

BIOSTRATIGRAPHY AND PALEOENVIRONMENTAL ANALYSIS OF BENTHIC FORAMINIFERA AND RADIOLARIANS IN PALEOGENE VARIEGATED SHALES IN THE SKOLE UNIT, POLISH FLYSCH CARPATHIANS

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Bąk, K., Bąk, M., Geroch, S. & Manecki, M., 1997. Biostratigraphy and paleoenvironmental analysis of benthic Foraminifera and radiolarians in Paleogene variegated shales in the Skole Unit, Polish Flysch Carpathians. *Ann. Soc. Geol. Polon.*, 67: 135–154.

Abstract: We studied Paleocene to middle Eocene variegated shales in the Skole Unit of the Polish flysch Carpathians at the Dylągówka sections in order to understand their depositional environments, using data on agglutinated foraminifera, Radiolaria and mineralogy. These deposits have been placed in the Paleocene *Rzehakina fissistomata* foraminiferal Zone, and in the lower through middle Eocene *Glomospira* spp. Assemblage Zone, *Saccamminoides carpathicus* Zone, and *Reticulophragmium amplexens* Zone of Geroch and Nowak (1984) which we correlate with the *Buriella clinata*, *Phormocyrtis striata striata* and *Theocotyle cryptocephala* radiolarian zones.

The deposition of variegated shales took place below the calcite compensation depth in the lower bathyal zone. The foraminiferal morphogroup and radiolarian faunal analyses indicate that paleoenvironmental changes during the Paleocene through middle Eocene caused changes in sedimentation rates, in nutrient supply, and oceanic circulation. The “Radiolaria Flood” in lower and middle Eocene deposits may have been caused by a change of surface circulation in the Carpathian basins, emphasised by the relatively slow rate of sedimentation below the CCD, and the mineralogy of fine-grained sediments were conducive to the preservation of radiolarian skeletons.

Abstrakt: Przeprowadzono analizę zespołów otwornic aglutynujących, radiolarii oraz składu mineralnego pstrych łupków w dwóch profilach jednostki skolskiej, w polskich Karpatach fliszowych. Celem badań była biostratygrafia tych osadów oraz rekonstrukcja warunków paleośrodowiska. Pstre łupki należą do poziomu *Rzehakina fissistomata* (paleocen), poziomu zespołowego *Glomospira* spp., oraz poziomów: *Saccamminoides carpathicus* i *Reticulophragmium amplexens* (dolny i środkowy eocen). Odpowiadają one 3 poziomom radiolarium: *Buriella clinata*, *Phormocyrtis striata striata* i *Theocotyle cryptocephala*.

Sedymentacja pstrych łupków miała miejsce poniżej CCD, w strefie dolnego batiału. Analiza morfogrów otwornic aglutynujących i zespołów radiolarii wskazuje na zmiany paleośrodowiska w czasie paleocenu–środkowego eocenu, związane ze zmianami w tempie sedymentacji, dostawie nutrientów i cyrkulacji oceanicznej. Bardzo liczna obecność radiolarii w pstrych łupkach jest związana ze zmianą cyrkulacji powierzchniowej w basenach karpackich we wczesnym i środkowym eocenie. Efekt ten został podkreślony przez niskie tempo sedymentacji osadów, poniżej CCD, a także skład petrograficzny drobnoziarnistych osadów, sprzyjający zachowaniu skorupki radiolarii.

Key words: Foraminifera, Radiolaria, Paleogene, stratigraphy, palaeoecology, Skole Unit, Polish flysch Carpathians.

Manuscript received 25 March 1996, accepted 6 May 1997

The research on variegated shales in the Skole Unit of the Outer Carpathians were initiated by Professor T. Wieser and Professor S. Geroch in the early 90s. They comprised both mineralogical and micropalaeontological studies, especially based on abundant radiolarians fauna and agglutinated foraminifera. Professor S. Geroch coordinated the micropalaeontological investigations and prepared the preliminary age assignment based on agglutinated foraminifera. His sudden death in June 1995 interrupted the study that we decided to continue.

We dedicate this paper to the memory of Professor Stanisław Geroch the best Teacher and Friend we have ever had.

INTRODUCTION

Variegated shales are characteristic deposits in the flysch Carpathians and include red, green and subordinate grey shales, claystones and mudstones. Most of the shale units are carbonate-free or contain only little calcium carbonate. In the flysch Carpathians the variegated shales extend from the Cenomanian to the upper Eocene (e.g., Geroch, 1960; Książkiewicz, 1962, 1975; Bieda *et al.*, 1963; Geroch & Gradziński, 1965; Koszarski, 1967; Geroch *et al.*, 1967, Rajchel, 1990). Similar red clay facies occur in other parts of the Carpathians, as well as in the Alps, Appenines, North Atlantic, Celebes Sea and Pacific (e.g., Andrusov, 1959; Prey, 1968; Winkler, 1983; Stefanescu & Micu, 1987; Moullade *et al.*, 1988; Kuhnt *et al.*, 1989b; Kuhnt & Kaminski, 1990; Kaminski & Huang, 1991; Morlotti & Kuhnt, 1992; K. Bąk, 1995b). Detailed description of the texture, sedimentary structures, facies and colour of the Carpathians variegated shales were given by Leszczyński and Uchman (1991). The characteristic red colour of the variegated shales is probably of early diagenetic origin, connected with an increased content of Fe-bearing minerals and low organic carbon content (cf. Narębski, 1957; Potter *et al.*, 1980; Lehner *et al.*, 1987). Changes in colour from red to green are ascribed to changing oxygenation of bottom water and sediment interstitial waters (Gardner *et al.*, 1977; Lehner *et al.*, 1987; Leszczyński & Uchman, 1991).

The lower boundary of the Paleogene variegated shales in the Skole Unit (Fig. 1) is a gradual transition from the

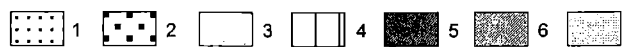
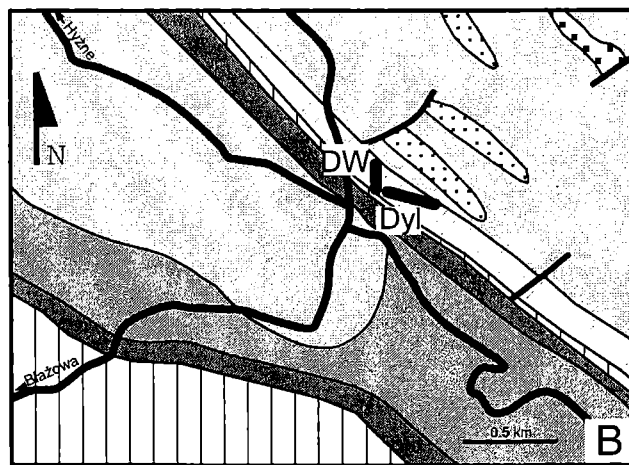
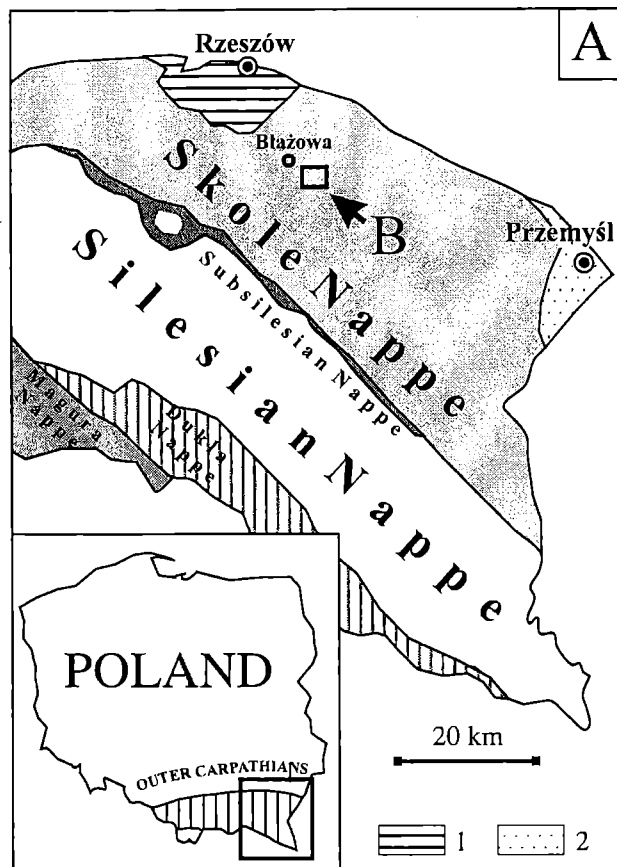


Fig. 2. A. Location of the investigated area on the base of simplified map of the Eastern Polish Carpathians: 1 – post-orogenic Neogene cover; 2 – Stebnice Unit. B. Detailed location of the studied sections on the base of geological map (simplified after Boryslawski *et al.*, 1980): 1 – thick-bedded sandstones of the Inoceranian Beds (Senonian), 2 – Węgierka Marls (Senonian), 3 – Variegated Shales and Hieroglyphic Beds (Paleogene), 4 – shales, sandstones and hornstones of Menilite Shales and Kliwa Sandstones (Oligocene), 5 – Niebylec Shales (Oligocene-Miocene), 6 – sandstones and shales of Upper Krosno Beds (Oligocene-Miocene); 7 – deluvial deposits

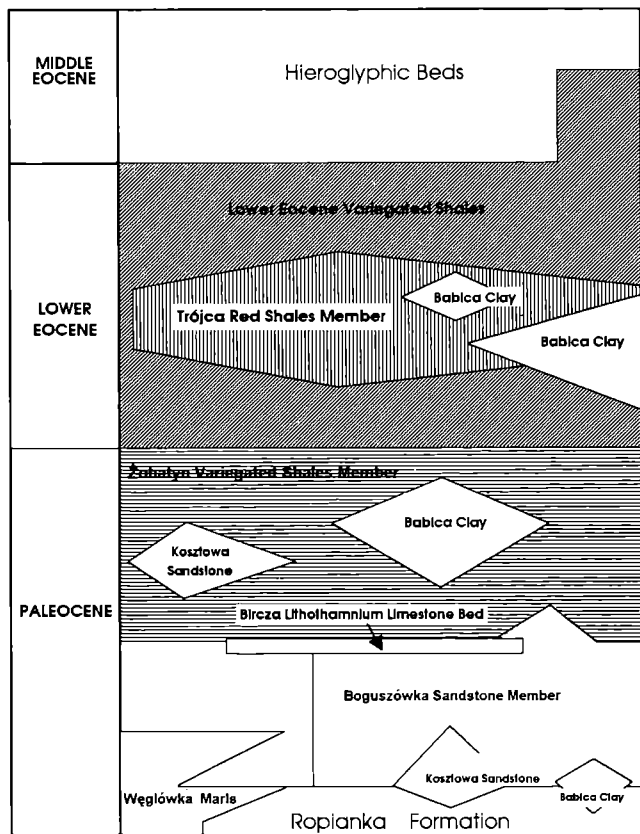


Fig. 1. Lithostratigraphy of the Variegated Shale Formation in the Skole Unit (after Rajchel, 1990, simplified)

flysch deposits of the Wola Korzeniowska Member or from other members of the uppermost part of the Ropianka Formation and Węglówka Marls (Kotlarczyk, 1978; Rajchel, 1990). The variegated shales have been classified as a lithostratigraphic formation in the Skole Unit (Rajchel, 1990) and subdivided, but incompletely, into a number of units (Fig. 1). The Bircza Lithothamnion Limestone Bed, and the stratigraphically discontinuous Babica Clays and Kosztowa Sandstone lithosomes have been defined as minor-range lithostratigraphic elements within the Variegated Shale Formation. The upper boundary of the Variegated Shale Fm. is a gradual transition into hemipelagic green shales or into flysch complex of the Hieroglyphic Beds (Rajchel, 1990). The Paleogene Variegated Shale Fm. is 130–190 m thick in the axial part of the Skole Unit, and the clastic deposits comprise about 50–70 m of the total formation thickness (Rajchel, 1990).

