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Radiolarian and agglutinated foraminiferal biostratigraphy of the Paleogene deep-water deposits on the northern margin of the Carpathian Tethys (Skole Unit)

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Radiolarian and agglutinated foraminiferal fauna within upper deposits of the Skole Unit of the Polish Flysch Outer Carpathians occur in the Variegated Shale and Hieroglyphic formations of Paleocene and Eocene age. About 70 radiolarian and 50 foraminiferal species have been identified and their stratigraphic distribution determined using both regional and local biozonations. Five radiolarian zones: the *Bekoma bidartensis* Interval Zone, the *Buryella clinata* Interval Zone, the *Phormocyrtis striata striata* Interval Zone, the *Theocotyle cryptocephala* Interval Zone and the *Dictyoprora mongolfieri* Interval Zone in the lower Eocene and in the lower part of the middle Eocene have been distinguished. In the upper part of the middle Eocene and in the uper Eocene the abundance of radiolarians decreases and their age assignment has not been possible. Five foraminiferal zones have been distinguished and correlated with radiolarian zones based on co-occurrence of both Protista groups in the deposits investigated. These are: the *Rzehakina fissistomata* Zone, the *Saccamminoides carpathicus* Zone, the *Reticulophragmium amplectens* Zone, the *Ammodiscus latus* Zone and the *Cyclammina rotundidorsata* Zone covering the time span from upper Paleocene to upper Eocene.

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Key words: Radiolaria, Foraminifera, Paleocene, Eocene, Skole Unit, Outer Carpathians.

INTRODUCTION

In this paper we present new radiolarian and agglutinated foraminiferal assemblages occurring in the Paleogene deposits of the Skole Unit (Flysch Outer Carpathians; Fig. 1). The microfauna studied was observed within the Variegated Shale Formation and the Hieroglyphic Formation (Fig. 2) within the uppermost Paleocene to the upper Eocene deposits.

The radiolarian biostratigraphic scheme proposed herein (after Sanfilippo and Nigrini, 1998*a*, *b*) has been correlated with the agglutinated foraminiferal biozones well-established for the Carpathian deposits (Geroch and Nowak, 1984; Olszewska, 1997) and covering the time span from Lower Cretaceous to Oligocene (Table 1).

In Paleogene deposits of the Carpathians Skole Unit, the microfauna is represented by deep-water, generally agglutinated Foraminifera and occasional calcareous Foraminifera, whereas planktonic Foraminifera and calcareous nannoplankton are absent. The planktonic Foraminifera were observed (Olszewska and Smagowicz, 1977) in Paleocene and Eocene deposits from the Carpathians Fore-Magura units (Fig. 1). The authors cited constructed a biostratigraphic scheme for planktonic Foraminifera, adapted another one for nannoplankton after Martini and Worsley (1971) and correlated these two zonation schemes.

Bąk *et al.* (1997) correlated the above-mentioned biostratigraphic schemes with the scheme based upon agglutinated Foraminifera from the Skole Unit after Geroch and Nowak (1984) for all the Carpathian successions. The same authors correlated the radiolarian zonation (after Sanfilippo *et al.*, 1985) with the deep-water agglutinated foraminiferal zonation from the Tethys developed by Geroch and Nowak (1984).

Only a few authors described rich Paleogene radiolarian assemblage from the Carpathian flysch: from the Skole Unit (Bąk, 1995; Bąk *et al.*, 1997; Rajchel *et al.*, 1998, 1999) and from the Sub-Silesian Unit (Bąk and Barwicz-Piskorz, 2005, 2006).

The Variegated Shale and Hieroglyphic formations represent hemipelagic sediments, deposited in deep-sea basins (bathyal depths) below the CCD (Leszczyński and Uchman, 1991; Bąk *et al.*, 1997). A Paleocene radiolarian fauna is absent or rare within the Skole Unit deposits, as opposed to the Eocene, where radiolarians are abundant (especially in the lower Eocene and in the middle part of the middle Eocene).

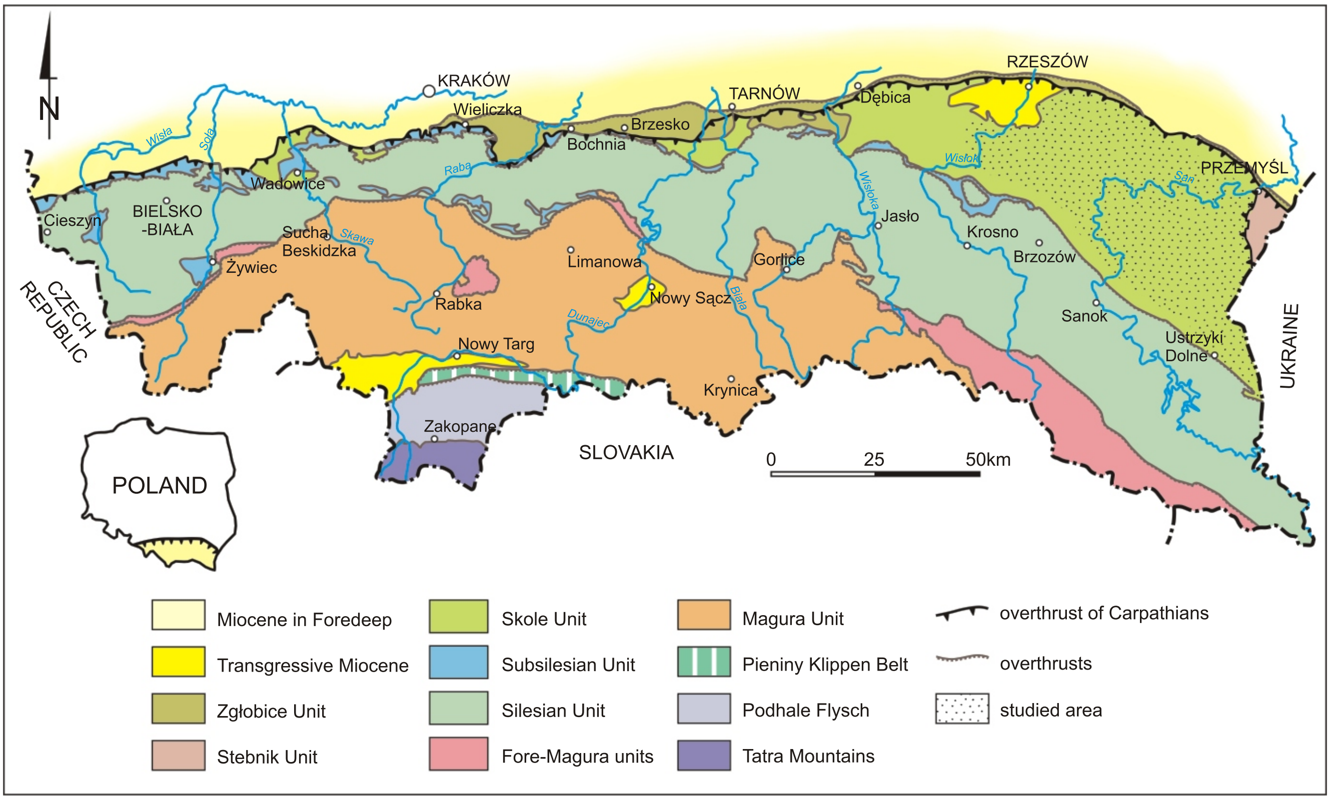


Fig. 1. Geological structure of the Polish Carpathians (after Żytko *et al*., 1989, changed, simplified) and the studied area

Large accumulations of radiolarian skeletons in the deposits studied may have been caused by high amounts of dissolved silica from enhanced weathering, volcanism and abundant nutrients in the seawater. The effects of a palaeooceanographic change of the surface water circulation in the Carpathian basin (Bąk *et al*., 1997) is also a factor to consider.

A global spatial-temporal distribution of deep-water sediments with rich radiolarian fauna is most typical of the Paleocene and early Eocene. An occurrence peak at about 50 Ma BP coincides with the time of the highest bottom-water temperatures of the early Eocene climatic optimum (EECO; Muttoni and Kent, 2007).

GEOLOGICAL SETTING

The Polish part of the Carpathian arc (Fig. 1) is divided into three tectonic units: the Inner Carpathians, the Pieniny Klippen Belt and the Outer Carpathians. As the latter are composed mainly of turbidite deposits, they are also referred to as the Flysch Carpathians. The Skole Unit is one of several important structural-tectonic units in the Outer Carpathians (Fig. 1). The Skole Unit is also present towards the SE in the Ukrainian and Romanian Carpathians. The strata of the Skole Unit belong to a single stratigraphic succession, ranging from the Lower Cretaceous to the lower Miocene. The profiles studied are confined to the Variegated Shale and Hieroglyphic formations in the Skole Unit (Fig. 2). The authors used the lithostratigraphic division of these two formations proposed by Rajchel (1990).

The Variegated Shale Formation (upper Paleocene–lower part of lower Eocene) of the Skole Unit is composed of red clayey and muddy shales with interbeds of green shales and lenses of various sandstones (Boguszówka Sandstone Member and Chmielnik Striped Sandstone Member). This material was derived from various sources. The formation also contains horizons of bentonitised tuffites (Rajchel, 1994). The thickness of this formation in the axial part of the Skole Unit ranges from 130 m in the east to 190 m in the west and thins near the basin margins.

The Variegated Shale Formation (Fig. 2) represents a deposit of lower bathyal and abyssal origin, formed below the CCD. It was deposited at a depth of about 3 km (Olszewska, 1984) in an environment with high oxidation potential (Leszczyński and Uchman, 1991, 1993). Periodic oscillations of this potential are marked by sedimentation of green noncalcareous shales and by rare occurrences of Fe, Cu and Pb sulphides (Franus and Rajchel, 1999). These changes could have been caused by fluctuations of the waters circulating within the Tethys Ocean and varying supplies of organic matter (Morgiel and Szymakowska, 1978; Leszczyński and Uchman, 1993; Bąk *et al*., 1997). The Paleocene part of the Variegated Shale Formation (Żohatyn Variegated Shale Member) is composed of dark red muddy and clayey shales, often with large lenses of sandstones and black clayey-muddy strata. At the base of this formation extends a regional correlation horizon of allodapic limestones, the Bircza Lithothamnium Limestone Bed, rich in material derived from the northern margin of the Skole basin (Rajchel and Myszkowska, 1998*a*, *b*). The lower Eocene part of the Variegated Shale Formation consists of

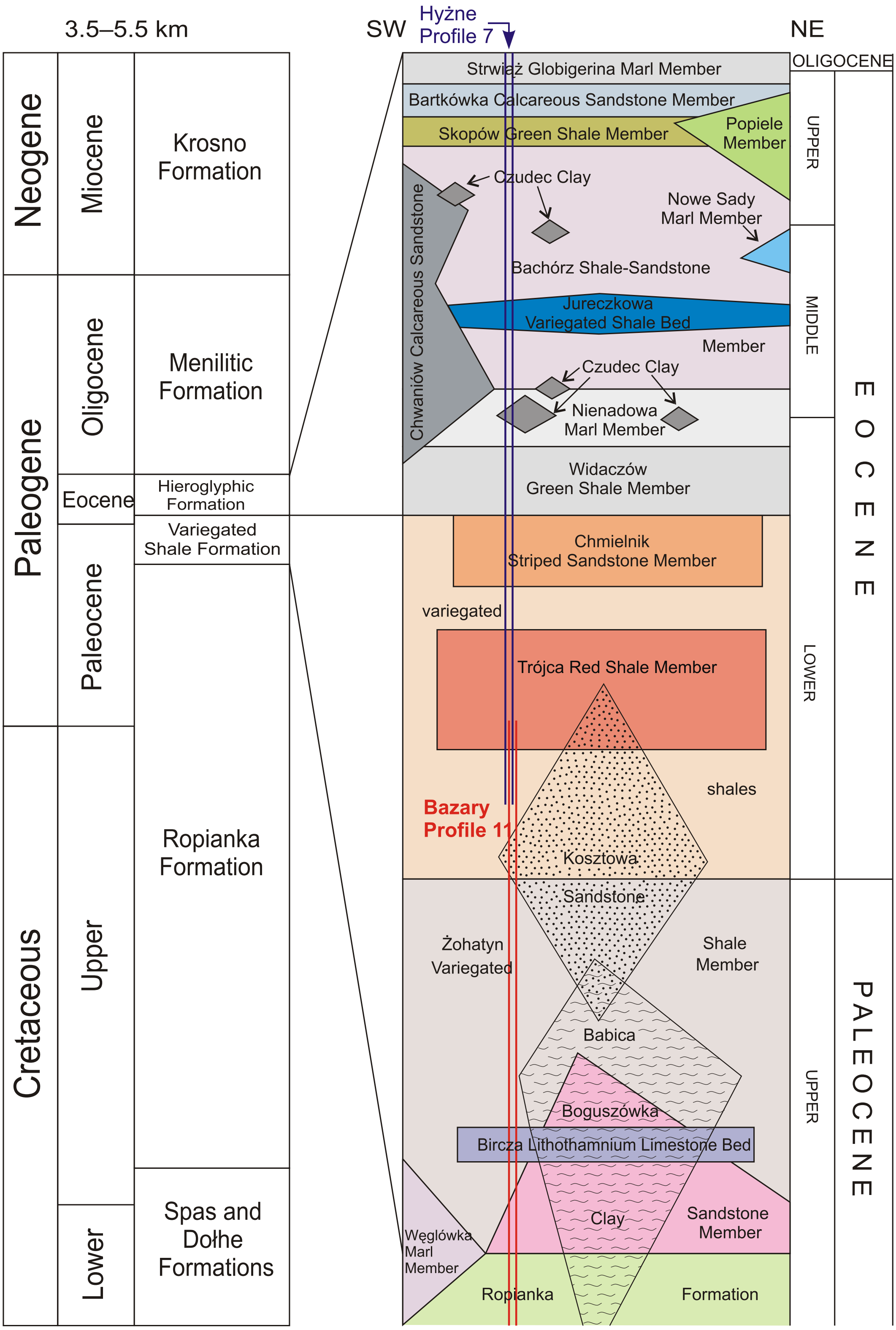


Fig. 2. Lithostratigraphic units in the Variegated Shale and Hieroglyphic formations of the Skole Unit (the Polish Carpathians) with the location of profile No. 7 from Hyżne and profile No. 11 from Bazary (after Rajchel, 1990, modified)

