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EARLY?–MIDDLE JURASSIC DINOFLAGELLATE CYSTS AND FORAMINIFERA FROM THE DARK SHALE OF THE PIENINY KLIPPEN BELT BETWEEN JARABINA AND LITMANOVÁ (SLOVAKIA): AGE AND PALAEOENVIRONMENT

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Abstract: The results presented are a part of the biostratigraphical and palaeoenvironmental studies of the authors on the microfauna and organic-walled dinoflagellate cysts from the Mesozoic dark deposits of the Pieniny Klippen Belt. The authors present the latest results from the Lower–Middle Jurassic strata, including the Szlachtowa and the Skrzypny Shale formations in the Slovak part of the Pieniny Klippen Belt near the villages of Jarabina, Kamienka and Litmanová. Material for the present study comes from exposures along the Malý Lipník, Veľký Lipník and Riečka Streams, and from the Jar-1 borehole, near Jarabina. The authors document the microfaunal and phytoplanctonic content of these rocks that contain over 50 foraminifera and 20 dinoflagellate cyst species. Their Middle Toarcian?–Aalenian to Bajocian–Bathonian ages are proposed and discussed. Quantitative and qualitative variations of both microfossil groups are interpreted as reflecting various sedimentary settings, related mainly to the variable intensity of influx of terrestrial matter into marine basins, leading to different bottom-water living conditions.

Key words: Dinoflagellate cysts, foraminifera, Jurassic, biostratigraphy, palynofacies, palaeoenvironment, Pieniny Klippen Belt.

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INTRODUCTION

The biostratigraphy and chronostratigraphy of dark-coloured Lower–Middle Jurassic strata of the Pieniny Klippen Belt are based on macrofaunal and micropalaeontological studies. Macrofauna is rare in the Magura Succession (Grajcarek/Šariš Unit; Pugaczewska, 1971; Birkenmajer and Myczyński, 1977; Krawczyk *et al.*, 1992; Gedl *et al.*, 2012), whereas fossils, particularly ammonites, occur frequently in the hemipelagic deposits of the klippen successions (e.g., Horwitz, 1937a, b; Myczyński, 1973, 2004; Pugaczewska, 1977; Birkenmajer and Myczyński, 1994, 2000; for older publications see Birkenmajer, 1977). On account of such fossil occurrences, the chronostratigraphy of the Lower–Middle Jurassic hemipelagites of the klippen successions (e.g., the Skrzypny Shale Formation) is based on ammonites and is well established, whereas the biostratigraphy of the coeval flysch and flyschoid strata of the Magura Succession (e.g., the Szlachtowa and Opaleniec formations) is based mainly on microfossils (e.g., Birkenmajer and Pazdro, 1963; Błaszyk, 1968; Pazdro, 1979; Dudziak, 1986; Tyszka, 1999; Birkenmajer and Gedl, 2004, 2007; Gedl, 2008, 2013). The palaeoenvironmental reconstructions, in turn, so far are based mainly on microfaunal records from the Magura Succession (e.g., Tyszka, 1994; Tyszka and Kaminski, 1995; Birkenmajer and Tyszka, 1996). The lack of ammonites in the Middle Jurassic of the Magura Succession implies that the accuracy of biostratigraphy based on microfossils is limited; its precision is further limited by the fact that the strata in question usually have been tectonized. Accordingly, the thick undisturbed sections in the Pieniny Klippen Belt must be regarded as unique. For this reason, the authors decided to perform integrated biostratigraphic and palaeoenvironmental studies that combine two microfossil groups: organic-walled dinoflagellate cysts (PG) and foraminifera (SJ) from the same set of samples, collected from the upper part of the Lower–Middle Jurassic dark fine-clastic strata of the Pieniny Klip-

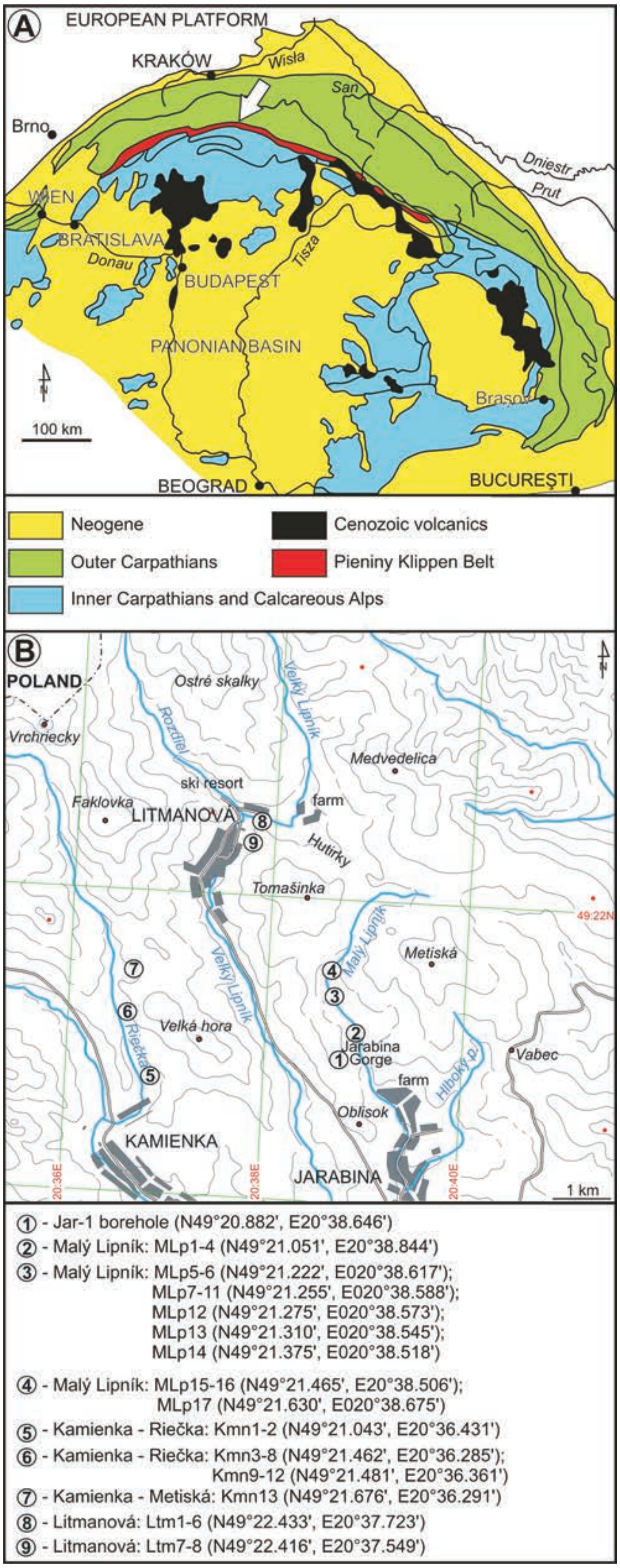


Fig. 1. Location of the study area. **A.** Position of the Pieniny Klippen Belt within the West Carpathian foldbelt (after Żytko, 1999) with location of the study area (arrowed); **B.** Locations of sites studied between Jarabina and Litmanová villages with sample GPS coordinates.

pen Belt. In this paper the authors present the results of their studies on the Skrzypny Shale Formation and the Szlachtowa Formation, exposed in the Slovak sector of the Pieniny Klippen Belt, between Jarabina and Litmanová (Fig. 1). The authors correlate the stratigraphic ranges of assemblages of both fossil groups and attempt to determine the chronostratigraphy of particular lithostratigraphic units. The authors also make an attempt to reconstruct the palaeoenvironment of the strata on the basis of the known environmental preferences of particular microfossil species or their assemblages. Observations on living foraminifera (e.g., Jones and Charnock, 1985; Kaminski *et al.*, 1988; Murray, 1991; Corliss and Chen, 1988), show the relationship between test morphology and microhabitat, while the composition of the assemblages is linked to the availability of nutrients and the oxygen content at the sediment surface and below (TROX model; Jorissen *et al.*, 1995; Van der Zwaan, 1999). The analysis of morphogroups also facilitates the interpretation of the palaeoenvironmental significance of the Jurassic fossil record (e.g., Tyszka, 1994; Reolid, 2010; Reolid *et al.*, 2012, Nagy *et al.*, 2009).

GEOLOGICAL SETTING

The Pieniny Klippen Belt represents an arch-like structure with a complicated structural development and a varied sedimentary record of predominantly Jurassic–Lower Cretaceous carbonates forming tectonic "klippen" or olistolites, embedded mostly in Late Cretaceous–Cenozoic marly or flysch deposits (e.g., Andrusov, 1945; Birkenmajer, 1977, 1986; Mišík, 1978, 1997; Aubrecht and Sýkora, 2004; Plašienka *et al.*, 2012). This extremely narrow geological structure (which stretches over the distance of nearly 600 km, but is rarely wider than 4–5 km), is known from Austria, Poland, Slovakia, Ukraine and Romania. It separates the Outer (Flysch) Carpathians to the north from the Inner Carpathians to the south (Fig. 1A). The stratigraphic succession of the Pieniny Klippen Belt in its central sector (Slovakia and Poland) consists of Lower Jurassic to Upper Cretaceous strata. Triassic deposits are very much incomplete here. They were folded during the latest Cretaceous–earliest Paleocene Laramian phase; then, a part of the Magura Succession (i.e., the southernmost part of the Outer Carpathian basin systems; Fig. 2) was tectonically incorporated into the Belt, forming now the Šariš (in Slovakia) and Grajcarek (in Poland) Unit (e.g., Birkenmajer, 1986). Later, this structure was folded once again during the Late Oligocene–Early Miocene folding phase when Palaeogene strata were incorporated.

The palinspastic reconstruction of the basin systems in question (Fig. 2) shows a generally shallow zone (the Czorsztyn Ridge) that separates them from the Outer Carpathian domain (the Magura Basin) to the north, its southern slope zone (the Czertezik and Niedzica units, i.e., the Subpieniny units) and the basinal zone (the Branisko and Pieniny units; e.g., Birkenmajer, 1977). The Lower–Middle Jurassic of the study area is developed mainly as dark-coloured hemipelagic and flysch strata, reflecting a dysoxic sedimentary environment. The former were accumulated generally in shal-

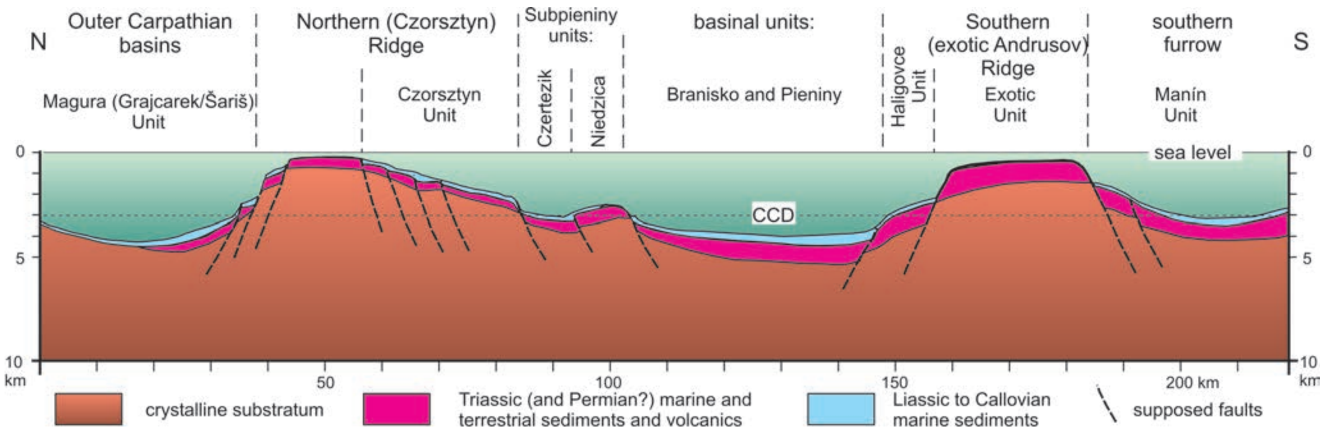


Fig. 2. Palinspastic reconstruction of the central sector (Poland and Slovakia) of the Pieniny Klippen Belt during the Middle Jurassic (from Birkenmajer, 1977).

lower areas of the Czorsztyn Ridge and its southern slope, whereas the flysch facies predominated in the deeper parts, mainly in the Magura Basin. The deposits studied, originally described by Uhlig (1890) as the *Opalinus*- and *Murchisonae-Schichten* and the *Posidonienschichten*, later were formally subdivided by Birkenmajer (1977) into the Krempachy Marl, Skrzypny Shale, Harcygrund Shale, Szlachtowa and Podzamcze Limestone formations. The localities studied in this paper represent the Subpieniny and Šariš (counterpart of the Grajcarek Unit in the Polish part of the Pieniny Klippen Belt) units of the Slovak part of the Pieniny Klippen Belt (Plašienka and Mikuš, 2010, Plašienka *et al.*, 2012). The Skrzypny Shale Formation of the study area is a part of the Czertezik and/or Niedzica successions (Scheibner, 1964a; Wierzbowski *et al.*, 2004).

MATERIAL

Material for this study comes from the Skrzypny Shale and the Szlachtowa formations that are characteristic and widely distributed Jurassic strata in the Slovak and Polish sectors of the Pieniny Klippen Belt; two samples for dinoflagellate cysts were collected from the Krempachy Marl Formation. Additional samples were taken from imbricated Upper Cretaceous strata. In total, 71 samples were collected for dinoflagellate cysts. For the purpose of this study, 29 samples were selected from dark shales for studies on foraminifera (21 of these samples were positive).

Black to dark-grey-brownish shales with frequent siderite concretions of the Skrzypny Shale Formation were sampled in the Metiská Quarry above the Riečka Stream near Kamienka (site 7 in Fig. 1B) and at Litmanová, in exposures along the Veľký Lipník Stream (site 8 in Fig. 1B). Both sites represent the Subpieniny units, presumably the Czertezik and/or Niedzica successions (Plašienka and Mikuš, 2010; see Fig. 2). Three samples were collected from the Metiská Quarry: one from the lower part (Kmn13), two from the upper part (Kmn14, Kmn15; Fig. 3D). The Litmanová site was described by Scheibner (1964a) as the so-called "*Murchisonae-Schichten*" with characteristic layers of concretions, bearing a well preserved fauna of pyritized ammonites. Two samples were taken for microfauna (Ltm1, Ltm2), and six for dinoflagellate cysts (Ltm1–6; Fig. 3E–G). Two additional samples were collected for dinoflagellate cysts from the Krempachy Marl Formation that forms a small exposure down the stream (Ltm7 and Ltm8; site 9 in Fig. 1B). Two samples of the Skrzypny Shale Formation (MLp3, MLp4) were collected from a small exposure in the lower course of the Malý Lipník Stream, where its black shale with siderite concretions tectonically contact with Cretaceous *fleckenmergel* facies (the Kapuśnica Formation?; samples MLp1, MLp2; site 2 in Fig. 1B; Fig. 4A–C). The latter facies (samples MLp5, MLp6; site 3 in Fig. 1B) contacts with red marl of the Malinowa Shale Formation (Fig. 4D).

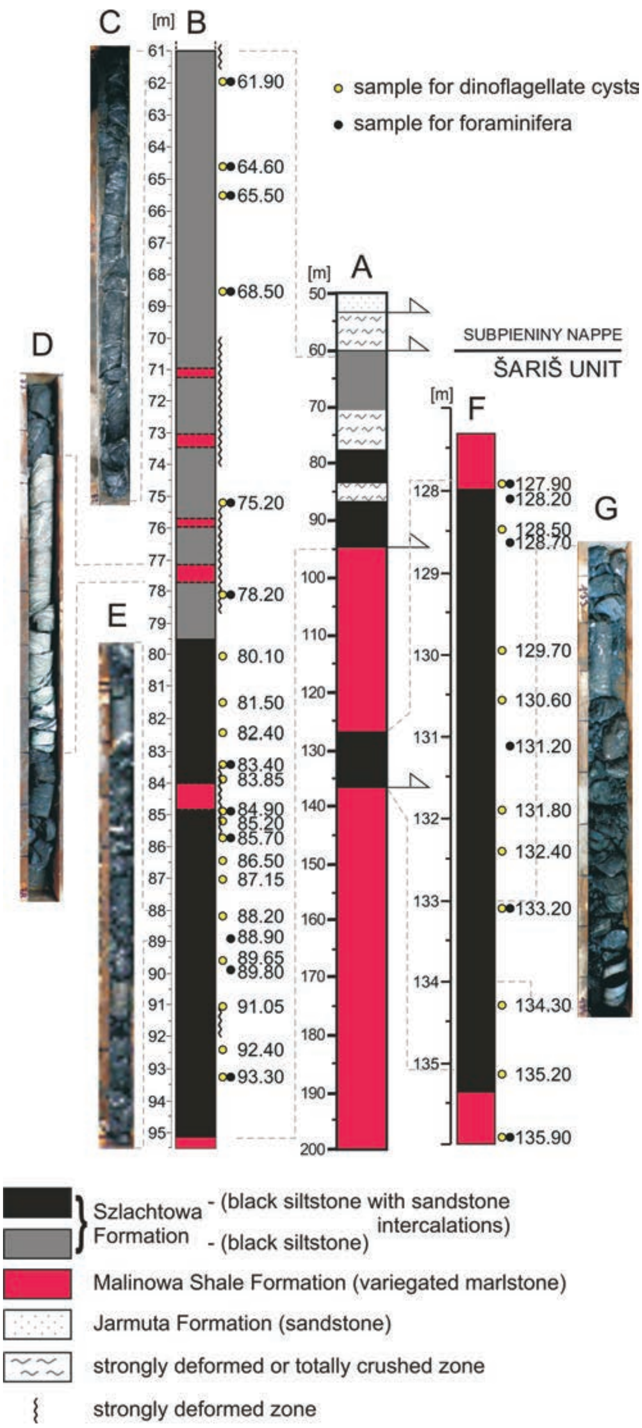
Outcrops of the siliciclastic Szlachtowa Formation are widely distributed in the Šariš Unit, which is present in a more southerly position with respect to the Subpieniny units (Plašienka and Mikuš, 2010). Mostly thick-bedded graded calcareous sandstones (Fig. 4E, G), with coal clasts in places (Malý Lipník Stream), are found with much finer pelitic micaceous siltstones. Birkenmajer and Turnau (1962) reported coal intercalations (observed by the authors along the lower course of the Malý Lipník Stream; site 3 in Fig. 1B; Fig. 4H) as being reworked from Carboniferous strata. Small crinoid columnals can be found within the sandstones. Shell beds in these siltstones with predominant *Bositra buchi* (Roemer), include scarce ammonites (in the upper course of the Malý Lipník Stream, Fig. 4J, K). There the Szlachtowa Formation is tectonically mixed with Upper Cretaceous red clay (the Malinowa Shale Formation; sites 3 and 4 in Fig. 1B; Fig. 4F, I, L) deposits; two samples were collected from the last mentioned strata for dinoflagellate cysts (MLp10 and MLp14). Samples MLp5, MLp7–9, MLp11–13, MLp15–17 come from the Szlachtowa Formation, exposed along the Malý Lipník Stream (Figs 1B, 4).