The studied sections (Dyl and DW) are located in the central part of the Skole Unit within the Jawornik–Dubiecko thrust sheet (Rajchel, 1989; Fig. 2), near the village of Dylagówka. The Variegated Shale Formation is represented mostly by red shales without CaCO₃, with thin green shales, intercalated by very thinly-bedded mudstones or claystones (less than 5%). The total thickness of the variegated shales is about 40–50 m in the studied sections (Fig. 3). These deposits are characterized by very abundant radiolarian assemblages (Fig. 3) in their Eocene part (M. Bąk, 1995). This study presents our attempt at combining micropaleontological and mineralogical investigations to arrive at palaeoenvironmental interpretations. During the transitional Paleocene–Eocene period, important changes occurred in global climate, in plate tectonic processes, in surface and deep-water patterns of ocean circulation and in global carbon cycle (see detailed discussion in Thomas & Shackleton, 1996). These changes in the deep-water environments are reflected in the composition of bathyal and abyssal foraminiferal faunas (e.g., Thomas, 1990, 1992; Kenett & Stott, 1991; Pak & Miller, 1992; Kaiho, 1991; Kaminski *et al.*, 1996). The question remains, whether the patterns of faunal change were similar in the Carpathians?

MINERALOGY

The variegated shales are montmorillonite-clinoptilolite claystones (Wieser, 1969). Rocks were analyzed for mineral and chemical composition using optical microscopy, scanning electron microscopy (SEM) with energy-dispersive X-ray spectrometry (EDS), powder X-ray diffractometry (XRD) and infra red spectrometry (IR). Radiolarians and clay fractions were separated by washing, ultrasonic disaggregation and settling in distilled water. The dominant minerals are Ca-montmorillonite (60–80 wt%) and clinoptilolite (15–30 wt%), with some quartz, feldspar, illite, illite-montmorillonite and kaolinite (all combined less than 15%). The claystones contain 3–6 vol.% of radiolarians composed of opal-CT. Two forms of clinoptilolite were found: fine, poorly crystallized and dispersed in the rock volume, and well-crystallized, euhedral grains inside radiolarian shells.

The lower Eocene clinoptilolite-montmorillonite clay-

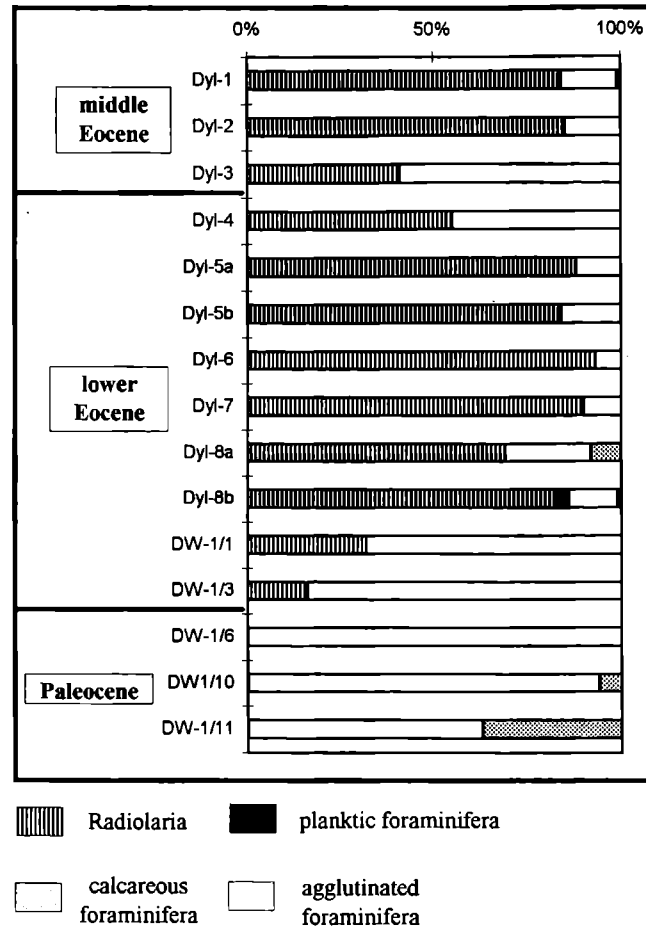


Fig. 3. Frequency distribution of the main groups of microfossils in the variegated shales

stones have been named eupelagic pelitic deposits with particles of mainly colloidal and subcolloidal size (Wieser 1969, 1994). The sediments contain glass-rich volcanic tuff which was probably a precursor for montmorillonite and clinoptilolite. The source of this tuff was rhyodacitic and dacito-andesitic volcanism active in the Central Carpathians from the Cretaceous to the Quaternary. Montmorillonite formed as a result of volcanic glass alteration (Rice *et al.* 1992; Wieser, 1994). Clinoptilolite was formed either by reaction of smectite with opal-CT (Wieser, 1969, 1994) or by direct alteration of volcanic glass to clinoptilolite and smectite (Lander & Hay, 1993). The formation of clinoptilolite is favoured by the high silica activities resulting from the occurrence with opal-CT. The clinoptilolite stability field is the largest when Al activities are controlled by assemblage amorphous silica and smectite (Bowers & Burns, 1990). Reactions require the presence of alkaline solutions (pH 7.5–10.5).

STRATIGRAPHY

The Foraminifera and Radiolaria were studied from the Paleogene variegated shales, in which calcareous nanoplankton are absent (M. Oszczytko and M. Kędzierski, *personal communication*, 1995). The chronostratigraphy is

based upon long-distance comparisons with the stratigraphic ranges of foraminiferal and radiolarian species in the Polish flysch Carpathians.

Foraminifera

Geroch and Nowak (1984) presented the deep-water agglutinated foraminifera (DWAF) biostratigraphy for the flysch Carpathians based upon composite sections from the flysch basins. But these zones were determined basing on the superposition of the benthic foraminiferal assemblages only, because of the lack of plankton in the largely noncalcareous sediments.

The Paleogene agglutinated foraminiferal biostratigraphy in the Polish flysch Carpathians has been calibrated to planktonic foraminifera and calcareous nannoplankton zones only in the Dukla Unit (Olszewska & Smagowicz, 1977). Using these data we can approximately calibrate the ranges of some stratigraphically important agglutinated taxa to planktonic zones and to the time scale of Berggren *et al.* (1995).

Olszewska and Smagowicz (1977) recognized the occurrence of *Rzehakina fissistomata* (Grzybowski) within their "*Globigerina triloculinoides* – *Globigerina varianta*" local Zone (P1-P4), corresponding to the Paleocene. They recognized an assemblage with abundant *Glomospira charoides* (Jones & Parker) within the *Globorotalia subbotinae* (= *Morozovella subbotinae*) Zone, corresponding probably, to the P6a Zone of the lowermost part of the lower Eocene according to Berggren *et al.* (1995). The acme of *Glomospira* spp. in the lower Eocene has been found from several locations in the Carpathians, Alps and North Atlantic (e.g., Bieda *et al.*, 1963; Grün *et al.*, 1964; Jurkiewicz, 1967; Jednorowska, 1968; Morgiel & Szymakowska, 1978; Winkler, 1984; Oszczytko *et al.*, 1990; Rajchel, 1990; Kaminski *et al.*, 1989, 1990, 1996). The base of the *Glomospira* spp. assemblage is interpreted here to occur near the Paleocene/Eocene (at P6a/6b) boundary. Morgiel and Szymakowska (1978) however, recognized a *Trochamminoides* assemblage beneath the *Glomospira* assemblage in the Skole Unit, which they correlated to the lowermost Eocene. On the other hand, an acme of *Trochamminoides* spp. was described as characteristic for the Paleocene in the Polish Carpathians by Morgiel and Olszewska (1981). A "Glomospira Event" has been observed in the lower and lower middle Eocene at many localities in the Western Tethys and North Atlantic regions (Kaminski *et al.*, 1996), and has been observed to be diachronous from east to west (older in the east regions).

The definition of the lower/middle Eocene boundary in the sediments of the Dukla Unit differs using the planktonic foraminifera and calcareous nannoplankton zones proposed by Olszewska and Smagowicz (1977). Zones P6a-c and NP12 only partially overlap (part of the P6c Zone) according to the timescale of Berggren *et al.* (1995). The species *Saccamminoides carpathicus* Geroch, an index taxon in the Geroch and Nowak zonation (1984) has its first occurrence within the *Globorotalia subbotinae* (= *Morozovella subbotinae*) Zone (Olszewska & Smagowicz, 1977) in the Dukla Unit. Unfortunately, these authors did not note the last oc-

currence of this taxon. In this paper, we accept, after Geroch and Nowak (1984) that the *Saccamminoides carpathicus* Zone represents the upper part of the lower Eocene. It approximately corresponds to Zones P6c and P7 *sensu* Berggren *et al.* (1995).

In the Dukla region the FO of *Reticulophragmium amplexens* (Grzybowski) is observed in the *Globorotalia subbotinae* (= *Morozovella subbotinae*) Zone, but its acme was recognized in the "*Turborotalia rotundimarginata* – *Globorotalia densa* Zone" of Olszewska and Smagowicz (1977), corresponding approximately to Zones NP15-17. The acme of this taxon can be correlated here with the middle Eocene (using the time scale of Berggren *et al.*, 1995), but not with the lowest part of this stage. A *Reticulophragmium amplexens* acme Zone has been reported from many localities outside of Carpathians. In the Alps it was described by Rögl *et al.* (1986) from the lower middle Eocene. In the North Sea, *R. amplexens* is abundant in the middle Eocene (Charnock & Jones, 1990). The acme of *R. amplexens* corresponds to the middle Eocene in the Labrador Sea (Kaminski *et al.*, 1989). In the Northern Rif this genus has its greatest abundance above the "Glomospira Event" (Kaminski *et al.*, 1996).

The local zonation proposed for the Dylagówka sections is based upon Geroch and Nowak (1984) with some modifications (Figs. 4, 5). The oldest investigated deposits (samples: DW-1/11, DW-1/10, DW-1/6) are **Paleocene** in age, documented by presence of *Rzehakina fissistomata* (Grzybowski) and single specimens of *Subbotina* cf. *triloculinoides* Plummer (Fig. 6). These assemblages are characterized by the numerous occurrence of tubular forms of the genera *Rhabdammina*, *Hyperammina* and *Bathysiphon*, as well as *Trochamminoides* spp. and *Recurvoides* spp. Additionally, *Glomospira* spp., *Ammodiscus* spp., *Kalamopsis grzybowskii* (Dylańska), *Haplophragmoides* cf. *kirki* Wicken, *H. walteri* (Grzybowski), *Spiroplectammina subhaeringensis* (Grzybowski), *Trochammina* sp. and *Karrerulina coniformis* (Grzybowski) are observed (Figs. 7, 8). Calcareous foraminifers from the genera *Cibicidoides* and *Gyroidinoides* occur here as well.

The younger deposits (samples: DW-1/5, DW-1/3, DW-1/1) are characterized by assemblages with numerous specimens of *Glomospira gordialis* (Jones & Parker), *Glomospira charoides* (Jones & Parker), *Glomospira serpens* (Grzybowski) and *Ammodiscus cretaceus* (Reuss). This assemblage can be correlated with the **lower part of the lower Eocene** (Fig. 5). Specimens of *Trochamminoides* spp., *Recurvoides* spp. and tubular forms are frequent as well. Siliceous sponge spicules (predominantly triaxons and tetraaxons) together with poorly preserved *Subbotina* sp. specimens are frequent in sample DW-1/5, taken from a mudstone layer, which was redeposited by a turbidity current from the shallower part of the basin.