Table 1

Radiolarian zones (after Sanfilippo and Nigrini, 1998*a*, *b*) recorded in the study area and compared with the Carpathian agglutinated foraminiferal zonation (after Geroch and Nowak, 1984; Olszewska, 1997)

Ages according to timescale of Haq *et al.* (1988)				Foraminiferal zones		Sanfilippo and Nigrini	
				Geroch and Nowak (1984)	Olszewska (1997)	(1998*b*) code number	(1998*a*) radiolarian zones
Ma	Olig.		Rupelian		*Globigerina ampliapertura*		
	EOCENE	upper	Priabonian	*Cyclammina rotundidorsata*	*Cyclammina rotundidorsata*	RP19 RP18 RP17	*Cryptocarpium ornatum* *Calocyclas bandyca* *Cryptocarpium azyx*
40		middle	Bartonian	*Ammodiscus latus*	*Ammodiscus latus*	RP16 RP15 RP14 RP13	*Podocyrtis goetheana* *Podocyrtis chalara* *Podocyrtis mitra* *Podocyrtis ampla*
			Lutetian	*Cyclammina amplectens*	*Reticulophragmium amplectens*	RP12 RP11 RP10 RP9	*Thyrsocyrtis triacantha* *Dictyoprora mongolfieri* *Theocotyle cryptpocephala* *Phormocyrtis striata striata*
50		lower	Ypresian	*Saccamminoides carpathicus*	*Saccamminoides carpathicus* *Glomospira* div. sp.	RP8 RP7	*Buryella clinata* *Bekoma bidartensis*
	Paleocene		Thanetian	*Spiroplectammina spectabilis*	*Rzehakina fissistomata*	RP6	*Bekoma campechensis*
			Danian	*Rzehakina epigona fissistomata*		RP5	
60	Creta-ceus		Maastrichtian				

bright cinnabar-red and green clayey shales. The Trójca Red Shale Member is about 20–30 m thick and contains a large amount of pyroclastic material, partly (to 30%) altered into clinoptillolite (Wieser, 1994; Bąk *et al.*, 1997). The richest radiolarian assemblage (50 species) occurs within these red shales (Bąk, 1995; Bąk *et al.*, 1997; Rajchel *et al.*, 1998, 1999).

The Hieroglyphic Formation (upper part of lower Eocene to lower part of Oligocene; Fig. 2) is a 130–180 m thick succession of green clayey shales (Widaczów Green Shale Member and Skopów Green Shale Member) with green sandstone interbeds (Bachórz Shale-Sandstone Member). Lithosomes of sandstones (Bartkówka Calcareous Sandstone Member), cherts, gaizes, red shales (Jureczkowa Variegated Shale Bed) and marls (Nienadowa Marl Member) form interbeds within the shales. The Strwiąż Globigerina Marl Member in the upper part of this formation is an important regional correlation horizon in the Outer Carpathians, marking the Eocene/Oligocene boundary (Rajchel, 1990; Leszczyński, 1997).

MATERIALS AND METHODS

Micropalaeontological samples were taken from 25 sections (22 natural exposures and three trenches) throughout the Paleogene-upper Paleocene to upper Eocene deposits located in the Polish part of the Skole Unit (Figs. 2 and 3). A small, representative area in the central part of the Skole Unit near Hyżne (Fig. 4) was subjected to more detailed investigations. A total of 238 samples were studied, out of which 139 samples contain radiolarian assemblages. The radiolarians were extracted from clayey shales by multiple heating of disaggregated rock samples in Glauber's salt solution. Then, the samples were washed, dried and separated using a 0.06 mm sieve.

The preservation of the microfauna is variable. Scanning electron microphotographs were obtained with a *JEOL ISM-5410* at the Jagiellonian University by Ms. J. Faber. As the inner parts of most specimens were poorly visible in transmitted light, only a few of these photographs are useful.

The amount of Radiolaria varies in a sample from rare (1 to 4 specimens) to abundant (more than 100, sometimes some thousands of specimens).

The radiolarian distribution in the upper Paleocene to upper Eocene deposits differs laterally, as shown previously by Morgiel and Szymakowska (1978). The present authors determined that the most abundant radiolarian assemblages generaly prevail in the axial part of Skole basin (Fig. 3): profile No. 1 in Chmielnik, profiles No. 5–8 in the vicinity of Hyżne (Fig. 4), profiles No. 9 and 10 near Dylągówka, profile No. 11 in Bazary, profile No. 12 in Łazy, profile No. 13 in Futoma and profile No. 16 in Bachów. In the profiles mentioned most Paleogene deposits contain radiolarians. In the profiles of Zabratówka (No. 2), Makłuczka (No. 3), Baryczka (No. 4), Bartkówka (No. 14), Leszczawa (No. 15), Trójca (No. 17), Cisowa (No. 18), Nienadowa (19), Grochowce (No. 20), Kniażyce (No. 21), Hujsko (No. 22), Turnica (No. 23), Leszczyny (No. 24) and Bandrów (No. 25) some layers of the Paleogene deposits contain poor radiolarian assemblages. There are also some profiles in the Paleogene deposits without any radiolarians. These are located mostly in peripheral parts of the Skole basin.

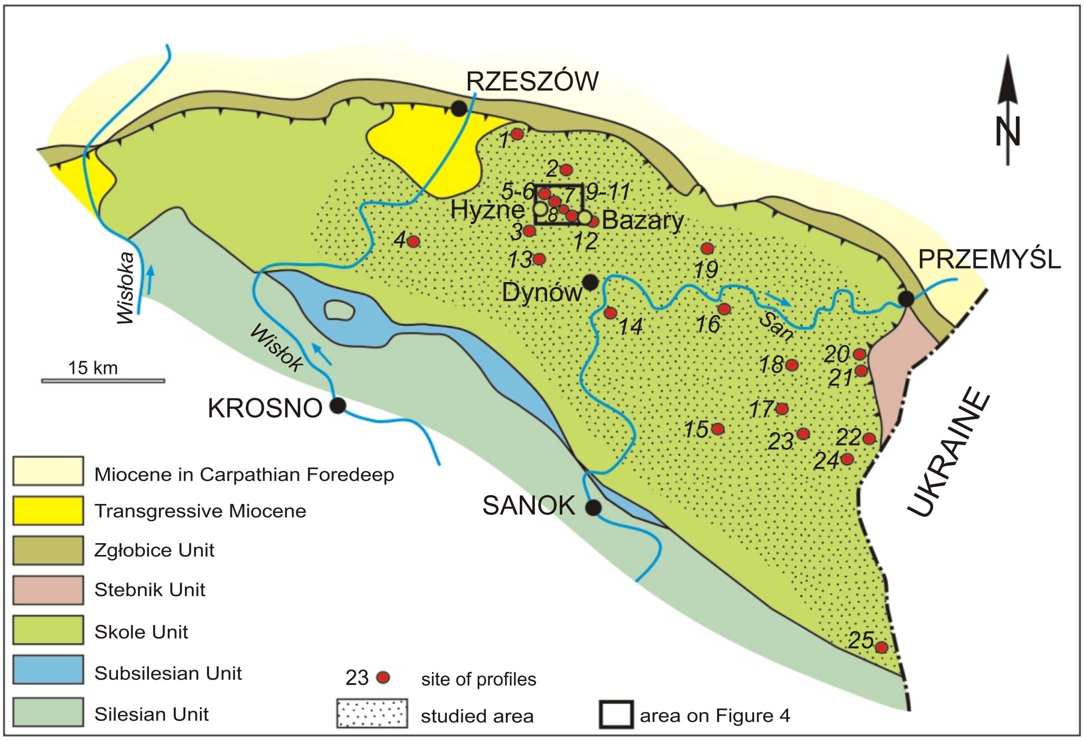


Fig. 3. Distribution of the profiles examined within the Variegated Shale and Hieroglyphic formations of the Skole Unit in the Polish Carpathians (after Żytko *et al.*, 1989; Rajchel, 1990, modified and simplified)

1 – Chmielnik, 2 – Zabratówka, 3 – Makłuczka, 4 – Baryczka, 5 – Nowa Wieś (trench 2), 6 – Nowa Wieś (trench 1), 7 – Hyżne, 8 – Wólka Hyżneńska, 9 – Dylągówka (trench), 10 – Przylasek, 11 – Bazary, 12 – Łazy, 13 – Futoma, 14 – Bartkówka, 15 – Leszczawa, 16 – Bachów, 17 – Trójca, 18 – Cisowa, 19 – Nienadowa, 20 – Grochowce, 21 – Kniażyce, 22 – Hujsko, 23 – Turnica, 24 – Leszczyny, 25 – Bandrów

Fig. 4. Geology of the vicinity of Dylągówka in the central part of the Skole Unit with the location of profiles No. 7 (Hyżne), No. 11 (Bazary) and others (after Wdowiarz, 1949; Rajchel, 1989, modified)

MICROFAUNA IN THE DEPOSITS EXAMINED

GENERAL CONTENT

In the deposits studied from the Skole Unit the microfauna generally contains rich deep-water agglutinated foraminiferal and radiolarian assemblages. Rare fish teeth and sponge spicules are also present. Calcareous benthic Foraminifera are rare and present only in the Paleocene and upper Eocene deposits. Planktonic Foraminifera and calcareous nannoplankton are absent.

Abundance changes of the main microfaunal components from the Hyżne and Bazary sections are shown in Figure 5.

The Paleocene section (Żohatyn Variegated Shale Member) includes common agglutinated benthic Foraminifera, rare calcareous benthic Foraminifera and variable amounts of Radiolaria. The low-diversity radiolarian assemblages in this section are represented by only three radiolarian families (Fig. 5, sample 2/11).

The Trójca Red Shale Member and the Chmielnik Striped Sandstone Member of the lower Eocene part of the section include rare to common agglutinated benthic Foraminifera and abundant Radiolaria. There are no calcareous benthic Foraminifera at all. The radiolarian assemblages are the most diverse of any sample from this study, with five to six families represented in each (Fig. 5, samples 2/7 and 3/7).

The Jureczkowa Variegated Shale Bed (middle Eocene part of the section) includes rare to common agglutinated benthic Foraminifera, rare calcareous benthic Foraminifera, and abundant, diverse Radiolaria (not illustrated because of true generally poor preservation of the specimens).

The Bachórz Shale-Sandstone Member (middle-upper Eocene) includes rare to common agglutinated benthic Foraminifera, rare calcareous benthic Foraminifera and common, diverse radiolarian assemblages with six to seven radiolarian families represented. Nassellaria are more diverse than in the other sections, with up to three families represented (Fig. 5, samples 7/7, 8/7 and 9/7).

The Bartkówka Calcareous Sandstone Member (upper Eocene) includes rare agglutinated benthic Foraminifera and rare to common diverse radiolarian assemblages, with three to six families represented (Fig. 5, sample 10/7).

RADIOLARIAN ASSEMBLAGES

The radiolarian fauna discussed here is dominated by the species known from low and middle geographic latitudes (Tochilina, 1985; Nishimura, 1992; Hollis, 1993, 2002, 2007; Khokhlova *et al*., 1994; Strong *et al*., 1995; Sanfilippo and Nigrini, 1998*a*; Sanfilippo and Hull, 1999; O'Connor, 2000; de Wever *et al*., 2001; Sanfilippo and Blome, 2001; Sanfilippo *et al*., 2003; Popova-Goll and Goll, 2006; Li Yalin *et al*., 2007).

The Paleogene deposits from the Skole Unit contain abundant and well-preserved Spumellaria, while Nassellaria are rather poorly presented. About 30% of the species in our material (especially large Spongodiscidae, some Actinommidae and a few nassellarian species – *Lamptonium f. fabaeforme*, *Tricolocampe* sp. and *Thyrsocyrtis hirsuta*) – are also known from the cold-water deposits of the Caucasus region (Krasheninnikov, 1960). Some large Spongodiscidae – *Sethocyrtis minimus* Lipman and *Lychnocanium conicum* – present in our material, were recognized in the cold-water environments represented in the Dnieper–Don depression (Gorbunov, 1979). The assemblages with elongated, spongy Spumellaria observed in the Eocene of the Turgay region – Russia (Blueford and Amon, 1993) are similar to our material from Carpathians.

Rich radiolarian assemblages from the Paleogene deposits of the Russian Platform (Voronezh Anticline) contain only a few species (Popova *et al*., 2002) known from our material.

In the upper part of some sections: Hyżne, Futoma, Leszczawa, Cisowa, Turnica, Trójca (the upper part of *Reticulophragmium amplectens* Zone, *Ammodiscus latus* Zone and *Cyclammina rotundidorsata* Zone – the middle and upper Eocene), the radiolarian abundance decreases, with only a few Nassellaria species and some Spumellaria. Locally Radiolaria are lacking. Nassellaria are represented by *Podocyrtis papalis*, *Theocotylissa ficus*, *Lychnocanoma* cf. *amphitrite*, and Spumellaria by *Phacodiscus lentiformis*, *Cenosphaera* cf. *eocenica* and *Lithocyclia aristotelis* (Ehrenberg).

