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Reworked nannofossils from the Lower Miocene deposits in the Magura Nappe (Outer Western Carpathians, Poland)

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Abstract: Studies, based on calcareous nannofossils, proved that the level of reworked microfossils had so far been underestimated. More recently detailed quantitative studies of calcareous nannoplankton of the Magura, Malcov, Zawada and Kremna formations from the Magura Nappe in Poland documented a degree of nannofossil recycling among those formations. In the Late Eocene–Early Oligocene pelagic Leluchów Marl Member of the Malcov Formation the level of redeposition is very low (0–3.80 %), however, in the flysch deposits of the Malcov Formation reworking increased to 31.4 %. Late Oligocene through Early Miocene "molasse" type deposits of the Zawada and Kremna formations contain 43.7–69.0 % of reworked nannofossils. Quantitative analyses of the reworked assemblages confirmed the domination of Paleogene nannofossil species over Cretaceous ones. The most abundant, reworked assemblages belong to the Early–Middle Eocene age.

Key words: stratigraphy, calcareous nannoplankton, reworked specimens, Paleogene–Lower Neogene, Outer Western Carpathians, Magura Succession.

Introduction

The Polish Outer Carpathians are composed of Upper Jurassic–Lower Miocene flysch deposits: deep-water siliciclastic turbidites, deposited by submarine gravity flows — mainly turbidity currents. The exception is the Late Cretaceous–Eocene Sub-Silesian succession, which is represented by variegated marls deposited in pelagic environments. The Carpathian flysch is composed of an alternation of conglomerates, sandstones, mudstones, claystones and, less frequently, by marls and cherts. In the Cretaceous–Paleogene flysch formations these components are mixed in different proportions.

The first stratigraphic studies of the Magura Nappe succession are more than 100 years old. The earliest biostratigraphic data, dating the youngest deposits of the Magura Nappe to the Eocene, were based upon large foraminifera. A significant qualitative change in biostratigraphic studies took place after the application on calcareous nannoplankton (Radomski 1967; Birkenmajer & Oszczypko 1989; Oszczypko et al. 1990). This research resulted in the introduction of formal lithostratigraphic schemes in the Krynica and Bystrica facies zones (for references see Oszczypko-Clowes 2001). Contemporary research on calcareous nannoplankton from the Krynica and Bystrica zones suggested the presence of mainly Early-Eocene age formations, while the younger data were found in the outer zones, mainly in the Siary Zone. Such a biostratigraphical framework strongly affected the contemporary paleogeographic and paleotectonic reconstructions — not only for the Magura Nappe, but also for the entire Outer Western Carpathians. Further studies, based on calcareous nannofossils, proved that the level of reworked microfossil associations had been underestimated (e.g. Birkenmajer & Oszczypko 1989; Oszczypko et al. 1990). The significance of these, detailed quantitative studies of calcareous nannoplankton from the Magura, Malcov, Zawada and Kremna formations of the Magura Nappe, is documented by the degree of nannofossils recycling and its impact on the age determination.

The concept of the turbidity current, as a mechanism responsible for the deposition of sandy/silty and muddy turbidites, was developed by Kuenen & Migliorini (1950). Over time turbiditic deposits were divided into several classes (see Einsele 2002): coarse-grained turbidites, sandy medium-grained turbidites (siliciclastic and carbonate), carbonate turbidites (calciturbidites or allodapic limestones) and mud turbidites. The hypothesis of medium-grained siliciclastic turbidites was popularized in literature by Bouma (1962). The Bouma (1962) concept of Ta division has been extended by Lowe (1982), who distinguished sub-divisions S1, S2, S3, which result from grain flows. The first two sub-divisions: (S1 and S2), with an inverse gradation, are represented by coarse-grained sandy turbidites, deposited by a bottom traction. A massive S3 division, resulting from grain-flow "freezing", displays water-escape structures (e.g. "dish") and levels of intraclasts, derived from the erosion of a bottom muddy-clay layer. A later modification of the Bouma Ta division was introduced by Shanmungan (2000) as gravelly traction intervals, R2 and R3.

In terms of the formation of gravitational flow deposits Einsele (2002) highlights the importance of: marine delta, prodelta slopes, submarine canyon heads, shelf break erosion, subduction-related depositional environments and deposits of the forearc basins.

The presence of allochthonous, shallow-marine faunas in sediment suspension currents have been known since the late 50's (Kuenen & Migliorini 1950). This was particularly related to turbidites derived from carbonate skeleton material and reef detritus from carbonate shelves and platforms (see Einsele 2002). At the end of the nineteenth century, and during the first half of the twentieth century, allochthonous faunas (e.g. ammonites, inoceramids, corals and larger foraminifera) were often the only basis for biostratigraphy of the flysch strata in the Outer Carpathians, the Apennines, Dinarides and other orogens. A revision of these views, based on small foraminifera and calcareous nannoplankton, sometimes provoked long controversy. Examples of such exchanges include discussions concerning the age of "black flysch" in the Pieniny Klippen Belt, in Poland (Sikora 1962; Birkenmajer & Pazdro 1968; Oszczypko et al. 2004; Birkenmajer & Gedl 2004; Birkenmajer et al. 2008; Oszczypko et al. 2008a,b), "Crete Nero" and the Cilento Flysch in the Southern Apennines (see Cieszkowski et al. 1994, 1995 and references therein). The most recent example of these scientific exchanges focuses on the principal age revision of the Outer Dinarides, flysch deposits in Slovenia, Croatia, Bosnia-Herzegovina and Montenegro (Mikes et al. 2008). The issue of reworked microfossils from the Western Carpathian flysch was also raised by Švábenická & Bubík (1992) and Švábenická et al. (2007).

Previous works

Polish Outer Carpathian flysch deposits, with massive reworked microfossil assemblages, were first recognized in the Paleogene Magura Succession deposits of the Nowy Sącz and Orava-Nowy Targ depressions (Fig. 1B).

In 1973 Oszczypko documented the presence of Upper Eocene/Oligocene deposits in the southern margin of the Nowy Sącz Basin (borehole Nowy Sacz I), occurring at the top of the Upper Eocene Magura Sandstone, which was regarded as the youngest beds of the Magura Succession. At the same time, in the Biegonice and Zawada sections (Bystrica Subunit), among the yellow-grey, massive marls of the Łącko, Blaicher (cf. Oszczypko 1973) recognized three different age, foraminifera assemblages (benthic and planktonic) which were mixed with each other and contained Early/Middle Eocene; Late Eocene/Oligocene and Oligocene species.

The youngest Oligocene foraminifera were considered autochthonous, while the two remaining assemblages were regarded as reworked. These sections (Fig. 1B) were once more revised by Oszczypko et al. (1999) and Oszczypko & Oszczypko-Clowes (2002) and were included in the Zawada Formation. These new studies documented the presence of Early Miocene foraminifera (N5) and calcareous nannoplankton (NN1–2) as well as large quantities of reworked Late Cretaceous to Middle Eocene foraminifera and calcareous nannoplankton in the Zawada Formation.

The history of biostratigraphical research of the Magura-type sandstones in the proximity of Nowy Targ (Krynica Subunit) was more or less similar. These thick-bedded sandstones with intercalations of grey marly claystones were regarded as the Inoceramian beds (Cenomanian–Turonian — Halicki 1959 or Turonian–Maastrichtian–Danian — Watycha 1963).

New data on the age of these deposits have been published by Cieszkowski & Olszewska (1986), who established these beds as the Malcov Formation (Late Eocene/Oligocene). Later Cieszkowski (1992) described the Lower/?Middle Miocene deposits of the Magura Succession in the Stare Bystre and Rogoźnik sections of the Podhale region (Fig. 1B). These strata revealed multiple layers of reworked foraminifera and calcareous nannoplankton of a Cretaceous and Paleogene age. The contemporaneous, Lower Miocene flysch of the Magura Succession was also drilled in the Nowy Targ 1 borehole (Paul & Poprawa 1992), at the northern boundary of the Pieniny Klippen Belt.

A similar approach was conducted via biostratigraphic studies in the Poprad valley, near Stará Ľubovňa (Ľubovnianska Vrchovina, East Slovakia). In this area (Fig. 1B), within the contact zone of the Magura Nappe and the Pieniny Klippen Belt, Matějka (1959) described the Kremna facies. Previously, those strata were included in the "Nordliche Granz Flysch Zone" (Uhlig 1890) or "Peri-Klippen Flysch" or "Inter Klippen Flysch" (Horwitz 1935). Stráník & Hanzlíková (1968) described the "Kremna facies" as a sandy-conglomeratic calcareous flysch, with intercalations of grey-greenish claystones and siltstones. On the basis of the foraminiferal studies, these strata were determined as Paleocene/Eocene to Late Eocene intermediate lithofacies between the PKB and Magura Paleogene. More recently, Oszczypko et al. (2005) defined these deposits as the development of the Kremna Formation, being the youngest (Oligocene–Early Miocene) member of the Magura Succession in the Peri-PKB zone. The calcareous nannoplankon studies of this formation showed a predominance (60 %) of reworked species, mainly Middle–Late Eocene, while the youngest species that were identified belonged to the Early Miocene (NN1 and NN2, see Oszczypko et al. 2005). The Kremna Formation is regarded as the equivalent of the Zawada and Stare Bystre formations in the Nowy Sącz and Podhale areas. Over recent years the Kremna Formation was recognized in the Krynica facies zone in the Muszyna and Jaworki areas (Oszczypko & Oszczypko-Clowes 2010; Oszczypko-Clowes 2010) as well as in the "Magura Autochthonous Paleogene" in the tectonic windows of the PKB (Oszczypko & Oszczypko-Clowes 2010; Oszczypko et al. 2010). Likewise, Lower Miocene strata were also found in the Krynica Zone within the vicinity of Humenné.

Regional settings and studied sections

The following selected profiles were examined in this research: Zawada, Leluchów and Ujak as well as the Kremna sections of the Magura Nappe and Pieniny Klippen Belt. Figure 2 shows the synthetic lithostratigraphic profiles of the Paleogene-to-Lower Miocene deposits across the Magura Nappe. These profiles are representative of the eastern sector of the Magura Nappe in Poland (Fig. 1B). The top of the variegated shales with *Reticulophragmium amplectens* (Middle–Late Eocene) or the Sub-Menilite Globigerina Marls (SMGM) were adopted as the correlation level.