Further exposures of the Szlachtowa Formation occur along the Riečka Stream (site 6 in Fig. 1B) near Kamienka. Here, ten samples were collected for dinoflagellate cysts (Kmn3–12; samples MLp9–12 come from a large exposure, described by Barski *et al.*, 2012; Fig. 3A–C); two additional

Fig. 3. Exposures of the Szlachtowa Formation and the Skrzypny Shale Formation along the Riečka Stream near Kamienka and the Veľký Lipník Stream at Litmanová (see Fig. 1B for detail locations; photographs A–C, E–G by P. Gedl, photograph D by Š. Józsa). **A.** Outcrop of the Szlachtowa Formation in western bank of the Riečka Stream (site 6, samples Kmn3–8 in Fig. 1B). **B.** Close-up of dark shale of the Szlachtowa Formation from the exposure shown in Fig. 3A. **C.** Large exposure of the Szlachtowa Formation along the eastern bank of the Riečka Stream (site 6, samples Kmn9–12 in Fig. 1B). **D.** A view on the northern wall of the Metiská Quarry above Riečka Stream and sample locations collected from the Skrzypny Shale Formation (site 7 in Fig. 1B). **E.** Close-up of the black shale of the Skrzypny Shale Formation exposed at Litmanová (see Fig. 3F), with characteristic siderite concretions. **F.** A view on the Skrzypny Shale Formation exposed along the northern bank of the Veľký Lipník Stream at Litmanová (site 8 in Fig. 1B). **G.** Close-up of shale surface covered by *Bositra buchi* shells.

Fig. 4. Exposures of the Szlachtowa Formation and the Skrzypny Shale Formation along the Malý Lipník Stream (photographs by P. Gedl, except of H by Š. Józsa). **A.** Exposure of the Skrzypny Shale Formation that tectonically contacts with Cretaceous marl (presumably the Kapuśnica Formation; site 2 in Fig. 1B). **B.** Close-up of the black shale of the Skrzypny Shale Formation. **C.** Spotted Cretaceous marl (presumably the Kapuśnica Formation). **D.** Contact between red marl of the Malinowa Shale Formation (Upper Cretaceous) and the *fleckenmergel* of presumably Kapuśnica Formation (site 3, samples MLp5, MLp6). **E.** Thick-bedded sandstone and dark shale of the Szlachtowa Formation (site 3 in Fig. 1B, sample MLp7). **F.** Tectonic contact between red marl of the Malinowa Shale Formation (Upper Cretaceous) and the Szlachtowa Formation (site 3 in Fig. 1B, near sample MLp10). **G.** Tectonized thick-bedded sandstone of the Szlachtowa Formation surrounded by dark shale (site 3, sample MLp12 in Fig. 1B). **H.** Coal clast from the Szlachtowa Formation near sample MLp8 (site 3, samples MLp7–11 in Fig. 1B). **I.** Exposure of the Szlachtowa Formation (site 4, samples MLp15, MLp16 in Fig. 1B) showing its tectonic contacts with the Palaeogene conglomerate of the Proč Formation (above) and red marl of the the Upper Cretaceous Malinowa Shale Formation (right lower corner of the photograph, detail of the contact shown in L). **J.** Shell of *Bositra buchi* from the Szlachtowa Formation collected near the sample MLp16 (see I). **K.** Ammonite *Brasilia* sp. from the Szlachtowa Formation, found by Dušan Plašienka near sample MLp16, and determined by Jan Schlögl (see Gedl *et al.*, 2012).

Fig. 5. Location of Jar-1 borehole (see also site 1 in Fig. 1B). A view from the top of a quarry at Jarabina (Lysá Skala Mt.).



samples, Kmn1 and Kmn2, were taken from Cretaceous *fleckenmergel* strata, exposed in the lower course of the Riečka Stream (site 5 in Fig. 1B).

A part of the material comes from the Jar-1 borehole, near Jarabina (site 1 in Fig. 1B; Figs 5, 6), where in general two tectonic slices of the Szlachtowa Formation were drilled through in the lower part of the borehole succession (Fig. 6A). This part of the borehole consists of repeated slices of mid-Jurassic (the Szlachtowa Formation) and Upper Cretaceous (the Malinowa Shale Formation), where silty and micaceous mudstones and calcareous sandstones of the former are imbricated with Cretaceous Oceanic Red Beds of the Malinowa Shale Formation (Fig. 6B, D). The top of the Šariš Unit in the Jar-1 borehole is strongly deformed and in many places totally crushed, in some parts into melange zones (70–79 m; Fig. 6A–D). Some of the better preserved parts with black siltstones from the top of the Jar-1 borehole frequently have a smooth soapy appearance on the cleavage planes with no visible macrofauna. In the lower part of the upper slice, organodetritic sandstone beds are present (Fig. 6E). The lower part of the borehole is somewhat more consistent and less tectonized, mostly made up of variegated shales of the Malinowa Shale Formation, where only a small sliver of micaceous black sandstones and mudstones of the Szlachtowa Formation is present (Fig. 6A, F, G). Thirty-one samples were taken from a core, 4 cm in diameter, for dinoflagellate cysts, and ten samples were taken for foraminifera (Fig. 6B, F).

METHODS

Common samples were divided into two halves, each processed with different methods. The rock portions for organic-walled dinoflagellate cysts (20 g) were processed in

Fig. 6. The Jar-1 borehole (core photographs by Vojtech Mikuš). **A.** General profile of the Jar-1 borehole (modified after Plašienka *et al.*, 2012). **B.** Upper tectonic scale of the Szlachtowa Formation (61–95 m). **C.** Black siltstone (61–62 m). **D.** Tectonic melange showing variegated shale of the Malinowa Shale Formation (Upper Cretaceous) incorporated into the Szlachtowa Shale Formation (77–78 m). **E.** Micaceous siltstone with intercalations of sandstone (88–89 m). **F.** Lower scale of the Szlachtowa Formation (128–135 m). **G.** Micaceous siltstone with intercalations of sandstone.

Table 1

Foraminifera morphogroups used in this study, A1–7 agglutinated morphogroups, C1–8 calcareous morphogroups (modified after Tyszka, 1994, complemented after Frenzel, 2000, Reolid *et al.*, 2010 and Cetean *et al.*, 2011)

Morphogroup	Test form	Life position	Feeding habit	Genera
A-1	Tubular	Epifaunal erect	Suspension feeders	*Hyperammina*, *Rhabdammina*
A-2	Planoconvex meandering	Epifaunal Attached	Passive herbivores	*Tolypammina*
A-3	Discoidal (Flattened coiled)	Epifaunal	Active deposit feeding (herbivores, detritovores)	*Glomospira*, *Ammodiscus*
A-4	Low trochospiral (planoconvex)	Epifaunal	Active deposit feeding (herbivores, detritovores)	*Trochammina*
A-5	High trochospiral (conical), planispiral, rounded streptospiral	Epifaunal to shallow infaunal	Active deposit feeding (detritovores, bacteriovores, herbivores)	*Conotrochammina*, *Haplophragmoides*, *Recurvoides*
A-6	Planispiral	Shallow infaunal	Active deposit feeders (detritovores, bacterial scavengers)	*Kutsevella*
A-7	Elongated, high trochospiral, quadriserial, triserial, biserial, uniserial	Shallow to deep infaunal	Active deposit feeders (detritovores, bacterial scavengers)	*Verneuilina*, *Verneuilinella*, *Verneuilinoides*, *Textularia*, *Reophax*
Morphogroup	Test form	Life position	Feeding habit	Genera
C-1	Trochospiral, biconvex or planoconvex	Epifaunal	Primary weed fauna (grazing herbivores)	*Epistomina*
C-2	Irregular, meandrine	Epifaunal	Deposit feeding	*Ramulina*
C-3	Planispiral (discoidal flattened) or trochospiral (planoconvex)	Epifaunal	Primary weed fauna (grazing herbivores, detritovores)	*Spirilina, Trocholina*
C-4	Planispiral (discoidal flattened)	Epifaunal	Active deposit feeders (grazing herbivores/detritovores)	*Ophthalmidium*, *Spirophthalmidium*
C-5	Elongated inflated	Shallow infaunal	Deposit feeders (grazing omnivores, and or bacterial scavengers)	*Nodosaria*, *Oolina*
C-6	Elongated flattened	Shallow to deep infaunal	Active deposit feeders (grazing omnivores)	*Astacolus*, *Planularia*, *Falsopalmula*, *Ichtyolaria*, *Citharina*
C-7	Elongated straight periphery	Shallow to deep infaunal	Deposit feeders (grazing omnivores, and or bacterial scavengers)	*Dentalina*, *Pseudonodosaria*, *Eoguttulina*
C-8	Biconvex	Epifaunal to deep infaunal	Active deposit feeders (grazing omnivores)	*Lenticulina*

Foraminiferal morphogroups (modified after Tyszka, 1994, supplemented by Frenzel, 2000, Reolid *et al*., 2010).

the micropalaeontological laboratory of the Institute of Geological Sciences, Polish Academy of Sciences, Research Centre in Kraków. The palynological procedure applied included 38% hydrochloric-acid (HCl) treatment, 40% hydrofluoric-acid (HF) treatment, heavy-liquid ($ZnCl_2$ + HCl; density 2.0 g·cm^{-3}) separation, ultrasound for 10–15 s and sieving at 10 µm on a nylon mesh. Nitric-acid (HNO_3) treatment was not applied. Palynological slides were made from each sample, using glycerine jelly as a mounting medium. The rock samples, palynological residues, and slides are stored in the collection of the Institute of Geological Sciences, Polish Academy of Sciences, Research Centre in Kraków.

For foraminifera, 100 g dry weight of crushed hard marlstones, siltstones and sandy mudstones were treated in detergents washed and sieved on 71, 125, 200 and 500 µm mesh sieves. Microfossils were picked from the 125 µm fraction and transferred into a cardboard microslide and counted. The microfossils for SEM study were mounted on a aluminium stub and gold coated. Foraminifera were mounted with water soluble fixing glue (Kreativika, prod. no. 90060), in order to take images from the same specimen from different views. SEM images were made in the Nature History Museum in Prague using a Hitachi S3700N instrument. Foraminifera photographed in immersion on a Leica DM2500P microscope were processed using combine Z5 software. Microslides with picked foraminifera are stored in the micropalaeontology collections at the Department of Geology and Paleontology, Faculty of Natural Sciences, Comenius University, in Bratislava.

The statistical methods used include palynofacies element proportions calculated by counting up to 500 elements, and diversity indexes of foraminiferal assemblages. No diversity indices of dinoflagellate cyst were calculated, owing to their mostly extremely low frequency (a few specimens per slide) and low taxonomical richness. The diversity of foraminifera was calculated by PAST software version 3.01 by Hammer *et al.* (2001), using the lower values. The Fisher alpha diversity is one of the most widely used indexes, formulated as: $S = a \cdot \ln(1 + n/a)$, where **S** is the number of taxa, **n** is the number of individuals and **a** is the Fisher alfa. For comparison, the Shannon-Wiener index was used, defined as: $H = -\mathrm{sum}((n_i/n) \ln(n_i/n))$, where $\mathbf{n_i}$ is the number of specimen in each species and **n** is the total number of specimens.

Foraminiferal morphogroups for this study are determined according to the scheme proposed by Tyszka (1994)

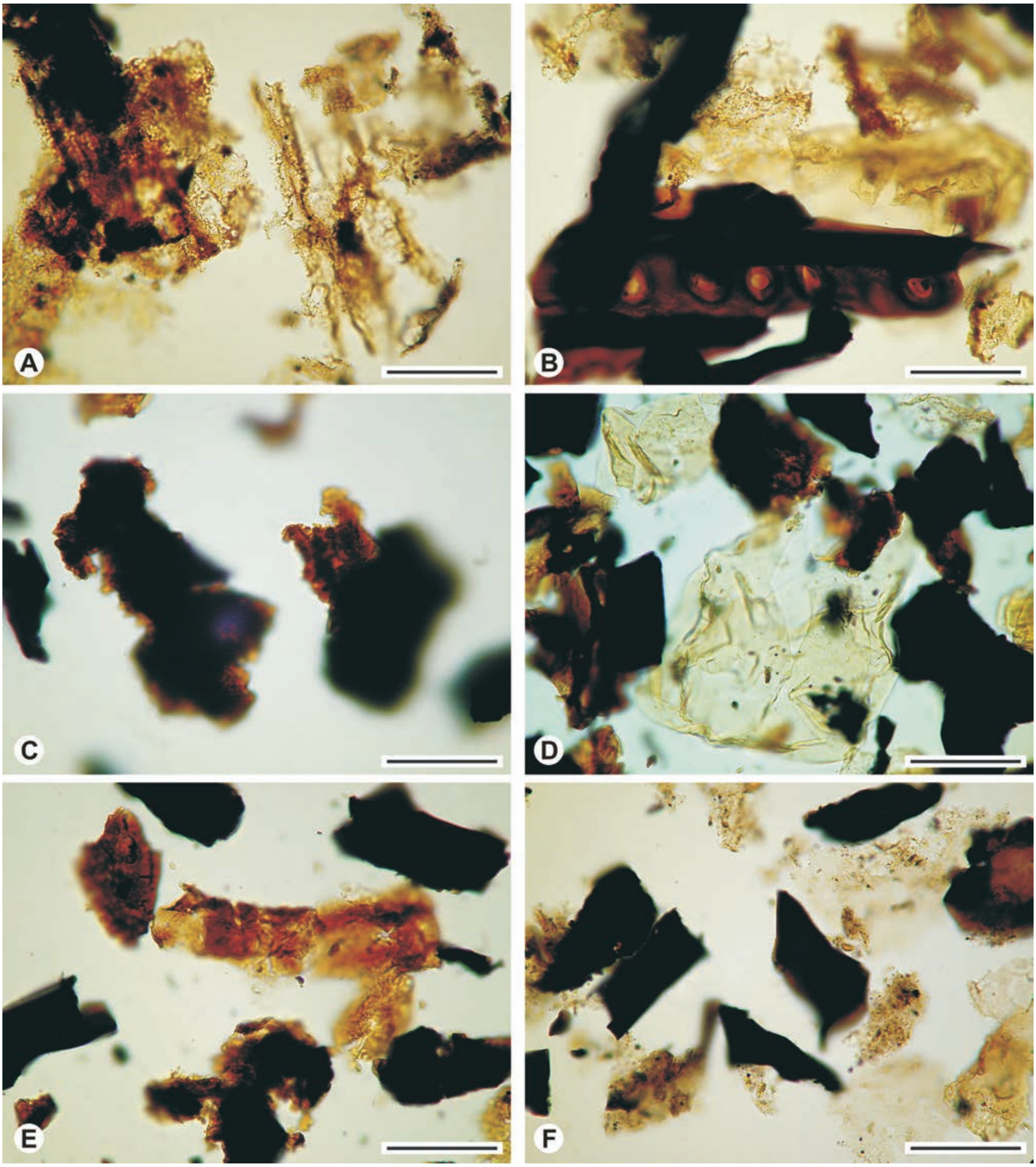


Fig. 7. Palynofacies of the Szlachtowa Formation. Scale bars = 25 µm. **A, B.** Sample Kmn3. **C.** Sample MLp8. **D.** Sample MLp12. **E.** Borehole Jar-1, sample depth 135.2 m. **F.** Borehole Jar-1, sample depth 61.9 m.

with slight modifications (Tab. 1). Schemes are complemented by studies of Nagy *et al.* (2009) and Frenzel (2000).

RESULTS

Palynofacies and dinoflagellate cysts

All samples contain palynological organic matter, composed chiefly of land-derived plant particles (Figs 7, 8) including phytoclasts (mainly black and opaque particles, e.g., Figs 7C, 8, and dark-brown, variously preserved palynodebris; Fig. 7E, D), cuticles (ranging from small 10–20 µm, to over 1 mm in diameter; Fig. 7A, B, E) and sporomorphs (their proportion rarely exceeds 1–2%); a common element is very thin, delicate particles of uncertain, but rather also terrestrial origin (Fig. 7F). Their proportions, however, vary: the palynofacies of the Szlachtowa Formation contain higher proportions of cuticles and dark brown palynodebris (Fig. 7), whereas that of the

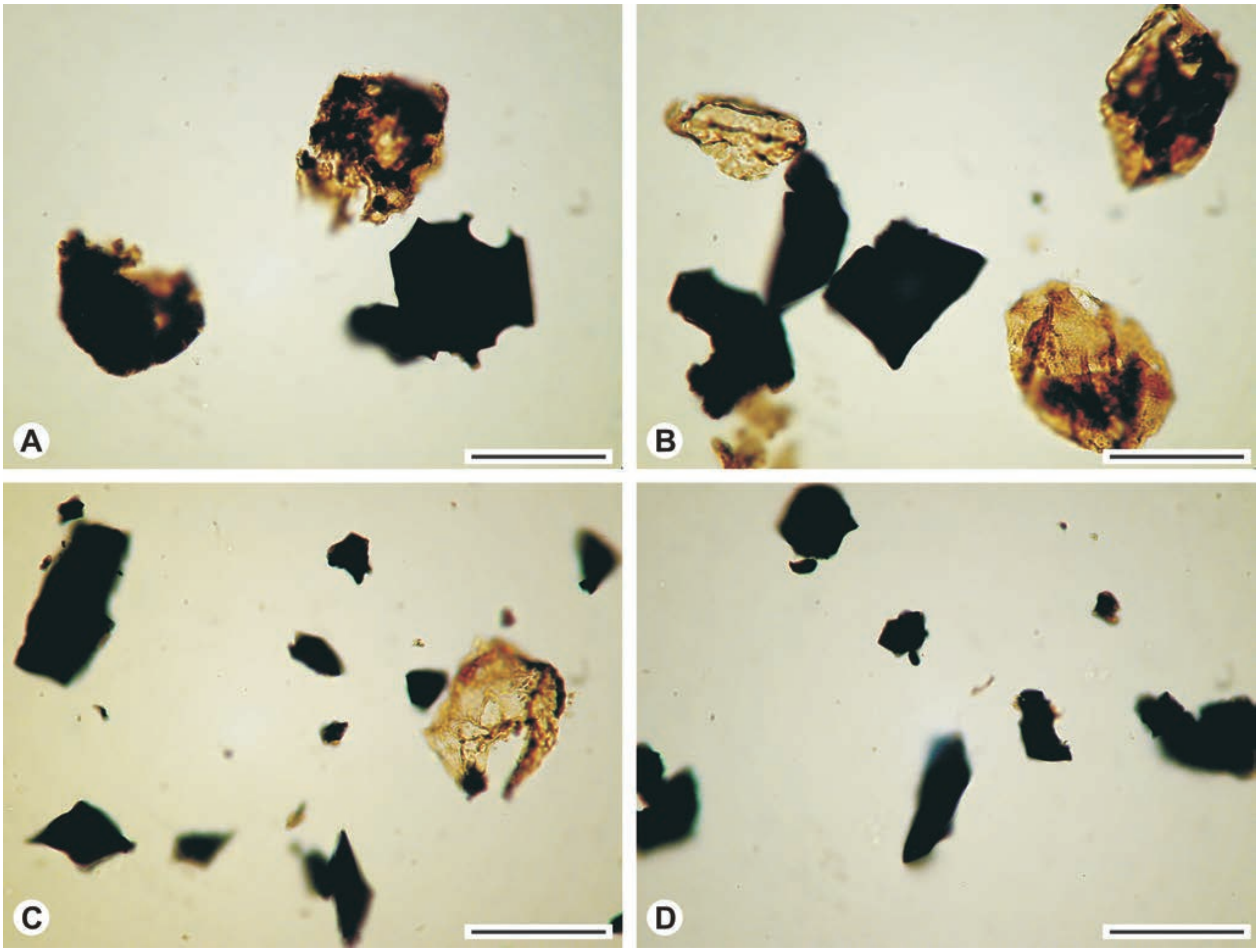


Fig. 8. Palynofacies of the Skrzypny Shale Formation. Scale bars = 25 µm. **A, B.** Sample Kmn15. **C.** Sample Kmn14. **D.** Sample Kmn13.

