

***Homotryblium*-dominated Eocene dinoflagellate cyst assemblages from Middle Miocene (Badenian) glauconitic sands at Lipowiec (Roztocze, SE Poland)**

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A section over 20 m thick of the basal Middle Miocene succession exposed at Lipowiec (Roztocze, SE Poland) was studied for palynology. Thirteen samples were collected from quartz and glauconitic-quartz sands and thin clay layers. Sand samples were barren but clay samples yielded dinoflagellate cysts. Their assemblages consist of reworked Paleogene specimens dominated by the *Homotryblium floripes* complex (*H. floripes* and morphologically similar *H. plectilum* and *H. vallum*). The presence of reworked Paleogene specimens indicates intense erosion of marine Paleogene strata during initial stages of the Middle Miocene transgression at Roztocze. Analysis of stratigraphical ranges of reworked dinoflagellate cysts and comparison with their occurrences in known epicontinental Paleogene sites of SE Poland suggest an Upper Eocene age of the washed-out strata. The taxonomic composition of the assemblages described suggests that the Upper Eocene deposits accumulated in a near-shore, lagoonal embayment characterized presumably by oligotrophic waters of slightly increased salinity. A high proportion of the *Homotryblium floripes* complex is also characteristic of reworked assemblages found in younger Miocene strata of neighbouring exposures in Roztocze, which indicates widespread Eocene lagoonal environments in this part of Roztocze. Coeval Eocene strata from the eastern part of Roztocze and from the Carpathian Foredeep show different taxonomic compositions suggesting varied sedimentary settings during Eocene transgression in this region. These differences reflect variable amounts of freshwater influence resulting in a range of environments that ranged from oligotrophic to brackish.

Key words: Eocene, Miocene, reworking, palaeoenvironment, Roztocze, SE Poland.

INTRODUCTION

Eocene and Oligocene marine strata were formerly widely distributed in SE Poland covering a part of the Carpathian foreland that now forms the Roztocze hills and the eastern part of the Carpathian Foredeep. Most of them were removed by post-Rupelian erosion that left only a few sites with preserved deposits of these ages (e.g., [Buraczyński and Krzowski, 1994](#); [Gaździcka, 1994](#); [Gedl, 2000, 2012, 2014, 2015](#); [Myśliwiec and Śmist, 2006](#)). This makes reconstruction of Eocene and Oligocene palaeogeography in SE Poland, and of their palaeoenvironmental characteristics, difficult. In such cases, reworked Paleogene microfossils, dinoflagellate cysts in particular, which occur in Miocene strata of the Carpathian Foredeep, are helpful. Reworked dinoflagellate cysts have been described from several Miocene sections, indicating a much wider extent of Eocene and Oligocene epicontinental seas in SE Poland than could be inferred from the basis of preserved Paleogene sites ([Gedl, 2012](#)).

Middle Miocene succession of Roztocze appears to be particularly rich in reworked Paleogene, particularly Eocene, dinoflagellate cyst species. Frequent reworked forms, commonly outnumbering Miocene specimens, have been described from Upper Badenian deposits that rest upon the evaporitic horizon at Józefów ([Gedl, 2012, 2016](#)).

Further discoveries of reworked Paleogene dinoflagellate cysts in the Lower Badenian strata of Roztocze, presented in this paper, indicate expansion of the time interval during which the Paleogene cover underwent erosion. I provide stratigraphical analysis of the assemblages to allow their dating, and qualitative analysis to make palaeoenvironmental reconstructions of now non-existing Eocene strata.

GEOLOGICAL BACKGROUND

The Carpathian Foredeep Basin developed as a foreland basin at the front of the northwards-migrating Carpathian orogen. It stretches along the front of Carpathians from Austria to Romania, a distance of over 1300 km. In the Polish part ([Fig. 1A](#)), the Carpathian Foredeep is divided into inner and outer parts. The inner part is nowadays covered by overthrust Carpathian nappes, or occurs as narrow belts of folded strata at the front of the Carpathians. It includes the Lower (mainly continental) and Middle Miocene (Badenian and Sarmatian depos-

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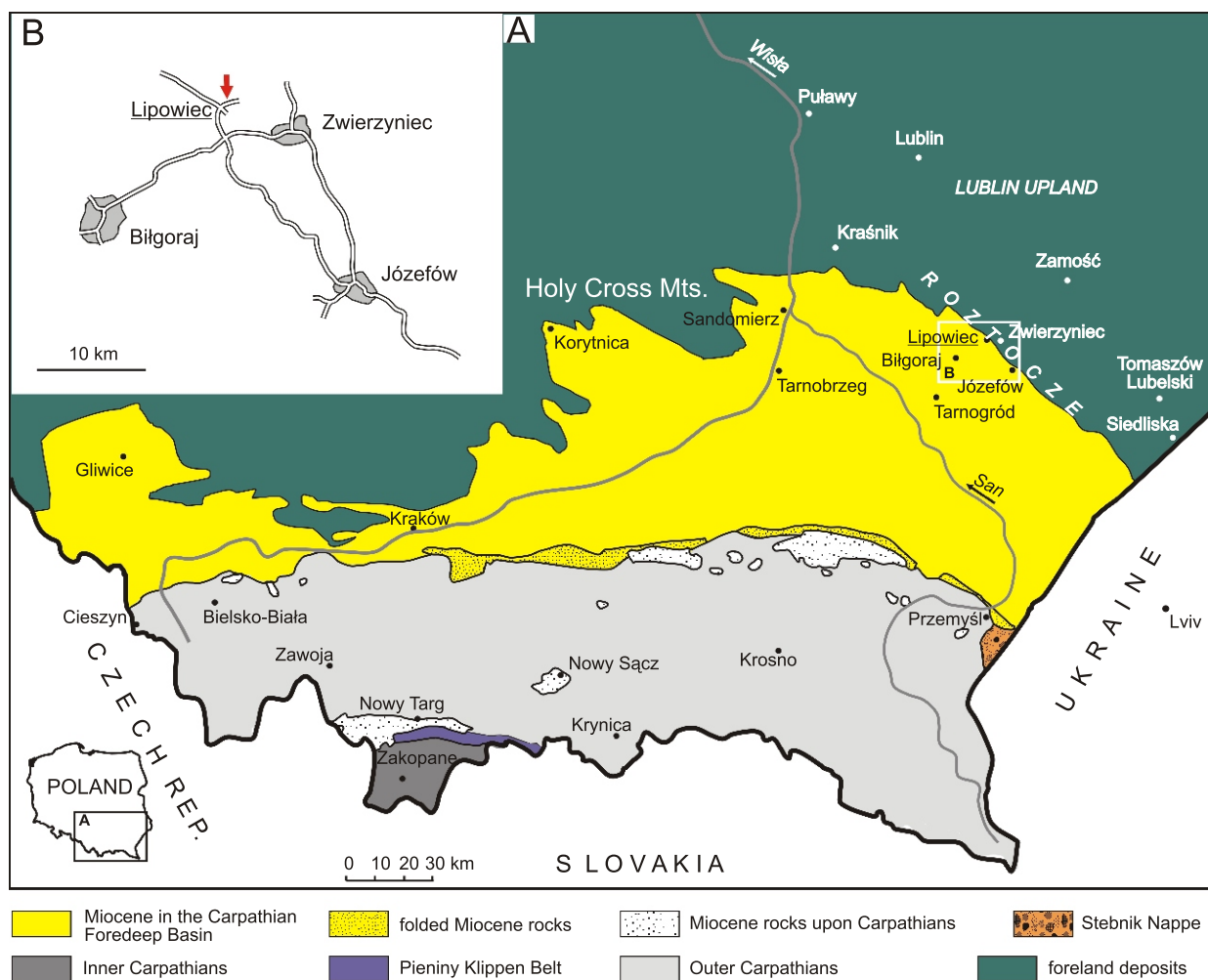


