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Oligocene turbidite fans of the Dukla Basin: New age data from the calcareous nannofossils and paleoenvironmental conditions (Cergowa beds, Polish–Slovakian borderland)

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Abstract: Calcareous nannofossils found in the Cergowa beds of the Dukla and Fore-Dukla tectonic units in the Outer Carpathians indicate a time of deposition in the range of the NP23–NP24 nannoplankton zones of the Lower Oligocene. Nannoplankton assemblages reflect the paleoecological changes at the Eocene–Oligocene transition from: (i) a greenhouse to an icehouse climate; (ii) brackish to normal salinity suggesting open sea conditions, which were controlled by the Paratethys Basin closure followed by opening and connection with the Tethyan Ocean. The absence of nannofossils of NP25 zone, but their presence in the tectonic windows between 40 and 80 km to the west, shows that deposition of the Cergowa beds in the western part of the basin lasted longer than in the east. Occurrences of nannofossils indicating zones NP16 and NP21, found in the uppermost mudstone-rich parts of studied sections, may prove the remobilization and redeposition of sediments of this stratigraphic age. Potentially, eroded material could be derived from some of the following lithostratigraphic units: NP16 — the Hieroglyphic beds, Przybyszów sandstones and Upper variegated shales; NP21 — the Globigerina marls, Mszanka sandstones and sub-Chert marls and shales and/or fine-grained equivalent of these units. Reworked specimens derived from the older Mesozoic strata occur occasionally in various samples.

Keywords: Flysch Carpathians, Cergowa beds, calcareous nannofossils, Lower Oligocene, Eocene–Oligocene icehouse.

Introduction

Observations on calcareous nannofossil assemblages from the Cergowa beds in the Dukla and the Fore-Dukla tectonic units (Fig. 1) have not been published until the most recent work of the present authors (Pszonka et al. 2014). Therefore the ages of these units were generally determined on the basis of foraminiferal assemblages that occur in the overlying rocks of the Menilite beds (Olszewska & Smagowicz 1977; Olszewska 1983, 1984). On the other hand, several publications on the calcareous nannofossils from the strata outcropping to the west of the Dukla Tectonic Unit, in tectonic windows within the Magura Tectonic Unit (Fig. 1), and considered as correlative to the Cergowa beds, were published in the last two decades (Oszczypko-Clowes & Oszczypko 2004, 2011; Oszczypko-Clowes & Ślączka 2006; Oszczypko-Clowes 2008).

The analysis of the calcareous nannofossils appears most informative for the purpose of biostratigraphical and paleogeographical determinations of the Cergowa beds. Therefore, the aim of this study is to: (i) present the data on the calcareous nannofossils providing more precise age determination of the Cergowa beds in the Dukla and Fore-Dukla tectonic units; (ii) discuss paleoecolgical conditions in the Dukla Basin; (iii) compare the time frame of deposition of the Cergowa beds on a regional scale.

Geological setting

The Cergowa beds were deposited in the basin, which has subsequently been partitioned during the Carpathian Orogenesis so that the Cergowa beds now occur in two tectonic units of the Flysch Carpathians: in the Dukla Tectonic Unit and in the southernmost part of the Silesian Tectonic Unit (also called the Fore-Dukla Tectonic Unit) adjacent to the north (Fig. 1). The Cergowa beds form a lenticular lithosome deposited by a variety of submarine mass gravity flows (Ślączka 1971; Pszonka 2015). The unit consists of two main lithofacies: (i) fine-grained sandstones in the axial part and (ii) fine-grained sandstones interbedded with shales, mudstones, marls and limestones in marginal zones (Ślączka 1971).

The Cergowa beds sandy lithosome, embedded within a generally fine-grained succession of the Menilite beds, records increased uplift and emergence of source areas related to the advancement of the Outer Carpathian orogenic wedge (Oszczypko 2004; Dirnerová et al. 2012). Paleocurrent patterns, facies trends and sediment provenance indicators suggest that a hypothetical Silesian Ridge located north-west acted as the main source supplying the terrigenous detritus transported by sediment gravity flows predominantly oriented towards the south-east (Fig. 1; Ślączka & Unrug 1976; Winkler

