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# DINOFLAGELLATE CYSTS AND PALYNOFACIES FROM THE UPPER BADENIAN (MIDDLE MIOCENE) OF THE ROZTOCZE AREA AT JÓZEFÓW AND ŻELEBSKO (CARPATHIAN FOREDEEP BASIN, POLAND): PALAEOENVIRONMENTAL IMPLICATIONS

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**Abstract:** The post-evaporitic upper Badenian (Middle Miocene) succession of the Roztocze (marginal zone of the Carpathian Foredeep Basin) consists of shallow-marine sands and organodetrital deposits. The latter, although predominantly coarse-grained, include very rare and usually very thin intercalations of fine-grained, loamy material. A few such clay layers were sampled for their palynological content in quarries at Józefów (Józefów and Pardysówka) and Żelebsko. The clay samples yielded palynological organic matter, in contrast to organodetrital limestone samples, which were barren. The palynofacies composition, both presence/absence of land-derived material and the specific composition of aquatic material, are useful for the palaeoenvironmental reconstructions of sedimentary settings. During late Badenian time, the sedimentary setting of the deposits studied was characterized by proximity to the shoreline, which, however, supplied limited input of terrestrial matter, and by restricted marine conditions caused by increased salinity. During the latest Badenian, water salinity presumably underwent a further increase, leading to the collapse of the dinoflagellate floras. The frequent occurrence of reworked Palaeogene dinoflagellate cysts in upper Badenian samples and their absence from the uppermost Badenian indicate variable intensity of erosion of the epicontinental Palaeogene strata during the Middle Miocene at Roztocze.

**Key words:** Dinoflagellate cysts, palynofacies, palaeoenvironment, Miocene, Palaeogene substratum, Roztocze, Carpathian Foredeep Basin.

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## INTRODUCTION

Fossil dinoflagellate cysts are widely distributed in the Miocene deposits of the Carpathian Foredeep Basin and can be used as tools for both stratigraphic and palaeoenvironmental studies (e.g., Gedl, 1996, 1997, 1999, 2005; Gedl and Peryt, 2011; Andreychouk *et al.*, 2014; Peryt *et al.*, 2014). In the Polish part of the foredeep, their distribution, however, shows an uneven pattern: their most diversified and prolific assemblages occur in sub-evaporitic deposits, such as the Korytnica Clay or the Baranów Beds; the evaporitic deposits contain no dinoflagellate cysts and the post-evaporitic strata usually contain infrequent and taxonomically impoverished assemblages (e.g., Gedl, 1997, 1999). The post-evaporitic deposits of the Roztocze area, a peripheral part of the Carpathian Foredeep Basin, are characterized by specific sedimentary and environmental conditions, reflecting their marginal palaeogeographic setting during the Middle Miocene (Wysocka, 2002, 2006a). These conditions, particularly aerobic bottom-water conditions and high-energy hydrodynamic conditions of a shallow-marine basin, played a crucial role for the preservation of dinoflagellate cysts. The Miocene rocks of the Roztocze, which were deposited in a high-energy hydrodynamic regime and well oxidized, shallow environments, commonly contain no organic-walled dinoflagellate cysts (unpublished data of the author), probably because of their susceptibility to decomposition in an aerobic environment, as well as being swept from their primary settings by even weak currents. However, rare and usually thin layers of clay, which occasionally occur in some exposures of coarse-grained Miocene deposits oftlinein the Roztocze, contain small-sized organic particles, including aquatic palynomorphs. Such fine-grained layers from two upper Badenian sections at Józefów and one uppermost Badenian section at Żelebsko were sampled for the present study. The results obtained add new data for

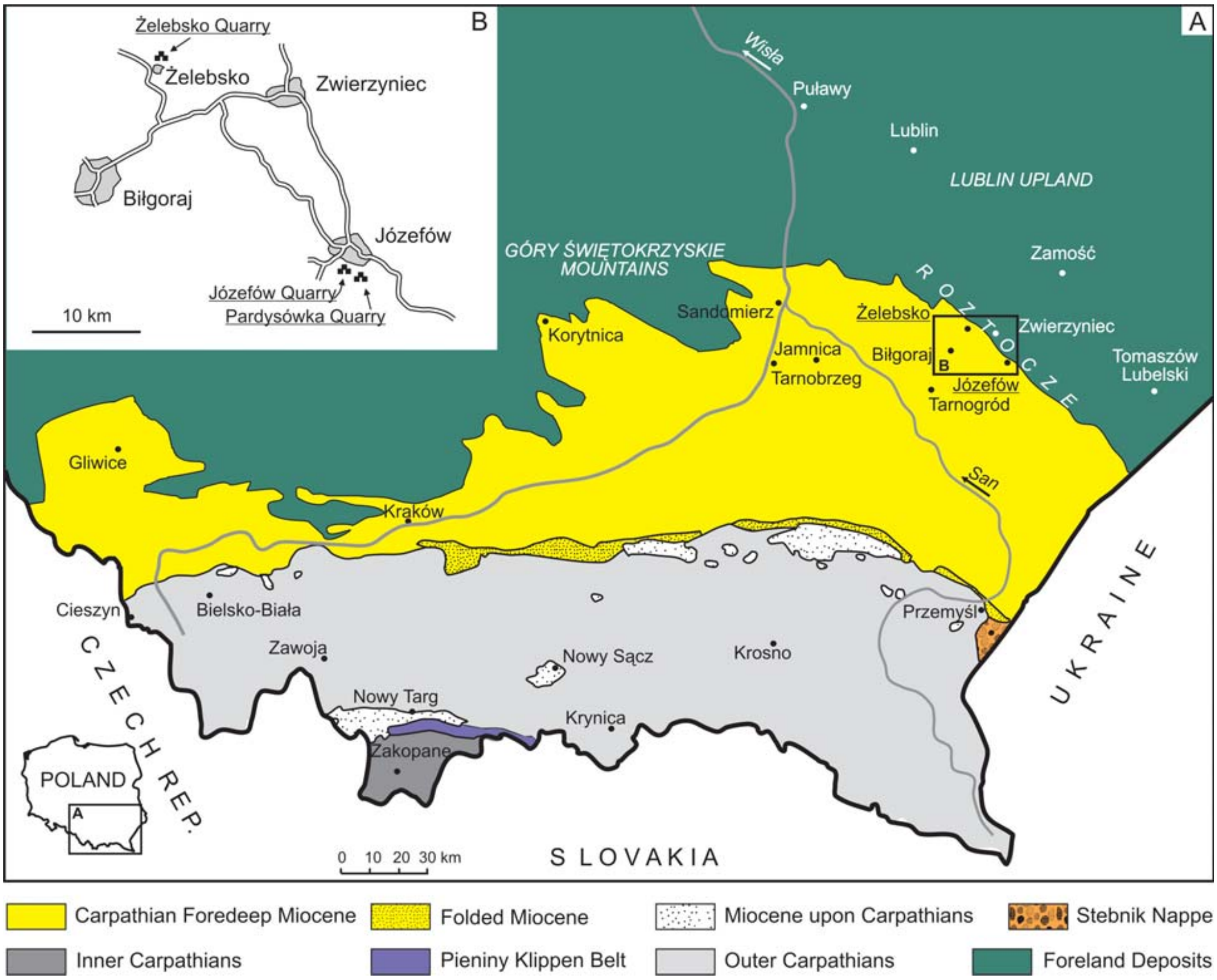


**Fig. 1.** Location of sites studied (**B**) and geological sketch map of Carpathian Foredeep Basin and surrounding areas (**A**; based on Żytko *et al.*, 1989, from Oszczypko, 1996).

the reconstruction of the palaeoenvironmental conditions during the Middle Miocene in the Roztocze area; they are compared with results of previous palynological studies of the Middle Miocene in the Ukrainian part of the Roztocze. However, frequently occurring reworked Palaeogene dinoflagellate cysts found in the material studied hinder final conclusions, because of difficulties in distinguishing between reworked and *in situ* species. Therefore, their presence is discussed and compared with the dinoflagellate cyst distribution pattern in coeval strata in neighbouring areas.

## GEOLOGICAL SETTING

The Miocene strata of the Roztocze area represent marginal facies of the Carpathian Foreland Basin (Fig. 1A), deposited in an area that was uplifted in relation to the basinal part of the foredeep basin (e.g., Jasionowski *et al.*, 2012). The Roztocze area was uplifted during the final stage of the Neogene Neo-Alpine orogeny in the Carpathians (Badenian–Sarmatian) along reactivated older, pre-Miocene fault systems on the boundary between the Precambrian East European Platform and Epi-Variscan Platform (Ney, 1969; Ney *et al.*, 1974; Żelichowski, 1974).

The Badenian transgression, which covered the Roztocze area, left much thinner Miocene strata (several to a few tens of metres), compared to almost 2,000 m in the basinal part (locally, up to 4.5 km thick in graben structures). The Miocene succession in the Roztocze area consists generally of shallow-marine sands, marls and organodetrital limestones (see e.g., Musiał, 1987; Buraczyński, 1997; Wysocka, 2002; Wysocka *et al.*, 2007; Jasionowski *et al.*, 2012), whereas the coeval basinal succession consists chiefly of fine-grained, siliciclastic deposits (e.g., Ney *et al.*, 1974).