Fig. 1. Location of the site studied and geology of the study area

A – geological sketch of SE Poland showing positions of main geological structures and localities mentioned in the text (based on Żytko et al., 1989, from Oszczypko, 1996); **B** – location of the exposure at Lipowiec (arrowed)

its), which are marine. The outer part of the Carpathian Foredeep is filled with Badenian and Sarmatian marine strata that reach up to 2000 m in thickness, and 5000 m in the Ukrainian part (for details see e.g., Ney et al., 1974; Kotlarczyk, 1985; Oszczypko et al., 2006).

The Miocene sequence of the outer part of the Carpathian Foredeep is associated with a marine transgression that started in early phases of the Badenian (i.e., Langhian). It traditionally comprises a tripartite division: pre-evaporitic, evaporitic (chemical deposits) and post-evaporitic strata (numerous informal lithostratigraphic divisions that are difficult to correlate). The stratigraphy of this sequence is based mainly on planktonic foraminifera and calcareous nannoplankton, which show that the bulk of the rocks may be correlated with the Middle Miocene NN5 to NN9 calcareous nannoplankton zones and the M5 to M8–11 planktonic foraminifera zones (e.g., Garecka et al., 1996; Garecka and Jugowicz, 1999; Olszewska, 1999).

A similar, tripartite division can be applied to the Miocene succession in the Roztocze area, which represents a marginal facies of the Carpathian Foredeep Basin. However, this succession, due to its unique tectonic position, shows a different

development than its counterparts in central areas of the sedimentary basin. Roztocze is an uplifted area (in relation to the Carpathian Foredeep to the south) in the southern part of the Lublin Upland; its longitudinal structure stretches NW–SE from Kraśnik in Poland to Lviv in Ukraine (Fig. 1A). Due to its uplifted position, the Middle Miocene (Badenian) transgression in Roztocze led to accumulation of thin (merely 30–40 m thick compared to over 2,000 m in the basal part) shallow-marine coarse siliciclastic and organodetrital deposits (Fig. 2). They rest upon Upper Cretaceous strata with locally preserved marine Paleogene. Locally, in the base of the Middle Miocene succession, continental phytogenic deposits of uncertain, presumably Lower Miocene (Karpatian, i.e., uppermost Burdigalian) age occur (e.g., Jankowski et al., 2014).

Both the marine Paleogene and continental strata underwent significant erosion during and after uplift movements responsible for formation of the Roztocze structure. Erosion led to almost complete removal of these strata. Most complete sections of the epicontinental marine Eocene in the Carpathian foreland are known from the Sołokija Graben in Roztocze, and from the Łukowa-4 borehole (Tarnogród vicinity) in the

Chronostratigraphy		Lithostratigraphy	Lithology
Middle Miocene	Sarmatian	supra-evaporitic deposits	serpulid-microbialite reef limestones, organodetrital limestones, subordinate loamy-muddy deposits
	Upper Badenian		organodetrital limestones and marls, coralline algae-vermetid reef limestones algal-coquina limestones, loamy sands and sandstones
	Middle Badenian	evaporitic horizon	quartz-algal sands and algal limestones quartz sands and sandstones
	Lower Badenian	sub-evaporitic deposits	micritic limestones and calcareous sands
	(Upper Cretaceous)	(platform deposits)	quartz and quartz-glaucanite sands (marls and geizes)

Fig. 2. Synthetic scheme of lithostratigraphy and lithology of Miocene strata in the Polish part of Roztocze (after Musiał, 1987, from Wysocka, 2002)

Carpathian Foredeep. They represent the Bartonian–Lower Priabonian in the Sołokija Graben (Gaździcka, 1994; Gedl, 2014), and the Priabonian in the Łukowa-4 borehole (Gedl, 2015). Isolated sandy deposits near Tomaszów Lubelski, which form a residual hill, are believed to represent the Paleogene, although no palaeontological evidence has been found so far (Buraczyński and Krzowski, 1994).

The presence of Eocene marine strata at Roztocze and in the Carpathian Foredeep suggests that the uplift of the Roztocze structure started in the Oligocene or later. Jankowski and Margielewski (2014) correlated phytogenic deposits of Roztocze (Siemiatycze, Rawa Ruska) and the neighbouring part of the foredeep basin (Tarnogród), and concluded that uplift movements began not earlier than after their accumulation in the Karpatian (Early Miocene; this view requires further studies because at least some of phytogenic deposits of the Carpathian Foredeep Basin may be of Oligocene age; Myśliwiec and Śmist, 2006; Gedl, 2015). According to Jankowski and Margielewski (2014), Roztocze was already an uplifted structure during deposition of organodetrital strata – dated to the Late Badenian according to e.g., Szczechura (1982), Musiał (1987), Wysocka (2002), and the Sarmatian–Pannonian according to Czepiec (1996), and Jankowski and Margielewski (2015), who treated Badenian microfossils as reworked, although no list of younger microfossils was given by the latter.

MATERIAL

Material for this study comes from sandy Miocene strata that occur in a scarp of a steep topographic ridge of the Roztocze hills (Fig. 1B). Samples were collected from an exposure and a shallow borehole located a few metres north of the road that leads from the village of Lipowiec to the top of a local hill at the hamlet of Lipowiec-Góry (GPS coordinates: N50°37.792', E022°52.172'). This exposure, over 10 m high, was described and illustrated in detail by Margielewski (in Krapiec et al., 2010: point 2) and Jankowski and Margielewski

(2014). It represents basal part of the Badenian (Middle Miocene) transgressive succession at Roztocze (the Cretaceous substrate was penetrated by drilling almost 9 m below the bottom of the exposure; see Jankowski and Margielewski, 2014: fig. 4). The higher part of the sandy succession is exposed some 100 m north, on the same side of the road; its topmost part consists of coralline algal limestone that forms the top of the hills.