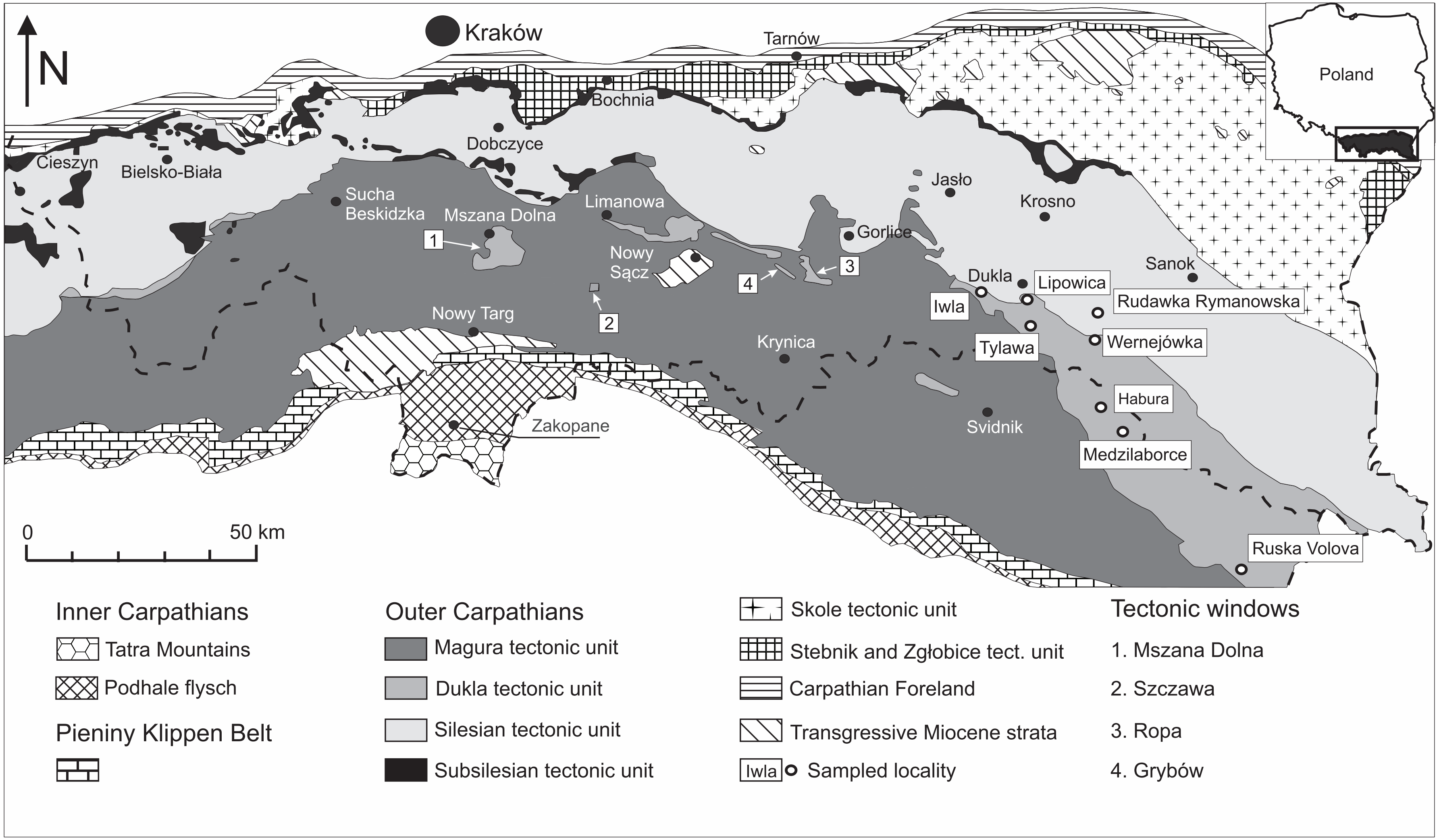

Fig. 1. Schematic tectonic map of the Outer Carpathians (simplified from Żytko et al. 1989). GPS coordinates of the sampled localities: Iwla — 49°33'06.0" N 21°37'17.4" E; Lipowica — 49°31'42.3" N 21°40'46.0" E; Tylawa — 49°27'53.2" N 21°43'52.3" E; Rudawka Rymanowska — 49°31'15.3" N 21°55'41.8" E; Wernejówka — 49°28'27.9" N 21°54'19.3" E; Medzilaborce — 49°16'20.8" N 21°54'23.6" E; Habura — 49°19'28.3" N 21°51'05.1" E; Ruská Volová — 48°57'15.3" N 22°22'54.8" E.

& Ślączka 1992; Dirnerová & Janočko 2014). Locally observed indicators show deviations of paleoflows to the south, suggesting the influence of local basin floor paleotopography (Dirnerová & Janočko 2014). Subordinate opposite paleoflow directions towards the north-west, observed in the lower part of the succession in the north-western part of the Dukla Tectonic Unit, were interpreted as reversals of turbidity currents caused by local paleotopography at an early stage of deposition (Wendorff & Pszonka 2015). Alternatively, supply from another source area was considered, namely from the hypothetical Fore-Magura Ridge at the southern margin of the Dukla Basin, now overthrust by the Magura Nappe (Cieszkowski et al. 2009). A longitudinal facies gradient within the Cergowa beds lithosome, generally parallel to the Dukla Basin axis and extending south-eastward from the proximal zone in the north-west part of the Dukla Tectonic Unit (Ślączka & Unrug 1976), appears to be reflected by regional trends in the recently identified sedimentary facies associations and inferred depositional mechanisms (Dirnerová et al. 2012; Dirnerová & Janočko 2014; Pszonka et al. 2014; Pszonka 2015); these are consolidated below.

Facies in the proximal sections of the succession, located in the western part of the Dukla Tectonic Unit at Iwla, Lipowica and Tylawa (Fig. 1), suggest sediment supply to the deep marine Cergowa beds depositional system by high-density turbidites and hyperpycnal flows as megaturbidite beds of the Central Carpathian Paleogene Basin (Starek et al. 2013) fed from a directly connected delta (Plink-Björklund & Steel 2004). Such a paleogeographic relationship is suggested by complexes of beds with sedimentary features implying deposition by aggrading sustained turbidity currents (Kneller & Branney 1995) and containing exceptionally high proportions of coalified plant detritus, including tree trunks present at Lipowica (Plink-Björklund & Steel 2004). Successions in the proximally located sections are characterized by very thick- and thick-bedded massive or laminated sandstones, absence of mudstone interbeds and are usually devoid of vertical sequences. Very low spread of paleocurrent directions measured in these sections implies deposition in confined troughs elongated from NW to SE.

Successions in the more distally located sections document mainly deposition from the short-lived, surge-type turbidity currents (Pszonka et al. 2014) and are characterized by vertical sequences and more “distally” developed facies associations represented by medium to thin-bedded sandstones displaying complete or incomplete sequences of Bouma divisions (Tabcde–Tcde). These are associated with thin to thick mudstone interbeds, deposited by turbidity currents with densities ranging from moderate to low. Facies related to low and very low energy turbidites and hemipelagic/pelagic deposition appear in considerable proportions in distal and marginal sections. These features suggest deposition within a classic turbidite fan system in an unconfined basin (Mutti et al. 2009) represented, for example, by the fan-shaped pattern of paleocurrents at Komańcza. A deep marine fan-shaped depositional body in the SE part of the basin is also suggested by coarsening upwards and fining upwards sedimentary cycles of outer-fan lobes documented by Dirnerová and Janočko (2014).

Therefore, comparisons of the facies associations and paleocurrent patterns throughout this part of the basin suggests a longitudinal transition between two domains. The proximal area in the NW part of the Dukla Tectonic Unit may be interpreted as partly confined, located on the slope, supplied directly from shelf-edge delta and passing to the south-east into a floor-fan distributary system deposited in the open part of the Dukla Basin.

Material and methods

Study of calcareous nannofossils from the Cergowa beds turbidite succession includes twenty-five samples from eight sections: Iwla, Lipowica, Tylawa, Rudawka Rymanowska, Wernejówka, Medzilaborce, Habura and Ruská Volová, representing their main lithofacies (Figs. 1, 2; Table 1). In the light of the submarine fan model (Walker 1978) the facies associations observed in the analysed sections of the Cergowa beds and described in the previous section can be interpreted as follows:

- NW sections, namely Iwla, Lipowica and Tylawa, contain successions deposited in the channelized upper part of mid-fan/suprafan because of very thick beds, with sedimentary features interpreted as products of sustained/hyperpycnal flows and rapidly depositing megaturbidites, very low spread of paleocurrent indicators reflecting transport towards the SE in elongated troughs or channels, and absence of vertical sequences, which suggests sedimentation by aggradation (Pszonka 2015);
- middle sections, namely Rudawka Rymanowska and Wernejówka represent mid-fan/suprafan lobes composed of sandstone–mudstone Bouma divisions deposited by turbidity currents of concentration normal to low and forming coarsening-upwards and fining-upwards vertical sequences (CU and FU) that reflect lateral shifts or changing intensity of the local sediment supply (Pszonka 2015);
- SE sections, namely Medzilaborce and Habura illustrate deposition in the lower/outer fan part of the Cergowa depository supplied by low and very low energy and highly diluted turbidity currents depositing thin and very thin sandstone beds (Tc), only locally interlayered with isolated thick massive sandstones interpreted as infills of small channels. These channels were occasionally incised into outer fan sediments and supplying new suprafan lobes (Dirnerová & Janočko 2014; Pszonka 2015) formed in the distal regions of the depositional system. Poor quality of the Ruská Volová outcrop does not provide ground sufficient for the interpretation of submarine fan facies association with confidence.