Skrzypny Shale Formation is dominated by black opaque phytoclasts (Fig. 8). Marine palynomorphs are represented by dinoflagellate cysts, foraminiferal organic linings and acritarchs. The two last mentioned groups are rare; their representatives occur as a few specimens and rarely more per sample. Dinoflagellate cysts were found in most of the samples studied; their frequency varies from sample to sample. A characteristic feature of phytoclasts and palynomorphs is that they exhibit various degrees of maturity. Most particles from the Skrzypny Shale Formation show a dark yellowish-brownish to dark brownish colouration. Their structure, particularly of the cuticles, shows a high degree of corrosion, partly caused by mineral (pyrite?) growth. Particles from the Szlachtowa Formation are lighter; their structures are much better preserved.

Kamienka. Dinoflagellate cyst distribution in samples from the Kamienka (Kmn) section is shown in Table 2. They are present in all samples, except sample Kmn4.

Samples Kmn1 and Kmn2, collected from mudstone of uncertain age yielded highly altered cuticles and black opaque phytoclasts; rare sporomorphs are also matured. Dinoflagellate cysts are extremely rare (Fig. 9) and show bimodal preservation. The majority are poorly preserved, dark-coloured, and commonly are indeterminable. *Palaeohystrichophora infusorioides* and some *Spiniferites* specimens are pale-coloured; their structure is well preserved (some traces of crystal growth are visible).

A different palynofacies occurs in the Szlachtowa Formation, exposed further upstream (Fig. 7A, B). It is composed of predominating cuticles and delicate particles of presumably land origin; dark brown and black phytoclasts are common and the latter frequently are elongated. Dinoflagellate cyst frequency varies from sample to sample (they are absent from sample Kmn4), but it is always subordinate to the terrestrial element. Dinoflagellate cyst frequency is the lowest in samples Kmn3–7 where a few to several specimens occur per slide, higher in samples Kmn8 and Kmn9 (1–2%), and the highest in samples Kmn10 (up to 10%) and Kmn11 (4–5%). Dinoflagellate cyst assemblages from these samples are taxonomically impoverished; they are composed of 2–3 species, and some rare additional ones (Tab. 2). The dominant species are *Nannoceratopsis gracilis*, *Dissiliodinium* spp. and *Kallosphaeridium praussii* (Fig. 10K–V). The latter two taxa are mostly thin-walled, and commonly folded, which makes their identification difficult. There are a number of "thin-walled" forms, which owing to folding, show no features (such as archaeopyle type) that could allow their precise taxonomical designation. As-

Table 2

Distribution of dinoflagellate cysts in Malý Lipník Stream and Kamienka sections

	Section	Malý Lipník																	Kamienka														
	Lithostratigraphy	K.F.		S.S.F.		K.F.		S.F.			M.F.	S.F.			M.F.	S.F.			U.C.		Szlachtowa Formation										S.S.F.		
	Taxon / Sample code	MLp1	MLp2	MLp3	MLp4	MLp5	MLp6	MLp7	MLp8	MLp9	MLp10	MLp11	MLp12	MLp13	MLp14	MLp15	MLp16	MLp17	Kmn1	Kmn2	Kmn3	Kmn4	Kmn5	Kmn6	Kmn7	Kmn8	Kmn9	Kmn10	Kmn11	Kmn12	Kmn13	Kmn14	Kmn15
1.	*Impagidinium* sp.	2																															
2.	*Spiniferites ramosus*	22	2				20								29																		
3.	*Litosphaeridium siphoniphorum*	1													?																		
4.	*Subtilisphaera cheit*	2																															
5.	*Pterodinium cingulatum*	14					9				5																						
6.	*Pterodinium* sp.	9													2																		
7.	*Pervosphaeridium* sp.	8					?																										
8.	*Craspedodinium* sp.	16																															
9.	*Codoniella campanulata*	1																															
10.	*Exochosphaeridium* sp.	1																															
11.	*Odontochitina* sp.	1													1				2	3													
12.	*Spiniferites* sp.	3	2			2	2				2								8	5													
13.	*Dissiliodinium* cf. *lichenoides*			2									32	2				6									3	1		6			
14.	*Kallosphaeridium praussii*			3	8					?		2						6			19					6	9	15	10	5			
15.	*Phallocysta elongata*			1	19									5		1	2									1					6	?	?
16.	*Nannoceratopsis ambonis*			25	2																											2	
17.	*Nannoceratopsis dictyambonis*			2	2					2		1		2		2	5	2													51	88	142
18.	*Nannoceratopsis evae*			2	8									6		1																	
19.	*Nannoceratopsis gracilis*			7	5	1				1		45	10	2		2	2	14			1		14	2	4	25	89	138	11	29	26	17	15
20.	*Escharisphaeridia* sp.			2																	2												1
21.	*Moesiodinium raileanui*			8																													
22.	*Dissiliodinium psilatum*			1	1							2						17			8		5			4	127	28	21	26			1
23.	*Nannoceratopsis spiculata*				3							1																					
24.	*Nannoceratopsis* sp.				73									3			3				2			7		2	7	12	5	10	12	31	36
25.	*Lithodinia*? sp.				1																												
26.	*Nannoceratopsis raunsgaardii*				1									1		5	4											7					
27.	*Palaeohystrichophora infusorioides*					1	19				4				6				2	4													
28.	*Spinidinium* sp.						3				2				2																		
29.	*Kiokansium*? sp.						2																										
30.	*Isabelidinium*? sp.						1																										
31.	*Oligosphaeridium* sp.						1																										
32.	*Maghrebinia*? sp.						1																										
33.	thin-walled form							5		3		98		54		41	2				12		2			64		25	14	8	3		2
34.	*Batiacasphaera* spp.							4					1					2									1	10	2	27	5		
35.	*Nannoceratopsis deflandrei*							1	12	35																							
36.	*Valvaeodinium* cf. *koessenium*									1													1			8							
37.	*Alterbidinium* spp.										6																						
38.	*Dissiliodinium lichenoides*											6						13					1					3	2	8	?		
39.	*Pareodinia* sp.											1																3					
40.	*Dissiliodinium* spp.												1					1															
41.	*Dissiliodinium giganteum*												123								8						7	3	5	4			
42.	*Circulodinium* sp.														1					2										1	63		
43.	*Scriniocassis priscus*															5	2																
44.	*Kallosphaeridium*? sp.																1																
45.	*Lithodinia*? sp.																1	1															
46.	*Kallosphaeridium* spp.																	1						4					1				
47.	*Florentinia* sp.																			1													
48.	*Durotrigia*? sp.																						1			1			3	1			
49.	*Valvaeodinium* spp.																									1			1				
50.	*Mendicodinium* sp.																												1				

Abbreviations: K.F. – Kapuśnica Formation; S.S.F. – Skrzypny Shale Formation; S.F. – Szlachtowa Formation; M.F. – Malinowa Shale Formation; U.C. – Upper Cretaceous.

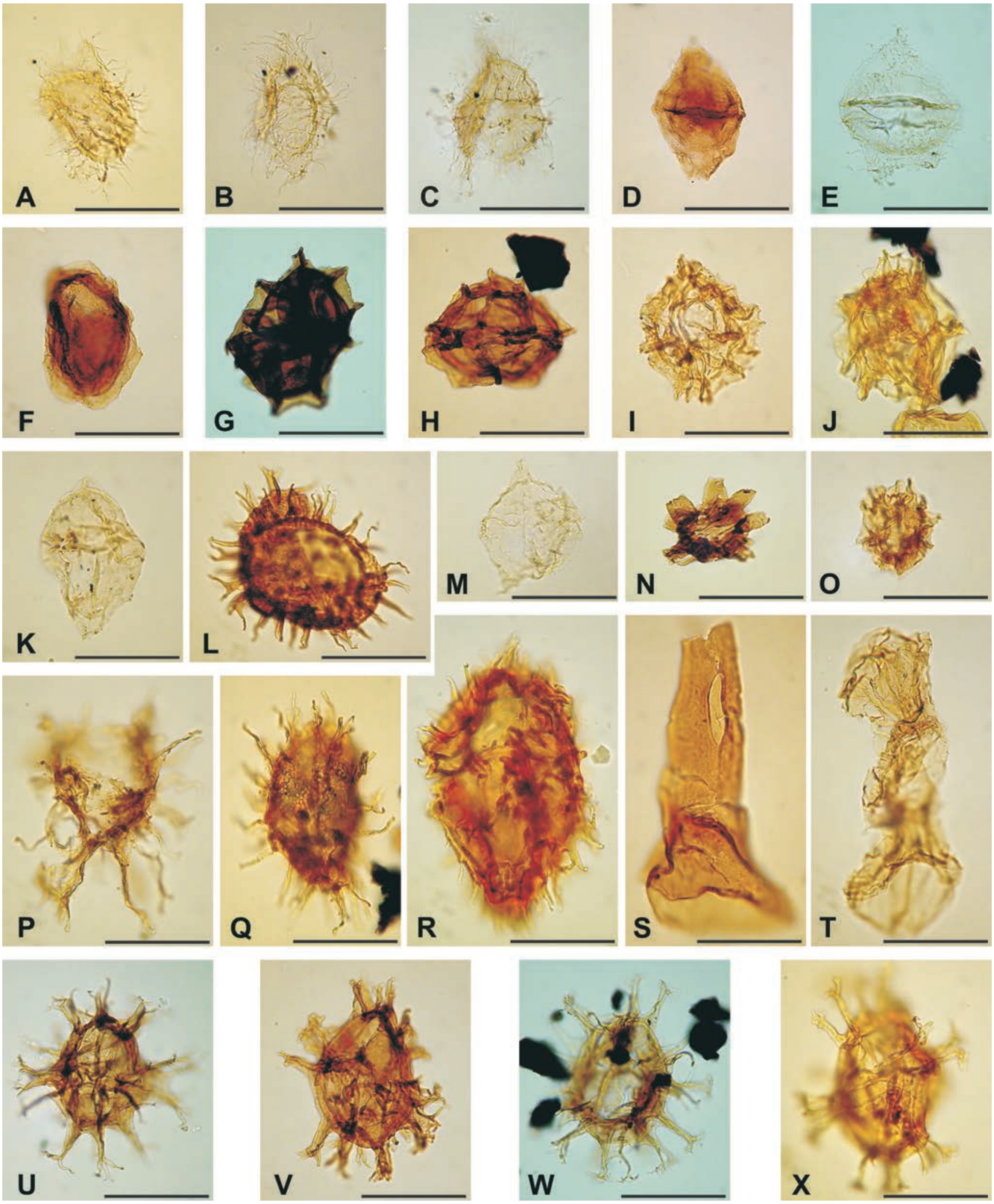


Fig. 9. Dinoflagellate cysts from Cretaceous strata of the study area. Scale bars = 25 µm. **A–C.** *Palaeohystrichophora infusorioides* (A: Kmn1; B: MLp6; C: Jar-1, 136.9 m). **D.** *Alterbidinium*? sp. (Jar-1, 127.9 m). **E.** *Palaeohystrichophora cheit* (MLp1). **F.** *Craspedodinium* sp. (MLp1). **G.** *Pterodinium cingulatum* (dark-coloured specimen; MLp1). **H.** *Pterodinium* sp. (MLp1). **I.** *Pterodinium cingulatum* (pale-coloured specimen; MLp1). **J.** *Pterodinium* sp. (MLp14). **K.** *Alterbidinium* sp. (MLp10). **L.** *Pervosphaeridium* sp. (MLp1). **M.** *Spinidinium* sp. (MLp6). **N.** *Litosphaeridium siphoniphorum* (MLp1). **O.** *Pterodinium* sp. (MLp1). **P, Q.** Poorly preserved chorate specimens (P: MLp10; Q: Kmn1). **R.** *Circulodinium* sp. (MLp14). **S.** *Odontochitina* sp. (MLp1). **T.** *Codoniella campanulata* (MLp1). **U–X.** *Spiniferites* spp. (U: Jar-1, 135.9 m; V: MLp1; W: MLp10; X: Kmn1).

semblages from samples Kmn3, Kmn8 and Kmn11 are dominated by these "thin-walled" specimens and *Kallosphaeridium-Dissiliodinium* ones (Fig. 10L, O, P); *Nannoceratopsis* (mainly *N. gracilis* ; Fig. 10S) predominates in samples Kmn5–7 and Kmn10. The assemblage from sample Kmn9, in turn, is characterized by the frequent occurrence of both *Dissiliodinium* (but represented here by thick-walled *D. giganteum*; Fig. 10T, U) and *Nannoceratopsis gracilis*.

Sample Kmn12 yielded a palynofacies dominated by cuticles and structured palynodebris; dark brown phytoclasts are common. Dinoflagellate cysts (a few per cent) are dominated by *Dissiliodinium* (*D. giganteum*, *D. lichenoides*, *D.* spp.; Fig. 10T–V) and *Batiacasphaera*; *Kallosphaeridium* and *Nannoceratopsis* (*N. gracilis*) are infrequent.

A different palynofacies is present in samples Kmn13–15 collected from the Skrzypny Shale Formation, exposed in the Metiská Quarry (Fig. 8). It is dominated by black opaque phytoclasts, highly disintegrated (Kmn13) or slightly larger (Kmn14), up to 90%; dinoflagellate cysts and sporomorphs represent a few to 10%. Sample Kmn15 contains a higher proportion (15%) of highly degraded dark brown particles of uncertain origin (tissue remains?). A characteristic feature of all three samples is the high maturation of organic particles, which are dark brown and their structure shows a high degree of alteration. This refers particularly to the spormorphs and plant tissue remains; dinoflagellate cysts show bimodal preservation: most of them are brownish, but relatively well preserved (e.g., *Nannoceratopsis dictyambonis*, *Dissiliodinium*, *Kalllosphaeridium*), whereas some (e.g., *N. gracilis*) are dark brown and highly degraded (Fig. 10A–J). The latter show also a high degree of damage, caused by crystal growth (pyrite?). The taxonomic composition of the dinoflagellate cyst assemblages from samples Kmn14 and Kmn15 is very similar: it consists of frequent *Nannoceratopsis* specimens (mainly *N. dictyambonis*; Fig. 10C, H) and rare *Kallosphaeridium-Dissiliodinium* specimens (Tab. 2). The assemblage from sample Kmn13 is characterized by a higher frequency of *Dissiliodinium*, which remains approximately in the same proportion as *Nannoceratopsis* does (mainly *N. dictyambonis*).

Malý Lipník. Samples from this section yielded various palynofacies and dinoflagellate cyst assemblages that reflect various ages of the strata in question.

The palynofacies of samples MLp1 and MLp2 is composed almost entirely of highly disintegrated black, opaque phytoclasts; they differ in the more frequent dinoflagellate cysts in sample MLp1 (almost absent in MLp2). Dinoflagellate cysts are well preserved, although some diversification in colouration may be observed (Fig. 9E–I, L, N, O, S, T, V). Most frequent are *Spiniferites*, *Pterodinium* and *Craspedodinium*. The same palynofacies occurs in samples MLp5 and MLp6 (rare cuticles, commonly highly degraded, are 2–5%). Dinoflagellate cysts are rare, particularly in sample MLp5; they show two different stages of preservation: peridinioids (e.g., *Palaeohystrichophora infusorioides*, *Spinidinium*), *Spiniferites* and *Pterodinium* are well preserved and pale-coloured (Fig. 9A–E); the chorate gonyaulacoids like *Kiokansium* and *Oligosphaeridium* are darker-coloured and their structure is damaged (Fig. 9P–R); spores are similarly preserved, they are dark-coloured. Sample MLp10 is another one that yielded a black phytoclast-dominated palynofacies and bimodal preserved rare dinoflagellate cysts: excellently preserved ones include *Palaeohystrichophora infusorioides* and other peridinioids (*Alterbidinium* spp., *Spinidinium*), *Pterodinium*, *S. ramosus* (Fig. 9K, W). Poorly preserved are indeterminable chorate gonyaulacoids (Fig. 9P). A similar assemblage showing various degrees of preservation (well preserved *P. infusorioides*, *Spinidinium* sp., and some specimens of *Spiniferites*, contrasting with very poorly preserved thick-walled gonyaulacoids), has been found in sample MLp14. Its palynofacies consists of black opaque phytoclasts and highly altered cuticles (15%); dinoflagellate cysts are below 1%.

A different palynofacies, characterized by a high proportion of spores and dinoflagellate cysts (up to 20–25%) in relation to black opaque phytoclasts, was found in samples representing the Skrzypny Shale Formation (MLp3 and MLp4); cuticles are infrequent (up to 5%); infrequent foraminiferal organic linings and acritarchs occur. Dinoflagellate cyst assemblages (Fig. 11A–C, E–K) are moderately diversified: *Nannoceratopsis* (*N. ambonis*, *N. gracilis*, *N. evae*) is the most common genus (Tab. 2).

The remaining samples, representing the Szlachtowa Formation, yielded large amounts of palynological organic matter, composed of black, dark brown and cuticle remains, palynodebris (Fig. 7C, D). Dinoflagellate cysts occur in various proportions; they are rare in samples MLp7–9, up to a few per cent in samples MLp15–17, and frequent (15–20%) in samples MLp11–13 (Fig. 11D, L–U). Their taxonomical composition is variable (Tab. 2). Samples MLp7–9 yielded *Nannoceratopsis deflandrei*, single *N. dictyambonis*, *N. gracilis*, and some thin-walled forms representing presumably *Dissiliodinium* and *Kallosphaeridium*. The latter forms are dominant in the remaining samples, in association with frequent *Nannoceratopsis gracilis* and rare *Dissiliodinium lichenoides* and *N. dictyambonis* (MLp11), *Nannoceratopsis* (*N. evae*, *N. dictyambonis*, *N. raunsgaardii*, *N. gracilis*) and rare *Dissiliodinium* cf. *lichenoides* (MLp13), *Nannoceratopsis* (*N. raunsgaardii* and *N. dictyambonis*), and rare *Scriniocassis prisca* and *Phallocysta elongata* in samples MLp15 and MLp16. The assemblage from sample MLp17 differs in the higher proportion of *Dissiliodinium* cf. *lichenoides* and *D. lichenoides*, whereas the one from sample MLp12 is outstanding in that it shows an acme of *Dissiliodinium giganteum* associated with *Dissiliodinum* cf. *lichenoides* and *Nannoceratopsis gracilis*.

Jar-1 borehole. Samples from the two scales of the Szlachtowa Formation from this borehole have been studied for dinoflagellate cysts (Fig. 6): the lower (128–135 m) and the upper scale (61–95 m). Most samples from the Szlachtowa Formation yielded a palynofacies dominated by dark brown and black phytoclasts, the latter frequently with transparent edges, commonly massive, and cuticle remains (Fig. 7E, F). They occur in variable proportions, associated with subordinate amounts of sporomorphs and dinoflagellate cysts.