The Krynica Zone

The Krynica facies' Zone (Figs. 1B, 2) provides an important insight for our understanding of the terminal history of the Magura Basin. This zone contains facies linked with the post-nappe: Late Eocene–Oligocene of the Central Carpathian Paleogene Basin and Pieniny Klippen Belt suture zone (Újak

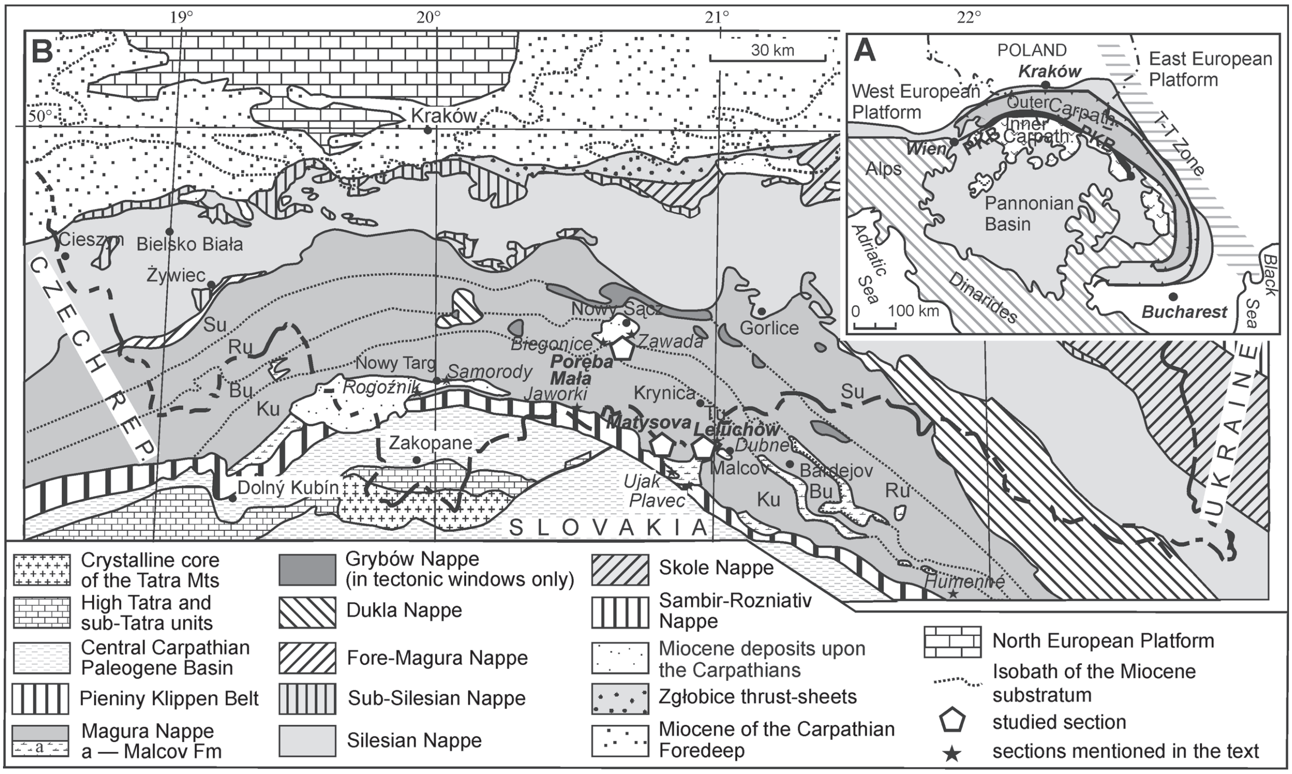

Fig. 1. A — Simplified tectonic scheme of the Alpine-Carpathian orogens (based on Picha 1996). **B** — Geological map of the Polish Carpathians (Żytko et al. 1989, modified), with location of studied areas. **Abbreviations:** Su — Siary, Ru — Rača, Bu — Bystrica, Ku — Krynica, Tu — Tylicz facies zones of the Magura Nappe.

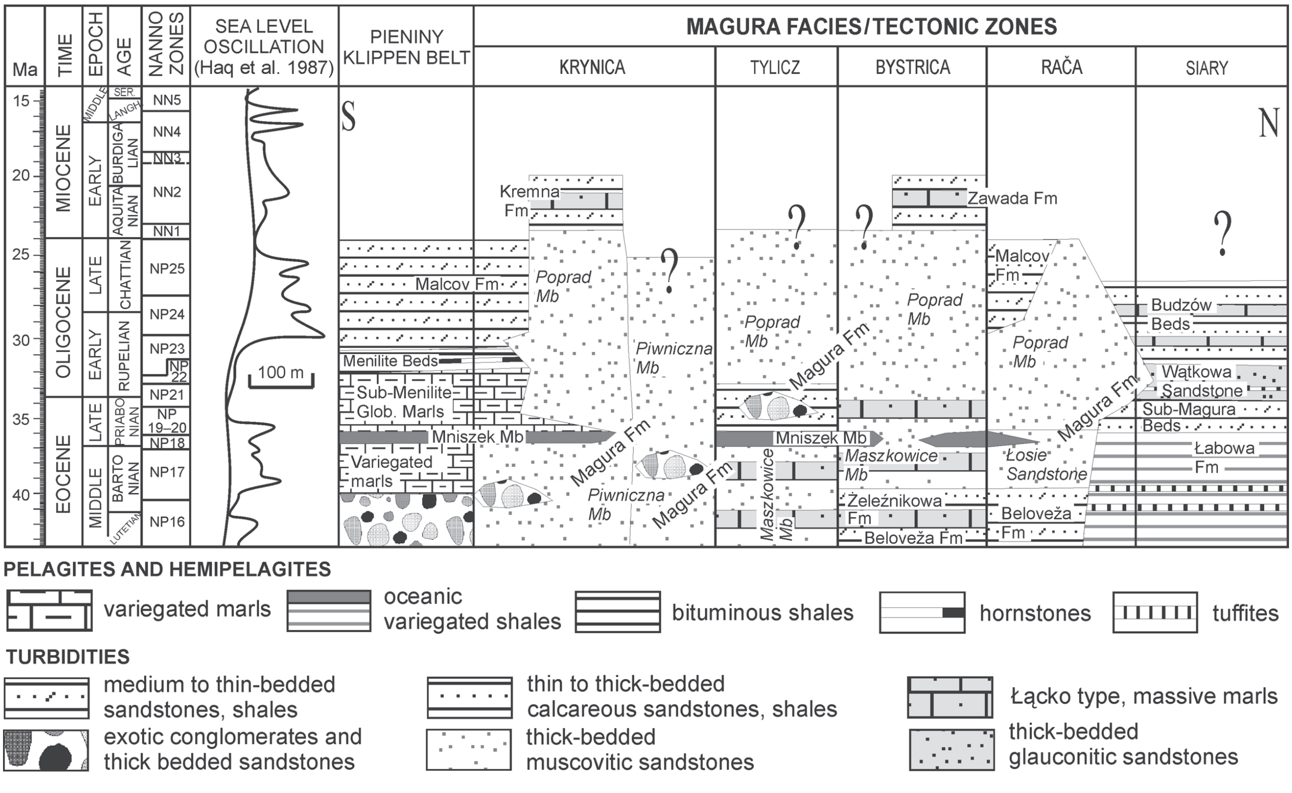

Fig. 2. Lithostratigraphic table of the Paleogene/Early Miocene deposits of the Magura Nappe and Pieniny Klippen Belt (Oszczypko & Oszczypko-Clowes 2009).

section, Fig. 1B). In the southern part of the Krynica Zone the youngest deposits belong to the Malcov and Kremna formations (Figs. 2, 3, 4). Until this point, the only outcrops of the Malcov Formation in Poland were located in the Leluchów section (for reference see Oszczypko-Clowes 2001; Oszczypko & Oszczypko-Clowes 2010). In the Leluchów profile (Fig. 3) the Malcov Formation is composed of the following, Upper Eocene–Oligocene lithostratigraphic units: the Leluchów Marl Member, the Smereczek Shale Member and the Malcov Formation *s.s.* The Leluchów Marl Member (see SMGM) consists of green and grey, marly shales covered by red, greyish-green, greenish and olive marls. The Smereczek Shale Member (Fig. 3) contains a marly development with a few tuffite intercalations in the lower portion whereas the upper portion consists of black non-calcareous, bituminous shales with a few layers of coarse-grained, thick-bedded sandstone. Thin-bedded turbidites, dark-grey marly shales occur in the uppermost part of the Leluchów section. These flat-lying, south dipping strata belong to the Malcov Formation *s.s.*

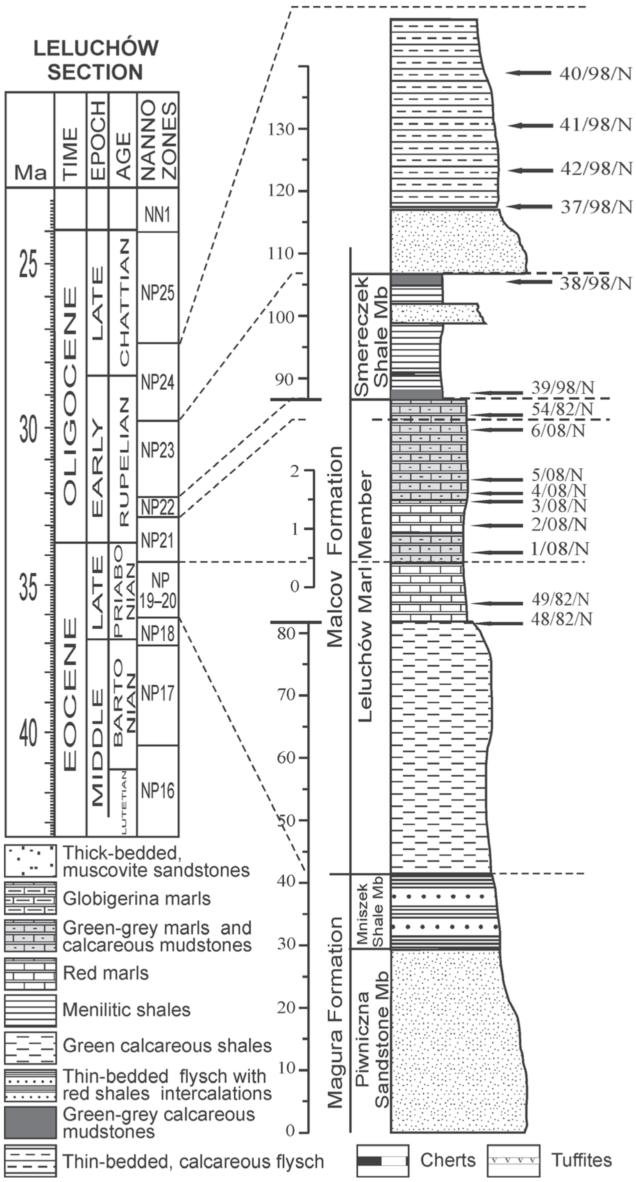

Fig. 3. Lithostratigraphic profile and sample intervals — Leluchów Succession, Krynica Zone of the Magura Nappe (Oszczypko-Clowes 2001; Oszczypko et al. 2005; Oszczypko-Clowes & Żydek 2012).

A similar type of the Malcov Formation, is also known from exposures in the Újak village near Stará Ľubovňa and Plaveč (Fig. 1B).

The sedimentary transition from the Poprad Sandstone Member to the Kremna facies is well exposed in the Matysova section (Fig. 4). A continuation of the Magura Formation from the Krynica-Muszyna-Leluchów area is visible in the northern part of the Ľubovnianska Vrchovina Range, SW of the Poprad River. In the Ľubovnianska Vrchovina Range the Poprad Sandstone Member (Strihov beds) fill the Hraničné-Kremna-Matysova, a 4–6 km wide synclinal zone (see Nemčok 1990; Oszczypko et al. 2005). The Poprad Sandstone Member, up to 1000 m thick, is underlain by the Mniszek Shale Member and covered by the Kremna Formation (Oszczypko et al. 2005). In the Matysova section, the lower part of formation (Fig. 4) is represented by coarse- to very coarse-grained, thick-bedded (0.40 to 2 m) sandstones, with sporadic intercalations of dark-grey, marly mudstones. A characteristic feature of these deposits is the occurrence of Magura type sandstones as well as 1.5–2.0 m thick intercalations of dark-grey-to-greenish calcareous Łącko type marly mudstones.

The thickness of the Kremna Formation varies from 200–300 m in the Matysova and Dubne section and ranges up to 500–600 m in the Kremna and Jaworki-Kosarzyska section (Figs. 1B, 4).

The Bystrica Zone

The youngest deposits of this zone belong to the Zawada Formation (Figs. 2, 5) which was documented on the southern periphery of the Nowy Sącz Basin (Fig. 1B). This formation was found in the Nowy Sącz 4 borehole as well as in Zawada Biegonice (Oszczypko et al. 1999; Oszczypko-Clowes 2001) and also the Poręba Mała sections (Oszczypko & Oszczypko-Clowes 2002). The Zawada Formation is represented by medium- to thick-bedded, sometimes glauconitic, sandstones with intercalations of thick-bedded marls and marly claystones. The thickness of the formation is at least 550 m (Figs. 2, 4).