The samples were collected from calcareous mudstones, marls and limestones. Their positions were precisely determined within the sedimentary succession on the basis of detailed bed-by-bed logging and are shown on generalized

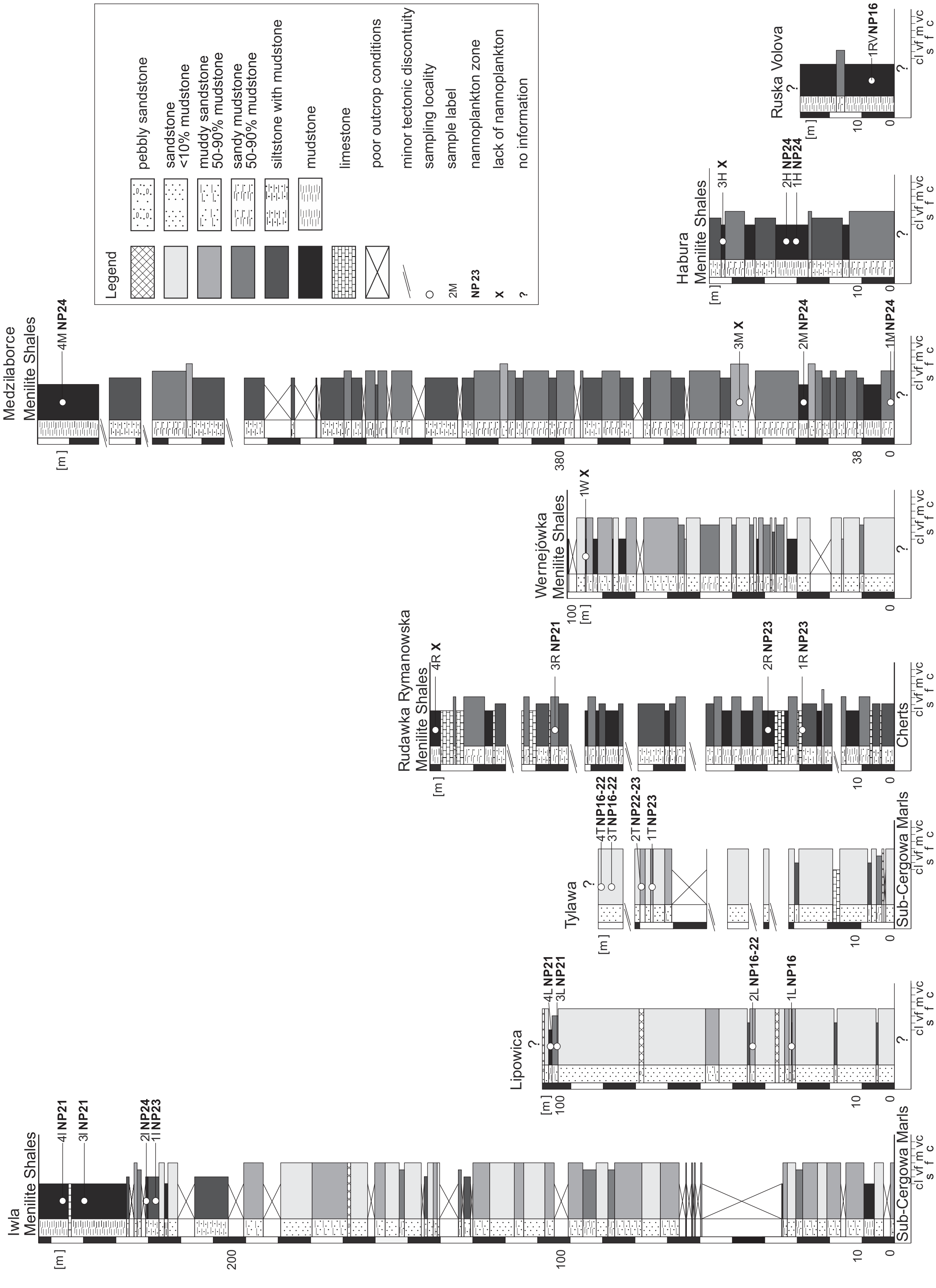

Fig. 2. Generalized sections of the Cergowa beds, documenting successions of lithofacies associations and indicating positions of samples collected for the calcareous nanoplankton analysis

sections (Fig. 2). The samples were prepared following the standard preparation technique according to Haq & Lohmann (1976) and studied with the polarizing microscope Carl Zeiss Axioskop 40 at magnification 1000×. The standard zonation by Martini (1971) and Berggren et al. (1995) was used for the stratigraphic interpretation. Paleoecology was developed following: Haq & Lohmann (1976), Wei & Wise (1990), Soták & Kováč (2002), Persico & Villa (2004), Villa et al. (2008), Oszczypko-Clowes (2012) and Ozdínová (2013).

Results

Iwla section

Samples in the Iwla section (Fig. 2) were taken from its stratigraphically youngest, mudstone–siltstone part. The lowermost sample 1I mostly contains *Reticulofenestra lockeri* and *Pontosphaera fibula.* It also comprises *Helicosphaera compacta, H. euphratis, Lanternithus minutus, Pontosphaera latelliptica, P. multipora* and *P. obliquipons*. In the next sample 2I, located 5 m above the sample 1I, the most numerously represented are: *Coccolithus eopelagicus* (Fig. 3.1, 3.2), *C. pelagicus*, *Cyclicargolithus abisectus*, *Reticulofenestra bisecta*, *R. lockeri, Lanternithus minutus*, *Pontosphaera fibula* and *Zygrhablithus bijugatus*. Furthermore, the assemblage contains high numbers of specimens of genera of *Chiasmolithus, Coccolithus*, *Cyclicargolithus* and *Reticulofenestra,* and less *Helicosphaera*, *Isthmolithus*, *Lanternithus*, *Pontosphaera* and *Zygrhablithus*, (particular species are listed in Table 2). The two uppermost samples 3I and 4I chiefly contain *Reticulofenestra lockeri*, and less common representatives of genera *Coccolithus* (Fig. 3.3), *Cribrocentrum*, *Cyclicargolithus* and *Reticulofenestra* (particular species are listed in Table 2). Rare occurrences of genus *Helicosphaera* were noted in samples 3I and 4I, and of *Isthmolithus* and *Pontosphaera* in sample 4I (particular species are listed in Table 2).

Lipowica section

Sample 1L from the lower part of Lipowica section (Fig. 2) contains *Cyclicargolithus floridanus* (Fig. 3.4), *Reticulofenestra bisecta* (Fig. 3.5), *R. umbilica* and less abundant *Coccolithus formosus*, *C. pelagicus*, *Helicosphaera compacta* and *Sphenolithus moriformis*. On the other hand, samples 3L and 4L from the uppermost part of this section primary imply *Reticulofenestra lockeri*. The presence of genera *Coccolithus*, *Cyclicargolithus* and *Reticulofenestra* (particular species are listed in Table 2) is also noted. *Isthmolithus recurvus* and *Lanternithus minutus* in sample 4L occur in low numbers. Sample 2L provided only poor nannofossils.