Strata exposed consist of white, beige and rusty, non-calcareous quartz sand that predominates in the upper part, and greenish non-calcareous quartz sand with glauconite in the basal part (Fig. 3). A few dark brown non-calcareous muddy clay layers occur. A hand-drilled borehole penetrated the underlying part of the succession, down to a depth of almost 5 m (i.e., it stopped ca. 4 m above the base of the Miocene succession; Fig. 3). This part consists of dominating greenish, fine-grained non-calcareous glauconitic-quartz loamy sands interlayered with rusty coarse-grained quartz sand layers. A few pale greenish clay layers are present. A total of thirteen samples was taken from the exposure and core. Seven samples were taken from clay layers, three samples were taken from loamy sand with glauconite from the lowermost drilled interval, and three samples from quartz sand from the upper part of the exposure (Fig. 3).

METHODS

The samples were processed in the micropalaeontological laboratory of the Institute of Geological Sciences, Polish Academy of Sciences, Research Centre in Kraków. The quantity of rock processed was variable, depending on the lithology: 30 g for clay samples and 500 g for sand samples. Samples were washed in water, and the fraction between 10 and 250 µm (sieved at 250 and 10 µm on a nylon mesh) was treated with 40% hydrofluoric acid (HF), heavy-liquid (ZnCl₂ + HCl; density 2.0 g·cm⁻³) separation. The residue was sieved again at 10 µm on a nylon mesh. No nitric acid (HNO₃) treatment was applied.

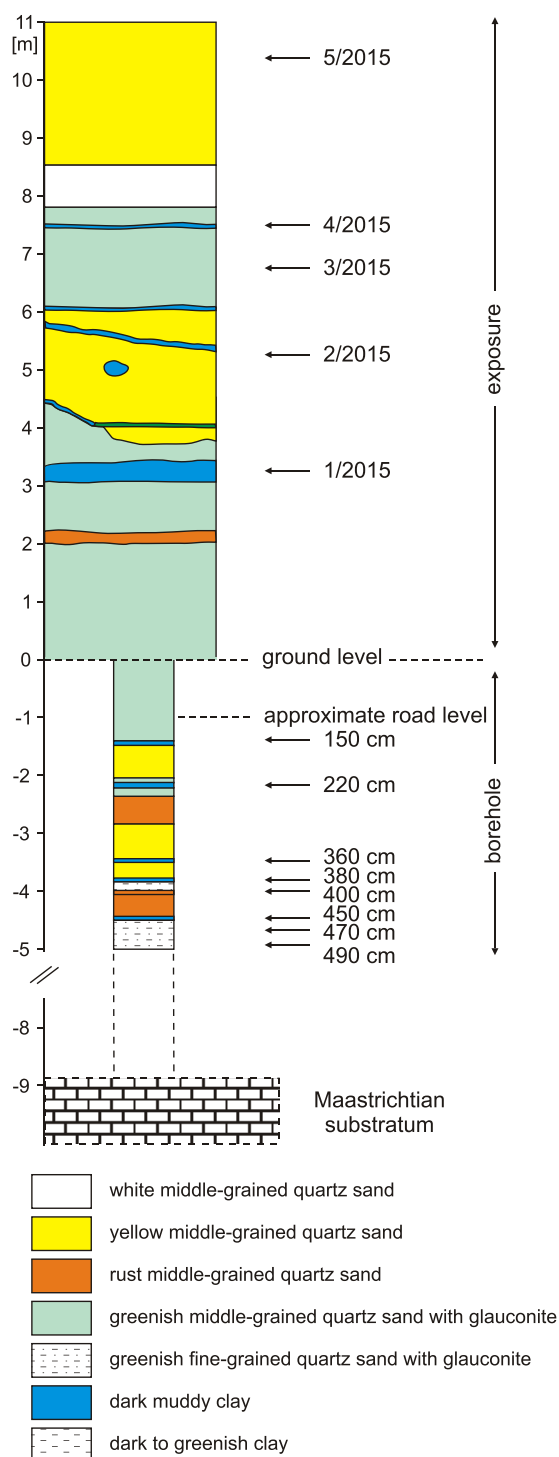


Fig. 3. Lipowiec exposure and borehole with position of samples collected (exposure lithology after Krapiec et al., 2010)

Two palynological slides were made from each sample using glycerine jelly as a mounting medium. All dinoflagellate cysts were counted from both slides using a Carl Zeiss Axiolab microscope. Photographs of aquatic palynomorphs were taken using a Sony DSC-S75 camera and Carl Zeiss Achroplan x100 oil lens. 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.

RESULTS

Samples from quartz sand (5/2015) and quartz-glauconitic sand (3/2015) were barren. Loamy glauconitic sand (400, 470 and 490 cm) yielded organic debris composed of very fine particles of black and dark brown phytoclasts and pale remains of land plant tissues. Rare bisaccate pollen grains occur; no dinoflagellate cysts have been found.

Clay samples yielded higher amounts of palynological matter, which, except for sample 1/2015, includes aquatic palynomorphs. The latter are marine dinoflagellate cysts present in all samples, and thin-walled spherical forms of uncertain origin found in the sample from 220 cm depth; their distribution is shown in Figure 4. Dinoflagellate cysts are pale-coloured, their wall structure shows no traces of increased maturity. However, they are commonly preserved as fragments (particularly large chorate forms such as *Areosphaeridium*; Fig. 5P, X) or they show traces of mechanical damage. The dinoflagellate cysts are illustrated in Figures 5 to 7.

The sample from 450 cm depth yielded infrequent fragments of undeterminable dinoflagellate cysts, some of these presumably being *Cleistosphaeridium*. The remaining clay samples yielded assemblages that consist of frequent *Homotryblium* representing a morphological complex (*H. floripes*, *H. plectilum*, *H. vallum*; see de Verteuil and Norris, 1996; p. 22; Fig. 5A–O, Q–S) associated with various proportions of other species (Fig. 4). The proportion of *Homotryblium* in these samples is as follows: 51% (380 cm), 96% (360 cm), 69% (220 cm), 88% (150 cm), 52% (2/2015), and 100% (4/2015).