According to Oszczypko et al. (1999), this formation occurs in the southern part of the Rača Subunit and at the front of the Bystrica Subunit of the Magura Nappe. Due to the lack of exposure, the relationship between the Malcov Formation of the Rača Subunit and the Zawada Formation is not yet clear.

Materials and methods

The current research utilizes samples previously used in the following papers: Oszczypko-Clowes 2001; Oszczypko & Oszczypko-Clowes 2002; Oszczypko et al. 2005; Oszczypko & Oszczypko-Clowes 2010.

All samples were analysed with a Nikon-Eclipse E 600 POL, at a 1000× magnification using both parallel and crossed nicols. The applied taxonomic framework is based

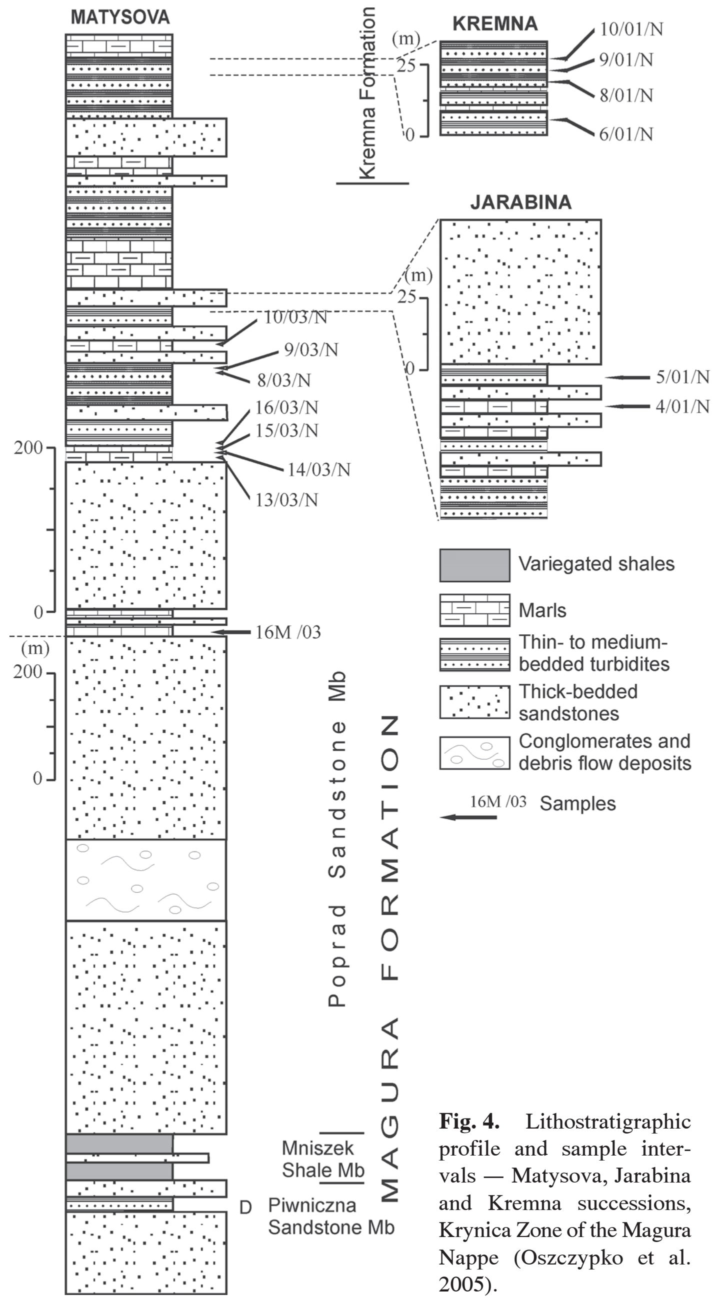

Fig. 4. Lithostratigraphic profile and sample intervals — Matysova, Jarabina and Kremna successions, Krynica Zone of the Magura Nappe (Oszczypko et al. 2005).

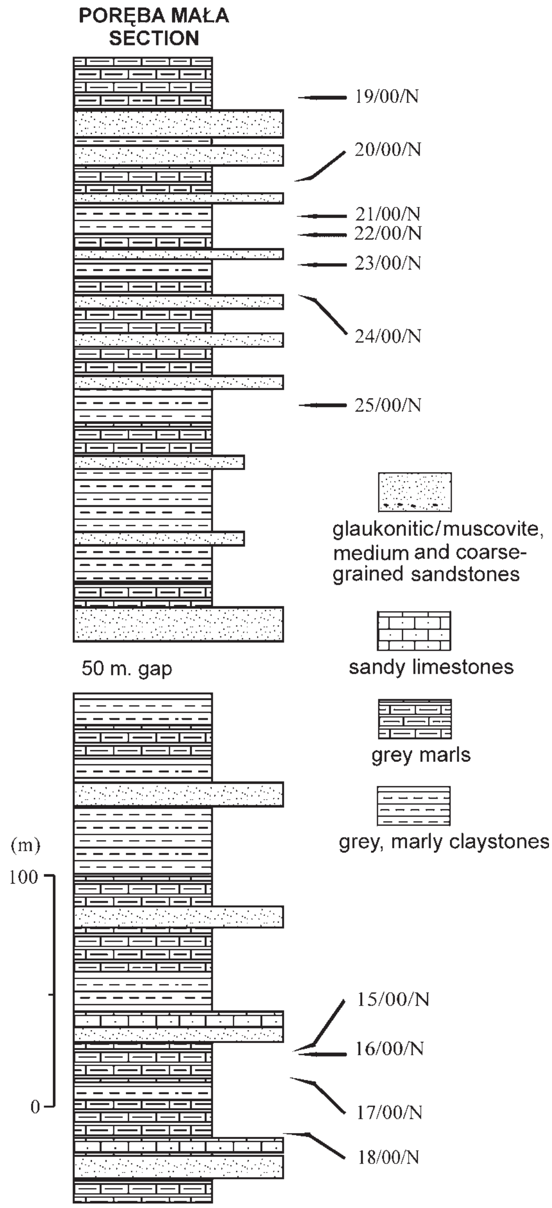

Fig. 5. Lithostratigraphic profile and sample intervals — Poręba Mała Succession, Bystrica Zone of the Magura Nappe (Oszczypko & Oszczypko-Clowes 2002).

upon Aubry (1984, 1988, 1989, 1990, 1999), Perch-Nielsen (1985), and Bown (1998 and references therein).

Quantitative analyses were performed using counts of 300 specimens per slide. The authors accepted a 5 % margin of error in analysis and calculation of percentage abundance of autochthonous and allochthonous assemblages. The nominal values as well as the percentage abundance, are presented in Tables 1, 2 and 3. Specimens photographed using the LM are illustrated in Figs. 6–7.

To distinguish reworked from in-place nannofossils the full stratigraphic ranges of species, were used. Individual species older than the youngest assemblage were identified as reworked taxa. Issues arise concerning long-ranging Cenozoic taxa, which also form a part of the Early Neogene assemblages. In such assemblages, autochthonous or allochthonous, both types occur together in the sample and cannot be distinguished from each other. In this study long-ranging taxa such *Braarudosphaera bigelowii*, *Cyclicargolithus floridanus*, *Coccolithus pelagicus* and *Sphenolithus moriformis* were counted as autochthonous species. In such a situation the calculated percent value of reworking should be interpreted as the minimum level of reworking.

Results

Calcareous nannofossil preservation and abundance

State of preservation is one of the methods used in identifying reworked fossils via the presence of very intensive