Tylawa section

Samples 1T and 2T from the Tylawa stratigraphic section (Fig. 2) were collected from the upper part of section. Sample T1 provided a poor nannofossil assemblage with low species diversity, containing mostly *Reticulofenestra bisecta* and *R. umbilica*, whilst *R. lockeri*, *R. ornata* and *Pontosphaera fibula* occur scarcely. A rich and well diversified assemblage was found in sample 2T, in which *Reticulofenestra ornata, R. reticulata* and *R. umbilica* dominate. Specimens of genera *Helicosphaera*, *Isthmolithus*, *Lanternithus* and *Pontosphaera* (particular species are listed in Table 2) in sample 2T occur in low numbers. Samples 3T and 4T provided only rare nannofossils.

Table 1: Localities of sampled sections, number of samples per locality and sample labels. Interpreted samples are shown in bold font; seven samples that have been excluded are shown in italics.

L.p.	Locality of sections	Number of samples to be analysed (labeled)
1.	Iwla/ Poland	4 (**1I**, **2I**, **3I**, **4I**)
2.	Lipowica/ Poland	4 (**1L**, *2L*, **3L**, **4L**)
3.	Tylawa/ Poland	4 (**1T**, **2T**, *3T*, *4T*)
4.	Rudawka Rymanowska/ Poland	4 (**1R**, **2R**, **3R**, *4R*)
5.	Wernejówka/ Poland	1 (*1W*)
6.	Medzilaborce/ Slovakia	4 (**1M**, **2M**, *3M*, **4M**)
7.	Habura/ Slovakia	3 (**1H**, **2H**, *3H*)
8.	Ruská Volová/ Slovakia	1 (**1RV**)
	Total:	**25**

Rudawka Rymanowska section

Samples 1R and 2R, which represent the lowermost part of the Rudawka Rymanowska section (Fig. 2) primarily provided *Reticulofenestra bisecta*, *R. lockeri* (Fig. 3.6), *Reticulofenestra ornata* (Fig. 3.7, 3.8) and *Pontosphaera fibula* (Fig. 3.9, 3.10). The next sample 3R from the upper part of the section (Fig. 2) mostly contains *Reticulofenestra lockeri* (Fig. 3.11) and genera *Coccolithus*, *Cyclicargolithus* and *Reticulofenestra* (particular species are listed in Table 2). The assemblage is complemented by significant species of *Helicosphaera compacta* and *Lanternithus minutus*. Sample 4R did not provide any nannofossils.

Wernejówka section

The only sample 1W from the Wernejówka section (Fig. 2) did not provide any nannofossils.

Habura section

Samples 1H and 2H from the Habura section (Fig. 2) contain rich but poorly diversified nannofossil assemblages with *Coccolithus pelagicus* and *Reticulofenestra bisecta*, whereas *C. eopelagicus*, *Cyclicargolithus abisectus* (Fig. 3.12), *C. floridanus, Lanternithus minutus*, *R. lockeri* and *Zygrhablithus bijugatus* occur in lower numbers. Genera *Helicosphaera, Isthmolithus, Pontosphaera* and *Sphenolithus* (particular species are listed in Table 2) are less abundant. Sample 3H did not provided any nannofossils.