The number of radiolarian species present in the Paleogene deposits of the Skole Unit is relatively lower than that in the Paleocene bottom deposits of the World Ocean. Only two species have been recognized – *Buryella clinata* and *Phormocyrtis striata striata,* which define the respective radiolarian zones. This may be the effect of a general poverty of radiolarian microfauna in the Skole basin as a result of its very narrow and distant connection with the Atlantic Ocean in the Paleogene (Golonka *et al*., 2000). A second reason for the poverty of microfauna discussed here is the fact that most of the material studied comes from samples which only partly disaggregated. The bibliographic data for separate radiolarian species are placed in the Appendix below. The most of identified radiolarian species are presented on Plate 1 to 5.

FORAMINIFERAL ASSEMBLAGES

The foraminiferal assemblages in Paleogene deposits of the Skole Unit are dominated by deep-water agglutinated species (Fig. 5 and Table 1). The calcareous benthic Foraminifera are rare and present only in the Paleocene and upper Eocene deposits. The planktonic Foraminifera are absent.

In the material investigated, except for numerous index species mentioned above, there are many long-range species occurring in variable quantity: *Glomospira gordialis* (Jones and Parker), *Gl. charoides* (Jones and Parker), *Gl. serpens* (Grzybowski), *Kalamopsis grzybovskii* (Dylążanka), *Haplophragmoides walteri* (Grzybowski), *Ammodiscus* sp., *Spiroplectammina spectabilis* (Grzybowski), *Karrerulina coniformis* (Grzybowski), *Revcurvoides* div. sp., *Trochamminoides* sp., *Cribrostomoides* sp., *Karrerulina* sp., *Rhabdamina* sp., *Hyperammina* sp. and many others. The calcareous benthic Foraminifera are very rare, poorly preserved and unrecognisable. The species mentioned here are known well in the literature concerning the Carpathians.

FORAMINIFERAL AND RADIOLARIAN BIOSTRATIGRAPHY

The occurrence of radiolarian and agglutinated foraminiferal assemblages allow the correlation of biostratigraphic schemes based on both groups of microorganisms.

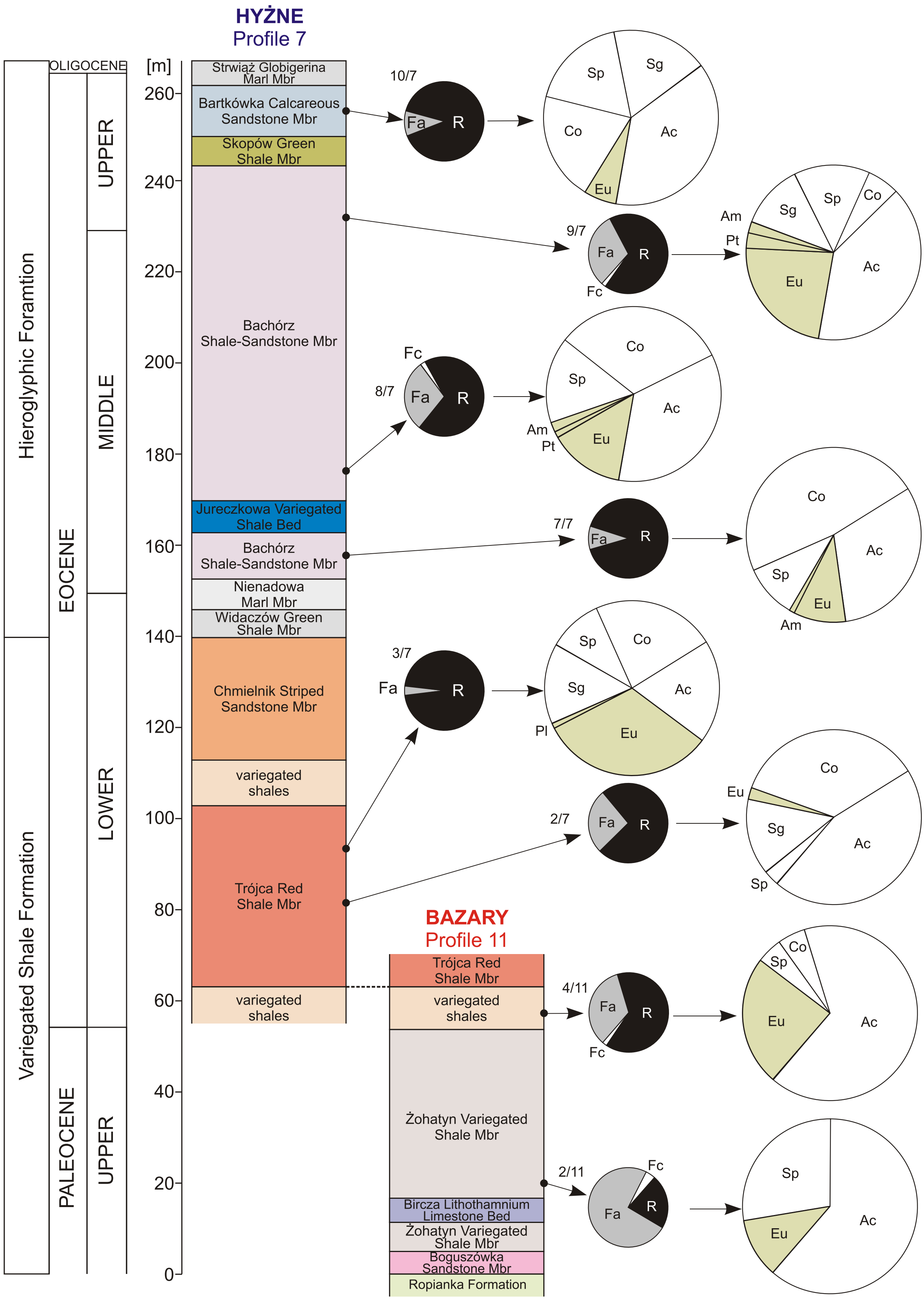


Fig. 5. Detailed profiles of the Variegated Shale and Hieroglyphic formations from Hyżne (No. 7) and Bazary (No. 11) in the central part of the Skole Unit with diagrams of radiolarian assemblages

Small pie charts show faunal components: Fa – agglutinated Foraminifera, Fc – calcareous Foraminifera, R – Radiolaria; large pie charts represent the distribution of radiolarian families: spumellarian families: Ac – Actinommidae + Stylosphaeridae, Sp – Spongodiscidae, Co – Coccodiscidae = Phacodiscidae + Heliodiscidae, Sg – Sponguridae; nassellarian families: Am – Amphipyndacidae + Artostrobiidae, Eu – Eucyrtidiidae + Theoperidae + Theocotylidae, Pt – Pterocorythidae

FORAMINIFERAL ZONATIONS

The foraminiferal species recognized here belong to five agglutinated foraminiferal zones established for the Polish Flysch Carpathians by Geroch and Nowak (1984) and Olszewska (1997). They are: the *Rzehakina fissistomata* Zone (upper Paleocene), the *Saccamminoides carpathicus* Zone (lower Eocene), the *Reticulophragmium amplectens* Zone (middle Eocene), the *Ammodiscus latus* Zone (middle Eocene) and the *Cyclammina rotundidorsata* Zone (upper Eocene).

RADIOLARIAN ZONATIONS

The radiolarian biostratigraphic scheme has been adapted after Sanfilippo and Nigrini (1998*a*) for low latitudes.

In the assemblages studied only some radiolarian species are stratigraphically important while most are long-ranging (Table 2). Using the zonation of Sanfilippo and Nigrini (1998*a*), the following radiolarian zones can be distinguished: the *Bekoma bidartensis* Interval Zone, the *Buryella clinata* Interval Zone, the *Phormocyrtis striata striata* Interval Zone, the *Theocotyle cryptocephala* Interval Zone and the *Dictyoprora mongolfieri* Interval Zone.

Bekoma bidartensis Interval Zone RP7

After Sanfilippo and Blome (2001), this zone has been described as the interval beginning at the evolutionary transition from *Pterocodon* (?) *anteclinata* to *Buryella clinata* and to the lowest morphotypic occurrence of *Bekoma bidartensis.*

R e m a r k s. – Because the index species are missing in our material, we give as the informal, local limits of this zone the first occurrence of *Calocycloma ampulla* (Ehrenberg) and *Theocotylissa auctor* Foreman (bottom) and the first occurrence of *Buryella clinata*, *Lamptonium sanfilippoae* and *Theocotyle nigriniae* (top).

Several radiolarian events occur within the zone. These are: the first occurrence of *Calocycloma castum* (in the lower part of the zone), the first occurrence of *Podocyrtis papalis* (near the middle of the zone), the first occurrence of *Theocotylissa auctor* and *Thyrsocyrtis (Thyrsocyrtis) hirsuta* (in the upper part of the zone), the first occurrence of *Theocotylissa ficus* (in the lower part of the zone). These radiolarian first occurrences are not synchronous with those described by Sanfilippo and Blome (2001) from low-latitude localities. For example, the first occurrence (FO) of the *Theocotylissa ficus* and *Thyrsocyrtis (Thyrsocyrtis) hirsuta* happens much later, and the FO of the *Theocotylissa auctor* takes place much earlier in the *B. clinata* Zone at low latitudes.

Buryella clinata Interval Zone RP8

After Sanfilippo and Blome (2001), this zone has been described as the interval beginning at the lowest occurrence of *Theocorys anaclasta* to the evolutionary transition from *Pterocodon* (?) *anteclinata* to *Buryella clinata.*

R e m a r k s. – Because some of the index species are missing in our material, we give as the informal, local limits of this zone the interval from the first occurrence of *Buryella clinata* Foreman and *Phormocyrtis striata exquisita*, *Calocycloma castum* (Haeckel), *Lamptonium sanfilippoae* Foreman and *Theocotyle nigriniae* Riedel and Sanfilippo (bottom) to the first occurrence of *Phormocyrtis striata striata* Brandt, *Bathropyramis quadrata* Haeckel, *Lychnocanium bellum* Clark and Campbell, *Eucyrtidium* cf. *montiparum*, *Lychnocanoma* cf. *amphitrite* Foreman and *Lamptonium fabaeforme fabaeforme* (top).

Sanfilippo and Blome (2001) reported the following events occurring within the zone: the last occurrence of *Phormocyrtis turgida* (Krasheninnikov) and the first occurrences of *Lamptonium sanfilippoae*, *Theocotyle nigriniae* and *Thyrsocyrtis (Thyrsocyrtis) hirsuta.*

Phormocyrtis striata striata Interval Zone RP9

After Sanfilippo and Blome (2001), this zone has been described as the interval beginning at the evolutionary transition from *Theocotyle nigriniae* to *Theocotyle cryptocephala* to the lowest occurrence of *Theocorys anaclasta*.

R e m a r k s. – Because most of the index species are missing in our material, we give as the informal, local limits of this zone the interval from the first occurrence of *Phormocyrtis striata striata*, *Bathropyramis quadrata*, *Lychnocanium bellum*, *Eucyrtidium* cf. *montiparum* Ehrenberg, *Lamptonium fabaeforme fabaeforme* (Krasheninnikov) and *Lychnocanoma* cf. *amphitrite* (base) to the first occurrences of *Spongatractus pachystylus* and *Amphiternis clava* and the last occurrence of *Eucyrtidium* cf. *montiparum*.

Sanfilippo and Blome (2001) reported the following events occurring within the zone: the last occurrences of *Lamptonium sanfilippoae* and *Phormocyrtis cubensis* and the first occurrences of *Thyrsocyrtis rhizodon* and *Lychnocanium bellum*.

Theocotyle cryptocephala Interval Zone RP10

After Sanfilippo and Blome (2001), this zone has been described as the interval beginning at the lowest occurrence of *Dictyoprora mongolfieri* to the evolutionary transition from *Theocotyle nigriniae* to *Theocotyle cryptocephala*.

R e m a r k s. – Because the index species are missing in our material, we give as the informal, local limits of this zone the first occurrence of *Spongatractus pachystylus* (Ehrenberg) and *Amphiternis clava* (Ehrenberg) (bottom), while the top of the zone as the last occurrence of *Spongurus bilobatus*, *Amphiternis clava* and *Bathropyramis quadrata.* The last occurrence of *Calocycloma castum* also occurs at the top of the *Theocotyle cryptocephala* Zone in our material.