The overlying assemblages of foraminifera (samples: Dyl-8b, Dyl-8a, Dyl-6, Dyl-5b, Dyl-5a, Dyl-4) can be placed in the *Saccamminoides carpathicus* Zone of Geroch and Nowak (1984), a indicator of the **lower Eocene** (Geroch & Nowak, 1984). A large number of *Glomospira charoides*, *G. gordialis*, *G. serpens* and *Ammodiscus cretaceus* are characteristic for this assemblage. The forms are

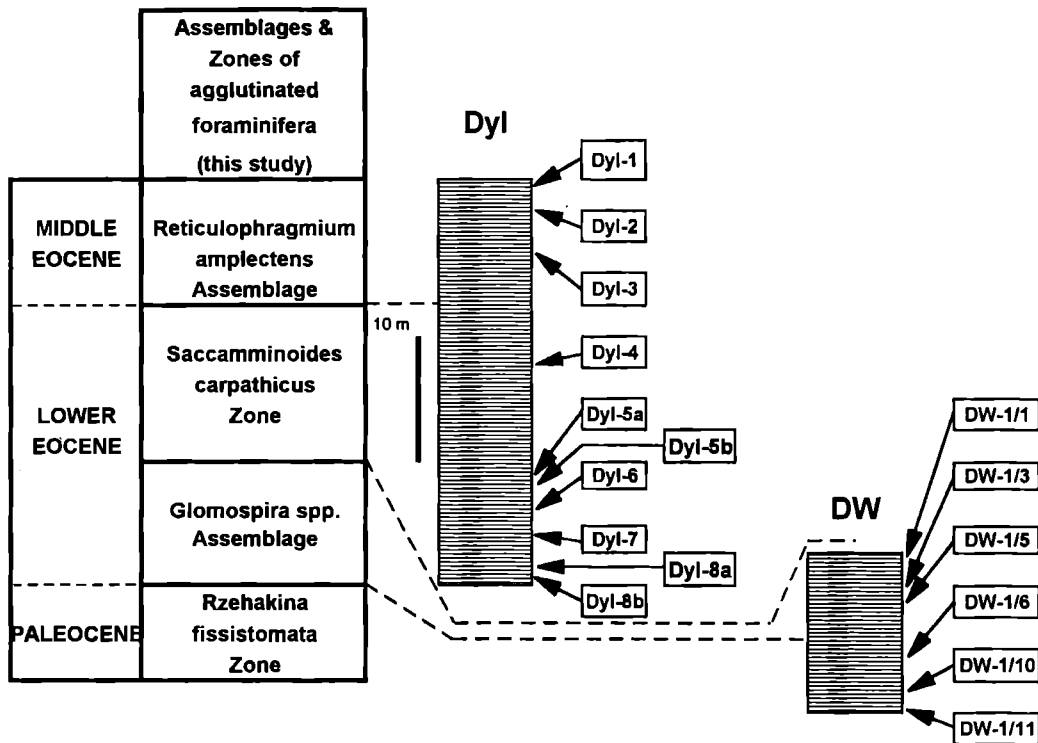


Fig. 4. Lithostratigraphical columns of the variegated shales and samples collected

accompanied by *Trochamminoides* sp., *Paratrochamminoides olszewskii*, *Recurvoides* spp., *Cribrostomoides* sp., *Trochammina* sp., *Karrerulina* sp. and *Spiroplectamina spectabilis* (Grzybowski). Tubular forms of *Rhabdammina* sp., *Nothia* sp. and *Bathysiphon* sp. are frequent in the lower part of these deposits only, and are much more rare in the

upper part.

The youngest variegated shales in the studied sections (Dyl-3, Dyl-2, Dyl-1) correspond to the middle Eocene, as recognized by abundant *Reticulophragmium amplexens* (Grzybowski); they are placed in the acme zone of this taxon. Foraminiferal assemblages are very similar to those from lower Eocene deposits, dominated by silicified specimens of *Glomospira* and *Ammodiscus*.

Radiolaria

Using the radiolarian data we could approximately correlate the variegated shales with the chronostratigraphy of Berggren *et al.* (1995). The radiolarian fauna is very rare in the Paleocene, where the chronostratigraphy is based on agglutinated foraminifera only. Only poorly preserved forms of the order Spumellaria have been found. The recognizable radiolarian fauna has its lowermost occurrence in sample D8b. Unfortunately, the radiolarian species are rather long-lived, and the index species are missing. The assemblage consists of forms belonging mostly to the suborder Spumellariina (Figs. 9, 10) such as *Cenosphaera eocenica* Campbell et Clark, *Lithocyclus ocellus* Ehrenberg, *Phacodiscus rotula* Haeckel, *Spongatractus balbis* Sanfilippo et Riedel, and species belonging to the genera *Acanthosphaera*, *Heliodiscus*, *Heliosoma* and *Spongodiscus*. Species from the suborder Nassellariina are less frequent, but more diverse, and include *Calocyclus ampulla* (Ehrenberg), *C. castum* (Haeckel), *Podocyrtis papalis* Ehrenberg, *Stylosphaera coronata coronata* Ehrenberg, *Theocotyle cryptocephala cryptocephala* (Ehrenberg) and *Theocotyle ficus* (Ehrenberg). Zone-diagnostic radiolaria such as *C. castum*, *C. am-*

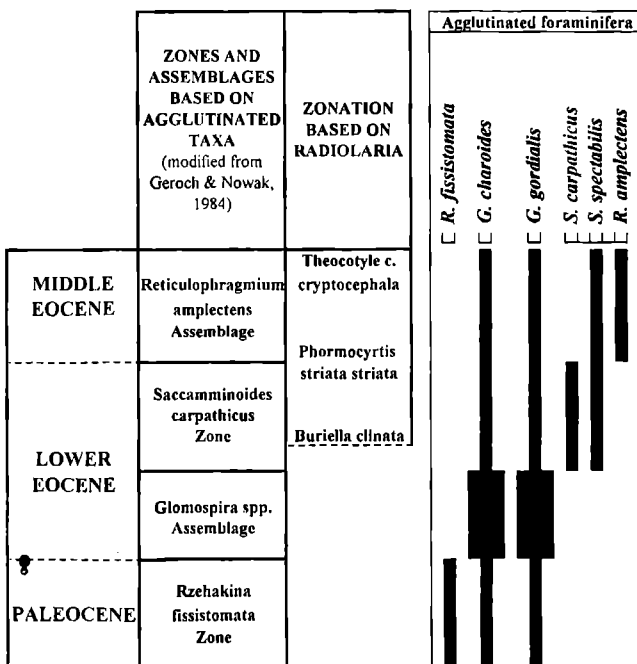


Fig. 5. Composite range chart of agglutinated foraminifera with biozonation for Paleocene through middle Eocene deposits in the Dylagówka sections

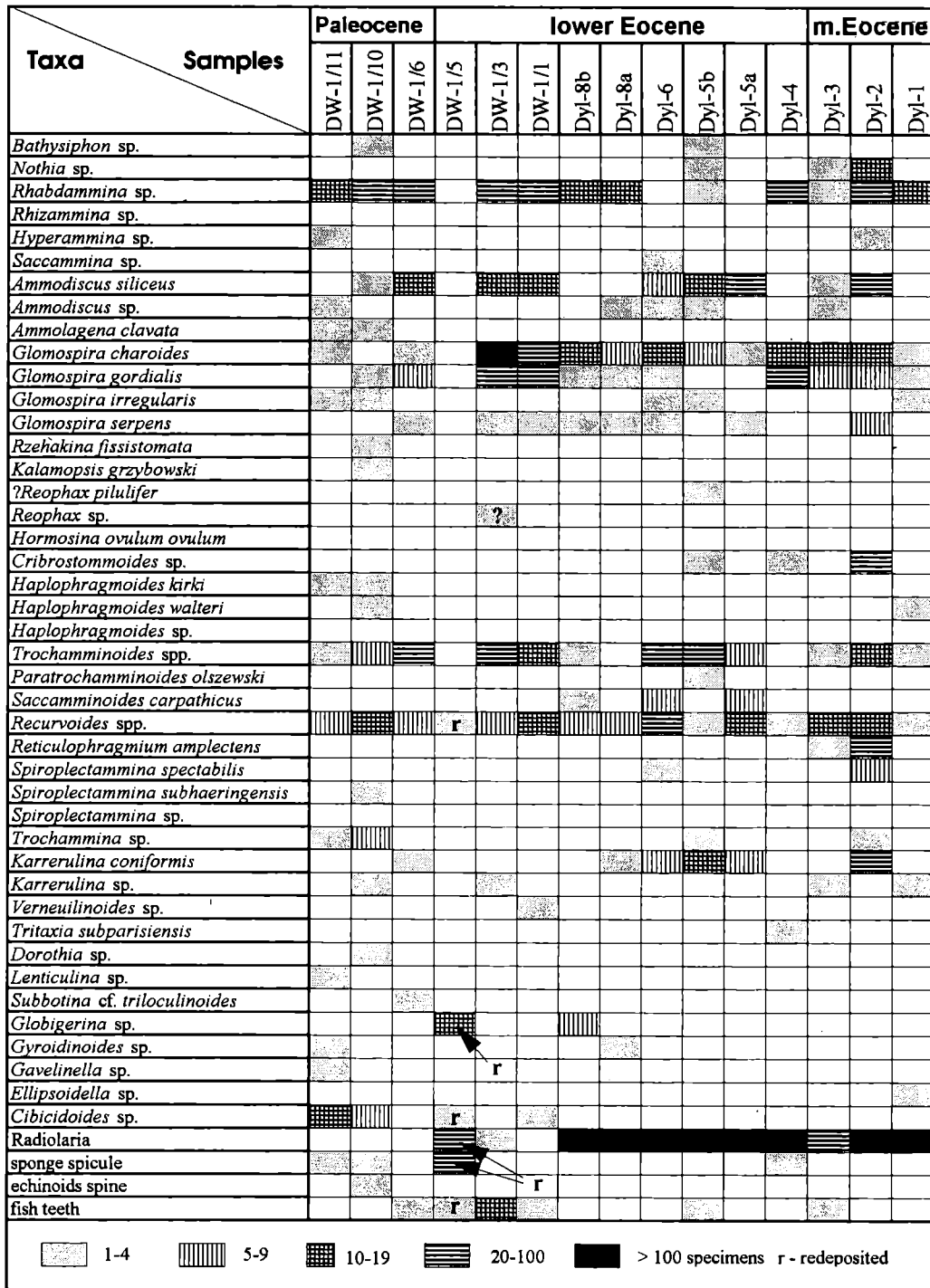


Fig. 6. Range chart showing the occurrence of investigated species

pula, *S. balbis*, *T. ficus* and *T. cryptocephala cryptocephala* were used to establish a radiolarian biozonation (M. Bak, 1995), but we found different data on the first and last occurrences of radiolarian index species in the published literature (Fig. 11; see Foreman, 1973; Sanfilippo & Riedel, 1973; Sanfilippo *et al.*, 1985; Nishimura, 1987). The FAD of *Theocotyle ficus* (Ehrenberg) occurs within the *Buriella clinata* Zone of Sanfilippo *et al.* (1985), and the LAD of *Calocyclus castum* (Haeckel) was at the top of the *Theocotyle cryptamcephala cryptamcephala* Zone of Sanfilippo *et al.* (1985) – Figs. 11 & 12. These forms are not the index

species, but the FAD of *T. ficus* and the LAD of *C. castum* are observed in our samples.

Based on these data the variegated shales between samples D8a and D2 have been included into the *Buriella clinata*, *Phormocythis striata striata* and *Theocotyle cryptocephala cryptocephala* zones *sensu* Sanfilippo *et al.* (1985), although it is impossible to find the zonal boundaries in the studied profiles. They may correspond to the lower Eocene (upper part of NP12 Zone of Martini & Worsley, 1971) through the lowermost part of middle Eocene (NP14 Zone) according to chronostratigraphy of Berggren *et al.* (1995).