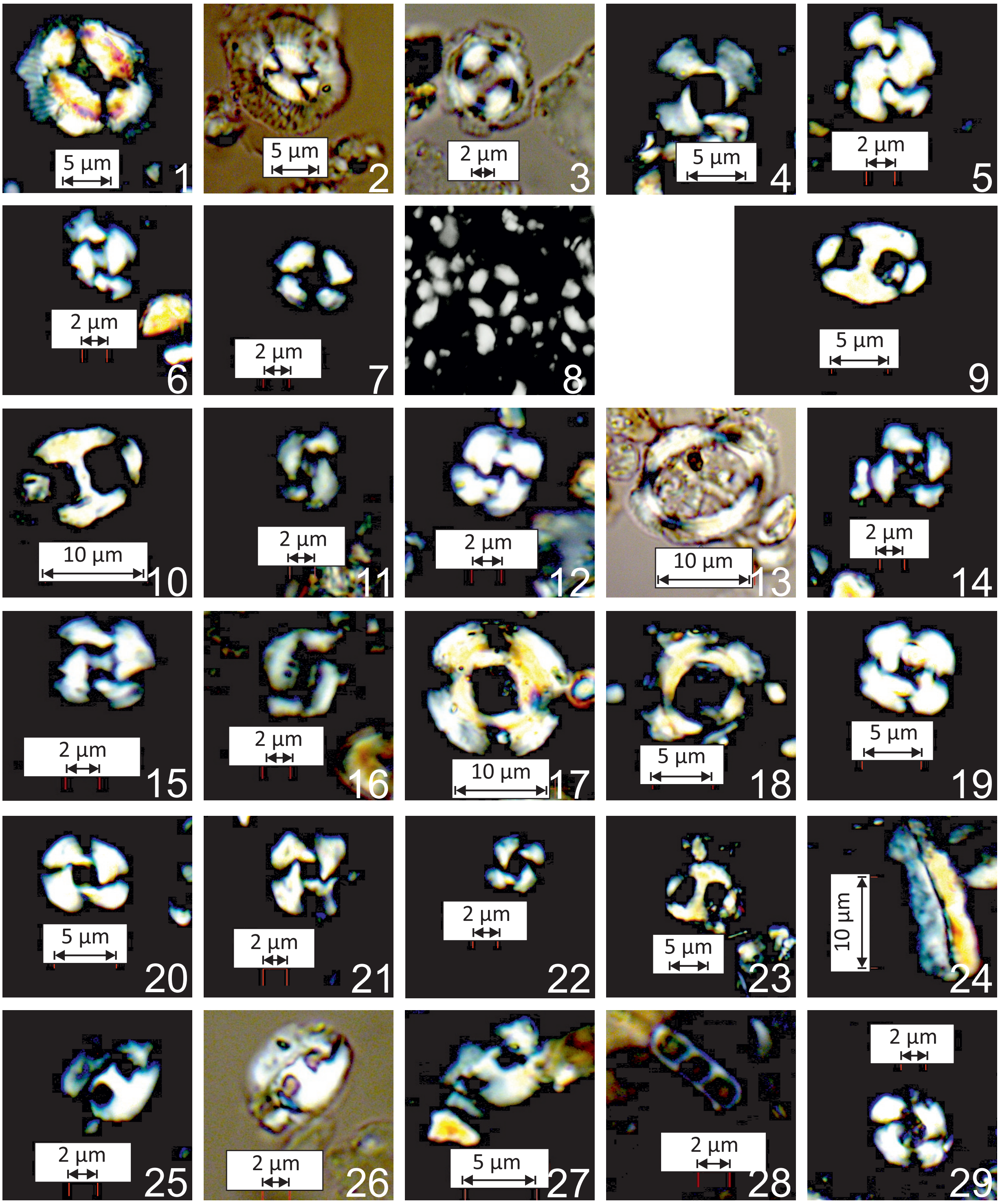

Fig. 3. Light microscope images of calcareous nannofossils from the Cergowa beds in the Dukla and Fore-Dukla tectonic units (CN — crossed nicols, NL — normal light): **1.** *Coccolithus eopelagicus,* CN, sample 2I; **2.** *Coccolithus eopelagicus,* NL, sample 2I; **3.** *Coccolithus pelagicus*, NL, sample 3I; **4.** *Cyclicargolithus floridanus,* CN, sample 1L; **5.** *Reticulofenestra bisecta,* CN, sample 1L; **6.** *Reticulofenestra lockeri*, CN, sample 1R; **7.** *Reticulofenestra ornata,* CN, sample 2R; **8.** *Reticulofenestra ornata,* CN, sample 2R; **9.** *Pontosphaera fibula,* CN, sample 2R; **10.** *Pontosphaera fibula*, CN, sample 2R.; **11.** *Reticulofenestra lockeri,* CN, sample 3R; **12.** *Cyclicargolithus abisectus,* CN, sample 1H; **13.** *Chiasmolithus oamaruensis,* NL, sample 1M; **14.** *Reticulofenestra reticulata,* CN, sample 1M; **15.** *Reticulofenestra lockeri,* CN, sample 4M; **16.** *Reticulofenestra lockeri,* CN, sample 1M; **17.** *Reticulofenestra umbilica,* CN, sample 4M; **18.** *Reticulofenestra umbilica,* CN, sample 1M; **19.** *Cyclicargolithus abisectus,* CN, sample 1M; **20.** *Cyclicargolithus floridanus*, CN, sample 4M; **21.** *Cyclicargolithus floridanus,* CN, sample 1M; **22.** *Cyclicargolithus floridanus,* CN, sample 1M; **23.** *Pontosphaera fibula,* CN, sample 1M; **24.** *Zygrhablithus bijugatus,* CN, sample 4M; **25.** *Helicosphaera recta,* CN, sample 4M; **26.** *Helicosphaera recta,* NL, sample 4M; **27.** *Helicosphaera recta,* CN, sample 4M; **28.** *Isthmolithus recurvus*, CN, sample 1M; **29.** *Reticulofenestra ornata,* CN, sample 1M.

Medzilaborce section

Samples 1M, 2M and 4M contain *Chiasmolithus grandis, Ch. oamaruensis* (Fig. 3.13)*, Coccolithus eopelagicus*, *C. formosus, C. pelagicus*, *Reticulofenestra reticulata* (Fig. 3.14)*, R. bisecta, R. lockeri* (Fig. 3.15, 3.16), *R. umbilica* (Fig. 3.17, 3.18), *Cyclicargolithus abisectus* (Fig. 3.19), *C. floridanus* (Fig. 3.20, 3.21, 3.22), *Pontosphaera fibula* (Fig. 3.23) and *Zygrhablithus bijugatus* (Fig. 3.24). Samples 1M and 4M additionally contain *Helicosphaera recta* (Fig. 3.25, 3.26, 3.27), *Isthmolithus recurvus* (Fig. 3.28) and *Reticulofenestra ornata* (Fig. 3.29). *Lanternithus minutus* was found in samples 1M and 2M and *Pontosphaera latelliptica* and *P. multipora* were present in 4M. Sample 3M was barren of nannofossils.

Ruská Volová section

The only sample 1RV from the Ruská Volová locality (Fig. 2) provided a low in numbers and poorly diversified nannofossil assemblage of *Reticulofenestra bisecta* and *R. umbilica*, and with smaller numbers of *Coccolithus eopelagicus*, *C. formosus, C. pelagicus*, *Cyclicargolithus floridanus*, and *Helicosphaera compacta*.

Nannoplankton biostratigraphic interpretations

Nannofossils from the Cergowa beds belong to the following groups:

- species characteristic of the Eocene standard zone NP16 (Late Lutetian/Early Bartonian; Table 3);
- species indicating the Oligocene standard zones: NP21 (Late Priabonian/Early Rupelian), NP23 (Rupelian) and NP24 (Late Rupelian/Early Chattian, Table 3);
- reworked nannofossils from the older Mesozoic strata. Poor preservation does not allow their more precise identification;
- corroded and recrystallized unidentifiable nannofossils.

The Middle Eocene, zone NP16 is the oldest stratigraphic age found in this study. It was determined in the lower part of the Lipowica section in the sample 1L and in the Ruská Volová section in the sample 1VR (Fig. 2). Zone NP16 was determined on the basis of species characteristic of an open water environment: *Helicosphaera compacta, Reticulofenestra bisecta* and *Cyclicargolithus floridanus,* all of which indicate moderate water temperature (Perch-Nielsen 1985).

Zone NP21 was identified according to the presence of *Reticulofenestra lockeri* in the upper part of three sections: Iwla in samples 3I and 4I, Lipowica in samples 3L and 4L and Rudawka Rymanowska in the sample 3R (Fig. 2). Assemblages of NP21 zone were found in Iwla and Rudawka Rymanowska localities above the strata that provide stratigraphically younger nannofossils from zones NP23 and NP24 (Fig. 2). On the contrary, in the Lipowica section, younger fauna (NP23 and NP24) has not been identified below zone NP21 (Fig. 2). The presence of genera *Coccolithus*, *Cyclicargolithus* and *Reticulofenestra* in these samples suggests an open-marine environment (Perch-Nielsen 1985), whereas the occurrence and abundance of species *Helicosphaera compacta* indicates a warm marine environment and also shallow-marine (Perch-Nielsen 1985; Nagymarosy & Voronina 1992). Open-marine genera are mixed with by far less abundant shallow-marine genera: *Helicosphaera*, *Isthmolithus*, *Lanternithus* and *Pontosphaera* (Perch-Nielsen 1985).

Zone NP23 was recorded in three sections: Iwla in the sample 1I, Tylawa in samples 1T and 2T and Rudawka Rymanowska in samples 1R and 2R (Fig. 2), based on species: *Reticulofenestra lockeri*, *R. ornata* and *Pontosphaera fibula*. The material representing zone NP23 occurs in the uppermost part of Tylawa and Iwla sections, and in the lower part of the Rudawka Rymanowska succession (Fig. 2). By comparison with all other zones, zone NP23 occupies the stratigraphically lowermost position in these three sections (Fig. 2). In both samples from Rudawka Rymanowska, where NP23 zone was recognized (samples 1R and 2R), the nannofossils reflect brackish water conditions on the basis of: *Pontosphaera fibula* and *Reticulofenestra ornata* (Nagymarosy & Voronina 1992). Samples 2T from Tylawa and 1I from Iwla contain genera characteristic for coastal waters: *Helicosphaera*, *Isthmolithus*, *Lanternithus*, and *Pontosphaera* (Perch-Nielsen 1985). Nannofossils from the sample 1T from Tylawa (Table 2) represent open shelf environment.