The Miocene succession in the Roztocze area rests on Upper Cretaceous (e.g., Musiał, 1987; Cieśliński and Rzechowski, 1993; Buraczyński 1997) and locally preserved Palaeogene strata (e.g., Buraczyński and Krzowski, 1994; Gaździcka, 1994; Gedl, 2012, 2014; Fig. 2). It starts with lower Badenian quartz sands (occurring mainly in the Ukrainian part of the Roztocze; see Wysocka, 2002, fig. 4), which pass upwards into marly deposits with common coralline algae (Fig. 2). There are almost no evaporitic deposits in the Polish part of the Roztocze; gypsum and the Ratyn Limestone (the latter lithostratigraphic unit is an equivalent of chemical deposits that are widespread in the basinal part of the foredeep basin; see e.g., Peryt and Kasprzyk, 1992; Peryt and Peryt, 1994; Peryt, 2001, 2006; Jasionowski *et*

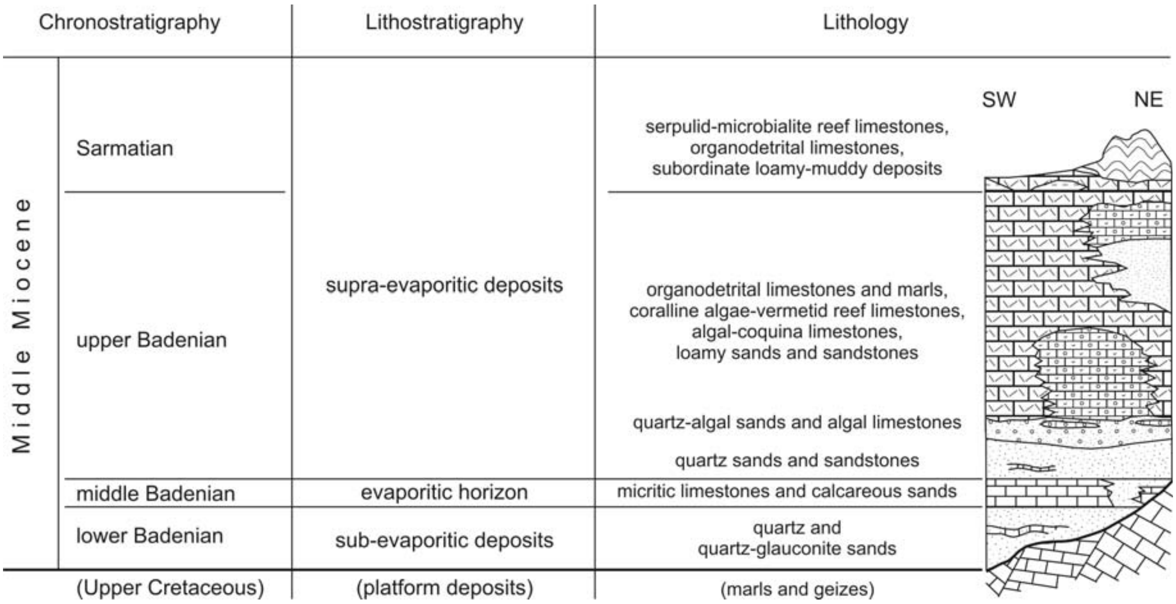


**Fig. 2.** Chronostratigraphy, lithostratigraphy and lithology of Miocene succession in the Roztocze area (after Musiał, 1987; from Wysocka, 2002).

*al.*, 2012) occur almost exclusively in the Ukrainian Roztocze. Higher, the upper Badenian sequence consists of shallow-water terrigenous clastics (mainly quartz sands) and organodetrital deposits, composed mainly of coralline algae fragments with subordinate amounts of other calcareous fossils and their remains, rhodoid deposits (Musiał, 1987; Wysocka *et al.*, 2007) and coralline algae-vermetid reefs (Pisera, 1985). The youngest strata of the Miocene succession in the Roztocze are represented by the Sarmatian, developed as clays, marls, organodetrital limestones (Wysocka *et al.*, 2007). A characteristic feature of the Sarmatian in the western part of the Roztocze is the common occurrence of serpulid-microbialite reefs (e.g., Pisera, 1996; Jasionowski, 2006).

## MATERIAL

Material for the present study comes from two quarries at Józefów and from one quarry at Żelebsko (Fig. 1B). The two quarries at Józefów, although located very close to each other, expose different upper Badenian deposits (Wysocka, 2002, 2006b), whereas the succession that is presently exposed at Żelebsko represents the uppermost Badenian and the Sarmatian (Jasionowski *et al.*, 2006).

The quarry at Józefów, known in the literature as the Pardysówka Quarry (see Wysocka, 2006b), exposes an upper Badenian sequence over 20 m thick (Fig. 3A). It consists of sandy organodetrital limestone (calcarenite to calcirudite) with common cross-stratification and trough cross-stratification structures (Wysocka, 2006b; Fig. 3B). Rare, fine-grained layers of presumed tuffaceous origin occur (Fig. 3C–E). According to Wysocka (2006b), the Pardysówka succession was deposited in a shallow-marine environment, characterized by relatively high-energy hydrodynamic activity in the bottom waters that was responsible for the transportation of clastic material and is reflected in the common cross-stratification structures. Moreover, Wysocka (2006b) described erosional channels, which according to her are evidence of water currents, typical for shallow-marine waters, most likely generated by storm-induced currents. Eight samples were collected from this site (Pds-1–8): two samples (Pds-1 and Pds-2) from very rare clay layers, up to 1 cm thick (greenish, soft, sandy, highly calcareous clay with abundant glauconite grains; Fig. 3C–E), and six samples (Pds-3–8) were taken from organodetrital limestone (GPS coordinates: N50°28′14.1511″, E23°3′38.5667″).

Another quarry at Józefów is located several hundred metres to the west of the Pardysówka Quarry (this quarry is referred here as the Józefów Quarry). It exposes a near-shore upper Badenian sequence (see Wysocka *et al.*, 2006). Its succession begins with breccias (cliff-deposits according to Jaroszewski, 1977), overlain by sands, which pass upwards into a complex of medium- to thick-layered, organodetrital limestone, several metres thick (Fig. 4A). Wysocka (2002) described in the latter complex horizons of fine-grained intercalations (Fig. 4B). Six samples (Jzf) were collected: two samples (Jzf-3 and Jzf-4) from such clay layers (dark greenish, highly calcareous clay with abundant shell detritus; Fig. 4C); the remaining four (Jzf-1, Jzf-2, Jzf-5, Jzf-6) from organodetrital limestone (GPS coordinates: N50°28′31.2109″, E23°2′45.4396″).

The quarry at Żelebsko exposes an upper Badenian complex over 20 m thick (its lowermost, loamy part is nowadays covered) and Lower Sarmatian (Jasionowski *et al.*, 2006; see also Wysocka, 2002; Fig. 5A). The exposed uppermost Badenian there consists of bimodal organodetrital limestone: fine-grained biocalcilutites with ripplemark structures in its lower part, and coarse-grained calcarenites in upper part (Fig. 5E). According to Jasionowski *et al.* (2006) these limestones consist mainly of coralline algae remains with subordinate amount of calcareous detritus (e.g., bryozoa, bivalves). The relatively rich and diversified benthonic foraminifera assemblage described by Szczechura (*in* Jasio-

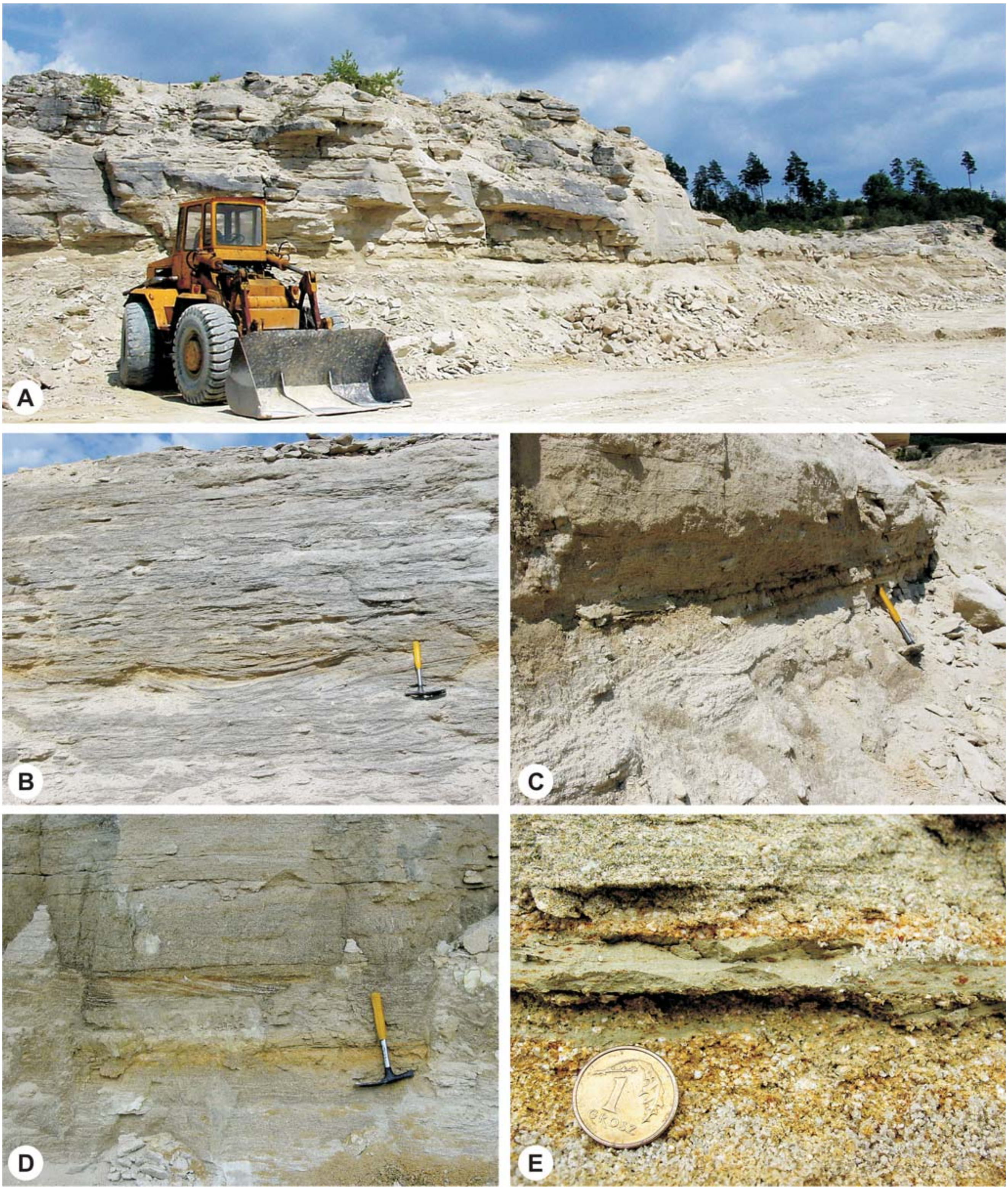


**Fig. 3.** Upper Badenian of the Pardysówka Quarry. **A.** General view of exposure at the Pardysówka Quarry. **B.** Cross-stratification, dominant structure in organodetrital limestone at Pardysówka. **C.** Clay layer: sample Pds-2. **D.** View of quarry face composed of organodetrital limestone with cross-stratifications and clay layer (sample Pds-1; see E). **E.** Close-up of clay layer in coarse grained organodetrital limestone (sample Pds-1; coin diameter: 15 mm).