Lower scale (128–135 m). This interval of the Szlachtowa Formation is underlain by the Upper Cretaceous strata (Fig. 6A, F). The sample from 135.9 m depth yielded a palynofacies composed of black opaque phytoclasts. Extremely

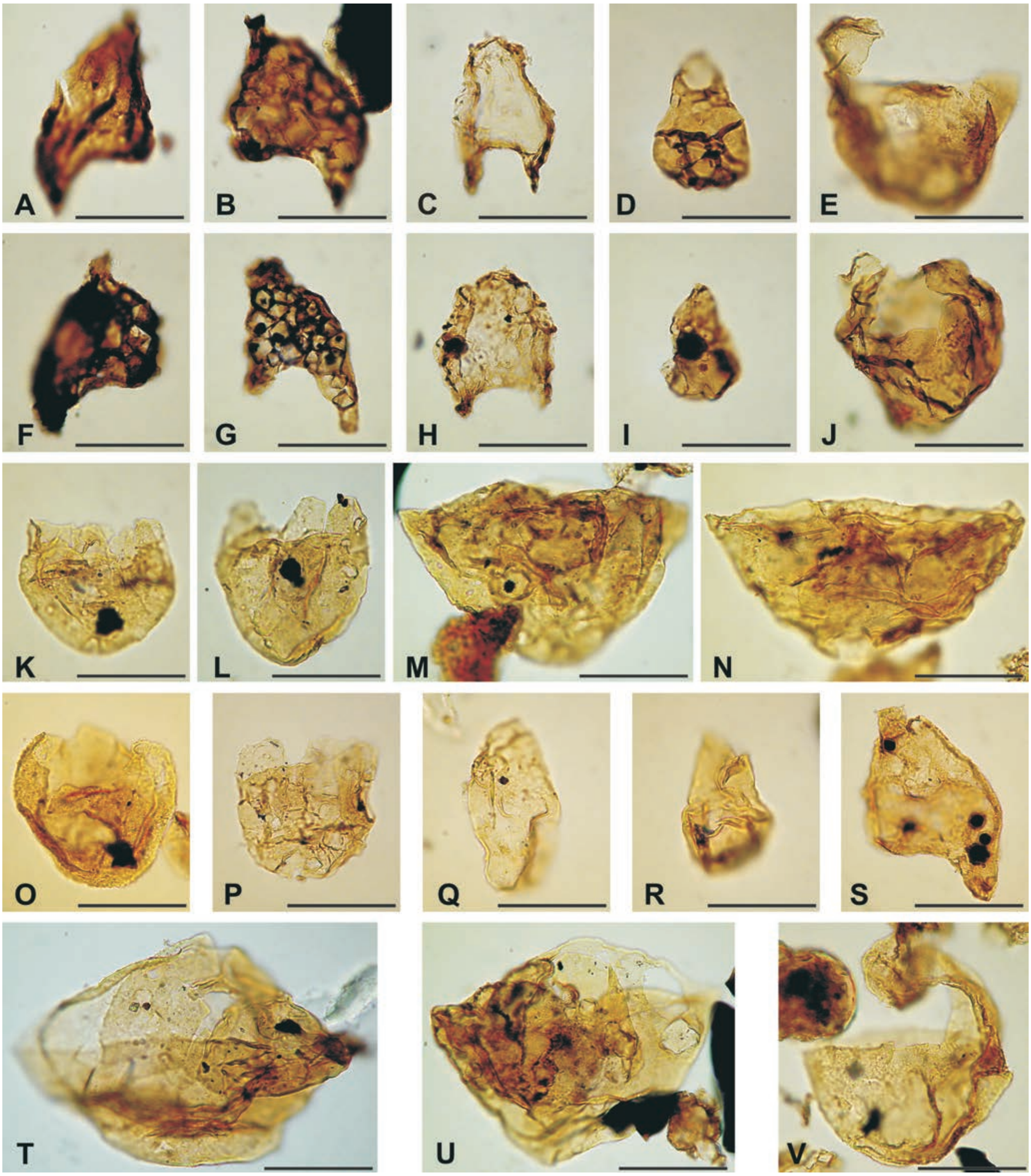


Fig. 10. Dinoflagellate cysts from the Skrzypny Shale Formation from the Metiská Quarry (A–J) and from the Szlachtowa Formation from the Riečka Stream near Kamienka (K–V). Scale bars = 25 μm. **A, B.** *Nannoceratopsis gracilis* (both specimens from Kmn13). **C.** *Nannoceratopsis dictyambonis* (Kmn13). **D.** *Phallocysta elongata* (Kmn13). **E.** *Kallosphaeridium* sp. (Kmn13). **F, G.** *Nannoceratopsis gracilis* (both specimens from Kmn15). **H.** *Nannoceratopsis dictyambonis* (Kmn15). **I.** *Phallocysta elongata* (Kmn13). **J.** *Kallosphaeridium* sp. (Kmn15). **K.** *Batiacasphaera* sp. (Kmn3). **L.** *Kallosphaeridium* sp. (Kmn3). **M, N.** *Dissiliodinium giganteum* (both specimens from Kmn3). **O.** *Kallosphaeridium* sp. (Kmn6). **P.** *Kallosphaeridium praussii* (Kmn8). **Q.** *Comparodinium* cf. *koessianum* (Kmn8). **R.** *Phallocysta elongata* (Kmn8). **S.** *Nannoceratopsis gracilis* (Kmn8). **T, U.** *Dissiliodinium giganteum* (both specimens from Kmn11). **V.** *Dissiliodinium lichenoides* (Kmn12).

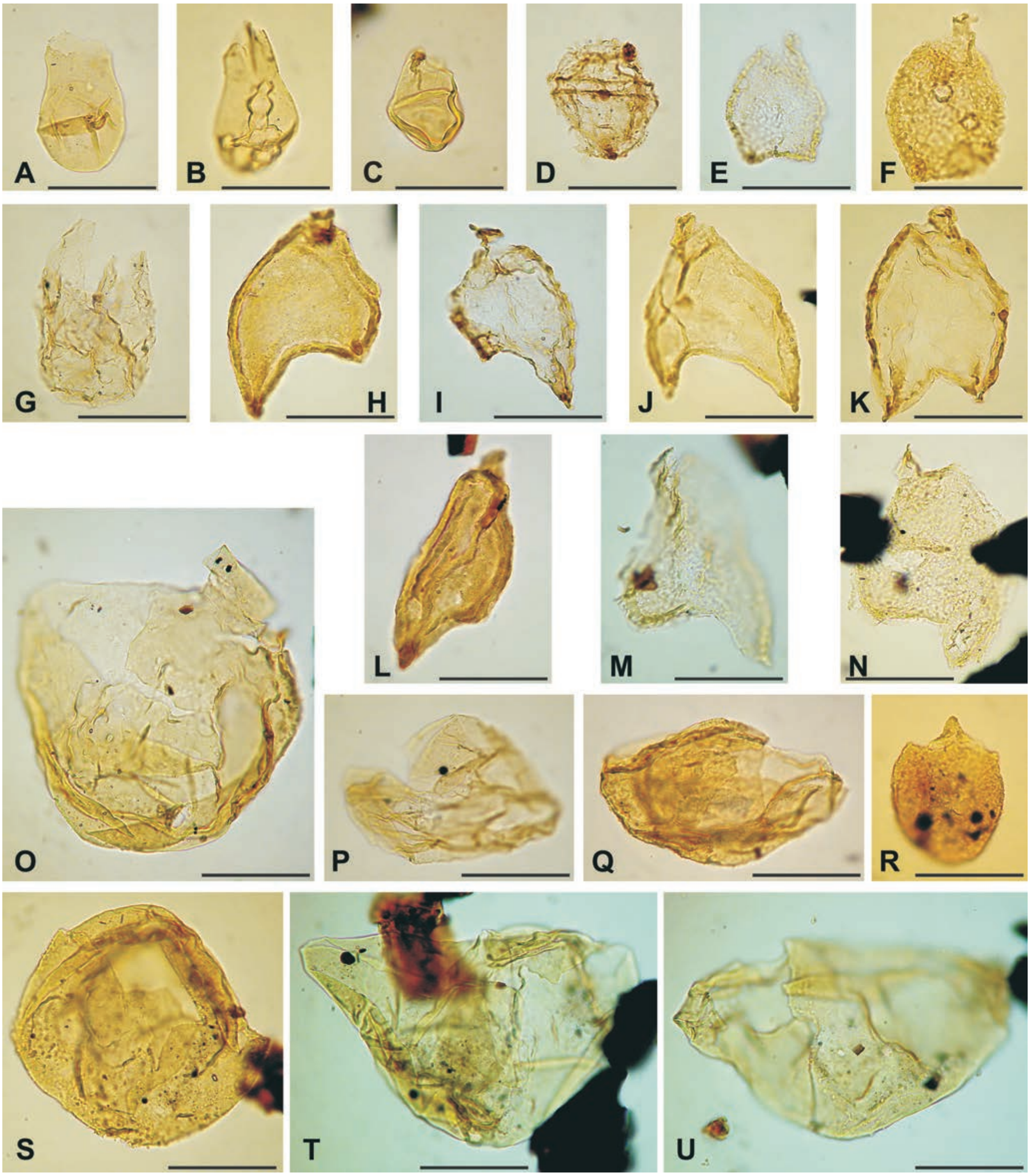


Fig. 11. Dinoflagellate cysts from the Skrzypny Shale Formation (A–C, E–K) and the Szlachtowa Formation (D, L–U) from Malý Lipník Stream. Scale bars = 25 µm. **A–C.** *Phallocysta elongata* (A: MLp3; B: MLp4; C: MLp16). **D.** *Moesiodinium raileanui* (MLp3). **E, F.** *Nannoceratopsis evae* (both specimens from MLp4). **G.** *Kallosphaeridium praussii* (MLp3). **H.** *Nannoceratopsis gracilis* (MLp3). **I.** *Nannoceratopsis dictyambonis* (MLp4). **J.** *Nannoceratopsis spiculata* (MLp4). **K.** *Nannoceratopsis dictyambonis* (MLp4). **L.** *Nannoceratopsis gracilis* (MLp9). **M, N.** *Nannoceratopsis deflandrei* (both specimens from MLp9). **O.** *Dissiliodinium giganteum* (MLp12). **P.** *Dissiliodinium* sp. (MLp7). **Q.** *Dissiliodinium lichenoides* (MLp11). **R.** *Pareodinia* sp. (MLp11). **S.** *Dissiliodinium* cf. *lichenoides* (MLp17). **T.** *Dissiliodinium giganteum* (MLp12). **U.** *Dissiliodinium* cf. *lichenoides* (MLp12).

Table 3

Distribution of dinoflagellate cysts in the Jar-1 borehole

	Section	Jar-1 borehole – lower scale										Jar-1 borehole – upper scale																				
	Lithostratigraphy	M.F.	Szlachtowa Formation								M.F.	Szlachtowa Formation																				
	Taxon / Sample depth [m]	135.9	135.2	134.3	133.2	132.4	131.8	130.6	129.7	128.5	127.9	93.3	92.4	91.05	89.65	88.2	87.15	86.5	85.7	85.2	84.9	83.85	83.4	82.5	81.5	80.1	78.2	75.2	68.5	65.5	64.6	61.9
1.	*Palaeohystrichophora infusorioides*	1																														
2.	*Pterodinium* sp.	2																														
3.	*Spiniferites* sp.	2																														
4.	*Dissiliodinium giganteum*		36	7	157	21	3	1																								
5.	*Dissiliodinium lichenoides*		4													?		1														
6.	*Dissiliodinium* cf. *lichenoides*		13	28			?		8						10	1																
7.	*Dissiliodinium* spp.		9	15	4	4	9	2	9			5	1			12	5															
8.	*Nannoceratopsis gracilis*		2	7		8	8	25	86				9		91	10	10	9	21	15	10		3	1		1		1		2	8	34
9.	*Pareodinia* sp.		2											1																		
10.	*Kallosphaeridium*? sp.		5										2	8	4	3	14			2						2			?			
11.	*Kallosphaeridium* spp.			9												1																
12.	*Batiacasphaera* spp.			5	2	9	2	6	2			1				4																
13.	*Nannoceratopsis ambonis*			1										6																		
14.	*Ctenidodinium cornigerum*					43	5	4																								
15.	*Nannoceratopsis* sp.						2					1								3					2			1				
16.	*Phallocysta elongata*						3		8			1	22	21	1		15		103	39	8		?	1	5				1	12		
17.	*Phallocysta* sp.							1					1	5					4	1	1											
18.	*Carpathodinium* sp. A							1							1																	
19.	*Ctenidodinium combazii*									97																						
20.	*Chytroeisphaeridia chytroeides*									4																						
21.	*Meiourogonyaulax* sp.									1																						
22.	*Lithodinia* sp.									1																						
23.	*Nannoceratopsis pellucida*									5																						
24.	*Epiplosphaera bireticulata*									4																						
25.	*Epiplosphaera* sp.									12																						
26.	*Valensiella* sp.									4																						
27.	*Taeniophora*? sp.																															
28.	*Spinidinium*? sp.										1																					
29.	*Alterbidinium*? sp.										2																					
30.	*Craspedodinium*? sp.										1																					
31.	*Valvaeodinium scalatum*											1																				
32.	*Valvaeodinium* cf. *koessenium*													1																		
33.	*Nannoceratopsis deflandrei*															?		?		1						2						
34.	*Nannoceratopsis dictyambonis*																15		2	24	8			1						33	10	
35.	*Chytroeisphaeridia*? sp.																	1														
36.	*Nannoceratopsis raunsgaardii*																															4

Abbreviation: M.F. – Malinowa Shale Formation.

rare dinoflagellate cysts (Tab. 3) are represented by *Spiniferites*, *Pterodinium cingulatum* and *Palaeohystrichophora infusorioides* (Fig. 9C, U). A similar palynofacies, but with different dinoflagellate cysts, occur in strata overlying the lower scale: the sample from a depth of 127.9 m yielded single peridinioids, representing *Spinidinium*?, *Alterbidinium*? and *Craspedodinium*? (Fig. 9D).

Most of samples from the black shale of the Szlachtowa Formation contain palynofacies, dominated by terrestrial palynodebris (black, opaque phytoclasts, dark brown phytoclasts, cuticle remains) and sporomorphs (1–8%; Fig. 7E); aquatic palynomorphs (mainly dinoflagellate cysts; Fig. 12) do not exceed 6–8%. The only exception is the sample from a depth of 133.2 m; dinoflagellate cysts comprise here almost 15% of the assemblage. The topmost sample from this interval (128.5 m) yielded an outstanding palynofacies, composed of black opaque phytoclasts and dinoflagellate cysts (10%). The three basal samples contain a high proportion of *Dissiliodinium* spp. The one from a depth of 133.2 m contains an acme of *Dissiliodinium giganteum*. The higher samples contain *Dissiliodinium* specimens, in association with frequent *Ctenidodinium cornigerum* (132.4 m; Fig. 12O, Q), which, although less frequent, is also present in the higher samples (131.8 m and 130.6 m), and frequent *Nannoceratopsis gracilis* in the sample from 129.7 m depth. An outstanding assemblage dominated by *Ctenidodinium combazii* occurs in the topmost sample (128.5 m; Fig. 12U, V).

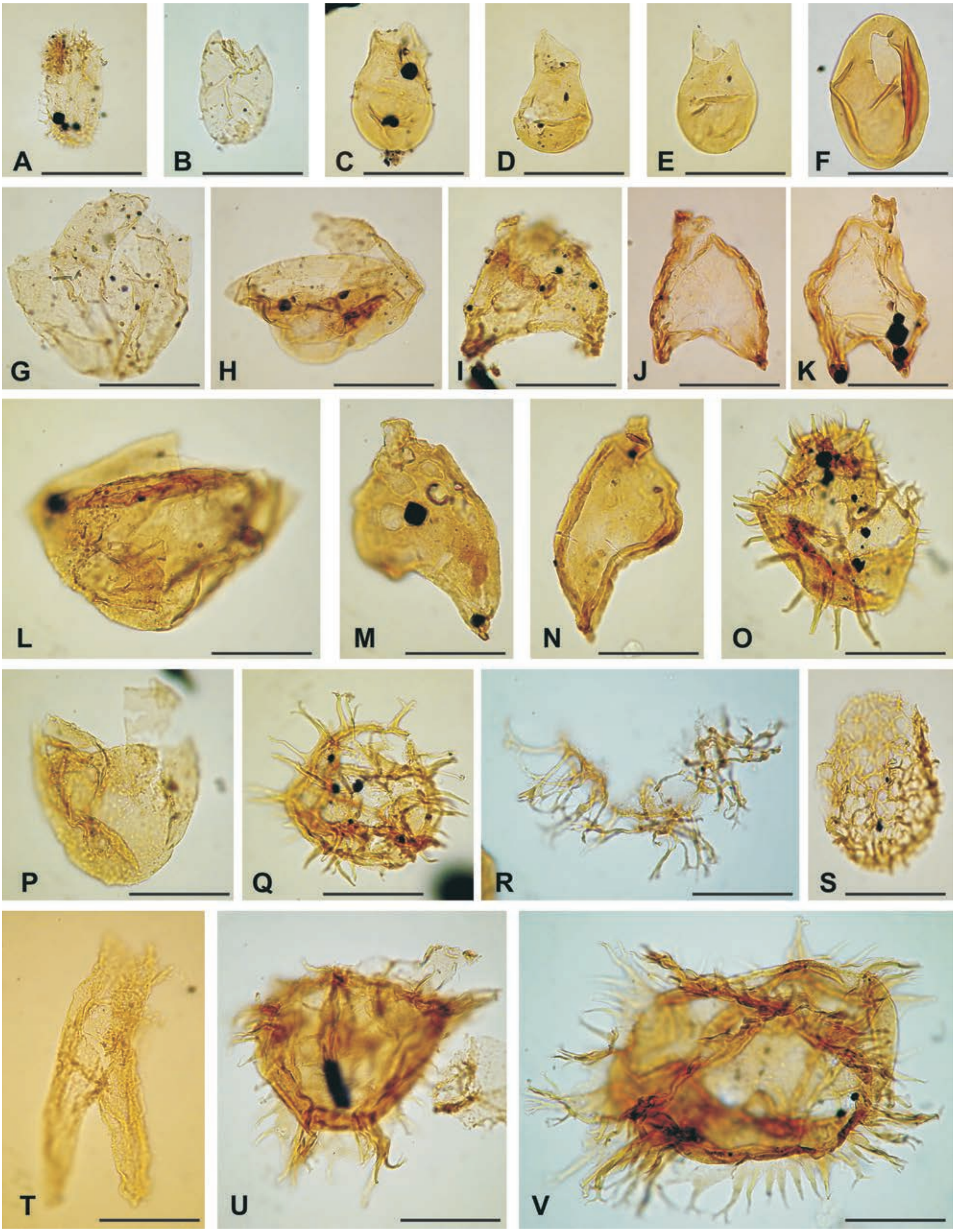


Fig. 12. Dinoflagellate cysts from the Szlachtowa Formation of the Jar-1 borehole. Scale bars = 25 µm. **A.** *Valvaeodinium scalatum* (93.3 m). **B.** *Valvaeodinium* cf. *koessenium* (91.05 m). **C–E.** *Phallocysta elongata* (C: 93.3 m; D, E: 91.05 m). **F.** *Chytroiesphaeridium chytroeides* (128.5 m). **G, H.** *Dissiliodinium* spp. (both specimens from 93.3 m). **I.** *Nannoceratopsis raunsgaardii* (61.9 m). **J, K.** *Nannoceratopsis dictyambonis* (both specimens from 87.15 m). **L.** *Dissiliodinium* cf. *lichenoides* (89.65 m). **M, N.** *Nannoceratopsis gracilis* (M: 89.65 m; N: 91.05 m). **O.** *Ctenidodinium cornigerum* (132.4 m). **P.** *Dissiliodinium* cf. *lichenoides* (89.65 m). **Q.** *Ctenidodinium cornigerum* (132.4 m). **R.** *Taeniophora*? sp. (incomplete specimen; 128.5 m). **S.** *Valensiella* sp. (128.5 m). **T.** *Nannoceratopsis pellucida* (128.5 m). **U, V.** *Ctenidodinium combazii* (both specimens from 128.5 m).