The youngest sediments of the Cergowa beds in the studied region were assigned to zone NP24 on the basis of *Coccolithus eopelagicus*, *C. pelagicus*, *Cyclicargolithus abisectus, Helicosphaera recta*, *Lanternithus minutus*, *Reticulofenestra bisecta, R. lockeri*, *Pontosphaera fibula* and *Zygrhablithus bijugatus*. Zone NP24 was interpreted in Iwla (2I), Medzilaborce (1M, 2M and 4M) and Habura (2 H) (Fig. 2). In the Medzilaborce and Habura sections nannofossil assemblages indicate zone NP24 (Fig. 2). In the Iwla section, nannofossils of zone NP24 were found about 5 m above the sample representing zone NP23 (Fig. 2). Zone NP24 in all analysed samples is characterized by numerous genera typical for open waters: *Coccolithus*, *Cyclicargolithus*, *Reticulofenestra* and *Chiasmolithus* (Perch-Nielsen 1985). In addition, the presence of cryophilic species: *Isthmolithus recurvus*, *Reticulofenestra lockeri* and *R. ornata* documents conditions of the cold Oligocene climate (Wei & Weise 1990; Aubry 1992; Oszczypko-Clowes 2001; Prothero 2003; Katz et al. 2008). Simultaneously, nannofossils indicating near-shore and coastal waters were present in all the above-mentioned samples. They include genera: *Helicosphaera*, *Isthmolithus*, *Lanternithus*, *Pontosphaera* and *Zygrhablithus* (Perch-Nielsen 1985).

In the lithostratigraphically continuous succession of the Cergowa beds at Iwla and Rudawka Rymanowska (Fig. 2) the samples with assemblages representing the nannofossils zone NP21 occur above younger assemblages corresponding to zone NP23, and therefore must be redeposited. Based on the progressively younging succession of sediments representing zone NP16 followed by zone NP21 in apparently continuous lithostratigraphic sequence at Lipowica (Fig. 2),

Table 2: Identified calcareous nannofossils species from the Cergowa beds with their assignment to the locality of section and the sample number. Abbreviations: X — autochthonous species, R — redeposited species.

Locality	**Ruská Volová**	**Medzilaborce**			**Habura**		**Rudawka Rymanowska**			**Tylawa**		**Iwla**				**Lipowica**		
Calcareous nannoplankton zones (Martini 1971; Berggren et al. 1995)	NP16	NP24	NP24	NP24	NP24	NP24	NP23	NP23	NP21	NP23	NP23	NP23	NP24	NP21	NP21	NP16	NP21	NP21
Sample number	1RV	1M	2M	4M	1H	2H	1R	2R	3R	1T	2T	1I	2I	3I	4I	1L	3L	4L
Arkhangelskiella cymbiformis	R	R	R	R							R	R	R	R			R	R
Arkhangelskiella maastrichtiana											R	R	R					
Braarudosphaera bigelowii		R		R	R		R	R			R							
Broinsonia parca constricta			R	R								R						
Broinsonia parca parca												R	R	R				
Calculites obscurus		R	R	R							R	R	R	R				R
Ceratolithina hamata falcata	R		R	R									R				R	
Chiasmolithus bidens			X											X			X	
Chiasmolithus expansus													X					
Chiasmolithus grandis	X		X	X							X	X	X	X			X	
Chiasmolithus oamaruensis		X									X		X				X	
Chiasmolithus solitus													X					
Coccolithus eopelagicus	X	X	X	X	X	X	X	X	X		X	X	X	X	X		X	
Coccolithus formosus	X	X	X	X		X			X		X	X	X	X	X	X	X	X
Coccolithus pelagicus	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X
Coronocyclus nitescens	X	X	X	X							X		X					
Cribrosphaerella ehrenbergii		R	R	R							R	R	R	R				
Cruciplacolithus tenuis			X								X						X	
Cyclicargolithus abisectus		X	X	X	X	X							X					
Cyclicargolithus floridanus	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X
Discoaster barbadiensis	X	X	X								X	X	X	X				
Discoaster deflandrei	X										X		X					
Discoaster distinctus																		X
Discoaster lodoensis		X	X								X	X	X					X
Discoaster multiradiatus		X	X	X							X		X	X		X		
Discoaster saipanensis	X	X	X										X					
Discoaster sublodoensis													X					
Discoaster tanii nodifer		X		X									X					
Eiffellithus eximius		R	R	R							R	R					R	
Eiffellithus gorkae											R							
Ellipsolithus macellus													X					
Ericsonia fenestrata			X		X	X					X							
Helicosphaera bramlettei				X														
Helicosphaera compacta	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X	X

Table 2 (continued): Identified calcareous nannofossils species from the Cergowa beds with their assignment to the locality of section and the sample number. Abbreviations: X — autochthonous species, R — redeposited species.

Locality	Ruská Volová	Medzilaborce			Habura		Rudawka Rymanowska			Tylawa		Iwla				Lipowica		
Calcareous nannoplankton zones (Martini 1971; Berggren et al. 1995)	NP16	NP24	NP24	NP24	NP24	NP24	NP23	NP23	NP21	NP23	NP23	NP23	NP24	NP21	NP21	NP16	NP21	NP21
Sample number	1RV	1M	2M	4M	1H	2H	1R	2R	3R	1T	2T	1I	2I	3I	4I	1L	3L	4L
Helicosphaera euphratis		X	X	X		X					X	X	X					
Helicosphaera lophota													X					
Helicosphaera recta		X		X														
Helicosphaera seminulum		X																
Isthmolithus recurvus		X		X	X	X					X		X	X				X
Lanternithus minutus		X	X		X	X			X		X	X	X					X
Lithraphidites praequadratus	R		R															
Lucianorhabdus cayeuxii			R	R														
Markalius inversus					R													
Micrantholithus hoschulzii			R	R		R					R	R	R			R		
Microrhabdulus decoratus		R	R	R								R	R	R				
Microrhabdulus undosus				R														
Micula murus		R	R			R							R			R		
Micula staurophora	R	R		R		R			R	R	R	R	R	R	R	R	R	R
Nannoconus steinmannii			R	R									R				R	
Nannotetrina fulgens												X	X					
Neococcolithes dubius		X									X							
Neococcolithes minutus			X	X														
Pontosphaera latelliptica	X			X	X						X	X	X					X
Pontosphaera fibula		X	X	X			X	X		X		X	X					
Pontosphaera multipora	X			X	X	X						X	X				X	X
Pontosphaera obliquipons				X								X	X					
Pontosphaera pulcheroides		X		X		X							X	X				
Prediscosphaera cretacea	R	R	R	R							R	R	R	R			R	R
Retecapsa surirella				R									R					
Reticulofenestra bisecta	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Reticulofenestra coenura								X	X		X	X	X					X
Reticulofenestra dictyoda											X							
Reticulofenestra lockeri		X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X
Reticulofenestra oamaruensis				X								X	X					
Reticulofenestra. ornata		X		X			X	X		X	X							
Reticulofenestra reticulata		X	X	X	X	X			X	X	X	X	X	X	X		X	
Reticulofenestra umbilica	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Sphenolithus anarrhopus	X										X							

Table 2 (continued): Identified calcareous nannofossils species from the Cergowa beds with their assignment to the locality of section and the sample number. Abbreviations: X — autochthonous species, R — redeposited species.