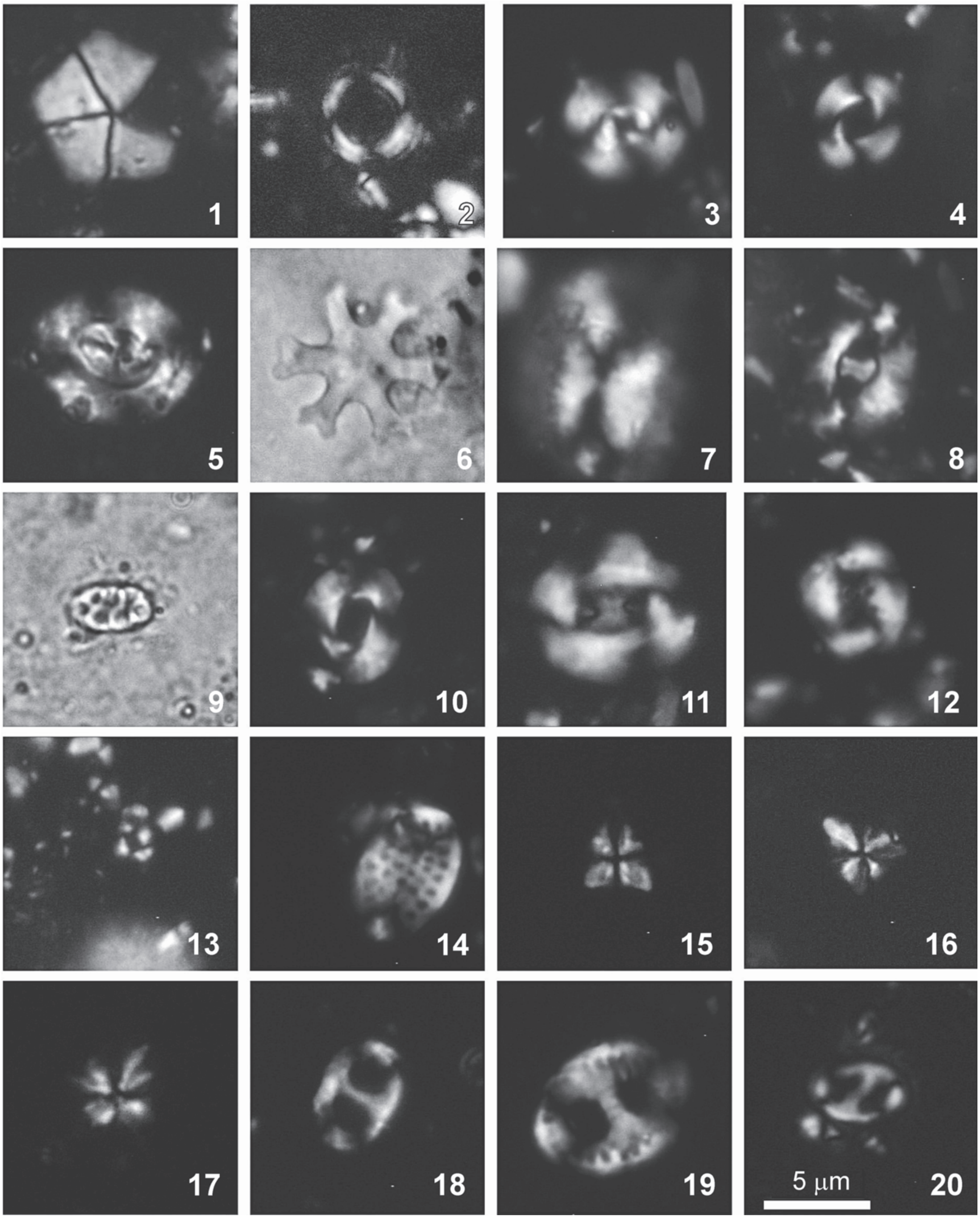

Fig. 6. Autochthonous species in LM (scale bar is the same for all photographs). **1** — *Braarudosphaera bigelowii* (Leluchów section, Smereczek Shale Mb, sample 38/98/N); **2** — *Coronocyclus nitescens* (Matysova section, Magura Fm, sample 9/03/N); **3** — *Cyclicargolithus abisectus* (Leluchów section, Malcov lithofacies, sample 41/98/N); **4** — *Cyclicargolithus floridanus* (Poręba section, Zawada Fm, sample 16/00/N); **5** — *Dictyococcites bisectus* (Leluchów section, Leluchów Marl Mb, sample 49/82/N); **6** — *Discoaster deflandrei* (Leluchów section, Malcov lithofacies, sample 40/98/N); **7** — *Helicosphaera compacta* (Leluchów section, Malcov lithofacies, sample 41/98/N); **8** — *Helicosphaera intermedia* (Poręba section, Zawada Fm, sample 17/00/N); **9** — *Holodiscolithus macroporus* (Jarabina section, Magura Fm, sample 5/01/N); **10** — *Reticulofenestra dictyoda* (Leluchów section, Leluchów Marl Mb, sample 48/82/N); **11** — *Reticulofenestra lockerii* (Leluchów section, Smereczek Shale Mb, 39/98/N); **12** — *Reticulofenestra ornata* (Leluchów section, Smereczek Shale Mb, 39/98/N); **13** — *Reticulofenestra* sp. *small* (Poręba section, Zawada Fm, sample 18/00/N); **14** — *Ponthosphaera multipora* (Kremna section, Kremna Fm, sample 8/01/N); **15, 16** — *Sphenolithus conicus* (Matysova section, Magura Fm, sample 9/03/N); **17** — *Sphenolithus dissimilis*; **18** — *Transversopontis fibula* (Leluchów section, Smereczek Shale Mb, 39/98/N); **19** — *Transversopontis pulcher* (Jarabina section, Magura Fm, sample 5/01/N); **20** — *Transversopontis pulcheroides* (Leluchów section, Leluchów Marl Mb, sample 54/82/N).

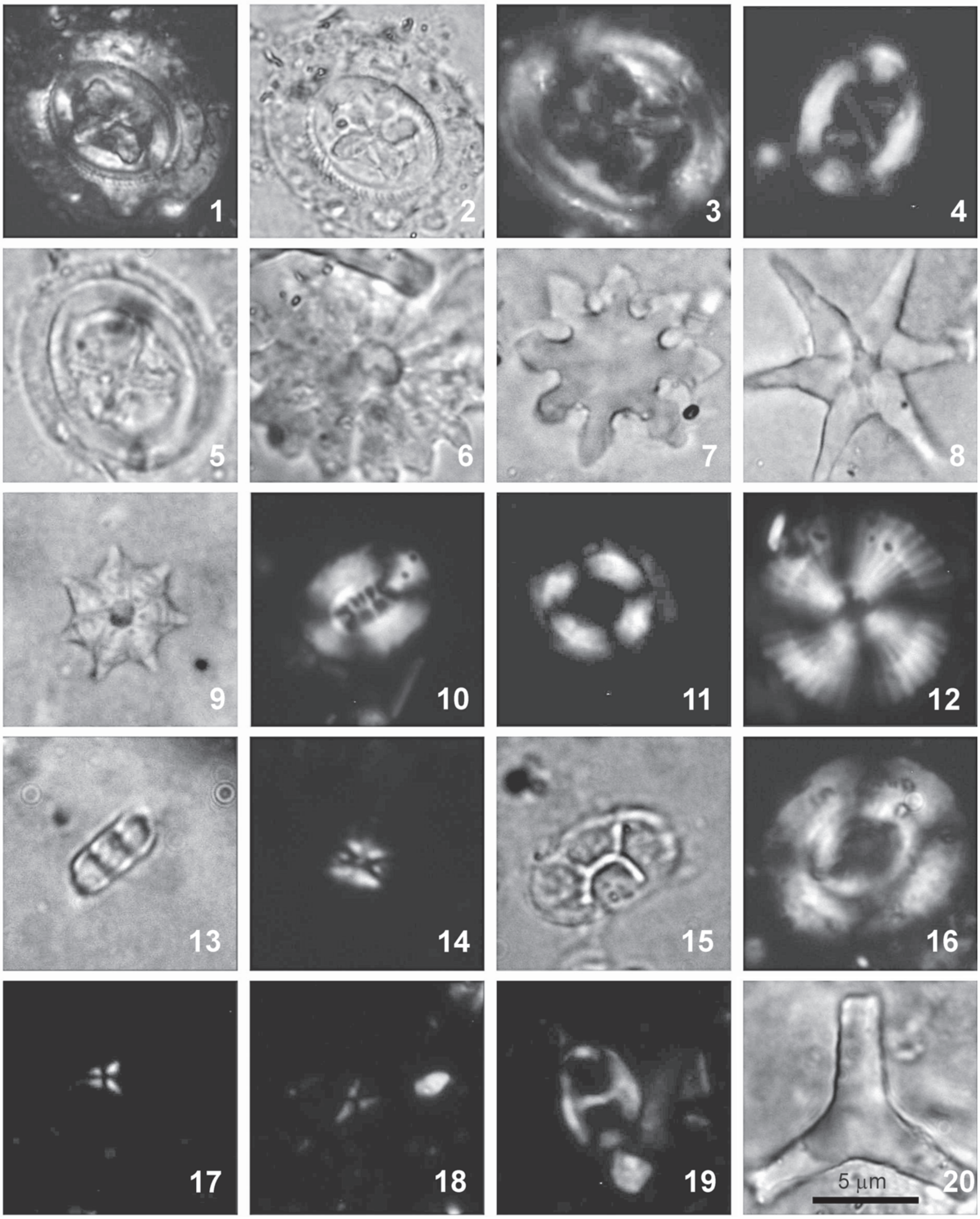

Fig. 7. Allochthonous species in LM (scale bar is the same for all photographs). **1, 2** — *Chiasmolithus gigas* (Matysova section, Magura Fm, sample 9/03/N); **3** — *Chiasmolithus grandis* (Matysova section, Magura Fm, sample 9/03/N); **4** — *Chiasmolithus solitus* (Matysova section, Magura Fm, sample 9/03/N); **5** — *Chiasmolithus oamaruensis* (Poręba section, Zawada Fm, sample 25/00/N); **6** — *Discoaster barbadiensis* (Poręba section, Zawada Fm, sample 16/00/N); **7** — *Discoaster binodosus* (Poręba section, Zawada Fm, sample 25/00/N); **8** — *Discoaster lodoensis* (Jarabina section, Magura Fm, sample 4/01/N); **9** — *Discoaster saipanensis* (Poręba section, Zawada Fm, sample 23/00/N); **10** — *Ellipsolithus macellus* (Matysova section, Magura Fm, sample 9/03/N); **11** — *Ericsonia formosa* (Jarabina section, Magura Fm, sample 4/01/N); **12** — *Heliolithus kleinpelli* (Matysova section, Magura Fm, sample 10/03/N); **13** — *Isthmolithus recurvus* (Jarabina section, Magura Fm, sample 5/01/N); **14** — *Lanternithus minutus* (Poręba section, Zawada Fm, sample 24/00/N); **15** — *Neococcolithes dubius* (Jarabina section, Magura Fm, sample 5/01/N); **16** — *Reticulofenestra hillae* (Poręba section, Zawada Fm, sample 16/00/N); **17, 18** — *Sphenolithus calyculus* (Poręba section, Zawada Fm, sample 24/00/N); **19** — *Transversopontis fibula* (Poręba section, Zawada Fm, sample 22/00/N); **20** — *Tribrachiatus orthostylus* (Matysova section, Magura Fm, sample 8/03/N).

mechanical damage as well as signs of etching, severe dissolution and overgrowth. When considering all investigated assemblages the preservation of calcareous nannofossils is moderate (m) or predominantly moderate-to-good (m-g) in all investigated samples (Tables 1, 2, 3 — published in the electronic version at the www.geologicacarpathica.sk). Nannofossils show minor etching and minor-to-moderate over growth. A good to moderate preservation of nannofossils indicates that little carbonate dissolution has occurred in these sediments.

Estimates of the nannofossil abundance for individual samples (Tables 1, 2, 3) was established using the following criteria: VH — very high (>20 specimens per 1 field of view), H — high (10–20 specimens per 1 field of view), M — moderate (5–10 specimens per 1 field of view), L — low (1–5 specimens per 1 field of view), VL — very low (<5 specimens per 5 fields of view).

Calcareous nannofossils biostratigraphy

Biostratigraphic analyses, using the standard Martini zonation (1971), confirmed results obtained through earlier research (Oszczypko et al. 1999, 2005; Oszczypko-Clowes 2001; Oszczypko & Oszczypko-Clowes 2002, 2010).

For reference purposes, the biostratigraphic framework can be summarized as follows:

Malcov Formation: Leluchów Marl Member — Zones NP19–20–NP22 (Late Eocene–Early Oligocene), Smereczek Shale Member — Zone NP23 (Early Oligocene) and the Malcov Formation *s.s.* — Zone NP24 (Early Late Oligocene);

Poprad Sandstone Member of Magura Formation: Zones NP25–NN1 (latest Oligocene–earliest Miocene);

Kremna Formation: NN2 (Early Miocene);

Zawada Formation: NN1–NN2 (Early Miocene).

The zone assignment of NP25 is based on the first occurrence (FO) of *Sphenolithus capricornutus* and *S. conicus*. Slightly less abundant are *Cyclicargolithus abisectus*, *Reticulofenestra lockeri*, *S. dissimilis* and *R. dictyoda*. *Dictyococcites bisectus* is present, though rare. The FO of *Sphenolithus conicus* has been frequently used as the base of the NN1 Zone, however, Bizon & Műller (1979), Biolzi et al. (1981) and Melinte (1995) observe the FO of this species as low as the upper part of the NP25 Zone.

The zone assignment of NN1 is based on a continuous range of *S. conicus* and *S. dissimillis* following the disappearance of *D. bisectus*. Traditionally the last occurrence (LO) of *Helicosphaera recta* was used to define the base of NN1 (Martini & Worsley 1970). It is now well-known that this species also appeared in the Early Miocene. As a result, Perch-Nielsen (1985), Berggren et al. (1995), Fornaciari & Rio (1996) and Young (in Bown 1998) suggested redefining the base of NN1 as the LO of *D. bisectus.* The biostratigraphic range of *S. delphix* is also problematic. According to Young (Young in Bown 1998), this species is only characteristic for the upper part of NN1, however this taxon was reported by Aubry (1985) from NP25 and NN1.

The NN2 assignment is based on the co-occurrence of the following species: *Sphenolithus conicus*, *Sphenolithus disbelemnos*, *Reticulofenestra pseudoumbilica* and *Triquetrorhabdulus carinatus*. At the same time *Dictyococcites bisectus*, *Cyclicargolithus abisectus* and *Zygrhablithus bijugatus* are absent from this association assemblage. According to Young (1998), the FO of *S. disbelemnos* and/or *Umbilicosphaera rotula* are reliable biostratigraphical events, characteristic for the lower limit of the NN2 Zone.

Additionally, the nannofossil association from the Zawada Formation contains *Discoaster druggi* and *Helicosphaera ampliaperta.* The presence of *D. druggi* was observed in ≥50 % of investigated samples, whereas the occurrence of *Helicosphaera ampliaperta* is extremely rare. The presence of *H. ampliaperta* can suggest the upper part of Zone NN2 (see Holcová 2002, 2005).