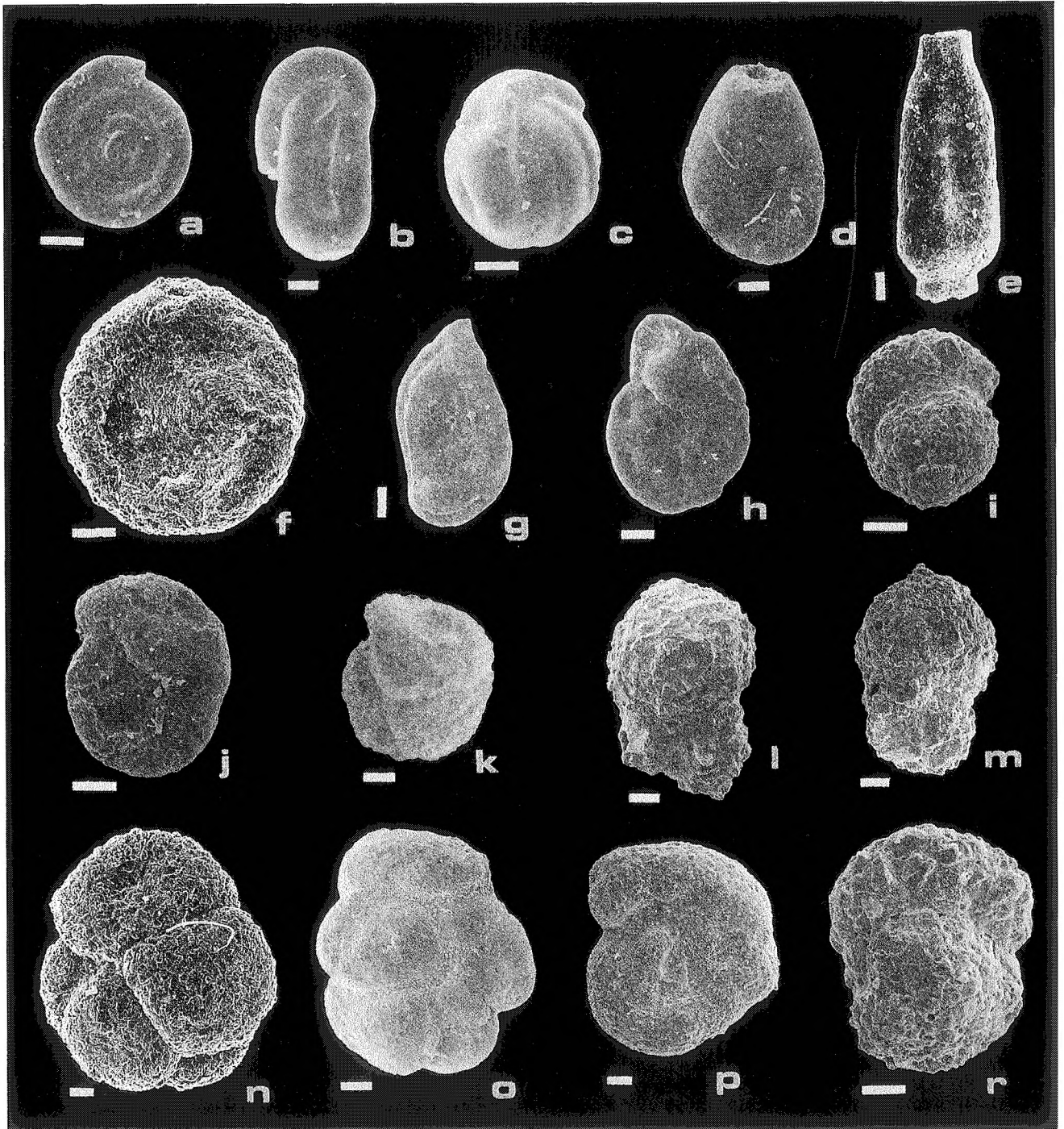


Fig. 7. Paleocene-middle Eocene agglutinated foraminifera from the Dylągówka sections: **a.** *Glomospira gordialis* (Jones & Parker) – sample Dyl-2, (middle Eocene); **b.** *Glomospira serpens* (Grzybowski) – sample Dyl-8b, (lower Eocene); **c.** *Glomospira charoides* (Jones & Parker) – sample Dyl-2, (middle Eocene); **d.** *Hyperammina dilatata* (Dyląganka) and *Ammolagena clavata* (Jones & Parker) – sample DW-1/11. (Paleocene); **e.** *Kalamopsis grzybowskii* (Dyląganka) – sample DW-1/10, (Paleocene); **f.** *Saccamina* sp. – sample Dyl-6 (lower Eocene); **g.** *Rzehakina fissistomata* (Grzybowski) – sample DW-1/10, (Paleocene); **h.** *Haplophragmoides walteri* (Grzybowski) – sample DW-1/10, (Paleocene); **i.** *Cribrostomoides* sp. – sample Dyl-2, (middle Eocene); **j.** *Haplophragmoides* sp. – sample DW-1/10 (Paleocene); **k.** *Haplophragmoides* cf. *kirki* Wickenden – sample Dyl-2, (middle Eocene); **l.** *Saccaminoides carpathicus* Geroch – sample Dyl-5b, (lower Eocene); **m.** *Saccaminoides carpathicus* Geroch – sample Dyl-5a, (lower Eocene); **n.** *Trochamminoides* sp. – sample Dyl-6, (lower Eocene); **o.** *Trochamminoides* sp. – sample Dyl-2, (middle Eocene); **p.** *Paratrochamminoides olszewskii* – sample Dyl-5b, (lower Eocene); **r.** *Recurvoides* sp. – sample Dyl-2, (middle Eocene). Scale bar = 100 μ m

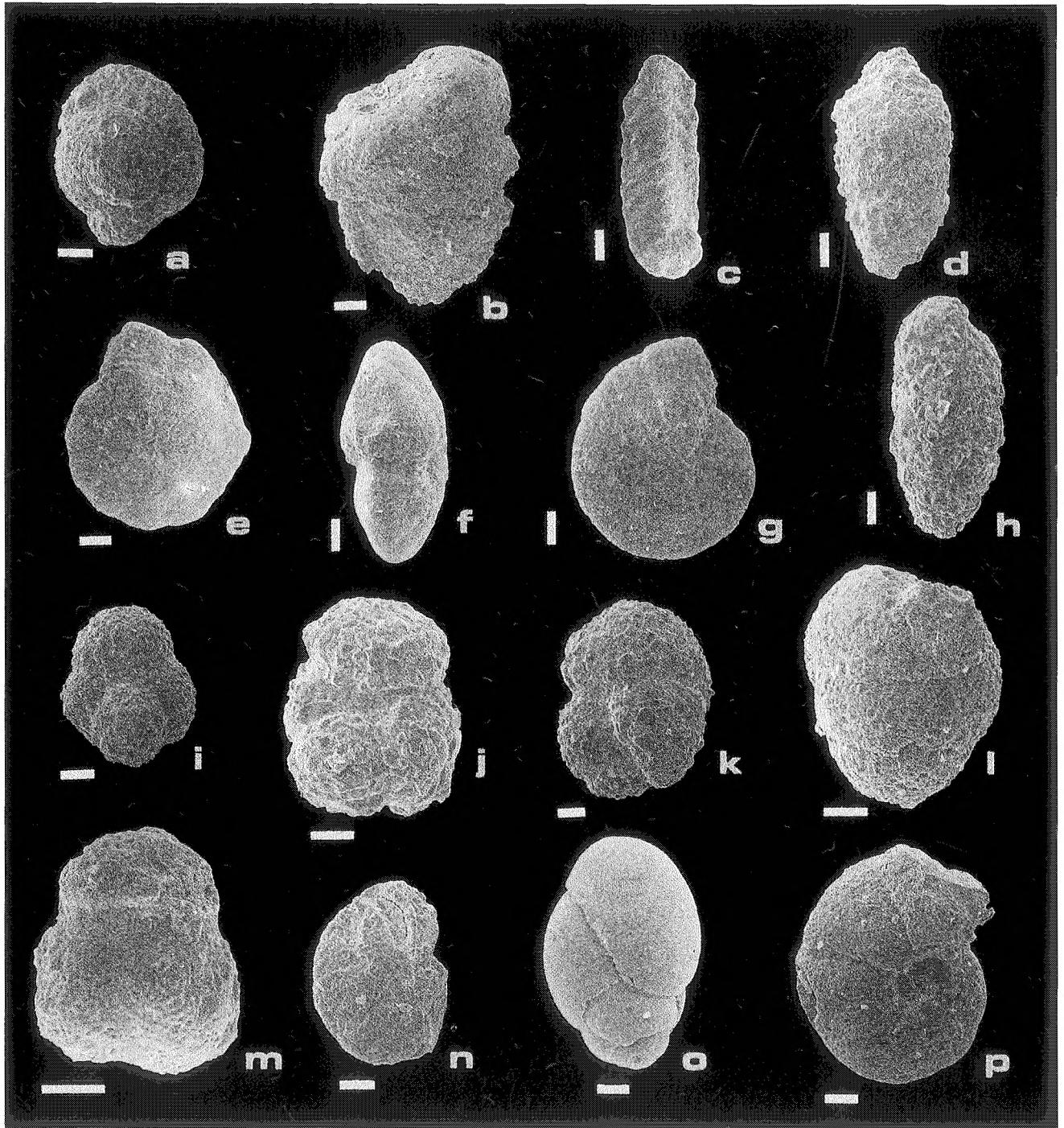


Fig. 8. Paleocene-middle Eocene foraminifera from the Dylągówka sections: **a.** *Recurvoides* sp. – sample Dyl-3, (middle Eocene). **b.** *Spiroplectammina subhaeringensis* (Grzybowski) – sample DW-1/11, (Paleocene); **c.** *Spiroplectammina spectabilis* (Grzybowski) – sample DW-1/3, (lower Eocene); **d.** **h.** *Karrerulina* sp. – sample DW-1/3, (lower Eocene); **e-g.** *Reticulophragmium amplexens* (Grzybowski) – sample Dyl-2, (middle Eocene); **i.** *Trochammina* sp. – sample Dyl-5b, (lower Eocene); **j.** *Trochammina* sp. – sample Dyl-2, (middle Eocene); **k.** *Trochammina* sp. – sample DW-1/11, (Paleocene); **l.** *Dorothia* sp. – sample DW-1/10, (Paleocene); **m.** *Subbotina* cf. *triloculinoides* Plummer – sample DW-1/6, (Paleocene); **n.** *Cibicidoides* sp. – sample DW-1/11, (Paleocene); **o.** *Bulimina* sp. – sample Dyl-1, (middle Eocene); **p.** *Cibicidoides* sp. – sample DW-1/1, (lower Eocene). Scale bar = 100 μ m

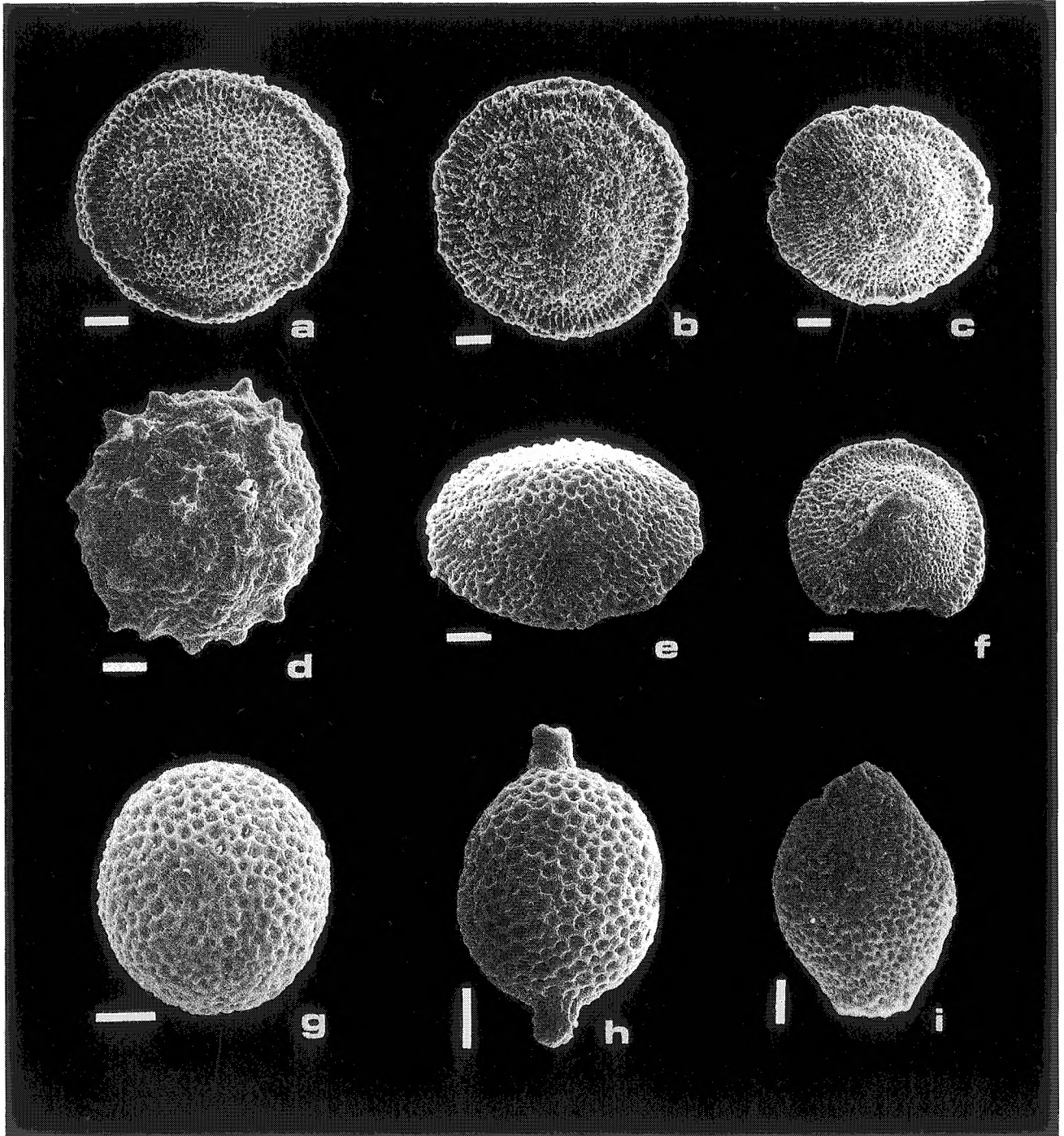


Fig. 9. Lower and middle Eocene Radiolaria from the Dylągówka sections: a. *Phacodiscus* sp. – sample Dyl-5a, (lower Eocene); b, c, f. *Phacodiscus rotula* Haeckel – sample Dyl-7; (lower Eocene); d. *Acanthosphaera* sp. – sample Dyl-2, (middle Eocene); e. *Lithocyclia ocellus* Ehrenberg – sample Dyl-5b, (lower Eocene); g. *Cenosphaera eocenica* Campbell et Clark – sample Dyl-3, (middle Eocene); h. *Spogatractus balbis* Sanfilippo et Riedel – sample Dyl-5a, (lower Eocene); (i) *Spongurus* (?) sp. – sample Dyl-5a, (lower Eocene). Scale bar = 100 μ m