Locality	**Ruská Volová**	**Medzilaborce**			**Habura**		**Rudawka Rymanowska**			**Tylawa**		**Iwla**				**Lipowica**		
Calcareous nannoplankton zones (Martini 1971; Berggren et al. 1995)	NP16	NP24	NP24	NP24	NP24	NP24	NP23	NP23	NP21	NP23	NP23	NP23	NP24	NP21	NP21	NP16	NP21	NP21
Sample number	1RV	1M	2M	4M	1H	2H	1R	2R	3R	1T	2T	1I	2I	3I	4I	1L	3L	4L
Sphenolithus furcatolithoides				X							X							
Sphenolithus moriformis		X	X	X	X	X			X	X	X	X	X	X	X	X	X	X
Sphenolithus obtusus		X	X									X						
Sphenolithus pseudoradians												X	X					
Sphenolithus radians	X	X	X	X								X	X	X	X		X	
Sphenolithus spiniger			X	X	X													
Toweius crassus												X	X					
Toweius eminens												X						
Tranolithus orionatus													R					
Tribrachitaus orthostylus													X					
Uniplanarius sissinghii	R												R	R				
Watznaueria barnesae	R	R	R	R	R		R	R	R	R	R	R	R	R	R	R	R	R
Watznaueria biporta							R											
Watznaueria britannica		R																
Watznaueria fossacincta																		
Watznaueria manivitae		R	R	R				R			R	R				R		
Watznaueria ovata				R									R				R	
Zeugrhabdotus embergeri		R	R	R							R				R			R
Zygrhablithus bijugatus		X	X	X	X	X			X		X		X	X	X		X	X

the nannofossils species that define these two zones must be considered as reworked ones because they have been documented in the literature as autochthonous in completely different lithostratigraphic divisions within the Dukla Unit and the southern part of the Silesian (Fore-Dukla) Unit. To be specific, the nannofossils defining zone NP16 are characteristic for the uppermost part of the Hieroglyphic beds, the Przybyszów sandstones and the Upper variegated shales (Oszczypko 2004), whereas zone NP21 is represented by the Globigerina marls, Mszanka sandstones and sub-Chert marls and shales (Ślączka 1971; Oszczypko 2004; Kotlarczyk et al. 2006). Furthermore, the stratigraphically continuous succession in Lipowica, documented at Cergowa Góra by Ślączka (1971), consists of the sub-Cergowa marls dated to zone NP23 (Kotlarczyk et al. 2006), which are followed by the Cergowa beds and the overlying part of the Menilite beds.

The nannoplankton zone NP24 is recorded in whole sections in Medzilaborce and Habura, and in the uppermost part of the Iwla suite. In Iwla nannofossils indicating zone NP23 also occur in the strata below zone NP24 (Fig. 2). Going further, zone NP23 is present in Tylawa and Rudawka Rymanowska (Fig. 2). Considering the above arguments, we have concluded that the Cergowa beds in the discussed sections represent a stratigraphic succession of two nannoplankton zones: NP23 and NP24.

Nannofossil paleoecology

Autochthonous calcareous nannofossils of the Cergowa beds from the Dukla and southern Silesian (Fore-Dukla) tectonic units identify the Lower Oligocene zones NP23 and NP24. In the Tethys area, this was a time of significant climatic, paleogeographical and paleoecological changes. These were caused by the global climate cooling and eustatic sea level fall (Haq et al. 1987, 1988), forced by the expansion of the Antarctic ice cap. Kominz & Pekar (2001) estimate that the eustatic sea level in the earliest Oligocene was lowered by

~55 m, while Katz et al. (2008) report the amount of ~67 m. This resulted in isolation of the Paratethys Basin in the northern part of the Tethyan Ocean (Piller et al. 2007) and impacted on the Carpathian Basin, which was the central part of Paratethys. Climatic cooling, sea-level fall and the isolation of Paratethys from the Carpathian basins during the Early Oligocene have been documented in several publications, including Soták (2010).

Important climatic changes resulted in disappearance of many genera, such as *Discoaster, Helicosphaera,* and *Sphenolithus* (Melinte 2005), which is noticeable in the analysed material. Distinct impoverishment of calcareous nannofossils in zones NP23–24 in the Carpathian successions was earlier observed by Oszczypko-Clowes (2001) and others. The decline and reduced diversity of nannofossil species defining zones NP23 and NP24 in the Cergowa beds can be related to the Lower Oligocene icehouse (Haq et al. 1987, 1988; Prothero 2003; Katz et al. 2008).

The presence of species in the samples 1I, 1T, 2T, 1R and 2R that are characteristic for brackish sea water environments during the NP23 zone, namely *Pontosphaera fibula*, *Braarudosphaera bigelowii* and *Reticulofenestra ornata* indicates a decrease of salinity as a consequence of increased intensity of freshwater supply (Nagymarosy & Voronina 1992; Melinte 2005). This may suggest that, due to the global sea level fall, the Dukla Basin became isolated from the Magura Basin to the south and from the Silesian Basin to the north at that stage of the Carpathian basins' development. This inference corresponds to an earlier opinion, based upon the distribution of the paleocurrent directions in the sandstone facies (Ślączka 1959), that the Carpathian basins became isolated from the Tethys and from each other at the turn of Eocene and Oligocene.

On the other hand, calcareous nannofossils belonging to zone NP24 prove the open sea conditions supported by simultaneous disappearance of brackish species and further cooling of climate, documented by the occurrence of cryophilic species such as *Isthmolithus recurvus*, *Reticulofenestra lockeri* and *R. ornata*. Thus, the autochthonous nannofossils from the Cergowa beds in the Dukla Basin document considerable paleogeographical changes in the Tethyan Ocean at the end of zone NP23. In particular, the previously isolated Paratethys Basin became connected with Tethys, which resulted in the open sea environment that was continuing through the Lower Oligocene icehouse (Melinte 2005).

The Eocene (NP16), Eocene/Oligocene (NP21) and Mesozoic species of calcareous nannofossils recognized in the Cergowa beds are redeposited, as indicated by their relative position above the autochthonous fossils in the analysed profiles (Fig. 2). The species representing zone NP16 document moderate temperature of sea water in the Late Lutetian and Early Bartonian, while species representing zone NP21 show higher temperature at the turn of the Late Priabonian and Early Rupelian in the time of Eocene-Oligocene transition from the high-diversity greenhouse to the glacial icehouse conditions (Prothero 2003).

Table 3: Correlation of international (Mediterranean) and regional (Central Paratethys) stages with standard nannoplankton NP zones (Martini 1971).