Species diversity — reworked assemblages

The Malcov Formation

Forty four species were identified during quantitative analyses of calcareous nannoplankton. Samples from the Leluchów Marl Member are characterized by a very low level of reworking, which does not exceed 3.80 % (sample 3/08/N). The greatest number of reworked specimens (13.3 %–31.35 %; Fig. 8; Table 1) were observed in samples taken from thin marly intercalations in the Smereczek Shale Member (39/98/N and 38/98/N) as well as the Malcov lithofacies (37/98/N, 42/98/N, 41/98/N and 40/98/N). The reworked assemblage is dominated by Paleogene taxa. They constitute between 11–30 % (samples 39/98/N 40/98/N, respectively) of all identified specimens. Cretaceous species are a minor component with less than 3 %. The main components of the Paleogene assemblage (Table 1) are *Discoaster* spp., *Reticulofenestra* spp. and *Ericsonia* spp., *Discoaster* spp. varies from 0.32 (sample 39/98/N) through 4.4 (sample 37/98/N) up to 14.2 %, (sample 40/98/N), whereas the abundance of *Reticulofenestra* spp. ranges from 3.5 (sample 39/98/N) up to 11.7 % (sample 41/98/N). The abundance of *Ericsonia* spp. does not exceed 8 % (sample 39/98/N).

The Poprad Sandstone Member of the Magura Formation

The quantitative analyses show a substantial quantity of reworked nannofossils (Fig. 8; Table 2). The greatest reworking is observed in sample 4/01/N (60.8 %), whereas the lowest amounts occur in sample 13/03/N (21.9 %). The remaining samples range from 37%–53 %.

Cretaceous species make up ~11 % (samples 16/03/N, 13/03/N, 14/03/N, 15/03/N), whereas the remaining samples contain between 2.9 % and 7.6 %. Cretaceous species (Fig. 9) are consistently less abundant compared with Paleogene species, with the exception of sample 15/03/N (Paleogene taxa — 16.5 %, Cretaceous taxa — 21 %). The Paleogene assemblage (Table 2) is composed mainly of *Discoaster* spp., *Sphenolithus* spp. and a heterogeneous group "other". The group labelled as "other" is composed of *Ellipsolithus macellus*, *Ericsonia fenestrata*, *E. formosa*, *Helicosphaera heezenii*, *Isthmolithus recurvus*, *Neococcolithes dubius*, *Pontosphaera lateliptica*, *P. plana*, *Reticulofenestra reticulata*, *Rhabdosphaera clavigera*, *Toweius rotundus*, *Tribrachiatus orthostylus*. The most common taxon is *T. orthostylus,* reaching a value of 18.05 % in sample 4/01/N. The content of *Discoaster* spp. is greatest in

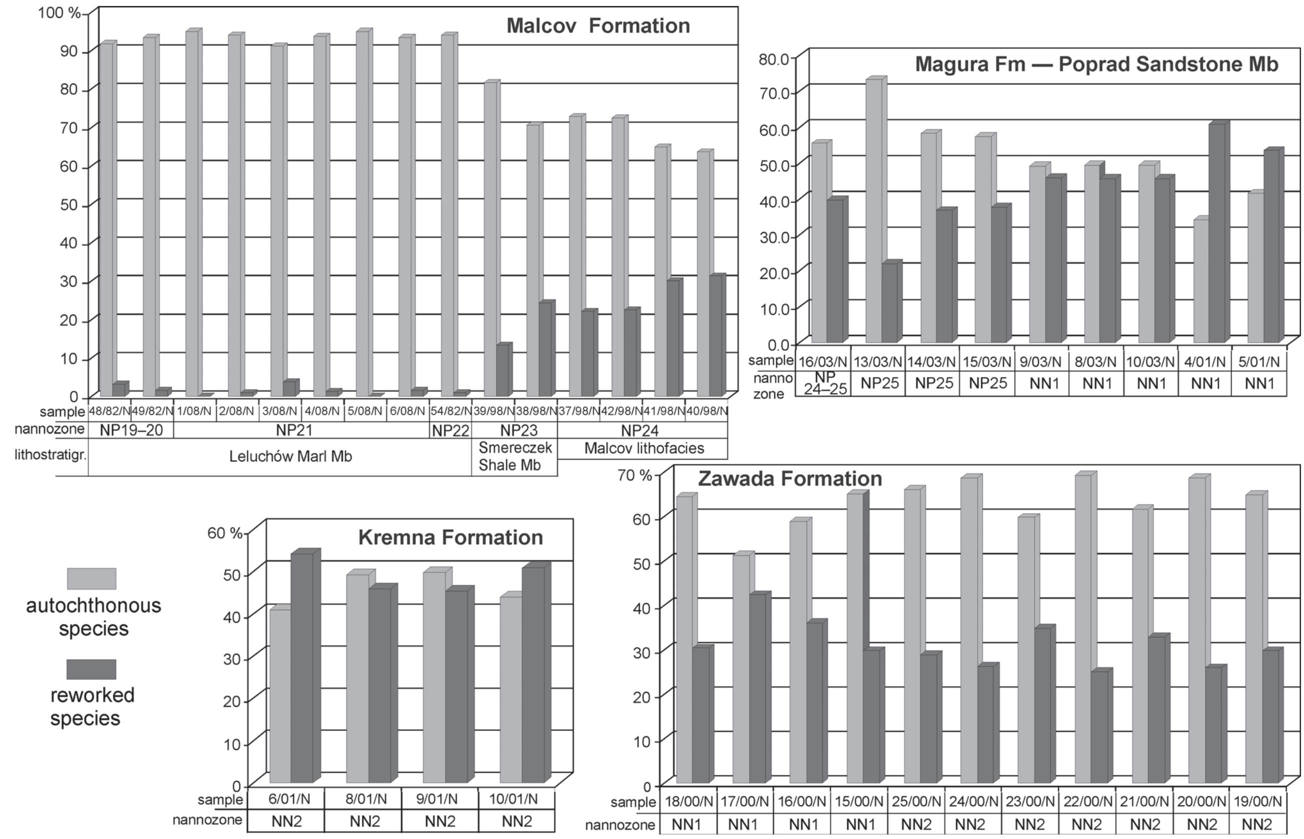

Fig. 8. Percentage abundance of autochthonous and allochthonous species in samples (Leluchów section after Oszczypko-Clowes & Żydek, 2012).

samples 16/03/N, 8/03/N and 4/03/N, reaching values of 19 %, 18 % and 16 %, respectively. The abundance of *Sphenolithus* spp. varies from 0 % (samples 16/03/N, 13/03/N, 15/03/N) through to 1.3 % and up to almost 15 % (5/03/N).

The Kremna Formation

The level of reworking is also high (Fig. 8; Table 2), ranging from 46.2 % (sample 9/01/N) up to 54.2 % (6/01/N). Percentages of Cretaceous species are very low and range from 4.1 % to a maximum of 13.3 % in sample 10/01/N (Fig. 9). Paleogene species account for 37.6 % to 50.03 % of the total assemblage. The most abundant is the group of species labeled as "other" which include: *Ellipsolithus macellus*, *E. fenestrata*, *E. formosa*, *Toweius* spp., *Transversopontis fibula* and *Tribrachiatus orthostylus*. This group forms nearly 23 % (sample 6/01/N) of all specimens, which decrease to a value not higher than 16.5 % (sample 10/01/N). The most common species is *T. orthostylus* reaching a value of 12 % in samples 6/01/N and 10/01/N. The genus *Discoaster* averages about 12 %, whereas *Sphenolithus* spp. is lower varying from 4.4 %–6.3 %.

The Zawada Formation

All investigated samples are characterized by the presence of reworked specimens (Fig. 8; Table 3). The level of reworking is highest in samples 17/00/N (maximum 42.4 %), 16/00/N, 23/00/N where reworked taxa represent more than 34 % of all identified species. This value decreases in samples 15/00/N, 18/00/N, 19/00/N, 21/00/N and 25/00/N with maximum values ≤29–32 %. The remaining samples contain less than 26 % of the reworked species.

The percent abundance of Cretaceous species varies from 1.5 %–9 % (Fig. 9; Table 3), with an average content less than 5 %. Paleogene species are much more abundant, and constitute 20 %–39 % of the total assemblage. The assemblage is dominated by specimens of genera *Chiasmolithus* and *Discoaster*. *Chiasmolithus* spp. range from 2 % up to nearly 10 % of all determined species, with an average content of ~4 %. *Discoaster* spp. average ~3 %. The highest abundance (10, 13 %) was observed in sample 16/00/N. *Helicosphaera* spp. are less abundant, with an average content of approximately 3 % reaching a maximum of 6.9 % in sample 21/00/N.

The group labeled as "other" is represented by the following species: *Holodiscolithus macroporus*, *Lanternithus minutus*, *Neococcolithes dubius*, *Pontosphaera lateliptica*, *Rhabdosphaera clavigera*, *R. inflata*, *Transversopontis fibula* and *Tribrachiatus orthostylus.* These taxa are generally very rare in the assemblage and, in sum, do not constitute more than 6 % of all determined species. In fact, the increased abundance of this group in samples 17/00/N, 24/00/N, 23/00/N and 21/00/N is linked to the increased abundance of *Neococcolithes dubius.* The most common species of this assemblage is *Ericsonia formosa*, with a value ranging from 3 %–8 % of all determined species.

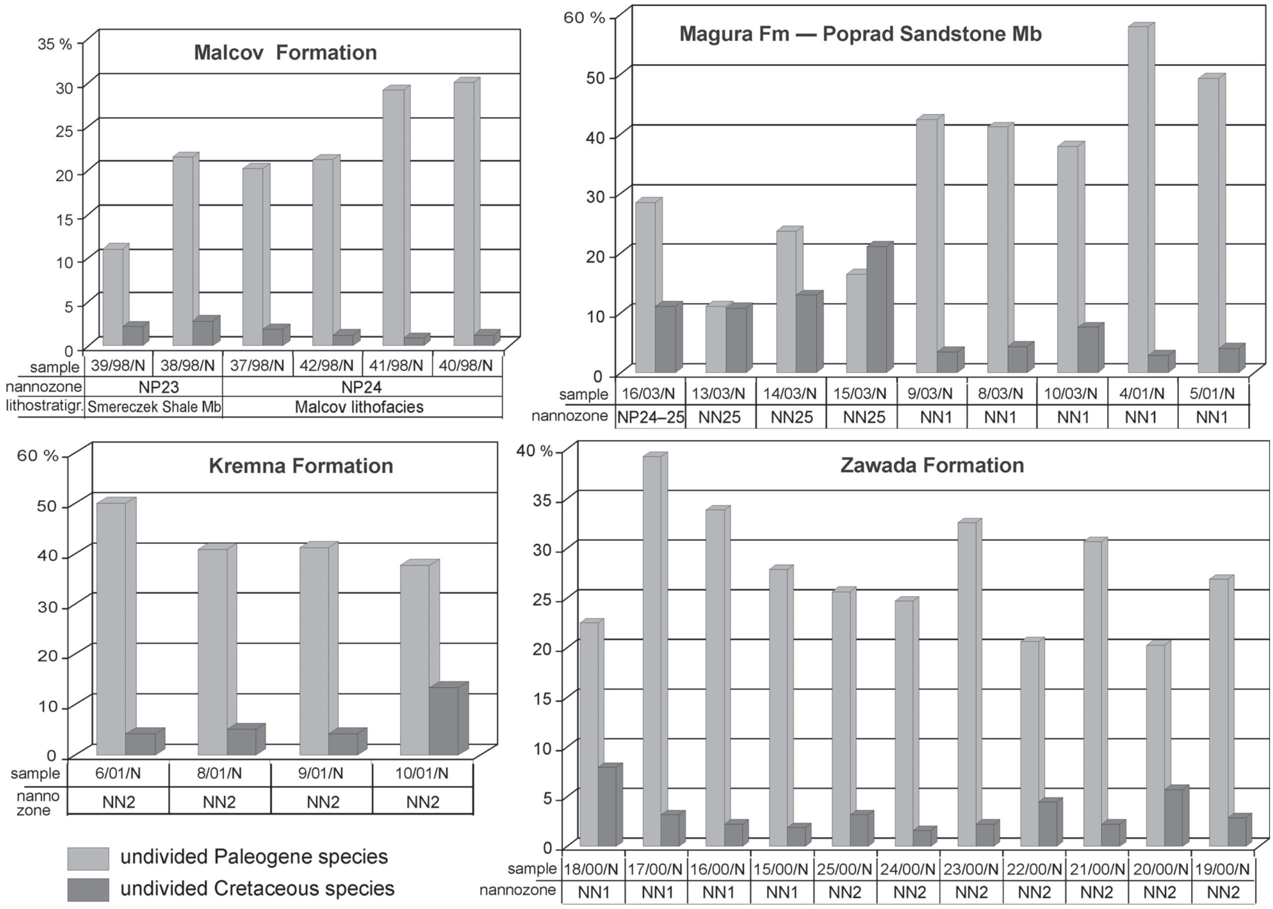

Fig. 9. Percent abundance of allochthonous species — Cretaceous versus Paleogene taxa.

