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STRATIGRAPHICAL AND ECOLOGICAL SIGNIFICANCE OF EARLY EOCENE RADIOLARIANS FROM THE SUBSILESIAN SERIES, POLISH FLYSCH CARPATHIANS

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Abstract: Variegated shales in the Early Eocene hemipelagic deposits of the Subsilesian series, Polish part of the Western Carpathians, have yielded rich siliceous microfossils comprising abundant radiolarians and rare diatoms. Forty-three radiolarian taxa have been recognised.

One new radiolarian species, *Amphisphaera subsilesianensis* n. sp. was described. The assemblage represents the *Phormocyrtis striata striata* radiolarian Zone of the tropical oceans. The deposits investigated have also yielded abundant agglutinated foraminifera which correlate with the lower Eocene *Saccamminoides carpathicus* foraminiferal Zone. The radiolarian assemblage comprises a low content of taxa characterising cool, oligotrophic water masses which also occur in the upper Paleocene deposits of the Subsilesian series. Most part of the assemblage is represented by abundant radiolarian species characteristic of tropical domain, which may indicate the incursion of warm water masses into the Subsilesian Basin during the Early Eocene Climatic Optimum Period.

Key words: Radiolaria, biostratigraphy, EECO, lower Eocene, Carpathians.

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INTRODUCTION

The Palaeogene represents one of the most climatically dynamic periods in Earth history. Reconstructions based on stable isotope record reveal a complex history of warming and cooling (Miller *et al.*, 1987; Miller & Katz, 1987; Stott & Kennett, 1989; Zachos *et al.*, 1994, 2001). This includes a gradual global warming trend that began in the late Paleocene and climaxed in the early Eocene (Early Eocene Climatic Optimum [EECO]), and a stepwise cooling trend that began in the early middle Eocene and culminated in the earliest Oligocene with the appearance of continental ice sheets (Hambrey *et al.*, 1991; Zachos *et al.*, 1992).

The EECO represents episode of sustained global warmth for 1–2 m. y. The isotopic data indicate that the high-latitude seas and bottom waters were warmer than today, leading to rise in the global mean temperature (Miller *et al.*, 1987; Shackleton & Boersma, 1981; Zachos *et al.*, 1994; Stott & Kennett, 1989). Marine and terrestrial biota responded to the changing of the climatic condition. The biogeographic ranges of subtropical to temperate fauna and flora extended even into polar latitudes (Axelrod, 1984; Estes & Hutchison, 1980; Wolfe, 1980).

Some radiolarian specimens seem to be exceptionally sensitive to water temperature change during the Palaeogene. They are present into restricted temperature ranges, and allow to define paleogeographically delimitated assemblages that characterise warm-water through cold-water conditions. Therefore, radiolarians have been successfully used for estimation of palaeotemperatures in this period (e.g., Maclean *et. al.*, 2003).

Herein we describe and interpret an abundant Eocene radiolarian assemblage, found for the first time in the Subsilesian series of the Polish Flysch Carpathians. The deposits investigated have yielded not only radiolarian species, but also diatoms and abundant agglutinated foraminifers which provide a good correlation between radiolarian and foraminiferal biochronologies. The fauna presented in this paper gives a new palaeontological and biostratigraphical information about the Eocene deposits of the Subsilesian series, and is important for correlation and distribution of the Palaeogene radiolarian assemblages, which strongly reflect the Cenozoic biogeographic pattern.

OUTLINE OF PREVIOUS STUDIES

There are numerous studies on Eocene radiolarians from different localities of the world. Many of the radiolarian assemblages have been reported and described, and new radiolarian zonation schemes have been proposed for distinctive biogeographic pattern (i. e., Sanfilippo *et al.*, 1985; Sanfilippo & Blome, 2001; Sanfilippo & Nigrini, 1998). In contrast, very little work has been done on radiolarians of this age from the Carpathians.

Eocene radiolarian fauna in the Outer Western Carpathians was first documented from the Polish part of the Skole series in the early 1990's. Bąk (1995) and subsequently Bąk *et al.* (1997) reported early to middle Eocene radiolarians from central part of the Skole series, determined thirty species, and recognized three radiolarian biozones: *Buryella clinata*, *Phormocyrtis striata striata*, and *Theocotyle cryptocephala cryptocephala*. Bąk *et al.* (1997) additionally correlated these radiolarian biozones with agglutinated foraminiferal zones.

Afterwards, new localities with well-preserved Eocene radiolarians were found and attempts were made at determinating stratigraphy and palaeoecology of the radiolarian-bearing strata. Rajchel *et al.* (1999) reported early to middle Eocene radiolarians from selected land sections of the eastern part of the Skole series, determined about 60 species, and recognizsed four radiolarian zones (*Becoma bidartensis*, *Buryella clinata*, *Phormocyrtis striata striata*, and *Theocotyle cryptocephala cryptocephala*) and correlated them with the agglutinated foraminiferal zonal scheme.

GEOLOGICAL SETTING

The Polish Carpathians comprise the northern part of the Carpathian Mountains, which is a part of the Alpine mountain chain. The Carpathians can be subdivided into two principal tectonic zones: the Inner and Outer Carpathians. The boundary between these two zones is marked by a narrow, tectonically complicated zone – the Pieniny Klippen Belt. The Outer Carpathians, also known as the Flysch Carpathians, contain several tectonic units, the deposits of which were laid down in separate basins, consisting of several longitudinal troughs and ridges, developed on the thinned continental crust of the southern margin of the Northern European Platform. The sedimentation composed mainly of turbidites, spanned the time between the late Jurassic and the late Miocene.

During the Palaeogene period, deep marine sedimentation continued in all the Outer Carpathian basins. At that time, the Subsilesian deposits were formed above CCD, and variegated marls and shales developed. The sedimentation of these deposits in the Subsilesian basin continued from the Cenomanian to the late Eocene (e.g., Książkiewicz, 1962; Bieda *et al.*, 1963; Geroch & Gradziński, 1965). Similar red and variegated facies also occur in other parts of the Carpathians, as well as in the Alps, Appenines, North Atlantic, and Pacific (e.g., Andrusov, 1959; Stefanescu & Micu, 1987; Moullade & Thurow, 1988; Kuhnt *et al.*, 1989; Kuhnt & Kaminski, 1990; Morlotti & Kuhnt, 1992).

Nowadays, the Subsilesian series crops out in two parallel zones to the west of the Dunajec River. The northern zone is located to the north of the Silesian Nappe, while the southern zone appears in a few tectonic windows between the Dunajec and Skawa Rivers, and in the Żywiec Basin. The studied section is located in the Wiśniowa tectonic window, in the central part of the southern zone of the Subsilesian Nappe (Fig. 1A).

The radiolarian section is located in the axial part of the Wiśniowa tectonic window, between Glichów and Czerwin settlements. It is located in the Czerwin creek – left tributary of the Lipnik creek, two kilometres from its mouth (Fig. 1B).

The deposits of the Subsilesian series presented in this study are folded and form two tectonic slices. They crop out in isolated exposures and, according to Burtan (1974) and Cieszkowski *et al.* (2001), consist of the following lithostratigraphic units: Węglówka-type marls, Senonian in age, and a Palaeogene sequence consisting of the Czerwin Sandstone (s. s.), Green Shales, and Variegated Shales (Figs 1C, 2).

The lowermost part of the Palaeogene sequence is represented by a complex of the Paleocene Czerwin Sandstone (s. s.), which consists of thick-bedded sandstone, mostly coarse-grained and calcareous, intercalated with green-grey marly shales. These deposits pass into a more calcareous complex of the Green Shales bearing thin-bedded sandstone intercalations. The age of this complex is indicated as the Paleocene through the early Eocene. Upward, the lower Eocene deposits are represented by the Variegated Shales including marly, green shales intercalated with brown and red shales, thin-bedded sandstone, and a few layers of benthonite in the uppermost part.

The outcrop from which our sample was collected is located in the bed of the creek and is approximately 60 cm high (Fig. 1C). The tectonic contact between the Węglówka-type marls and Variegated Shales is visible here. The radiolarian samples used in this study were collected from greenish clayey shales of the Variegated Shales, above the first benthonite layer visible in the outctop.

RESULTS ON BIOSILICEOUS MICROFOSSIL ANALYSES

The biosiliceous component consists of radiolarians and diatoms. All microfossils were extracted from clayey shales by using standard preparation methods, including the multiple heating of disaggregated rock-sample into Glauber's salt solution. Then, the sample was washed, dried and sieved with a 42 micrometers sieve. Radiolarians dominate in the fraction ranges between 42–63 micrometers. Diatoms are rare and poorly preserved.