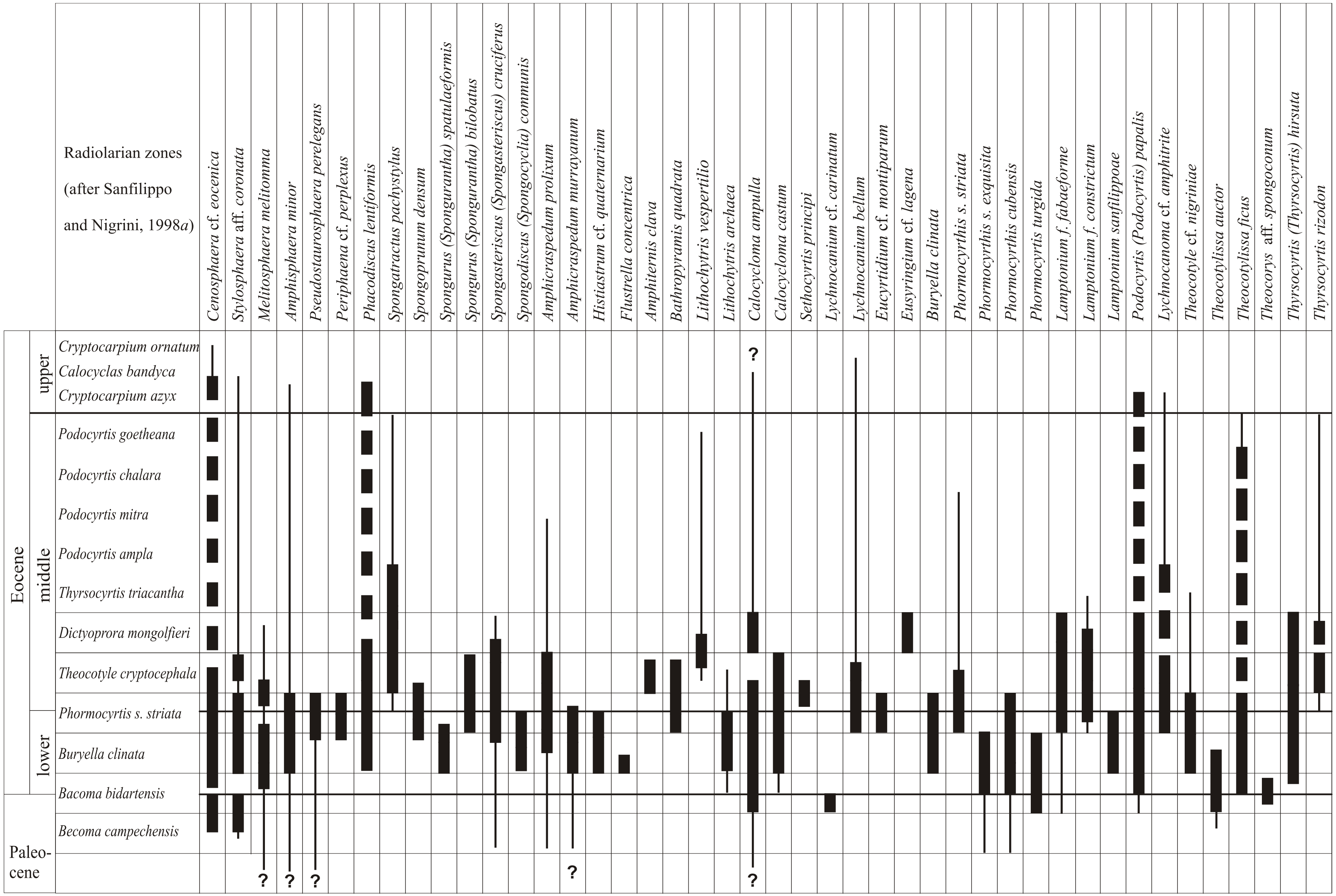
Dictyoprora mongolfieri Interval Zone RP11

After Sanfilippo and Blome (2001), this zone has been described as the interval beginning at the lowest occurrence of *Eusyringium lagena* to the lowest occurrence of *Dictyoprora mongolfieri.*

R e m a r k s. – Because one of the index species is missing in our material, we give as the informal, local limits of this zone the interval from the last occurrence of *Calocycloma castum*, *Amphiternis clava*, *Bathropyramis quadrata* and *Spongurus bilobatus* (bottom) to the last occurrence of *Lamptonium fabaeforme fabaeforme* and *Thyrsocyrtis (Thyrsocyrtis) hirsuta* (top).

Table 2

Time ranges of Paleogene Radiolaria (after Sanfilippo and Nigrini, 1998*a*)



Solid continuous black columns – ranges of common species in the Skole Unit; discontinuous black columns – ranges based on very rare specimens in the Skole Unit; thin black lines – species ranges from the literature

CORRELATION

The radiolarian and foraminiferal zones from the Paleogene deposits of the Skole Unit are shown in Table 1.

The radiolarian Zone RP7 coincides in the Skole Unit with the upper part of the *Rzehakina fissistomata* Zone and the lower part of the *Saccamminoides carpathicus* Zone and is upper Paleocene to lowermost Eocene in age.

The radiolarian Zone RP8 coincides in the Skole Unit with the *Saccamminoides carpathicus* Zone and is lower Eocene in age.

The radiolarian Zone RP9 coincides in the Skole Unit with the uppermost part of the *Saccamminoides carpathicus* Zone and the lowermost part of the *Reticulophragmium amplectens* Zone and is uppermost lower Eocene and the lowermost middle Eocene in age.

The radiolarian Zone RP10 coincides, in the Skole Unit, with the lower part of the *Reticulophragmium amplectens* Zone and is lower middle Eocene in age.

The radiolarian Zone RP11 coincides in the Skole Unit with the middle part of the *Reticulophragmium amplectens* Zone and is lower part of the middle Eocene in age.

The radiolarian zonation presented herein approximates to the low-latitude radiolarian biozonation.

The correlation of the five newly established radiolarian zones with the zonations of other authors (Bąk, 1995; Bąk *et al*., 1997; Bąk and Barwicz-Piskorz, 2005) have also been made in the area of the Skole and Sub-Silesian units (Table 3). The zonation for the bottom deposits of the World Ocean low and middle latitudes (Sanfilippo and Nigrini, 1998*a*) has formed the basis for establishing a radiolarian zonation for the regions mentioned here.

The radiolarian zonations for the boreal region (Russian Platform) by Kozlova (1984, 1990, 1993) have been found inappropriate for low latitudes (Sanfilippo and Nigrini, 1998*a*). In the material from the Skole Unit, the *Phormocyrtis striata striata* Interval Zone is the only zone common to both zonations (boreal and low-latitude), but its stratigraphic position is lower in the boreal zonation (Table 4).

Table 3

Radiolarian zones and agglutinated foraminiferal zones (recognized until now in the Polish part of the Flysch Carpathians)

Age		Foraminiferal zones Carpathians	Radiolarian zones			
		Geroch and Nowak (1984)	Bąk (1995) Skole Unit, Dylągówka profile	Bąk *et al*. (1997) Dylągówka region	Bąk and Barwicz-Piskorz (2005) Subsilesian Unit, Czerwin region	Barwicz and Rajchel (this paper) Skole Unit, 25 profiles
Eocene	middle	*Cyclammina rotundidorsata* *Ammodiscus latus*				*Dictyoprora mongolfieri*
Eocene	middle	*Reticulophragmium amplectens*	*Phormocyrtis striata striata*	*Theocotyle cryptocephala* *Phormocyrtis striata striata* *Buryella clinata*	*Phormocyrtis striata striata*	*Theocotyle cryptocephala* *Phormocyrtis striata striata* *Buryella clinata* *Bekoma bidartensis* *Bekoma campechensis*
Eocene	lower	*Saccaminoides carpathicus*				
Paleocene upper		*Rzehakina fissistomata*				

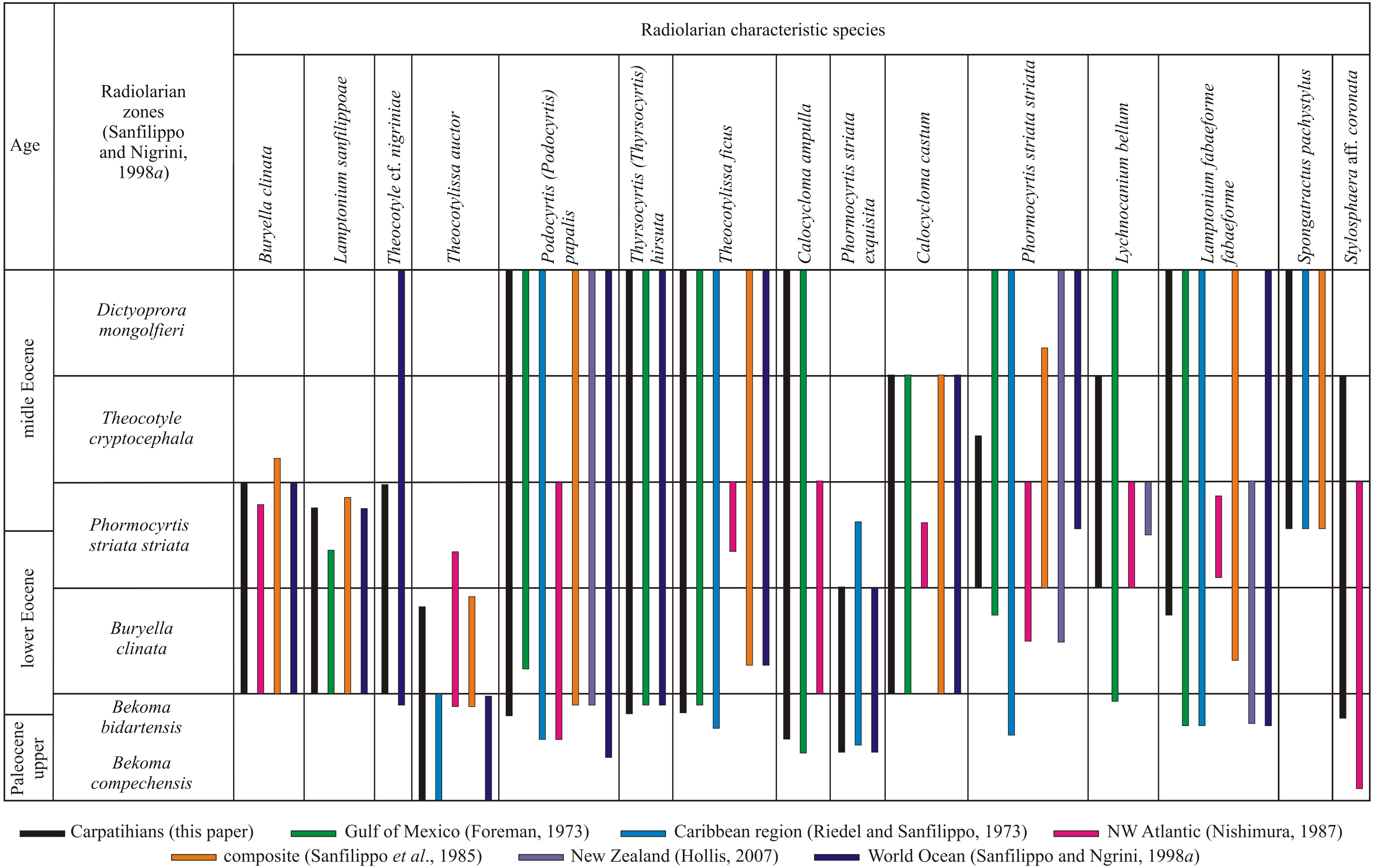
Table 4

Comparison of the radiolarian zonations from low and middle latitudes in the World Ocean (Sanfilippo and Nigrini, 1998*a*) with those from North Eurasia (Kozlova, 1990; Lipman, 1993)

Age		Barwicz and Rajchel (this paper) Carpathians	Sanfilippo and Nigrini (1998*a*) World Ocean	Kozlova (1990) Russian Platform	Lipman (1993) North Eurasia
Eocene	middle	*Dictyoprora mongolfieri* *Theocotyle cryptocephala*	*Podocyrtis goetheana* *Podocyrtis chalara* *Podocyrtis mitra* *Podocyrtis ampla* *Thyrsocyrtis triacantha* *Dictyoprora mongolfieri* *Theocotyle cryptocephala*	*Etmosphaera polysiphona* *Cyrtoformis alta* *Heliodiscus quadratus* *Lychnocanium separatum*	*Spongurus biconstrictus* Zone *Amphicaridiscus fuscideus*–*Amphibrachium gracilis* Zone
Eocene	lower	*Phormocyrtis striata striata* *Buryella clinata* *Bekoma bidartensis*	*Phormocyrtis striata striata* *Buryella clinata* *Bekoma bidartensis*	*Phormocyrtis striata striata* *Heliodiscus lentis* *Spongatractus paciferus* *Petalospyris fiscella*	*Amphycaridiscus fuscideus*–*Amphibrachium gracilis* layer with Spongodiscidae *Sethodiscus vialovi* *Ellipsostylus inclarus*
Paleocene upper		*Bekoma campechensis*	*Bekoma campechensis*	layer with *Phormocyrtis cubensis*	*Cromyodruppa regularis* *Porodiscus ornatus*

Table 5

The first and last occurrences of the most important radiolarian species from the Carpathians and some selected regions



Note: the data from NW Atlantic (Nishimura, 1987) concern profile from the *Bekoma compechensis* Zone to the *Phormocyrtis striata striata* Zone only

The radiolarian zonations for North Eurasia (Kozlova, 1990; Lipman, 1993) differ from the zonation for low and middle latitudes in the World Ocean (Sanfilippo and Nigrini, 1998*a*). The radiolarian zones common to these districts cannot be distinguished.

DISCUSSION

The research carried out in the Variegated Shale and Hieroglyphic formations of the Skole Unit resulted in the first wide spread identification of populations of Radiolaria and accompanied agglutinated Foraminifera in the Paleogene deposits of the Carpathian flysch. Previous research was mostly based on limited material (Bąk, 1995; Bąk *et al*., 1997).

Our zonation has been compared to the radiolarian zonation of boreal districts, i.e. of the Russian Platform (Kozlova, 1990) and North Eurasia (Lipman, 1993). The radiolarian zonations for many parts of the boreal realm (Table 4) differ from the zonation for low and middle latitudes in the World Ocean (Sanfilippo and Nigrini, 1998*a*) as there are no common species.

The range of the first and the last occurrences of some selected index species from the Carpathians has been compared to the range of radiolarian species from other districts of low and middle latitudes, such as the Gulf of Mexico (Foreman, 1973), the Caribbean region (Riedel and Sanfilippo, 1973), the NW Atlantic (Nishimura, 1987), New Zealand (Hollis, 2007), the World Ocean (Sanfilippo *et al*., 1985; Sanfilippo and Nigrini, 1998*a*). It turns out that in some cases the data on the first and last occurrences of radiolarian species differ in the literature mentioned above (Table 5).

CONCLUSIONS

The Skole basin in the Paleogene formed the northern part of the Tethys Ocean. It extends along the southern edge of the northern European Platform.