nowski *et al.*, 2006) shows that the upper Badenian at Żelebsko was deposited in a shallow-marine environment with normal salinity. Planktonic foraminifera, in turn, are relatively frequent in the lower part of the upper Badenian succession and they gradually become infrequent toward the top (Szczechura *in* Jasionowski *et al.,* 2006). This suggests a gradual shallowing of the late Badenian basin.

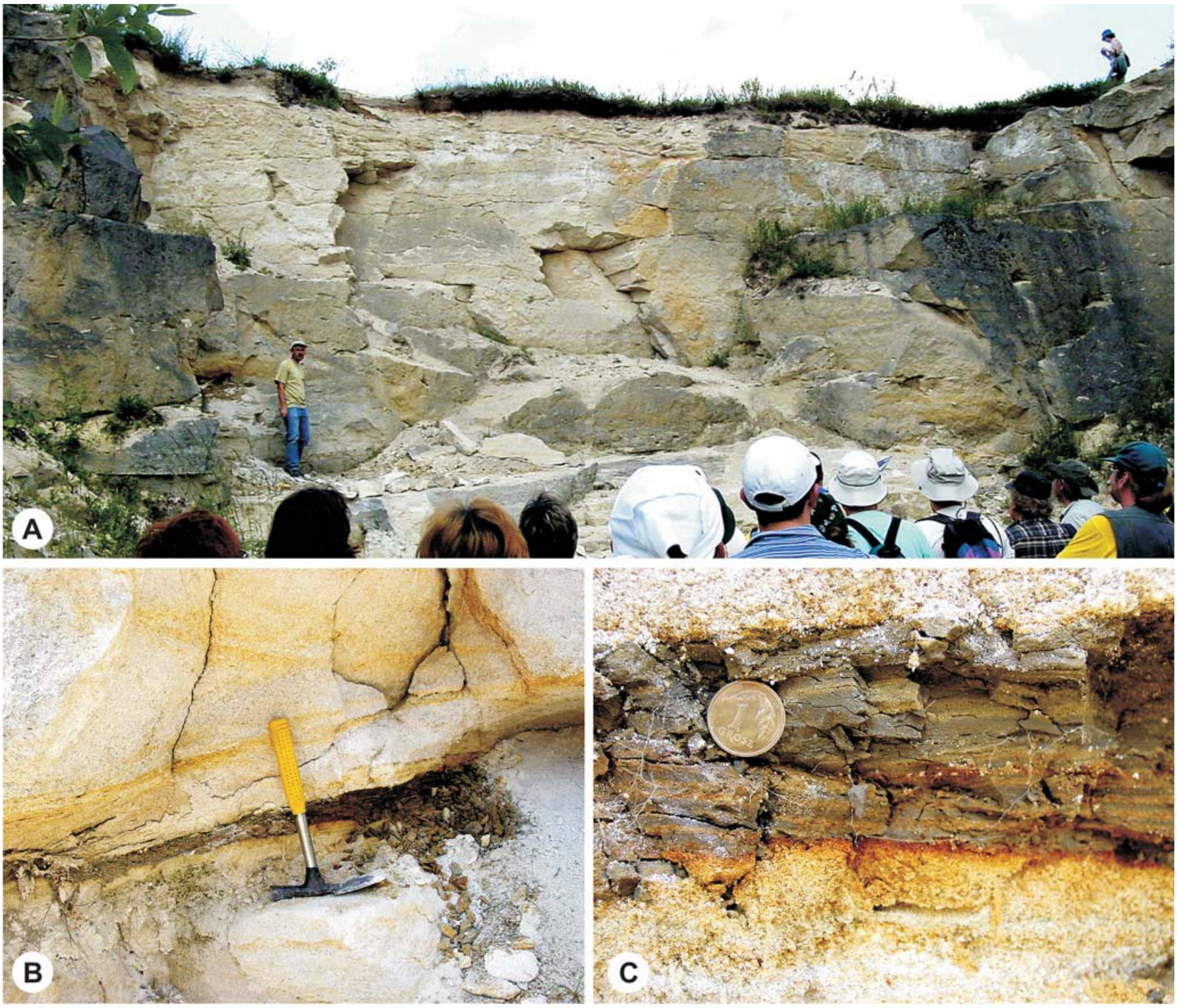


**Fig. 4.** Upper Badenian of the Józefów Quarry. **A.** General view of quarry face composed of organodetrital limestone. B. Clay layer in organodetrital limestone (sample Jzf-1; see C). C. Close-up of clay layer and surrounding limestone (sample Józefów-1; coin diameter: 15 mm).

Within the upper part of the upper Badenian sequence in the Żelebsko Quarry a marly clay layer approximately 30 cm thick occurs; sample Żlb-1 was collected from this layer (black arrow on Fig. 5A, B; Fig. 5C, D). It represents pale beige to olive-beige, massive, highly calcareous marly clay (GPS coordinates: N50°37′44.1108″, E22°47′28.3752″).

Higher, Sarmatian strata a few metres thick occur. They consist of loamy-marly deposits and bioclastic limestone with tiny serpulid-microbialite bioherms. According to Szczechura (*in* Jasionowski *et al.*, 2006), these Sarmatian strata were deposited in very near-shore, partly lagoonal, environments.

## METHODS

The samples were processed in the micropalaeontological laboratory of the Institute of Geological Sciences, Polish Academy of Sciences, Research Centre in Kraków. The applied palynological procedure 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. No nitric acid ($HNO_3$) treatment was applied.

The quantity of rock processed was variable, depending on the lithology: 30 g for clay samples and 200 g for organodetrital limestone samples. 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 a Carl Zeiss Achroplan ×100 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.