The radiolarian fauna consists of 43 species. According to the radiolarian systematic schemes of Riedel (1967) and Petrushevskaya (1971a, b) with Hollis (1997) emendations, these species belong to four families of the order Nassellaria (Acanthodesmiidae, Artostrobiidae, Pterocorythidae and Eucyrtidiidae), and to five families of Spumellaria (Actinommidae, Phacodiscidae, Sponguridae, Spongodiscidae and Porodiscidae).

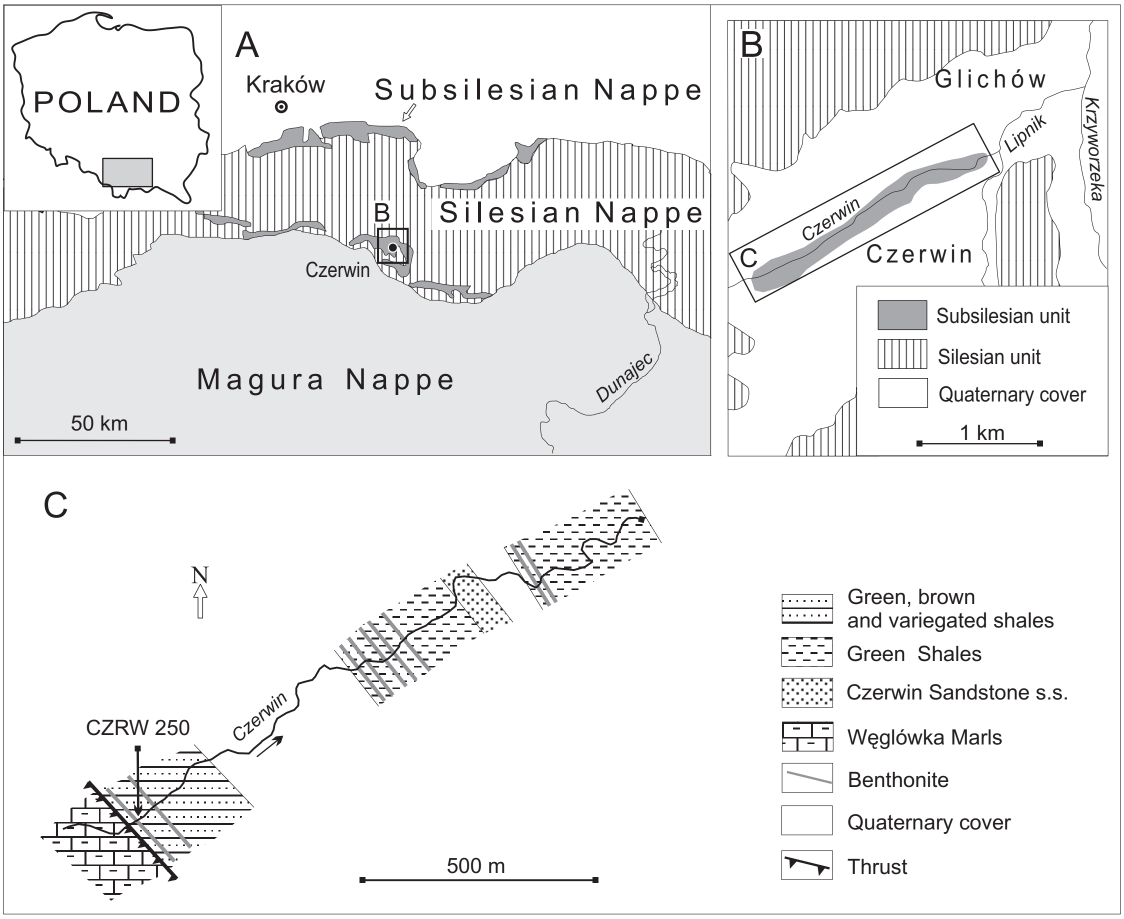

Fig. 1. Location map of the study area. **A** – Geological sketch map of the study area (geology after Żytko *et al.*, 1988) – simplified). **B** – Precise location of the outcrop. **C** – Details of the Czerwin creek section (after Waśkowska-Oliwa *et al.*, 2001); CZRW 250 – location of the deposits with abundant radiolarians

The major component of the assemblage is represented by radiolarian species typical for tropical realm. The specimens typical of low latitudes prevail. However, some taxa present in the Subsilesian series have been reported previously from the areas of mixing Tethyan and Boreal influences (e.g., *Heliodiscus heliasteriscus* Clark & Campbell, *H. perplexus* Clark & Campbell, *Gorgospyris hemisphaerica* Clark & Campbell) (Popova *et al.*, 2002) or from the Boreal province (e.g., *Phacodiscus duplus* Kozlova) (Kozlova & Gorbovetz, 1966).

The radiolarian assemblage comprises few spiny spumellarians (e.g., *Amphisphaera coronata* (Ehrenberg), *Amphisphaera minor minor* (Clark & Campbell), *Haliomma* (?) *faceta* (Krasheninnikov)) and nassellarians from the genus *Buryella* which characterise cool, oligotrophic water-masses (Maclean *et al.*, 2003). Similar taxa are also present in the upper Palaeocene deposits of the Subsilesian series.

The dominant specimens, typical of low latitudes (e.g., *Amphicraspedum prolixum* Sanfilippo & Riedel and *Podocyrtis papalis* Ehrenberg) may indicated an incursion of warm water masses into the Subsilesian Basin. Similar radiolarian assemblages have recently been reported from the lower Eocene pelagic deposits of New Zealand by Maclean *et al.* (2003) who correlate this fact with the incursion of warm-water radiolarian taxa with the Paleocene–Early Eocene thermal maximum (PETM).

Diatoms represent less than one per cent of the biosiliceous components. They are represented mostly by triangular specimens of the genus *Triceratium*, and discoidal forms belonging to the genus *Coscinodiscus*. The diatoms content

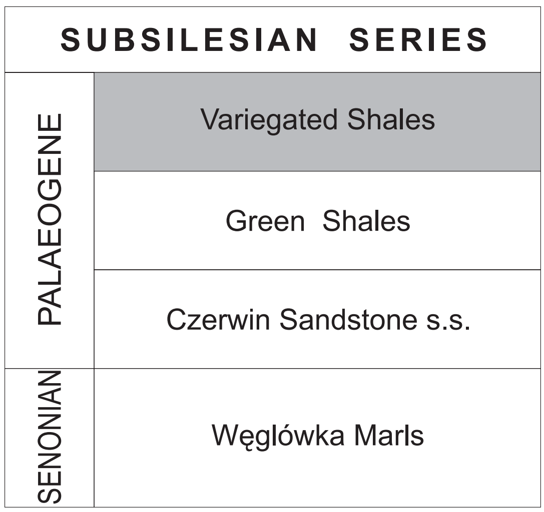

Fig. 2. Informal lithostratigraphic units of the Senonian through Palaeogene deposits of the Subsilesian series in the Wiśniowa tectonic window (after Burtan, 1974, simplified). Deposits studied marked by grey colour

in the sediment could be diminished by the dissolution in the water column, in the sediment-water interface, or during the diagenetic change of the sediment.

REMARKS ON FOSSILIZATION PROCESS

All radiolarian specimens and diatom frustules are pyritized, whereas all foraminiferal specimens are not pyritized. Different degrees of pyritization, which transforms siliceous frustules and radiolarian skeletons to internal mold of pyrite, to pyritization with conservation of the ornamentation are present. Pyrite framboids that usually replaced the siliceous tests and filled them, and screening their inner structures, make the observation of inner structures difficult or even impossible. Excellent replacement by pyrite would be explained by pyritization of biosiliceous tests while they were still suspended in the anoxic/disoxic water column (Bąk & Sawłowicz, 2000). Another explanation might be the pyritization in the sediment, during an early diagenesis after the initial faecal pellet deposition (Berner, 1984). Both models require an increased fertility of the upper layer of the ocean (Jacot des Combes *et al.*, 1999; Bąk & Sawłowicz, 2000). On the other way, pyritization of siliceous skeletons signifies conditions for silica dissolution in the water column, or in the water-sediment interface. This means that the high radiolarian/diatom ratio in the rock is a result of the fact that radiolarians are more resistant to dissolution than diatoms.