Paleogene sedimentation in the Skole basin took place in deep-water conditions below the CCD. The microfauna was composed generally of agglutinated Foraminifera and Radiolaria. The Radiolaria represent an association of warm-water species but poorer than the one known from the World Ocean.

The radiolaria and agglutinated Foraminifera mentioned above belong to five radiolarian zones (after Sanfilippo and Nigrini, 1998*a*) and to five agglutinated foraminiferal zones (after Geroch and Nowak, 1984), being upper Paleocene to middle Eocene in age. The radiolarian zonation may be correlated with the deep-water agglutinated foraminiferal zonation from Tethys.

Radiolarian assemblages of low and middle latitudes (include Carpathian) differ distinctly from those of the boreal zone (North Eurasia). There are no common species.

The first and the last occurrences of individual species from the study area and those from the literature show some differences. The exception is *Buryella clinata* – the index species of the *Buryella clinata* Zone. In the deep-water deposits of the World Ocean, the New Zealand region and the Carpathians, its first occurrences are on the boundary between the *Bekoma bidartensis* Zone and the *Buryella clinata* Zone, the last occurrences, however, are near the boundary of the *Phormocyrtis striata striata* Zone and the *Theocotyle cryptocephala* Zone.

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APPENDIX

Species list (systematics after P. de Wever *et al*., 2001)

Class ACTINOPODA
Subclass RADIOLARIA Müller 1858
Superorder POLYCYSTINA Ehrenberg 1838, emend. Riedel 1967
Order SPUMELLARIA Ehrenberg 1875, emend. de Wever *et al.,* 2001
Family STYLOSPHAERIDAE Haeckel 1881

Amphisphaera minor (Clark and Campbell)
(Pl. 1d)

Stylosphaera minor Clark and Campbell, 1942, p. 27, pl. 5, figs. 1, 2, 12.
Amphisphaera minor (Clark and Campbell);
Sanfilippo and Riedel, 1973, p. 486, pl. 1, figs. 1–5; pl. 22, fig. 4;
Nishimura, 1987, p. 719, pl. 1, fig. 5;
Liu and Aitchison, 2002, p. 147, pl. 1, fig. 7;
Hollis, 2007, pl. 1, fig. 4;
Bąk and Barwicz-Piskorz, 2005, p. 142, fig. 3F.

***Amphisphaera* ?** sp.
(Pl. 4e)

Stylosphaera aff. ***coronata*** Ehrenberg
(Pl. 1b)

Stylosphaera coronata Ehrenberg, 1873, p. 258; 1875, pl. 25, fig. 4.
Stylosphaera coronata coronata Ehrenberg;
Sanfilippo and Riedel, 1973, p. 520, pl. 1, figs. 13–17; pl. 25, fig. 4;
Nishimura, 1987, p. 729, pl. 1, figs. 1, 2;
Bąk, 1995, p. 150, pl. 4, figs. 1, 2.
Amphisphaera coronata s.l. (Ehrenberg);
Hollis, 1997, p. 35, pl. 2, figs. 14–17;
Hollis, 2007, pl. 1, fig. 1.
Stylosphaera coronata Ehrenberg;
Bąk and Barwicz-Piskorz, 2005, p. 142, fig. 3C, E.

Stylosphaera cf. ***eocenica*** Gorbovetz
(Pl. 4f)

Stylosphaera eocenica Gorbovetz;
In: Kozlova and Gorbovetz, 1966, p. 55, pl. 8, figs.1, 2.

Pseudostaurosphaera perelegans Krasheninnikov
(Pl. 1e, f)

Pseudostaurosphaera perelegans Krasheninnikov, 1960, p. 267, pl. 1, fig. 6.

Pseudostaurosphaera ? sp.
(Pl. 4g)

Spongatractus pachystylus (Ehrenberg)
(Pl. 1j)

Spongosphaera pachystyla Ehrenberg, 1873, p. 256; 1975, pl. 26, fig. 3;
Sanfilippo and Riedel, 1973, p. 519, pl. 2, figs. 4–6; pl. 25, fig. 3;
Sanfilippo *et al*., 1985, p. 652, fig. 6.2;
Sanfilippo *et al*., 2003, p. 10, pl. 2, fig. 17.

Family ACTINOMMIDAE Ehrenberg 1875

Cenosphaera cf. ***eocenica*** Clark and Campbell
(Pl. 1a)

Cenosphaera eocenica Clark and Campbell, 1942, p. 26, pl. 1, fig. 6;
Blueford and White, 1984, p. 77, pl. 2, fig. 6;
Bąk, 1995, p. 147, pl. 1, figs. 1–4.

Conosphaera orthoconus Haeckel
(Pl. 4d)

Conosphaera orthoconus Haeckel, 1887, p. 221, pl. 12, fig. 2.

Conosphaera platyconus Haeckel
(Pl. 4c)

Conosphaera platyconus Haeckel, 1887, p. 221, pl. 12, fig. 3.
Acantosphaera sp.;
Bąk, 1995, p. 147, pl. 3, figs. 7–10.

Melitosphaera melitomma Haeckel
(Pl. 1c)

Melitosphaera melitomma Haeckel, 1887, p. 73, pl. 20, fig. 4.

Plegmosphaera maxima Haeckel
(Pl. 4a, b)

Plegmosphaera maxima Haeckel, 1887, p. 88.

Family PHACODISCIDAE Haeckel, 1881
Family COCCODISCIDAE Haeckel, 1862,
emend. Sanfilippo and Riedel, 1980
Lithocyclia aristotelis (Ehrenberg)
(Pl. 2d)

Astromma aristotelis Ehrenberg, 1847, p. 55, fig. 10.
Lithocyclia aristotelis (Ehrenberg);
Riedel and Sanfilippo, 1971, pl. 3A, figs. 2, 4, 5;
Sanfilippo *et al*., 1985, 653, fig. 7. 2a–c.

Lithocyclia ? sp.
(Pl. 4m, n)

Phacodiscus lentiformis Haeckel
(Pl. 1h, i)

Phacodiscus lentiformis Haeckel, 1887, p. 425, pl. 35, fig. 8.
Phacodiscus rotula Haeckel, 1887;
Bąk, 1995, p. 149, pl. 2, figs. 3–5;
Bąk and Barwicz-Piskorz, 2005, p. 143, fig. 3N.

Phacodiscus sp. 1
(Pl. 4i, j)

Phacodiscus sp. 2
(Pl. 4k, l)

Family HELIODISCIDAE Haeckel 1881
Heliodiscus pentasteriscus Clark and Campbell
(Pl. 4h)

Heliodiscus pentasteriscus Clark and Campbell, 1942, p. 39, pl. 3, fig. 8;
Bąk and Barwicz-Piskorz, 2005, p. 142, fig. 3J, K.

Heliodiscus cf. ***perplexus*** Clark and Campbell
(Pl. 1g)

Heliodiscus perplexus Clark and Campbell, 1942, p. 40, pl. 3, fig. 12;
Bąk and Barwicz-Piskorz, 2006, p. 142, fig. 3L.

Family HAGIASTRIDAE Riedel 1971
?*Crucella* cf. ***espartoensis*** Pessagno
(Pl. 5d)

Crucella espartoensis Pessagno, 1971, p. 54, pl. 18, figs. 1–4;
Foreman, 1973, p. 429, pl. 13, fig. 14.

Family SPONGODISCIDAE Haeckel 1862,
emend. Riedel 1967
Spongotrochus (Spongasteriscus) cruciferus
(Clark and Campbell)
(Pl. 1n)

Spongasteriscus (Spongasteriscinus) cruciferus Clark and Campbell, 1942, p. 50, pl. 1, figs. 1–6, 8, 10–11, 16–18.
Spongotrochus cruciferus (Clark and Campbell);
Petrushevskaya, 1975, p. 575, pl. 5, fig. 5.
Spongodiscus ex gr. *cruciferus* (Clark and Campbell);
Popova *et al*., 2002, p. 48, fig. 17M, S.

Spongotrochus echinodiscus Clark and Campbell, 1942
(Not illustrated)

Spongotrochus echinodiscus Clark and Campbell;
Clark and Campbell, 1942, p. 48, pl. 2, fig. 3.

Spongodiscus (Spongocyclia) communis Clark and Campbell
(Pl. 2a)

Spongodiscus (Spongocyclia) communis Clark and Campbell, 1942, p. 47, pl. 2, figs. 1, 11, 13, 14, pl. 3, figs. 1, 4;
Bąk and Barwicz-Piskorz, 2005, p. 143, fig. 3O–R.

Flustrella circularis (Clark and Campbell)
(Pl. 5c)

Porodiscus circularis Clark and Campbell, 1942, p. 42, figs. 2, 6, 10.

Flustrella concentrica Ehrenberg
(Pl. 2e)

Flustrella concentrica Ehrenberg, 1838, p. 132;
Ehrenberg, 1875, p. 160, pl. 22, fig. 13;
Barwicz-Piskorz, 1978, p. 238, pl. 1, fig. 6, pl. 5, fig. 1a, b.

Family ARCHAEOSPONGOPRUNIDAE Pessagno 1973
Spongoprunum densum Clark and Campbell
(Pl. 1k)

Spongoprunum densum Clark and Campbell, 1942, p. 37, pl. 4, fig. 3.

Family SPONGURIDAE Haeckel 1862,
emend. Petrushevskaya 1975
Spongurus (Spongurantha) bilobatus Clark and Campbell
(Pl. 1m)

Spongurus (Spongurantha) bilobatus Clark and Campbell, 1942, p. 36, pl. 1, figs. 7, 9.
Spongurus bilobatus Clark and Campbell group;
Hollis, 2002, p. 291, pl. 2, figs. 11a, b, 12–14;
Bąk and Barwicz-Piskorz, 2005, p. 143, fig. 4C.

Spongurus (Spongurantha) spatulaeformis
Clark and Campbell
(Pl. 1l)

Spongurus (Spongurantha) spatulaeformis Clark and Campbell, 1942, p. 36, pl. 1, fig. 15;
Aita *et al*., 1997, pl. 3, figs. 6, 7.

Spongurus sp. 1
(Pl. 4o, p)

Amphicraspedum murrayanum Haeckel
(Pl. 2c)

Amphicraspedum murrayanum Haeckel, 1887, p. 523, pl. 44, fig. 10;
Sanfilippo and Riedel, 1973, p. 524, pl. 10, figs. 3–6; pl. 28, fig. 1;
Nishimura, 1987, p. 719, pl. 1, figs. 14, 18;
Sanfilippo *et al*., 2003, p. 6, pl. 2, fig. 11;
Hollis 2007, pl. 1, figs. 18, 19.

Amphicraspedum prolixum Sanfilippo and Riedel
(Pl. 2b)

Amphicraspedum prolixum Sanfilippo and Riedel, 1973, p. 524, pl. 10. figs. 7–11; pl. 28, figs. 3, 4;
Aita *et al*., 1997, pl. 3, fig. 5;
Hollis, 2007, pl. 1, figs. 14, 20, 21;
Bąk and Barwicz-Piskorz, 2005, p. 143, fig. 4A, B.

Amphibrachium paleogenicum Gorbunov
(Pl. 5a, b)

Amphibrachium paleogenicum Gorbunov, 1979, p. 130, pl. 7, fig. 2; pl. 9, fig. 1a–j.

Order NASSELLARIA Ehrenberg 1875
Family ACROPYRAMIDIDAE Haeckel 1881
***Artostrobus* ?** sp.
(Pl. 5l)

Bathropyramis quadrata Haeckel
(Pl. 2f)

Bathropyramis quadrata Haeckel, 1887, p. 1159, pl. 54, fig. 1.

Family ARTOSTROBIIDAE Riedel 1967,
emend. O'Connor 2001
(according to De Wever *et al*., 2001 *Buryella* belongs to the family Eucyrtidiidae)
Buryella clinata Foreman
(Pl. 3b)

Buryella clinata Foreman, 1973, p. 433, pl. 8, figs. 1–3; pl. 9, fig. 19;
Nishimura, 1987, p. 720, pl. 2, figs. 5–6;
Sanfilippo *et al*., 2003, p. 6, pl. 1, fig. 6;
Bąk and Barwicz-Piskorz, 2005, p. 144, fig. 4I;
Bąk and Barwicz-Piskorz, 2006, p. 50, pl. 1, figs. 4–10, 16.

Family PTEROCORYTHIDAE Haeckel 1881,
emend. Riedel 1967, emend. Moore 1972
Theocorys cf. ***anaclasta*** Riedel and Sanfilippo
(Pl. 5h)

Theocorys anaclasta Riedel and Sanfilippo, 1970, p. 530, figs. 2, 3;
Foreman, 1973, p. 440, pl. 5, figs. 14–15;
Sanfilippo *et al.,* 2003, p. 9, pl. 1, fig. 4.

Theocorys aff. ***spongoconum*** (Kling)
(Pl. 3n)

Theocorys spongoconum Kling, 1971, p. 1087, pl. 5, fig. F.
Theocorys spongoconum (Kling);
Riedel and Sanfilippo, 1971, p. 1596, pl. 2F, fig. 4; pl. 3C, fig. 3.

Podocyrtis (Lampterium) cf. ***mitra*** Ehrenberg
(Pl. 5j)

Podocyrtis mitra Ehrenberg, 1854, pl. 36, fig. 320; 1873, p. 251,
Podocyrtis (*Lampterium*) *mitra* Ehrenberg;
Riedel and Sanfilippo, 1970, p. 534, pl. 11, figs. 5, 6;
Nigrini, 1974, p. 1070, pl. 1L, fig. 2.