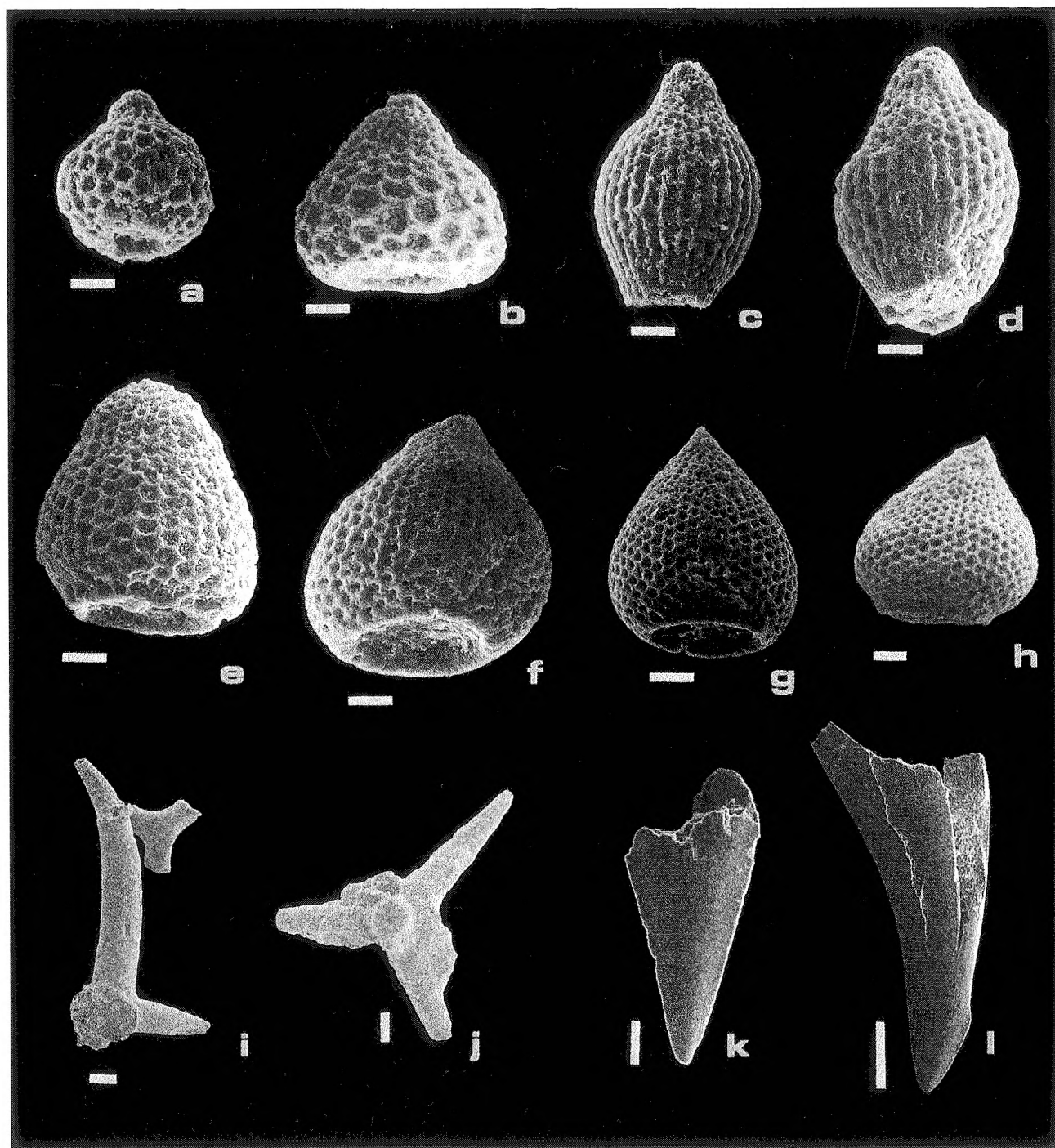


Fig. 10. Lower and middle Eocene Radiolaria, sponge spicules and fish teeth from the Dylągówka sections: **a.** *Calocycloma ampulla* (Ehrenberg) – sample Dyl-5a, (lower Eocene); **b.** *Calocycloma castum* (Haeckel) – sample Dyl-2, (middle Eocene); **c.** **d.** *Podocrtis papalis* Ehrenberg – sample Dyl-5a, (lower Eocene); **e-h.** *Theocotyle ficus* (Ehrenberg) – sample Dyl-7, (lower Eocene); **i.** sponge spicule – sample DW-1/11, (Paleocene); **j.** sponge spicule – sample DW-1/5, (lower Eocene); **k.** **l.** fish teeth – sample DW-1/3, (lower Eocene). Scale bar = 100 μ m

MORPHOGROUP DESCRIPTIONS

Morphogroup analysis is based on the assumption that the morphology of the foraminiferal test is connected with the feeding strategy of benthic foraminifera, and therefore with their microhabitat preferences (Jones & Charnock, 1985;

Corliss, 1985; Kaiho, 1991; Murray, 1991; Nagy, 1992; Tysza, 1994; Nagy *et al.*, 1995; Kaminski *et al.*, 1995). Changes of water depth, oxygenation, currents strength and accessibility to food can be interpreted by comparing the changes between the particular morphogroups.

Taking into account the criteria of the test shape differ-

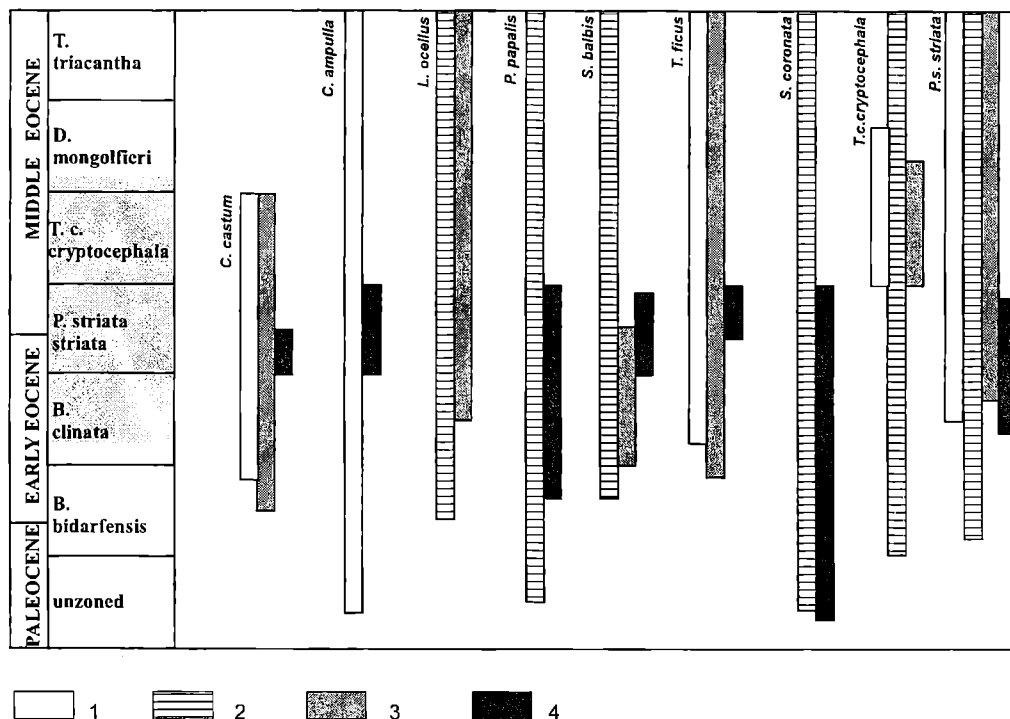


Fig. 11. Ranges of selected Paleocene-middle Eocene Radiolaria from: 1 – the Gulf of Mexico (Foreman, 1973), 2 – the Caribbean region (Riedel & Sanfilippo, 1973), 3 – the Western North Atlantic (Nashimura, 1987), 4 – composite (Sanfilippo *et al.*, 1985)

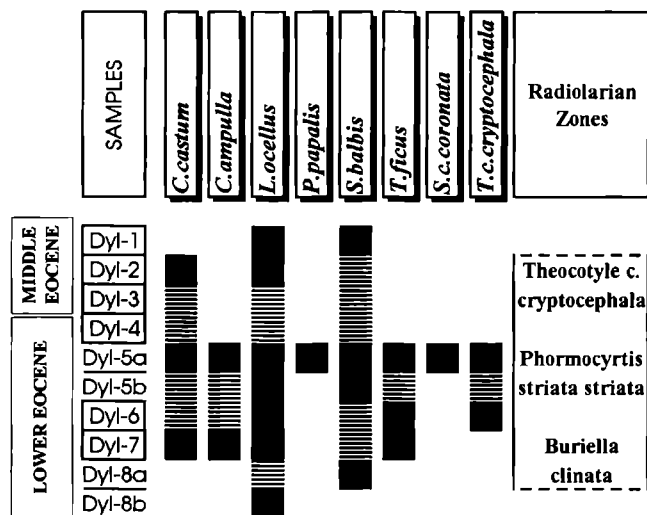


Fig. 12. Range chart of Radiolaria with biozonation for Paleocene through middle Eocene deposits in the Dylągówka sections

entation proposed by Nagy (1992) and Nagy *et al.* (1995), the foraminiferal agglutinated species data have been combined into six morphogroups (Tab. 1).

Morphogroup A1 consists of tubular or branched forms. A contemporary example is *Saccorhiza ramosa*, which builds a pseudopodal net above the sediment/water interface in order to feed (Altenbach *et al.*, 1988). Other examples are the recent species *Rhizammina algaeformis* with a similar feeding strategy (Kaminski, 1985), which can penetrate into the uppermost part of sediment, and *As-*

trorhiza limicola as well as *A. arenaria* (Gooday, 1990).

Morphogroup A2 comprises flattened forms, planispiral encoiled and irregular, in the genera *Ammodiscus*, *Glomospira*, *Rzehakina*, *Trochamminoides* and *Paratrochamminoides*. The feeding strategy of this morphogroup is not quite clear. Modern *Ammodiscus* is the most frequently found as mobile epifaunal detritivores (Kaminski *et al.*, 1988; Nagy *et al.*, 1995). Living species of *Glomospira charoides* live at the surface of the sediment or in the topmost 1.5 cm (Mackensen & Douglas, 1989). Irregular spired forms of *Tolypammina* have been observed as attached to erect fragments on the sea-bed (Nagy *et al.*, 1995). It is possible that the same habitat preferences characterize the life-position of *Trochamminoides* and *Paratrochamminoides*, which are numerous in the sediments deposited by turbidity currents (Kuhnt *et al.*, 1989a).

Plano-convex and concavo-convex forms such as *Trochammina*, *Saccamminoides* and *Saccammina* have been included in **morphogroup A3**. They live on the bottom surface with the aperture submerged in the sediment, supposedly similar to the modern *Saccammina* (Nagy *et al.*, 1995) and *Astrammina rara* (De Laca, 1986). Some of the modern trochamminids can be attached to the invertebrate shells (Mackensen & Douglas, 1989) or to tubes of *Rhabdammina* (Nagy *et al.*, 1995).

Morphogroup A4a consists of rounded forms such as *Recurvoides* and *Cribrostomoides*. They tend to live as shallow infauna, 1–4 cm below the sediment/water interface (Mackensen & Douglas, 1989). Some of these, such as the recent *Recurvoides turbinatus*, however have been found to a depth of 15 cm (Hunt & Corliss, 1993).

