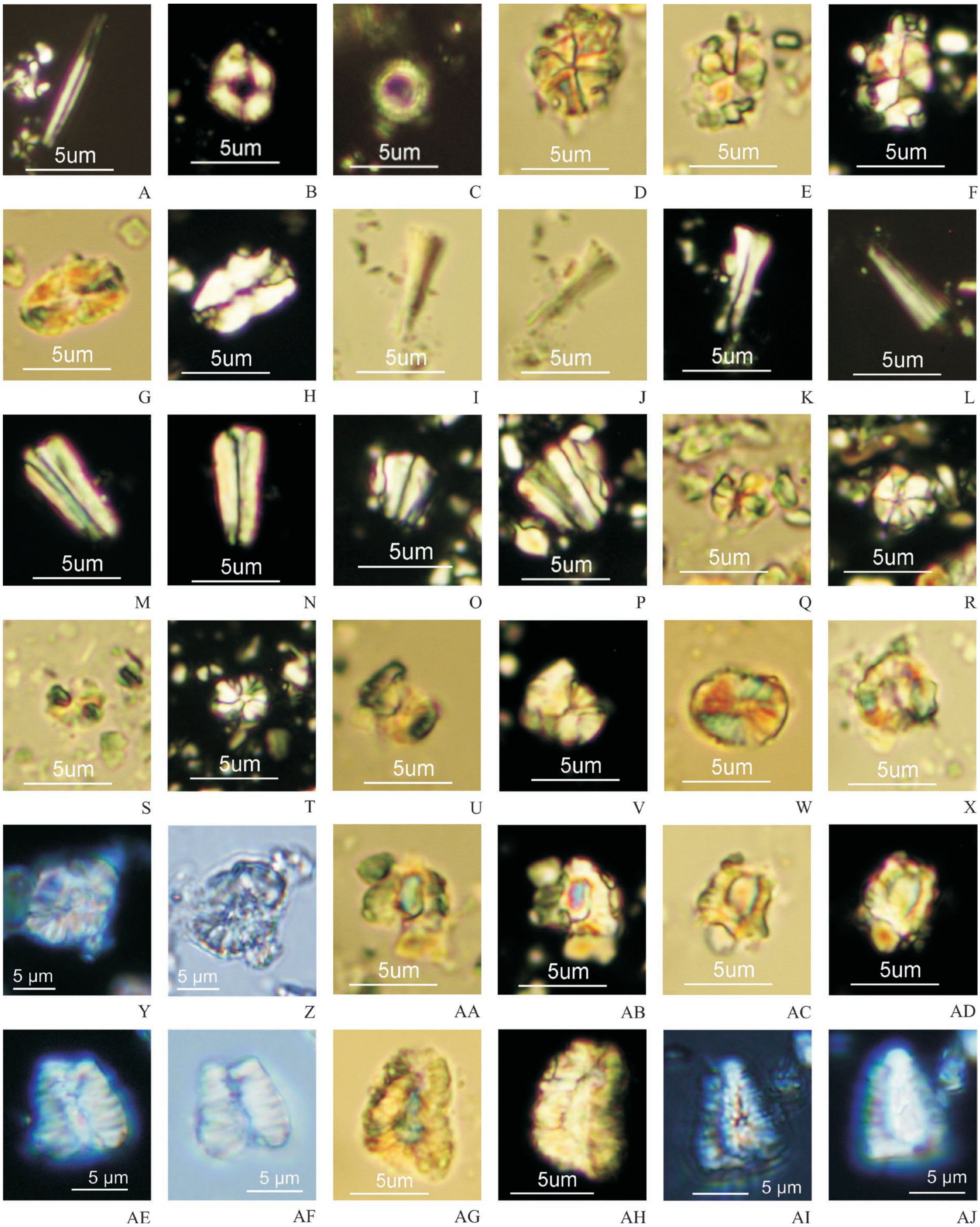

Fig. 7. Kurovice section, calcareous nannofossils, Nannoliths including Eoconusphaeraceae, Nannoconaceae and uncertain "polycycloliths". Photographs in cross polarized light, D, E, G, I, J, Q, S, U, W, X, Z, AA, AC, AF and AG in plane polarized light. **A** — *Lithraphidites carniolensis*, sample 142 s; **B** — *Diazomatolithus lehmanii*, sample 1t; **C** — *Rotelapillus crenulatus,* sample 133/134; **D** — pentalith, sample 8/9; **E, F** — *Hexalithus noeliae*, sample 100 limestone; **G, H** — *Assipetra infracretacea*, sample 138; **I–L** — *Conusphaera* sp.: I–K — sample 103 (specimen in 0° and 30°), L — sample 1a; **M, N** — *Conusphaera mexicana mexicana*, sample 69 (specimen in 0° and 30°); **O** — *Conusphaera mexicana minor*, sample 1t (specimen in 0°); **P** — *Conusphaera mexicana minor*, sample 1t (specimen exceeding the size of 4 µ), cf.; **Q, R** — *Polycostella beckmanii*, sample 5b; **S, T** — *Nannoconus* sp., sample 1t; **U, V** — *Nannoconus puer,* sample 5b; **W** — *Nannoconus compressus,* sample 133/134, reworked specimen; **X** — *Nannoconus globulus minor,* sample 75; **Y, Z** — *Nannoconus globulus globulus,* sample 132; **AA, AB** — *Nannoconus wintereri,* sample 100 limestone; **AC, AD** — *Nannoconus wintereri*, sample 100 limestone (probably early form of *N. wintereri*), cf.; **AE, AF** — *Nannoconus steinmannii minor*, sample 145; **AG, AH** — *Nannoconus kamptneri minor*, sample 133/134; **AI, AJ** — *Nannoconus kamptneri kamptneri*, sample 124.

Table 1a: Distribution of calcareous nannofossils in the Kurovice section. Semi-quantitative data as follows. Nannofossil abundance: EL (extremely low=1–10 specimens per 20 FOM); VL (very low=1–10 specimens per 10 FOM); L (low=1–10 specimens per FOM); M (moderately=10–40 specimens per FOM). Nannofossil total abundance: A (abundant=>5 specimens per FOM); C (common=1–5 specimens per FOM); F (few=>1 specimen per FOM); R (rare=0–1 specimen per FOM); VR (very rare=<5 specimens per sample); ER (extremely rare=1–2 specimens per sample). Nannofossil preservation: EP (extremely poor=strong etching and overgrowth); VP (very poor=strong dissolution); P (poor=moderate etching). Nannofossil zones follow Casellato (2010); r=reworked; ?=uncertain specimen; f=fragment. Stratigraphically significant taxa marked with grey colour.

Chronostratigraphy	Zonation (Casellato 2010)	Sample No.	Nannofossil abundance	Nannofossil preservation	*Assipetra infracretacea*	*Biscutum ellipticum*	*Conusphaera mexicana mexicana*	*Conusphaera mexicana minor*	*Conusphaera* sp. 1	*Cretarhabdus* sp.	*Cruciellipcis cuvillieri*	*Cyclagelosphaera argoensis*	*Cyclagelosphaera deflandrei*	*Cyclagelosphaera margereli*	*Cyclagelosphaera reinhardtii*	*Diazomatolithus lehmanii*	*Discorhabdus* cf. *ignotus*	*Ethmorhabdus gallicus*	*Ethmorhabdus hauterivianus*	*Favioconus multicolumnatus*	*Helenea chiastia*	*Helenea staurolithina*	*Hexalithus noeliae*	*Hexalithus strictus*	*Lithraphidites carniolensis*	*Lotharingius hauffii*	*Lotharingius sigillatus*	*Manivitella pemmatoidea*	*Micrantholithus* sp.	*Miravestina favula*	*Nannoconus colomi*	*Nannoconus compressus*	*Nannoconus erbae*	*Nannoconus globulus globulus*	*Nannoconus globulus minor*	*Nannoconus infans*	*Nannoconus kamptneri kamptneri*	*Nannoconus kamptneri minor*	*Nannoconus puer*	*Nannoconus steinmannii minor*	*Nannoconus st. steinmannii*
B e r r i a s i a n	NK-1	148	VL	EP			VR						R	F									ER											ER	ER						
		147 b	VL	EP	?				ER			VR	VR	VR																			?		VR			ER		ER	
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		144 s	VL	VP			ER						VR	R		ER					ER				ER									?	ER						
		143 b	VL	EP			VR		ER			ER	R	R-F																					VR						
		142 s	L-M	P			R	VR	ER			VR	VR	R							?				f									?	VR						
		140	EL	VP			VR						VR	R		VR			?ER							?r	?r	?f						ER							ER
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		106 t	VL	VP			R	VR	ER			ER	R	F									ER												ER						
		106 b	L	VP			VR	VR					R	F									VR										ER		ER						
		105 s	EL	VP			VR	ER				ER	R	R		ER							ER																		
		105 b	L	VP			ER						R	R		ER	ER						ER							f											
		103	L	VP			VR		VR				VR	R		ER							ER																		
		102	VL	VP			R	VR	ER			ER	R	R		ER							ER												ER	ER					
		101 t	L	VP			R	VR					R	R-F		ER							VR											ER	ER						
		101 y	VL	VP			R	VR					R	R		ER							ER										?ER		ER						
		101 x	L	VP			R	VR	ER			VR	R	R-F		ER							ER																	?ER	
		101 b	L	VP			R	VR	ER			VR	R	C									VR											ER	ER						
		100 lime	EL	EP	ER		ER							VR			ER						ER							f											
		100 marl	L	P			ER		ER				VR	R-F														f?	ER												
		99 t	EL	EP	ER		R	VR					R	F									ER										ER		ER						
		99 b	EL	EP	ER		R	VR				ER	R	R		ER							VR	ER																	
		98	EL	EP			ER	ER					R	F-C							ER		ER																		
		97	VL	EP	ER		R	VR					R	F		ER							ER				r								VR				ER	?ER	
		96	VL	EP			R	VR				ER	R	F									ER												ER				ER		
		95 t	EL	EP				VR				ER	R	C									ER												ER						
		95	L	VP			ER						ER	R			ER								f				ER												
		95 b	VL	VP			R	VR				ER	R	F		ER							VR											ER	ER						
		94	L	VP			R	R					R	F-C									ER												?ER						
		93	VL	VP			R	VR					R	F									ER								ER				ER						
		92 t	VL	EP	ER		R	VR					R	F		ER							ER											ER	ER					ER	

Table 1b (continued):

Chronostratigraphy	Zonation (Casellato 2010)		Sample No.	Nannofossil abundance	Nannofossil preservation	*Assipetra infracretacea*	*Biscutum ellipticum*	*Conusphaera mexicana mexicana*	*Conusphaera mexicana minor*	*Conusphaera* sp. 1	*Cretarhabdus* sp.	*Cruciellipcis cuvillieri*	*Cyclagelosphaera argoensis*	*Cyclagelosphaera deflandrei*	*Cyclagelosphaera margereli*	*Cyclagelosphaera reinhardtii*	*Diazomatolithus lehmanii*	*Discorhabdus* cf. *ignotus*	*Ethmorhabdus gallicus*	*Ethmorhabdus hauterivianus*	*Favioconus multicolumnatus*	*Helenea chiastia*	*Helenea staurolithina*	*Hexalithus noeliae*	*Hexalithus strictus*	*Lithraphidites carniolensis*	*Lotharingius hauffii*	*Lotharingius sigillatus*	*Manivitella pemmatoidea*	*Micrantholithus* sp.	*Miravestina favula*	*Nannoconus colomi*	*Nannoconus compressus*	*Nannoconus erbae*	*Nannoconus globulus globulus*	*Nannoconus globulus minor*	*Nannoconus infans*	*Nannoconus kamptneri kamptneri*	*Nannoconus kamptneri minor*	*Nannoconus puer*	*Nannoconus steinmannii minor*	*Nannoconus st. steinmannii*
Berriasian	NJT 17 Zone	NJT 17b Subzone	92 b	VL	VP			R	ER	ER		ER	ER	R	R									ER		?ER	r								ER	ER						
			91	VL	EP			R	VR	ER			?ER	R	R-F									ER																		
			90	L	P			R	VR			?ER	ER	R	R-F		ER							ER			?r							ER								
			89	VL	VP	?ER		R	VR	ER				R	R		ER							ER			r															
			88	L	VP	?ER		R	ER		?ER			R	F		ER					?ER														ER						
			87	EL	EP	?ER		R	VR	?ER				R	R						?ER							?r														
			86/87	EL	EP	ER		R	VR	ER			VR	R	R		ER																			VR						
			86	VL	EP			R	R	ER				R	R-F									ER				?r								ER						
Tithonian			85/86	VL	EP			R	VR				ER	R	R-F									VR										?ER		ER						
			85	VL	EP	ER		R	VR	VR			ER		F		ER																		ER	ER						
			84	VL	EP			R	VR	ER				R	R-F		ER																							ER		
			82	VL	EP	ER		VR	VR				ER	R	C							ER		ER				?r														
			81	VL	P		ER	R	VR				ER	R	F		ER																		ER	ER				?ER		
			79/80	VL	VP	?ER	?ER	R	ER			ER		R	F									ER																		
		NJT 17a Subzone	79	VL	VP			R	ER					R	F		ER						ER																			
			78	VL	EP					ER			fER	ER	R		ER																									
			75	EL	EP			R	VR	ER				R	R-F		ER																			ER						
			71/72	EL	EP			R	VR				ER	R	F		VR																									
			70 t	VL	VP			ER						VR	R									ER		f		?r						?		ER				ER		
			69	EL	EP			R	VR					R	F		ER					?ER	ER				?r															
			66/67	EL	VP			R	VR			?ER		R	F		VR					ER		ER		?ER																
			66 t	L	VP			R	ER						R				f?																							
			66	VL	EP			ER							R																											
			60	L	VP	?ER		VR	VR					R	R		ER					?ER		ER																ER		
			55	VL	EP			VR	ER					R	F																					ER						
	NJT 16 Zone		52/52	M	VP	?ER		VR	VR	ER				R	R		ER							ER																?ER		
			50/51	VL	EP							?		VR	R																											
			46	L	EP	?		ER	fER				ER	R	R							?ER	ER										?									
			44 t	VL	EP			ER	?	ER				ER	R							ER	ER	ER																		
			43	L	EP			?ER					VR	R	R		ER		?																							
			42/43	L	EP									ER	R		ER				f																					
			40 b	VL	EP			ER						VR	R		?																									
			36	L	EP			VR	ER				VR	VR	R																											
			30	H	VP	?ER		R	ER		fER			R	F			ER																								
			29	EL	EP			ER						ER	VR																											
			24/25	L-M	P			ER						VR	R-F			ER																		?ER						
			20/21	L	EP			VR					ER	VR	R-F																											
			20	L	EP								fER	fER	R																											
			14 t	M	P			R	ER				ER	R	F		VR	ER				?ER																				
			13	L	EP			ER						ER	R																											
			9	L-M	VP			VR	ER				ER	VR	F											?																
			8/9	L	P	?ER							ER	R	F		VR	ER				ER																				
			5 b	M	P			VR					VR	VR	F		ER					VR	VR																	ER		
			3	L	EP			ER	ER					ER	R		ER				f?																					
			1 t	VH	P			VR	R		fER		VR	R	F		ER	ER	fER		f?	?ER	ER								fER		?							VR		
	NJT 15 Zone	NJT 15b Sbz	-1	L-M	P			ER	ER				ER	R	R																											
			-2	L-M	P				ER					R	F		ER																									
			-3	L-M	P			ER	VR	ER				VR	F		ER						ER																			
			-6	L	P			ER						VR	R																		ER									
			-7	L	VP			VR	ER				ER	ER	R																											
			-8	L-M	VP			ER	ER				ER	VR	F																											
			-11	L-M	P			VR		ER			ER	VR	F																											
			-13	L	P			R	VR	ER				VR	F		ER																									
			-16	L	P			R	ER	ER			ER	VR	R-F		ER						ER										?				?					
			-17	L-M	P			VR	ER				ER	VR	R-F																											
			-19	L	VP		ER	R	ER	ER			ERE	VR	R		ER	ER																								
			-20	VL	VP			VR	ER				ER	ER	R		ER																									
			-21	L	P			R	ER	ER				ER	R		ER																									
			-26	EL	EP			VR	ER	ER					R		ER																									
			-28	VL	EP								VR		R	ER	ER																									
			-29 t	VL	EP			VR		VR					ER																											
			-29	L	VP			VR					VR		R	ER	ER																ER									