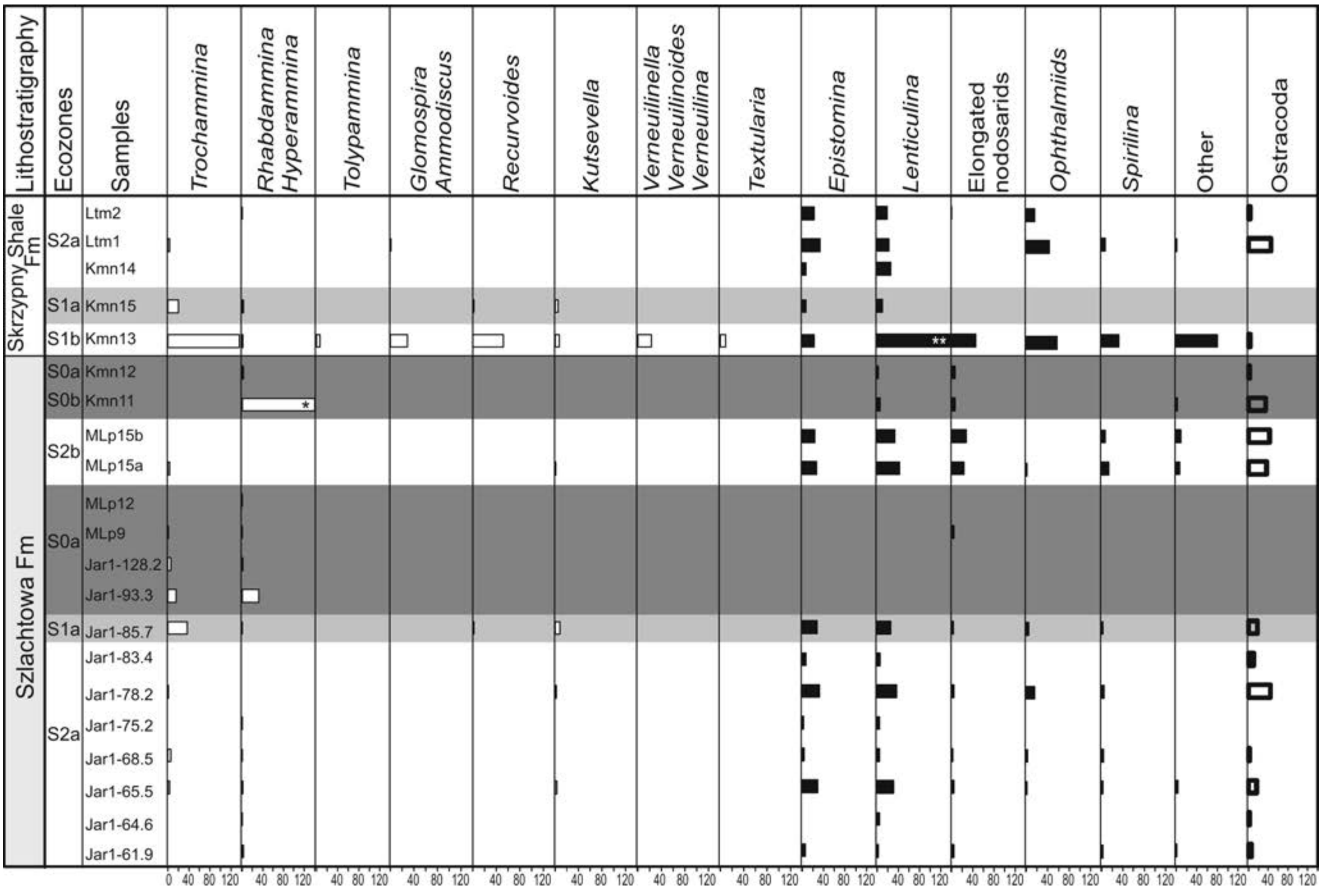


Fig. 13. Distribution and abundances of foraminifera and ostracods in the samples studied. White colour stands for agglutinated and black for calcareous foraminifera. All data are indicated as number of specimens. * – specimen count is more than 280 individuals; ** – specimen count is more than 350 individuals.

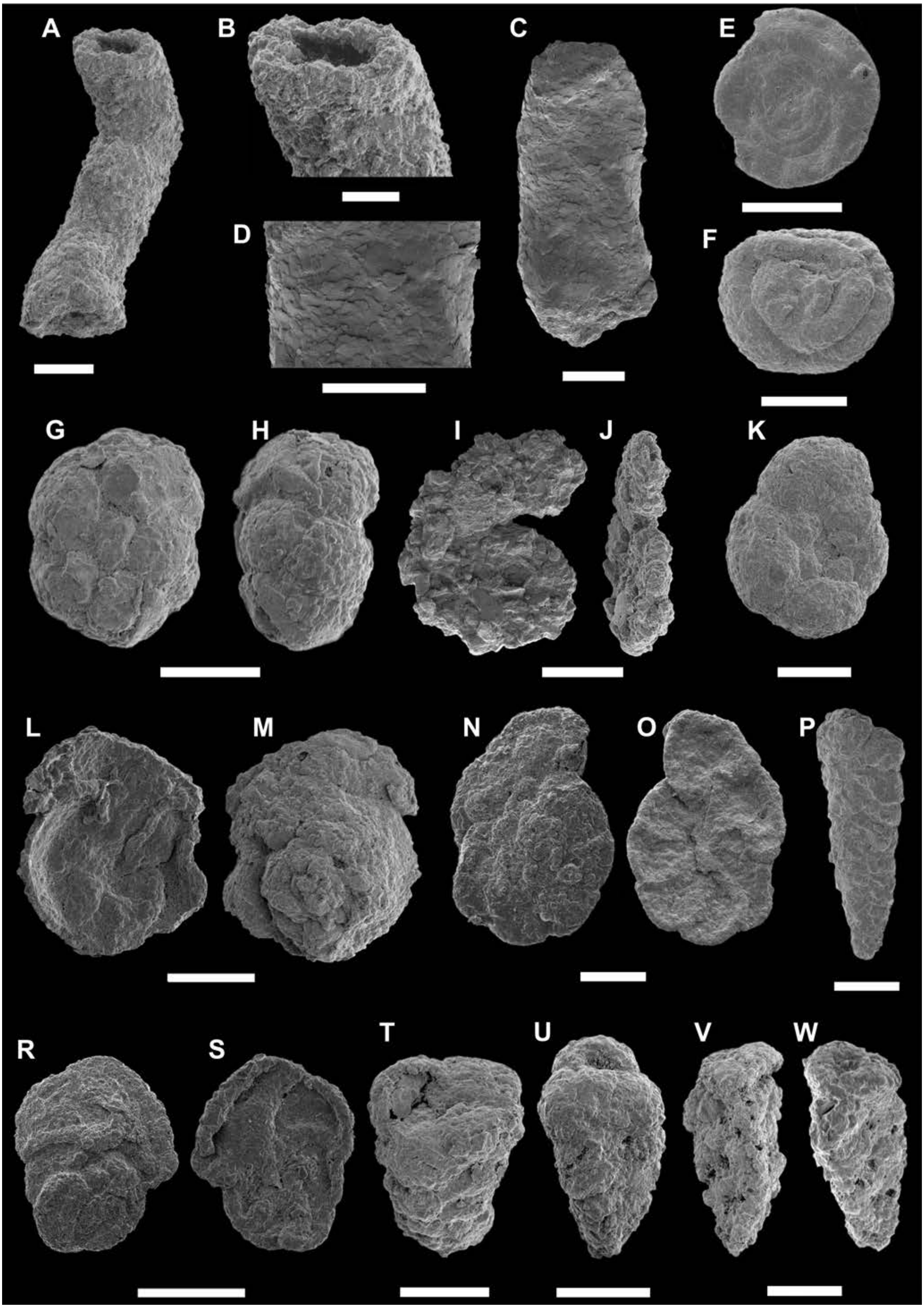
Upper scale (61–95 m). Black shale from this interval yielded generally small amounts of palynological organic matter; their palynofacies is dominated by black phytoclasts, commonly with transparent edges – over 70–80% in most samples (only two uppermost samples from depths of 64.6 m and 61.9 m yielded lower proportions varying around 50–60%); cuticles are subordinate, being most frequent in the basal samples (93.3 m, 91.05 m, 89.65 m, 88.2 m – 15–20%). Some samples, particularly from the upper interval (68–61 m), contain brown, highly disintegrated phytoclasts without preserved structures (Fig. 7F). Sporomorphs occur in all samples studied; their proportion oscillates from 2 to 5%, the highest values occur in samples from basal depths: 93.3 m (12%), 91.05 m (10%), 87.15 m (8%). Dinoflagellate cysts are most frequent in the basal interval 92.4–87.15 m (Tab. 3), but even there they do not exceed 2–3%. They are rare or absent in the higher interval, except in the samples from depths of 85.2 m and 85.7 m, where their proportion reaches 5% and 12%, respectively. Most samples contain similar dinoflagellate cyst assemblages, composed mainly of *Nannoceratopsis* (chiefly *N. gracilis*, *N. dictyambonis*), *Dissiliodinium* spp., and *Phallocysta elongata* (Fig. 12). The last mentioned species forms an acme in the sample from 85.7 m depth. Rare specimens of *Valvaeodinium* occur at basal depths (Tab. 3; Fig. 12A, B). Single specimens of *Nannoceratopsis deflandrei* were found in two samples from the depths of 85.2 m and 80.1 m (Tab. 3).

Litmanová. The samples collected from the Skrzypny Shale Formation yielded a uniform palynofacies, composed entirely of black opaque phytoclasts. There are neither terrestrial palynomorphs (sporomorphs), nor marine ones. Samples of the Krempachy Marl Formation (Ltm7 and Ltm8) yielded very small amounts of palynological organic matter, composed entirely of black opaque phytoclasts.

Foraminifera

The samples studied yielded various microfaunal content, diversified both quantitatively and qualitatively (Fig. 13). Some samples are barren; they represent the Szlachtowa Formation: Malý Lipník Stream sample MLp8, Jar-1 borehole samples from the following depths: 84.9 m, 88.9 m, 89.9 m, 128.7 m, 131.2 m, 133.2 m, and Kamienka (Riečka Stream) samples Kmn3 and Kmn9. The identified foraminifera represent both agglutinated (Fig. 14) and calcareous benthic (Figs 15, 16) forms. During the study, relatively frequent ostracods were found (Fig. 16).

Kamienka and Malý Lipník. The single sample MLp8 taken from the Szlachtowa Formation exposed along the lower course of the Malý Lipník Stream is barren. The rest of them contains impoverished agglutinated assemblages (MLp9, MLp12; Fig. 13) with *Rhabdammina* or *Hyperammina* and rare *Trochammina* only (Fig. 14). Sample MLp15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from the upper course of Malý Lipník Stream, in turn, yielded rich and diversified assemblages of mostly calcareous benthic foraminifera with dominant *Epistomina, Spirillina* and smooth-walled *Lenticulina*; they are accompanied by common *Dentalina*, *Citharina*, *Falsopalmula*, *Ichtyolaria*, *Pseudonodosaria* and *Nodosaria* (Fig. 15). Agglutinated foraminifera, represented by *Kutsevella* and *Trochammina*, are very rare (MLp15a; Fig. 13).

A different assemblage, dominated by superabundant medium to coarsely agglutinated *Rhabdammina*, was found in the Szlachtowa Formation exposed along the Riečka Stream near Kamienka (Kmn11; Fig. 14A, B). It contains also very rare specimens of *Dentalina*, *Lenticulina*, *Citharina* and *Planularia*.

The Skrzypny Shale Formation sampled in the Metiská Quarry, near Kamienka (samples Kmn13–15), yielded various assemblages. The one from sample Kmn13 (lower part of the quarry; Fig. 3D) consists of abundant small agglutinated foraminifera, represented by *Glomospira*, *Ammodiscus*, *Kutsevella*, *Trochammina*, *Recurvoides*, *Conotrochammina*, *Verneuilinella, Verneuilina, Verneuilinoides* and *Textularia*; the most abundant are *Trochammina* and *Lenticulina* (Fig. 13). An increased abundance of smooth-walled *Astacolus* was noted there too; small ophthalmids are present as rare specimens only. In the samples from the Skrzypny Shale Formation in the upper scale of the quarry (Kmn14 and Kmn15; Fig. 3D), different associations have been found. Both samples yielded sparse and badly preserved foraminifera. Sample Kmn14 yielded only calcareous forms, whereas sample Kmn15 contains a mixed association of agglutinated and calcareous foraminifera. The most frequent genera are *Lenticulina* and *Epistomina*.

A different microfaunal assemblage was found in the Skrzypny Shale Formation from Litmanová (samples Ltm1 and Ltm2 from exposures along the Velký Lipník Stream; Fig. 3F). It consists almost exclusively of calcareous benthic foraminifera with dominant *Epistomina* and ophthalmids (Fig. 13). It is noteworthy that *Planularia cordiformis* (Terquem) and *Tolypammina* sp. have been found in the Skrzypny Shale Formation only.

Jar-1 borehole. The Szlachtowa Formation from the upper scale of the Jar-1 borehole (samples from the depth interval 61–95 m; Fig. 6) yielded common to relatively abundant foraminifera. The assemblage from the lowermost sample at a depth of 93.3 m consists exclusively of agglutinated forms, represented by abundant *Hyperammina* with a typical glassy appearance. When observed under SEM, the wall structure shows its texture consists of fine imbricated mica flakes (Fig. 14C, D). They are associated with common *Trochammina* and rare *Haplophragmoides* (Fig. 13). Higher in the borehole, the foraminifera assemblage consists of taxonomically diversified, mixed agglutinated and calcareous taxa: a significant decrease in *Hyperammina*, an increase in *Trochammina*, and occasional occurrences of *Kutsevella*, rare *Conotrochammina* and *Recurvoides* were observed (85.7 m; Fig. 13). Among the calcareous benthic foraminiferas, *Epistomina* and *Lenticulina* are the most frequent in most of the samples from both formations. Small *Spirillina* is only present as pyritised moulds. The assemblages from the higher part of the upper scale of the Szlachtowa Formation (83.4–61.9 m) are characterized by the strong predominance of calcareous benthic foraminifera over agglutinated ones; the former are dominated again by *Epistomina* and *Lenticulina* (Fig. 13). The exclusive occurrence of small *Ophthalmidium* sp. was noted in the upper scale of the Jar-1 borehole. Notable is the nearly perfect positive correlation between the increase of *Lenticulina,* ostracods and *Epistomina* in the Szlachtowa Formation of the Jar-1 borehole (Fig. 13). Broken specimens of *Lenticulina*, assigned to *Lenticulina* cf. *chicheryi*, were found in the sample from a depth of 61.9 m (Fig. 15P, R).

Only scarce and impoverished agglutinated foraminifera were found in the lower scale of the Jar-1 borehole represented by *Rhabdammina* sp. and *Trochammina* sp.

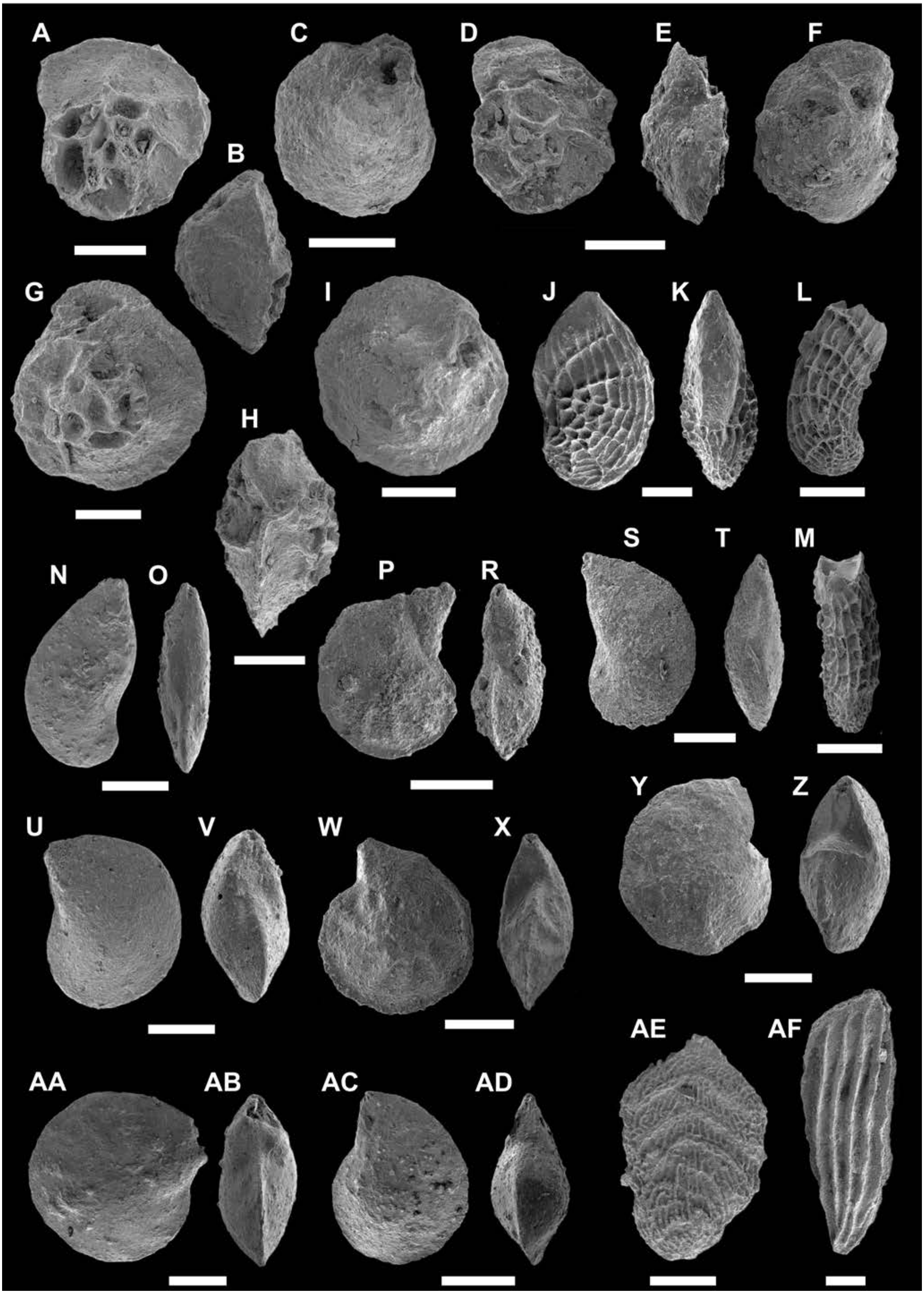
INTERPRETATION

Biostratigraphy

The biostratigraphy of the formations studied is based mainly on dinoflagellate cysts, which allow relatively precise age dating (Fig. 17). They also allow the separation of the Jurassic rocks from the surrounding Cretaceous ones. The foraminifera, mainly agglutinated species, are long-ranging species with more limited dating precision; moreover, their assemblages are commonly taxonomically impoverished (see e.g., Fig. 13).