Podocyrtis (Podocyrtis) papalis Ehrenberg
(Pl. 3i)

Podocyrtis papalis Ehrenberg, 1847, fig. 2;
1854, pl. 36, fig. 23;
Riedel and Sanfilippo, 1970, p. 533, pl. 11, fig. 1;
Sanfilippo and Riedel, 1973, p. 531, pl. 20, figs. 11–14, pl. 36, figs. 2, 3;
Nishimura, 1987, p. 727–728, pl. 2, fig. 17;
Bąk, 1995, p. 149, pl. 4, fig. 7;
Sanfilippo and Blome, 2001, p. 215, fig. 10f;
Popova *et al*., 2002, p. 46, fig. 7H;
Sanfilippo *et al*., 2003, p. 8, pl. 2, fig. 8;
Bąk and Barwicz-Piskorz 2005, p. 144, fig. 4M, P, Q.

Family AMPHIPYNDACIDAE Riedel 1967
Amphiternis clava (Ehrenberg)
(Pl. 2g)

Lithocampe ? *clava* Ehrenberg, 1873, p. 238; 1875, p. 76, pl. 4, fig. 2.
Eucyrtidium clava (Ehrenberg);
Bütschli, 1882, pl. 30, fig. 22.
Lithocampe clava Ehrenberg;
Haeckel, 1887, p. 1507;
Amphiternis clava (Ehrenberg);
Foreman, 1973, p. 430, pl. 7, figs. 16, 17; pl. 9, fig. 2.

Family EUCYRTIDIIDAE Ehrenberg 1847
Calocycloma ampulla (Ehrenberg)
(Pl. 2j)

Eucyrtidium ampulla Ehrenberg, 1854, pl. 36, fig. 15a–c; 1873, p. 225.
Calocycloma ampulla (Ehrenberg);
Foreman 1973, p. 434, pl. 1, figs. 1–5, pl. 9, fig. 20;
Nishimura, 1987, p. 721, pl. 3, fig. 2;
Bąk and Barwicz-Piskorz, 2005, p. 144, fig. 5A, B.

Calocycloma castum (Haeckel)
(Pl. 2l)

Calocyclas casta Haeckel, 1887, p. 1384, pl. 73, fig. 10.
Calocycloma castum (Haeckel);
Foreman, 1973, p. 434, pl. 1, figs. 7, 9, 10';
Nishimura, 1987, p. 721, pl. 3, fig. 1;
Sanfilippo and Blome, 2001, p. 211, fig. 8n, o;
Sanfilippo *et al.*, 2003, p. 6, pl. 1, fig. 19.

Calocycloma sp.
(Pl. 5k)

Eucyrtidium cf. ***montiparum*** Ehrenberg
(Pl. 3a)

Eucyrtidium montiparum Ehrenberg, 1875, pl. 9, fig. 11.

Phormocyrtis cubensis (Riedel and Sanfilippo)
(Pl. 3c)

Eucyrtidium cubense Riedel and Sanfilippo, 1971, p. 1594, pl. 7, figs. 10, 11;
Phormocyrtis cubensis (Riedel and Sanfilippo);
Foreman, 1973, p. 438, pl. 7, figs. 11–12, 14;
Sanfilippo *et al.*, 2003, p. 8, pl. 1, fig. 20;
Hollis, 2007, pl. 2, figs. 15–17.

Phormocyrtis striata striata Brandt
(Pl. 3d)

Phormocyrtis striata striata Brandt, 1935;
In: Wetzel, 1935, p. 55, pl. 9, fig. 12;
Riedel and Sanfilippo, 1970, p. 532, pl. 10, fig. 7;
Foreman, 1973, p. 438, pl. 7, figs. 5, 6, 9;
Sanfilippo *et al*., 1985, p. 679, fig. 20.1a, b;
Sanfilippo *et al*., 2003, p. 6, pl. 2, fig. 18;
Hollis, 2007, pl. 2, fig. 12;
Bąk and Barwicz-Piskorz, 2005, p. 145, fig. 6E, F.

Phormocyrtis striata exquisita (Kozlova)
(Pl. 3e, 5g)

Podocyrtis exquisita Kozlova, 1966;
In: Kozlova and Gorbovetz, 1966, p. 106, pl. 17, fig. 2.
Phormocyrtis striata exquisita (Kozlova);
Foreman, 1973, p. 438, pl. 7, figs. 1–4, 7–8, pl. 12, fig. 5;
Sanfilippo *et al*., 1985, p. 678, figs. 20, 2a–c;
Liu and Aitchison, 2002, p. 147, pl. 1, fig. 7;
Hollis, 2007, pl. 2, fig. 11.

Phormocyrtis turgida (Krasheninnikov)
(Pl. 5f)

Lithocampe turgida Krasheninnikov, 1960, p. 301, pl. 12, fig. 6.
Phormocyrtis turgida (Krasheninnikov);
Foreman, 1973, p. 438, pl. 7, fig. 10, pl. 12, fig. 6;
Liu and Aitchison, 2002, p. 147, pl. 1, fig. 7;
Sanfilippo *et al*., 2003, p. 8, pl. 2, fig. 15;
Hollis, 2007, pl. 2, figs. 13, 14.

Family THEOPERIDAE Haeckel 1881
Lychnocanium bellum Clark and Campbell
(Pl. 2m)

Lychnocanium bellum Clark and Campbell, 1942, p. 72, pl. 9, figs. 35, 39;
Riedel and Sanfilippo, 1970, p. 529, pl. 10, fig. 5.
Lychnocanoma bellum (Clark and Campbell);
Foreman, 1973, p. 437, pl. 1, fig. 17; pl. 11, fig. 9 ;
Sanfilippo and Blome, 2001, p. 214, fig. 9n';
Sanfilippo *et al*., 2003, p. 8, pl. 2, fig. 12.
Lychnocanium bellum Clark and Campbell;
Bąk and Barwicz-Piskorz, 2005, fig. 5L–N.

Lychnocanium cf. ***carinatum*** Ehrenberg
(Pl. 2n)

Lychnocanium carinatum Ehrenberg, 1875, p. 78, pl. 8, fig. 5.
Lychnocanium ? *carinatum* Ehrenberg;
Nishimura 1987, p. 727, pl. 3, figs. 6, 11.

Lychnocanoma cf. ***amphitrite*** Foreman
(Pl. 3j, 5n, o)

Lychnocanoma amphitrite Foreman, 1973, p. 437, pl. 11, fig. 10;
Sanfilippo and Blome, 2001, fig. 9g–j.

Lithochytris archaea Riedel and Sanfilippo
(Pl. 2i)

Lithochytris archaea Riedel and Sanfilippo, 1970, p. 528, pl. 9, fig. 7;
Riedel and Sanfilippo, 1971, p. 1594, pl. 7, fig. 13;
Foreman, 1973, p. 436, pl. 2, figs. 4–5;
Nishimura, 1987, p. 726, pl. 3, fig. 9.

Lithochytris vespertilio Ehrenberg
(Pl. 2h)

Lithochytris vespertilio Ehrenberg, 1873, p. 239; 1875, pl. 4, fig. 10.
Lithochytris cheopsis Clark and Campbell, 1942, p. 81, pl. 9, fig. 37.
Lithochytris vespertilio Ehrenberg;
Riedel and Sanfilippo, 1970, p. 528, pl. 9, figs. 8, 9;
Foreman, 1973, p. 436, pl. 2, figs. 2, 3; pl. 11, fig. 3;
Sanfilippo, *et al*., 2003, p. 6, pl. 2, fig. 10.

Family THEOCOTYLIDAE Petrushevskaya 1971
Lamptonium fabaeforme fabaeforme (Krasheninnikov)
(Pl. 3f)

Cyrtocalpis fabaeformis Krasheninnikov, 1960, p. 296, pl. 3, fig. 11.
Lamptonium (?) *fabaeforme fabaeforme* (Krasheninnikov);
Riedel and Sanfilippo, 1970, p. 523, pl. 5, fig. 6;
Nishimura, 1987, p. 726, pl. 2, fig. 20.
Lamptonium fabaeforme fabaeforme (Krasheninnikov);
Sanfilippo *et al*., 1985, p. 674, fig. 18.2;
Hollis, 2007, pl. 2, figs. 18, 19.

Lamptonium fabaeforme constrictum Riedel and Sanfilippo
(Pl. 3g)

Lamptonium (?) *fabaeforme* (?) *constrictum* Riedel and Sanfilippo, 1970, p. 523, pl. 5, fig. 7.
Lamptonium fabaeforme (?) *constrictum* Riedel and Sanfilippo;
Foreman, 1973, p. 436, pl. 6, figs. 13, 14;
Nishimura, 1987, p. 726, pl. 2, fig. 21.
Lamptonium fabaeforme constrictum Riedel and Sanfilippo;
Sanfilippo *et al*., 1985, p. 674, fig. 18.4;
Sanfilippo *et al*., 2003, p. 6, pl. 1, fig. 16.

Lamptonium sanfilippoae Foreman
(Pl. 3h)

Lamptonium sanfilippoae Foreman, 1973, p. 436, pl. 6, figs. 15, 16;
Sanfilippo *et al.,* 1985, p. 674, fig. 18.5.

Thyrsocyrtis (Thyrsocyrtis) hirsuta (Krasheninnikov)
(Pl. 3o, 5i)

Podocyrtis hirsutus Krasheninnikov, 1960, p. 300, pl. 3, fig. 16.
Thyrsocyrtis hirsuta hirsuta (Krasheninnikov);
Riedel and Sanfilippo, 1970, p. 526, pl. 7, figs. 8, 9;
Foreman, 1973, p. 441, pl. 3, figs. 3–8, pl. 12, fig. 15.
Thyrsocyrtis hirsuta (Krasheninnikov);
Aita *et al*., 1997, pl. 4, figs. 11, 12.
Thyrsocyrtis (Thyrsocyrtis) hirsuta (Krasheninnikov);
Sanfilippo and Riedel, 1982, p. 173, pl. 1, figs. 3, 4;
Sanfilippo *et al.,* 2003, p. 10, pl. 2, fig. 13.

Theocotyle cf. ***nigriniae*** Riedel and Sanfilippo
(Pl. 3k)

Theocotyle cryptocephala (?) *nigriniae* Riedel and Sanfilippo, 1970, p. 525, pl. 6, figs. 5, 6.
Theocotyle nigriniae Sanfilippo and Riedel, 1982, p. 78, pl. 2, figs. 1–3;
Sanfilippo *et al.,* 1985, p. 685, figs. 25, 1a–b.
Theocotyle cf. *nigriniae* Riedel and Sanfilippo;
Aita *et al*., 1997, pl. 4, fig. 8.

Theocotylissa auctor Foreman
(Pl. 3l)

Theocotyle (Theocotylissa) auctor Foreman, 1973, p. 441, pl. 4, figs. 8–10; pl. 12, fig. 13.
Theocotylissa auctor Foreman;
Sanfilippo and Riedel, 1982, p. 180, pl. 2, figs. 14, 15
Sanfilippo *et al*., 2003, p.10. pl. 1, fig. 18.

Theocotylissa ficus (Ehrenberg)
(Pl. 3m)

Eucyrtidium ficus Ehrenberg, 1873, p. 228;
1875, p. 70, pl. 11, fig. 19.
Theocotyle (?) *ficus* (Ehrenberg);
Riedel and Sanfilippo, 1970, p. 525, pl. 7, figs. 3–5.
Theocotyle (Theocotylissa) ficus (Ehrenberg);
Foreman, 1973, p. 441, pl. 4, figs. 16–20.
Theocotylissa ficus (Ehrenberg);
Sanfilippo and Riedel, 1982, p. 180, pl. 2, figs. 19, 20.l;
Bąk and Barwicz-Piskorz, 2005, p. 146, fig. 6K, L.

Nassellaria incertae sedis
Sethocyrtis principi Clark and Campbell
(Pl. 2k)

Sethocyrtis principi Clark and Campbell, 1942, p. 75, pl. 7, figs. 5, 6, 13.