Age determination of reworked assemblages

Cretaceous species commonly occur together with Cenozoic taxa. The precise age determination of Paleogene assemblages is not easy, especially as an overlap pattern of several index species is visible.

The Malcov Formation

The Lower Eocene assemblage is represented by *Discoaster multiradiatus* (range: NP9–11) and *Discoaster lodoensis* (NP12–14). The long-lasting species include *Discoaster barbadiensis* (NP10–20), *D. nodifer* (NP15–22), *D. saipanensis* (NP15–20), *D. tanii* (NP16–22), *Isthmolithus recurvus* (NP19/20–22), *Lanternithus minutus* (NP16–22), *Reticulofenestra hillae* (NP16–22) and *R. umbilica* (NP16–22). The presence of *Isthmolithus recurvus* suggests that the entire assemblage may be not older than Zone NP19/20 and not younger than NP22 (as *R. umbilica* is the index species for the upper limit of Zone NP22).

The Poprad Sandstone Member of the Magura Formation and the Kremna Formation

A number of characteristic taxa of the Early/Middle Paleogene are present such as *Chiasmolithus gigas* (NP15), *Ch. grandis* (NP11–17), *Ch. solitus* (NP10–16), *Discoaster barbadiensis* (NP10–20), *D. binodosus* (Lower to Middle Eocene), *D. multiradiatus* (NP9–11), *D. salisburgensis* (NP9–12), *Ericsonia formosa*, *Toweius* spp., *Tribrachiatus orthostylus* (NP11–12). On the basis of the stratigraphic range of the above given species it is possible to interpret two independent assemblages: Early Eocene — not older than NP9 and not younger than NP12 and Middle Eocene spanning from NP15 to NP16 or even NP17. As for the Late Eocene or rather Early Oligocene, specimens of *Isthmolithus recurvus* (NP19/20–22), *Pontosphaera lateliptica*, *Transversopontis fibula* NP23 (only observed in the Kremna Formation) occurred across the entire studied material.

The Zawada Formation

In this formation the assemblages are even more mixed with overlapping species much more prominent. The Early Eocene is represented by *Discoaster multiradiatus* (NP9–11), *D. distinctus* (NP12–14), *D. lodoensis* (NP12–14).

Longer ranging species, spanning from the Middle Eocene to Early Oligocene, include *Chiasmolithus gigas* (NP15), *Discoaster tanii* (NP16–22), *Helicosphaera bramlettei* (NP14–23), *Lanternithus minutus* (NP16–22), *Reticulofenestra umbilica* (NP16–22). These taxa may constitute either Middle Eocene, Late Eocene or even Early Oligoceene assemblages. The presence of the Middle Eocene could be dated by the *Chiasmolithus gigas* zonal marker, whereas the presence of *Chiasmolithus oamaruensis* (NP18–22) may suggest Late Eocene or Early Oligocene.

Concurrently, there is a biostratigraphic overlap with typical Oligocene species, such as *Pontosphaera lateliptica*, *Transversopontis fibula* and, very rarely, *Sphenolithus capricornutus* and *S. calyculus.* The two latter species are typical of the latest Oligocene period.

Discussion

The Oligocene–Early Miocene closing of the northern sector of the Outer Carpathian sedimentary area is manifested by the deposition of the Krosno synorogenic lithofacies, which occupied the Grybów-Dukla-Silesian/Sub-Silesian/Skole and Boryslav-Pokuttya basin system. These lithofacies represent fining and thinning upward sequences. Towards the top, these sedimentary sequences are dominated by marly pelites. The beginning and termination of these deposits was diachronic and migrated across the basins towards the north (Garecka 2008).

The Malcov lithofacies, an equivalent of the Krosno types, are typical for the Pieniny Klippen Belt/Magura Basin. In the PKB and Krynica Zone of the Magura Basin, the deposition of the Malcov lithofacies was initiated during the NP24 and persisted until the NP25 Zone. In Rača Zone Malcov lithofacies belong to NP24 and NP25 zones (Oszczypko-Clowes 2001). In the northern part of the Magura Basin (Siary Zone) the youngest deposits (so-called Supra-Magura beds) belong to the NP24 Zone (Oszczypko-Clowes 2001). In the Grybów-Dukla units, the Krosno shaly facies belong to NP25 (Oszczypko-Clowes 2008; Oszczypko-Clowes & Oszczypko 2011).

During the Late Oligocene (NP25/NN1), the frontal part of the Magura Nappe thrust northwards onto the terminal Krosno flysch basin (Oszczypko & Oszczypko-Clowes 2009). The northward thrusting of the Magura Nappe was accompanied by the formation of the piggy-back basin on the Magura Nappe and was filled with synorogenic turbidites from the Zawada and Kremna formations (NN1 and NN2 zones).

Reworked microfossils can be used to determine the source of sediments in order to provide information on the processes of source rock erosion, transportation, sedimentation and preservation.

A majority of the allochthonous nannoflora consists of Middle Eocene taxa, together with less abundant Cretaceous, Early Eocene and Oligocene nannofossils. Various age distributions provide an insight into the Cretaceous to Cenozoic sediment reworking history in the remnant flysch basin. Cretaceous species, as well as Early Eocene taxa, are reworked into Middle Eocene sediments. These sediments, most likely formed low, consolidated basin slopes periodically incorporated into gravity flows. These flows provided a significant proportion of older, many times redeposited forms in the studied material. The presence of reworked Oligocene nannofossil shows a more or less continuous erosion of newly deposited sediments on the sea floor during the Early Miocene. The scarcity of Paleocene nannofloral elements is probably due to the unavailability of Paleocene sediments for reworking processes. The diversity of Paleocene index species and their resistance to degradation would permit them to be abundant in Cenozoic flysch sediments. The same reworking pattern was observed throughout the entire flysch belt of the Outer Dinaride nappe front by Mikes et al. (2008).

In the studied material, Paleogene derived nannofossils show preservation as good as, or even better, than that of the original rock. This may be due to transportation in a coated muddy suspension. In addition, all reworked species are resistant to dissolution. In such situations the original assemblages had to be much more diversified.

It is very difficult to show precisely the lithological formations which formed the source rocks for the reworked material. This is connected with a 23° clockwise rotation of the eastern

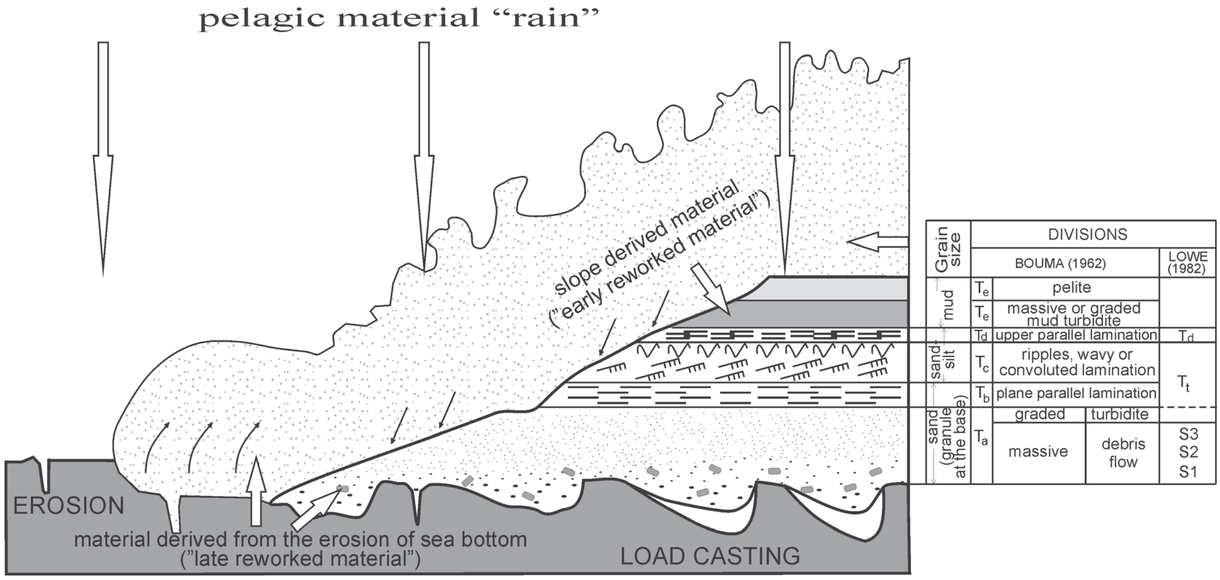

Fig. 10. Model of gravity flow deposition versus coccoliths settling (Bouma 1962; Lowe 1982; Einsele 2002, supplemented).

part of the Alpine-Carpathian-Pannonian region which took place in the Early Miocene, 20 Ma BP (Ustaszewski et al. 2008). According to this reconstruction the maximal width of the Magura Basin at that time ranged up to 200 km.

The percentage of reworked species is clearly associated with lithology (Fig. 8). This is very clearly visible in the Malcov Formation. The lowest number (0 %–3.8 %) of reworked species was recorded in samples from marly, pelagic facies from the Leluchów Marl Member. Turbidite facies, from the Malcov lithofacies, are characterized by an increased reworking, reaching 31.4 %. The values are even higher for the Poprad Sandstone Member and Kremna Formation, where the samples were collected from massive marly claystones (Te), originating from the finest cloud suspension.

The quantitative analyses proved that the level of reworking is high and very high for flysch deposits, which led to age misinterpretations in the past. Age determination based on the youngest assemblage can be approximated, and always should be phrased as not older than. The most reliable indicator for the determination of age can be observed via muddy-clay intraclasts (S3), which were eroded by the gravitational front directly from the sea floor (Fig. 10), as well as from pelagic "rain". That is why nannofossils remain the most important tool for biostratigraphic interpretations in flysch.

Conclusion

1. The youngest deposits of the Magura Basin belong to the Zawada/Kremna formations of the Early Miocene age (NN1, NN2).

2. These synorogenic turbidite facies are characterized by a high level of reworked nannofossils.

3. A quantitative analysis of the reworked assemblages confirmed the domination of Paleogene nannofosssil species over Cretaceous ones.

4. The most abundant, reworked assemblages belong to the Early-Middle Eocene age.

5. The reworked assemblages are also much better preserved than the autochthonous ones which has led to misinterpretations concerning their age in the past.