Cretaceous dinoflagellate cysts (Fig. 9) were identified in samples from strata underlying (135.9 m) and overlying (127.9 m) the lower scale of the Szlachtowa Formation in the Jar-1 borehole (Fig. 6), and in some samples from the Malý Lipník Stream (MLp1, MLp2, MLp5, MLp6, MLp10, MLp14) and the Kamienka section (Riečka Stream: Kmn1, Kmn2). Their assemblages are commonly impoverished, making precise dating impossible, but the presence of *Palaeohystrichophora infusorioides* in most of these samples (Tabs 2, 3) indicates that their age is latest Albian–Early

Fig. 14. Agglutinated foraminifera. Scale bars in A, E, I, J, L, M, R, S = 200 μm. Scale bars in B–D, F–H, K, N, O, P, T–W = 100 μm. **A, B.** *Rhabdammina* sp.; B: detail of the open end and wall structure, sample Kmn11. **C, D.** *Hyperammina* sp.; D: detail of the wall structure with imbricated mica crystalls, sample Jar-1: 65.5 m. **E.** *Ammodiscus* sp., sample Kmn13. **F.** *Glomospira* sp., sample Kmn13. **G, H.** *Recurvoides* sp.; G: side view, H: apertural view, sample Kmn13. **I, J.** *Kutsevella* sp.; I: dorsal, J: peripheral view, sample MLp15a. **K.** *Haplophragmoides* sp., dorsal view, sample Kmn13. **L, M.** *Trochammina* aff. *eoparva* (Nagy et Johansen); L: spiral, M: umbilical view, sample Kmn13. **N, O.** *Trochammina pulchra* Ziegler; N: dorsal, O: umbilical view, sample Jar-1: 65.7 m. **P.** *Textularia haeusleri* Kaptarenko, sample Kmn13. **R, S.** *Trochammina* sp.; R: dorsal, S: umbilical view, sample Ltm1. **T.** *Verneuilinella pieninica* Tyszka et Kaminski, sample Kmn13. **U.** *Verneuilinoides* sp., sample Kmn13. **V, W.** *Verneuilina* sp.; W: towards peripheral view, sample Kmn13.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Maastrichtian (e.g., Williams *et al.*, 2004). Samples Kmn1 and Kmn2 might be slightly older. They yielded *Litosphaeridium siphoniphorum* (Late Albian–latest Cenomanian according to Williams *et al.*, 2004), but they were without *P. infusorioides*. A similar age can be suggested for poorly preserved assemblage from a depth of 127.9 m (Tab. 3).

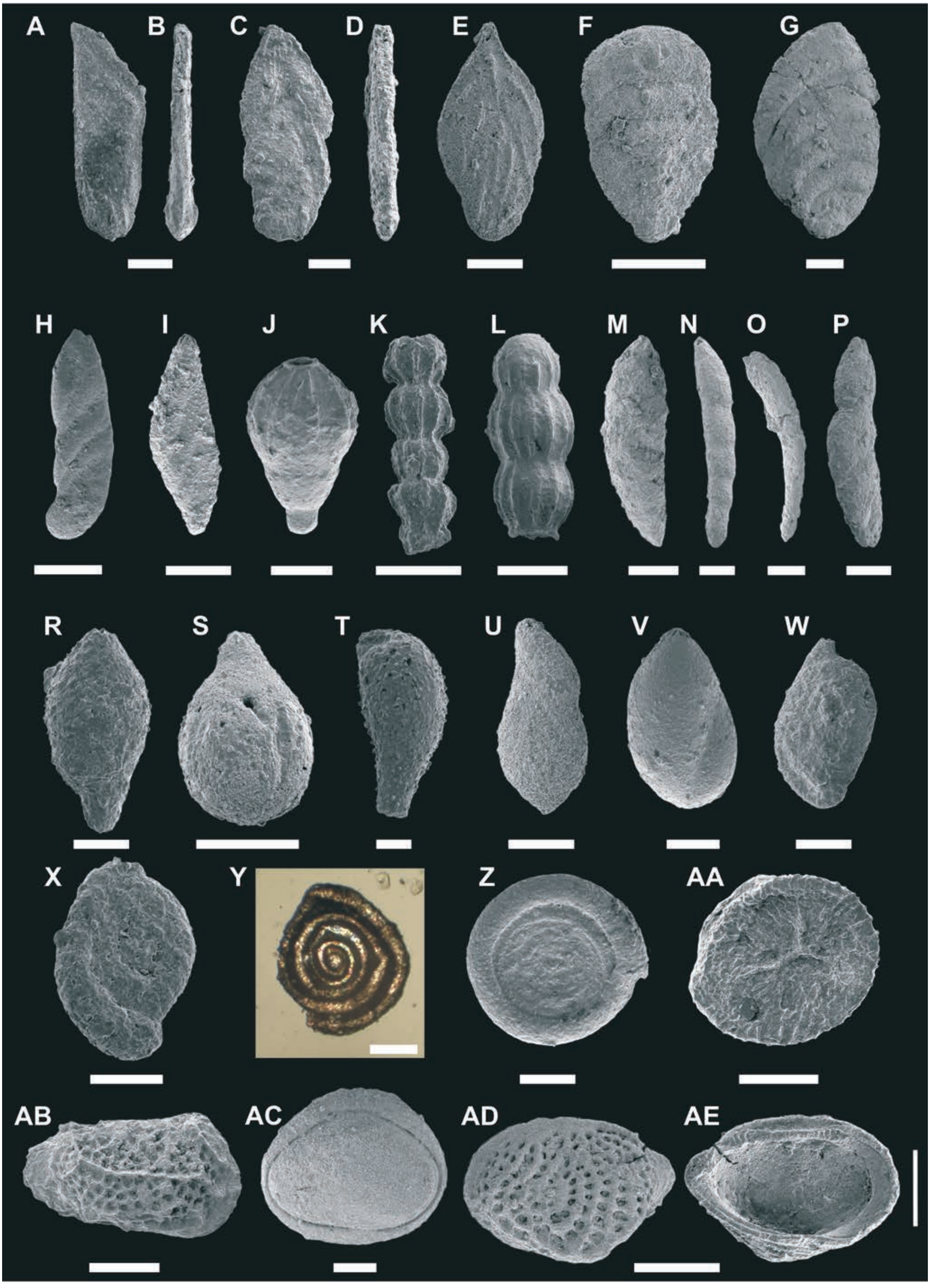
Presumably, the oldest Jurassic microfossils are those found in a single sample of the Szlachtowa Formation in the Jar-1 borehole, at a depth 61.9 m. Dinoflagellate cysts are represented by two species: *Nannoceratopsis gracilis* and *N. raunsgaardii*; both having long stratigraphical ranges, including Pliensbachian to Bajocian (e.g., Bucefalo Palliani and Riding, 1997). Foraminifera from this sample are poorly preserved, but broken specimens assigned to *Lenticulina* cf. *chicheryi* were found (Fig. 15P, R). The presence of *L. chicheryi* was the basis for distinguishing the Middle Toarcian Lenticulina chicheryi Zone (Ruget and Nicollin in Cairou and Hantzpergue, 1997). Broken specimens of this species allow only a questionable correlation of the material studied with this zone (Fig. 17A). Higher samples from this borehole contain species that appeared for the first time during the Late Toarcian (e.g., *Nannoceratopsis dictyambonis*; Tab. 3).

A younger dinoflagellate cyst assemblage in the Szlachtowa Formation occurs in the middle course of the Riečka Stream (samples Kmn4–7; site 6 in Fig. 1B; Fig. 3A, B) and in some samples from the upper scale of this unit in the Jar-1 borehole. This assemblage consists of *Nannoceratopsis* (*N. gracilis*) and *Kallosphaeridium-Dissiliodinium* specimens (commonly thin-walled, wrinkled, difficult to determine, but different than *D. lichenoides* and *D. giganteum*). Another characteristic feature is the lack of *Phallocysta elongata*, although a single specimen of this species was found in sample Kmn8, collected a few meters from sample Kmn7 (Fig. 3A), where the strata dip, indicating that both samples are from strata in stratigraphic continuity; *Valvaeodinium* cf. *koessianum sensu* Gedl (2008) occurs in sample Kmn5. A similar assemblage, composed chiefly of *Nannoceratopsis* (mainly *N. deflandrei* in this case, single *N. dictyambonis*, *N. gracilis*), was found in samples MLp7– 9 from exposures along the Malý Lipník Stream (site 3 in Fig. 1; Fig. 4E; note: in these exposures coal clasts occur: Fig. 4H). Sample MLp9 yielded a single specimen of *Valvaeodinium* cf. *koessianum sensu* Gedl (2008). Samples from the upper scale of the Szlachtowa Formation in the Jar-1 borehole generally contain *Phallocysta elongata*, but some, particularly from the uppermost part, are devoid of this species (depths: 88.2 m, 86.5 m, 80.1 m, 78.2 m, 75.2 m, 64.6 m, and 61.9 m). Three of these samples yielded *Nannoceratopsis deflandrei* (80.1 m; questionably in the case of 88.2 m and 86.5 m). A precise age for these assemblages is difficult to determine. The presence of *Nannoceratopsis deflandrei* suggests an Toarcian age (Bucefalo Palliani and Riding, 1997). The presence of *Kallosphaeridium-Dissiliodinium* specimens may indicate a Late Toarcian age, since the oldest representatives of these genera appeared for the first time during this time or later (e.g., Prauss, 1989). An early Late Toarcian age can be supported by the presence of *Nannoceratopsis dictyambonis* in sample MLp9 (first appearance during the Late Toarcian according to Bucefalo Palliani and Riding, 1997), and the lack of *Phallocysta elongata*, which appeared for the first time in northwest Europe during the latest Toarcian (Levesquei Zone; Riding, 1994). However, in a more southern Boreal-Tethyan transitional area (the Quercy Region, SW France), *P. elongata* was recorded also in middle Upper Toarcian strata (Thouarsense Zone; Bucefalo Palliani and Riding, 1997). Dinoflagellate cyst assemblages from the Kamienka section can be correlated with assemblages described from the Szlachtowa Formation, in Poland (sites: Krupianka, sample Krp0; Sztolnia, upper course, samples: Szt21, Szt26, Szt39; Grajcarek-Jarmuta; Gedl, 2008), whereas the ones from Malý Lipník resemble an assemblage described from the Trawne site, in Poland (sample Trw6; Gedl, 2008). All these Polish samples were included in the Nannoceratopsis spp. Zone, tentatively correlated with the Upper Toarcian (Gedl, 2008). Birkenmajer and Myczyński (1977) described the Early Aalenian ammonites *Leioceras opalinum* and *Leioceras* cf. *comptum* from limestone intercalations close to samples Szt26 and Szt39, but this section is highly tectonized (see e.g., Gedl, 2008, fig. 22B).

Foraminifera from the samples described above have limited stratigraphic value: they are very rare and not age-diagnostic (e.g., sample MLp9: Fig. 13) or, as in the case of the upper part of the upper scale of the Szlachtowa Formation in the Jar-1 borehole (depths: 78.2 m, 75.2 m, 64.6 m), they correspond to the Upper Toarcian–Aalenian foraminiferal Lenticulina d'orbignyi Zone. The ones from a depth of 61.9 m presumably can be correlated with the Middle Toarcian foraminiferal Lenticulina chicheryi Zone (Fig. 17).

Assemblages believed to be younger are those, which contain *Phallocysta elongata* and lack *Dissiliodinium liche-*

Fig. 15. Calcareous benthic foraminifera. Scale bars in A–I, L–O, S–AF = 200 μm: Scale bars in J, K, P, R = 100 μm. **A–C.** *Epistomina arcana* Antonova; A: dorsal, B: peripheral, C: umbilical view, sample MLp15a. **D–F.** *Epistomina semiornata* (Schwager); D: dorsal, E: peripheral, F: umbilical view, sample MLp15a. **G–I.** *Epistomina coronata* Terquem; G: dorsal, H: peripheral, I: umbilical view, sample Ltm1. **J, K.** *Lenticulina d'orbignyi* (Roemer); J: dorsal, K: peripheral view, sample Jar-1: 65.5 m. **L, M.** *Lenticulina d'orbignyi* (Roemer); L: dorsal, M: peripheral view, sample Kmn13. **N, O.** *Astacolus* sp.; N: dorsal, O: peripheral view, sample Jar-1: 65.5 m. **P, R.** *Lenticulina* cf. *chicheryi* (Payard); P: dorsal, R: peripheral view, sample Jar-1: 61.9 m. **S, T.** *Lenticulina varians* (Bornemann); S: dorsal, T: peripheral view, sample Ltm1. **U, V.** *Lenticulina muensteri* (Roemer); U: dorsal, V: peripheral view, sample Ltm1. **W, X.** *Lenticulina quenstedti* Gümbel; W: dorsal, X: peripheral view, sample Ltm1. **Y, Z.** *Lenticulina polygonata* (Franke); Y: dorsal, Z: peripheral view, sample Jar-1: 85.7 m. **AA, AB.** *Lenticulina* cf. *toarcense* (Payard); AA: dorsal, AB: peripheral view, sample Jar-1: 65.5m. **AC, AD.** *Lenticulina muensteri* (Roemer); AC: dorsal, AD: peripheral view, sample Jar-1: 65.5 m. **AE.** *Falsopalmula tenuistriata* (Franke), sample MLp15a. **AF.** *Citharina macilenta* (Terquem), sample MLp15a.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noides and *D. giganteum* (Fig. 17). Their host rocks can be correlated with the uppermost Toarcian Phallocysta elongata Zone of Gedl (2008). Presumably, they can be also correlated with the younger Nannoceratopsis evae Zone, although *N. evae*, the index species, is very rare in the material studied (Tab. 2). Such assemblages occur in the Szlachtowa Formation in the lower part of its upper scale in the Jar-1 borehole (depths: 93.3 m, 92.4 m, 91.05 m, 87.15 m, 85.7 m, 85.2 m, 84.9 m, 83.4 m, 82.5 m, 81.5 m, 68.5 m, 65.5 m; Tab. 3). The assemblage from sample MLp16 also contains *P. elongata* and lacks younger species (Tab. 2), but this sample was collected from the same outcrop where sample MLp15, remaining in stratigraphic continuity was collected (Fig. 1B: site 4; Fig. 4I); the latter sample yielded *Nannoceratopsis evae*. Also sample Kmn8 may represent the same assemblage (see two paragraphs above). Similar assemblages occur in the Skrzypny Shale Formation exposed in the Metiská Quarry (samples Kmn13–15; Fig. 1B: site 7; Fig. 3D). In sample Kmn13 (Skrzypny Shale Formation from the Metiská Quarry), a single, very poorly preserved specimen was found, questionably assigned to *Dissiliodinium lichenoides* (Tab. 2). The age of these assemblages can be estimated as latest Toarcian and correlated with the uppermost Toarcian Phallocysta elongata Zone of Gedl (2008). However, an Aalenian, particularly an Early–early Late Aalenian age, cannot be excluded, owing to the rarity of *N. evae*, an index species of the Nannoceratopsis evae Zone of Gedl (2008). Also the presence of the questionable *D. lichenoides* in Kmn13 may indicate a Late Aalenian age; the presence of *Lenticulina d'orbignyi* (Roemer) in the same sample indicates a Late Toarcian–Aalenian age.

The occurrence of *Nannoceratopsis evae* allows dating its host rocks as Lower–lower Upper Aalenian (the first appearance of this species is dated at the base of Aalenian; opalinum Zone; Prauss, 1989). In the material studied, this species occurs in the Skrzypny Shale Formation exposed along the upper course of the Malý Lipník Stream (samples MLp3 and MLp4; Fig. 1B: site 2; Fig. 4A, C), and in the Szlachtowa Formation exposed in the lower course of that stream (sample MLp15; Fig. 1B: site 4; Fig. 4I). Samples with *N. evae* can be thus correlated with the Lower–lower Upper Aalenian Nannoceratopsis evae Zone of Gedl (2008). In the case of the Malý Lipník samples, such an age is confirmed by the occurrence of the Aalenian ammonite *Brasilia* sp. (Fig. 4K; Gedl *et al.*, 2012). The presence of *Dissiliodinium* cf. *lichenoides* and the questionably determined *D. lichenoides* in the Skrzypny Shale Formation of the Malý Lipník Stream and the Metiská Quarry (MLp3, Kmn13, respectively) may indicate a Late Aalenian age for part of this unit (Fig. 17).

Foraminifera from the samples, correlated with the Phallocysta elongata and Nannoceratopsis evae zones, as is the case with the older Nannoceratopsis spp. Zone, represent calcareous assemblages belonging to the Upper Toarcian–Aalenian foraminiferal Lenticulina d'orbignyi Zone (Fig. 17).

The presence of *Dissiliodinium lichenoides*, commonly associated with *D.* cf. *lichenoides*, indicates a Late Aalenian age, since the stratigraphic range of this species is limited to the latest Middle Aalenian and the earliest Early Bajocian (Feist-Burkhardt, 1990: as ?*Dissiliodinium* sp. A; Feist-Burkhardt and Monteil, 2001). The strata in question that contain this species, also devoid of *D. giganteum*, can be correlated with the Upper Aalenian Dissiliodinium lichenoides Zone of Gedl (2008). They are represented in the material studied by the samples from the Szlachtowa Formation exposed in the Malý Lipník Stream (MLp11, MLp13, and MLp17; Fig. 1B: sites 3 and 4) and from the Jar-1 borehole (lower scale: 129.70 m; upper scale: 89.65 m, 88.20 m, 86.50 m). Two specimens of *D.* cf. *lichenoides* were found in a sample MLp3 from the Skrzypny Shale Formation exposed in lower course of the Malý Lipník Stream (Fig. 1B: site 2) indicating that a part of this unit may represent the Upper Aalenian (the neighbouring sample MLp4 was correlated with the older Nannoceratopsis evae Zone; see above). *Nannoceratopsis dictyambonis* becomes absent or rare in samples attributed to this zone.

The youngest dinoflagellate cyst assemblages found in the samples studied indicate Early Bajocian (assemblage with *Dissiliodinium giganteum*), and Late Bajocian–Middle Bathonian (assemblage with *Ctenidodinium*) ages (Fig. 17). The assemblages with *D. giganteum* were found in the lower part of the Szlachtowa Formation in the Jar-1 borehole (samples from interval 130–135 m; Tab. 3) and in exposures in the Malý Lipník (MLp12) and Riečka Streams (Kmn3, Kmn9–12). The presence of the index species shows that its host strata can be correlated with the Lower Bajocian ammonite discites-sauzei zones (Feist-Burkhardt and Monteil, 2001), and with the Dissiliodinium giganteum Zone of Gedl (2008). However, three samples from the above mentioned interval of the Jar-1 borehole (132.4 m, 131.8 m, 130.6 m) yielded also *Ctenidodinium cornigerum*.

Fig. 16. Calcareous benthic foraminifera and ostracods. Scale bars in G–I, K, M–P, AA–AE = 200 μm. Scale bars in A–F, J, L, R–Z = 100 μm. **A, B.** *Citharina colliezi* (Terquem); A: dorsal, B: peripheral view, sample Ltm1. **C, D.** *Falsopalmula deslongchampsi* (Terquem); C: dorsal, D: peripheral view, sample MLp15b. **E.** *Falsopalmula* sp., sample Kmn13. **F.** *Ichtyolaria* sp., sample Kmn13. **G.** *Planularia cordiformis* (Terquem); sample Kmn13. **H.** *Planularia protracta* (Bornemann), sample Jar-1: 65.7 m. **I.** *Planularia* sp., sample Jar-1: 61.9 m. **J.** *Nodosaria* cf. *pulchra* (Franke), sample Jar-1: 65.5 m. **K, L.** *Nodosaria fontinensis* Terquem; K: sample MLp15a, L: sample Jar-1: 85.7 m. **M.** *Dentalina* sp., sample MLp15a. **N, O.** *Dentalina pseudocommunis* (Franke), sample MLp15b. **P.** *Dentalina vetusta* d'Orbigny, sample MLp15a. **R.** *Pseudonodosaria vulgata* (Bornemann), sample MLp15a. **S.** *Oolina* sp., sample Kmn13. **T.** *Ramulina* sp., sample Kmn13. **U.** *Eoguttulina bilocularis* (Terquem), sample Kmn13. **V.** *Eoguttulina* sp., sample Jar-1: 65.5 m. **W.** *Spirophthalmidium* sp. 1, sample Ltm1. **X.** *Spirophthalmidium* sp. 2, sample Kmn13. **Y.** *Ophthalmidium* sp., sample Jar-1: 78.2 m. **Z.** *Spirillina infima* Strickland, sample Jar-1: 65.5 m. **AA.** Fern spore, sample MLp9. **AB.** *Eucytherura transversiplicata* (Bate et Coleman), sample Kmn13. **AC.** *Ogmoconcha* sp., sample Ltm1. **AD, AE.** *Kinkelinella* sp.; AD: external, AE: internal view.