RADIOLARIAN BIOSTRATIGRAPHY

The biostratigraphic age determination of the studied deposits is based on the presence of radiolarian taxa widely distributed in the low-latitude lower Eocene, such as: *Phormocyrtis striata striata* Brandt, *Lychnocanium bellum* Clark & Campbell, *Thyrsocyrtis rhizodon* Ehrenberg, *Calocycloma ampulla* (Ehrenberg), *Buryella clinata* Foreman, *Lychnocanoma auxilla* Foreman, and other representatives of the *Phormocyrtis striata striata* radiolarian Zone (RP9) established for the tropics (Foreman, 1973; emend. Riedel & Sanfilippo, 1978), and revised and standardised by Sanfilippo & Nigrini (1998). However, this radiolarian zonation was found to be not fully applicable for dating and correlating the investigated radiolarian faunas. Some species whose first and last occurrences define this low-latitude tropical zone were either missing or the species proved to have different ranges in the Subsilesian series than in the tropics. For example, *Lychnocanoma auxilla* Foreman has its last occurrence in the Subsilesian series later than in the tropics; *Theocotyle venezuelensis* Riedel & Sanfilippo is present in the Subsilesian deposits, although its first appearance in the tropics is noted in the *Theocotyle cryptocephala* Zone (RP 10); and *Buryella tetradica* Foreman, widely distributed in tropical localities of all three major oceans and present also in Subantarctic sediments from the Pacific and the Atlantic (Nigrini & Sanfilippo, 2001), has its last occurrence later in the Subsilesian series. Species missing in the Subsilesian series by comparison with the tropical faunas are: *Theocorys anaclasta* Riedel & Sanfilippo, the lowest occurrence of which defines the lower limit of the *Phormocyrtis striata striata* radiolarian Zone, and *Lamptonium fabaeforme constrictum* Riedel & Sanfilippo and *Podocyrtis (Lampterium) acalles* Sanfilippo & Riedel, the first occurrence of which is approximately synchronous with the lower limit of RP9 zone. Species of the *Lithocyclia ocellus* group Ehrenberg are also missing here, although they are common to abundant in the Skole series of the Western Polish Carpathians (Bąk *et al.*, 1997). Different first and last occurrences or the absence of some radiolarian species in the lower Eocene deposits of the Subsilesian series may result from many factors including preservation, reworking, geographical distribution of species, and their dependence on oceanic water masses and currents.

CORRELATION

The radiolarian assemblage from the deposits of the Subsilesian series co-occurs with abundant agglutinated foraminifers. Studies on radiolarians and foraminifers from the same rock samples gives a possibility of precise correlation of biozonal schemes based on these microfossil groups.

The foraminiferal assemblage consists of well-preserved and diversified agglutinated taxa (Waśkowska-Oliwa *et al.*, 2001; Waśkowska-Oliwa, 2002). Numerous specimens of *Saccamminoides carpathicus* Geroch, *Gerochammina conversa* (Grzybowski), *Glomospira gordialis* (Jones & Parker), *G. charoides* (Jones & Parker), *Haplophragmoides walteri* Grzybowski, *H. kirki* Wickenden, *Paratrochamminoides* spp., *Recurvoides* spp., and *Rhabdammina* sp. are characteristic for this assemblage. These species are accompanied by *Ammodiscus* spp., *Arenobulimina* sp., *Glomospirella grzybowskii* (Jurkiewicz), *Karrerulina coniformis* (Grzybowski), *Nothia excelsa* (Grzybowski), *Praecystammina* cf. *seveni* Gradstein et Kaminski, *Reophax elongatus* Grzybowski, *R. pilulifer* Brady, *Spiroplectammina spectabilis* (Grzybowski), and *Trochammina* spp. The foraminiferal assemblage can be placed in the *Saccamminoides carpathicus* foraminiferal Zone of Geroch & Nowak (1984), an indicator of the lower part of the lower Eocene in the Carpathians (Olszewska, 1997).

DISCUSSION

The occurrence of siliceous microfossils in the Subsilesian series provided an opportunity to make an analysis of radiolarian population changes during the early Palaeogene period. Radiolarians found in separated tectonic slices show that the late Paleocene and earliest Eocene assemblages are dominated by spiny spumellarians. Radiolarian abundance and diversity increase markedly in the deposits corresponding to the *Saccamminoides carpathicus* foraminiferal Zone. Simultaneously, radiolarian assemblage changed from typical to cool water-masses, which dominated the late Paleocene and the earliest Eocene, to an assemblage typical of subtropical-tropical region. The appearance of many low-latitude radiolarian species and scarcity of diatoms indicate an incursion of warm waters into the Subsilesian Basin.

Similar abrupt change in the radiolarian association has also been noted in the deposits of the *S. carpathicus* Zone, from several sections of the Skole series (Bąk 1995; Bąk *et al.*, 1997; Rajchel *et al.*, 1999). This suggests that this trend in siliceous microfossil populations signed a major change in water-masses characteristics along the Western Carpathians Basins, most probably associated with the EECO.

SYSTEMATIC PALAEONTOLOGY

Systematic schemes of Hollis (1997) have been used to classify radiolarian taxa described in this paper. The types of all species are currently housed in the authors' collection (Institute of Geological Sciences, Jagiellonian University), on strewn slides or scanning electron microscope stubs. All species presented below are illustrated on Figs 3–6.

Order SPUMELLARIA Ehrenberg 1875
Family Actinommidae Haeckel 1862, emend Riedel 1967
Genus *Cenosphaera* Ehrenberg 1854

Cenosphaera ? sp.
Fig. 3A

Description: Test spherical consists of one or more (?) simple porous sphere. Pores irregular, subuniform, subcircular to circular two times as broad as the bars, ten on the radius.
Occurrence in the Carpathians: rare in the Subsilesian series (this study).

Genus *Haliomma* Ehrenberg 1838

Haliomma (?) *faceta* (Krasheninnikov) 1960
Fig. 3B

1960 *Cenosphaera faceta* Krasheninnikov: Krasheninnikov; p. 274, pl. 1, fig. 4.
1999 *Haliomma* (?) *faceta* (Krasheninnikov): Kozlova; p. 73, pl. 21, fig. 1; pl. 25, fig. 4; pl. 37.

Occurrence in the Carpathians: rare in the Subsilesian series (this study).

Genus *Amphisphaera* Haeckel 1881,
emend. Petrushevskaya 1975

Amphisphaera coronata (Ehrenberg) 1873
Fig. 3C–E

1873 *Stylosphaera coronata* Ehrenberg: Ehrenberg; p. 258.
1997 *Amphisphaera coronata* s. l. (Ehrenberg): Hollis; p. 35, pl. 2, figs 14–17.

Occurrence in the Carpathians: common in the lower through middle Eocene deposits of the Skole series. Common in the lower Eocene deposits of the Subsilesian series (this study).

Amphisphaera minor minor (Clark & Campbell) 1942
Fig. 3F

1942 *Stylosphaera minor minor* Clark & Campbell: Clark & Campbell; p. 27, pl. 5, figs 1, 2, 2a, 12.
1973 *Amphisphaera minor* (Clark & Campbell): Sanfilippo & Riedel; p. 486, pl. 1; figs 1–5; pl. 22, fig. 4.

Occurrence in the Carpathians: common in the lower Eocene and lowest part of middle Eocene deposits of the Skole series. Rare in the lower Eocene deposits of the Subsilesian series (this study).

Amphisphaera subsilesianensis n. sp.
Fig. 3G–I

Holotype: Specimen Czrw 250202 illustrated on Fig. 3G.
Type-locality: Czerwin creek, near Lipnik, southern Poland.
Type-level: Green brown and variegated shales in the Subsilesian Nappe, sample CZRW 250.
Etymology: Species name derived from the Subsilesian Nappe.
Description: Large spherical to slightly ellipsoidal test with two unequal polar spines and three minor spines. Cortical shell has circular pores medium in size set in hexagonal frames, with surface usually roughened by raised nodes at junctions of pore frames. Less than ten pores across half-equator (8–9). All spines three-bladed. Longer polar spine ranges from 3/4 to one the length of main axis. Short polar spine about half the length of main axis. Three additional spines in length of shorter polar spine lie in one plane perpendicular to polar spines or each of them forming 30° angle with this equatorial plane. Angles between spines are 120°-120°-120° or 90°-90°-180°. Probably one medullary shell.
Material: 12 specimens, well preserved, pyritized, spines partly broken off.
Dimensions:(in µm) (range of 12 specimens [mean]): diameter of cortical shell: 104–115, length of spine: 30–70, diameter of pores 6–8.
Remarks: This species is distinguished from *A. minor minor* and *A. coronata* by its three spines situated in the plane perpendicular to axis of polar spines.
Occurrence in the Carpathians: rare in Lower Eocene deposits of the Subsilesian series (this study).