Table 1c (continued):

Chronostratigraphy	Zonation (Casellato 2010)	Sample No.	Nannofossil abundance	Nannofossil preservation	*Nannoconus wintereri*	*Nannoconus* sp.	*Nannoconus* sp. (cross-section)	*Parhabdolithus marthae*	*Parhabdolithus* sp.	penthaliths	*Pickelhaube furtiva*	placoliths (outer rims)	*Placozygus* sp.	*Polycostella beckmannii*	*Polycostella senaria*	*Retacapsa octofenestrata*	*Retacapca schizobrachiata*	*Retacapsa surirella*	*Retacapsa* sp. (outer rim)	*Rhagodiscus nebulosus*	*Rhagodiscus* sp.	*Rotelapillus crenulatus*	*Speetonia colligata*	*Staurolithites* sp.	*Thoracosphaera* sp.	*Umbria granulosa minor*	*Watznaueria barnesiae*	*Watznaueria biporta*	*Watznaueria britannica*	*Watznaueria communis*	*Watznaueria cynthae*	*Watznaueria fossacincta*	*Watznaueria manivitiae*	*Watznaueria ovata*	*Zeugrhabdotus cooperi*	*Zeugrhabdotus embergerii*	*Zeugrhabdotus erectus*	*Zeugrhabdotus fluxus*	*Zeugrhabdotus* sp. 1 sensu Bown 1992	*Zeugrhabdotus* sp.
Berriasian	NK-1	148	VL	EP		ER	ER												ER								C		VR			ER	VR		ER	ER				
		147 b	VL	EP					r	?		ER													VR		F	ER	VR	R	ER	ER	VR		?	ER				
		145	L	VP						ER							f			ER							F-C	ER	VR	R		ER	VR							
		144 s	VL	VP								VR							ER								R-F		ER	ER	ER	VR	ER			ER				
		143 b	VL	EP		VR	ER		r							ER		?	ER								C		VR		ER	VR	VR							
		142 s	L-M	P		f						ER		ER													C	ER	VR	VR		VR	VR		VR	ER				
		140	EL	VP		ER	ER					VR				?f			VR							?ER	C		VR			VR	VR	ER						
		138	L-M	VP			ER					ER															F-C	ER	VR	VR		R	VR		ER					
		136	EL	EP															ER								R		ER			ER	ER							
		135	L	VP																							F		ER	VR		VR	ER							
		133/134	VL	VP			ER						?			ER			ER		?	ER	ER		R	?	R		VR	VR	ER	ER	ER	ER						
		132	M	P														cf.	ER								F-C		VR		ER	ER	R		ER	ER				
		131	VL	EP		ER	ER																		?ER		F-C		VR			VR	R			ER				
		130 t	L-M	VP			ER																				F		ER		ER	ER	VR		ER	ER				
		129	VL	EP	?ER	VR	VR																				C-A	ER	VR	ER		ER	R			ER				
		128	EL	EP	?ER	VR						ER															C	ER	VR	ER		ER	R			VR				
		127	VL	VP		ER	ER					ER							?ER								C		VR				VR		ER	ER				
		126	L	P																							F		ER			ER	ER			ER				
		124	VL	VP		VR	ER																				C-A		VR				VR			ER				
	NKT ZONE	122	VL	EP	ER	ER	ER																				C		VR			ER	R							
		120	M	P	ER	VR	ER																				C		VR				VR		ER	ER				
		118	M	P		ER						ER													ER		F-C		R		ER	ER	R		ER	ER				
		116	VL	VP	?ER	VR	ER					ER				?ER											C		VR		ER	ER	VR							
		114	L-M	VP		ER													ER								C		VR			ER	R							ER
		112	L	VP		VR						ER															C		R	ER	ER		R			ER				
		111/112	M	P		ER																					C		VR		ER	ER	VR	VR	ER					
		110	VL	EP		ER	ER					ER				ER											C		VR		ER	ER	R							
		109	L	VP	?ER	VR													ER								C		ER				R			ER				
		107	VL	VP							f?								fER								R		VR		ER	ER								
		106 t	VL	VP	ER	VR	ER					ER															A		VR			ER	R			ER				
		106 b	L	VP	?ER	ER																			ER		A		R	ER		ER	R							
		105 s	EL	VP			ER																				C-A	ER	VR				R			ER				
		105 b	L	VP			ER				?								f								F		ER	ER	VR	VR	VR	VR	fER					
		103	L	VP																							R-F		ER			ER	ER	ER						
		102	VL	VP		VR																					C		R			VR	R			ER				
		101 t	L	VP		VR	VR																				C		R	ER		VR	VR		ER		cf.			
		101 y	VL	VP		VR	ER																				R		VR		ER		R		ER					
		101 x	L	VP		VR	ER																				C-A	ER	VR			VR	VR			ER				ER
		101 b	L	VP		ER	ER																				R-F		R			ER	R	ER						
		100 lime	EL	EP										ER												ER	VR		ER			ER								
		100 marl	L	P																					?		F		VR				VR							
		99 t	EL	EP		VR	ER																		ER		A		R			ER	R		ER	ER				
		99 b	EL	EP	?VR	ER																			?ER		A	ER	R		ER	VR	R							ER
		98	EL	EP			ER												ER								A		R		ER	ER	R		ER					
		97	VL	EP	?ER	ER	ER																				A		VR			VR	R		ER					
		96	VL	EP	ER	VR	ER					ER															C		VR		ER		R		ER					
		95 t	EL	EP	ER	VR																					A		VR			ER	R	ER		ER				
		95	L	VP										ER											?		F		VR			ER	VR							
		95 b	VL	VP	?ER	ER	ER																				C		VR			ER	R	ER						
		94	L	VP		ER				?ER																	C		R				R							
		93	VL	VP	?ER	VR																					C		VR		ER		R		ER					
		92 t	VL	EP		VR	ER		?r																		C		VR				VR							

Table 1d (continued):

Chronostratigraphy	Zonation (Casellato 2010)		Sample No.	Nannofossil abundance	Nannofossil preservation	*Nannoconus wintereri*	*Nannoconus* sp.	*Nannoconus* sp. (cross-section)	*Parhabdolithus marthae*	*Parhabdolithus* sp.	penthaliths	*Pickelhaube furtiva*	placoliths (outer rims)	*Placozygus* sp.	*Polycostella beckmannii*	*Polycostella senaria*	*Retacapsa octofenestrata*	*Retacapca schizobrachiata*	*Retacapsa surirella*	*Retacapsa* sp. (outer rim)	*Rhagodiscus nebulosus*	*Rhagodiscus* sp.	*Rotelapillus crenulatus*	*Speetonia colligata*	*Staurolithites* sp.	*Thoracosphaera* sp.	*Umbria granulosa minor*	*Watznaueria barnesiae*	*Watznaueria biporta*	*Watznaueria britannica*	*Watznaueria communis*	*Watznaueria cynthae*	*Watznaueria fossacincta*	*Watznaueria manivitiae*	*Watznaueria ovata*	*Zeugrhabdotus cooperi*	*Zeugrhabdotus embergerii*	*Zeugrhabdotus erectus*	*Zeugrhabdotus fluxus*	*Zeugrhabdotus* sp. 1 sensu Bown 1992	*Zeugrhabdotus* sp.
Berriasian	NJT 17 Zone	NJT 17b Subzone	92 b	VL	VP		ER	ER																				F	ER	R				R		ER					
			91	VL	EP		ER	ER					ER															C-A		VR			ER	VR			ER				
			90	L	P	ER		ER																				F-C		R		ER	ER	R							
			89	VL	VP		ER				ER									ER						?		F	ER	VR				R	ER						
			88	L	VP	?ER	ER	ER																		ER		F		R		?ER		R		ER					
			87	EL	EP	?ER	ER			?r																		C		R		?ER	ER	R		ER					
			86/87	EL	EP	ER	VR																					A		R		ER	ER	R		ER	ER				
			86	VL	EP	?ER	VR	ER			?ER																	F		R			ER	R							ER
Tithonian			85/86	VL	EP	ER	VR	ER					ER													ER		C		R		ER	ER	R	ER	ER					
			85	VL	EP	ER	VR																			ER		F		R	ER		ER	R							
			84	VL	EP			ER		r																ER		R		R				R			ER				
			82	VL	EP		VR																					F		R			ER	R		ER					
			81	VL	P	?ER	VR	ER												ER						ER		C		VR			ER	R			ER				
			79/80	VL	VP	ER	ER	ER																				F-C	?ER	R				R							
		NJT 17a Subzone	79	VL	VP		ER	ER																				F	ER	R				R							
			78	VL	EP																							R		ER		fER		ER							
			75	EL	EP			ER		r			ER				ER											C		R		ER		R							ER
			71/72	EL	EP			ER																				F-C		R			ER	R							
			70 t	VL	VP								ER													?	?f	R-F		VR	R	ER	ER	ER							
			69	EL	EP																					?		F-C	ER	R			ER	R		ER					
			66/67	EL	VP		VR								?ER											?	?ER	F-C		R				R							
			66 t	L	VP										ER											?		F		VR				R	ER						
			66	VL	EP																							R						VR							
			60	L	VP		VR			r					VR											?		F-C	ER	VR				R		ER					
			55	VL	EP		ER	ER					ER													?ER		F-C		VR			ER	VR							
	NJT 16 Zone		52/52	M	VP			ER					ER		ER													C	ER	VR				VR							
			50/51	VL	EP															ER								R-F		VR	R		ER	R							
			46	L	EP															ER					f?			R-F		R	R	?	R	VR	ER	ER	ER				
			44 t	VL	EP										VR					ER								R-F		ER	R		VR	ER							
			43	L	EP								ER															C-A		VR			ER	R			ER				
			42/43	L	EP																							F		VR	R		VR	ER			ER				
			40 b	VL	EP										?		ER			ER								R-F		VR		?	R	VR	ER		ER	cf.		ER	
			36	L	EP															ER								C-A		VR			VR	R							ER
			30	H	VP					r					R					ER								C-A	?ER	R		?	VR	VR	?	VR	ER			ER	
			29	EL	EP																							R		ER			ER								
			24/25	L-M	P				r	r			ER		ER												?f	F		VR			R	ER		ER					
			20/21	L	EP																							F		VR			VR			ER					
			20	L	EP			?ER												ER								R		VR			VR	ER							
			14 t	M	P								ER		R		?ER											C		R			R	R	ER	ER					
			13	L	EP																							F					ER	ER							
			9	L-M	VP										VR					ER								F-C		ER			ER	ER		ER					ER
			8/9	L	P					r	ER									VR								F-C		VR	R-F		R	R	ER	ER					
			5 b	M	P				r	r					R	ER				ER								F-C		R			R	VR		ER					
			3	L	EP										ER													F					ER	ER		fER					
			1 t	VH	P		ER			r	ER	?			VR					ER								C-A		VR				R		VR					
	NJT 15 Zone	NJT 15b Sbz	-1	L-M	P																					ER		C-A	ER	VR			ER	R		ER	ER				
			-2	L-M	P										VR											ER		F		VR				R		ER	ER				
			-3	L-M	P										VR											?		F		R				R		VR	ER				
			-6	L	P		?								VR													F		R	ER		VR	ER		ER	ER		ER		
			-7	L	VP										ER											?		F		R			ER	VR							
			-8	L-M	VP										VR											?		F		R			ER	VR			ER				
			-11	L-M	P		?		?	r					VR					ER						VR		F		R			R	ER		ER			ER		ER
			-13	L	P										R											ER		F	ER	R			ER	VR		ER					
			-16	L	P		?			r					R												?	F		R	VR		R	VR		VR	ER				
			-17	L-M	P										ER											VR		F-C		R			ER	VR		ER					
			-19	L	VP										R													F		ER	?		ER	ER			fER				
			-20	VL	VP										VR											ER		F		R				VR		ER					
			-21	L	P										VR											ER		F-C		VR			ER	VR			ER				
			-26	EL	EP										VR															VR				ER							
			-28	VL	EP																					?		R-F		VR	VR		ER	VR							
			-29 t	VL	EP										ER													VR						ER							
			-29	L	VP					r					VR					ER								F	ER	R	VR		VR	VR	ER						