Taxa other than the dominant *Homotryblium* are *Glaphyrocysta*, *Cleistosphaeridium*, *Heterosphaeridium*, and *Membra-*

Number	Species	Sample						
		450 cm	380 cm	360 cm	220 cm	150 cm	2/2015	4/2015
1	<i>Cleistosphaeridium placacanthum</i>	?	5	1	1	2	3	
2	<i>Glaphyrocysta</i> sp.		2					
3	<i>Glaphyrocysta</i> cf. <i>semitecta</i>		2					
4	<i>Homotryblium floripes</i>		22	31	19	15	12	12
5	<i>Homotryblium plectilum</i>		13	12	10	6		5
6	? <i>Areosphaeridium michoudii</i>		3		2		2	
7	<i>Cleistosphaeridium</i> sp. A		4		1			
8	<i>Glaphyrocysta semitecta</i>		3		2	1		
9	<i>Heterosphaeridium</i> sp. A		8					
10	<i>Pentadinium?</i> sp.		1					
11	<i>Membranophoridium aspinatum</i>		1					
12	<i>Membranophoridium connectum</i>		1		4		1	
13	<i>Adnatosphaeridium multispinosum</i>		1		1			
14	<i>Cleistosphaeridium</i> cf. <i>placacanthum</i>		2			1	3	
15	<i>Homotryblium vallum</i>				5	1		
16	<i>Spiniferites pseudofurcatus</i>				1	1		
17	<i>Enneadocysta</i> sp.				1			
18	<i>Homotryblium aculeatum</i>				1			
19	spherical palynomorphs				42			
20	<i>Areosphaeridium diktyoplokum</i>						1	
21	<i>Glaphyrocysta microfenestrata</i>						1	

Fig. 4. Dinoflagellate cyst occurrence at Lipowiec

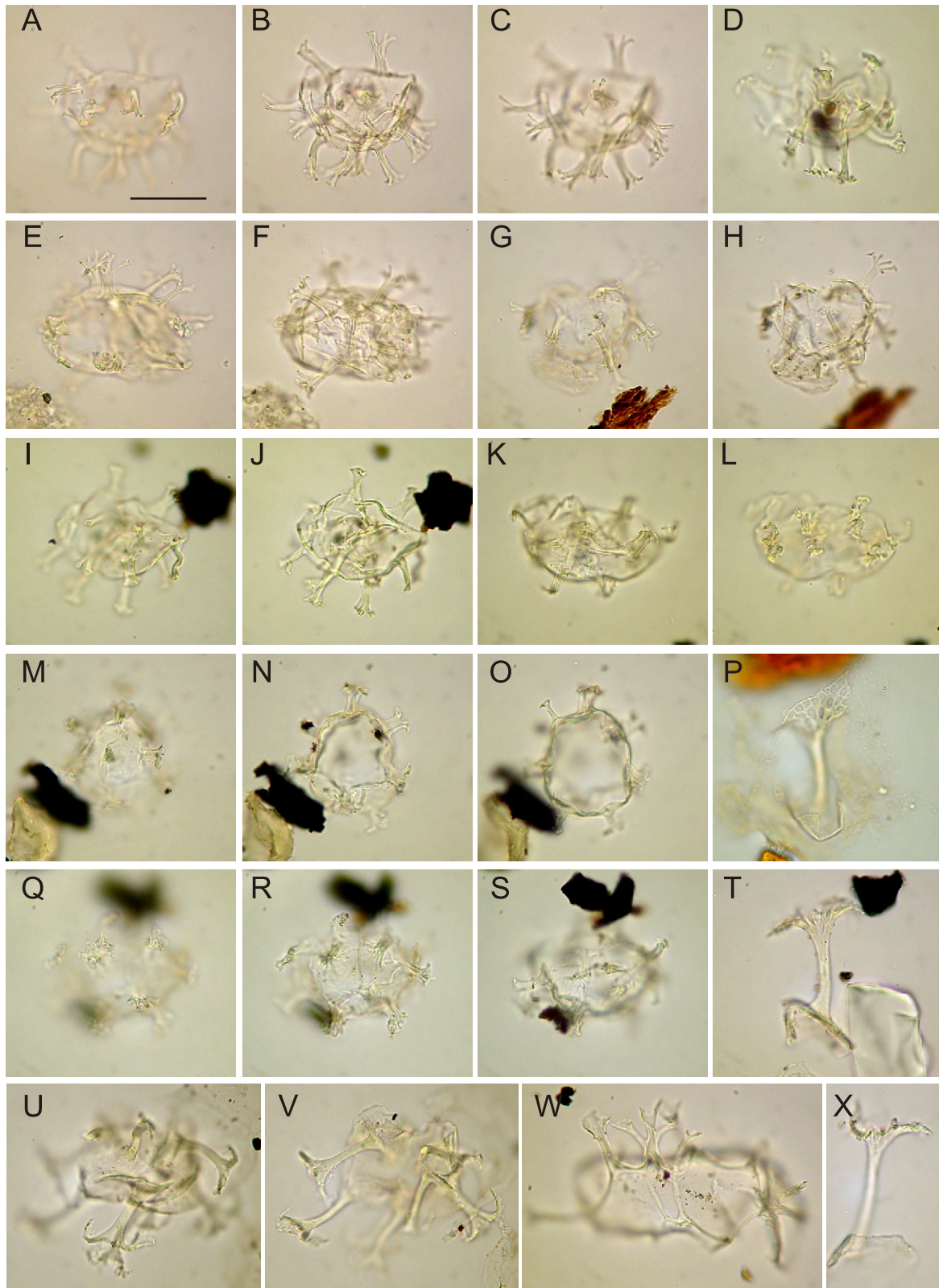


Fig. 5. Dinoflagellate cysts from sandy deposits at Lipowiec (scale bar = 25 μ m)

A–C – *Homotryblium floripes* (150 cm); **D** – *Homotryblium plectilum* (380 cm); **E, F** – *Homotryblium floripes* (150 cm); **G, H** – *Homotryblium floripes* (380 cm); **I, J** – *Homotryblium plectilum* (220 cm); **K, L** – *Homotryblium vallum* (220 cm); **M–O** – *Homotryblium vallum* (360 cm); **P** – *Areosphaeridium diktyoplokum*: isolated paraplata with a process terminated with a characteristic platform (2/2015); **Q–S** – *Homotryblium vallum* (360 cm); **T** – isolated process, presumably of *Areosphaeridium michoudii* (380 cm); **U, V** – *Areosphaeridium michoudii* (380 cm); **W** – incomplete specimen of *Spiniferites pseudofurcatus* (380 cm); **X** – isolated process, presumably of *Areosphaeridium michoudii* (380 cm)