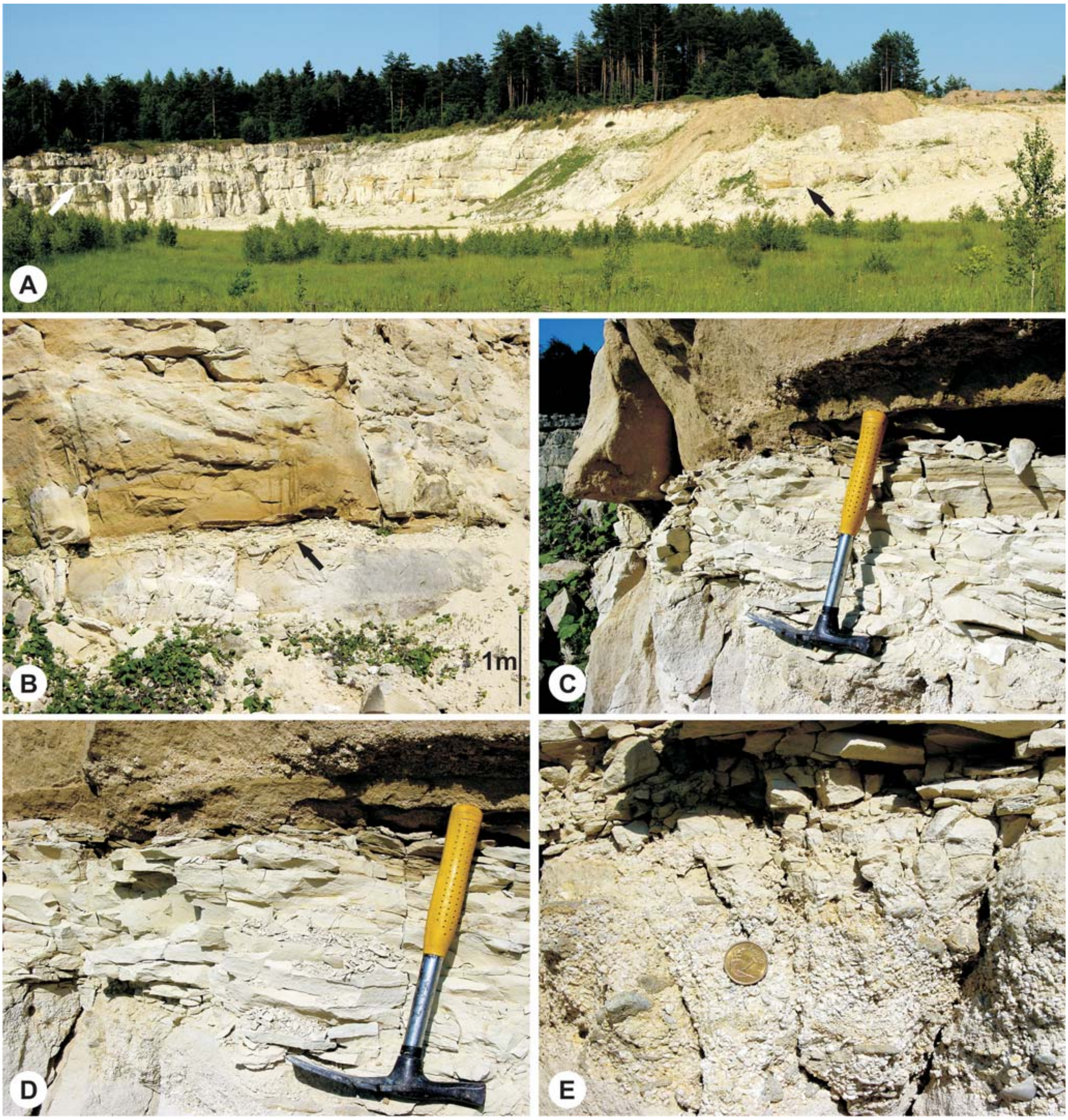


**Fig. 5.** The Żelebsko Quarry. **A.** General view of the quarry exposing uppermost Badenian and Sarmatian deposits; white arrow indicates possible boundary between Badenian and Sarmatian (black arrow points at position of sample Żlb-1). **B.** View of quarry face with well exposed marly clay layer (black arrow indicates location of sample Żlb-1). **C, D.** Marly clay layer, from which sample Żlb-1 was collected. **E.** Close-up of organodetrital coarse-grained calcarenite underlying marly clay layer (coin diameter: 15 mm).

## RESULTS

Only clay samples yielded palynological organic matter; all organodetrital limestone samples were barren. A concise description of sample content is provided below. The occurrence of dinoflagellate cysts, *Leiosphaeridia*, and sporomorphs in the material studied is shown in Figure 6. The palynomorphs are illustrated in Figures 7 to 10.

**Pds-1.** The sample contains palynological organic matter, consisting of dark brownish and black opaque, easily disintegrated phytoclasts (90%) and dinoflagellate cysts, which are the most frequent palynomorphs. Noteworthy is the almost complete lack of sporomorphs; only single grains of bisaccate pollen grains were found. The majority of dinoflagellate cysts are excellently preserved, pale-coloured and with an intact wall structure. Some specimens are wrinkled or torn off only; other specimens are extremely pale-coloured and barely discernible from the light background.

The dinoflagellate cysts assemblage is taxonomically impoverished. It is composed of dominant specimens of

| Number | Species \ Sample | Pds-1 | Pds-2 | Jzf-3 | Jzf-4 | Żlb-1 |
|---|---|---|---|---|---|---|
| | Age | upper Badenian | | | | |
| 1 | *Adnatosphaeridium multispinosum* Williams et Downie 1966* | 1 | | | | |
| 2 | *Areoligera* sp.* | 3 | | | | |
| 3 | ?*Areosphaeridium michoudii* Bujak 1994* | 5 | 8 | 3 | | |
| 4 | *Batiacasphaera compta* Drugg 1970* | 1 | 3 | | | |
| 5 | *Cleistosphaeridium placacanthum* (Deflandre et Cookson 1955) Eaton *et al.* 2001 | 121 | 112 | 42 | 1 | |
| 6 | *Cordosphaeridium gracile* (Eisenack 1954) Davey et Williams 1966* | 1 | 1 | | | |
| 7 | *Enneadocysta* sp.* | 2 | | | | |
| 8 | *Glaphyrocysta* spp.* | 8 | 5 | 3 | | |
| 9 | *Homotryblium floripes* (Deflandre et Cookson 1955) Stover 1975* | 17 | 21 | 7 | | |
| 10 | *Homotryblium plectilum* Drugg et Loeblich Jr. 1967* | 3 | 2 | 2 | | |
| 11 | *Homotryblium vallum* Stover 1977* | 2 | 3 | | | |
| 12 | ?*Impagidinium* sp. | 1 | | | | |
| 13 | *Lingulodinium machaerophorum* (Deflandre et Cookson 1955) Wall 1967 | 16 | 11 | 9 | | |
| 14 | *Membranophoridium aspinatum* Gerlach 1961* | 2 | | | | |
| 15 | *Pentadinium* sp. | 7 | 3 | 1 | | |
| 16 | *Polysphaeridium subtile* Davey et Williams 1966 | 91 | 74 | 21 | 2 | 1 |
| 17 | *Polysphaeridium zoharyi* (Rossignol 1962) Bujak *et al.* 1980 | 3 | 2 | 7 | | |
| 18 | *Spiniferites pseudofurcatus* (Klumpp 1953) Sarjeant 1970 | 10 | 12 | 9 | 1 | |
| 19 | *Areosphaeridium diktyoplokum* (Klumpp 1953) Eaton 1971* | | 2 | | | |
| 20 | ?*Enneadocysta arcuata* (Eaton 1971) Stover et Williams 1995* | | 1 | | | |
| 21 | *Homotryblium tenuispinosum* Davey et Williams 1966* | | 1 | | | |
| 22 | *Leiosphaeridia* sp. | 2 | 7 | 2 | | 118 |
| 23 | Bisaccate pollen grains | 5 | | 2 | 3 | 321 |
| 24 | Spores | | | | | 7 |

**Fig. 6.** Frequency of dinoflagellate cysts and other palynomorphs in samples studied. Reworked Palaeogene taxa indicated by an asterisk.

*Cleistosphaeridium* and *Polysphaeridium* (mainly *P. subtile*; rare *P. zoharyi* also occur). *Homotryblium floripes* is subordinate. Additionally, infrequent *Spiniferites pseudofurcatus* and *Lingulodinium machaerophorum*, and rare *Pentadinium* sp. and *Homotryblium vallum* occur. A single specimen, questionably determined as *Impagidinium* sp., was found. In addition to all these forms mentioned above, infrequent, commonly incomplete specimens of extremely pale-coloured taxa *Areoligera*, *Glaphyrocysta*, *Areosphaeridium michoudii*?, *Enneadocysta* and *Adnatosphaeridium* occur. A single specimen of *Batiacasphaera compta* (Gen. et spec. indet. of Gedl, 2013, p. 151, fig. 84E, H, I) was found.

Pds-2. The palynofacies of this sample is very similar to the one from sample Pds-1. The proportion of dinoflagellate cysts is approximately 10%. The taxonomical composition and preservation are similar. The dominant species are *Cleistosphaeridium placacanthum* and *Polysphaeridium subtile*, the other taxa include *Spiniferites pseudofurcatus*, *Homotryblium floripes*, and *Lingulodinium machaerophorum*.

This sample, like sample Pds-1, yielded very pale-coloured dinoflagellate cysts: e.g., *Areosphaeridium diktyoplokum*, *Glaphyrocysta* sp., ?*Enneadocysta arcuata*, and *Batiacasphaera compta*.

**Jzf-3.** The sample contains relatively infrequent dinoflagellate cysts; compared to the samples from Pardysówka, they are more poorly preserved: the majority are extremely pale-coloured. However, their taxonomical composition is similar: *Cleistosphaeridium placacanthum* dominates (40%), *Polysphaeridium subtile* is also common (Fig. 6). *Lingulodinium machaerophorum*, *Spiniferites pseudofurcatus*, *Homotryblium* spp. are subordinate. Rare *Areosphaeridium michoudii* and *Glaphyrocysta* spp. occur.

**Jzf-4.** Sample contains palynological organic matter, which consists almost exclusively of black opaque phytoclasts. Palynomorphs are extremely rare: they include dinoflagellate cysts (*Polysphaeridium subtile*, *Spiniferites pseudofurcatus* and *Cleistosphaeridium placacanthum*; Fig. 6) and very rare bisaccate pollen grains. Dinoflagellate cysts are well preserved and pale-coloured.

**Żlb-1.** The palynofacies of this sample is different from those of the samples from Józefów and Pardysówka. It consists of predominating sporomorphs (mainly pollen grains); easily disintegrable black opaque phytoclasts are subordinate. Aquatic palynomorphs are represented almost exclusively by *Leiosphaeridia* (a single specimen of poorly preserved *Polysphaeridium subtile* was found). Both sporomorphs and *Leiosphaeridia* are excellently preserved: they are pale-coloured and their wall structure is intact.

*Leiosphaeridia* (presumably a prasinophycean alga; see Guy-Ohlson, 1996) from Żlb-1 is compressed, subspherical to ovoid; it has a very delicate, unornamented, very thin and uniform wall with dense folding; neither perforations nor openings appear.