Family Phacodiscidae Haeckel 1881
Genus *Heliodiscus* Haeckel 1862

Heliodiscus heliasteriscus Clark & Campbell 1942
Fig. 3J, K

1942 *Heliodiscus (Heliodiscetta) heliasteriscus* Clark & Campbell: Clark & Campbell; p. 39, pl. 3, figs 10, 11.

Remarks: The species posses a cortical shell with rough surface and 8–10 short rays, that are three-angled in proximal portion.
Occurrence in the Carpathians: rare in lower Eocene deposits of the Subsilesian series (this study).

Heliodiscus perplexus Clark & Campbell 1942
Fig. 3L

1942 *Heliodiscus perplexus* Clark & Campbell: Clark & Campbell; p. 40, pl. 3, fig. 12.

Occurrence in the Carpathians: rare to common in the lower–middle Eocene deposits of the Skole series, rare in the lower Eocene deposits of the Subsilesian series (this study).

Genus *Phacodiscus* Haeckel 1881

Phacodiscus duplus Kozlova 1966
Fig. 3M

1966 *Phacodiscus duplus* Kozlova & Garbovetz: Kozlova & Garbovetz; p. 69, tab. 11, fig. 2.

Occurrence in the Carpathians: rare in the lower Eocene deposits of the Subsilesian series (this study).

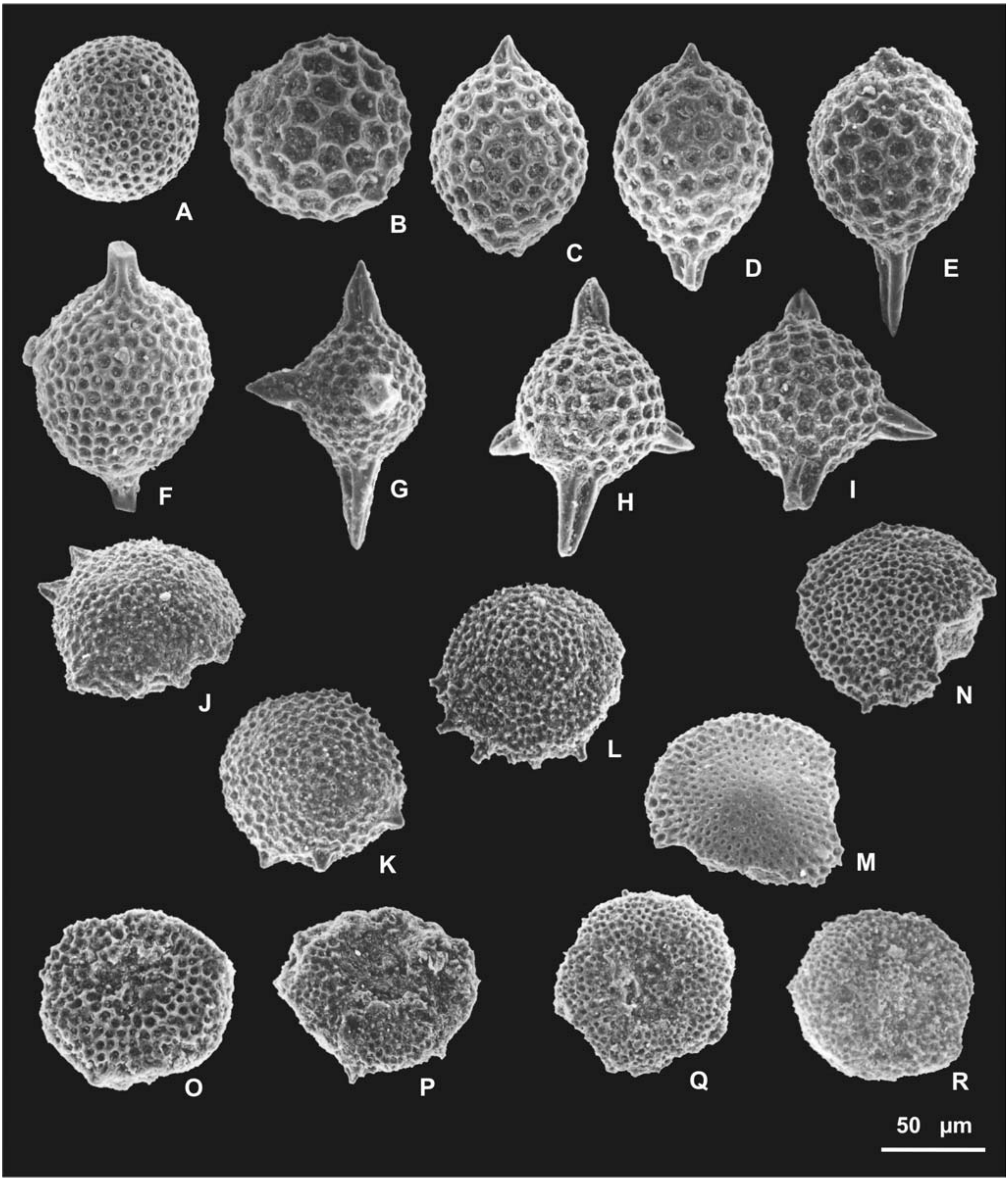

Fig. 3. **A** – *Cenosphaera* sp., Czrw 251408. **B** – *Haliomma* (?) *faceta* (Krasheninnikov), Czrw 250206. **C–E** – *Amphisphaera coronata* (Ehrenberg), C – Czrw 250304; D – Czrw 250512, E – Czrw 250203. **F** – *Amphisphaera minor minor* (Clark & Campbell), Czrw 251116. **G–I** – *Amphisphaera subsilesianensis* n. sp., G – Czrw 250202 – holotype; H – Czrw 250029, I – Czrw 250606. **J, K** – *Heliodiscus heliastericus* Clark & Campbell, J – Czrw 250802; K – Czrw 250703. **L** – *Heliodiscus perplexus* Clark & Campbell, Czrw 250047. **M** – *Phacodiscus duplus* Kozlova, Czrw 251603. **N** – *Phacodiscus lentiformis* Haeckel, Czrw 250037. **O–R** – *Spongodiscus communis* Clark & Campbell, O – Czrw 250019; P –Czrw 250039; Q – Czrw 250054; R – Czrw 251601

Phacodiscus lentiformis Haeckel 1887
Fig. 3N

1887 *Phacodiscus lentiformis* Haeckel: Haeckel; p. 425, pl. 35. fig. 8.

Occurrence in the Carpathians: common to abundant in the Paleocene and Eocene deposits of the Skole series; rare in the lower Eocene deposits of the Subsilesian series (this study).

Family Spongodiscidae Haeckel 1862,
emend. Riedel, 1967b, emend. Hollis 1997
Genus *Spongodiscus* Ehrenberg 1854

Spongodiscus communis Clark & Campbell 1942
Fig. 3O–R

1942 *Spongodiscus (Spongocyclia) communis* Clark & Campbell: Clark & Campbell; p. 47, pl. 2, figs 1, 11, 13, 14; pl. 3, figs 1, 4.

Remarks: Our specimens are much smaller and thicker than *S. communis* described and illustrated in previous works.

Occurrence in the Carpathians: few to common in the lower Eocene deposits of the Skole series, rare in the lower Eocene deposits of the Subsilesian series (this study).

Family Sponguridae Haeckel 1862
emend. Petrushevskaya 1975
Genus *Amphicraspedum* Haeckel 1887

Amphicraspedum prolixum Sanfilippo & Riedel 1973
Fig. 4A, B

1973 *Amphicraspedum prolixum* Sanfilippo & Riedel: Sanfilippo & Riedel; p. 524, pl. 10, figs 7–11; pl. 28, figs 3, 4.

Occurrence in the Carpathians: few in Eocene deposits of the Skole series, rare in the Subsilesian series (this study).

Genus *Spongurus* Haeckel 1862

Spongurus bilobatus Clark & Campbell 1942
Fig. 4C

1942 *Spongurus bilobatus* Clark & Campbell: Clark & Campbell; p. 36, pl. 1, figs 7, 9.

Occurrence in the Carpathians: few to common in the lower Eocene to lower part of the middle Eocene deposits of the Skole series, very rare in the lower Eocene deposits of the Subsilesian series (this study).

Family Porodiscidae Haeckel 1881, emend.
Kozlova *in* Petrushevskaya & Kozlova 1972
Genus *Trochodiscus* Haeckel 1881

Trochodiscus spinosus Borisenko 1958
Fig. 4D

1958 *Trochodiscus spinosus* Borisenko: Borisenko; p. 95, pl. 6, fig. 8

Occurrence in the Carpathians: rare in the Lower Eocene deposits of the Subsilesian series (this study).