radiolaria–spiculae microfacies (wackstones), pelbiomicrosparitic limestone of radiolaria–spiculae microfacies and crinoidal–radiolaria–spiculae or crinoidal microfacies (packstone) and pelbiointraclastic limestones (grainstones) belonging to SMF2 and SMF3 were observed (Fig. 8A–C). Radiolarians and sponges are locally concentrated in clusters, occasionally as a result of bioturbation. They are calcified, and in some beds replaced by chalcedony or microcrystalline quartz. Some bioclasts are silicified or phosphatized. Rocks contain scattered pyrite, less often framboidal pyrite, and a silty clastic admixture composed of quartz, muscovite, and rare glauconite. Bioclasts impregnated with pyrite sometimes make up cluster concentrations. Clasts of volcanic rocks were recorded. The matrix is occasionally penetrated by fractures filled by calcite. The deposits contain rare aptychi, ostracods, foraminifers, radiolarians, sponge spicules, crinoids, bivalve fragments, spores of *Globochaeta alpina*, calcareous cysts of *Parastomiosphaera malmica* (Fig. 9A), *Colomisphaera carpathica* (Fig. 9C), *C. lapidosa* (Fig. 9D), less frequent *C. cieszynica, C. radiata* (Fig. 9G), *C. pieniniensis, Carpistomiosphaera tithonica* (Fig. 9E), *Committosphaera pulla, Cadosina semiradiata fusca* (Fig. 9K), *C. semiradiata semiradiata* (Fig. 9J), *C. semiradiata cieszynica, Stomiosphaera moluccana* (Fig. 9B), *Committosphaera czestochowiensis, C. sublapidosa,* and *C. ornata* (Fig. 9H).

Beds −6 to 35 (~7.7–35.5 m): Micrite limestones — biomicritic, pelbiomicritic, pelbiointraclastic and marly limestones to silty limestones (mudstones, wackestones and packstones), SMF2,3,4. Rocks are slightly laminated and locally bioturbated or they exhibit a slightly recrystallized or silicified matrix and microfossils. In some places, the gradation of allochems is distinct. Fragments of ostracods, bivalves, crinoids (including planktonic *Saccocoma* sp.) may create "allodapic" beds. Foraminifers, aptychi, the alga *Girvanella*, microproblematica of *Gemeridella minuta* and other unrecognizable microfossils dominate. In the lower part of interval, dinoflagellate cysts are more abundant and indicate *Cadosina*–spiculite–radiolarian microfacies type. Radiolarians and sponge spicules, occasionally also saccocomids, are replaced by chalcedony or microcrystalline quartz. A few bioclasts are phosphatized. Locally abundant fractures filled by calcite penetrate the matrix and frutexites (Fig. 8D). The matrix is rich in pyrite and organic matter. Rocks contain a silty clastic admixture composed of quartz, muscovite and rare glauconite. Among the calcareous cysts, *Cadosina semiradiata fusca* and *C. semiradiata semiradiata* dominate over specimens of the genera *Colomisphaera, Stomiosphaera, Committosphaera, Parastomiosphaera* and *Carpistomiosphaera*.

Beds 36–42 (~35.5–37.65 m): Micrite limestones — biomicritic, pelbiomicritic of spiculite and radiolarian–spiculite microfacies (wackestones to packstones), locally bioturbated or slightly laminated. In some beds smooth laminae rich in small, occasionally graded bioclasts (crinoid columnals, *Saccocoma* sp., and sponge spicules) are present. Rich framboidal pyrite scattered in matrix is documented in a few beds. Pyrite clusters partially replace bioclasts. Limestones contain silty quartz, muscovite and glauconite. Calcified radiolarians and sponge spicules, locally replaced by chalcedony or microcrystalline quartz, dominate over rare ostracod and crinoid fragments. Calcareous dinoflagellate cysts of the genera *Colomisphaera* (including *C. fortis*), *Committosphaera* and *Cadosina* were documented. The presence of the genera *Stomiosphaera, Carpistomiosphaera* and *Parastomiosphaera* is shown by reworked material from the older, Early Tithonian, strata.

Beds 42/43–84 (~37.65–51.9 m) are divided into three intervals:

A) Beds 42/43–51/52 (~37.65–42.9 m): Micrite limestones — biomicritic, pelbiomicritic locally slightly recrystallized of spiculite and radiolarian–spiculite microfacies (wackestones, packstones to mudstones), silty, slightly laminated limestones of spiculite microfacies (packstones) locally with silt rich laminae, and siliceous siltstones rich in tiny plant fragments. The deposits can be interpreted as SMF2 and SMF3. Radiolarians and sponge spicules are concentrated in clusters. A silt admixture is abundant in places. Some beds are rich in organic matter and pyrite, which is scattered in the matrix, impregnates bioclasts or creates clusters. Bioclasts are locally phosphatized. The matrix is penetrated by numerous fractures and veins filled by calcite. Calcified radiolarians and sponge spicules dominate over crinoids, ophiurids, ostracods, bivalves, aptychi, *Saccocoma* sp. and spores of *Globochaete alpina*. The first rare calpionellids are recorded here — *Tintinnopsella remanei, Praetintinnopsella andrusovi, Calpionella alpina* and specimens of the genus *Crassicollaria*. The occurrence of calcareous dinoflagellate cysts points to reworking of material from older Jurassic strata.

B) Beds 52–70 (~42.9–48.25 m): The character of deposits and microfacies SMF2 and SMF3 are similar to the previous interval. Sample 66 shows the erosion surface which separates an interval of slightly laminated wackestone to mudstone from graded pelbiomicrosparitic interval (grainstone) with clasts of volcanic rocks (SMF4). Above the erosion surface, frutextites (Maslov) and radiolarians predominate. The rocks contain calcified radiolarians, sponge spicules, ostracods, globochaetes, *Spirillina* sp. and a few further fragments of benthic foraminifers. Calpionellids are more common and associations are represented by the genus *Crassicollaria* (Fig. 10A), *Calpionella* (Fig. 10B–D, J, K) and *Tintinnopsella* (Fig. 10L). Some of the crassicollarian loricae are deformed. Dinoflagellate cysts are represented by the genera *Colomisphaera, Committosphaera, Stomiosphaera*, *Cadosina, Carpistomiosphaera,* and *Parastomiosphaera.* The majority of these are reworked from older Jurassic strata (Figs. 11, 12).

C) Beds 70/71–84 (~48.25–51.9 m, Košťák et al. 2018): Micrite limestones — biomicritic, pelbiomicritic, slightly laminated and locally bioturbated limestones of spiculite–radiolarian microfacies — wackestones, occasionally mudstones or packstones; SMF3 prevails. Allochems locally show grading. Some of the bioclasts and matrix are silicified. Fractures filled by calcite penetrate the matrix in different directions (three directions are common), and cut small

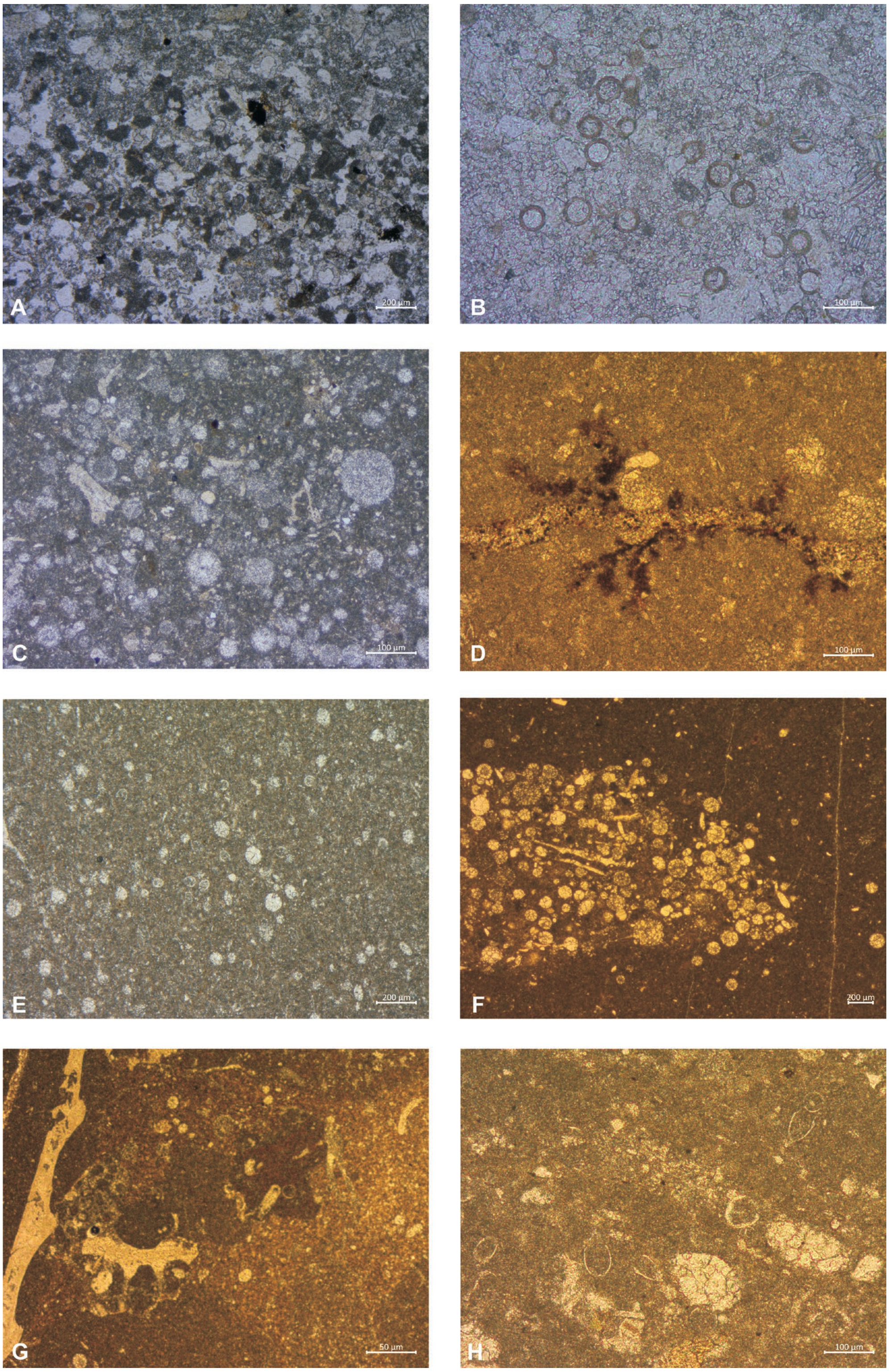

Fig. 8. Important microfacies determinated in the Kurovice section. SMF=standard microfacies type. **A** — Pelbiomicritic laminated limestone of crinoid-radiolaria-spiculae microfacies (packstone). SMF 2, sample −9. **B** — Bioclastic limestone of Cadosina-crinoid microfacies (packstone). SMF 2, sample −2; **C** — Pelbiomicritic limestone of radiolaria–spiculae microfacies (packstone) with rare *Saccocoma* sp. SMF 2, sample −16; **D** — Frutextite in biomicritic limestone of radiolaria–spiculae microfacies (wackestone). SMF 3, sample 3/1; **E** — *Calpionella alpina* event across the J–K boundary in biomicritic limestone of spiculae–radiolaria microfacies (wackstone). SMF 3, sample 86; **F** — Accumulation of bioclasts in bioturbated limestone of spiculae–radiolaria microfacies (wackestone). SMF 3, sample 109; **G** — Microbreccia limestone with variable types of extraclasts and bioclasts derived from the shallow carbonate platform environment. SMF 4, sample 105t; **H** — Extraclast of the Late Tithonian biomicritic limestone of the Crassicollaria Zone, Intermedia Subzone with large forms of *Calpionella* sp. and *Crassicollaria intermedia* in the Berriasian deposits of the Alpina Subzone of Calpionella Zone. SMF 4, sample 101x.

caverns filled by silica. The matrix is locally rich in scattered pyrite and organic matter, in the form of tiny plant fragments. The rocks contain calcified radiolarians, sponge spicules, and fewer fragments of ostracods, bivalves and foraminifers. Among calpionellids, specimens of the genus *Crassicollaria* outnumber *Calpionella alpina* and *Calpionella* sp., *Calpionella grandalpina*, *C. elliptalpina* and *Tintinnopsella carpathica*. Deformed crassicollarian loricae are still present. The abundance of calcareous dinoflagellate cysts decreases. These include an autochthonous species, *Stomiosphaerina proxima,* and reworked specimens of *Colomisphaera*, *Committosphaera, Cadosina* and *Parastomiosphaera* (Figs. 11, 12).