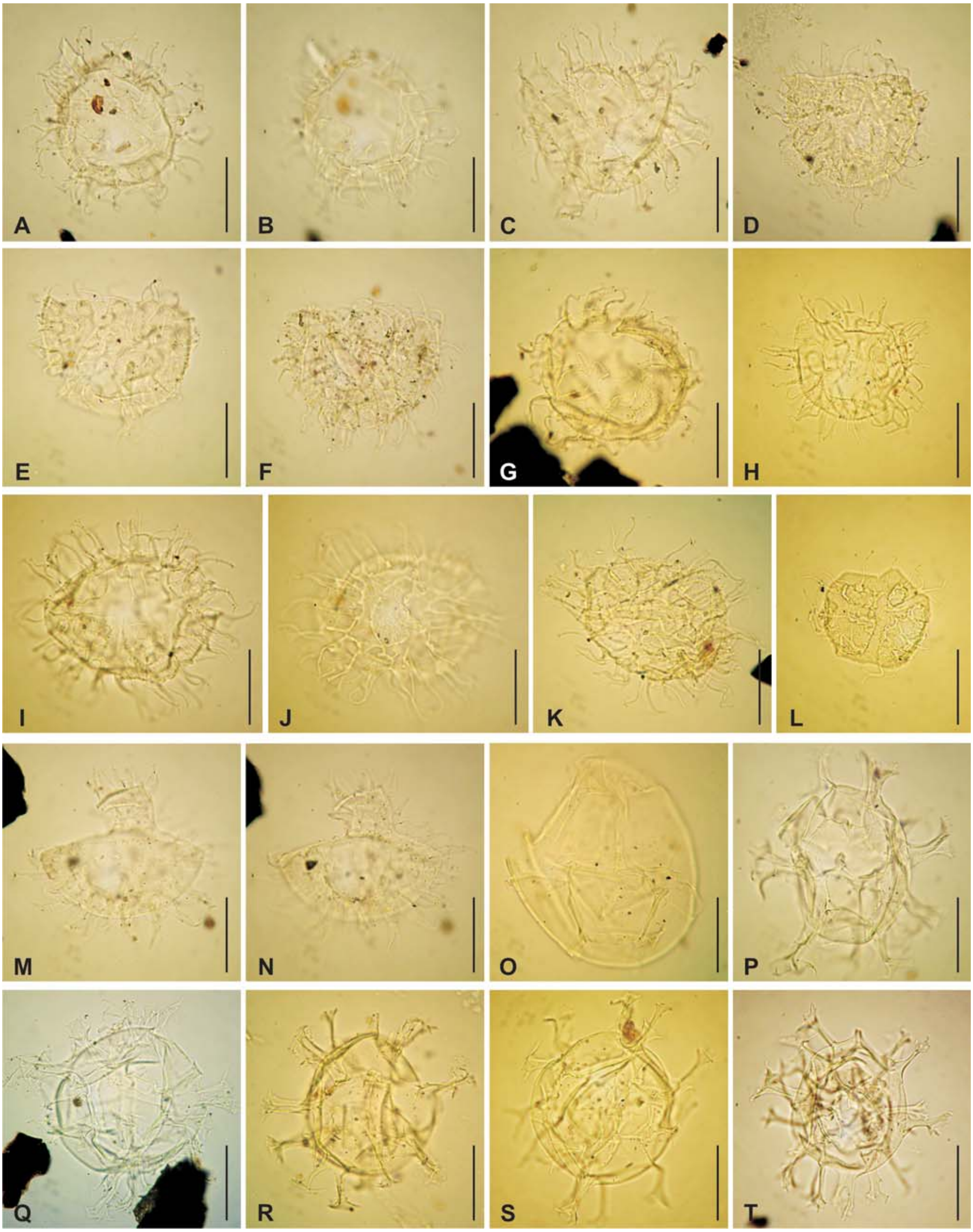


**Fig. 7.** Dinoflagellate cysts from upper Badenian at Józefów. Scale bars = 25 µm. **A–L.** *Cleistosphaeridium placacanthum* (A–F, I, J: Pds-2; A, B – same specimen, various foci; G, H, K, L: Pds-1; L – isolated operculum). **M, N.** *Lingulodinium machaerophorum* (same specimen with 5P archaeopyle, various foci; Pds-2); O. *Pentadinium* sp. (Pds-1). **P–T.** *Spiniferites pseudofurcatus* (P, Q: Pds-2; R–T: Pds-1).

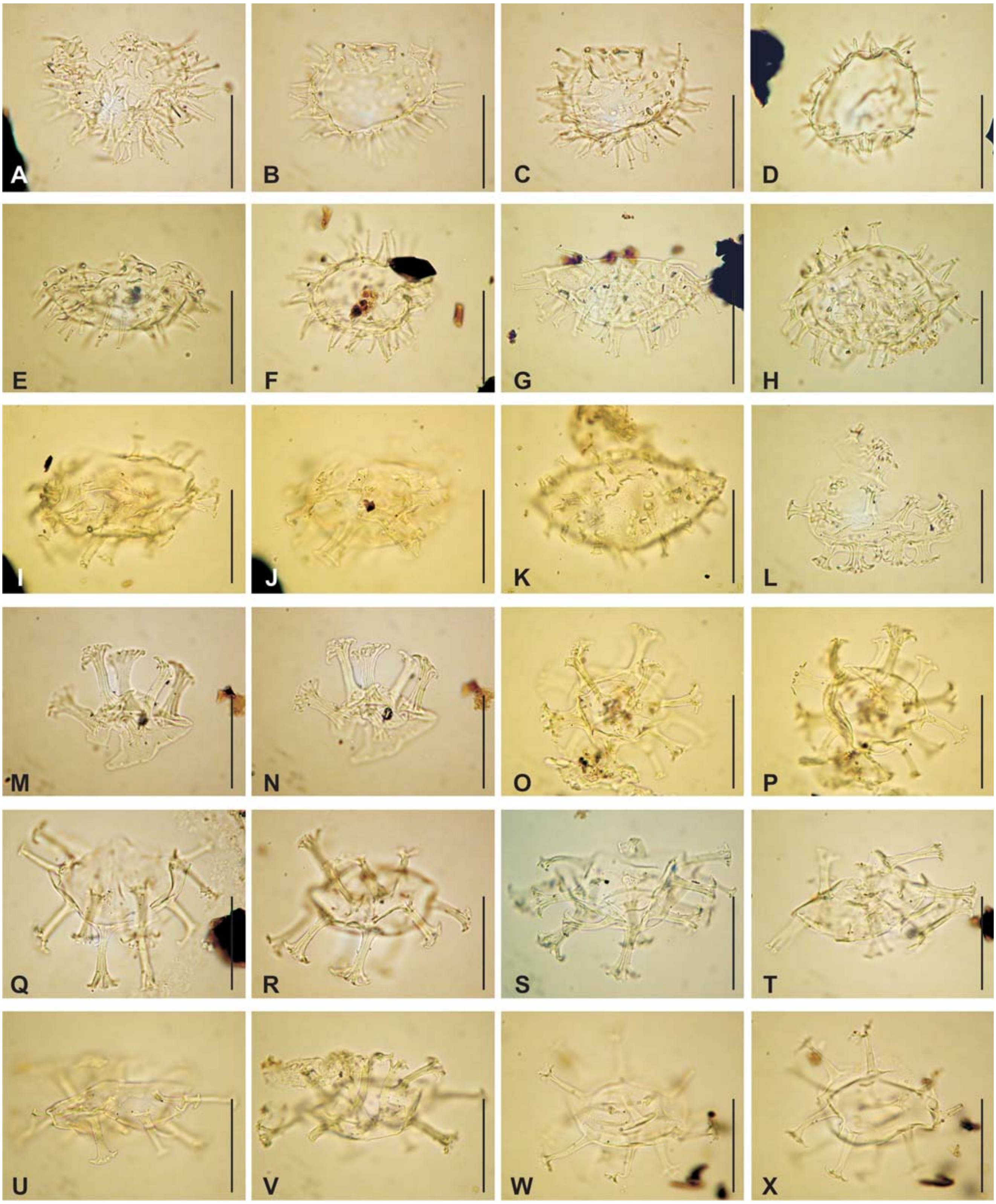


**Fig. 8.** Dinoflagellate cysts from upper Badenian at Józefów. Scale bars = 25 µm. **A–F.** *Polysphaeridium subtile* (A–E: Pds-1; F: Pds-2; B, C: same specimen, various foci); **G–K.** *Polysphaeridium zoharyi* (all specimens: Pds-1; J, K: same specimen, various foci); **L.** *Homotryblium vallum* (presumably reworked; Pds-1); **M–S.** *Homotryblium floripes* (M–R: Pds-1; S: Pds-2; M, N and O, P: same specimens, various foci); **T–V.** *Homotryblium plectilum* (all specimens: Pds-2); **W, X.** *Homotryblium tenuispinosum* (Pds-2; same specimen, various foci).