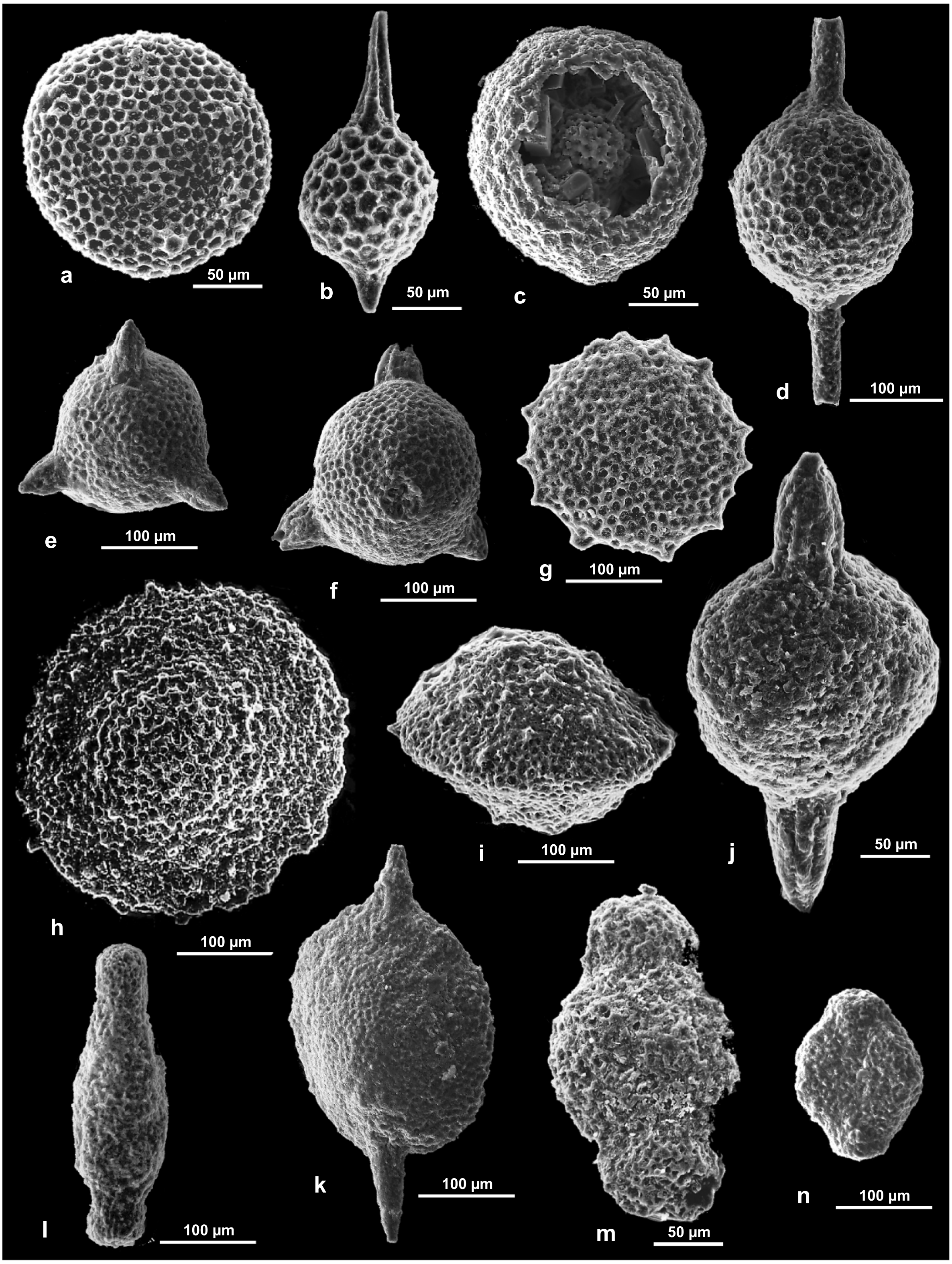
Sethocyrtis minimus Lipman
(Pl. 5e)

Sethocyrtis minimus Lipman 1950, p. 61, pl. 2, fig. 7;
Gorbunov, 1979, p. 146, pl. 14, fig. 2a–b.

Tricolocampe ? sp.
(Pl. 5m)

Nassellaria sp. 1
(Pl. 5p)

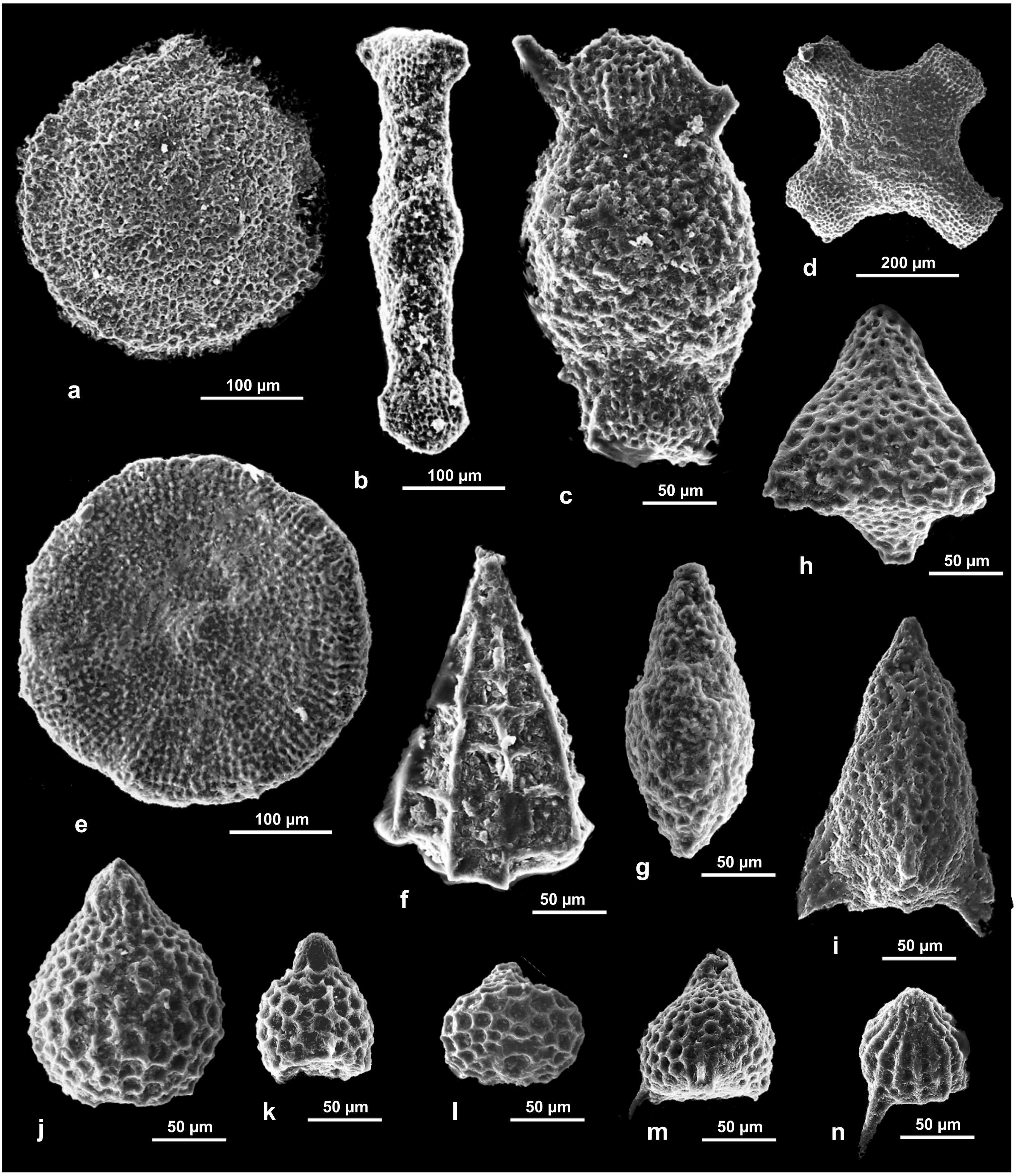
Plate 1



All figures are electron scanning micrographs of Eocene Spumellaria from the Skole Unit

a – *Cenosphaera* cf. *eocenica* Clark and Campbell, loc. Chmielnik, profile no 1, middle Eocene; **b** – *Stylosphaera* aff. *coronata* Ehrenberg, loc. Chmielnik, profile no 1, lower Eocene; **c** – *Melitosphaera melitomma* Haeckel, loc. Dylągówka, profile no 9, middle Eocene; **d** – *Amphisphaera minor* (Clark and Campbell), loc. Nowa Wieś (trench 2), profile no 5, middle Eocene; **e**, **f** – *Pseudostaurosphaera perelegans* Krasheninnikov: e – front view, loc. Chmielnik, profile no 1, middle Eocene; f – back view, loc. Chmielnik, profile no 1, middle Eocene; **g** – *Heliodiscus* cf. *perplexus* Clark and Campbell, loc. Nowa Wieś (trench 2), profile no 5, middle Eocene; **h**, **i** – *Phacodiscus lentiformis* Haeckel: h – front view, loc. Chmielnik, profile no 1, lower Eocene; i – side view, loc. Chmielnik, profile no 1, lower Eocene, **j** – *Spongatractus pachystylus* (Ehrenberg), loc. Nowa Wieś (trench 2), profile no 5, middle Eocene; **k** – *Spongoprunum densum* Clark and Campbell, loc. Nowa Wieś (trench 1), profile no 6, lower Eocene; **l** – *Spongurus (Spongurantha) spatulaeformis* Clark and Campbell, loc. Nowa Wieś (trench 1), profile no 6, lower Eocene; **m** – *Spongurus (Spongurantha) bilobatus* Clark and Campbellm, loc. Nowa Wieś (trench 1), profile no 6, lower Eocene; **n** – *Spongasteriscus (Spongasteriscinus) cruciferus* Clark and Campbell, loc. Chmielnik, profile no 1, lower Eocene

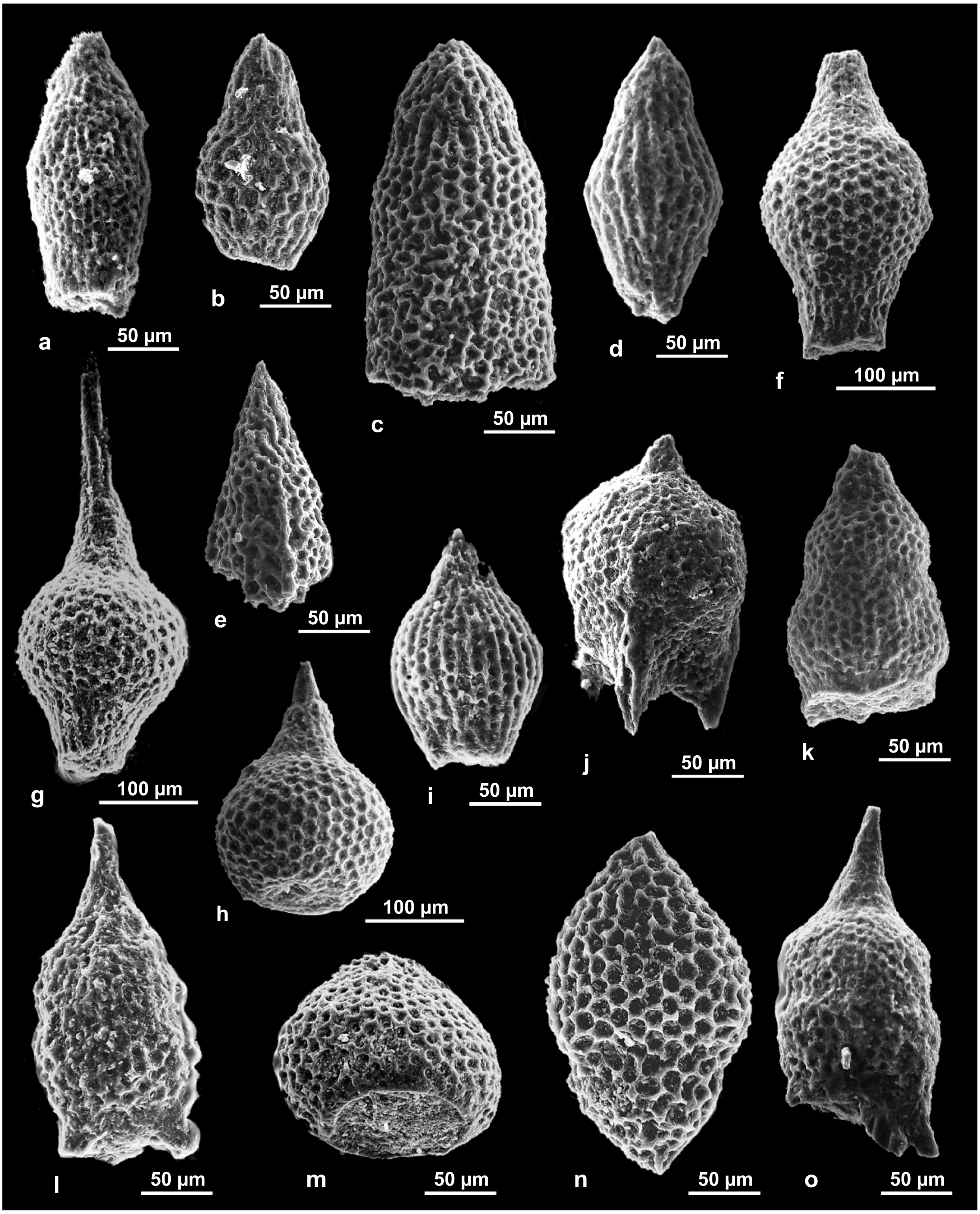
Plate 2



All figures are electron scanning micrographs of Eocene Spumellaria (a–e) and Nassellaria (f–n) from the Skole Unit

a – *Spongodiscus (Spongocyclia) communis* Clark and Campbell, loc. Hyżne, profile no 7, middle Eocene; **b** – *Amphicraspedum prolixum* Sanfilippo and Riedel, loc. Chmielnik, profile no 1, lower Eocene; **c** – *Amphicraspedum murrayanum* Haeckel, loc. Nowa Wieś (trench 2), profile no 6, lower Eocene; **d** – *Lithocyclia aristotelis* (Ehrenberg), loc. Hyżne, profile no 7, middle Eocene; **e** – *Flustrella concentrica* Ehrenberg, loc. Nowa Wieś (trench 2), profile no 5, middle Eocene; **f** – *Bathropyramis quadrata* Haeckel, loc. Nowa Wieś (trench 2), profile no 5, middle Eocene; **g** – *Amphipternis clava* Ehrenberg, loc. Nowa Wieś (trench 2), profile no 5, middle Eocene; **h** – *Lithochytris vespertilio* (Ehrenberg), loc. Nowa Wieś (trench 2), profile no 5, middle Eocene; **i** – *Lithochytris archaea* Riedel and Sanfilippo, loc. Dylągówka, profile no 9, lower Eocene; **j** – *Calocycloma ampulla* (Ehrenberg), loc. Dylągówka, profile no 9, lower Eocene; **k** – *Sethocyrtis principi* Clark and Campbell, loc. Nowa Wieś (trench 2), profile no 5, middle Eocene; **l** – *Calocycloma castum* (Haeckel), loc. Hyżne, profile no 7, lower Eocene; **m** – *Lychnocanium bellum* (Clark and Campbell), loc. Hyżne, profile no 7, lower Eocene; **n** – *Lychnocanium* cf. *carinatum* Ehrenberg, loc. Hyżne, profile no 7, lower Eocene