Beds 85/86 to 148 (~51.9–76.7 m) are also divided into three intervals (Košťák et al. 2018):

A) Beds 85/86 to 118 (~51.9–68.5 m) are represented by micrite slightly laminated and locally bioturbated limestones of spiculite–radiolarian microfacies (wackestones to mudstones, SMF3). Bioturbated intervals contain rich bioclasts (mainly radiolarians and sponge spicules) concentrated into "nests". Marly intercalations contain clastic admixture, fragments of plants and small clasts of micritic *Calpionella* bearing limestones are recognized. Further, the microbreccia limestones (slightly laminated pelbiomicritic) bear the bioclasts derived from a carbonate-ramp environment, extraclasts of dolomitic limestones, limestones with Tithonian crassicollarian, shales and volcanic rocks (SMF4). Bioclasts and the matrix are slightly silicified and some of bioclasts are phosphatized. Limestone matrices contains fine silt, composed of quartz, muscovite, rare glauconite and volcanic ash. Frutextites appear in some beds. Abundant fractures filled by calcite penetrate the matrix in different directions. Discontinuous veinlets (Mišík 1971) of calcitic veins are documented. Microfossils are represented by calcified radiolarians, sponge spicules, less common fragments of ostracods, bivalves, aptychi, crinoids, ophiurids, bryozoans, and benthic foraminifers (*Nodosaria* sp., *Dentalina* sp., miliolids), and spores of *Globochaete alpina* and *Didemnum carpaticum.* Small spherical forms of *Calpionella alpina* dominate over *Crassicollaria parvula, Calpionella* sp., and infrequent *C. elliptalpina, C. grandalpina,* and *Tintinnopsella carpathica* (Fig. 12). The majority of crassicollarians have deformed loricae. As in the underlying strata, dinoflagellates include specimens of the genera *Colomisphaera, Cadosina, Stomiosphaerina, Parastomiosphaera, Colomisphaera,* and *Carpistomiosphaera.* A few loricae of the larger *Calpionella* morphotypes, deformed crassicollarians and some dinoflagellate cysts were redeposited from Jurassic sediments.

B) Beds 119–131 (~68.5–71.8 m): Micrite, locally slightly laminated and bioturbated limestones (wackestones, sporadically mudstones and packstones, SMF3 predominates) and rare siltstones. The matrix contains rich, scattered pyrite and a silty admixture, and is sometimes penetrated by fractures and veins filled by calcite. Some small bioclasts are phosphatized. Calcified radiolarians and sponge spicules dominate in bioclastic wackestones. Moreover, rare fragments of ostracods, crinoids, bivalves and aptychi, and very rare calpionellids occur there. Loricae of the genus *Remaniella* (including *R. catalanoi, R. duranddelgai, R. ferasini* and *R. colomi*) are observed here for the first time (Fig. 10F–I). They are accompanied by *Calpionella alpina, Tintinnopsella doliphormis, T. carpathica,* and *Lorenziella hungarica* (Figs. 11, 12). A large number of deformed loricae is a typical phenomenon in these beds. Calpionellid loricae in the autochthonous matrix are thin and bear marks of dissolution, whereas loricae of reworked specimens have significantly thicker calcite walls. A small number of dinoflagellate cysts of the genera *Colomisphaera, Stomiosphaera, Cadosina* and *Parastomiosphaera malmica* are present. They are considered allochthonous components of these deposits. *Colomisphaera fibrata* has been recorded only here (Fig. 12) and may document erosion of Early Tithonian strata.

C) Beds 132–148 (~71.8–76.7 m): In this, the highest interval in the quarry sequence, micrite slightly laminated, bioturbated or slightly recrystallized limestones of spiculite–radiolarian microfacies (wackestones, mudstones and also packstones) and slightly laminated silty limestones (mudstones) corresponding to SMF2 and SMF3 were documented. Bioclasts usually create nest-shaped accumulations in bioturbated beds. The matrix is rich in scattered pyrite, admixed silt, and it is penetrated by fractures and veins filled with calcite. Some small bioclasts are phosphatized. The sediments contain calcified radiolarians, sponge spicules, rare fragments of ostracods and foraminifers. Calpionellids occur rarely and many of them, mainly remaniellids, have damaged collars, which makes their identification difficult. Numerous deformed crassicollarian loricae are still present. Calpionellids are represented by *Calpionella elliptica, C. alpina, Crassicollaria parvula, Tintinnopsella carpathica* and *Lorenziella hungarica* (Fig. 10). Cyst associations are mixed and contain reworked specimens. They include locally abundant *Cadosina semiradiata fusca* and, as in the underlying strata, *Colomisphaera*, *Committosphaera, Parastomiosphaera,* and *Stomiosphaera*.

Palynomorphs

Palynomorphs are rare and usually poorly preserved due to the high $CaCO_3$ content and the presence of pyrite. Pyrite crystals are often found inside specimens and usually corrode them. Most rock types provided abundant phytoclasts of brown or black colour with rare and often broken non-calcareous dinoflagellate cysts, acritarchs, pteridophyte spores, gymnosperm pollen, planispiral agglutinated foraminiferal linings and, occasionally, some prasinophyte algae. The vertical distribution of palynomorphs is given in Fig. 13. No palynomorph was detected in samples 33, 39, 41, 43, 46, 56, 70, 97/98, 100/101, 108/109, 130/131, 134/135 and 135/136.

The following spectra were found:

Sample 25: abundant black phytoclasts with non-calcareous dinocysts of *Amphorula dodekovae, A. metaelliptica, Circulodinium distinctum, Cometodinium habibii, Cribroperidinium* sp., *Glossodinium dimorphum, Prolixosphaeridium anasillum, P. mixtispinosum, Subtilisphaera* sp., *Systematophora daveyi,*

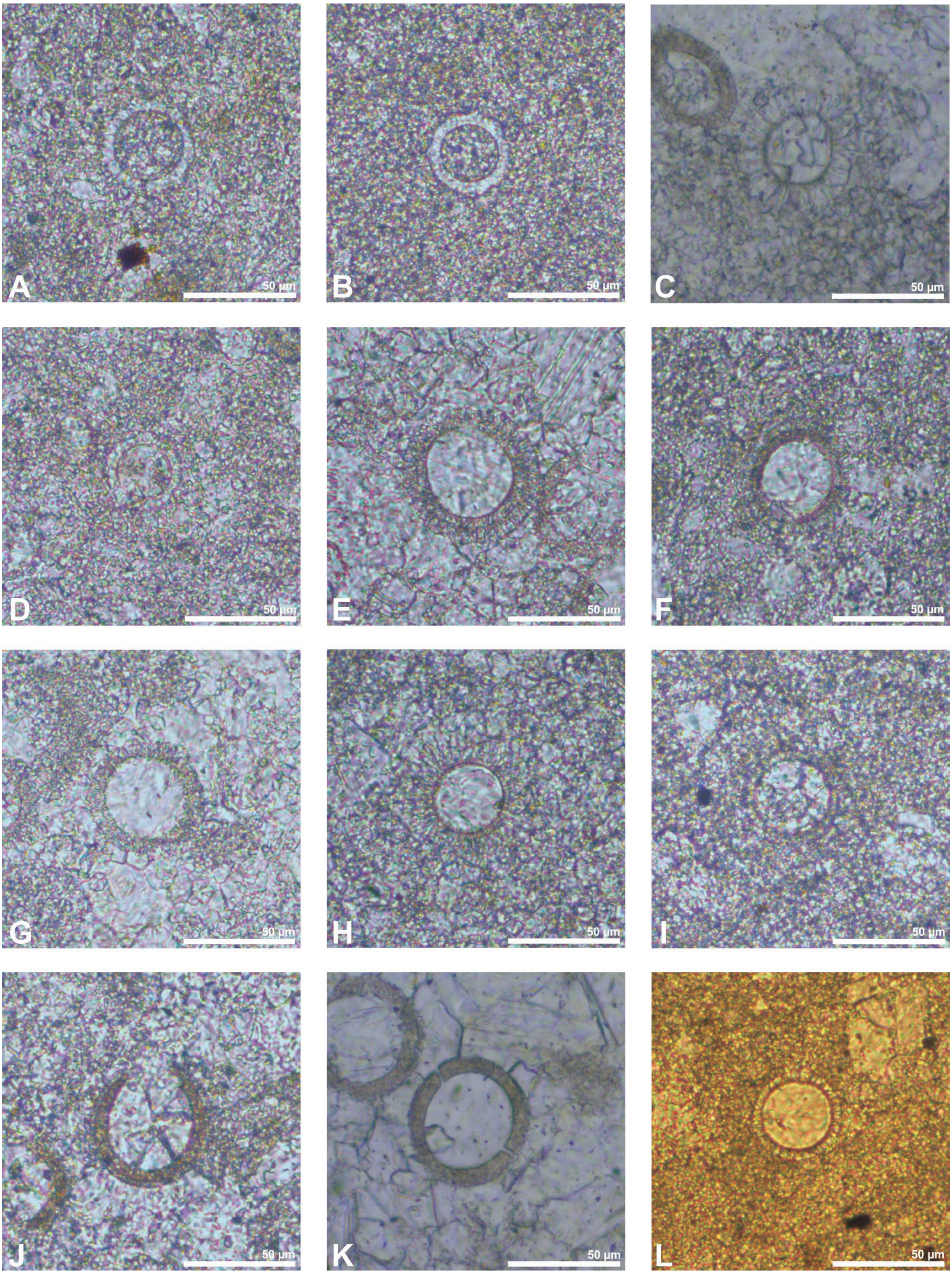

Fig. 9. Kurovice section, calcareous dinoflagellate cysts. **A** — *Parastomiosphaera malmica*, sample −12; **B** — *Stomiosphaera mollucana*, sample −19; **C** — *Colomisphaera carpathica*, sample −2; **D** — *Colomisphaera lapidosa*, sample −12; **E** — *Carpistomiosphaera tithonica*, sample −2; **F** — *Committosphaera pulla*, sample −12; **G** — *Colomisphaera radiata*, sample −10; **H** — *Commitosphaera ornata*, sample −27; **I** — *Colomisphaera pieniniensis*, sample −20; **J** — *Cadosina semiradiata semiradiata*, sample −3; **K** — *Cadosina semiradiata fusca*, sample −2; **L** — *Colomisphaera fortis*, sample 148.

S. orbifera and *S. silybum*, the acritarch *Micrhystridium* sp., a prasinophyte alga *Pterospermella helios,* spores of the fern *Cyathidites minor,* and gymnosperm *Classopollis torosus* pollen. The palynospectrum corresponds to the Tithonian age.

Sample 30a: frequent phytoclasts of brown and black colour with broken non-calcareous dinoflagellate cysts, namely: *Gonyaulacysta* sp., *Gochteodinia* cf. *virgula*, *Ctenidodinium ornatum*, *Pareodinia* sp., the acritarch *Micrhystridium stellatum, Veryhachium irregulare,* and pollen of *Classopollis torosus* — often present in tetrads.

Sample 49: frequent phytoclasts of brown and black colour with a rich assemblage of non-calcareous dinoflagellate cysts similar to associations in the underlying strata and, additionally**,** *Cribroperidinium globatum, C. sarjeantii, Pareodinia robusta, Gonyaulacysta helicoidea, Hystrichodinium pulchrum, Neuffenia willei*, *Oligosphaeridium pulcherrimum, Sentusidinium* sp., *Stiphrosphaeridium dictyophorum, Systematophora areolata,* and *Tanyosphaeridium isocalamum.* Sporadic *Micrhystridium* sp. and gymnosperm pollen, *Classopollis torosus,* also occur.

Sample 50: common phytoclasts of brown and black colour, tracheids of Pinaceae, non-calcareous dinoflagellate cysts, namely: *Dingodinium tuberosum*, *Oligosphaeridium* aff. *patulum*, *Chytroeisphaeridia chytroeides*, *Jansonia* sp., isolated opercula of *Cribroperidinium* sp. and *Wallodinium* sp., linings of planispiral agglutinated foraminifers, the acritarch *Micrhystridium* sp., *Leiosphaeridia* sp., *Pterospermella australiensis,* pteridophyte spores *Gleicheniidites senonicus*, *Neoraistrickia truncata*, *Lycopodiumsporites* sp., *Polycingulatisporites* and *Classopollis torosus, Spheripollenites subgranulatus.* The palynospectrum corresponds to the Tithonian age.

Sample 85: abundant black phytoclasts with *Micrhystridium* sp., and the prasinophyte alga *Pterospermella.* Dinocyst association is similar to underlying strata.

Sample 105: brown and black phytoclasts and radiolarian remains. Non-calcareous dinocysts are represented both by species derived from underlying strata and by *in situ* taxa *Dissiliodinium giganteum, Prolixosphaeridium deirense, Prolixosphaeridium* sp. A *sensu* Monteil (1993), and *Tehamadinium evittii.*

Sample 111/112: abundant black phytoclasts, amorphous organic matter, broken radiolarian tests, linings of agglutinated foraminifers, rich dinoflagellate cyst association with species known from the underlying strata as well as *Achomosphaera neptuni, Circulodinium vermiculatum, Dapsilidinium multispinosum, Endoscrinium campanula, E.* cf. *pharo, Gonyaulacysta* sp., *Kiokansium polypes, P. anasillum,* and *Classopollis torosus.* The palynospectrum corresponds to the Berriasian age with the redeposition of Jurassic species.

Sample 132: brown and black phytoclasts, radiolarian remnants, non-calcareous dinocysts similar to the assemblages of the underlying strata with new taxa *Cyclonephelium hystrix, Spiniferites sp.* and *Sirmidiniopsis sp.* An admixture of continental pteridophyte spores (*Echinatisporites* sp.) and gymnosperm pollen (*Classopollis torosus* and *Cerebropollenites macroverrucosus*) is subsidiary. It corresponds to the Berriasian age with the redeposition of Jurassic species.

Sample 132/133: abundant black phytoclasts, non-calcareous dinoflagellate cysts *Circulodinium* sp., *Dichadogonyaulax bensonii, Endoscrinium campanula*, *Gonyaulacysta* sp., *Leptodinium* sp., *Oligosphaeridium asterigerum* and *Prolixosphaeridium granulosum*. Pteridophyte spores *Densoisporites velatus, Gleicheniidites* sp. and conifers of *Classopollis torosus* is subsidiary. It corresponds to the Berriasian age with the redeposition of Jurassic species.

Selected palynomorphs are shown in Figures 14 and 15.

Biostratigraphy

Despite the poor preservation, microorganisms provide important data that help us to detect the Jurassic/Cretaceous boundary at Kurovice. According to the calcareous dinoflagellate cyst and calpionellid zonations (*sensu* Reháková 2000; Reháková & Michalík 1997) the section spans the interval from the Early Tithonian cyst Malmica Zone up to the Early Berriasian Calpionella Zone, Elliptica Subzone (Figs. 11, 12, 16). Nannofossils confirm this stratigraphic interpretation, with a zonal range from NJT 15b up to NK-1 (zones of Casellato 2010; Bralower et al. 1989).