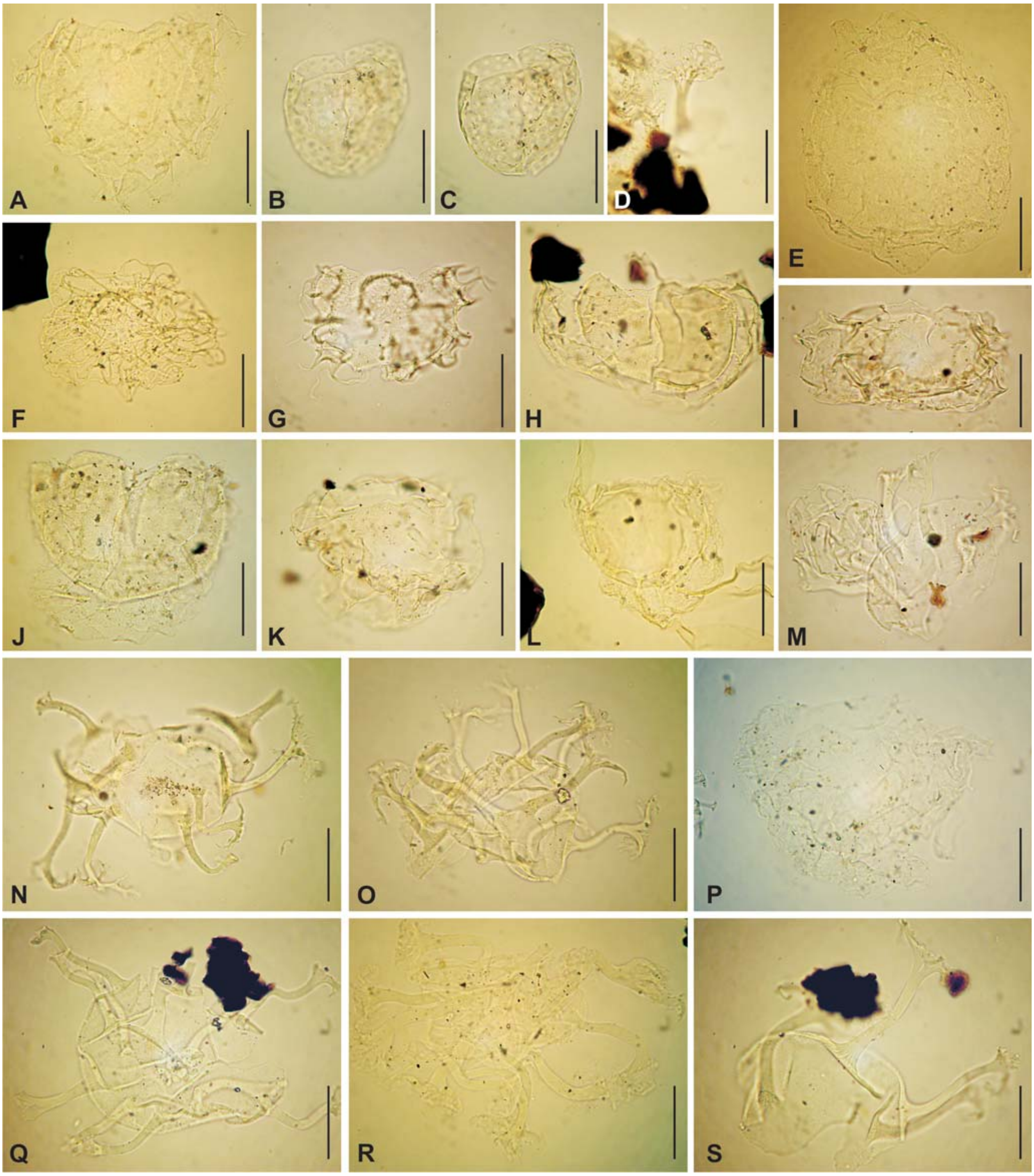


**Fig. 9.** Dinoflagellate cysts from upper Badenian at Józefów. Scale bars = 25 µm. **A.** *Glaphyrocysta* sp. (Pds-2). **B, C.** *Batiacasphaera compta* (same specimen, various foci; Pds-2). **D.** *Areosphaeridium diktyoplokum* (isolated paraplate, presumably from operculum; Pds-2). **E.** *Membranophoridium aspinatum* (Pds-1). **F.** *Adnatosphaeridium multispinosum* (Pds-1). **G.** *Areoligera* sp. (Pds-1). **H.** *Glaphyrocysta* sp. (Pds-2). **I.** *Glaphyrocysta* sp. (Pds-1). J. *Glaphyrocysta* sp. (Jzf-1). **K.** *Glaphyrocysta* sp. (Pds-2). **L.** *Glaphyrocysta* sp. (Pds-1). **M.** Two specimens: *Enneadocysta* sp. (left side), *Areosphaeridium michoudii* (right side; Pds-1). **N.** ?*Enneadocysta arcuata* (Pds-2). **O.** *Areosphaeridium michoudii* (Pds-2). **P.** *Glaphyrocysta* sp. (Pds-2). Q. *Areosphaeridium michoudii* (Pds-1). **R.** *Areosphaeridium michoudii* – a very transparent, pale specimen (Pds-1). **S.** n *Areosphaeridium michoudii* (Pds-1).

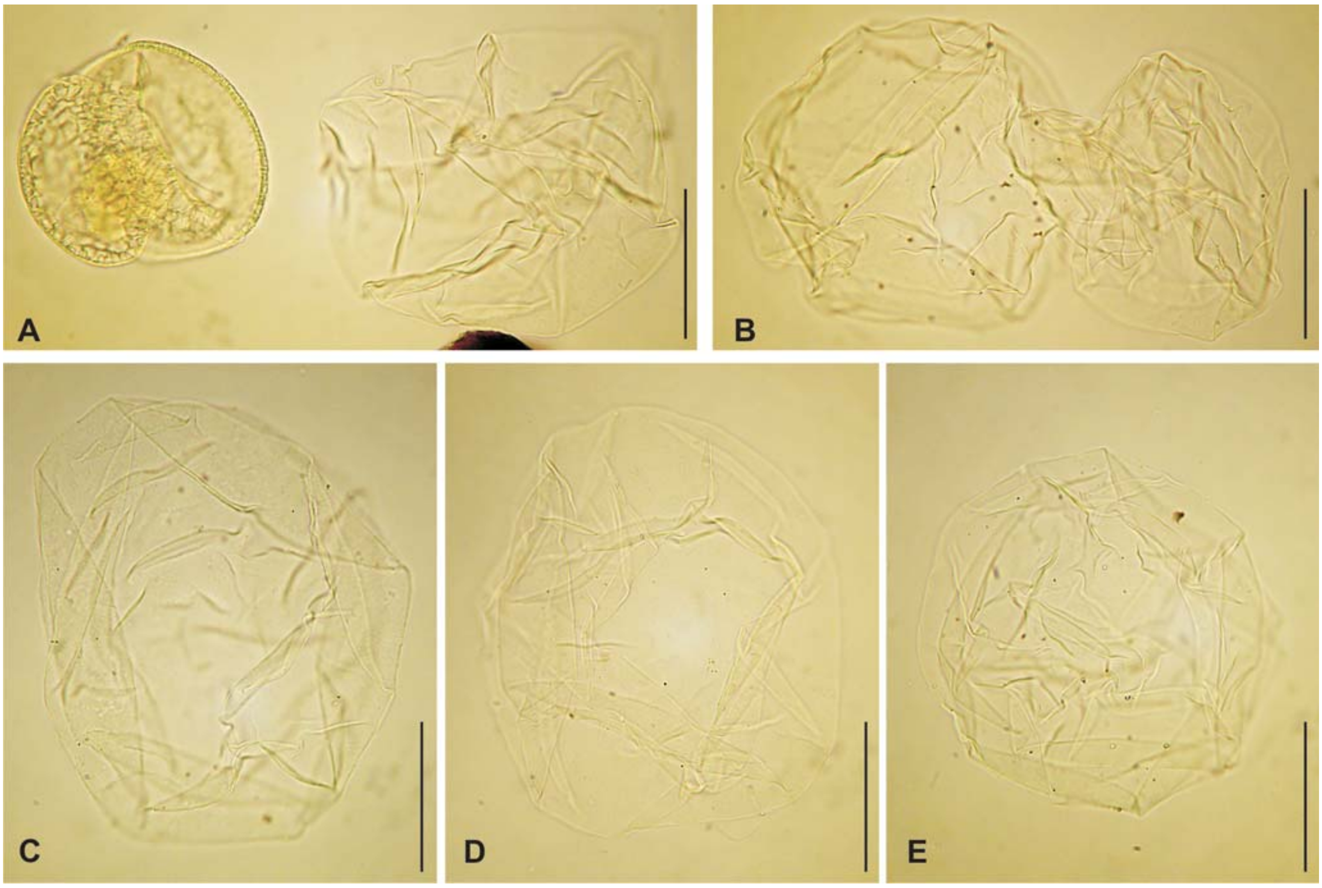


**Fig. 10.** Aquatic palynomorphs and sporomorphs from uppermost Badenian marly clay layer at Żelebsko. Scale bars = 25 μm. **A.** Bisaccate pollen grain (left side) and *Leiosphaeridia* sp. (right side; Żlb-1). **B.** Two specimens of *Leiosphaeridia* sp. (Żlb-1). **C–E.** *Leiosphaeridia* sp. (Żlb-1).

## INTERPRETATION

The presence of palynological material in the clay layers in organodetrital limestone may serve as an indicator of palaeoenvironmental conditions and their changes during deposition of the upper Badenian sequence at the sites studied. However, a serious impediment to palaeoenvironmental reconstruction is the presence of reworked Palaeogene dinoflagellate cysts and difficulties in differentiating them from *in situ* forms. It is important to note that none of the forms described has a known stratigraphic range that starts in the Middle Miocene.

### Reworked Palaeogene dinoflagellate cysts

A significant part of dinoflagellate cysts assemblages from upper Badenian of Józefów is believed to have been reworked. This refers to all these taxa, which have known stratigraphic ranges limited to pre-Middle Miocene times (asterisked in Fig. 6). Their state of preservation does not differ significantly from that of other forms, which might be *in situ* specimens. Only some of them show a slightly worse preserved wall structure by being thinner and more pale-coloured than other specimens. The precise status of the forms treated here as *in situ* is disputable because of their long stratigraphic range that spans both the Palaeogene and the Miocene. In this case, their interpretation as *in situ* forms is based on a comparison with their frequent occurrences in other coeval Carpathian Foredeep sections, where reworked Palaeogene forms are not present.

The taxa *Cleistosphaeridium placacanthum*, *Lingulodinium machaerophorum*, *Pentadinium* sp., *Polysphaeridium subtile*, *P. zoharyi*, and *Spiniferites pseudofurcatus* are well known from Palaeogene and Miocene strata (e.g., Stover *et al.*, 1996). They all occur in the upper Badenian post-evaporitic strata of the Ukrainian part of the Roztocze, where they occur as the most frequent dinoflagellate cysts (Gedl and Peryt, 2011; Peryt *et al.*, 2014). Although less frequent, they also occur in the post-evaporitic karst filling in the Ukrainian part of the Carpathian Foredeep Basin (Andreychouk *et al.*, 2014), and in the post-evaporitic basinal facies of the Polish part of the Carpathian Foredeep Basin (Gedl, 1997, 1999). This, but in particular their frequent occurrence in neighbouring sections of the Ukrainian Roztocze, makes it likely that these taxa are *in situ* in the sections studied.