Order NASSELLARIA Ehrenberg 1875
Suborder Spyridae Ehrenberg 1847,
emend. Petrushevskaya 1971a
Family Acanthodesmiidae, Ehrenberg, 1847,
emend. Petrushevskaya 1971a
Genus *Dorcadospyris* Haeckel 1882

Dorcadospyris confluens Ehrenberg 1873
Fig. 4E

1873 *Pentalospyris confluens* Ehrenberg: p. 246.

Occurrence in the Carpathians: rare in the lower Eocene deposits of the Subsilesian series (this study).

Dorcadospyris pentas Ehrenberg 1873
Fig. 4F

1873 *Dorcadospyris pentas* Ehrenberg: Ehrenberg; p. 247.

Occurrence in the Carpathians: rare in the lower Eocene deposits of the Subsilesian series (this study).

Genus *Gorgospyris* Haeckel 1881

Gorgospyris hemisphaerica Clark & Campbell 1942
Fig. 4G

1942 *Gorgospyris hemisphaerica* Clark & Campbell: Clark & Campbell; p. 61, pl. 9, fig. 6.

1966 *Gorgospyris hemisphaerica* Clark & Campbell: subsp. sibirica Kozlova & Gorbovetz; p. 97, pl. 15, fig 8.

Occurrence in the Carpathians: rare in the lower Eocene deposits of the Subsilesian series (this study).

Genus *Tessarospyris* Haeckel 1881

Tessarospyris (?) *bicaudalis* Clark & Campbell 1942
Fig. 4H

1942 *Tessarospyris* (?) *bicaudalis* Clark & Campbell: Clark & Campbell; p. 56, pl. 9, fig. 7.

Occurrence in the Carpathians: rare in the lower Eocene deposits of the Subsilesian series (this study).

Suborder Cyrtida Haeckel 1862,
emend. Petrushevskaya 1971a
Family Artostrobiidae Riedel 1967,
emend. O'Connor 2001
Genus *Buryella* Foreman 1973

Buryella clinata Foreman 1973
Fig. 4I

1973 *Buryella clinata* Foreman: Foreman; p. 433, pl. 8, figs 1–3; pl. 9, fig. 19.

Occurrence in the Carpathians: upper part of lower Eocene deposits to lower part of middle Eocene deposits (*Buryella clinata–Phormocyrtis striata striata* Zones) of the Skole series. Rare in the lower Eocene deposits of the Subsilesian series (this study).

Buryella spp.
Fig. 4J, K

Description: All specimens with three or four segments, fusiform or lobate in outline, with constricted aperture. Cephalis always possesses apical horn of varying length, and a distinct vertical pore at the collar stricture. All specimens posses pronounced vertical

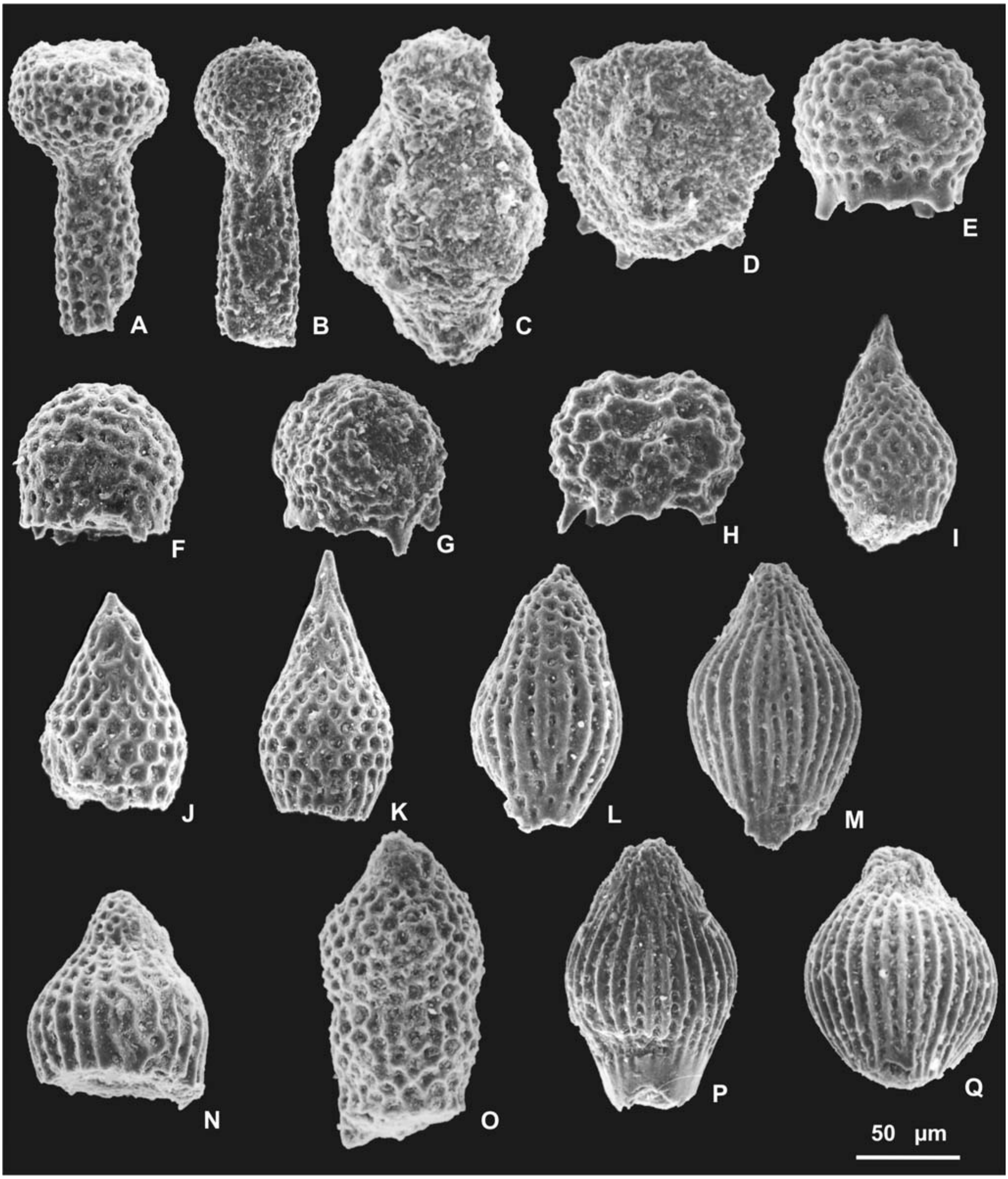

Fig. 4. **A, B** – *Amphicraspedium prolixum* Sanfilippo & Riedel, A – Czrw 250040; B – Czrw 250062. **C** – *Spongurus bilobatus* Clark & Campbell, Czrw 251402. **D** – *Trochodiscus spinosus* Borisenko, Czrw 251012. **E** – *Dorcadospyris confluens* Ehrenberg, Czrw 251510. **F** – *Dorcadospyris pentas* Ehrenberg, Czrw 250051. **G** – *Gorgospyris hemisphaerica* Clark & Campbell, Czrw 250076. **H** – *Tessarospyris (?) bicaudalis* Clark & Campbell, Czrw 250074. **I** – *Buryella clinata* Foreman, Czrw 250101**. J, K** – *Buryella* spp., J – Czrw 252525; K – Czrw 250250. **L** – *Buryella tetradica* Foreman, Czerw 255225. **M, P, Q** – *Podocyrtis (Podocyrtis) papalis* Ehrenberg, M – Czrw 251103; P – Czerw 250704; Q – Czerw 250308. **N** – *Anthocyrtium byronense* Clark & Campbell, Czrw 250027. **O** – *Aphetocyrtis gnomabax* Sanfilippo & Caulet, Czrw 250023

tube, rounded or elongate, that might extend to the base of apical horn.
Occurrence in the Carpathians: common in the lower Eocene deposits It is present within radiolarian *Phormocyrtis striata striata* Zone and foraminiferal *Saccamminoides carpathicus* Zone.

Buryella tetradica Foreman 1973
Fig. 4L

1973 *Buryella tetradica* Foreman: Foreman; p. 433, pl. 8, figs 4, 5; pl. 9, figs 13, 14.

Occurrence in the Carpathians: lower Eocene, radiolarian *Phormocyrtis striata striata* Zone.