The following calcareous dinocyst and calpionellid zones compared to nannofossil events were identified:

The calcareous dinocyst Malmica Zone (Nowak 1968), early Early Tithonian was established in the lowermost part of the sequence (samples −29 to −7; ~0–7.7 m) by the presence of *Parastomiosphaera malmica*. Nannofossil assemblages contain *Polycostella beckmanii* and are assigned to the NJT 15b Nannofossil Subzone. The first, questionable, small nannoconids were found in sample −16 (Table 1b).

The following calcareous dinoflagellate and calpionellid zones were previously mentioned by Elbra et al. (2018a):

The Semiradiata Zone (Reháková 2000), Early Tithonian (samples −6 to 35; ~7.7–35.5 m; Elbra et al. 2018a) was recognized based on the abundance of the cysts *Cadosina semiradiata semiradiata* and *C. semiradiata fusca*. The first occurrence (FO) of *Helenea chiastia* (NJT 16 Nannofossil Zone) was recorded immediately above the base of the Semiradiata Zone in sample 3.

The Tenuis-Fortis Zone**,** early Late Tithonian (samples 36–42, ~35.5–37.65 m). It was not possible to strictly separate the Tenuis from the Fortis zones (Řehánek 1992) because of the absence of *Colomisphaera tenuis*. Only one specimen of *Colomisphaera* sp. was found in sample 20. Reháková (2000) assumed that the Fortis Zone coincided with the disappearance of chitinoidellids and their substitution by the first transitional hyaline–microgranular calpionellids of the Praetintinnopsella Zone. A single lorica of *Praetintinnopsella andrusovi* was found in the sample 42/43, but in the overlying Crassicollaria Zone. This phenomenon confirms the opinion of Reháková (2000).

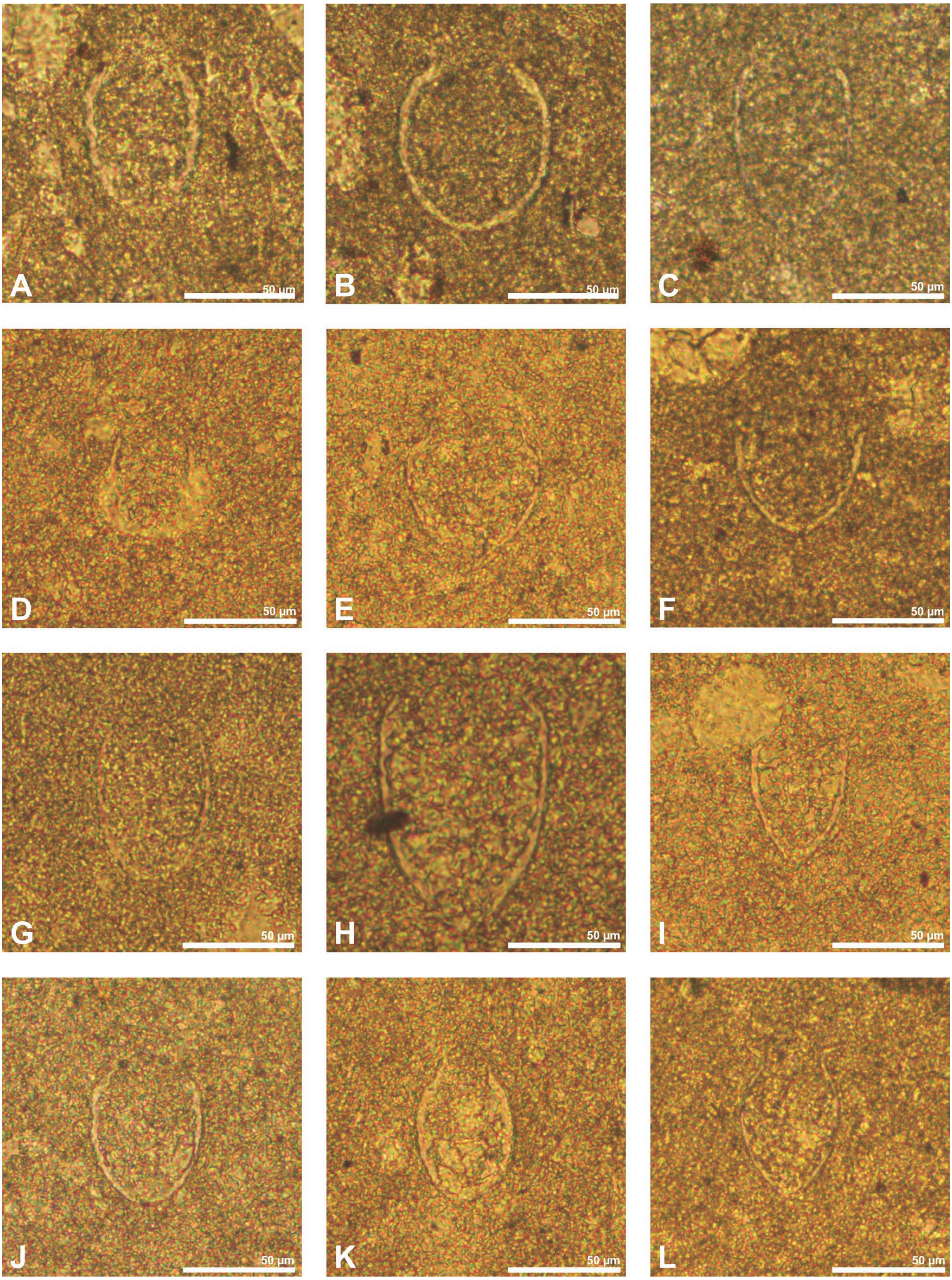

Fig. 10. Kurovice section, calpionellids. **A** — *Crassicollaria massutinianna*, sample 100; **B** — *Calpionella grandalpina*, sample 101b; **C** — *Calpionella elliptalpina*, sample 88; **D** — *Calpionella* sp., sample 125; **E** — *Lorenziella hungarica*, sample 124; **F** — *Remaniella duranddelgai*, sample 132; **G** — *Remaniella borzai*, sample 120; **H** — *Remaniella colomi*, sample 125; **I** — *Remaniella ferasini*, sample 127; **J** — *Calpionella elliptica*, sample 133; **K** — *Calpionella elliptica*, sample 134; **L** — *Tintinopsella carpathica*, sample 139.

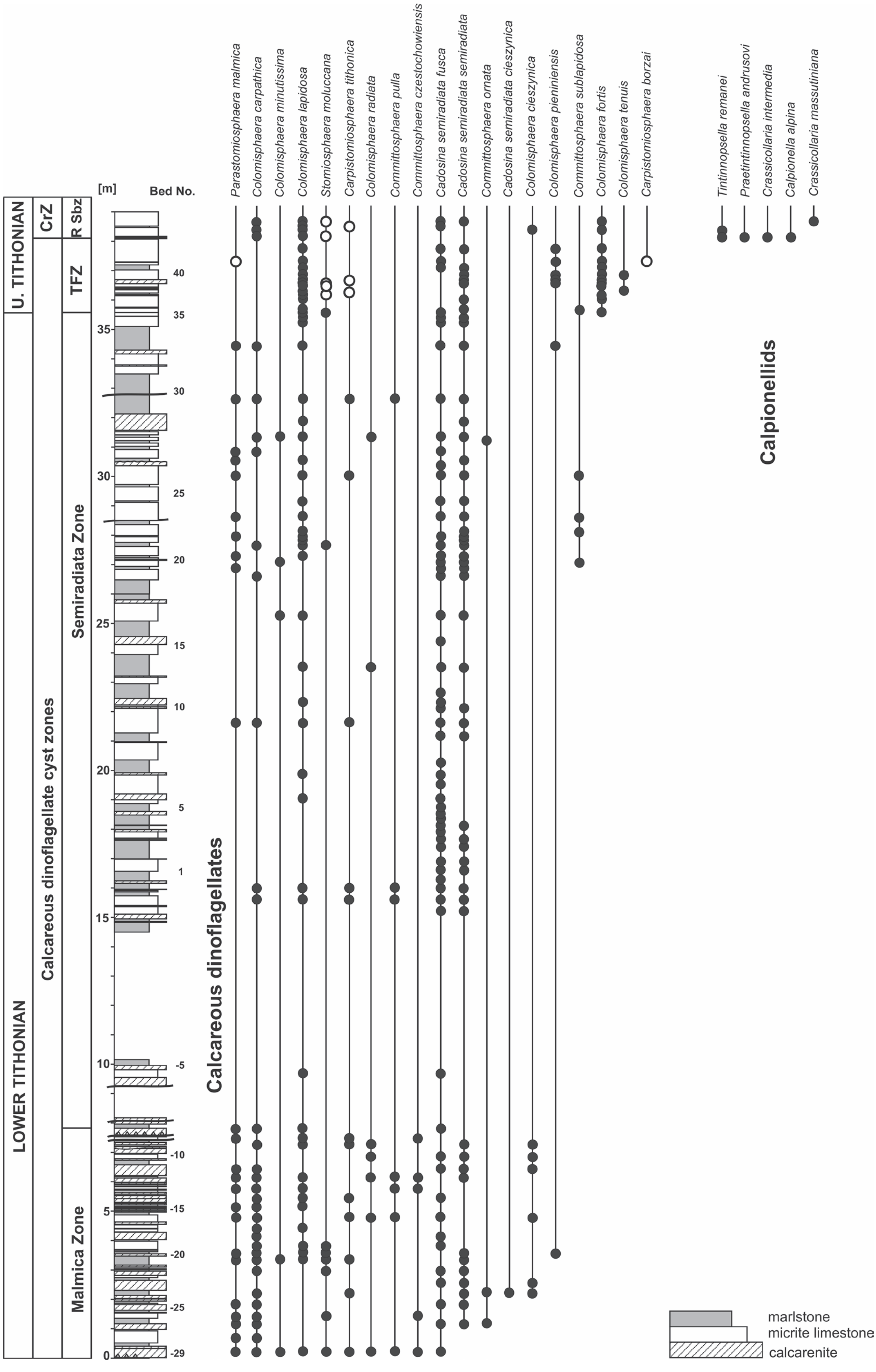

Fig. 11. Kurovice section, lithology and vertical distribution of calpionellids and calcareous dinoflagellate cysts. TFZ — Tenuis–Fortis Zone; R Sbz — Remanei Subzone; CrZ — Crassicollaria Zone. Open circles indicate reworked specimens. Lithology after M. Bubík in Košťák et al. (2018). Calpionellid zones after Reháková & Michalík (1997), cyst zones sensu Reháková (2000).

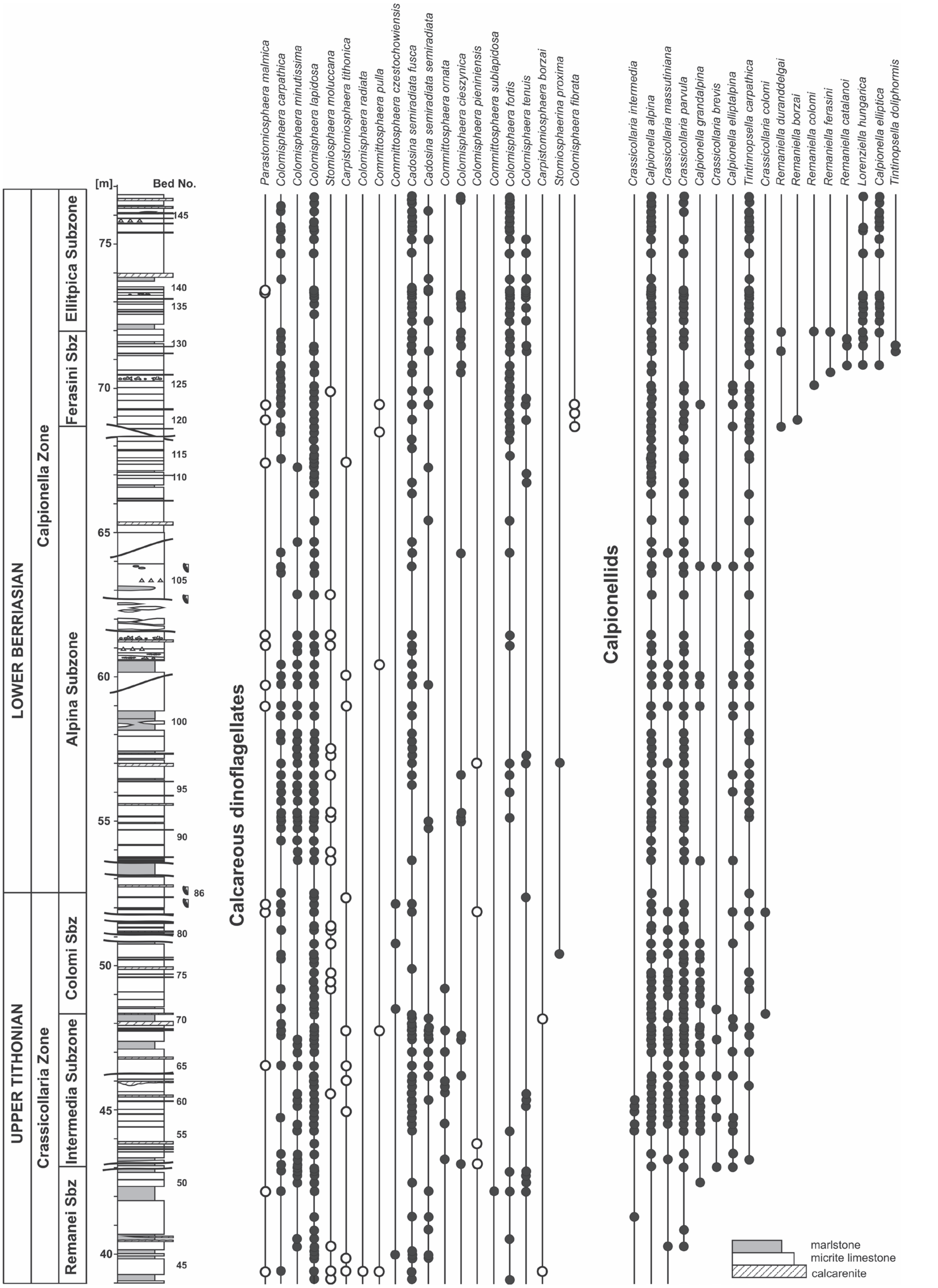

Fig. 12. Kurovice section, lithology and vertical distribution of calpionellids and calcareous dinoflagellate cysts. Open circles indicate reworked specimens. Lithology after M. Bubík in Košťák et al. (2018). Calpionellid zones after Reháková & Michalík (1997), cyst zones sensu Reháková (2000).