Planispiral, biconvex forms have been included in **mor-**

Table 1

Agglutinated (A) foraminiferal morphogroups and their inferred life position as well as feeding habits

MORPHOGROUP	TEST SHAPE	POSITION WITHIN SEDIMENTS	FEEDING STRATEGY	MAIN GENERA
A1	tabular or branched	epifaunal erect	suspension feeders	<i>Bathysiphon</i> <i>Rhizammina</i> <i>Hyperammina</i> <i>Rhabdammina</i>
A2	flattened	epifaunal	deposit feeders	<i>Ammodiscus</i> <i>Glomospira</i> <i>Trochamminoides</i> <i>Paratrochamminoides</i> <i>Rzehakina</i>
A3	plano-convex, concavo-convex	epifaunal	herbivores detritivores	<i>Trochammina</i> <i>Saccamminoides</i> <i>Saccammina</i>
A4a	rounded	epifaunal shallow infaunal	detritivores	<i>Recurvoides</i> <i>Cibrostomoides</i>
A4b	biconvex	shallow to deep infaunal		<i>Haplophragmoides</i> <i>Reticulophragmium</i>
A5	elongate subcylindrical tapered	shallow to deep infaunal		<i>Dorothia</i> <i>Karrerulina</i> <i>Spiroplectammina</i> <i>Reophax</i> <i>Verneulinoides</i>

phogroup 4b, shallow to deep infaunal forms such as the modern *Cribrostomoides subglobulosus*, *C. crasimargo* and *C. jeffreysi*, similar in shape to *Haplophragmoides kirki*. They live just below (0–2 cm) the surface of the sediment (Kaminski *et al.*, 1988; Hunt & Corliss, 1993). Elongated forms (*Haplophragmoides walteri* and *Reticulophragmium amplexens*) with a straight periphery might have been good burrowers, as was noted by Tyszka (1994) for calcareous forms of genera *Lenticulina*.

Elongated subcylindrical or tapered forms have been classified in **morphogroup A5**, modern taxa live as deep infauna. An example is *Reophax*, found more than 10 cm below the sediment surface (Kaminski *et al.*, 1988; Hunt & Corliss, 1993; Mackensen & Douglas, 1989), *Spiroplectammina biformis*, *Textularia torquata* (Hunt & Corliss, 1993) as well as *Karrerulina conversa* (Nagy *et al.*, 1995), observed in culture to be mobile, shallow to deep infaunal forms. This morphogroup comprises species from the genera *Dorothia*, *Karrerulina*, *Spiroplectammina*, *Reophax* and *Verneulinoides*.

PALEOECOLOGICAL INTERPRETATIONS

Energy of depositional environment

The Paleocene variegated shales are characterized by large amounts (45%) of suspension feeding forms (morphogroup A1), and a high content (37%) of mobile epifauna

(morphogroup A2), active deposit feeders (Figs. 13, 14). The whole content of epifaunal forms – nearly 90% – suggests that the sedimentation of these deposits took place under the high-energy conditions where the food was supplied by distal turbidity currents. Similar assemblages have been described by Jurkiewicz (1960) from the Silesian Unit (Czarnorzeki shales = Upper Istebna shales). “The assemblage with *Dendrophrya excelsa* and *Rhabdammina abyssorum*” are Paleocene in age, with predominating tubular forms.

Early Eocene benthonic assemblages are extremely enriched in the mobile epifaunal, deposit feeding forms (morphogroup A2 – 58%). The content of another epifaunal morphogroup – A1 – was less than 1/2 as common as in Paleocene. A high abundance of epifauna (more than 85%) was very characteristic for these assemblages. This composition of the microfauna shows lower rate of sedimentation, with less common gravitational currents.

Epifaunal morphogroups remain consistently dominant during the lower middle Eocene, but their significance decreased markedly (65%). Tubular forms comprise only 12% of the whole benthos. The content of shallow and deep infauna (morphogroups A4a, A4b and A5) increased to 35%. These suggest a continued lowering of the sedimentation rate. The relatively higher species diversity within morphogroups A4a, A4b and A5 indicates a more intensive exploitation of infaunal niches. However, the amount of food in the sediment was very restricted, as indicated by the lack of macrofaunal bioturbation of these type deposits

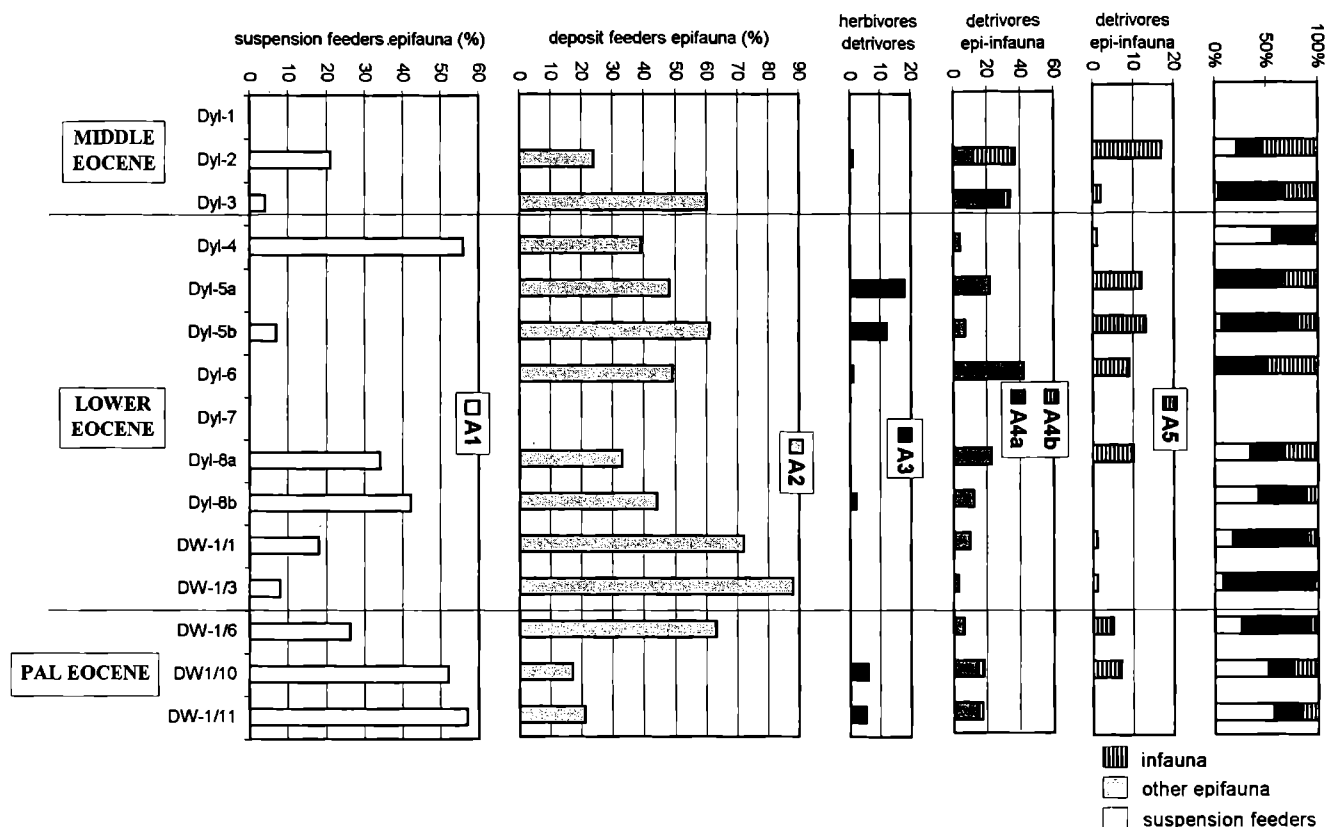


Fig. 13. Distribution of foraminiferal morphogroups (A1-A5) in the variegated shales

noted by Leszczyński and Uchman (1993).

Calcite compensation depth

The variegated shales are devoid of foraminiferal plankton except for a few specimens of *Subbotina* sp., probably redeposited. Calcareous benthos, with a low diversity, occurs very rarely, only in single samples, and may be redeposited as well. However, in two samples its content is about 30%, and the foraminifers (predominantly from the genus *Cibicidoides*) are well preserved. Redeposition of the assemblages in the clay clasts and in coprolites can explain this fact. Nannoplankton were absent in the studied samples.

Calcareous-free deposits devoid of calcareous microfauna indicate deposition below the CCD. Deposits above and below the variegated shales are characterized by siliceous or clayey cement. Examples in the Skole Unit are the upper part of the Ropianka Formation (the lower Paleocene Wola Korzeniecka Member; Kotlarczyk, 1978), the Paleocene to lower Eocene Babica Clay, the lower to middle Eocene Hieroglyphic Beds, and the middle Eocene Green Shales (Rajchel, 1989, 1990; Kotlarczyk, 1978). Calcareous components occur in those deposits very rarely as slumps or mudflows, redeposited from the shallower parts of the basin. An example is the Birza Limestone Bed (BLB) in the variegated shales. The BLB includes bryozoans, lithothamnion fragments, and single discocyclines (Gucik, 1961; Kotlarczyk, 1961). Another example are deposits in the Babica Clays which are interpreted as the cohesion flow deposits (e.g., Dżułyński *et al.*, 1979). These have been transported from the shelf (para-reef environments) and upper bathyal

depths, as documented by mixed assemblages of foraminifers (Olszewska & Geroch, 1991).

It is very difficult to estimate the level of the CCD during the deposition of the Paleocene–middle Eocene variegated shales in the Skole Unit. In the early Eocene the CCD in the world oceans rose up to about 3 500 m (Van Andel, 1975). This change could be attributed to a low input of carbonate in the oceans from strongly weathered continents, or to large changes in the distribution of carbonate deposition between shallow and deep seas. The early Eocene was characterized by the highest temperatures (11–15°C) of deep water, recorded by stable isotopes (Shackleton, 1986; Kenett & Stott, 1991; Pak & Miller, 1992; Zachos *et al.*, 1993, 1994). High latitude surface waters were very warm at the end of the Paleocene, which resulted in benthic foraminiferal extinction (Kenett & Stott, 1991). The temperature of high latitude surface waters warmed from about 10°C to about 20°C, forced by greenhouse effects (Stott, 1992). In consequence, a decrease in the difference in density between deep water and overlying surface water could have been the cause of reversed and sluggish circulation in the oceanic basins (Kaiho, 1991). Hence, the nutrient supply to the surface water would have been restricted, and the production of calcareous plankton decreased, affecting a rise of the CCD.

The location of CCD in the world ocean during Paleocene/Eocene varied from lower bathyal depths in the north seas (e.g., Charnock & Jones, 1990; Kaminski *et al.*, 1990) to more than 3400 m in the Southern Ocean (Thomas & Shackleton, 1996). Additional aspects which should be born

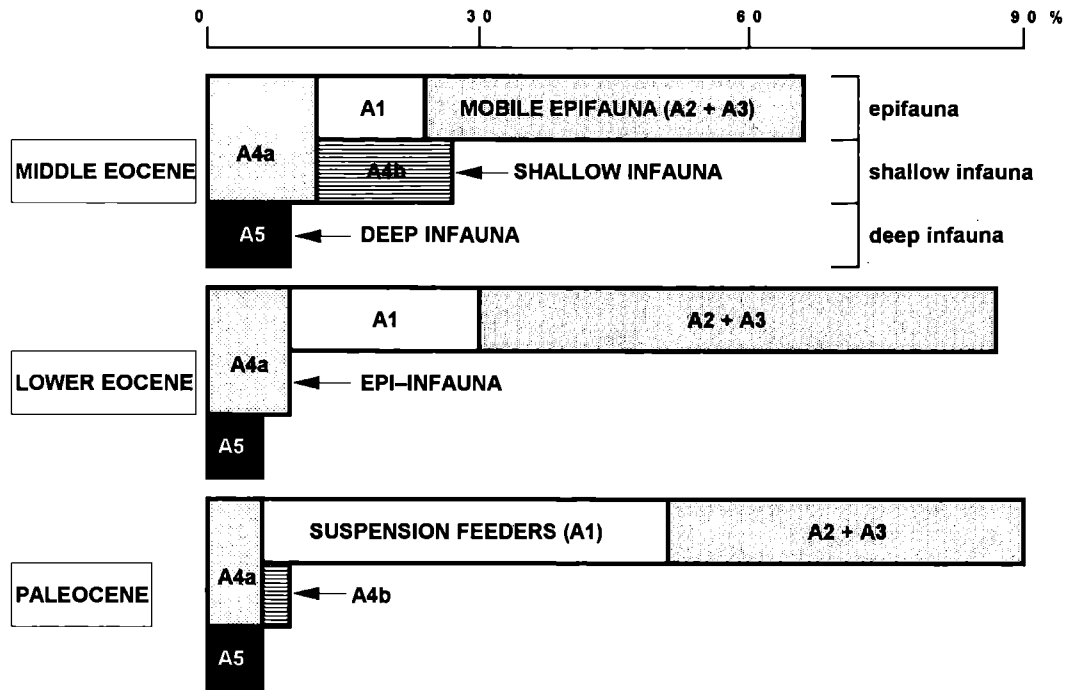


Fig. 14. Distribution of generalized benthic foraminiferal community structure during the Paleocene, lower Eocene and middle Eocene

in mind to determine the level of the CCD is the fact that the CCD rises near the slopes of the continents. Comparing the agglutinated assemblages including deep water *Reophax pilulifer*, *Recurvoides* sp. and *Trochamminoides* sp. with assemblages described by Charnock and Jones (1990) from the Paleogene in North Sea as well as by Morlotti and Kuhnt (1992) from the Eocene in the Northern Apennines, and Kaminski *et al.* (1990) from the Norwegian–Greenland Sea, the CCD could be located at lower bathyal depths. A similar depth (up to 2 500 m) for the central part of Skole basin has been interpreted in the Oligocene using the ichthyofauna in the noncalcareous Menilite Beds by Jerzmańska and Kotlarczyk (1968, 1991).