Taxa *Adnatosphaeridium multispinosum*, *Areoligera* sp., ?*Areosphaeridium michoudii*, *Areosphaeridium diktyoplokum*, *Cordosphaeridium gracile*, *Enneadocysta* sp., ?*Enneadocysta arcuata*, *Glaphyrocysta* spp., *Homotryblium tenuispinosum*, and *Membranophoridium aspinatum* are treated as reworked, since they appeared for the last time before the Miocene; their known stratigraphic ranges (e.g., Köthe, 1990, 2003; Powell, 1992; Bujak and Mudge, 1994; Stover *et al.*, 1996; Williams *et al.*, 2004; Köthe and Piesker, 2007) indicate that they were derived from eroded Middle–Upper Eocene strata. Noteworthy is the fact that reworked dinoflagellate cysts are represent exclusively by gonyaulacoids; there are no peridinioids.

These criteria cannot be used in the case of a long-ranging genus *Impagidinium*, represented by a single poorly preserved specimen that is questionably assigned to this genus (sample Pds-1); neither the state of preservation nor a comparison with its distribution pattern in the Miocene of the Carpathian Foredeep Basin can be taken as unequivocal evidence that it is reworked or *in situ*. Other problematic species are the morphologically similar *Homotryblium floripes*, *H. plectilum*, and *H. vallum* (included in a morphological complex by de Verteuil and Norris, 1996, p. 22). Determining whether they are reworked or not is significant, because *Homotryblium* is an important genus for palaeoenvironmental reconstructions: it is widely associated with nearshore, littoral environments and commonly with increased salinity (e.g., Köthe, 1990; Brinkhuis, 1994; Pross and Schmiedl, 2002), although Dybkjær (2004) linked this genus to decreased salinity (see Sluijs *et al.*, 2005, p. 296–297 for discussion). Most authors report their Lower Miocene (mostly uppermost Aquitanian–lowermost Burdigalian) or older highest occurrences in north-western Europe, the North Sea, and North America (e.g., Edwards, 1986; Powell, 1992; de Verteuil and Norris, 1996; Stover *et al.*, 1996; Munsterman and Brinkhuis, 2004; Köthe, 2007; Köthe and Piesker, 2007). Their similar upper range limits are reported from the Tethyan domain (e.g., Powell, 1986a, b; Soliman and Piller, 2007). Although some authors (e.g., Wrenn and Kokinos, 1986; Dybkjær and Piasecki, 2010) have reported the occurrence of *Homotryblium* in Upper Miocene or even younger strata, these occurrences are most likely the results of reworking (see de Verteuil and Norris, 1996, p. 20, 22 for full list of references and discussion). The distribution of *Homotryblium* in Middle Miocene of Carpathian Foredeep Basin in Poland further supports the conclusion of de Verteuil and Norris (1996). This genus is missing in the majority of sections studied and if present, it occurs as evidently reworked (poorly preserved specimens from the Carpathian Palaeogene; e.g., Gedl, 1999) or associated by other evidently reworked specimens (e.g., Gedl, 1999, 2005). In summary, *Homotryblium floripes*, *H. plectilum*, and *H. vallum*, found in the upper Badenian at Józefów are almost certainly reworked.

## Palaeoenvironment reconstruction

The presence of very rare and thin layers of fine-grained clastics within the generally coarse-grained upper Badenian organodetrital limestone (biocalcarenites and biocalcirudites) in the Roztocze indicates short periods of calmer sedimentation. They were presumably much more frequent than one would infer from the rare remaining clay layers, because the high-energy hydrodynamics of the bottom waters would be responsible for large-scale movement of the coarse-grained material (see e.g., Wysocka, 2002, 2006b), presumably causing synsedimentary erosion of such layers. The palynomorphs preserved in these clay layers can serve as indicators of the intensity of terrestrial influx and hence, indirectly, distance from the shore. The composition of dinoflagellate cyst assemblages may be helpful in tracing of water salinity changes.

**Distance from shore and intensity of terrestrial input.** An outstanding feature of palynofacies from the upper Badenian at the Pardysówka and Józefów quarries is the lack of sporomorphs. Their absence contrasts with very abundant occurrences of sporomorphs (particularly bisaccate pollen grains) in coeval basinal facies of the Carpathian Foredeep Basin (e.g., Gedl, 1999). The absence of terrestrial palynomorphs and phytoclasts indicates an almost complete lack of land influence in these marginal part of the foredeep basin during the late Badenian. The sedimentary settings of the Józefów successions must have been separated from areas, through which huge amounts of terrestrial palynodebris were transported into the nearby offshore basin (i.e., river mouths). The coeval post-evaporitic deposits from the central areas of the Carpathian Foredeep Basin contain huge amounts of cellular land-plant debris and sporomorphs (e.g., Gedl, 1999). It is likely that pollen grains, as highly buoyant particles, were "swept away" by water currents (so typical for the marginal facies of the Roztocze; see e.g., Wysocka, 2002) into more offshore, basinal areas. The lack of pollen grains in the deposits studied may be linked to the so-called "Neves effect" of Chaloner and Muir (1968), which assumes that the frequency of sporomorphs, which are transported from the place of origin to the marine realm, is inversely related to the distance from the source to depositional area. In this case, the nearshore sedimentary setting of Józefów would be devoid of pollen grains, in contrast to the more remote areas.

The dinoflagellate cysts from the Józefów sections indicate a rather nearshore, littoral environment. This conclusion is based on the frequent occurrence of *Polysphaeridium*, which is a typical littoral genus (e.g., Wall and Dale, 1969; Bradford and Wall, 1984), and *Cleistosphaeridium placacanthum*, which although cosmopolitan, commonly occurs in proximal settings (Gedl and Peryt, 2011; Peryt *et al.*, 2014). The latter comment also is applicable to *Lingulodinium machaerophorum*; Morzadec-Kerfourn (1983) described a *Lingulodinium machaerophorum* Association from inner coastal waters with a depth of 10–30 m. Gedl and Peryt (2011) interpreted an assemblage, composed of *Cleistosphaeridium placacanthum* and *Lingulodinium machaerophorum*, as typical for proximal settings; more offshore settings in the upper Badenian of the Roztocze are characterized by the frequent occurrence of *Operculodinium*, a genus that is not present in the sections studied. This general littoral, shallow-water character of the dinoflagellate cyst assemblage at Józefów is supported by the lack of offshore taxa, such as *Nematosphaeropsis* and *Impagidinium* sp. (see e.g., Morzadec-Kerfourn, 1977; Wall *et al.*, 1977; Harland, 1983; Brinkhuis, 1994). A single specimen, questionably identified as *Impagidinium* and found in sample Pds-1, if not reworked (see subchapter above), may indicate the weak influences of offshore waters. This genus, which is important for palaeoenvironmental reconstructions, is evidently environmentally controlled in the coeval, marginal upper Badenian deposits of the Ukrainian Roztocze, because it is absent in samples from marginal settings and rare or common in samples that yielded more offshore microfossils (Gedl and Peryt, 2011; Peryt *et al.*, 2014). *Impagidinium* is also known from the pre-evaporitic lower Badenian deposits of the Polish part of the Carpathian Foredeep Basin, where it commonly occurs in offshore facies, such as the Skawina Beds or the Baranów Beds (e.g., Gedl, 1995). Rare specimens of this genus were also found in more proximal facies, such as the Korytnica Clay (Gedl, 1996). The post-evaporitic strata of the basinal facies of the Carpathian Foredeep Basin contain frequent *Impagidinium*, especially in the lower parts, whereas it is commonly absent from the upper parts (Gedl, 1997, 1999). The approximately coeval clay of the Zoloushka Cave yielded rare specimens of this genus (Andreychouk *et al.*, 2014).

The frequent occurrence of bisaccate pollen grains at Żelebsko, compared to their scarcity at Józefów, may be related either to calmer sedimentation and/or increased pollen productivity by coniferous trees in the hinterland areas.

**Salinity.** Taxonomical impoverishment of dinoflagellate cyst assemblages from the upper Badenian of Pardysówka and Józefów points to restricted conditions. This and the high frequency of *Polysphaeridium* may indicate that the marine waters of the Roztocze during the late Badenian were characterized by increased salinity. *Polysphaeridium* is a genus widely associated with nearshore environments in tropical to sub-tropical settings, because it is tolerant of hypersaline conditions (Wall and Dale, 1969; Dale, 1976; Wall *et al.*, 1977; Morzadec-Kerfourn, 1979, 1983; Bradford and Wall, 1984). However, Marret and Zonneveld (2003) and Edwards and Andrle (1992) associated *P. zoharyi* with brackish environments and suggested that it was euryhaline. *Lingulodinium machaerophorum*, a relatively common species in the Józefów assemblages (Fig. 6), is believed to be a euryhaline species (e.g., Wall and Dale, 1973; Dale, 1996) with process length, according to some authors (e.g., Ellegaard, 2000; Mertens *et al.*, 2012), related to salinity level. However, the data presented show no indications of freshwater influences. These would be freshwater algae (e.g., *Botryococcus* and/or *Pediastrum*) or increased numbers of land-plant remains; both are missing in the material studied. Therefore, rather slightly increased salinity can be suggested during deposition of the successions at Józefów.