The Crassicollaria Zone (Remane et al. 1986), early to late Late Tithonian (samples 42/43–84, ~37.65–51.9 m) is subdivided into three subzones:

The Remanei Subzone (Remane et al. 1986) (samples 42/43 –51/52; ~37.65–42.9 m) is identified by very rare calpionellids *Tintinnopsella remanei* and *Crassicollaria intermedia,* followed by rare *C. massutiniana, C. parvula* and *Calpionella alpina*.

The Intermedia Subzone (Remane et al. 1986) (samples 52–70; ~42.9–48.25 m) is clearly recognizable by a frequent and more diversified association with *Calpionella alpina, C. grandalpina, C. elliptalpina, Crassicollaria intermedia, C. massutiniana, C. parvula, C. brevis,* and *Tintinnopsella carpathica*. In the lower part of this interval (sample 55) is the FO of *Nannoconus globulus minor*, so that the base of the NJT17a Nannofossil Subzone is recorded (Fig. 16). Just above this bioevent, the last occurrence of *Polycostella beckmannii* was identified.

The Colomi Subzone (Pop 1994) (samples 70/71–84; ~48.25–51.9 m) is characterized by the dominance of *Crassicollaria parvula*, associated with scarce *C. colomi* and other deformed crassicollarians. Larger forms of *Calpionella grandalpina* and *C. elliptalpina* show rapid quantitative decline. The FO of *Nannoconus wintereri* was found in the upper part of this interval in sample 79/80. This bioevent defines the base of the NJT17b Subzone which has a short stratigraphic interval spanning the uppermost Tithonian (Casellato 2010). The overlying bed, unit 81, yielded the first *Nannoconus globulus globulus*.

The Calpionella Zone, Early Berriasian in age, is here subdivided again into three subzones.

The Alpina Subzone (*sensu* Pop 1974; Remane et al. 1986) was first detected in the sample 85/86 and its top was recorded in sample 118; spanning the interval from ~51.9 m to 68.5 m with disappearance of large *Calpionella* species and domination of small spherical specimens of *Calpionella alpina* (*Calpionella alpina* event *sensu* Kowal-Kasprzyk & Reháková 2019). The species *Crassicollaria parvula* and *Tintinnopsella carpathica* are very rare. The base of the calcareous nannofossil NKT Zone is marked by the FO of *Nannoconus steinmannii minor* in sample 92.

The Ferasini Subzone (Remane et al. 1986), Early Berriasian in age (samples 119–131; ~68.5–71.8 m) is distinguished by a decrease in the number of calpionellids. The *Remaniella ferasini* was not recorded in sample 119, so, the base of the biozone is fixed on the FO of *R. duranddelgai* (sample 119) and the appearance of other remaniellids. The FO of *Nannoconus kamptneri kamptneri* (NK-1 Zone) occurs in sample 124.

The Elliptica Subzone (Pop 1974), late Early Berriasian (samples 132–148; ~71.8–76.7 m) was established on the presence of *Calpionella elliptica* accompanied by rare specimens of the genera *Calpionella*, *Remaniella*, *Tintinnopsella* and *Lorenziella*. The FO of *Speetonia colligata* was registered in sample 133/134.

The species *Nannoconus infans*, *N. kamptneri minor* and *N. steinmannii steinmannii* appear sporadically in the limestone sediments at Kurovice, and for this reason their first occurrences are not used in our stratigraphic interpretations (Table 1).

The above-mentioned stratigraphic data are reinforced by that provided by palynomorphs. The non-calcareous dinoflagellate cysts *Amphorula metaelliptica, Dingodinium tuberosum*, *Systematophora areolata,* and *S. silybum* support a Tithonian age for sample 30a, the uppermost part of the Semiradiata Zone, and for sample 50 — an assignment to the Remanei Subzone. Dinoflagellate cysts of Berriasian age — *Achomosphaera neptunii, Prolixosphaeridium* sp. A and *Tehamamadinium evittii* — were recorded in samples 105 and 111/112 in the Alpina Subzone and in the samples 132 and 132/133 in the Elliptica Subzone.

Prolixosphaeridium sp. A (sample 105) is mentioned by Monteil (in Stover et al. 1996) within the ammonite Jacobi Subzone (within the calpionellid Alpina Subzone) of the Early Berriasian. According to Leereveld (1995), the FO of *Achomosphaera neptunii* (sample 111/112) is connected to the late Early Berriasian (uppermost part of the Jacobi ammonite Zone; calpionellid Elliptica Subzone; Reboulet et al. 2014, Wimbledon 2017) along with the FO of *Dichadogonyaulax bensonii* (sample 132/133). Monteil (1992, 1993) correlates the FOs of both species in the Berriasian type section with the late Early Berriasian, the uppermost part of the Alpina Subzone, respectively. Monteil (1993) and Hunt (2004) combine the first occurrences of the *D. bensonii*, *Endoscrinium campanula* (sample 111/112) and *Tehamadinium evittii* (sample 105) as key range bases for correlation with the ammonite Grandis Subzone (upper Jacobi Zone) and Subalpina subzone (that is lowest Occitanica Zone). The similar relative age is indicated by calpionellids and nannofossils.

Paleoecology

According to Elbra et al. (2018a), the sediments at Kurovice were deposited on the continental slope during the Late Tithonian–Early Berriasian. The section is characterized by distal limestone sediments with sporadic turbidites. Košťák et al. (2018) supposed tsunami deposition/influence which might explain the presence of debris in the abyssal environment. Pelagic sediments are characterized by the large proportion of calcareous and siliceous marine microplankton which predominates over the turbidity material. These statements are in line with microfacies analyses (see above). The interpretation of the deposits as the standard microfacies types SMF2, SMF3 and SMF4 indicates deposition on a deep shelf margin within facies zone FZ3, changing into a basinal environment in its later/upper part, facies zone FZ1 (Wilson 1975).

Sedimentation occurred under the influence of enhanced water dynamics, which affected nutrient supply and caused the periodical erosion and redeposition of older rocks. The nutrient supply is here demonstrated by the quantitative predominance of radiolarians and sponge spicules. Calpionellids are generally rare and they are represented almost exclusively by hyaline species, which first appear in the Late Tithonian. The absence of typical microgranular chitinoidellids from the late Early Tithonian and the early Late Tithonian can be explained by the dominant presence of radiolarians. These microorganisms with silica tests preferred conditions rich in nutrients, something not suitable for calpionellids, and their development was probably inhibited. The location of the depositional area on the northern margin of Tethys (Golonka et al. 2006) and the possible influence of incoming northern waters can also not be ignored.

The nannoconids *Conusphaera* and *Polycostella beckmannii* are referred to as predominantly Tethyan taxa (Bown & Cooper 1998; Bown et al. 1998). Other nannofossils that confirm the Tethyan province are randomly found — *Watznaueria manivitiae, Zeugrhabdotus embergeri, Cruciellipsis cuvillieri*, and *Speetonia colligata* (Bown & Cooper 1998; Bown et al. 1998). The small percentage of these taxa found in our study may be explained by the paleogeographic location on the margin of Tethys (Golonka et al. 2006; Svobodová et al. 2018). This region could have been affected by cold waters from

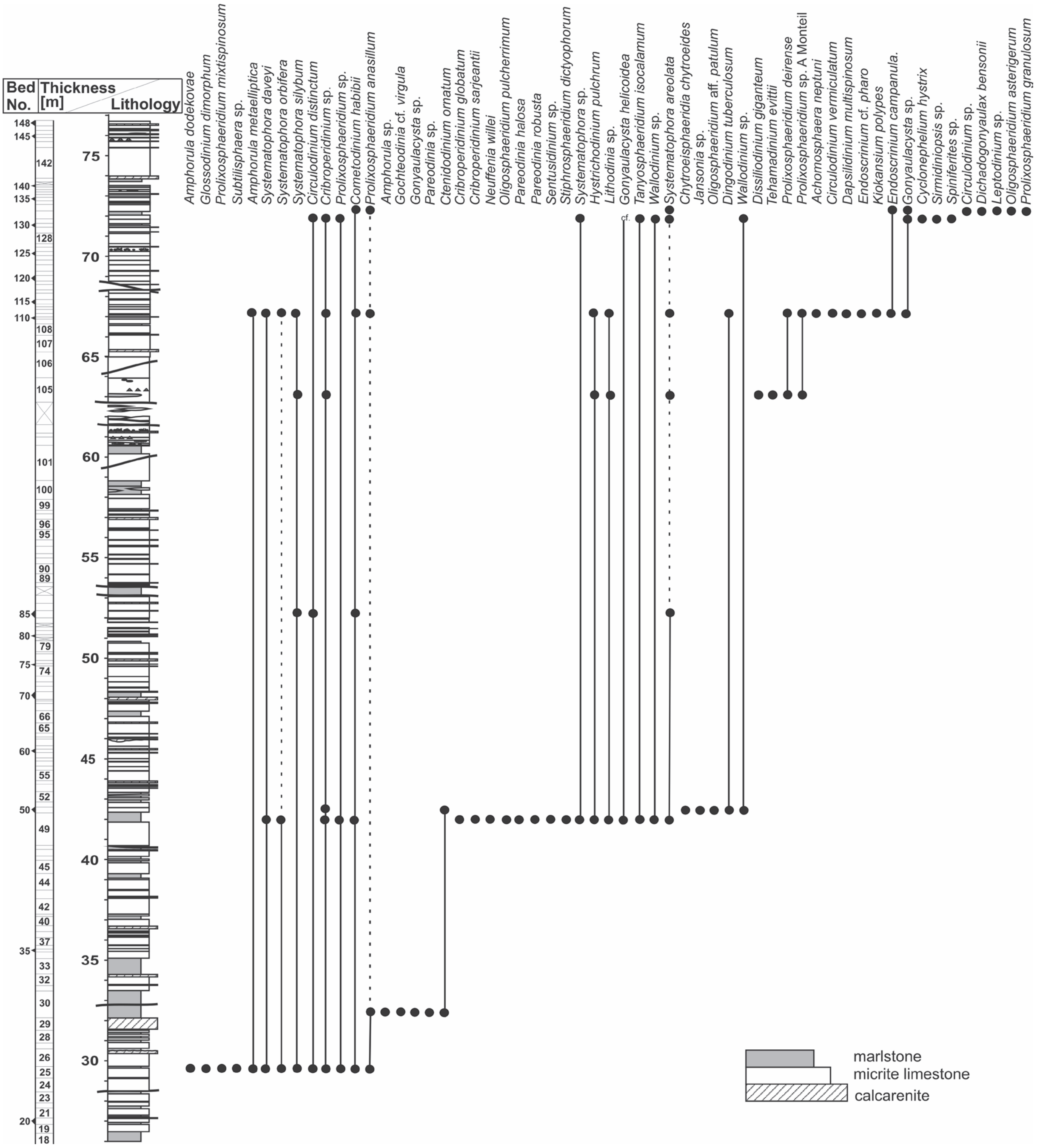

Fig. 13. Kurovice section, lithology and vertical distribution of palynomorfs and non-calcareous cysts. Reworked specimens marked with dashed line. Lithology after M. Bubík in Košťák et al. (2018).

Fig. 14. Kurovice section, palynomorphs. Scale bar 10 µm. A–F, L–N, P sample 50 middle, G–K, O sample 132. **A** — *Dingodinium tuberosum*; **B** — aff. *Oligosphaeridium patulum*; **C** — *Ctenidodinium ornatum*; **D** — *Chytroeisphaeridia chytroeides*; **E** — *Jansonia* sp.; **F** — *Pterospermella australiensis*; **G** — *Tanyosphaeridium isocalamum*; **H** — radiolarian remnant; **I** — *Circulodinium distinctum*; **J** — *Gonyaulacysta* cf. *helicoidea*; **K** — *Cribroperidinium* sp., fragment; **L** — *Gleicheniidites senonicus*; **M** — *Neoraistrickia* sp.; **N** — *Classopollis torosus*; **O** — *Densoisporites velatus*; **P** — *Corollina* sp.