Family Pterocorythidae Haeckel 1881, emend. Riedel 1967, emend. Moore 1972
Genus *Podocyrtis* Ehrenberg, 1847

Podocyrtis (Podocyrtis) papalis Ehrenberg 1847
Figs 4M, P, Q

1847 *Podocyrtis papalis* Ehrenberg: Ehrenberg; fig. 2;
1854 *Podocyrtis papalis* Ehrenberg: Ehrenberg; pl. 36, fig. 23;
1873 *Podocyrtis papalis* Ehrenberg: Ehrenberg; p. 251.

Occurrence in the Carpathians: common in the Paleocene to upper Eocene deposits of the Skole series. Common in the lower Eocene deposits of the Subsilesian series (this study).

Family Eucyrtidiidae Ehrenberg 1847
Genus *Anthocyrtium* Haeckel 1887

Anthocyrtium byronense Clark & Campbell 1942
Fig. 4N

1942 *Anthocyrtium (Anthrocyrturium) byronense* Clark & Campbell: Clark & Campbell; p. 73, pl. 7, figs 1–4, 7.

Occurrence in the Carpathians: rare in the Eocene deposits of the Subsilesian series (this study).

Genus *Aphetocyrtis* Sanfilippo & Caulet 1998

Aphetocyrtis gnomabax Sanfilippo & Caulet 1998
Fig. 4O

1998 *Aphetocyrtis gnomabax* Sanfilippo & Caulet: Sanfilippo & Caulet, p.16, pl. 2, fig. 6, 7, 10, 11, 14–17; pl.7, figs 10–13.

Remarks: Specimen badly preserved and with internal cephalic structure indistinct. However, some external features allow species determination. They are: subsphaerical, weakly perforated cephalis, with apical horn (broken in our specimen), and cylindrical, rather long abdomen.
Occurrence in the Carpathians: rare in the lower Eocene deposits of the Subsilesian series (this study).

Genus *Calocycloma* Haeckel 1887

Calocycloma ampulla (Ehrenberg) 1854
Fig. 5A, B

1854 *Eucyrthidium ampulla* Ehrenberg: Ehrenberg; pl. 36, figs 15a–c.
1972 *Calocycloma ampulla* (Ehrenberg): Petrushevskaya & Kozlova; p. 543, pl. 34, fig. 4.

Occurrence in the Carpathians: rare to common in the lower and middle Eocene deposits of the Skole series (*Becoma bidartensis–Theocampe mongolfieri* Zones) and the lower Eocene deposits of the Subsilesian series (this study).

Genus *Carpocanobium* Haeckel 1887

Carpocanobium sp.
Fig. 5C

Diagnosis: Test two-segmented, broadly ovate. Cephalis small, partially hidden within thorax. Pores large, circular. About 12 pores on half the equator of thorax, and about 9 pores longitudinally. Aperture circular, narrow.
Remarks: Our specimens are similar to *Carpocanobium* sp. aff. *C. setosa* (Ehrenberg) described by Petrushevskaya & Kozlova (1972) from the Oligocene deposits.
Occurrence in the Carpathians: the lower Eocene deposits of the Subsilesian series (this study).

Genus *Clathrocyclas* Haeckel 1887

Clathrocyclas universa amplaspina
Clark & Campbell 1942
Fig. 5D, E

1942 *Clathrocyclas universa amplaspina* Clark & Campbell: Clark & Campbell; p. 89, pl. 7, fig. 16.

Occurrence in the Carpathians: rare in the Eocene deposits of the Subsilesian series (this study).

Genus *Lamptonium* Haeckel 1887

Lamptonium fabaeforme chaunothorax
Riedel & Sanfilippo 1970
Fig. 5F, G

1970 *Lamptonium ? fabaeforme ? chaunothorax* Riedel & Sanfilippo: Riedel & Sanfilippo; p. 524, pl. 5, figs 8, 9.
1973 *Lamptonium fabaeforme chaunothorax* Riedel & Sanfilippo: Foreman; pl. 6, figs 10-12.

Occurrence in the Carpathians: rare in the lower Eocene deposits of the Subsilesian series (this study).

Genus *Lithostrobus* Butshli 1882

Lithostrobus sp.
Fig. 5H

Description: Narrowly conical multisegmented test with at least 7 narrow segments. Cephalis hemispherical, sparsely perforated. Thorax inflated, subsequent segments narrow, separated by moderately developed strictures. Pores on thorax and subsequent segments circular, medium size, set in hexagonal frames and diagonally arranged in 3–4 rows per segment.
Occurrence in the Carpathians: rare in the Eocene deposits of the Subsilesian series (this study).

Genus *Lychnocanoma* Haeckel 1887

Lychnocanoma auxilla Foreman 1973
Fig. 5I

1973 *Lychnocanoma auxilla* Foreman: Foreman; p. 436, pl. 2 fig. 6; pl. 11, figs 1, 2.

Occurrence in the Carpathians: common in the lower Eocene deposits of the Subsilesian series (this study).

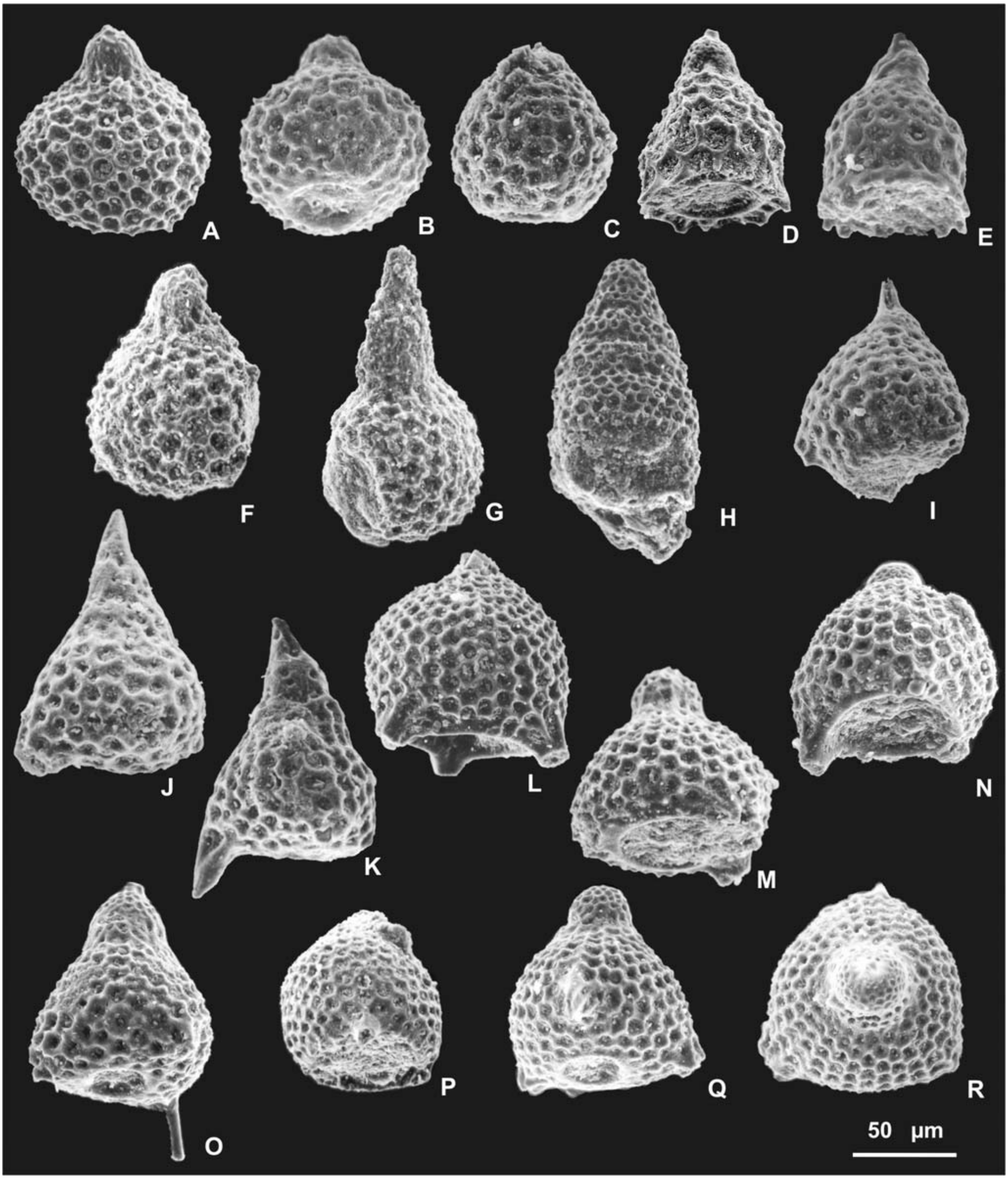

Fig. 5. **A, B** – *Calocycloma ampulla* (Ehrenberg), A – Czrw 251015; B –Czrw 251014. **C** – *Carpocanobium* sp., Czrw 250052. **D** – *Clathrocyclas universa amplaspina* Clark & Campbell, Czrw 250061. **E** – *Clathrocyclas universa amplaspina* Clark & Campbell, Czrw 251208. **F, G** – *Lamptonium fabaeforme chaunothorax* Riedel & Sanfilippo, Czrw 250912; G – Czrw 251411. **H** – *Lithostrobus* sp., Czrw 250078. **I** – *Lychnocanoma auxilla* Foreman, Czrw 250069. **J, K** – *Lychnocanoma babylonis* (Clark & Campbell), J – Czrw 250053; K –Czrw 250063. **L–N** – *Lychnocanium bellum* Clark & Campbell, L – Czrw 250706; M – Czrw 250067; N – Czrw 250034. **O** – *Lychnocanium conicum* Clark & Campbell, Czrw 250715. **P** – *Lychnocanium tripodium* Ehrenberg, Czrw 251410. **Q, R** – *Lychnocanium* sp. A, Q – Czrw 250713; R – Czrw 250502