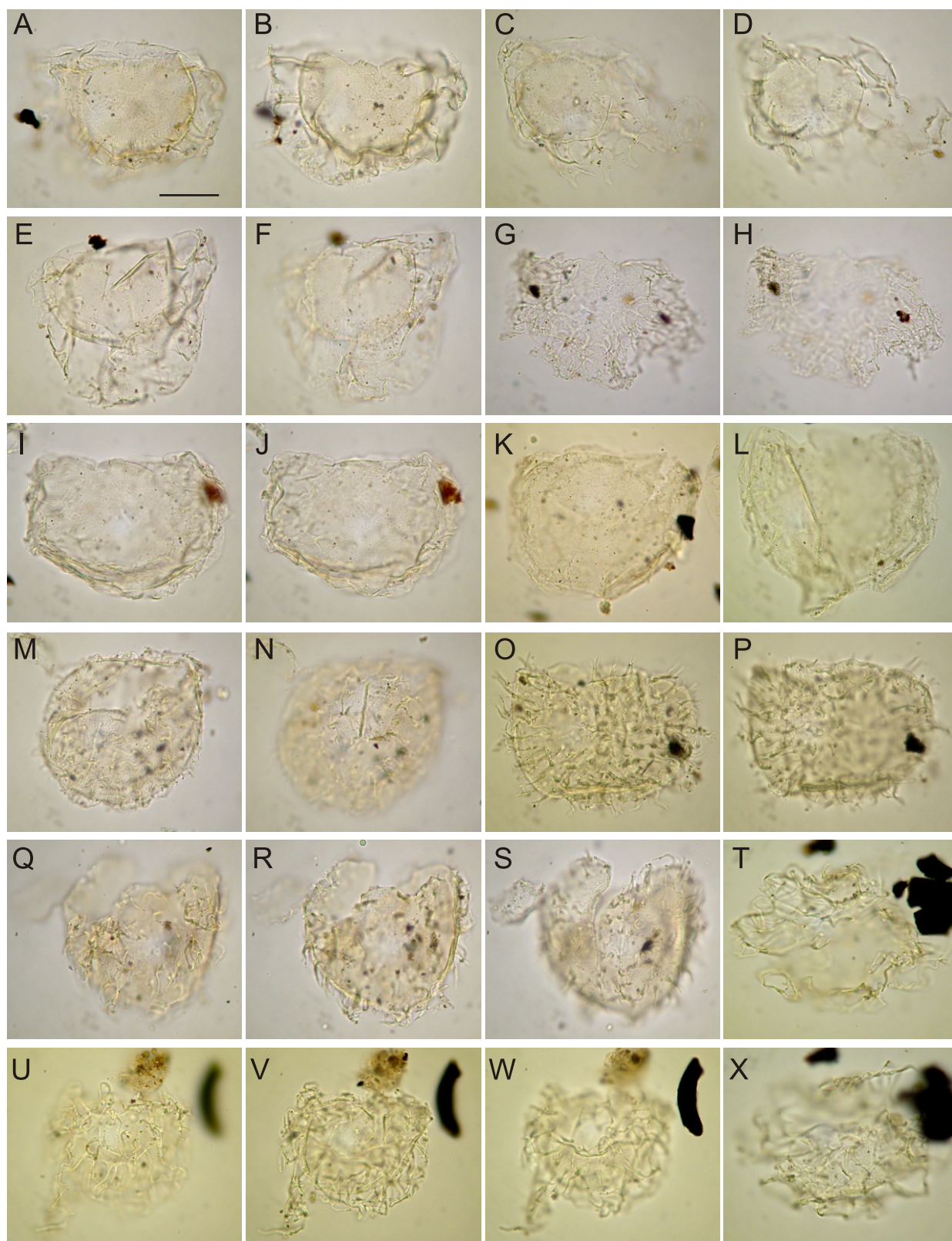


Fig. 6. Dinoflagellate cysts from sandy deposits at Lipowiec (scale bar = 25 μ m)

A, B – *Glaphyrocysta* sp. (380 cm); **C, D** – *Glaphyrocysta semitecta* (380 cm); **E, F** – *Glaphyrocysta* cf. *semitecta* (380 cm); **G, H** – *Glaphyrocysta microfenestrata* (sample 2/2015); **I, J** – *Membranophoridium connectum* (380 cm); **K** – *Membranophoridium connectum* (220 cm); **L** – *Membranophoridium aspinatum* (220 cm); **M, N** – *Heterosphaeridium* sp. A sensu Gedl, 2013 (380 cm); **O, P** – *Heterosphaeridium* sp. A sensu Gedl, 2013 (380 cm); **Q–S** – *Heterosphaeridium* sp. A sensu Gedl, 2013 (380 cm); **T, X** – *Adnatosphaeridium multispinosum* (220 cm); **U–W** – *Adnatosphaeridium multispinosum* (380 cm)

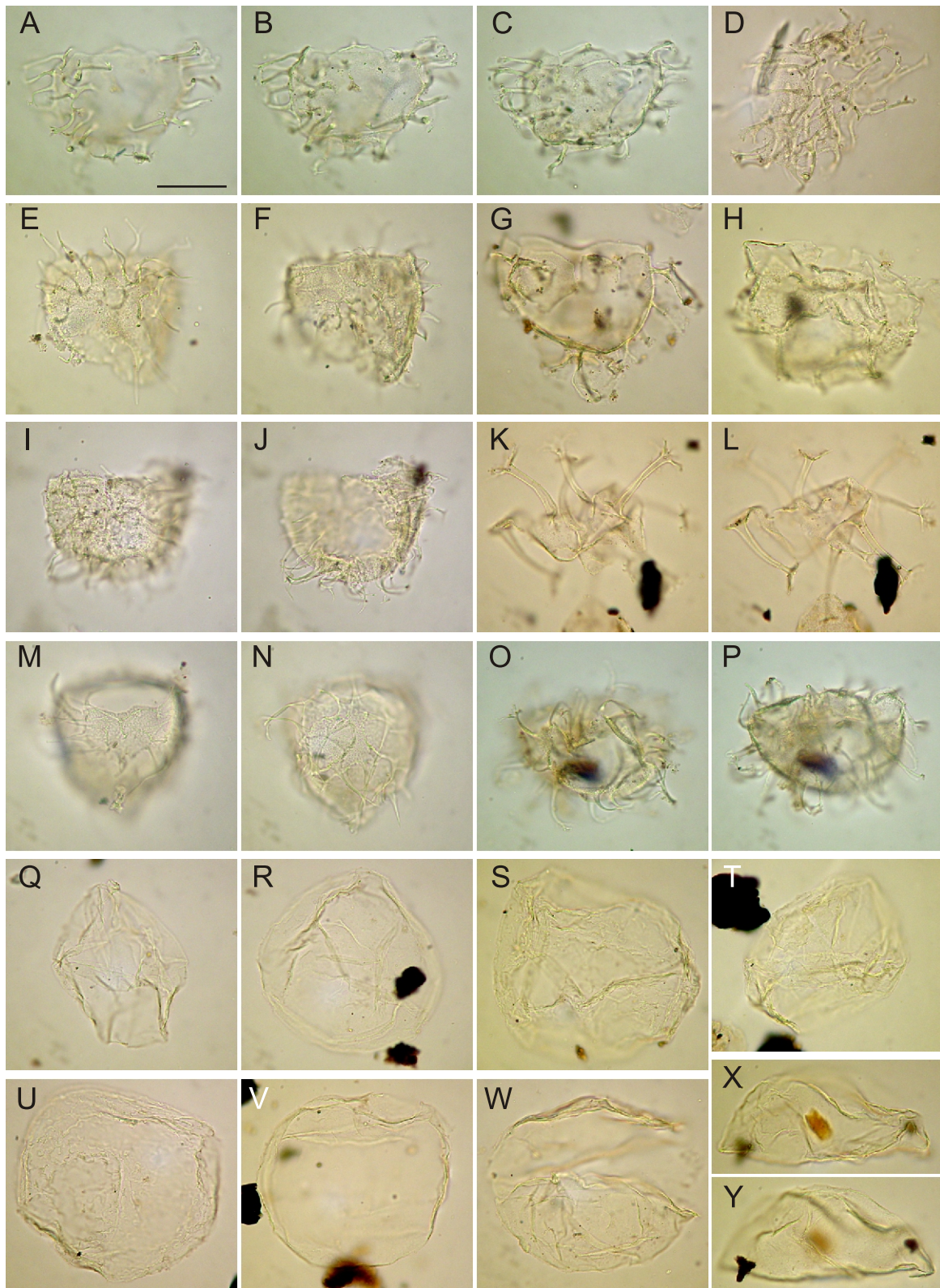


Fig. 7. Dinoflagellate cysts from sandy deposits at Lipowiec (scale bar = 25 μ m)