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Appendix

Nannofossil taxa in text, in alphabetic of genera epihets

Blackites creber (Deflandre, 1954) Roth, 1970
Braarudosphaera bigelowii (Gran & Braarud, 1935) Deflandre, 1947
Calcidiscus leptoporus (Murray & Blackman, 1898) Loeblich & Tappan, 1978
Chiasmolithus altus Bukry & Percival, 1971
Chiasmolithus bidens (Bramlette & Sullivan, 1961) Hay & Mohler, 1967
Chiasmolithus expansus (Bramlette & Sullivan, 1961) Gartner, 1970
Chiasmolithus gigas (Bramlette & Sullivan, 1961) Radomski, 1968
Chiasmolithus grandis (Bramlette & Riedel, 1954) Radomski, 1968
Chiasmolithus medius Perch-Nielsen, 1971
Chiasmolithus modestus Perch-Nielsen, 1971
Chiasmolithus oamaruensis (Deflandre, 1954) Hay, Mohler & Wade, 1966
Chiasmolithus solitus (Bramlette & Sullivan, 1961) Locker, 1968
Coccolithus pelagicus (Wallich, 1871) Schiller, 1930
Coronocyclus nitescens (Kamptner, 1963) Bramlette & Wilcoxon, 1967
Cyclicargolithus abisectus (Müller, 1970) Wise, 1973
Cyclicargolithus floridanus (Roth & Hay *in* Hay et al., 1967) Bukry, 1971
Cyclicargolithus luminis (Sullivan, 1965) Bukry, 1971
Dictyococcites bisectus (Hay, Mohler & Wade, 1966) Bukry & Percival, 1971
Discoaster barbadiensis Tan, 1927
Discoaster binodosus Martini, 1958
Discoaster deflandrei Bramlette & Riedel, 1954
Discoaster distinctus Martini, 1958
Discoaster druggi Bramlette &Wilcoxon, 1967
Discoaster kuepperi Stradner, 1959
Discoaster lodoensis Bramlette & Riedel, 1954
Discoaster multiradiatus Bramlette & Reidel, 1954
Discoaster saipanensis Bramlette & Riedel, 1954
Discoaster salisburgensis Stradner, 1961
Discoaster sublodoensis Bramlette & Sullivan, 1961
Discoaster tanii Bramlette & Riedel, 1954
Discoaster tanii nodifer (Bramlette & Riedel, 1954) Bukry, 1973
Ellipsolithus macellus (Bramlette & Sullivan, 1961) Sullivan, 1964
Ericsonia fenestrata (Deflandre & Fert, 1954) Stradner *in* Stradner & Edwards (1968)
Ericsonia formosa (Kamptner, 1963) Haq, 1971
Ericsonia subdisticha (Roth & Hay *in* Hay et al., 1967) Roth *in* Baumann & Roth, 1969
Helicosphaera ampliaperta Bramlette & Wilcoxon, 1967
Helicosphaera bramlettei Müller, 1970
Helicosphaera carteri (Wallich, 1877) Kamptner, 1954
Helicosphaera compacta Bramlette & Wilcoxon, 1967
Helicosphaera euphratis Haq, 1966
Helicosphaera heezenii (Bukry, 1971) Jafar & Martini, 1975
Helicosphaera intermedia Martini, 1965
Helicosphaera lophota Bramlette & Sullivan, 1961
Heliolithus kleinpelli Sullivan, 1964
Isthmolithus recurvus (Deflandre *in* Deflandre & Fert, 1954)
Lanternithus minutus Stradner, 1962
Neococcolithes dubius (Deflandre *in* Deflandre & Fert, 1954) Black, 1967
Neococcolithes minutus (Perch-Nielsen, 1967) Perch-Nielsen, 1971
Pontosphaera discopora Schiller, 1925
Pontosphaera lateliptica (Báldi-Beke & Baldi, 1974) Perch-Nielsen, 1984
Pontosphaera multipora (Kamptner, 1948) Roth, 1970
Pontosphaera plana (Bramlette & Sullivan, 1961) Perch-Nielsen, 1971
Reticulofenestra callida (Perch-Nielsen, 1971) Bybell, 1975
Reticulofenestra daviessi (Haq, 1968) Haq, 1971
Reticulofenestra dictyoda (Deflandre *in* Deflandre & Fert, 1954) Stradner *in* Stradner & Edwards, 1968
Reticulofenestra hillae Bukry & Percival, 1971
Reticulofenestra ornata Müller, 1970
Reticulofenestra pseudoumbilica (Gartner, 1967) Gartner, 1969
Reticulofenestra reticulata (Gartner & Smith, 1967) Roth & Thierstein, 1972
Reticulofenestra umbilica (Levin, 1965) Martini & Ritzkowski, 1968
Sphenolithus calyculus (Bukry, 1985)
Sphenolithus capricornutus Bukry & Percival, 1971
Sphenolithus conicus Bukry, 1971
Sphenolithus delphix Bukry, 1973
Sphenolithus disbelemnos Fornaciari & Rio, 1996
Sphenolithus dissimilis Bukry & Percival, 1971
Sphenolithus editus Perch-Nielsen *in* Perch-Nielsen et al., 1978
Sphenolithus moriformis (Brönnimann & Stradner, 1960) Bramlette & Wilcoxon, 1967
Sphenolithus radians Deflandre *in* Deflandre & Fert, 1954
Sphenolithus spiniger Bukry, 1971
Transversopontis fibula Gheta, 1975
Transversopontis pulcher (Deflandre *in* Deflandre & Fert, 1954) Hay, Mohler & Wade, 1966
Transversopontis pulcheroides (Sullivan, 1964) Báldi-Beke, 1971
Tribrachiatus orthostylus Shamrai, 1963
Triquetrorhabdulus carinatus Martini, 1965
Triquetrorhabdulus milowii Bukry, 1971
Umbilicosphaera rotula (Kamptner, 1956) Varol, 1982
Zygrhablithus bijugatus (Deflandre *in* Deflandre & Fert, 1954) Deflandre, 1959

Table 1: Nominal and percentage distribution of calcareous nannoplankton in Leluchów section. x — species too rare to be included in count.

	Leluchów Marl Mb																		**Smereczek Shale Mb**				**Malcov lithofacies**							
Calc. nannofossil Zone (Martini 1971)	**NP19–20**				**NP21**												**NP22**		**NP23**				**NP24**							
Sample	**48/82/N**		**49/82/N**		**1/08/N**		**2/08/N**		**3/08/N**		**4/08/N**		**5/08/N**		**6/08N**		**54/82/N**		**39/98/N**		**38/98/N**		**37/98/N**		**42/98/N**		**41/98/N**		**40/98/N**	
Sample abundance	**H**		**H**		**VH**		**VH**		**VH**		**VH**		**VH**		**VH**		**H**		**M**		**M**		**M**		**H**		**H**		**H**	
Nannofossil preservation	**M**		**M**		**G**		**G**		**G**		**G**		**G**		**G**		**G**		**M**		**M**		**M**		**M**		**M**		**M**	
Chiasmolithus grandis																							1	0.3			1	0.3		
Chiasmolithus medius									X		X		X		X						X		X		X		X		1	0.3
Chiasmolithus oamaruensis	1	0.3																							1	0.3				
Chiasmolithus sp.	2	0.6							X		2	0.6													X		2	0.6		
Discoaster barbadiensis									X												6	1.9	1	0.3	2	0.6	6	1.9	11	3.5
Discoaster lodoensis																					2	0.6	X		3	1.0	X		1	0.3
Discoaster multiradiatus	3	1.0	2	0.6																			3	1.0	X		4	1.3	2	0.6
Discoaster saipanensis							X		X												2	0.6	X		3	1.0	X		2	0.6
Discoaster sp.																			1	0.3	9	2.9	6	1.9	3	1.0	15	4.8	14	4.4
Discoaster tanii																					1	0.3	2	0.6	4	1.3	3	1.0	9	2.9
Discoaster tanii nodifer																					3	1.0	2	0.6	1	0.3	5	1.6	6	1.9
Ericsonia fenestrata																							X		X					
Ericsonia formosa																			13	4.1	25	7.9	18	5.7	17	5.4	16	5.1	21	6.7
Ericsonia subdisticha																									X					
Isthmolithus recurvus																			10	3.2			2	0.6	5	1.6	3	1.0	3	1.0
Lanternithus minutus																							X		X					
Neococcolithes dubius																					1	0.3		0.0	2	0.6				
Reticulofenestra dictyoda																			6	1.9			4	1.3			11	3.5	5	1.6
Reticulofenestra hillae																					12	3.8	3	1.0	4	1.3	5	1.6	7	2.2
Reticulofenestra reticulata																			5	1.6	2	0.6	3	1.0	4	1.3	1	0.3	X	
Reticulofenestra umbilica																					4	1.3	19	6.0	15	4.8	20	6.3	13	4.1
Sphenolithus predistentus					X																									
Sphenolithus radians																					1	0.3			2	0.6				
Sphenolithus spiniger			2	0.6	X		X		3	1.0	2	0.6																		
Tribrachiatus orthostylus			X																						1	0.3				0.0
undivided Cretaceous species	5	1.6	1	0.3			3	1.0	9	2.9					5	1.6	3	1.0	7	2.2	9	2.9	6	1.9	4	1.3	3	1.0	4	1.3
REWORKED SPECIES	**11**	**3 %**	**5**	**2 %**			**3**	**1 %**	**12**	**4 %**	**4**	**1.3 %**			**5**	**2 %**	**3**	**1 %**	**42**	**13 %**	**77**	**24 %**	**70**	**22 %**	**71**	**22 %**	**95**	**30 %**	**99**	**31 %**
Braarudosphaera bigelowii			X								1	0.3									2	0.6	3	1.0	X					
Chiasmolithus oamaruensis	1	0.3																												
Coccolithus pelagicus	53	17	82	26	79	25	75	24	66	21	122	39		25	34	11	44	14	56	18	51	16	65	21	72	23	34	11	65	21
Coronocyclus nitescens	8	2.5	3	1.0	2	0.6	X		2	0.6					1	0.3	2	0.6	X						2	0.6	3	1.0		
Cyclicargolithus abisectus																							5	1.6	10	3.2	11	3.5	6	1.9
Cyclicargolithus floridanus	4	1.3	31	9.8	61	19	91	29	110	35	47	15	70	22	89	28	81	26	41	13	50	16	46	15	56	18	68	22	44	14
Dictyococcites bisectus	83	26	73	23	64	20	47	15	42	13	66	21	87	28	27	8.6	77	24	99	31	76	24	77	24	45	14	44	14	57	18
Dictyococcites sp.	X		2	0.6	6	1.9	2	0.6	4	1.3	11	3.5	9	2.9	7	2.2	4	1.3			7	2.2	4	1.3	12	3.8	22	7.0	14	4.4
Discoaster barbadiensis	5	1.6	2	0.6																										
Discoaster deflandrei	X		X		X				1	0.3											X		X		1	0.3	X		2	0.6
Discoaster saipanensis	X		1	0.3																										
Discoaster sp.	4	1.3	6	1.9	X		1	0.3			X																			
Discoaster tanii	1	0.3	1	0.3	3	1.0									2	0.6														
Discoaster tanii nodifer			X						X		1	0.3																		
Ericsonia fenestrata					X		1	0.3			X		X		3	1.0	X		X											
Ericsonia formosa	4	1.3	7	2.2	11	3.5	5	1.6	1	0.3	2	0.6	X		X															
Ericsonia subdisticha					11	3.5	12	3.8	9	2.9	14	4.4	16	5.1	2	0.6			X		X									
Helicosphaera bramlettei													1	0.3							1	0.3			X		X		1	0.3
Helicosphaera compacta			X										X		1	0.3			2	0.6					X		3	1.0	2	0.6
Isthmolithus recurvus	X		X		9	2.9	5	1.6	3	1.0	1	0.3			2	0.6	7	2.2												
Lanternithus minutus					X		2	0.6			X		X		91	29	47	15	3	1.0	X									
Pontosphaera multipora															1	0.3			2	0.6					X					
Reticulofenestra callida									4	1.3	3	1.0	1	0.3																
Reticulofenestra dictyoda	15	4.8	10	3.2	4	1.3	3	1.0	2	0.6			3	1.0																
Reticulofenestra hillae	26	8.2	4	1.3	X		2	0.6	4	1.3			1	0.3	4	1.3	X													
Reticulofenestra lockerii																			19	6.0	15	4.8	11	3.5	3	1.0	2	0.6		
Reticulofenestra ornata																			22	7.0	11	3.5	7	2.2	11	3.5	10	3.2	X	
Reticulofenestra reticulata	2	0.6	X								X		2	0.6	3	1.0	2	0.6												
Reticulofenestra umbilica	84	27	67	21	36	11	36	11	29	9.2	1	0.3	3	1.0	X		3	1.0												
Sphenolithus dissimilis																							3	1.0	5	1.6	2	0.6	4	1.3
Sphenolithus moriformis	X		5	1.6	14	4.4	14	4.4	11	3.5	15	4.8	22	7.0	3	1.0	15	4.8	4	1.3	8	2.5	8	2.5	11	3.5	4	1.3	5	1.6
Sphenolithus predistentus					X																									
Transversopontis fibula																			1	0.3										
Transversopontis pulcher													X		6	1.9	X		2	0.6			1	0.3	1	0.3				
Transversopontis pulcheroides																	3	1.0							X		1	0.3	1	0.3
Zygrhablithus bijugatus			1	0.3	X		1	0.3	X		12	3.8	7	2.2	19	6.0	12	3.8	7	2.2	2	0.6	X		X		1	0.3		
AUTOCHTONOUS SPECIES	**290**	**92 %**	**295**	**93 %**	**300**	**95 %**	**297**	**94 %**	**288**	**91 %**	**296**	**94 %**	**300**	**95 %**	**295**	**93 %**	**297**	**94 %**	**258**	**82 %**	**223**	**71 %**	**230**	**73 %**	**229**	**73 %**	**205**	**65 %**	**201**	**64**