A possible further salinity increase might have taken place during the latest Badenian in the Roztocze. This is suggested on the basis of the palynological assemblage, found in sample Żlb-1 from the Żelebsko Quarry. This sample contains almost no dinoflagellate cysts (a single specimen of *Polysphaeridium subtile* was found), but it yielded very frequent *Leiosphaeridia*. Such an assemblage of aquatic palynomorphs points to conditions hostile for dinoflagellate cysts, perhaps except for *Polysphaeridium*, and favourable for *Leiosphaeridia*, which occurs as infrequent specimens in older samples from the Pardysówka and Józefów quarries (Fig. 6). Salinity increase seems to be the most logical explanation of the palaeoenvironmental conditions of the Żelebsko aquatic palynomorphs. Salinity decrease is unlikely, because no indications of freshwater and/or brackish environment have been found. Although the palaeoenvironmental preferences of *Leiosphaeridia* sp. are enigmatic, this form, known from the Precambrian from a variety of sedimentary environments, was frequently associated with nearshore, restricted settings (e.g., Riegel, 1974). This genus was also associated with hypersaline conditions (e.g., Brugman *et al.*, 1994). Similar, the hypersaline environmental preferences of *Leiosphaeridia* can be deduced on the basis of its occurrence in the Miocene of the Carpathian Foredeep Basin, where it was found in evaporitic series (e.g., Gedl, 1997, 2004; Gedl *in* Peryt *et al.*, 1997) or in strata closely overlying these deposits (e.g., it commonly occurs in the *Pecten* Beds, overlying evaporitic deposits in the Jamnica S-119 borehole; Gedl, 1999).

## DISCUSSION

### Palaeoenvironment

Sedimentological data indicate rather a shallow-water setting during the accumulation of the upper Badenian organodetrital series at Józefów (Wysocka, 2002). The dinoflagellate cyst assemblages from Józefów, although they cannot be treated as direct indicators of water depth owing to the planktonic mode of life of their motile stages, are rather typical for inshore environments. The frequent occurrence of *Polysphaeridium* and taxonomically impoverished assemblages, indicate not only a shallow-water environment, but also a restricted, lagoonal environment (see e.g., Bradford and Wall, 1984). This contrasts with the interpretations by Wysocka (2002) who implies a rather open-sea environment, and the results of Szczechura (*in* Wysocka, 2002; *in* Jasionowski *et al.*, 2006), who found shallow-water, benthonic foraminifera that are typical of open-sea environments in the Józefów succession. Additionally, Szczechura found rare planktonic foraminifera, which even more evidently indicate the offshore character of the marine basin at Józefów. It is possible that *Polysphaeridium* and other *in situ* forms are resedimented from lagoonal environments by offshore water currents, which are known from sedimentological analysis (Wysocka, 2002). In such a case, the rare occurrence of *Impagidinium* would be a result of mixing with offshore waters. However, such a scenario would imply a more diversified dinoflagellate cyst assemblage with taxa like *Spiniferites ramosus*, *Operculodinium centrocarpum* and *Nematosphaeropsis labyrinthus*, all of which are missing in the material studied.

The restricted conditions of the late Badenian sea of the Roztocze, implied on the basis of present study, are related to changes in water salinity. The frequent occurrence of *Polysphaeridium*, and subsequent monospecific blooms of *Leiosphaerida* may reflect at first slightly increased (late Badenian; Józefów and Pardysówka), then more increased (latest Badenian; Żelebsko) salinity. In contrast, the foraminiferal record from Józefów points to normal marine conditions (Szczechura *in* Wysocka, 2002; *in* Jasionowski *et al.*, 2006). Data from sedimentological analysis (Wysocka 2002) show stenohaline calcareous algae (order Rhodophyta, family Corallinaceae) as the main component of the Badenian organodetrital limestone of the Roztocze (with subordinate ratios of other stenohaline fossil groups, such as echinoids), and indicate normal-marine salinity. A possible explanation of this inconsistency may be differences in "sensitivity" of particular fossil groups to salinity changes. The dinoflagellate cyst assemblages from the other upper Badenian sections in Roztocze show taxonomical diversity that reflects environmental fluctuations (Gedl and Peryt, 2011; Peryt *et al.*, 2014). Their diversity spans monospecific *Polysphaeridium* assemblages, reflecting most restricted, likely high-saline conditions, through *Polysphaeridium -Cleistosphaeridium* dominated assemblages, to diversified assemblages, reflecting relatively normal marine conditions. The Józefów and Pardysówka samples yielded assemblages that resemble those in samples K and L collected from the base of the rhodoidal complex, just above the Ratyn Limestone at Kudryntsi (Ukraine; Gedl and Peryt, 2011). Foraminifera from these samples, dominated by spiny elphidiids and miliolids, were interpreted as typical for shallow-marine waters with slightly increased salinity.

Another explanation would imply salinity stratification between the bottom-water environment, inhabited by benthic foraminifera and rhodoliths, and much more saline surface waters. But the high-energy environment, as deduced on the basis of e.g., rhodolith shapes (Jasionowski and Wysocka, 1997) in the case of such a shallow environment makes this explanation unlikely.

### Reworked Palaeogene

The presence of frequent and well preserved specimens of Palaeogene dinoflagellate cysts in the upper Badenian studied indicates the intense erosion of Palaeogene strata. This is a common phenomenon in the Polish part of the Miocene Carpathian Foredeep Basin (see Gedl, 2012). There are two sources of Palaeogene specimens: the deep-water flysch strata of the folded Carpathian nappes and the epicontinental sandy deposits of Carpathian foreland (Gedl, 2005, 2012). Reworked specimens found at the Józefów and Pardysówka quarries originated from the latter source, being practically the only trace of epicontinental marine Palaeogene deposits in SE Poland. Their stratigraphic ranges indicate that they were derived from the Middle–Upper Eocene deposits that now are missing in south-eastern Poland; the erosional southern boundary of the continuous cover of Eocene lies on the northern slopes of the Lublin Upland (e.g., Piwocki, 2004). South of this boundary, scattered spots of sandy deposits occur (see Buraczyński and Krzowski, 1994 for a review). Among them, only a few have ages that have been well documented palaeontologically; they occur in the so-called Sołokija Graben near Tomaszów Lubelski (Gaździcka, 1994; see also Cieśliński and Rzechowski, 1993; Rzechowski, 1997; Piwocki, 2002) and in the vicinity of Tarnogród (Myśliwiec and Śmist, 2006; Gedl, 2015).

There are no exclusively Oligocene species among those found in the samples studied. This excludes the Oligocene epicontinental deposits, recognized in the neighbourhood (Gedl, 2000; Myśliwiec and Śmist, 2006) as a source of reworked dinoflagellate cysts. Although *Homotryblium vallum* is treated by some authors as a Late Oligocene–Early Miocene species (Stover *et al.*, 1996), it is also known from Eocene marginal strata of the Flysch Carpathian Basin (Gedl, 2013). Interestingly, in the same strata is *Batiacasphaera compta* (Gen. et spec. indet. of Gedl, 2013; Bartonian–Priabonian: Williams and Bujak, 1985), which was found in the Pardysówka samples (Fig. 9B, C). This may indicate some connections between these two areas in the Eocene (see Gedl, 2012).

Another source for reworked dinoflagellate cysts might be the sands that underlie the chemical and supra-evaporitic deposits of the Miocene succession at Roztocze. Frequent *Homotryblium floripes*, *H. plectilum* and *H. vallum* have been found there recently (Gedl, 2016). *Homotryblium floripes* occurs also in the Eocene strata in the vicinity of Tarnogród (Gedl, 2015) and in the Upper Eocene strata of the Sołokija Graben (Gedl, 2014).

## CONCLUSIONS

1. Very rare, fine-grained intercalations that occur within medium- and coarse-grained, organodetrital limestone of late Badenian age at three sites in the Roztocze (Józefów, Pardysówka and Żelebsko quarries) yielded palynological organic matter; this contrasts with surrounding organodetrital limestone that is barren.

2. Palynofacies of clay samples from the upper Badenian of Józefów and Pardysówka quarries is dominated by black opaque phytoclasts. Palynomorphs are represented almost solely by dinoflagellate cysts. The palynofacies of an uppermost Badenian sample from the Żelebsko Quarry, in turn, is dominated by bisaccate pollen grains; aquatic palynomorphs are represented by very frequent *Leiosphaeridia*, which are rare in older samples; there are practically no dinoflagellate cysts.

3. Dinoflagellate cyst assemblages from the Józefów and Pardysówka quarries consist of specimens that were reworked from Eocene strata and specimens believed to be *in situ*. The latter are taxonomically impoverished: they are dominated by *Cleistosphaeridium placacanthum* and *Polysphaeridium* specimens, whereas *Lingulodinium machaerophorum* and *Spiniferites pseudofurcatus* are subordinate; rare specimens of *Pentadinium* occur. A single specimen of *Polysphaeridium subtile* was found in the Żelebsko sample; no reworked dinoflagellate cysts were found there.

4. The composition of the organic assemblages is interpreted as an indication of a near-shore sedimentary setting, characterized by a lack of terrestrial influences. Lagoonal, slightly restricted conditions, manifested mainly by slightly increased salinity, can be suggested for the upper Badenian successions of Józefów and Pardysówka. A similar sedimentary setting, but with presumably higher water salinity that was favourable for *Leiosphaeridia*, is indicated for the uppermost Badenian at Żelebsko.

The dinoflagellate cyst assemblages from Józefów and Pardysówka are similar to assemblages from coeval strata in the Ukrainian part of the Roztocze, in which the sedimentary setting was interpreted as a shallow-marine environment with slightly increased salinity. No comparable *Leiosphaeridia*-dominated assemblage has been found so far in the upper Badenian of the Carpathian Foredeep Basin. Similar assemblages were found in middle Badenian chemical strata of the basinal part of the Carpathian Foredeep Basin.

5. The frequent occurrence of reworked Palaeogene dinoflagellate cysts at Józefów and Pardysówka points to erosion of epicontinental Middle–Upper Eocene in this part of the Carpathian Foredeep Basin during the late Badenian.

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