A–C – *Cleistosphaeridium* sp. A sensu Gedl, 2013 (380 cm); **D** – *Cleistosphaeridium* sp. A sensu Gedl, 2013: a wrinkled specimen showing granular structure of the cyst wall (380 cm); **E, F** – *Cleistosphaeridium* cf. *placacanthum* (380 cm); **G** – *Glaphyrocysta* sp. (380 cm); **H** – *Pentadinium*? sp.: specimen with thick and granular endocyst (380 cm); **I, J** – *Cleistosphaeridium* cf. *placacanthum* sp. (380 cm); **K, L** – *Homotryblum aculeatum* (220 cm); **M, N** – *Cleistosphaeridium placacanthum* (150 cm); **O, P** – *Cleistosphaeridium placacanthum* (2/2015); **Q–Y** – spherical thin-walled palynomorphs (all 220 cm)

nophoridium, which are most frequent in the sample from 380 cm depth. The sample from 220 cm depth is characterized by the frequent occurrence of thin-walled proximate forms of uncertain origin (Fig. 7Q–Y). Most of these are smooth, bi-layered; none has a pylome. Some show a girdle in equatorial position, along which a split is observed in some specimens (Fig. 7W). This split leads to a complete separation of two equal halves (Fig. 7X, Y). This feature resembles epicystal dinoflagellate cysts such as *Mendicodinium*, but in the case of the Lipowiec specimens no typical dinoflagellate plate arrangement (e.g., a sulcal notch) was observed.

INTERPRETATION

BIOSTRATIGRAPHY

Miocene strata of the Polish part of Roztocze have so far yielded relatively infrequent dinoflagellate cysts. This is due to sedimentary conditions specific for this area, which include shallow-marine, high-energy conditions (e.g., Wysocka, 2002) that were presumably hostile for dinoflagellates and/or for their preservation. Most of the coarse-grained, commonly organo-detrital rocks that build Roztocze are barren. Dinoflagellate cyst assemblages are found in infrequent fine-grained layers; they consist there of a mixture of reworked Eocene species, and ones believed to be *in situ*. The similar state of preservation makes separating these two groups difficult in the case of long-ranging species. The assemblages described from Lipowiec consist almost exclusively of species that appeared for the last time before the Middle Miocene. A short overview of their ranges is given below:

- *Adnatosphaeridium multispinosum*: Early–Late Eocene (Powell, 1992), Early–Middle Eocene (Stover et al., 1996), Eocene–Early Oligocene (Köthe and Piesker, 2007), Middle Eocene (Vasilyeva, 2013);
- *Areosphaeridium diktyoplakum*: latest Early–Late Eocene (Powell, 1992), Early–Late Eocene (Stover et al., 1996; Köthe and Piesker, 2007); the last appearance of this species is reported from the Eocene/Oligocene boundary interval (see Eldrett et al., 2004, for discussion);
- *Areosphaeridium michoudii*: Early Eocene (Vasilyeva, 2013); last appearance: Middle Priabonian (Bujak and Mudge, 1994; Mudge and Bujak, 1994; Eldrett et al., 2004); Late Priabonian (Heilmann-Clausen and van Simaey, 2005; Thomsen et al., 2012);
- *Enneadocysta* sp.: Middle Eocene–Early Oligocene (Stover et al., 1996 as the *Enneadocysta arcuata* “complex”; Köthe and Piesker, 2007 as *Enneadocysta* spp.);
- *Glaphyrocysta microfenestrata*: latest Middle Eocene–earliest Oligocene (Powell, 1992), Early Oligocene: Köthe and Piesker, 2007);
- *Glaphyrocysta semitecta*: Bartonian–Rupelian (De Coninck, 1995); Lutetian–Rupelian (Heilmann-Clausen and van Simaey, 2005), Bartonian–Priabonian (Vasilyeva, 2013); a total range of *G. semitecta* in Northern Hemisphere mid-latitudes: latest Lutetian–Early Rupelian (Williams et al., 2004); last appearance: earliest Rupelian (Mudge and Bujak, 1994);
- *Membranophoridium aspinatum*: Middle Eocene–Oligocene (Powell, 1992), Late Eocene–Early Oligocene (De Coninck, 1995), Late Eocene–Oligocene (Stover et al., 1996); Priabonian (Heilmann-Clausen and van Sima-

ey, 2005); Munsterman and Brinkhuis (2004) report the highest occurrence of this species from uppermost Chattian–Lower Aquitanian of the North Sea.

A Paleogene, most likely Eocene age can be referred to the species *Cleistosphaeridium* sp. A and *Heterosphaeridium* sp. A, both described by the author from the Eocene Popiele Beds (Gedl, 2013).

Precise dating of the dinoflagellate cyst assemblages in question is enabled by *Homotryblium floripes*, and the morphologically similar *H. plectilum* and *H. vallum*, which are most frequent in the material studied. Being widely distributed in Paleogene and Early Miocene strata, the occurrence of *Homotryblium* occurrence in the Middle and Upper Miocene is less evident. Dybkjær and Piasecki (2010) reported an acme of *Homotryblium* (including *H. plectilum* and *H. tenuispinosum*) from the uppermost Oligocene–lowermost Miocene of the North Sea. A similar acme of *Homotryblium floripes/plectilum* was reported by Munsterman and Brinkhuis (2004) from the coeval interval of the North Sea Miocene. The same authors reported the highest occurrence of *Homotryblium vallum* in the Lower Miocene of the North Sea (uppermost Aquitanian–lowermost Burdigalian). A similar age of this event is given by de Verteuil and Norris (1996). Stover et al. (1996) show a Lower Miocene highest occurrence of *H. plectilum* and *H. vallum* in northwestern Europe and offshore eastern North America. Powell (1986) reports a Chattian last appearance of *H. plectilum* and Aquitanian last appearance of *H. floripes* in NW Italy. According to Williams et al. (1993) both *H. floripes* and *H. vallum* appeared for the last time in North Atlantic in late Early Miocene. Several authors (e.g., Wrenn and Kokinos, 1986; Dybkjær and Piasecki, 2010) reported the occurrence of *Homotryblium* in the Upper Miocene or even younger strata, but according to de Verteuil and Norris (1996: p. 20, 22; see this publication for full reference list and discussion) these records are presumably the result of reworking.