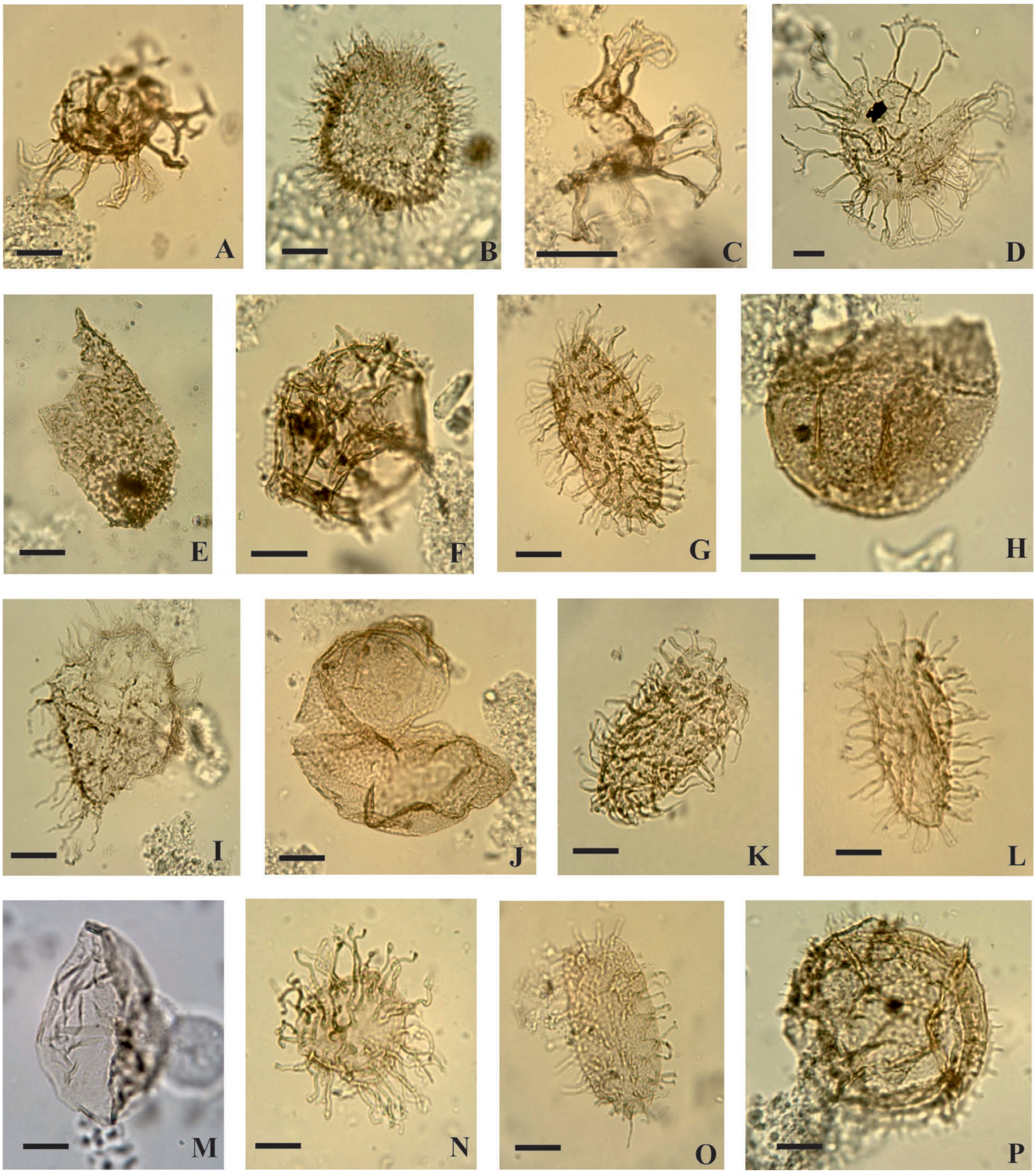

Fig. 15. Kurovice section, non-calcareous dinoflagellate cysts. Scale bar 10 µm. A–F sample 49 middle, G–J sample 105, K–M sample 111/112, N–P sample 132/133. **A** — *Systematophora daveyi*; **B** — *Cometodinium habibii*; **C** — *Stiphrosphaeridium dictyophorum*, archeopyle; **D** — *Systematophora orbifera;* **E** — *Pareodinia robusta;* **F** — *Gonyaulacysta helicoidea;* **H** — *Lithodinia* sp.; **K** — *Prolixosphaeridium anasillum*; **L** — *Prolixosphaeridium* sp. A sensu Monteil (1993); **M** — *Endoscrinium campanula*; **N** — *Systematophora areolata*; **O** — *Prolixosphaeridium granulosum*; **P** — *Dichadogonyaulax bensonii*.

Subboreal regions, such as the Russian Platform. The influence from higher latitudes might also be shown by the scarce presence of *Nannoconus compressus* (Fig. 7Y) mentioned in the Atlantic Ocean (Bralower et al. 1989; Casellato 2010). Stoykova et al. (2018) mentioned *N. compressus* from the SW Bulgaria, and Halásová in Bakhmutov et al. (2018) from the Crimea (southern Ukraine). The question remains whether these areas were also under marine influence from the north.

Significantly higher percentages of nannoconids (up to 20 % in the Berriasian), conusphers (up to 50 % in the Late Tithonian and 20–40 % in the Early Berriasian) and *P. beckmannii* (up to 20–30 % in Late Tithonian) are mentioned in

Michalík et al. (2016) from the Pienniny Klippen Belt. Similar nannofossil percentages were mentioned by Svobodová & Košťák (2016) from further west in Tethys, on the southern passive margin of the Iberian Plate.

The occurrence of non-calcareous cavate cysts of *Dingodinium*, proximate cysts of *Cribroperidinium*, rare chorate cysts, and the frequent presence of agglutinated microforaminiferal linings indicate a shallow sea and probably reworking of terrestrial, brackish and shallow-water species into a deeper marine environment. Reworking is documented by the high diversity of *Systematophora* species, which characterize a littoral environment. Prasinophyte algae and acritarchs are known from the brackish to shallow marine conditions (Batten 1996). They could have been flushed into the shallow sea and continuously transported into the deeper water.

Discussion

Compared to most localities in Tethys, small differences in calpionellid succession are evident. Chitinoidellids, the first calpionellid representatives have not been recorded (Svobodová et al. 2018). Their absence may be explained by the blooming of siliceous microorganisms which probably suppressed chitinoidellids. This phenomenon could also have been associated with cold water influence at the margin of Tethys.

The calcareous dinoflagellate Malmica Zone corresponds in the Kurovice sequence to magnetozone M21r, as at Brodno (Central Western Carpathians; Michalík et al. 2009) and Lokút (Transdanubian range; Grabowski et al. 2010a, 2017). Even though aragonite shells did not survive sedimentation and early diagenesis of Kurovice limestones, magnetozones M20r to M17r in the upper part of the section may also be used to approximate the ammonite zones from Micracanthoceras microcanthum to Subthurmannia occitanica in the Vocontian Basin (Wimbledon et al. 2013; Frau et al. 2016a,b,c; Elbra et al. 2018b).

Nannofossil events and their stratigraphic correlations in the J/K boundary interval are more or less comparable with the other localities in Tethys. The first occurrence (FO) of *Nannoconus globulus minor* is situated in magnetozone M19r and the Intermedia Subzone, as at Puerto Escaño (Svobodová & Košťák 2016). The last occurrence (LO) of *Polycostella beckmannii* was recorded in the lower part of M19n.2n, still in the Intermedia Subzone, as with the Brodno locality (Michalík et al. 2009). The FO of *N. wintereri* lies in the upper part of the Crassicollaria Zone, in M19n.2n as with Puerto Escaño (Svobodová & Košťák 2016) and Le Chouet (Wimbledon et al. 2013). The FO of *N. wintereri* in M19n.2n is also mentioned at Torre de' Busi (Casellato 2010; Channell et al. 2010), before the FO of *N. globulus globulus*. In the Kurovice succession, the FO of *N. globulus globulus* occurs just above the FO of *N. wintereri* as with Le Chouet (Wimbledon et al. 2013). The FO of *N. steinmannii minor* was recorded in the lower part of the Alpina Subzone, approximately in the middle part of M19n.2n similar to the Strapková locality (Central Western Carpathians) — Michalík et al. (2016). At Brodno (Michalík et al. 2009), this bioevent also occurs in the lower part of the Alpina Subzone, but within the M18r. At Torre de' Busi, Casellato (2010) and Channell et al. (2010) mentioned the FO of *N. steinmannii minor* in subzone M19n.1n, and the FO of *N. kamptneri kamptneri* in the middle part of the Ferasini Subzone and M18n. Generally, Wimbledon (2017) mentions the FOs of *N. wintereri* and *N. steinmannii minor* in Western Tethys within M19n.2n, immediately below the Calpionella Zone, J/K boundary.

The nannofossil record clearly depends on the lithological character of the strata and this reality may affect the final stratigraphic and paleoenvironmental interpretations. As mentioned above, calcarenites provide scarce fragmented specimens, whereas micrite limestones contain rare and poorly preserved nannofossils. In contrast, marlstone intercalations contain abundant and diversified assemblages. This could be the cause of the scarce and irregular occurrence of genus *Nannoconus* in some parts of the section, and the fact that the first occurrences of *N. infans*, *N. kamptneri minor* and *N. steinmannii steinmanni* could not be relied upon for stratigraphic interpretations. Strata provided *N. wintereri* (Fig. 7AA,AB) and also specimens that can be consider as an early forms of this species (Fig. 7AC,AD).

Nannofossils were not recognized in thin sections prepared for the calpionellid and facies investigation.

The quantitative predominance of the genera *Watznaueria* and *Cyclagelosphaera* furnish proof of probable secondary post-mortem modification of the original nannoflora. Other placoliths that are easily destroyed are found scarcely and mostly as fragments.

Through the Kurovice sequence, the irregular occurrence of unknown specimens of *Conusphaera* was observed. They are forms characterized by a thinner structure than *Conusphaera mexicana*, and are here mentioned as *Conusphaera* sp. 1 (Fig. 7I–L). As the ecological affinities of *Conusphaera* spp. are unclear (Bornemann et al. 2003; Tremolada et al. 2006), *Conusphaera* sp. 1 is an object suitable for further study. Moreover, specimens that look like *C. mexicana* cf. *minor* (Fig. 7P), but which reach larger dimensions, of about 5 µm, were recorded. The height given in the original description of *C. mexicana minor* does not exceed 4 µm (Bown & Cooper 1989). The high content of calcium carbonate and oxic conditions were also the cause of poor preservation of palynomorphs.

Sediments throughout the sequence contain reworked calcareous dinoflagellates, such as *Colomisphaera fibrata, C. tenuis, C. fortis*, *Stomiosphaera moluccana, Commitosphaera pulla, Carpistomiosphaera tithonica, C. borzai,* and *Parastomiosphaera malmica,* which have been mentioned from the Late Oxfordian and Early Tithonian exclusively (Lakova et al. 1999; Reháková 2000; Ivanova & Kietzman 2017). Sometimes during the Berriasian, calpionellids such as *Calpionella grandalpina, C. elliptalpina,* and *Crassicollaria*

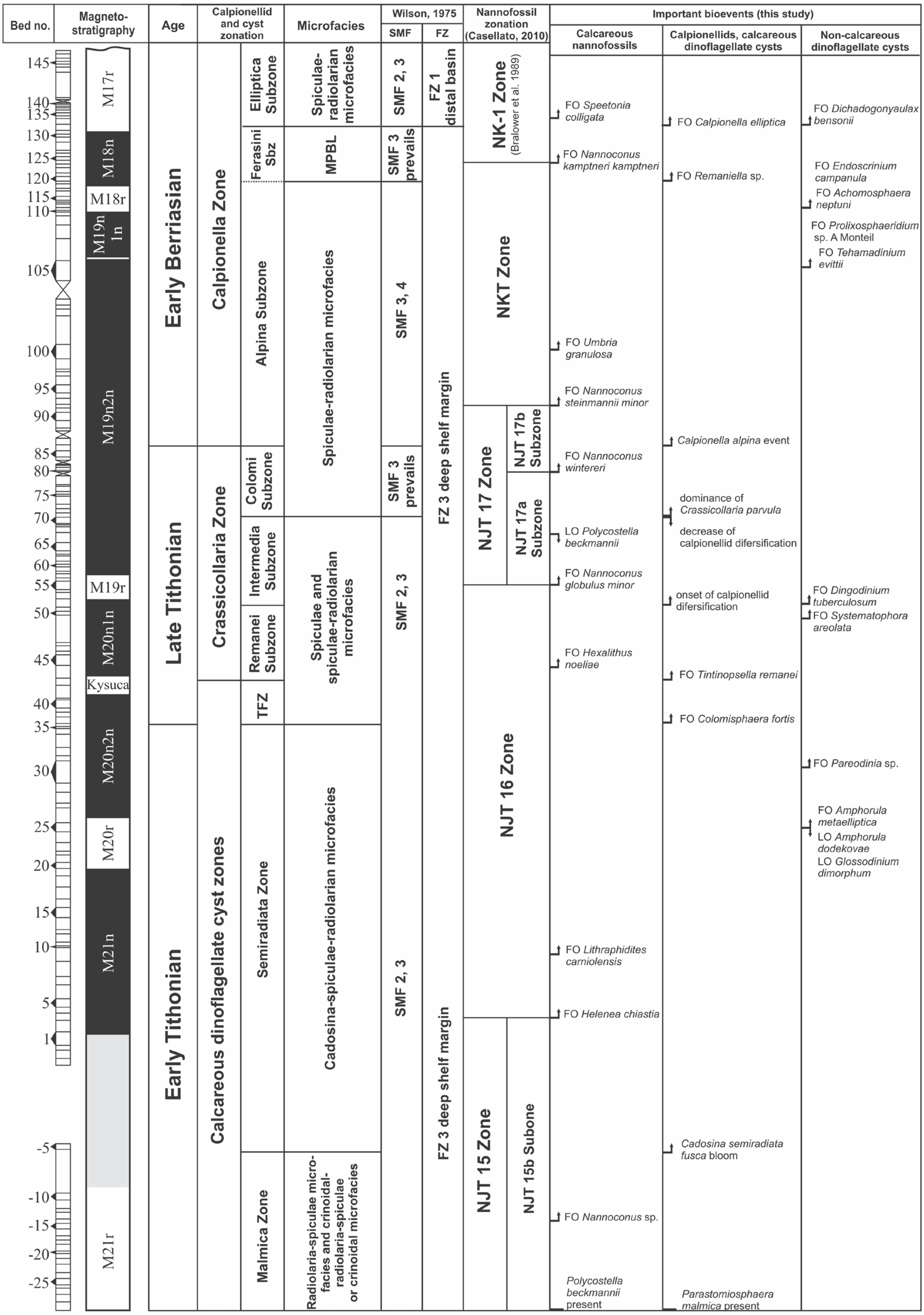

Fig. 16. Integrated biostratigraphic correlations, microfacial interpretations, important bioevents and magnetostratipgraphy of the Kurovice section. Magnetostratigraphy as well as calpionellid, calcareous dinoflagellate and nannofossil zonations of 1–148 beds interval are modified from Elbra et al. (2018a). Black — normal polarity; white — reversed polarity; gray — unclear polarity due to lack of samples or stable magnetic component. Magnetostratigraphy of sample beds −1 to −29 is preliminary. TFZ — Tenius-Fortis Zone; MPBL — microfacies prevailed in biomicrite limestone; SMF — standard microfacies types; FZ — facies zones. Calpionellid zones after Reháková & Michalík (1997); dinoflagellate cyst zones sensu Reháková (2000).

massutiniana, were reworked from the Tithonian strata. The nannofossil species *Parhabdolithus* cf. *marthae* has been found in the lower part of section, in the NJT 16 zone, and it indicates a source of material of Early Sinemurian age, in the NJ2a zone (Bown & Cooper 1998). Scarce *Lotharingius hauffii* (NJ 5a–NJ 12a) and *L. sigillatus* (NJ 5b–NJ 15a) (Table 1a, b) document source rocks in the upper Pliensbachian–lower Callovian up to lower Oxfordian interval (Bown & Cooper 1998; Mattioli & Erba 1999). Reworked non-calcareous dinoflagellate cysts of Jurassic age (*Systematophora areolata, Prolixosphaeridium anasillum*) were found in samples 132 and 132–133 in the nannofossil NK-1 Zone and the Elliptica Subzone. The same strata also provided reworked *Nannoconus compressus* that is mentioned only in the Tithonian (Bralower et al. 1989; Casellato 2010). A relatively high number of *Polycostella beckmannii* which supposedly occurs exclusively in the Tithonian was found in sample 142s in the Berriasian (Fig. 4, Table 1c). The presence of these allochthonous microorganisms is testimony to the dynamics of the depositional area and to repeated sediment erosion.