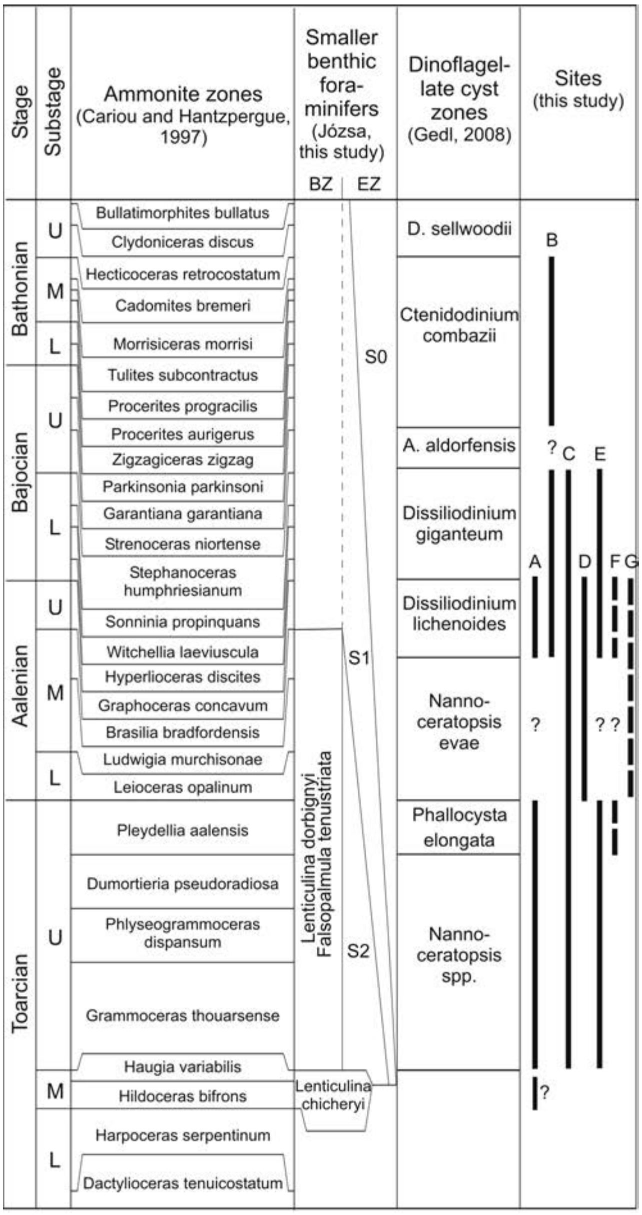

Fig. 17. Jurassic microbiostratigraphy of the sites studied. Dotted lines are for sites questionably dated, owing to fossil scarcity or poor preservation. **A.** Szlachtowa Formation of the Jar-1 borehole, upper scale (61.9–93.3 m). **B.** Szlachtowa Formation of the Jar-1 borehole, lower scale (135.2–128.5 m). **C.** Szlachtowa Formation of the Malý Lipník section (MLp7–9, MLp11–13, MLp15–17). **D.** Skrzypny Shale Formation of the Malý Lipník section (MLp3, MLp4). **E.** Szlachtowa Formation of the Kamienka section, Riečka Stream (Kmn3–12). **F.** Skrzypny Shale Formation of the Kamienka section, Metiská Quarry (Kmn13–15). **G.** Skrzypny Shale Formation at Litmanová (Veľký Lipník Stream, Ltm1, Ltm2). BZ – biozones, EZ – ecozones.

The last mentioned species is known from younger strata – Bathonian of British Isles (Riding *et al.*, 1991; Riding and Thomas, 1992) and Late Bajocian–Early Bathonian of Western France (Feist-Burkhardt and Monteil, 1997). Co-occurrence of Early Bajocian (*D. giganteum*) and Late Bajocian–Bathonian (*C. cornigerum*) species may indicate either reworking of the former or earlier appearance of the latter species in the Pieniny basins. But *C. cornigerum* has never been described so far from the Lower Bajocian strata of the Pieniny Klippen Belt; it was described from strata dated as Upper Bajocian–Bathonian (Gedl, 2008).

The above mentioned deposits yielded only a low-diversity agglutinated foraminifera assemblage (S0a and S0b ecozones). These Bajocian assemblages are associated with common to abundant sponge spicules that have no precise stratigraphical significance.

The *Ctenidodinium*-assemblage, found in a single sample of the Szlachtowa Formation from the Jar-1 borehole (128.5 m), contains the species *Ctenidodinium combazii*, *Nannoceratopsis pellucida*, *Chytroeisphaeridia chytroeides*, all appearing for the first time during the Late Bajocian (e.g., Prauss, 1989; Bucefalo Palliani and Riding, 1997). Their presence allows the correlation of this sample with the Upper Bajocian–Middle Bathonian Ctenidodinium combazii Zone of Gedl (2008). In the Polish part of the Pieniny Klippen Belt, this zone was recognized in two samples of the Szlachtowa Formation (Szt39A, Szt40), collected from a highly tectonized exposure of this unit in the upper course of the Sztolnia Stream (Gedl, 2008, fig. 22B), and it is widespread in the Opaleniec Formation.

The lack of dinoflagellate cysts in the Skrzypny Shale Formation exposed along the Veľký Lipník Stream at Litmanová (Fig. 1B, site 8) does not allow dating of it. Foraminifera found in the Litmanová samples are not of much biostratigraphical value. The composition of the foraminiferal association is different from that of other localities. However, the characteristic common occurrence of *Epistomina arcana* Antonova, *Epistomina coronata* Terquem and *Epistomina semiornata* (Schwager) might indicate an age younger than mid Aalenian (with respect to Tyszka, 1999; Fig. 17). This site is known for its well preserved pyritised ammonite fauna, ranging from mid Aalenian to Early Bajocian (Scheibner, 1964a).

Palaeoecology

The microfauna studied shows variations in composition in both the Skrzypny Shale and Szlachtowa formations, reflecting various palaeoenvironmental settings. One of the bathymetrically shallower types of assemblage occurs in the Skrzypny Shale Formation exposed at Litmanová along the Veľký Lipník stream. This assemblage consists almost exclusively of calcareous benthic foraminifera and ostracods; epifaunal morphogroups are the most frequent there. These black, occasionally organodetritic, marls yielded assemblages, composed of predominantly epifaunal taxa, mainly the *Epistomina* (morphogroup C1), associated frequently with small ophthalmids (C4) and scarce *Spirillina* (C3). No ornamented *Lenticulina* was noted at this site. The agglutinated foraminifera represent only small part of the assemblage. Mostly epifaunal morphogroups (A3/A4, C1–C4) in the samples indicate well oxygenated conditions (Ltm1; Fig. 18). The same strata examined for palynology showed an exceptional palynofacies, composed entirely of black phytoclasts and devoid of dinoflagellate cysts. The lack of the latter could be explained with reference to highly oxic bottom conditions indicated by an interpretation of the

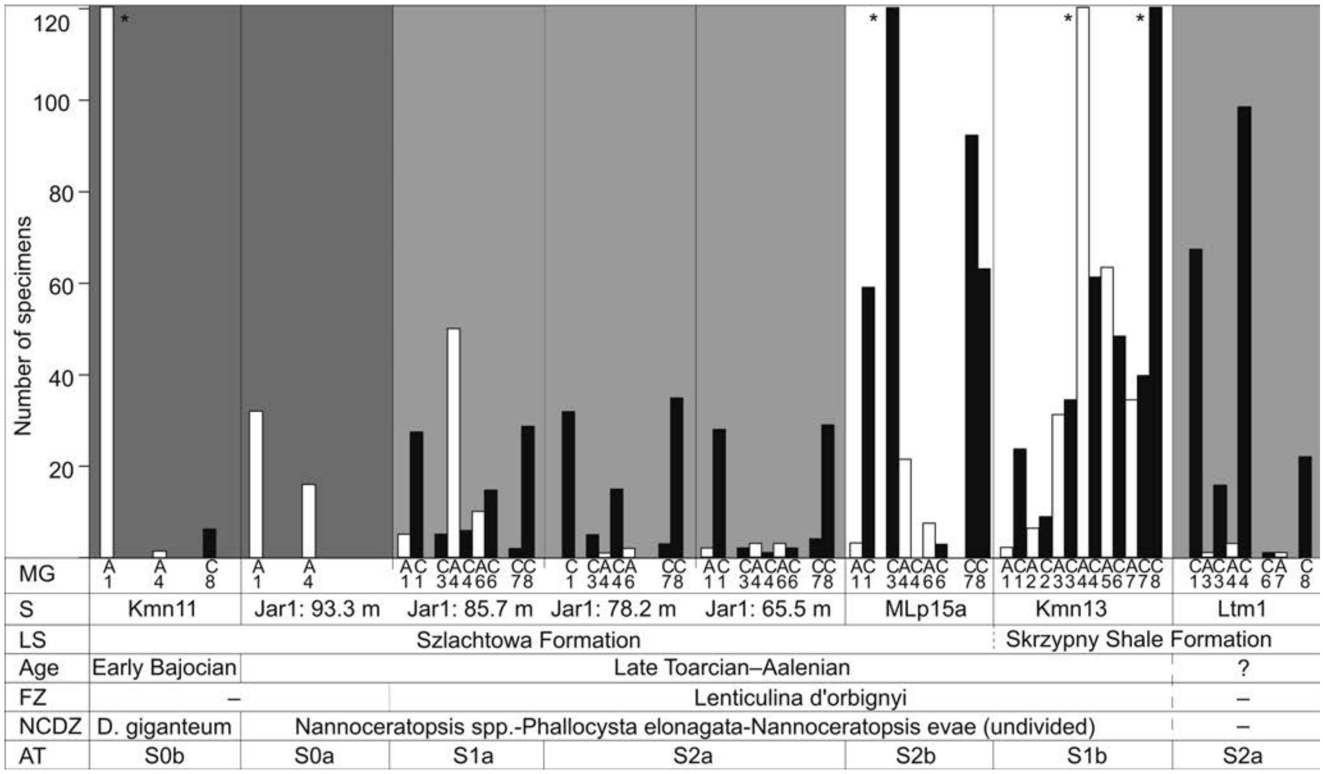

Fig. 18. Distribution of foraminiferal morphogroups in selected samples vs various attributes. MG – morphogroup; S – sample; LS – lithostratigraphy; FZ – foraminiferal zonation; NCDZ – non-calcareous dinoflagellate cyst zonation; EZ – ecozone; asterisks indicate counts exceeding 120 specimens.

foraminifera. Such a palynofacies of dark fine-clastic marine Jurassic strata of the Pieniny Klippen Belt is exceptional (Gedl, 2008). The lack of dinoflagellate cysts can be explained by the post-depositional history, which involves considerable tectonic rearrangement of the strata in question, leading to complete palynomorph degradation.

A different foraminifera assemblage was found in the Skrzypny Shale Formation in the Metiská Quarry, near Kamienka, where, in contrast to the previous site, an increase in agglutinated foraminifera was noted. Common infaunal morphotypes of both agglutinated and calcareous forms are present (the most common morphogroups are represented by *Kutsevella* A6, *Dentalina*, *Nodosaria*, *Ichtyolaria*, *Falsopalmula* and *Eoguttulina* C5–C7). Epifaunal and shallow infaunal agglutinated foraminifera are dominated by *Trochammina,* while *Glomospira* and *Ammodiscus* are rather scarce. A maximum occurrence of the deep infaunal agglutinated morphogroup A7 of *Textularia*, *Verneuilinella*, *Verneuilina* and *Verneuilinoides* was noted in a single sample from the Metiská quarry (Kmn13; Fig. 18). Also a significant increase in *Recurvoides* was observed (morphogroup A5). A diverse deep infauna indicates poorly oxygenated conditions. The conditions evidenced by these strata seem to be less oxic by comparison with the Litmanová ones, which is in agreement with the presence of dinoflagellate cysts preserved in a less oxidizing environment. Dinoflagellate cysts present in the Metiská Quarry samples (Kmn13–15) point to a marine environment.

The Szlachtowa Formation yielded slightly different foraminifera assemblages in quantitative and qualitative terms. Most of the samples studied from the Malý Lipník Stream and the Jar-1 borehole contain mostly agglutinated forms, though low in abundance. Their assemblages characterise strict epifaunal morphogroups A1 (*Rhabdammina*/*Hyperammina*), A4 (*Trochammina*) and occasional A3 (*Glomospira*). Other morphogroups that share an infaunal mode of life, e.g., *Conotrochammina* (A5), *Recurvoides*, *Kutsevella* (A6) or *Reophax* (A8), are very rare or absent, especially where calcareous benthic foraminifera are absent as well. Calcareous benthic foraminifera from the Szlachtowa Formation in the upper slice of the Jar-1 borehole, if present, contain scarce epifaunal *Epistomina* (C1), *Spirillina* (C3), *Falsopalmula* (C6), *Dentalina* (C7), *Lenticulina* (C8), and ophthalmids (C4). Only sample MLp15a from the Szlachtowa Formation exposed in the upper course of the Malý Lipník Stream yielded assemblage very similar to the one from the Skrzypny Shale Formation in the Metiská Quarry (Kmn13).

The foraminiferal assemblages from the localities studied from both formations show different characteristics and can be subdivided with respect to abundance, ecologic structuring and diversity into several ecozones (Fig. 19):

S0a. Low-abundance and low-diversity agglutinated ecozone: with exclusive presence of agglutinated epifaunal morphogroups (A1, A4) and absent infauna. This assemblage was noted in the Szlachtowa Formation of the Jar-1 borehole (93.3 m, 128.2 m) and in samples from the lower course of the Malý Lipník Stream (MLp9, MLp12).

S0b. High-abundance and low-diversity agglutinated-predominant ecozone: with almost exclusive, sometimes su-

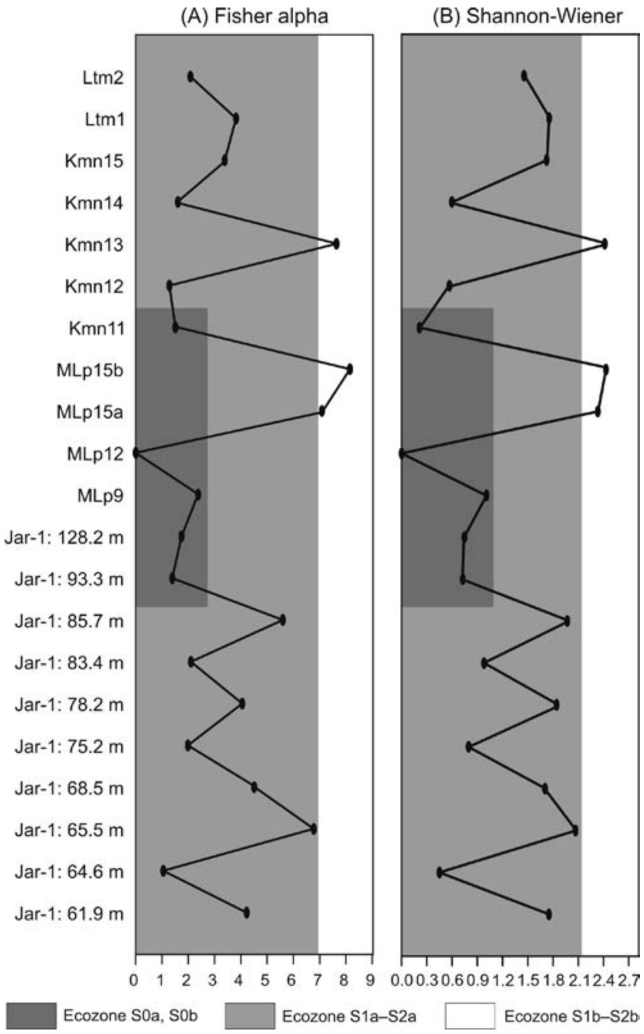

Fig. 19. Values of the Fisher alpha (A) and the Shannon-Wiener (B) indexes for the assemblages studied with ecozones marked.

perabundant epifaunal morphogroup A1. This assemblage was found only in the Szlachtowa Formation of the Kamienka section (Kmn11).

S1a. Low-abundance, low-diversity ecozone with mixed agglutinated and calcareous foraminifera: with dominance of grazing herbivorous epifaunal morphogroups (C1, A4 less C3 and C4), common shallow infaunal morphogroups (A6, C6) and rare deep calcareous infaunal morphogroups (C7). This assemblage was noted in the Szlachtowa Formation of the Jar-1 borehole (85.7 m) and in the Skrzypny Shale Formation, exposed in the Metiská Quarry (Kmn15).

S1b. High-abundance, high-diversity ecozone with mixed agglutinated and calcareous foraminifera, with grazing herbivorous morphogroups (common C1, A3, C3, and abundant A4 and C4). Infaunal morphogroups from shallow to deep infauna are common to abundant (C5–7, A5–7). This ecozone was noted only in a single sample from the Skrzypny Shale Formation in the Metiská Quarry (Kmn13).

S2a. Low–moderate-abundance, low-diversity calcareous ecozone: with the C1 and C8 morphogroups dominant (Metiská Quarry: Kmn14). An overall increase in the C4 morphogroup was also noted in the Skrzypny Shale Formation at Litmanová (Velký Lipník Stream: Ltm1, Ltm2). The Szlachtowa Formation from the upper part of the Jar-1 borehole (61.9–83.4 m) yielded a similar assemblage, except for a drop in the C4 morphogroup and the presence of scarce ornamented *Lenticulina d'orbignyi* (Roemer).

S2b. High-abundance, high-diversity, predominantly calcareous ecozone: with the C3 morphogroup dominant. Morphogroup C1 is also notably higher than in other samples. Compared to other samples, the C4 morphogroup is scarce. The most abundant C7 morphogroup was observed in all samples. This assemblage was found in the Szlachtowa Formation from the upper course of the Malý Lipník Stream (MLp15).

Some of the foraminiferal assemblages reflect oxygen-depleted conditions in bottom-water and sediment. However, some variations of their composition show that the oxygen level in bottom waters fluctuated during the deposition of the sediments. The conditions closest to anoxic are the ones evidenced by the Szlachtowa and Skrzypny Shale formations with increased infaunal morphogroups of agglutinated foraminifera (S1b, S2b; sample Kmn13 from the Metiská Quarry, sample MLp15 from the upper course of Malý Lipník Stream). The remaining assemblages of the Szlachtowa Formation and the ones from the Skrzypny Shale Formation indicate that in case of both formations they were deposited for the most part in a bottom environment with slightly better oxidization (low oxic-dysoxic). The palynofacies of both units show a high ratio of land-derived organic particles, partly responsible for the low oxygen content in the bottom waters, but their character, and especially their influx rate can explain differences between the microfaunal assemblages. The highest ratio of cuticles, which presumably reflects a high rate of terrestrial input into the basin, was generally noted in the Szlachtowa Formation, in samples which yielded foraminifera attributed to the morphogroups S0a and S0b. Some other samples studied from this unit are characterized by a higher proportion of black, opaque phytoclasts and a generally lower content of palynological organic matter (upper scale of the Szlachtowa Formation in the Jar-1 borehole), which may reflect a lower sedimentation rate and/or a lower ratio of terrestrial input into the basin. This is a good example of the relation of palynofacies to foraminifera: the basal sample from this interval (93.3 m) contains the highest proportion of cuticles, which corresponds to the S0a foraminiferal morphogroup. Higher in the interval, the lower proportion of cuticles, corresponds with changes in the morphogroups to S1a (85.7 m) and S2a (83.4–61.9 m interval).