First appearance data of the *Homotryblium floripes* complex show that these species appeared for the first time in the Eocene, mainly during the Late Eocene. Williams et al. (2004) report a total range of *H. floripes* from equatorial areas as Lutetian–Late Miocene, but in higher latitudes its oldest occurrences are known from the Priabonian (Heilmann-Clausen and van Simaey, 2005; Vasilyeva, 2013) and Bartonian–?Priabonian (Gedl, 2014, 2015). *H. vallum*, in turn, is known already from Eocene strata, e.g., uppermost Priabonian (Köthe and Piesker, 2007), and Bartonian–Priabonian (Gedl, 2013).

The distribution of *Homotryblium* in the Miocene of the Carpathian Foredeep Basin supports the thesis of de Verteuil and Norris (1996). This genus is missing in most Middle Miocene (Badenian) sections studied, and if present, it occurs as evidently reworked (poorly preserved from the Carpathian Paleogene; e.g., Gedl, 1999) or associated with other evidently reworked specimens (e.g., Gedl, 1999, 2005, 2016). Soliman and Piller (2007), who studied the Karpatian/Badenian boundary interval in the Styrian Basin in Austria, noted the rare occurrence of *Homotryblium* sp. in Karpatian strata only; Badenian strata, devoid of reworked Paleogene forms, contained no *Homotryblium*.

The species with the longest stratigraphic ranges among those found in the samples studied are *Cleistosphaeridium placacanthum* – Middle Eocene to Late Miocene (e.g., Eaton et al., 2001) and *Spiniferites pseudofurcatus* – Cretaceous–Middle Miocene (e.g., Stover et al., 1996). Both species could thus be *in situ*. They have been encountered as *in situ* forms in the Upper Badenian of Polish Roztocze, where they co-occur with Eocene species (Gedl, 2016). They are also known from coeval strata of the Ukrainian part of the Carpathian Foredeep Basin,

where they occur in assemblages devoid of reworked specimens (Gedl and Peryt, 2011) or they are associated with rare reworked Paleogene specimens (Peryt et al., 2014).

This overview of stratigraphic ranges suggests that dinoflagellate cyst assemblages from Lipowiec are of Late Eocene age. The question of whether *C. placacanthum* and *S. pseudo-furcatus* are *in situ* or they are reworked remains unsolved; the lack of any other Eocene species, like those from younger strata of Roztocze (e.g., *Polysphaeridium*), suggests that they are also reworked.

PALAEOENVIRONMENT

The lack of Miocene dinoflagellate cysts in the deposits studied points to a restricted sedimentary setting. Too little data is available for a precise environmental reconstruction, but the most likely factor hostile for dinoflagellates and/or their preservation was the very shallow water and high-energy hydrodynamic conditions. The latter, easily visible in sedimentary structures (e.g., Jankowski and Margielewski, 2014), may be responsible for the lack of dinoflagellate cysts. During periods of calmer deposition, clay layers accumulated. They yielded reworked specimens only; the lack of *in situ* taxa shows that environmental conditions were still not favourable for dinoflagellates. The presence of *incertae sedis* forms (spherical paly-nomorphs) in the sample from 220 cm depth, possibly *in situ*, may be related to these specific sedimentary conditions, but so long as their palaeoenvironmental preferences are unknown, nothing more can be suggested.

Reworked dinoflagellate cysts can be much more useful, representing the only palaeontological trace of eroded Eocene strata. Although their assemblages may be incomplete due to selective erosion and/or re-accumulation processes, on their basis an attempt of Late Eocene Roztocze environment reconstruction can be undertaken.

The presence of marine assemblages shows that this part of Roztocze was also flooded by a marine transgression during the Late Eocene. The lack of offshore species such as *Impagidinium* (e.g., Wall et al., 1977; Harland, 1983; Edwards and Andrie, 1992; Brinkhuis, 1994; Rochon et al., 1999; Boessenkool et al., 2001) and *Nematosphaeropsis* (Brinkhuis, 1994; Dale, 1996; Rochon et al., 1999) suggests a near-shore, proximal marine setting. This interpretation is supported by frequent occurrences of *Homotryblium*. This genus is widely associated with near-shore, littoral environments, commonly with increased salinity (e.g., Köthe, 1990; Brinkhuis, 1994). The latter feature may indicate slightly increased salinity of the marine waters, although Dybkjær (2004) suggested that *Homotryblium* may also benefit from decreased salinity conditions.

Another characteristic feature of the Lipowiec assemblages is a lack of peridinioids, which are mainly heterotrophs and thrive in waters with increased nutrient availability (e.g., deltaic or upwelling waters; see e.g., Biffi and Grignani, 1983; Brinkhuis, 1994; Sprangers et al., 2004; Sluijs et al., 2005). Their lack may thus reflect oligotrophic conditions. This reconstruction is supported by a lack of *Lingulodinium machaerophorum*, an autotroph, which is commonly associated with eutrophic proximal waters (e.g., Targarona et al., 1999; Boessenkool et al., 2001).

All these features suggest that dinoflagellate cysts found in sands at Lipowiec inhabited a near shore, presumably shallow marine setting with rather oligotrophic waters with slightly increased salinity. Therefore, a lagoonal embayment can be reconstructed for this part of Roztocze during the Late Eocene.

DISCUSSION

This is the first report of dinoflagellate cyst occurrence in the basal part of the Middle Miocene (Badenian) succession in this part of Roztocze. Attempts to search for dinoflagellate cysts in coeval deposits undertaken by the author during the last few years have proved fruitless: quartz sands exposed at Gleboviti and Stradč (Ukrainian part of Roztocze; see Wysocka and Roniewicz, 2004: fig. 3 for correlation) were found to be barren. Data presented in this and previous papers show that during the Badenian transgression in the Polish part of Roztocze intense erosion of marine Eocene strata took place. Clay layers within Upper Badenian organodetrital limestone in the vicinity of Józefów yielded frequent Middle and Late Eocene dinoflagellate cysts (Gedl, 2012). Jankowski et al. (2014) reported calcareous nannoplankton typical of the NP 17 Zone (Bartonian) from clays overlying Miocene brown-coal deposits in Siedliska.