Lychnocanoma babylonis (Clark & Campbell) 1942
Fig. 5J, K

1942 *Dictyophimus babylonis* Clark & Campbell: Clark & Campbell; p. 67, pl. 9, figs 32, 36.
1973 *Lychnocanoma babylonis* (Clark & Campbell) group: Foreman; p. 437, pl. 2. fig. 1.

Occurrence in the Carpathians: rare in the lower Eocene deposits of the Subsilesian series (this study).

Genus *Lychnocanium* Ehrenberg, 1847

Lychnocanium bellum Clark & Campbell 1942
Fig. 5L–N

1942 *Lychnocanium bellum* Clark & Campbell: Clark & Campbell; p. 72, pl. 9, figs. 35, 39.

Occurrence in the Carpathians: common in the lower and middle Eocene deposits of the Skole series (*Phormocyrtis striata striata* Zone). Few in the lower Eocene deposits of the Subsilesian series (this study).

Lychnocanium conicum Clark & Campbell 1942
Fig. 5O

1942 *Lychnocanium conicum* Clark & Campbell: Clark & Campbell; p. 71, pl. 9. fig. 38.

Occurrence in the Carpathians: few to common in the lower and middle Eocene deposits of the Skole series. Rare in the lower Eocene deposits of the Subsilesian series (this study).

Lychnocanium tripodium Ehrenberg 1873
Fig. 5P

1873 *Lychnocanium tripodium* Ehrenberg: Ehrenberg; p. 245.

Occurrence in the Carpathians: rare in the lower Eocene deposits of the Subsilesian series (this study).

Lychnocanium sp. A
Fig. 5Q, R

Description: Test two-joined bearing three feet. Cephalis hemispherical with small pores and apical horn which is broken off in our specimens. Thorax large, bell-shaped with narrow aperture and rough surface. Pores small, circular usually hexagonally framed. Feet thick, three-bladed partially broken off arising from the distal third of thorax.
Occurrence in the Carpathians: rare in the lower Eocene deposits of the Subsilesian series (this study).

Lychnocanium sp. B
Fig. 6A, B

Description: Test two-joined, bearing three feet. Cephalis subhemispherical, partially broken. Thorax campanulate with pores subcircular, subequal in size. Feet three-bladed partially broken off.
Occurrence in the Carpathians: rare in the lower Eocene deposits of the Subsilesian series (this study).

Lychnocanium sp. C
Fig. 6C, D

Description: Test two-segmented divided by transverse constriction into cephalis and thorax, bearing three radial feet. Cephalis sphaerical, with small apical horn. Thorax subspherical, with subcircular pores set in polygonal framed, equal in size. Feet three-bladed, partially broken of.
Remarks: This species is similar to *Lychnocanium* sp. 2 (Popova *et al.*, 2002) from the Palaeogene deposits of the Russian Platform.
Occurrence in the Carpathians: rare in the lower Eocene deposits of the Subsilesian series (this study).

Genus *Phormocyrtis* Haeckel 1887

Phormocyrtis striata striata Brandt, 1935
Fig. 6E, F

1935 *Phormocyrtis striata striata* Brandt: Brandt, in Wetzel; p. 55, pl. 9, fig. 12.

Occurrence in the Carpathians: common in the upper part of the lower Eocene deposits and rare in the lower part of middle Eocene deposits of the Skole series. Common in the lower Eocene deposits of the Subsilesian series (this study).

Genus *Rhopalocanium* Ehrenberg 1847

Rhopalocanium pyramis (Haeckel 1887)
Fig. 6G–I

1887 *Dictyophimus pyramis* Haeckel: Haeckel; 1330, pl. 68, fig. 7.
1999 *Rhopalocanium pyramis* (Haeckel): Kozlova; pl. 7, fig. 16.

Occurrence in the Carpathians: rare in the lower part of the lower Eocene deposits of the Skole series. Common in the Eocene deposits of the Subsilesian series (this study).

Genus *Theocotyle* Riedel & Sanfilippo 1970

Theocotyle venezuelensis Riedel & Sanfilippo 1970
Fig. 6J

1970 *Theocotyle venezuelensis* Riedel & Sanfilippo: Riedel & Sanfilippo; p. 525, pl. 6, figs 9, 10; pl. 7, figs 1, 2.

Remarks: Our specimens are much smaller than the ones described by Riedel and Sanfilippo (1970).
Occurrence in the Carpathians: rare in the lower Eocene deposits of the Subsilesian series (this study).

Genus *Theocotylissa* Foreman 1973

Theocotylissa ficus (Ehrenberg 1873)
Fig. 6K, L

1873 *Eucyrthidium ficus* Ehrenberg: Ehrenberg; p. 228; 1875, pl. 11, fig. 19.
1970 *Theocotyle* (?) *ficus* (Ehrenberg); Riedel & Sanfilippo p. 525, pl. 7, fig. 3–5.
1982 *Theocotylissa ficus* (Ehrenberg); Sanfilippo & Riedel, p. 180, pl 2, figs 19, 20.

Occurrence in the Carpathians: rare in the lower Eocene deposits of the Subsilesian series (this study).

Theocotylissa sp.
Fig. 6M

Description: Cephalis subspherical, with few small pores, and apical horn. Thorax conical. Lumbar stricture indistinct or not expressed externally. Abdomen longer than thorax, barrel-shaped. Wall of abdomen and thorax thick, with pores arranged in longitudinally aligned rows which may unite or separate. Peristome flat, with three short, triangular feet.
Occurrence in the Carpathians: lower Eocene deposits of the Subsilesian series (this study).