Food accessibility

Benthonic foraminiferal species diversity is generally very low (6–15 species per sample) in the variegated shales. Diversity decreased from the Paleocene (mean 13) to the lower and middle Eocene assemblages (mean 9 and 10 respectively), with concurrent decreasing intensity of turbidite sedimentation. This fact, together with the small amounts of microfauna in the samples can be interpreted as the result of extremely oligotrophic conditions at the sea floor. That can be confirmed by analysis of biogenic structures in the well-oxygenated deep-water deposits in similar, red (variegated) facies from the Outer Carpathians, Pieniny Klippen Belt and Julian Prealps (Leszczyński & Uchman, 1993; K. Bąk, 1995a; Tunis & Uchman, 1995). Macrobio-turbators in the low-diversity assemblages of the red deposits suggest a restriction of food to the thin uppermost layer of the sediment. However, the comparison of lower and middle Eocene agglutinated morphogroups (Fig. 14) shows a change in the trophic conditions, with higher food levels in the *Reticulophragmium amplexens* Zone (middle Eocene). A similar

situation in the Northern Morocco has been interpreted by Kaminski *et al.* (1996) as a change from lowered productivity and widespread oxygenation of deep-waters during the early Eocene (*Glomospira* biofacies) greenhouse conditions, to more eutrophic conditions in the middle Eocene (*R. amplexens* biofacies), reflecting renewed higher productivity.

“Radiolaria Flood”

The presence of Radiolaria in sedimentary deposits indicates normal marine salinity. The recovered specimens represent a low-latitude assemblage (Foreman, 1973; Nishimura, 1987; Riedel & Sanfilippo, 1970, 1978; Sanfilippo & Riedel, 1973; Sanfilippo *et al.*, 1985). They mostly belong to the order Spumellariina which dominate the shelf waters in the modern ocean (Casey, 1993). The Spumellariina to Nassellariina ratio is 0.9 to 1.0, suggesting that sedimentation took place under oceanic conditions, but near the edge of the shelf (in much deeper water). The low radiolarian diversity supports this interpretation. Intercalations of calcareous and siliceous micro- and macrofauna in the turbidity deposits (cf. sample DW-1/5 or Bircza Limestone Beds; Kotlarczyk, 1961) or in the cohesion flow deposits and olistostromes (cf. Babica Clays; Olszewska & Geroch, 1991) also show that the edge of the “Skole shelf” was very near. These facts suggest that, there was a relatively steep northern slope in the Skole basin during the Paleogene. The existence of a steep slope, intersected by faults and cut by canyons has been also interpreted by Jucha (1985) and Kotlarczyk (1991) from upper Eocene–Oligocene deposits.

Rich radiolarian faunas in the lower and middle Eocene occurred world-wide, at many localities in the Atlantic (e.g., Dzinoridze *et al.*, 1978; Foreman, 1973; Nishimura, 1987),

Pacific (Foreman, 1975; Riedel & Sanfilippo, 1971, 1978), Antarctic, Southern Oceans, Arctic, California, Soviet Union, Japan and others (e.g., Clark & Campbell, 1942; Chen, 1975; Kiminami *et al.*, 1990; Lipman, 1950; Takemura, 1990). In contrast, Paleocene Radiolaria are very rare or absent (Moore, 1973; Sanfilippo *et al.*, 1985; Blueford, 1989), suggests that these distributions reflect different palaeocirculation patterns in the Paleocene and Eocene. The low abundance of biosiliceous (radiolarian) deposits in the Paleocene oceans may reflect the restriction of the flow of water masses in which radiolarians lived. Such a change is observed in the Skole Unit, where the Eocene radiolarian-rich deposits might reflect more open ocean circulation. In Paleocene deposits no radiolarians were observed, whereas the Eocene deposits contain abundant and well-preserved assemblages. The episode of radiolarian abundance of the same age has been noted from many localities in the Skole Unit (cf. Morgiel & Szymakowska, 1978; Rajchel, 1990), in the variegated shales of the Magura Unit (M. Cieszkowski, *personal information*, 1995). Possibly a change of surface circulation in the Carpathian basins are responsible for the "Radiolaria Flood" during the early and middle Eocene. This effect has been emphasized by relatively slow rate of sedimentation, below the CCD. The approximate rate of sediment accumulation during the early Eocene (5.5–6.5 mln years according to Berggren *et al.*, 1995) can be estimated as 4–5 m/My. Moreover, the fine grained sediments and their mineralogy were conducive to the preservation of radiolarian shells. Probably, the glass-rich volcanic tuffs were the precursor for the main minerals of the variegated claystones. Evidence for volcanic eruptions in the Carpathians has been found as bentonites and tuff horizons in the Paleocene–middle Eocene deposits of the Dukla, Magura, Silesian and Sub-Silesian units (Kamieński & Skoczylas-Ciszewska, 1956; Tokarski, 1957; Parachoniak, 1957; Ślaczka, 1959; Sikora & Wieser, 1959; Wieser & Żytko, 1959; Sikora, 1962; Wieser, 1985). The tuffite horizons occur in the variegated shales of the Skole Unit as well (Fig. 15). They have been reported from many localities of this unit (see detailed description in Rajchel, 1994).

CONCLUSIONS

The Paleogene variegated shales deposited in the studied sections of the Skole Unit range in age from the *Rzehakina fissistomata* Zone (Paleocene) through the *Reticulophragmium amplexens* Zone (middle Eocene) of Geroch and Nowak (1984). They are devoid of calcium carbonate and include abundant, low-latitude radiolarian faunas, deep-water agglutinated foraminifera, with scarce or absent, redeposited calcareous benthonic and planktonic forms. Based on the microfaunal analyses the sedimentation of the variegated shales took place under oceanic conditions at lower bathyal depths but close to the edge of the shelf, below the CCD. The position of the CCD in the water column in the Skole Basin might be estimated taking into account the (1) upward rise in the CCD in the world oceans (Van Andel, 1975) during the early and middle Eocene, caused by the low input of calcium carbonate to the oceans (2) the high

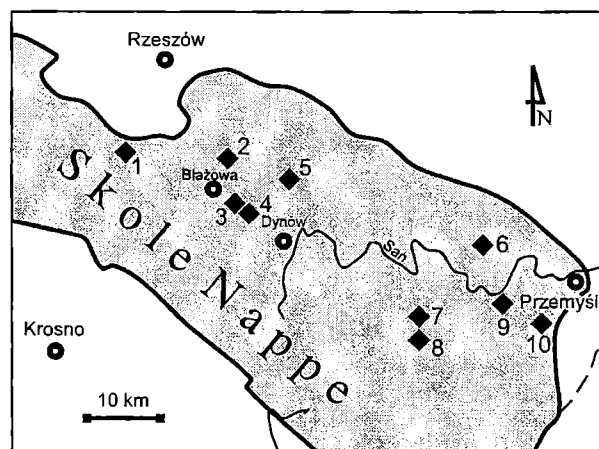


Fig. 15. The Paleocene–middle Eocene tuffite horizons in the Skole Nappe: 1 – Siedliska (Koszarski, L. & Koszarski, A., 1985), 2 – Hyżne (Rajchel, 1990), 3 – Futoma (Rajchel, 1994), 4 – Futoma (Kotlarczyk, 1966), 5 – Szklary IG-1 (Wieser, 1970), 6 – Wola Krzywiecka (Rajchel, 1994), 7 – Bircza (Rajchel, 1990), 8 – Wola Korzeniecka (Rajchel, 1994), 9 – Olszyny (Rajchel, 1990), 10 – Książyce (Rajchel, 1994)

temperatures of deep water in the early Eocene (Zachos *et al.*, 1994) which caused sluggish circulation (Kaiho, 1991), and thus low productivity of calcareous plankton, and (3) short distance from the edge of the shelf.

The foraminiferal morphogroup analysis shows that the sedimentation of these deposits during the Paleocene took place under high-energy conditions, and that the organic matter was supplied by dilute turbidity currents. In the lower Eocene deposits the foraminiferal morphogroups reflect a lower rate of sedimentation (4–5 m/My), with reduced influence of turbidity currents. The epifaunal morphogroup remains consistently dominant during the middle Eocene, suggesting a continued decrease of sedimentation rate.

Low-diversity assemblages of benthonic foraminifera, compared with the low-diversified assemblages of trace fossils in the red, well-oxygenated facies of other Carpathian regions can be interpreted as the result of oligotrophic conditions at the sea floor. However, the comparison of lower and middle Eocene agglutinated morphogroups shows a change in the trophic conditions, with higher food levels in the *Reticulophragmium amplexens* Zone (middle Eocene). It may be interpreted as a change from lowered productivity and widespread oxygenation of deep-waters during the Paleocene and early Eocene to more eutrophic conditions in the middle Eocene reflecting renewed higher productivity.

The abundance of radiolarians in the lower and middle Eocene, and their lack in the Paleocene deposits might suggest the change in the oceanic circulation, emphasized by relatively slow rate of sedimentation, below the CCD, and the mineralogy of fine-grained sediments which were conducive to preservation of radiolarian shells.

Acknowledgements

We would like to express our sincere appreciation to Prof. T. Wieser who introduced us to the geology of the area investigated and Drs M. A. Kaminski and E. Thomas (Wesleyan University)

for their constructive advice and critical reviews. Special thanks are also go to Prof. A. Manecki, Dr hab. J. Rajchel, Dr hab. M. Cieszkowski and Prof. A. Ślącza for the discussion and helpful suggestions. MSc M. Oszczytko and M. Kędzierski made the nanno-plankton analyses. Ms J. Faber most kindly made the scanning electron micrographs.