The Lipowiec dinoflagellate cyst assemblages show qualitative and quantitative similarities to the reworked assemblages from Józefów in the frequent occurrence of *Homotryblium floripes* complex representatives (Gedl, 2016). Three samples collected from the Józefów quarries yielded the following proportions of *H. floripes* plus *H. plectilum* and *H. vallum* (calculated for reworked forms only): 49% (sample Pds-1), 55% (Pds-2), and 30% (Jzf-3). High proportions of *Homotryblium* and a simultaneous lack of peridinioids suggest that during both the Early and Late Badenian similar lagoonal Eocene settings were gradually washed out in this part of Roztocze. The lower proportion of *Homotryblium* in the Upper Badenian samples, associated with a higher number of taxa such as *Areosphaeridium michoudii*, *Areoligera* spp., and *Batiacasphaera ?compta* (gen. et spec. indet. *sensu* Gedl, 2013), may indicate a gradual erosion of the Eocene succession in Roztocze, and their subsequent inverted accumulation during the Badenian. During the Early Badenian the top of the Priabonian succession underwent erosion (and hence the youngest assemblages composed almost entirely of *Homotryblium* were washed out and accumulated); during the Late Badenian, in turn, erosion reached the base of the Eocene succession (Bartonian–?Priabonian), and older assemblages with less common *Homotryblium* were eroded. Acceptance of this scenario suggests that the original Eocene succession in this part of Roztocze accumulated in a gradually shallowing marine environment, gradually transforming to a lagoonal embayment, reflected by the increasing proportion of *Homotryblium*.

Reworked dinoflagellate cysts from Lipowiec show some taxonomic similarities (particularly when *Homotryblium floripes* complex representatives are considered) to Eocene assemblages that occur *in situ* at Roztocze. An assemblage with common *Homotryblium floripes*, dated to the latest Bartonian?–Early Priabonian, was described by the author from the top of the Eocene succession of the Solokija Graben in Roztocze; on the base of its composition, a very shallow marine, presumably partly restricted setting was reconstructed (Gedl, 2014). The *Homotryblium floripes*-dominated Solokija assemblages differ, however, by the co-occurrence of peridinioids and *Lingulodinium machaerophorum*, which are missing in material from Lipowiec. Moreover, strata from the top of the Solokija, which contain these assemblages, are separated by layers that yielded almost monospecific *Deflandrea* assemblages.

The occurrence of peridinioids is also typical of the Priabonian succession in the Carpathian Foredeep (Łukowa-4 borehole); rare specimens of *Lingulodinium machaerophorum* have been found there (Gedl, 2015). Although these strata

yielded frequent specimens of *Homotryblium* too, in this case they represent *H. aculeatum*; *H. floripes* is rare there.

Homotryblium plectilum, in turn, is a common species in Priabonian dark mudstones of the Popiele Beds at Koniusza (Gedl, 2013). The sedimentary setting of these mudstones was interpreted as a marginal, proximal, near-shore zone of the Carpathian sea. Also in this case, peridinioids (mainly *Deflandrea*), although subordinate, occur as an important part of dinoflagellate cyst assemblages (Gedl, 2013: figs. 13 and 14).

The comparison presented above shows that the Lipowiec assemblages are notable for the lack of peridinioids and *Lingulodinium machaerophorum*. The other assemblages from coeval strata, although also including frequent *Homotryblium*, contain peridinioids and *L. machaerophorum*. Occurrences of the two latter species presumably reflect slightly higher availability of nutrients, possibly caused by a higher influx of freshwater. This is clearly visible, particularly in case of the Sołokija succession, where levels with *Homotryblium* are interlayered with levels with monospecific *Deflandrea* assemblages, likely reflecting brackish conditions.

The assemblages from Lipowiec are thus presumably further traces of Late Eocene near-shore marine settings that surrounded the emerged areas to the north of the present day Lublin Upland; to the south they passed into the deep marine basins of the Carpathian sea. These settings were characterized by frequent palaeoenvironmental changes, typical of shallow-marine, proximal marine environments, where lagoonal, tidal, deltaic and other sedimentological settings commonly replaced or interfingered with each other. The Lipowiec assemblages presumably reflect lagoonal oligotrophic environments, whereas coeval assemblages from neighbouring areas inhabited settings influenced by freshwater influx.

CONCLUSIONS

1. The sandy succession that occurs in basal parts of the Miocene at Roztocze usually contains no fossils and its stratigraphic position is based on superposition (Musiał, 1987). The results presented in this paper are the first documentation of their dinoflagellate cyst content. Their assemblages, however, are reworked.

2. Lack of Miocene dinoflagellate cysts in deposits studied suggests that environmental conditions during early stages of the Badenian transgression at Roztocze were unfavourable for dinoflagellates and/or inappropriate for their preservation (e.g., high energetic hydrodynamic conditions during coarse grain fraction accumulation).

3. The discovery of reworked Eocene dinoflagellate cysts in the Lower Badenian, the basal part of succession, as described in this paper, shows that erosion of the marine Paleogene cover started simultaneously with the Badenian transgression.

4. The taxonomic composition of the reworked assemblages shows that they were washed out from near-shore, shallow-water Upper Eocene deposits accumulated presumably in a lagoonal embayment characterized by oligotrophic high-salinity waters. Erosion of similar deposits, although presumably slightly older, lasted also during the Late Badenian when

organodetrital carbonate deposits accumulated in this part of Roztocze.

5. Comparison of the Lipowiec assemblages with Late Eocene dinoflagellate cyst assemblages from other sites at Roztocze and the Carpathian foreland shows that the latter, although also shallow-marine and partly lagoonal, accumulated in slightly different environments. Lack of taxa that benefited from high concentration of nutrients in marine waters, such as peridinioids and *Lingulodinium machaerophorum*, suggest oligotrophic conditions in the case of Lipowiec. The occurrence of both peridinioids and *L. machaerophorum* (in various proportions) at other sites shows that these areas were influenced, to a certain degree, by freshwater influx in the Late Eocene.

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SPECIES LIST

(taxonomy and citations follow Fensome et al., 2008):

- Adnatosphaeridium multispinosum* Williams et Downie, 1966
Areosphaeridium diktyoplokum (Klumpp, 1953) Eaton, 1971
 ?*Areosphaeridium michoudii* Bujak, 1994
Cleistosphaeridium placacanthum (Deflandre et Cookson, 1955) Eaton et al., 2001
Cleistosphaeridium cf. *placacanthum* (Deflandre et Cookson, 1955) Eaton et al., 2001
Cleistosphaeridium sp. A *sensu* Gedl, 2013
Enneadocysta sp.
Glaphyrocysta microfenestrata (Bujak, 1976) Stover et Evitt, 1978
Glaphyrocysta semitecta (Bujak, 1980) Lentin et Williams, 1981
Glaphyrocysta cf. *semitecta* (Bujak, 1980) Lentin et Williams, 1981
Glaphyrocysta sp.
Heterosphaeridium sp. A *sensu* Gedl, 2013
Homotryblium aculeatum Williams, 1978
Homotryblium floripes (Deflandre et Cookson, 1955) Stover, 1975
Homotryblium plectilum Drugg et Loeblich Jr., 1967
Homotryblium vallum Stover, 1977
Membranophoridium aspinatum Gerlach, 1961
Membranophoridium connectum Stover et Hardenbol, 1994
Pentadinium? sp.
Spiniferites pseudofurcatus (Klumpp, 1953) Sarjeant, 1970

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