The 'Nannofossil Calcification Event' (NCE) *sensu* Bornemann et al. (2003) could be applied to the nannofossil record in the Kurovice section. However, it relates only to Assemblage 1 and Assemblage 2 (*sensu* fig. 17 in Bornemann et al. 2003). Morphometric measurements were not an aim of this study.

Conclusions

Detailed studies of microfacies and high-resolution recording of microfossils and calcareous nannofossils in the extended Kurovice section provide more precise stratigraphic results and paleoenvironmental interpretations across the Jurassic/Cretaceous boundary interval.

The stratigraphic range of the sequence is from the Early Tithonian calcareous dinoflagellate Malmica Zone up to the Early Berriasian calpionellid Elliptica Subzone, that is magnetozone M21r to M17r, and nannofossil zone NJT 15b to NK-1. The absence of calpionellid Chitinoidella Zone is explained by the blooms of silica preferring microorganisms which could have suppressed the development of microgranular chitinoidellids. The J/K *Calpionella alpina* boundary event indicated by size change of lorice of this species coincides with the NJT 17b Subzone and M19n.2n, and with the presence of *Nannoconus wintereri*. The dinoflagellate cysts, *Prolixosphaeridium* sp. A *sensu* Monteil 1993, *Tehamamadinium evittii, Achomosphaera neptunii, Endoscrinium campanula,* and *Dichadogonyaulax bensonii,* that are present in the upper part of the section support an Early Berriasian age.

The identified standard microfacies types SMF 2, SMF 3 and SMF 4 suggest an origin for the deposits here on the deep shelf margin, facies zone FZ 3, passing in time into the more distal basinal conditions, in facies zone FZ 1, with standard microfacies types SMF 2 and SMF 3 being formed.

The sediments bear the marks of the enhanced water dynamics that caused nutrient mobility, periodical erosion and overflow of sediments from the coeval and older Jurassic strata including also littoral and brackish palynomorphs accompanied by additional supply of terrestrial pollen and spores.

The nannofossil record and nannofossil preservation depend on the lithological character of deposits. The quantitative predominance of the genera *Watznaueria* and *Cyclagelosphaera* furnish proof of the probable secondary post-mortem modification of the nannoflora. Nannoconids — *Conusphaera* and *Polycostella* — and placoliths of *Watznaueria manivitiae, Zeugrhabdotus embergeri, Cruciellipsis cuvillieri*, and also *Speetonia colligata*, which are referred to as predominantly Tethyan taxa, formed a significantly small percentage in assemblages as compared to ones of the same age in other regions of Tethys. This may be explained by the location of depositional area at the margin of Tethys where there might have been some influence of cold waters coming from boreal regions.

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Appendix

Lists of microfossils and calcareous nannofossils mentioned in the text in alphabetical order:

Calcareous nannofossils

Assipetra infracretacea (Thierstein, 1973) Roth, 1973
Biscutum ellipticum (Górka, 1957) Grün *in* Grün and Allemann, 1975
Conusphaera mexicana subsp. *mexicana* Trejo, 1969
Conusphaera mexicana subsp. *minor* (Trejo, 1969) Bown & Cooper, 1989
Cretarhabdus conicus Bramlette and Martini, 1964
Cruciellipsis cuvillieri (Manivit, 1966) Thierstein, 1973
Cyclagelosphaera argoensis Bown, 1992
Cyclagelosphaera deflandrei (Manivit, 1966) Roth, 1973
Cyclagelosphaera margerelii Noël, 1965
Cyclagelosphaera reinhardtii (Perch-Nielsen, 1968) Romein, 1977
Diazomatholithus lehmannii Noël, 1965
Discorhabdus ignotus (Górka, 1957) Perch-Nielsen, 1968
Ethmorhabdus gallicus Noël, 1965
Ethmorhabdus hauterivianus (Black, 1971) Applegate et al. *in* Covington and Wise, 1987
Faviconus multicolumnatus Bralower *in* Bralower et al., 1989
Helenea chiastia Worsley, 1971
Helenea staurolithina Worsley, 1971
Hexalithus noeliae Loeblich and Tappan, 1966
Hexalithus strictus Bergen, 1994
Lithraphidites carniolensis Deflandre, 1963
Lotharingius hauffii Grün and Zweili *in* Grün et al., 1974
Lotharingius sigillatus (Stradner, 1961) Prins *in* Grün et al., 1974
Manivitella pemmatoidea (Deflandre *in* Manivit, 1965) Thierstein, 1971
Miravetesina favula Grün *in* Grün and Allemann, 1975
Nannoconus colomii (de Lapparent 1931) Kamptner 1938
Nannoconus compressus Bralower and Thierstein *in* Bralower et al., 1989
Nannoconus erbae Casellato 2010
Nannoconus globulus subsp. *globulus* Brönnimann, 1955
Nannoconus globulus subsp. *minor* (Brönnimann, 1955) Bralower *in* Bralower et al., 1989
Nannoconus infans Bralower *in* Bralower et al., 1989
Nannoconus kamptneri subsp. *kamptneri* Brönnimann, 1955
Nannoconus kamptneri subsp. *minor* (Brönnimann, 1955) Bralower *in* Bralower et al., 1989
Nannoconus puer Casellato 2010
Nannoconus steinmannii subsp. *minor* (Kamptner, 1931) Deres and Achériéguy, 1980
Nannoconus steinmanni subsp. *steinmannii* Kamptner, 1931
Nannoconus wintereri Bralower and Thierstein, in Bralower et al. 1989
Parhabdolithus marthae Deflandre *in* Deflandre and Fert, 1954

Pickelhaube furtiva (Roth, 1983) Applegate et al. *in* Covington and Wise, 1987
Polycostella beckmannii Thierstein, 1971
Polycostella senaria Thierstein, 1971
Retecapsa octofenestrata (Bralower *in* Bralower et al., 1989) Bown *in* Bown and Cooper, 1998
Retecapsa schizobrachiata (Gartner, 1968) Grün *in* Grün and Allemann, 1975
Retecapsa surirella (Deflandre and Fert, 1954) Grün *in* Grün and Allemann, 1975
Rotelapillus crenulatus (Stover, 1966) Perch-Nielsen, 1984
Speetonia colligata Black, 1971
Umbria granulosa Bralower and Thierstein *in* Bralower et al., 1989
Watznaueria barnesiae (Black in Black & Barnes, 1959) Perch-Nielsen, 1968
Watznaueria biporta Bukry, 1969
Watznaueria britannica (Stradner, 1963) Reinhardt, 1964
Watznaueria communis Reinhardt, 1964
Watznaueria cynthae Worsley, 1971
Watznaueria fossacincta (Black, 1971) Bown *in* Bown and Cooper, 1989
Watznaueria manivitiae Bukry, 1973
Watznaueria ovata Bukry, 1969
Zeugrhabdotus cooperi Bown, 1992
Zeugrhabdotus embergeri (Noël, 1959) Perch-Nielsen, 1984
Zeugrhabdotus fluxus Casellato, 2010

Calcareous dinoflagellates
Cadosina semiradiata cieszynica (Nowak, 1966)
Cadosina semiradiata fusca (Wanner, 1940)
Cadosina semiradiata semiradiata (Wanner, 1940)
Carpistomiosphaera borzai (Nagy,1966)
Carpistomiosphaera tithonica Nowak,1968
Colomisphaera carpathica (Borza, 1964)
Colomisphaera cieszynica Nowak, 1968
Colomisphaera fibrata (Nagy, 1966)
Colomisphaera fortis Řehánek, 1982
Colomisphaera lapidosa (Vogler, 1941)
Colomisphaera minutissima sensu Nowak 1968
Colomisphaera pieniniensis (Borza, 1969)
Colomisphaera radiata (Vogler, 1941)
Colomisphaera tenuis (Nagy, 1966)
Committosphaera czestochowiensis Řehánek, 1993
Committosphaera ornata (Nowak, 1968)
Committosphaera pulla (Borza, 1964)
Committospahera sublapidosa (Vogler 1941)
Parastomiosphaera malmica (Borza, 1964)
Stomiosphaera moluccana Wanner, 1940
Stomiosphaerina proxima Řehánek,1987

Calpionellids
Calpionella alpina Lorenz,1902
Calpionella elliptalpina Nagy, 1986
Calpionella elliptica Cadisch 1932
Calpionella grandalpina Nagy, 1986
Crassicollaria brevis Remane, 1962
Crassicollaria intermedia (Durand-Delga, 1957)
Crassicollaria massutiniana (Colom, 1948)
Crassicollaria parvula Remane, 1962
Lorenziella hungarica Knauer and Nagy, 1964
Praetintinnopsella andrusovi Borza, 1969
Remaniella borzai Pop, 1996
Remaniella catalanoi Pop, 1996
Remaniella colomi Pop, 1996
Remaniella duranddelgai Pop,1996
Remaniella ferasini (Catalano, 1965)
Tintinnopsella carpathica (Murgeanu and Filipescu,1933)
Tintinnopsella doliphormis (Colom, 1939)
Tintinnopsella remanei Borza, 1969

Palynomorphs including non-calcareous dinoflagellates
*Achomosphaera neptuni (*Eisenack, 1958) Davey and Williams, 1966
Amphorula dodekovae Zotto et al., 1987
Amphorula metaelliptica Dodekova, 1969
Chytroeisphaeridia chytroeides (Sarjeant 1962) Downie and Sarjeant 1965, emend. Davey 1970
Cerebropollenites macroverrucosus (Thiergart) Schulz 1967
Circulodinium distinctum (Deflandre and Cookson 1955) Jansonius 1986
Circulodinium vermiculatum Stover and Helby, 1987
Classopollis torosus (Reissinger) Balme, 1957
Cometodinium habibii Monteil, 1991
Cribroperidinium globatum (Gitmez and Sarjeant, 1972) Helenes, 1984
Cribroperidinium sarjeantii (Vozzhennikova, 1967) Helenes, 1984
Ctenidodinium ornatum (Eisenack 1935) Deflandre 1938
Cyathidites minor Couper 1953
Cyclonephelium hystrix (Eisenack, 1958) Davey, 1978
Dapsilidinium multispinosum (Davey, 1974) Bujak et al., 1980
Densoisporites velatus Weyland and Krieger 1953
Dichadogonyaulax bensonii Monteil, 1992
Dingodinium tuberosum (Gitmez 1970) Fisher and Riley 1980
Dissiliodinium giganteum Feist-Burkhardt, 1990
Endoscrinium campanula (Gocht, 1959) Vozzhennikova, 1967
Endoscrinium pharo Duxbury 1977
Gleicheniidites senonicus Ross 1949
Glossodinium dimorphum Ioannides et al., 1977
Gochteodinia virgula Davey 1982b
Gonyaulacysta helicoidea (Eisenack and Cookson 1960)
Hystrichodinium pulchrum Deflandre, 1935
Kiokansium polypes (Cookson and Eisenack, 1962) Below, 1982
Micrhystridium stellatum Deflandre 1945
Neoraistrickia truncata (Cookson) Potonié 1956
Neuffenia willei Brenner and Dürr, 1986
Oligosphaeridium asterigerum (Gocht, 1959) Davey and Williams, 1969
Oligosphaeridium patulum Riding and Thomas 1988
Oligosphaeridium pulcherrimum (Deflandre and Cookson, 1955) Davey and Williams, 1966
Pareodinia halosa (Filatoff, 1975) Prauss, 1989
Pareodinia robusta Wiggins, 1975
Prolixosphaeridium anasillum Erkmen and Sarjeant 1980
Prolixosphaeridium granulosum (Deflandre, 1937) Davey et al., 1966
Prolixosphaeridium deirense Davey et al., 1966
Prolixosphaeridium mixtispinosum (Klement, 1960) Davey et al., 1969
Prolixosphaeridium sp. A Monteil, 1993
Pterospermella australiensis (Deflandre and Cookson 1955) Eisenack 1972
Pterospermella helios Sarjeant 1959
Spheripollenites subgranulatus Couper 1958
Stiphrosphaeridium dictyophorum (Cookson and Eisenack, 1958) Lentin and Williams, 1985
Systematophora areolata Klement 1960
Systematophora daveyi Riding and Thomas, 1988
Systematophora orbifera Klement, 1960
Systematophora silybum Davey, 1979
Tanyosphaeridium isocalamum (Deflandre and Cookson 1955) Davey and Williams 1969
Tehamadinium evittii (Dodekova, 1969) Jan du Chêne et al., 1986
Veryhachium irregulare de Jekhowsky 1961