EPOCH		STANDARD MEDITERRANEAN STAGES	CENTRAL PARATETHYS STAGES	ZONE (Martini 1971)
OLIGOCENE	LATE	CHATTIAN	EGERIAN	NP25
OLIGOCENE	LATE	CHATTIAN	KISCELLIAN	NP24
OLIGOCENE	EARLY	RUPELIAN	KISCELLIAN	NP23
OLIGOCENE	EARLY	RUPELIAN	KISCELLIAN	NP22
OLIGOCENE / EOCENE	EARLY / LATE	RUPELIAN / PRIABONIAN	KISCELLIAN / PRIABONIAN	NP21
EOCENE	LATE	PRIABONIAN	PRIABONIAN	NP19-20
EOCENE	LATE / MIDDLE	PRIABONIAN / BARTONIAN	PRIABONIAN / BARTONIAN	NP18
EOCENE	MIDDLE	BARTONIAN	BARTONIAN	NP17
EOCENE	MIDDLE	BARTONIAN / LUTETIAN	BARTONIAN / LUTETIAN	NP16

Discussion

Climatically controlled eustatic global sea-level fall resulted in separation of the Carpathian basins from Paratethys in the Early Oligocene (Haq et al. 1987, 1988; Kominz & Pekar 2001; Piller et al. 2007; Katz et al. 2008). The direct effect of that is recorded in the NP23 zone by the appearance of brackish water nannofossils that are absent in the NP21 zone containing open marine assemblage (however recycled). In the analysed samples, transformation from greenhouse to icehouse during the Oligocene is reflected by a significant transition from the nannofossil assemblage typical for a warm climate in NP21 to the fossils characteristic for cold conditions during NP24. This change may also be reflected by the occurrences of brackish nannofauna, which is present in the samples assigned to NP23, but absent from the overlying strata belonging to NP24. In this respect, it is suggested that the evolution of climate from warm to cold resulted in reduced precipitation and consequently fresh water runoff into the basin, which in turn reduced the volume and extent of the brackish water environment during the time represented by the nannofossil zone NP24.

Regionally autochthonous calcareous nannoplankton zones NP23 (Rupelian) and NP24 (Late Rupelian/Early Chattian) recognized here in the main area of the Cergowa beds occurrences, namely the Dukla and southern Silesian tectonic units, correlate with nannoplankton zones recognized in the western region of occurrences of this lithostratigraphic unit (Fig. 1). The latter successions were assigned to the Fore-Magura group of units (Oszczypko-Clowes & Oszczypko 2004, 2011; Oszczypko-Clowes & Ślączka 2006; Oszczypko-Clowes 2008) outcropping in the tectonic windows (Fig. 1) listed below and dated as follows:

- the Mszana Tectonic Window — zones NP23–25,
- the Szczawa Tectonic Window — zone NP24,
- the Grybów Tectonic Window — zones NP24–25 and
- the Ropa Tectonic Window — zone NP25.

The calcareous nannoplankton zone NP25 has not been identified in the analysed samples of the Cergowa beds. However,the fact that it was recorded by the previous authors in the lithostratigraphically equivalent strata outcropping in the above-mentioned tectonic windows to the west of the Dukla Tectonic Unit suggests that deposition of the Cergowa beds in the western part of the basin lasted longer than in its eastern part. Such stratigraphic relations, coupled with regional direction of sediment supply towards the SE, indicates that (i) the Cergowa beds become younger towards the SE, with facies progradation from the onset of deposition during NP23 in the NW and middle sections to NP24 in the SE sections, and (ii) the final stage of deposition of the Cergowa beds was characterized by retrogradation from NP24 in the SE part of the Dukla Basin to NP25 in what is now the Mszana area in the NW.

Conclusions

- The assemblages of autochthonous calcareous nannofossils recognized in the Lower Oligocene-age Cergowa beds of the Dukla Tectonic Unit indicate zones NP23 (Rupelian) for the suprafan of the Cergowa depository represented by NW and middle sections and NP24 (Late Rupelian/Early Chattian) for the outer fan parts in SE sections.
- Nannoplankton zones younger than NP23 and older than NP24 were not found in the Cergowa beds of this part of the Flysch Carpathians.
- The documented nannofossil species reflect the Lower Oligocene climate, paleogeographical and paleoecological changes. They document the Eocene-Oligocene transition from greenhouse to icehouse, closure and subsequent opening of the Parathetys Basin and its partial connection to the Mediterranean and the related salinity fluctuations.
- A relatively high number of reworked specimens derived from strata containing nannofossil assemblages older than the NP23 zone and redeposited into the uppermost, mudstone-rich parts of the analysed sections, may be related to remobilization and redeposition of the older, mostly fine-grained deposits affected by the orogenic tectonic movements at the margin of the basin: (i) the uppermost part of the Hieroglyphic beds, the Przybyszów sandstones and the Upper variegated shales representing zone NP16, and (ii) the Globigerina marls, Mszanka sandstones and sub-Chert marls and shales associated with zone NP21.
- Absence of nannofossils indicative of zone NP23 in the sections Habura and Medzilaborce suggests migration of the Cergowa beds depositional area to SE sections.
- Absence of calcareous nannofossils indicating the NP25 zone in the studied area in contrast to their presence in the tectonic windows further to the west reflect a longer deposition time of the Cergowa beds in the western part of the Dukla Tectonic Basin.

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Appendix

Braarudosphaera bigelowii (Gran & Braarud, 1935) Deflandre, 1947
Chiasmolithus grandis (Bramlette & Riedel, 1954) Radomski, 1968
Chiasmolithus oamaruensis (Deflandre & Fert, 1954) Hay, Mohler & Wade, 1966
Coccolithus eopelagicus (Bramlette & Riedel, 1954) Bramlette & Sullivan, 1961
Coccolithus formosus (Kamptner, 1963) Wise, 1973
Coccolithus pelagicus (Wallich, 1877) Schiller, 1930
Cyclicargolithus abisectus (Müller, 1970) Wise, 1973
Cyclicargolithus floridanus (Roth & Hay, in Hay et al., 1967) Bukry, 1971
Helicosphaera compacta Bramlette & Wilcoxon, 1967
Helicosphaera euphratis Haq, 1966
*Helicosphaera recta (*Haq, 1966) Jafar & Martini, 1975
Isthmolithus recurvus Deflandre & Fert, 1954
Lanternithus minutus Stradner, 1962
Pontosphaera fibula Gheta, 1976
Pontosphaera latelliptica (Báldi-Beke & Baldi, 1974) Perch-Nielsen, 1984
Pontosphaera multipora (Kamptner, 1948 ex Deflandre in Deflandre & Fert, 1954) Roth, 1970
Pontosphaera obliquipons (Deflandre, 1954) Romein, 1979
Reticulofenestra bisecta (Hay, Mohler & Wade, 1966) Roth, 1970
Reticulofenestra lockeri Müller, 1970
Reticulofenestra ornata Müller, 1970
Reticulofenstra reticulata (Gartner & Smith, 1967) Roth & Thierstein, 1972
Reticulofenestra umbilica (Levin, 1965) Martini & Ritzkowski, 1968
Zygrhablithus bijugatus (Deflandre & Fert, 1954) Deflandre, 1959