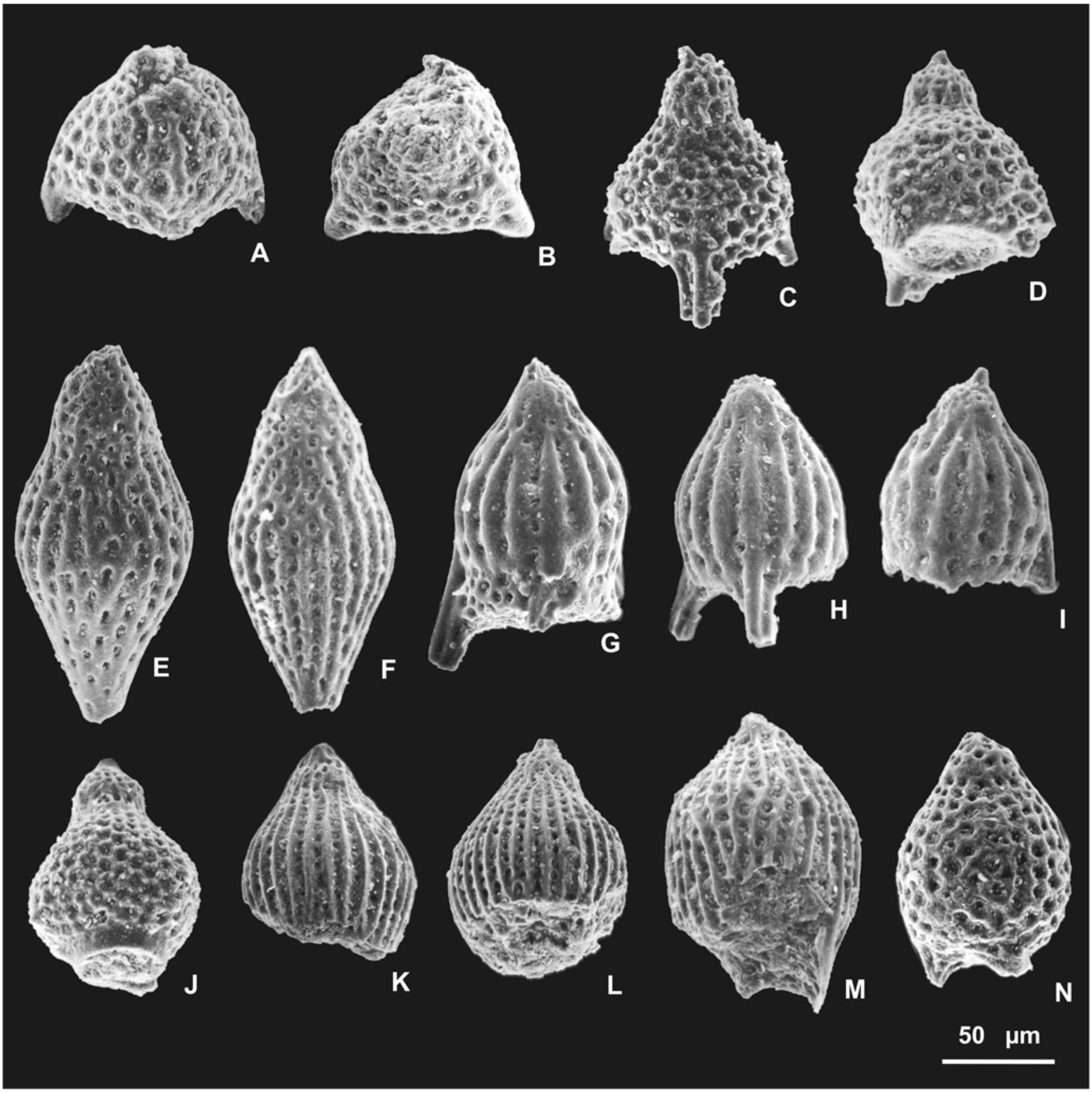

Fig. 6. **A, B** – *Lychnocanium* sp. B, A – Czrw 250059, B – Czrw 250306. **C, D** – *Lychnocanium* sp. C, C – Czrw 250042; D – Czrw 250026. **E, F** – *Phormocyrtis striata striata* Brandt, E – Czrw 251405; F – Czrw 250080. **G–I** – *Rhopalocanium pyramis* (Haeckel), G – Czrw 251013; H – Czrw 251206; I – Czrw 251303. **J** – *Theocotyle venezuelensis* Riedel & Sanfilippo, Czrw 250049. **K, L** – *Theocotylissa ficus* (Ehrenberg), K – Czrw 250605; L – Czrw 250055. **M** – *Theocotylissa* sp., Czrw 252205. **N** – *Thyrsocyrtis rhizodon* Ehrenberg, Czrw 250048

Genus *Thyrsocyrtis* Ehrenberg, 1847

Thyrsocyrtis rhizodon Ehrenberg 1873
Fig. 6N

1873 *Thyrsocyrtis rhizodon* Ehrenberg: Ehrenberg; p. 262.

Description: Form barrel-shaped. Cephalis subspherical with few small pores bearing apical horn. Thorax campanulate. Abdomen subcylindrical, inflated, with pores larger than of thorax and quincuncially arranged. Three short feet tapered from peristome.

Occurrence in the Carpathians: rare in the lower Eocene deposits of the Subsilesian series (this study).

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Streszczenie

ZNACZENIE STRATYGRAFICZNE I EKOLOGICZNE WCZESNOEOCEŃSKICH RADIOLARII Z SERII PODŚLĄSKIEJ, POLSKIE KARPATY FLISZOWE

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Radiolarie eoceńskie z polskich Karpat fliszowych są stosunkowo słabo poznane. Istnieje tylko kilka prac dotyczących tych mikroskamieniałości z eocenu jednostki skolskiej (Bąk, 1995; Bąk *et al.*, 1997; Rajchel *et al.*, 1999).

Prezentowany zespół radiolarii pochodzi z utworów dolnego eocenu jednostki podśląskiej, odsłaniających się w potoku Czerwin, w obrębie okna tektonicznego Wiśniowej (Fig. 1A, B). W odsłonięciu widoczne są utwory górnokredowych margli z Węglówki oraz paleogeńskich piaskowców z Czerwina, oraz zielonych i pstrych łupków (Fig. 2). Radiolarie zostały znalezione w zielonkawych łupkach ilastych należących do serii łupków pstrych, ponad pierwszą odsłaniającą się w profilu wkładką bentonitu (Fig. 1C).

Badany zespół radiolarii obejmuje 43 gatunki należące do czterech rodzin z rzędu Nassellaria (Trissocyclidae, Arthostrobiidae, Pterocorythidae i Eucyrtidiidae) i do pięciu rodzin z rządu Spumellaria (Actinommidae, Phacodiscidae, Sponguridae, Spongodiscidae i Porodiscidae) (Figs 3–6). Wyróżniono także nowy gatunek – *Amphisphaera subsilesianensis* n. sp. (Fig. 3G–I). Na podstawie obecności wielu charakterystycznych gatunków promienic jak: *Calocycloma ampulla* (Ehrenberg), *Buryella clinata* Foreman, *Phormocyrtis striata striata* Brandt, *Lychnocanium bellum* (Clark & Campbell), *L. auxilla* Foreman, *L. babylonis* (Clark & Campbell), *Amphisphaera minor* (Clark & Campbell), *Amphisphaera coronata* (Ehrenberg), badany zespół zaliczono do zony radiolariowej *Phormocyrtis striata striata*, wyróżnionej przez Riedel & Sanfilippo (1987) dla regionów tropikalnych. Współwystępowanie zespołów otwornic aglutynujących wraz z radiolariami umożliwiło korelację tego poziomu radiolariowego z poziomem otwornicowym *Saccamminoides carpathicus* (Geroch & Nowak, 1984).

Opisany zespół radiolarii wskazuje wyraźnie na ingresję ciepłych wód powierzchniowych do basenu podśląskiego we wczesnym eocenie, w których mogły żyć gatunki tropikalne i subtropikalne. Podobne zespoły taksonów występują w utworach jednostki skolskiej należących do tych samych poziomów biostratygraficznych (Bąk *et al.*, 1997). Może to wskazywać na zmianę termiki wód oceanicznych na skalę regionalną, która mogła być związana z wczesnoeoceńskim optimum klimatycznym.

Opis nowego gatunku

Rząd Spumellaria Ehrenberg 1875
Rodzina Actinommidae Haeckel, 1862, emend. Riedel, 1967
Rodzaj *Amphisphaera* Haeckel 1881,
emend. Petrushevskaya 1975

Amphisphaera subsilesianensis n. sp.

Holotyp: Okaz CZ250202 ilustrowany na figurze 3G–I.
***Locus typicus*:** potok Czerwin, koło Lipnika, południowa Polska.
***Stratum typicum*:** zielono-brązowe i pstre łupki płaszczowiny podśląskiej, próbka CZRW 250.
***Derivatio nominis*:** nazwa gatunku pochodzi od płaszczowiny podśląskiej.
Opis: Skorupka duża, kulista lub lekko elipsoidalna z dwoma kolcami polarnymi nierównej długości i trzema kolcami mniejszymi. Skorupka korowa posiada pory okrągłe, średniej wielkości z sześciobocznymi obrzeżeniami. Powierzchnia skorupki zwykle chropowata z powodu obecności guzków i zgrubiałych obrzeżeń por. Pory na połowie obwodu skorupki w liczbie mniejszej niż 10 (8–9). Wszystkie kolce o przekroju trójkątnym. Rozmiar dłuższego kolca biegunowego stanowi zwykle około 3/4 całej długości głównej osi. Krótki kolec polarny ma długość około połowy głównej osi. Trzy dodatkowe kolce tej samej długości jak krótszy polarny kolec leżą w jednej płaszczyźnie prostopadłej do polarnych kolców lub każdy z nich tworzy kąt 30° z płaszczyzną równikową. Kąty między kolcami mają 120°-120°-120° lub 90°-90°-180°. Prawdopodobnie jedna skorupka rdzeniowa.
Materiał: 12 okazów raczej dobrze zachowanych, spirytyzowanych, kolce częściowo odłamane.
Wymiary (w µm): oparte są na 12 okazach; średnica skorupki korowej: 104–115, długość kolca: 30–70, średnica por: 6–8.
Występowanie: Karpaty, w osadach dolnego eocenu jednostki podśląskiej (potok Czerwin).