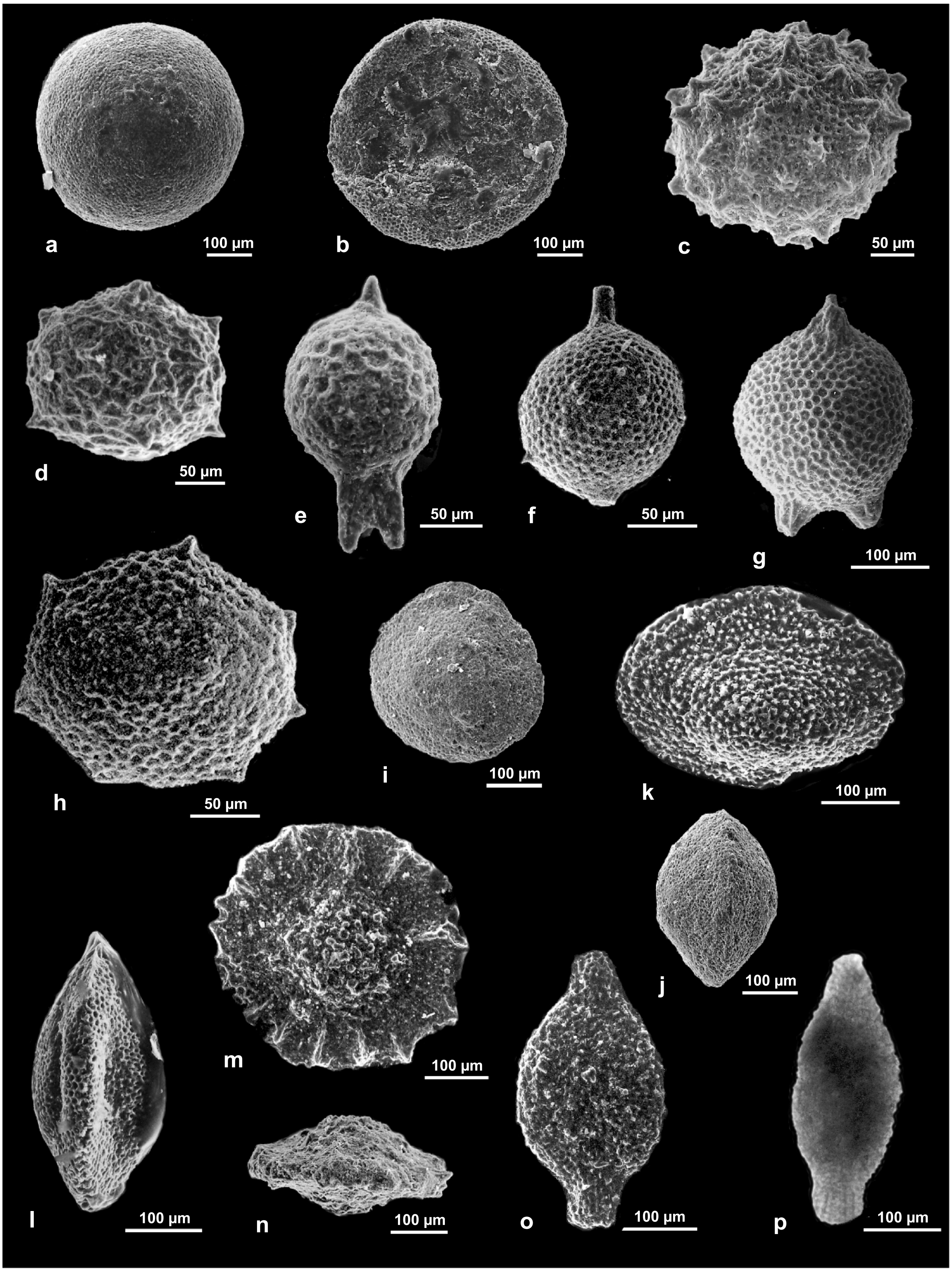
Plate 3



All figures are electron scanning micrographs of Eocene Nassellaria from the Skole Unit

a – *Eucyrtidium* cf. *montiparum* Ehrenberg, loc. Dyłągówka, profile no 9, lower Eocene; **b** – *Buryella clinata* Foreman, loc. Przylasek, profile no 10, lower Eocene; **c** – *Phormocyrtis cubensis* (Riedel and Sanfilippo), loc. Łazy, profile no 12, lower Eocene; **d** – *Phormocyrtis striata striata* Brandt, loc. Chmielnik, profile no 1, lower Eocene; **e** – *Phormocyrtis striata exquisita* Kozlova, loc. Nowa Wieś (trench 1), profile no 6, lower Eocene; **f** – *Lamptonium fabaeforme fabaeforme* (Krasheninnikov), loc. Chmielnik, profile no 1, lower Eocene; **g** – *Lamptonium fabaeforme constrictum* Riedel and Sanfilippo, loc. Chmielnik, profile no 1, lower Eocene; **h** – *Lamptonium sanfilippoae* Foreman, loc. Chmielnik, profile no 1, middle Eocene; **i** – *Podocyrtis (Podocyrtis) papalis* Ehrenberg, loc. Nowa Wieś (trench 2), profile no 5, middle Eocene; **j** – *Lychnocanoma* cf. *amphitrite* (Foreman), loc. Dyłągówka, profile no 9, lower Eocene; **k** – *Theocotyle* cf. *nigriniae* Riedel and Sanfilippo, loc. Bazary, profile no 11, lower Eocene; **l** – *Theocotylissa auctor* Foreman, loc. Hyżne, profile no 7, middle Eocene; **m** – *Theocotylissa ficus* (Ehrenberg), loc. Łazy, profile no 12, lower Eocene; **n** – *Theocorys* aff. *spongoconum* (Kling), loc. Nowa Wieś (trench 2), profile no 5, middle Eocene; **o** – *Thyrsocyrtis (Thyrsocyrtis) hirsuta* (Krasheninnikov), loc. Przylasek, profile no 10, lower Eocene

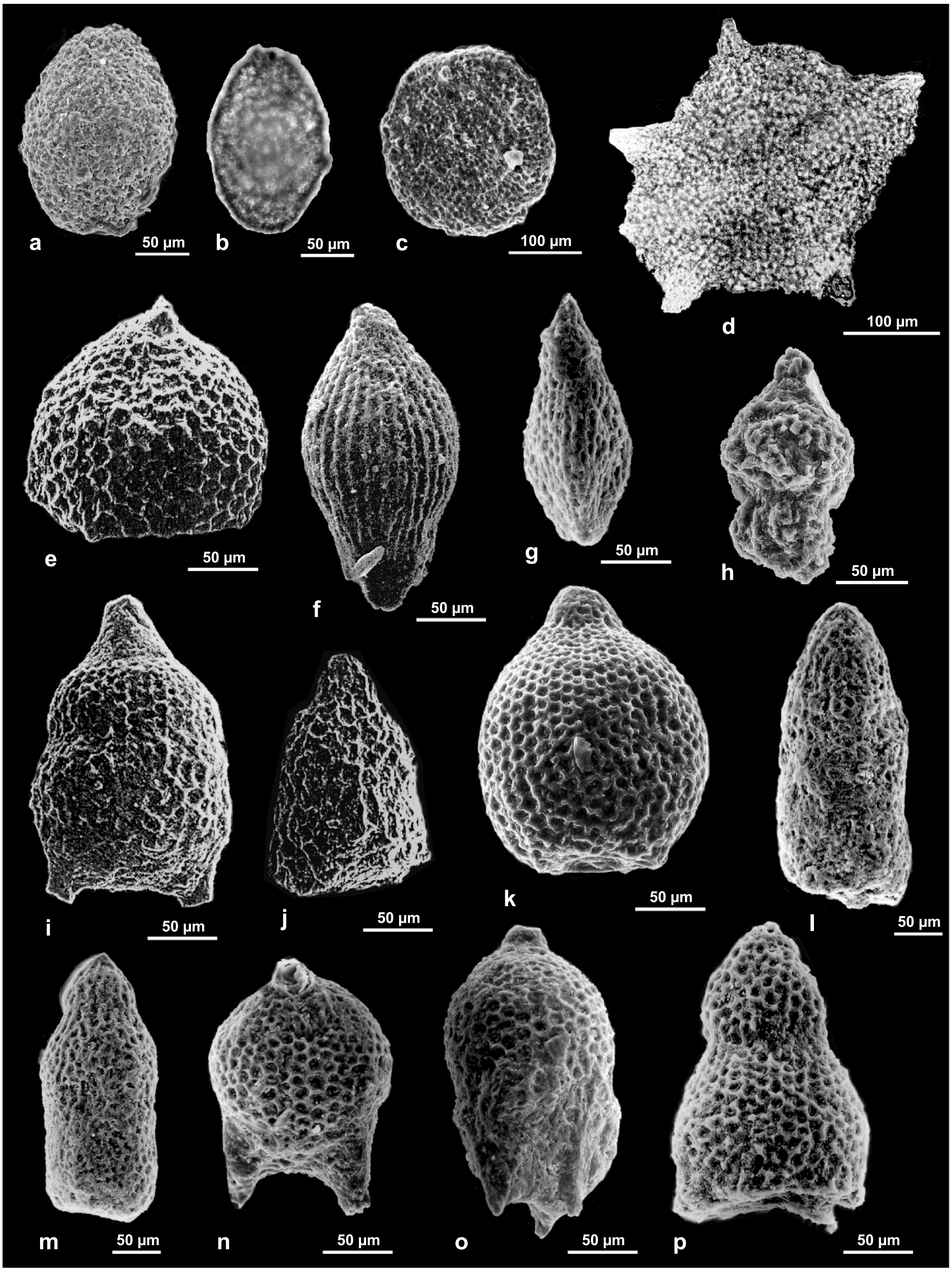
Plate 4



All figures are electron scanning micrographs of Eocene Spumellaria from the Skole Unit (except p – photo in transmitted light)

a, **b** – *Plegmosphaera maxima* Haeckel: a – side view, loc. Nowa Wieś (trench 2), profile no 5, middle Eocene; b – inside, loc. Nowa Wieś (trench 2), profile no 5, middle Eocene; **c** – *Conosphaera platyconus* Haeckel, loc. Chmielnik, profile no 1, lower Eocene; **d** – *Conosphaera orthoconus* Haeckel, loc. Nowa Wieś (trench 2), profile no 5, middle Eocene; **e** – *Amphisphaera* ? sp., loc. Wólka Hyżneńska, profile no 8, middle Eocene; **f** – *Stylosphaera* cf. *eocenica* Gorbovetz, loc. Hyżne, profile no 7, lower Eocene; **g** – *Pseudostaurosphaera* ? sp., loc. Dylągówka, profile no 9, middle Eocene; **h** – *Heliodiscus pentasteriscus* Clark and Campbell, loc. Chmielnik, profile no 1, middle Eocene; **i**, **j** – *Phacodiscus* sp. 1: i – front view, loc. Nowa Wieś (trench 2), profile no 5, middle Eocene; j – side view, loc. Nowa Wieś (trench 2), profile no 5, middle Eocene; **k**, **l** – *Phacodiscus* sp. 2: k – front view, loc. Nowa Wieś (trench 2), profile no 5, middle Eocene; l – side view, loc. Nowa Wieś (trench 2), profile no 5, middle Eocene; **m**, **n** – *Lithocyclia* ? sp., m – front view, loc. Chmielnik, profile no 1, lower Eocene; n – side view, Chmielnik, profile no 1, lower Eocene; **o**, **p** – *Spongurus* sp., o – front view, loc. Nowa Wieś (trench 2), profile no 5, middle Eocene; p – view in transmitted light, loc. Nowa Wieś (trench 2), profile no 5, middle Eocene

Plate 5



All figures are electron scanning micrographs of Eocene Spumellaria (a–d) and Nassellaria (e–p) from Skole Unit (except b, d – photos in transmitted light)

a, **b** – *Amphibrachium paleogenicum* Gorbunov, a – front view, loc. Łazy, profile no 12, lower Eocene; b – view in transmitted light, loc. Łazy, profile no 12, lower Eocene; **c** – *Flustrella circularis* (Clark and Campbell), loc. Przylasek, profile no 10, lower Eocene; **d** – ?*Crucella* cf. *espartoensis* Pessagno, view in transmitted light, loc. Hyżne, profile no 7, lower Eocene; **e** – *Sethocyrtis minimus* Lipman, loc. Hyżne, profile no 7, lower Eocene; **f** – *Phormocyrtis turgida* (Krasheninnikov), loc. Dylągówka, profile no 9, lower Eocene; **g** – *Phormocyrtis striata exquisita* (Kozlova), loc. Przylasek, profile no 10, lower Eocene; h –. *Theocorys* cf. *anaclasta* Riedel and Sanfilippo, loc. Nowa Wieś (trench 2), profile no 5, middle Eocene; **i** – *Thyrsocyrtis (Thyrsocyrtis) hirsuta* (Krasheninnikov), loc. Dylągówka, profile no 9, lower Eocene; **j** – *Podocyrtis (Lampterium)* cf. *mitra* Ehrenberg, loc. Nowa Wieś (trench 2), profile no 5, middle Eocene; **k** – *Calocycloma* sp., loc. Chmielnik, profile no 1, lower Eocene; **l** – *Artostrobus* ? sp., loc. Bazary, profile no 11, lower Eocene; **m** – *Tricolocampe* ? sp., loc. Nowa Wieś (trench 2), profile no 5, middle Eocene; **n**, **o** – *Lychnocanoma* cf. *amphitrite* (Foreman), loc. Futoma, profile no 13, middle Eocene; **p** – Nassellaria sp. 1, loc. Futoma, profile no 13, lower Eocene