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- się w 2 profilach, w Dylągówce (Fig. 2). Osady te składają się z czerwonych, bezwapniowych łupków, przelawionych cienkimi ławicami łupków zielonych i bardzo cienkimi ławicami mułowców i piaszczowców (5% mięszości). Mięszczość osadów w profilach wynosi około 40–50 m. Eoceńska część pstrych łupków jest silnie wzbogacona w radiolarie (M. Bąk, 1995; Fig. 3).
- Celem badań było sprecyzowanie biostratygrafii tych osadów w oparciu o otwornice aglutynujące i radiolarie oraz interpretacja paleośrodowiska. Na przełomie paleocenu i eocenu zachodziły ważne zmiany w zespołach głębokowodnej mikrofauny otwornicowej zanotowane w osadach z Pacyfiku, Atlantyku i Tetydy, a wywołane zmianami klimatu, zmianami w globalnej tektonice i cyrkulacji oceanów (Thomas & Shackleton, 1996; Thomas, 1990, 1992; Kenett & Stott, 1992; Pak & Miller, 1992; Kaiho, 1994; Kaminski et al., 1996). Autorzy postawili pytanie: czy takie zmiany miały miejsce również w basenie karpaccim i jakie były ich przyczyny?
- Nannoplankton wapienny jest w osadach nieobecny (M. Oszczytko i M. Kędzierski; *informacja ustna*, 1995). Z tego powodu biostratygrafia osadów zasadza się na kalibracji zasięgów stratygraficznych otwornic aglutynujących do poziomów opartych na otwornicach planktonicznych i nannoplanktonie w jednostce dukielskiej (Olszewska & Smagowicz, 1977). Na tej podstawie dokonano kalibracji zasięgów stratygraficznie ważnych gatunków otwornic aglutynujących do poziomów planktonu i skali czasu wg Berggren et al. (1995).
- Lokalną zonację biostratygraficzną pstrych łupków oparto na propozycji Gerocha i Nowaka (1984), wprowadzając jej modyfikację (Fig. 4 & 5). Najstarsze badane osady (próbki DW-1/11, DW-1/10, DW-1/6) należą do poziomu *Rzehakina fissistomata* (paleocen). Obok taksonu indeksowego zawierają one pojedyncze formy z gatunku *Subbotina* cf. *triloculinoides* Plummer (Fig. 6). Zespoły te charakteryzuje obecność licznych otwornic rurkowatych z rodzaju *Rhabdammina*, *Hyperammina* i *Bathysiphon*, a także *Trochamminoides* spp. i *Recurvoides* spp. Ponadto występują tam *Glomospira* spp., *Ammodiscus* spp., *Kalamopsis grzybowskii* (Dylańska), *Haplophragmoides* cf. *kirki* Wickenden, *H. walteri* (Grzybowski), *Spiroplectammina subhaeringensis* (Grzybowski), *Trochammina* sp., *Karrerulina coniformis* (Grzybowski) oraz otwornice wapienne z rodzaju *Cibicoides* i *Gyroldinoides* (Fig. 7 & 8).
- Młodsze osady (próbki: DW-1/5, DW-1/3, DW-1/1) charakteryzują zespoły z licznymi osobnikami *Glomospira gordialis* (Jones et Parker), *Glomospira charoides* (Jones et Parker), *Glomospira serpens* (Grzybowski) i *Ammodiscus cretaceus* (Reuss). Ten zespół został skorelowany z dolną częścią dolnego eocenu (Fig. 5). Licznie występują tam otwornice z rodzaju *Trochamminoides* spp., *Recurvoides* spp. oraz formy rurkowate. W próbie pobranej z cienkiej ławicy mułowca (DW-1/5) znaleziono liczne igły gąbek oraz pojedyncze, źle zachowane otwornice planktoniczne z rodzaju *Subbotina* sp. Mikrofauna w tych osadach jest redeponowana.
- Osady młodsze (próbki: Dyl-8b, Dyl-8a, Dyl-6, Dyl-5b, Dyl-5a, Dyl-4) należą do poziomu *Saccamminoides carpathicus* (dolny eocen). Zespoły otwornicowe tego poziomu charakteryzuje liczna obecność form należących do *Glomospira charoides*, *G. gordialis*, *G. serpens* i *Ammodiscus cretaceus*. Ponadto występują tam otwornice z rodzaju *Trochamminoides* sp., *Paratrochamminoides olszewski*, *Recurvoides* spp., *Cribrostomoides* sp., *Trochammina* sp., *Karrerulina* sp. i *Spiroplectammina spectabilis*. Formy rurkowate są liczne tylko w niższej części tego poziomu.
- Najmłodsze pstre łupki w badanych profilach (próbki: Dyl-3, Dyl-2, Dyl-1) należą do poziomu *Reticulophragmium amplexans* (środkowy eocen). Zespoły otwornic są podobne jak w osadach dolnego eocenu.
- Radiolarie są bardzo liczne w osadach dolnego i środkowego

Streszczenie

ANALIZA BIOSTRATYGRAFICZNA I PALEOŚRODOWISKOWA PALEOGENSKICH PSTRYCH ŁUPKÓW W JEDNOSTCE SKOŁSKIEJ (KARPATY FLISZOWE), W OPARCIU O OTWORNICE BENTONICZNE I RADIOLARIE

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Pstre łupki są bardzo charakterystyczną facją w górnej kredzie i paleogenie Karpat fliszowych (Geroch, 1960; Książkiewicz, 1962, 1965; Bieda et al., 1963; Geroch & Gradziński, 1965; Koszarski, 1967; Geroch et al., 1967; Rajchel, 1990). Szczegółowy opis ich tekstury, struktur sedimentacyjnych oraz składu mineralnego przedstawili m.in. Narębski (1957), Rajchel (1990) oraz Leszczyński i Uchman (1991).

Przedmiotem badań autorów była formacja pstrych łupków (fm.) w jednostce skołskiej (Rajchel, 1990; Fig. 1), odsłaniająca

eocenu. Większość z nich należy do spumelarii (Fig. 9 & 10) i jest reprezentowana przez następujące gatunki: *Cenosphaera eocenica* Campbell et Clark, *Lithocyclus ocellus* Ehrenberg, *Phacodiscus rotula* Haeckel, *Spongatractus balbis* Sanfilippo et Riedel. Ponadto występują formy należące do rodzajów: *Acanthosphaera*, *Heliodiscus*, *Heliosoma* i *Spongodiscus*. Radiolarie należące do Nassellaria są mniej liczne ale bardziej zróżnicowane i należą do gatunku *Calocycloma ampulla* (Ehrenberg), *C. castum* (Haeckel), *Podocyrtis papalis* Ehrenberg, *Stylosphaera coronata coronata* Ehrenberg, *Theocotyle cryptocephala cryptocephala* (Ehrenberg) i *Theocotyle ficus* (Ehrenberg). Znaczenie stratygraficzne mają radiolarie z gatunku *C. casum*, *C. ampulla*, *S. balbis*, *T. ficus* i *T. cryptocephala cryptocephala* (M. Bałk, 1995). Porównując zasięgi stratygraficzne tych taksonów w różnych podziałach biostratygraficznych (Fig. 11; Foreman, 1973; Sanfilippo & Riedel, 1973; Sanfilippo *et al.*, 1985; Nishimura, 1987) określono, że próbki od D8a do D2 należą do poziomów *Buriella clinata*, *Phormocyrtis striata striata* i *Theocotyle cryptocephala cryptocephala sensu* Sanfilippo *et al.* (1985) – Fig. 12. Może to odpowiadać dolnemu eocenowi (górną część poziomu NP12 wg Martini & Woostey, 1971) i najniższej części środkowego eocenu (poziom NP14), korelując z chronostratyfografią wg Berggren *et al.* (1995).

W rekonstrukcjach paleośrodowiska wykorzystano analizy morfogrów otwornic aglutynujących. Opierają się one na zależnościach cech skorupki i strategii żywienia otwornic bentonicznych. Zmiany w udziale poszczególnych morfogrów mogą być podstawą do interpretacji zmian głębokości basenu, natlenienia wód i osadu, energii prądów i dostępności pożywienia (Jones & Charnock, 1985; Corliss, 1985; Kaiho, 1991; Murray, 1991; Nagy, 1992; Tyska, 1994; Nagy *et al.*, 1995; Kaminski *et al.*, 1995).

Paleoceńskie pstry łupki charakteryzuje obecność licznych zawieszonożerców (45%) i mobilnej epifauny (37%) – Fig. 13 i 14. Epifauna stanowi prawie 90% udziału w zespołach bentosu aglutynującego, co świadczy o tym, że sedymentacja osadów zachodziła w warunkach wysokiej energii środowiska, w czasie której pożywienie było dostarczane przez prądy zawieszinowe.

Zespoły bentosu we wczesnym eocenie były wzbogacone w mobilną epifaunę, zbierającą pożywienie z dna (58%). Udział innych morfogrów należących do epifauny był mniejszy o ponad 50% w stosunku do paleocenu. Te proporcje wskazują na niższe tempo sedymentacji, z mniejszą częstością prądów zawieszinowych.

Epifauna aglutynująca nadal dominowała w czasie środkowego eocenu, ale jej udział wyraźnie się zmniejszył (65%). Zawieszonożercy stanowią tylko 12% w całym zespole bentosu aglutynującego. Wzrósł natomiast udział płytkiej i głębokiej infauny, co wskazuje na dalsze obniżenie tempa sedymentacji.

Takie proporcje morfogrów (Fig. 13, 14) dowodzą skrajnych warunków oligotroficznych, jakie panowały na dnie basenu, co potwierdzono dodatkowo brakiem obecności makrobioturbacji osadów (Leszczyński & Uchman, 1993). Niemniej jednak, porównując zespoły morfogrów, można stwierdzić wyraźną zmianę w warunkach troficznych (wzrost pożywienia) w czasie poziomu *Reticulophragmium amplexans*. Kaminski *et al.* (1996) udokumentowali podobne zjawisko w osadach tego wieku, w północnym Maroku. Autorzy Ci zinterpretowali ten fakt jako wzrost produktywności i poprawę natlenienia głębokich wód w basenie.

Bezwapniałość pstrych łupków, brak wapiennego bentosu (z wyjątkiem form redeponowanych) oraz pojedyncze i źle zachowane otwornice planktoniczne wskazują na sedymentację tych

osadów poniżej CCD. Uwzględniając zmiany (podniesienie) CCD w oceanie światowym na granicy paleocenu/eocenu, związane z zmianami termiki wód oceanu, cyrkulacją i produktywnością w warstwie fotycznej (Van Andel, 1975; Shackleton, 1986; Kenett & Stott, 1991; Pak & Miller, 1992; Stott, 1992; Zachos *et al.*, 1993, 1994), oraz porównując zespoły mikrofauny z innymi obszarami w tym czasie (Charnock & Jones, 1990; Kaminski *et al.*, 1990; Thomas & Shackleton, 1996; Morlotti & Kuhnt, 1992) autorzy określili głębokość basenu na strefę dolnego batiálu. Podobnej głębokości (do 2 500 m) była centralna część basenu skolskiego w czasie sedymentacji warstw menilitowych, określona przez Jerzmańską i Kotlarczyka (1968, 1991) na podstawie ichtiofauny.

Obecność licznych zespołów radiolarii w pstrych łupkach może świadczyć o normalnym zasoleniu basenu. Przewaga wśród nich spumelarii (90–100%), żyjących obecnie w wodach szelfowych (Casey, 1993) oraz niski współczynnik zróżnicowania taksonomicznego wśród radiolarii sugeruje, że sedymentacja odbywała się niedaleko brzegu szelfu (w warunkach głębokowodnych). Przelawienia osadów turbidytowych z wapienną i krzemionkową mikro- i makrofauną pochodzącą z szelfu lub jego krawędzi (por. próbka DW-1/5 lub warstwa wapienia z Birczy; Kotlarczyk, 1961), a także obecność osadów kohezyjnych i olistostromy (por. ily babickie; Dzułyński *et al.*, 1979; Olszewska & Geroch, 1991) wskazują, że krawędź „szelfu skolskiego” była blisko i musiała ona być stosunkowo stroma. Stromość krawędzi w czasie eocenu i oligocenu potwierdzają również inni autorzy (Jucha, 1985; Kotlarczyk, 1991).

Bogate w radiolarie osady dolnego i środkowego eocenu znane są z wielu obszarów na Atlantyku (Dzinoridze *et al.*, 1978; Foreman, 1973; Nishimura, 1987), Pacyfiku (Foreman, 1975; Riedel & Sanfilippo, 1971, 1978), z Antarktyki, ocenu południowego, Arktyki, Kaliforni, wschodniej Azji (Clark & Campbell, 1942; Chen, 1975; Kiminami *et al.*, 1990; Lipman, 1950; Take-mura, 1990). Przeciwnie, w osadach paleocenu radiolarie są bardzo nieliczne (Moore, 1973; Sanfilippo *et al.*, 1985; Blueford, 1989). To może wskazywać, że ich rozprzestrzenienie było efektem zmiany cyrkulacji oceanicznej na granicy paleocenu i eocenu. Taka zmiana, w kierunku wzrostu intensywności cyrkulacji mogła zaistnieć również w basenie skolskim. Osady biogeniczne tego samego wieku, z dużym udziałem radiolarii były wcześniej opisane z innych rejonów jednostki skolskiej (Morgiel & Szymakowska, 1978; Rajchel, 1990). Występują one również w jednostce magurskiej (M. Cieszkowski, *informacja ustna*, 1995). Efekt wzbogacenia w radiolarie został prawdopodobnie podkreślony przez niskie tempo sedymentacji (4–5 m/mln lat dla badanych profili) odbywającej się poniżej CCD. Ponadto, dobremu zachowaniu skorupki radiolarii mogły sprzyjać drobnoziarnistość osadów i ich skład mineralny. Analiza składu mineralnego pstrych łupków wykazała, że ich głównym składnikiem jest klinoptylolit i montmoryllonit (Wieser, 1969, 1994). Radiolarie stanowiące 3–6% objętości skały są zbudowane z opalu-CT i wypełnione wewnątrz klinoptylolitem. Materiałem wyjściowym dla montmoryllonitu i klinoptylolitu były prawdopodobnie bogate w szklivo tufy wulkaniczne. Ślady wulkanizmu tego wieku w Karpatach w postaci horyzontów tufitów i bentonitów zostały znalezione w osadach jednostki magurskiej, śląskiej i podśląskiej (m.in. Sikora & Wieser, 1959; Sikora, 1962), a także w obrębie pstrych łupków jednostki skolskiej (Fig. 15; Kotlarczyk, 1966; Koszarski, L. & Koszarski, A., 1985; Rajchel, 1990, 1994).