However, some samples (e.g., MLp15), show a relatively high proportion of cuticles, but their foraminiferal assemblages represent the S2b morphogroup; the other, like the one from a depth of 128.2 m, contains black phytoclasts, but its foraminiferal assemblage is attributed to the S0a morphogroup.

Sporomorphs and black to dark brown phytoclasts in the Skrzypny Shale Formation point to a slower sedimentation rate, whereas frequent cuticles in the Szlachtowa Formation reflect presumably a higher terrestrial influx rate. The deposition of large amounts of land elements on the sea floor causing, the oxygen-depleted conditions, due to decay processes, combined with a generally higher sedimentation rate in the case of the Szlachtowa Formation, made bottom living conditions less favourable for the microfauna.

DISCUSSION

Biostratigraphy. Results previously obtained showed that the oldest Szlachtowa Formation represents the Upper Toarcian (Gedl, 2008; in bimodal division, the Lower Toarcian includes the tenuicostatum/polymorphum–bifrons chronozones, the Upper Toarcian – variabilis/gradata–aalensis; see e.g., Page, 2003). The present study indicates an older, Middle Toarcian age (bifrons–variablilis of the tripartite division; e.g., Hardenbol *et al.*, 1998) of the Szlachtowa Formation from the Jar-1 borehole sample from a depth of 61.9 m (questionable owing to the poor preservation of the index species *Lenticulina* cf. *chicheryi)*. This age interpretation is supported by the impoverished dinoflagellate cyst assemblage, lacking species that appeared prior to the latest Toarcian.

A detailed subdivision of the Upper Toarcian–Lower Aalenian on the basis of foraminifera is difficult, as the assemblages are similar with only gradual changes of some characteristic Middle Jurassic taxa (Cannales and Henriques, 2008). *Epistomina arcana* (Antonova), has proven to be of little stratigraphic value, as it was found in an assemblage together with *Lenticulina d'orbignyi* (Roemer) along with other calcareous foraminifera at most localities (Metiská Quarry, upper scale of the Jar-1 borehole, upper course of the Malý Lipník Stream). The Bajocian Epistomina arcana Zone was recognized in the Skrzypny Shale Formation at Litmanová (Veľký Lipník Stream) by Tyszka (1999). However, ammonites from the same outcrop at Litmanová mostly support a Middle–Late Aalenian age (Scheibner, 1964a). No index foraminifera were found, although the lack of ornamented taxa, such as *Citharina* spp., *Lenticulina d'orbignyi* (Roemer), and *Falsopalmula tenuistriata* Franke, might have been caused by a palaeoecological factor.

Dinoflagellate cysts allow more precise dating of the deposits studied. The results support a Late Toarcian–Aalenian to Bajocian–Bathonian age for the Szlachtowa Formation, and generally an Aalenian age for the Skrzypny Shale Formation. Both lithostratigraphic units occurring in the study area are highly tectonized and frequently embedded in mid–Upper Cretaceous strata.

The dinoflagellate cyst assemblages studied can be correlated with the zonal scheme, proposed by Gedl (2008) for the neighbouring Polish part of the Pieniny Klippen Belt. The oldest Nannoceratopsis spp. and Phallocysta elongata zones were distinguished in the Szlachtowa Formation in the study area. Their Late Toarcian age was assigned by Gedl (2008) tentatively, without correlation with ammonite data. Correlation with foraminiferal data (this study) does not allow a precise interpretation, since these deposits belong to the long-ranging Upper Toarcian–Aalenian foraminiferal Lenticulina d'orbignyi Zone. The age of the younger, Nannoceratopsis evae Zone, correlated by Gedl (2008) with the Aalenian at the base of the range of the index species, is supported now by the discovery of an Aalenian ammonite *Brasilia* in an exposure of the Szlachtowa Formation in the Malý Lipník Stream. The youngest dinoflagellate cyst assemblages from the Szlachtowa Formation – Early and Late Bajocian–Bathonian (with *Dissiliodinium giganteum* and with *Ctenidodinium*, respectively) allow their correlation with the Dissiliodinium giganteum and Ctenidodinium combazii zones, established in the Polish part of the Pieniny Klippen Belt. This shows that this lithostratigraphic unit in the Slovak part of the Pieniny Klippen Belt has a similar range as in Poland. This also does not support the interpretation, based on dinoflagellate cysts, of Barski *et al.* (2012), who suggested only a Bajocian age for the Szlachtowa Formation. The scarcity of ammonites in this lithostratigraphic unit, despite its wide occurrence (see e.g., Birkenmajer, 1977), does not help to solve this problem. Ammonites have been found in the Szlachtowa Formation so far in Poland (Early Aalenian *Leioceras opalinum* and *Leioceras* cf. *comptum*; Birkenmajer and Myczyński, 1977) and in Slovakia (Aalenian *Brasilia*; Gedl *et al.*, 2012).

Dinoflagellate cysts from two localities of the Skrzypny Shale Formation show an Aalenian, presumably Late Aalenian age (based on the presence of *Dissiliodinium* cf. *lichenoides*) in the Malý Lipník Stream, and in the Metiská Quarry. They can be correlated with the Aalenian Nannoceratopsis evae Zone and the Upper Aalenian Dissiliodinium lichenoides Zone of Gedl (2008). Such an interpretation confirms the results of macrofaunal studies of ammonites in this lithostratigraphic unit, which are Middle Aalenian–earliest Bajocian (e.g., Birkenmajer, 1963; Scheibner, 1964a, b, 1968; Myczyński, 1973, 2004).

Foraminifera palaeobathymetry. The dark sediments were deposited in two different Middle Jurassic basin sectors: the Skrzypny Shale Formation studied was assigned by previous studies to the generally shallow Niedzica and/or Czertezik succession (Wierzbowski *et al.*, 2004), whereas the siliciclastic flysch and flyschoid sediments of the Szlachtowa Formation were deposited in the deeper Magura Basin (Fig. 2; Birkenmajer 1977). The results show that the samples from the Skrzypny Shale Formation yielded foraminifera assemblages, typical for a rather shallow bathymetry. The ones from the Szlachtowa Formation can be compared with deeper palaeobathymetric domains.

Tyszka (1994) distinguished two main foraminiferal ecozones in the Upper Aalenian–Lower Bajocian of the Pieniny Klippen Belt related to the palaeobathymetry. Tyszka (1994) differentiated between shallow settings of the elevated Czorsztyn Ridge and deeper, basinal parts of the Branisko palaeobathymetric domain (see Fig. 2). The composition of the assemblages from the Skrzypny Shale Formation from the Metiská Quarry is similar to the ecozone S1 of Tyszka (1994) described from the Czorstyn and Niedzica palaeobathymetric zones, whereas the Litmanová assemblages are somewhat similar to ecozone S2 of the Niedzica palaeobathymetric zone (see Fig. 2). The agglutinated foraminifera from the Szlachtowa Formation might be correlated with the deepest part of the sedimentary area of the Pieniny Klippen Belt basin, while the calcareous assemblages show similarities to shallower palaeobathymetric zones. However, none of the calcareous or mixed assemblages were dated as Bajocian. Bajocian facies are found almost exclusively as agglutinated ecozones (ecozones S0a, S0b). This might reflect different conditions between the Magura and klippen sedimentation areas, as suggested by Birkenmajer and Gedl (2008), Gedl (2008) and Barski *et al.* (2012).

Foraminifera palaeoecology. Foraminifera were first reported from the Skrzypny Shale Formation (former "Murchisonae shales") by Scheibnerová (1968) and attributed to a stagnant, oxygen-deficient environment. Tyszka (1994) suggested a more complex distribution model of the microfossils in this unit. Tyszka and Kaminski (1995) suggested that foraminiferal distribution is controlled by oxygen content *vs*. nutrient influx ratio. They described a low-abundance assemblage with *Trochammina* aff. *eoparva*, which can be found in the lower part of the Skrzypny Shale Formation and is similar also to the observed assemblages presented in this study from the Szlachtowa Formation (ecozones S0a, S0b, S1a). The younger *Rhabdammina* assemblage, from the Skrzypny Shale Formation of the Branisko paleobathymetric zone, Kapuśnica locality (Tyszka and Kaminski 1995), was noted also in the Szlachtowa Formation exposed in the Kamienka section along the Riečka Stream (S0b). The *Verneuilinella pieninica-Trochammina globoconica* assemblage of Tyszka and Kaminski (1995) was not observed in the material studied. The *Rhabdammina-Trochammina-Ammobaculites* assemblage, described in the upper part of the Skrzypny Shale Formation of the Niedzica Succession by Tyszka and Kaminski (1995), is closest to the samples from the Metiská Quarry (S1a, S1b). However, these samples are rather poor on *Rhabdammina* and ostracods, and *Epistomina* is not dominant there. Foraminifera from the Litmanová – Veľký Lipník Stream show a resemblance with this assemblage as well and only come with scarce epifaunal agglutinated foraminifera and lack infaunal agglutinated and calcareous foraminifera. As compared above, the assemblages show slight differences, mostly regarding the Szlachtowa Formation, but are closest to the assemblages of the Branisko palaeobathymetric zone of Tyszka and Kaminski (1995). Similarities can also be found in the Skrzypny Shale Formation as well, assuming that the sedimentation of this formation in this area took place in the Niedzica/Czertezik palaeobathymetric domain. The role of oxygen content in both modern and fossil environments, as illustrated by various studies (e.g., Bernhard, 1986; Kaiho, 1994; Kaminski *et al.*, 1995), shows that a large proportion of epifauna means well-oxygenated conditions, in contrast to a large proportion of infauna, which means poorly oxygenated conditions. A similar situation is noted in both the Skrzypny Shale and Slachtowa formations. This is supported by the abundance of the A1 morphogroup, which preffers higher rates of dissolved oxygen content and lower rates of carbon flux (Tyszka, 1994). The dominant A1 morphogroup is observed only in ecozones S0a and S0b. An opposite situation appears to be in ecozones S1b and S2b, where the increased rate of infaunal morphogroups indicates low oxic conditions in an eutrophic environment. The A1 morphogroup is insignificant also in the low-abundance ecozones S1a and S2a. However, they are noteworthy for the presence of other epifaunal morphogroups also indicating higher levels of oxygen content.

The presence of abundant *Recurvoides* was noted in the Skrzypny Shale Formation from the Metiská Quarry. Tyszka and Kaminski (1995) reported this genus only as rare in the oxygen-depleted facies of the Czorstyn Succession. The rest of the samples show mostly the absence or very low abundance of the entire A5 morphogroup. The spherical test shape of *Recurvoides* is mostly associated with an epifaunal mode of life (e.g., Cetean *et al.*, 2011). The distribution of calcareous foraminifera morphogroups in Kmn13 shows a gradual decrease in quantity from superabundant epifaunal to common deep infaunal morphogroups (the C8 morphogroup excluded) and a similar trend is shown, if *Recurvoides* is considered as epifaunal to shallow infaunal, instead of strictly epifaunal (Fig. 18; Kmn13).

Although *Lenticulina* is epifaunal in modern environments (Corliss and Chen, 1988; Murray, 1991), its abundance values correlate with a decrease in the C7 morphogroup, indicating that *Lenticulina* shared its environment with the infaunal morphotypes, as suggested by Tyszka (1994), but preferring a more oxic environment (Canales and Henriques, 2008). The role of dissolution of calcareous foraminifera in a low-pH environment, plays a minor role in mixed assemblages, as other less resistant calcareous foraminifera are present (e.g., *Epistomina*, as documented by Williamson and Stam, 1988, has an aragonite test).

In the high-abundance assemblages, the dominance of small epifaunal species of morphogroup C4 in the Skrzypny Shale Formation is apparent, whereas C3 is more abundant in the Szlachtowa Formation. The increased presence of C4 in the Niedzica Succession might be linked to the edge effect (Thompson *et al.*, 1985), which causes the appearance of high bacterial production, the main nutrition source for mainly infaunal morphogroups of agglutinated foraminifera, as observed in the Metiská Quarry.

According to observations of Tyszka and Kaminski (1995), dominant *Trochammina* correlates with a high flux of land-derived higher-plant remains. These might have provided a nutrition source for these grazing herbivores, although this is not an easily metabolizable food source for foraminifera. Very high abundances of the same taxon were observed in the Skrzypny Shale Formation with abundant plant debris present in the residue (Kmn13).

CONCLUSIONS

1. The dark marine strata of the Pieniny Klippen Belt, exposed between Jarabina and Litmanová (Slovakia), yielded variable dinoflagelate cyst and foraminiferal assemblages. Over 50 foraminifera and 20 dinoflagellate cyst species were found in this study.

2. The Jurassic strata in the study area are highly tectonized; they are commonly imbricated with Cretaceous strata. Dinoflagellate cysts allow separation of them.

3. The age of the dark marine Jurassic strata in the study area is Middle Toarcian?–Aalenian to Bajocian–Bathonian. Questionably a Middle Toarcian age of a part of the Szlachtowa Formation is based on poorly preserved specimens of *Lenticulina* cf. *chicheryi*, associated with an impoverished dinoflagellate cyst assemblage. The younger dinoflagellate

cysts from this unit show various ages, ranging from Late Toarcian?–Aalenian to at least Late Bajocian. Corresponding strata yielded foraminiferal assemblages correlated with the Upper Toarcian–Aalenian foraminiferal Lenticulina d'orbignyi Zone. Most of the low-abundance wholly or mostly agglutinated assemblages are dated by means of organic-walled dinoflagellates as Bajocian. The combined facies of the Skrzypny Shale Formation and partly of the Szlachtowa Formation contain more diversified microfaunal assemblages, corresponding to the foraminiferal Lenticulina d'orbignyi Zone, also dated by the dinoflagellate cyst assemblages and ammonites as Aalenian.

4. A comparison of the data presented indicates that the composition of microfaunal assemblages is controlled by palaeoenvironmental conditions, particularly by the rate of food supply and, as a consequence, by the oxygen content in the bottom waters. Most of the foraminiferal assemblages show a low abundance, indicating a low nutrient influx. The siliciclastic facies of the Szlachtowa Formation, characterized by a high rate of supply of organic matter, contain impoverished assemblages of foraminifera. More diversified microfaunal assemblages from the Skrzypny Shale Formation and partly of the Szlachtowa Formation evidence mostly a better oxygenated environment (Kamienka Riečka stream, the lower course of Malý Lipník stream, Jar-1 borehole, Litmanová), whereas some of the assemblages indicate a decrease in oxygen content (Metiská Quarry, the upper course of Malý Lipník Stream).

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Appendix A

An alphabetical listing of the dinoflagellate cyst taxa found in the Cretaceous and Jurassic strata studied is provided below. Full taxonomic citations are given in Fensome *et al.* (2008)

Alterbidinium spp.
Alterbidinium? sp.
Batiacasphaera spp.
Carpathodinium sp. A
Chytroeisphaeridia chytroeides (Sarjeant, 1962) Downie et Sarjeant, 1965
Chytroeisphaeridia? sp.
Circulodinium sp.
Codoniella campanulata (Cookson et Eisenack, 1960) Downie et Sarjeant, 1965
Craspedodinium sp.
Craspedodinium? sp.
Ctenidodinium combazii Dupin, 1968
Ctenidodinium cornigerum (Valensi, 1953) Jan du Chêne *et al.*, 1985
Dissiliodinium giganteum Feist-Burkhardt, 1990
Dissiliodinium lichenoides Feist-Burkhardt et Monteil, 2001
Dissiliodinium cf. *lichenoides* Feist-Burkhardt et Monteil, 2001
Dissiliodinium psilatum Prauss, 1989
Dissiliodinium spp.
Durotrigia? sp.
Epiplosphaera bireticulata Klement, 1960
Epiplosphaera sp.
Escharisphaeridia sp.
Exochosphaeridium sp.
Florentinia sp.
Impagidinium sp.
Isabelidinium? sp.
Kallosphaeridium praussii Lentin et Williams, 1993
Kallosphaeridium spp.
Kallosphaeridium? sp.
Kiokansium? sp.
Lithodinia sp.
Lithodinia? sp.
Litosphaeridium siphoniphorum (Cookson et Eisenack, 1958) Davey et Williams, 1966
Maghrebinia? sp.
Meiourogonyaulax sp.
Mendicodinium sp.
Moesiodinium raileanui Antonesçu, 1974
Nannoceratopsis ambonis Drugg, 1978
Nannoceratopsis deflandrei Evitt, 1961
Nannoceratopsis dictyambonis Riding, 1984
Nannoceratopsis evae Prauss, 1989
Nannoceratopsis gracilis Alberti, 1961
Nannoceratopsis pellucida Deflandre, 1939
Nannoceratopsis raunsgaardii Poulsen, 1996
Nannoceratopsis spiculata Stover, 1966
Nannoceratopsis sp.
Odontochitina sp.

Oligosphaeridium sp.
Palaeohystrichophora cheit (Below, 1981) Mahmoud, 1998 (Fig. 9E)
Palaeohystrichophora infusorioides Deflandre, 1935
Pareodinia sp.
Pervosphaeridium sp.
Phallocysta elongata (Beju, 1971) Riding, 1994
Phallocysta sp.
Pterodinium cingulatum (Wetzel, 1933) Below, 1981
Pterodinium sp.
Scriniocassis priscus (Gocht, 1979) Below, 1990
Spinidinium sp.
Spinidinium? sp.
Spiniferites ramosus (Ehrenberg, 1838) Mantell, 1854
Spiniferites sp.
Taeniophora? sp.
Valensiella sp.
Valvaeodinium cf. *koessenium* (Morbey, 1975) Below, 1987
Valvaeodinium scalatum (Wille et Gocht, 1979) Below, 1987
Valvaeodinium spp.
thin-walled form

Appendix B

An alphabetical listing of the foraminifera taxa found in the Jurassic strata studied is provided below

Ammodiscus sp.
Astacolus sp.
Citharina colliezi (Terquem)
Citharina macilenta (Terquem)
Citharina sp.
Conotrochammina sp.
Dentalina pseudocommunis (Franke)
Dentalina sp.
Dentalina vetusta (Franke)
Eoguttulina bilocularis (Terquem)
Eoguttulina sp.
Epistomina arcana Antonova
Epistomina coronata Terquem
Epistomina semiornata (Schwager)
Falsopalmula deslongchampsi (Terquem)
Falsopalmula sp.
Falsopalmula tenuistriata (Franke)
Glomospira sp.
Haplophragmoides sp.
Hyperammina sp
Ichtyolaria sp.
Kutsevella sp.
Lenticulina cf. *chicheryi* Payard
Lenticulina cf. *quenstedti* (Gümbel)
Lenticulina cf. *toarcense* Payard
Lenticulina d'orbignyi (Roemer)
Lenticulina muensteri (Roemer)
Lenticulina polygonata (Franke)
Lenticulina sp.
Lenticulina varians Bornemann
Nodosaria cf. *pulchra* (Franke)
Nodosaria fontinensis Terquem
Nodosaria sp.
Oolina sp.
Ophthalmidium sp.
Planularia cordiformis (Terquem)
Planularia protracta (Bornemann)
Planularia sp.
Pseudonodosaria sp.
Pseudonodosaria vulgata (Bornemann)
Ramulina sp.
Recurvoides sp.
Reophax sp.
Rhabdammina sp.
Spirillina infima Strickland
Spirophthalmidium spp.
Textularia haeusleri Kaptarenko
Tolypammina sp.
Trochammina aff. *eoparva* (Nagy et Johansen)
Trochammina pulchra Ziegler
Trochammina sp.
Verneuilinella pieninica Tyszka et Kaminski
Verneuilinella sp.
Verneuilinoides sp.