Table 2: Nominal and percentage distribution of calcareous nannoplankton in Matysova, Jarabina and Kremna sections. x — species too rare to be included in count.

	Matysova														Jarabina				Kremna							
Lithostratigraphy	**Magura Fm**																		**Kremna Fm**							
Age	**OLIGOCENE**																**O/M**		**MIOCENE**							
Calcareous nannofossil Zones Martini (1971)	NP24/25		NP25		NP25		NP25		NN1		NN1		NN1		NN1		NN1		NN2		NN2		NN2		NN2	
Sample Nos.	16/03/N		13/03/N		14/03/N		15/03/N		9/03/N		8/03/N		10/03/N		4/01/N		5/01/N		6/01/N		8/01/N		9/01/N		10/01/N	
Sample abundance	H		M		M		M		M		M		M		M		M		H		H		M		L	
Nannofossil preservation	M		M		M		M		P		P		P		M		P		M		M		M		P	
Chiasmolithus bidens	1	0.3		0		0		0		0		0		0		0		0	5	1.6	1	0.3	1	0.3		0
Chiasmolithus gigas	X		1	0.3	2	0.6		0	5	1.6	1	0.3	1	0.3		0	1	0.3		0		0		0		0
Chiasmolithus grandis		0		0		0		0	1	0.3	1	0.3		0		0		0	11	3.5	5	1.6	5	1.6	1	0.3
Chiasmolithus medius		0		0		0		0		0		0		0		0	2	0.6		0		0	1	0.3		0
Chiasmolithus solitus	5	1.6		0	1	0.3	3	1.0	11	3.5	4	1.3		0	6	1.9		0	6	1.9	8	2.5	12	3.8	6	1.9
Discoaster barbadiensis	45	14.3	14	4.4	20	6.3	7	2.2	17	5.4	13	4.1	16	5.1	7	2.2	8	2.5	14	4.4	15	4.8	21	6.7	31	9.8
Discoaster binodosus	10	3.2	3	1.0	14	4.4	13	4.1	15	4.8	22	7.0	7	2.2	29	9.2	10	3.2	18	5.7	8	2.5	7	2.2	7	2.2
Discoaster kuepperi	0		0		0		0		0		0		0		5	1.6	3	1.0		0		0		0		0
Discoaster lodoensis	0		0		0		0		1	0.3	2	0.6	0		8	2.5	6	1.9	6	1.9	X			0		0
Discoaster multiradiatus	6	1.9	0		0		1	0.3	8	2.5	11	3.5	13	4.1	0	0	1	0.3	4	1.3	4	1.3	4	1.3	2	0.6
Discoaster saipanensis	0		0		0		0		0	0		0	0		0	0		0		0	3	1.0	3	1.0		0
Discoaster salisburgensis		0	X			0		0		0	9	2.9	5	1.6	1	0.3		0	2	0.6		0		0		0
Discoaster sp.	0	0	6	1.9	4	1.3	4	1.3		0		0	1	0.3		0		0	3	1.0	3	1.0	1	0.3	X	0
Discoaster tanii	0		0		0		0		0		0		0		0	0	1	0.3		0	9	2.9		0		0
Discoaster tanii nodifer	0		0		0		0		0		0		0		0	0	1	0.3		0		0		0	2	0.6
Ellipsolithus macellus	0		0		6	1.9	0		9	2.9	1	0.3	6	1.9	2	0.6		0	9	2.9	9	2.9	12	3.8		0
Helicosphaera papilata																	X									
Ericsonia fenestrata	0	0	0	0	0	0	0	0	0	0	1	0.3	1	0.3	0	0	5	2	1	0.3	0	0	0	0	0	0
Ericsonia formosa		0		0		0		0	4	1.3	8	2.5	8	2.5	16	5.1	11	3	6	1.9	7	2.2	3	1.0	7	2.2
Heliolithus kleinpelli					3	1.0	2	0.6					2	0.6		0		0		0	1	0.3	3	1.0		0
Helicosphaera heezenii																	X									
Isthmolithus recurvus									X		X		X				1	0.3			X					
Neococcolithes dubius							1	0.3								0	6	1.9		0	1	0.3		0		0
Pontosphaera lateliptica	1	0.3	2	0.6			1	0.3	1	0.3													1	0.3		
Pontosphaera plana									4	1.3	1	0.3									7	2.2				
Reticulofenestra reticulata					1	0.3																				
Rhabdosphaera clavigera																	22	7.0								
Sphenolithus editus									8	2.5	1	0.3			34	10.8	29	9.2		0		0		0		0
Sphenolithus radians					1	0.3			20	6.3	3	1.0	26	8.2	10	3.2	18	5.7	18	5.7	19	6.0	14	4.4	18	5.7
Sphenolithus spiniger															1	0.3		0.0		0	1	0.3		0		0
Toweius rotundus	14	4.4	4	1.3	5	1.6	9	2.9	7	2.2	10	3.2	13	4.1	7	2.2	1	0.3	12	3.8	5	1.6	8	2.5	8	2.5
Transversopontis fibula																			5	1.6	3	1.0	2	0.6		0
Tribrachiatus orthostylus	8	2.5	5	1.6	21	6.7	13	4.1	23	7.3	42	13.3	23	7.3	57	18.1	30	9.5	38	12.0	21	6.7	35	11.1	37	11.7
undivided Cretaceous species	35	11.1	34	10.8	41	13.0	67	21.2	11	3.5	14	4.4	24	7.6	9	2.9	13	4.1	13	4.1	16	5.1	13	4.1	42	13.3
REWORKED SPECIES	**125**	**39.6 %**	**69**	**21.9 %**	**119**	**37.7 %**	**121**	**38.3 %**	**145**	**45.9 %**	**144**	**45.6 %**	**146**	**46.2 %**	**192**	**60.8 %**	**169**	**53.5 %**	**171**	**54.2 %**	**146**	**46.2 %**	**146**	**46.2 %**	**161**	**51.0 %**
Braarudosphaera bigelowii	27	8.6	11	3.5	4	1.3	32	10.1	1	0.3	1	0.3	15	4.8		0	1	0.3	1	0.3	2	0.6	1	0.3	10	3.2
Chiasmolithus oamaruensis		0		0	1	0.3		0	1	0.3		0.0		0		0		0		0		0		0		0
Coccolithus pelagicus	28	8.9	54	17.1	51	16.2	49	15.5	36	11.4	53	16.8	50	15.8	50	15.8	48	15.2	41	13.0	34	10.8	40	12.7	77	24.4
Coronocyclus nitescens	2	0.6		0	2	0.63	2	0.63	7	2.22	5	0		0	4	1.3	6	1.9		0		0		0	3	0.95
Cyclicargolithus abisectus	4	1.3	1	0.3	3	1.0	7	2.2	4	1.3		0		0		0		0		0	2	0.6		0	2	0.6
Cyclicargolithus floridanus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0.6	6	1.9	0	0	0	0	0	0	0	0
Cyclicargolithus luminis	0	0	0	0	0	0	0	0	10	3.2	0	0	0	0	0	0	0	0	2	0.6	15	4.8	18	5.7	0	0
Dictyococcites bisectus	5	1.6	6	1.9	1	0.3	2	0.6		0		0		0		0		0	X		X			0	X	
Discoaster deflandrei	1	0.3	X	0	0	0	0	0	1	0.3	0	0	X	0	1	0.3	1	0.3	0	0	0	0	0	0	X	0
Helicosphaera carterii	0		0		0	0	0		0	0	0	0	X		0	0	0		0		0		0		0	
Helicosphaera compacta															X				X		X		X			
Helicosphaera euphratis																					X		X			
Holodiscolithus macroporus																0	2	0.6		0		0		0		0
Pontosphaera discopora					1	0.3									0	0	0	0	3	1.0	8	2.5	2	0.6	2	0.6
Pontosphaera multipora			1	0.3									X								4	1.3				
Reticulofenestra daviessi									1	0.3	2	0.6														
Reticulofenestra dictyoda									5	1.6	1	0.3														
Reticulofenestra sp. small	0		0		0		0		7	2.2	0	0.0			0	0	6	1.9	5	1.6	16	5.1	0	0	0	0
Reticulofenestra ornata	1	0.3																								
Sphenolithus conicus			5	1.6	8	2.5			10	3.2	15	4.8	8	2.5	9	2.9	5	1.6	8	2.5	4	1.3	4	1.3	9	2.9
Sphenolithus delphix															1	0.3	3	1.0								
Sphenolithus disbelemnos													4	1.3	0	0	0	0	0	0	X	0	1	0.3	X	0
Sphenolithus dissimilis	3	0.3	5	1.6	4	0.6	4	0.6	5	0.6	5	1.3	2	0.6	0	0	1	0.3	1	0.3	13	1.3	0	0	5	0.3
Sphenolithus moriformis	72	22.8	79	25.0	62	19.6	67	21.2	35	11.1	65	20.6	53	16.8	24	7.6	20	6.3	43	13.6	30	9.5	40	12.7	20	6.3
Transversopontis pulcher													1	0.3	0	0	9	2.9	6	1.9	7	2.2	2	0.6	0	0
Transversopontis pulcheroides	1	0.3													0	0	0	0	4	1.3	3	1.0	15	4.8	4	1.3
Triquetrorhabdulus carinatus															0	0	0	0	0	0	2	0.6	0	0	X	0
Zygrhablithus bijugatus	31	9.8	69	21.9	44	13.9	16	5.1	32	10.1	9	2.9	21	6.7	17	5.4	23	7.3	14	4.4	14	4.4	31	9.8	3	1.0
AUTOCHTONOUS SPECIES	**175**	**55.4 %**	**231**	**73.2 %**	**184**	**58.3 %**	**181**	**57.3 %**	**155**	**49.1 %**	**156**	**49.4 %**	**156**	**49.4 %**	**108**	**34.2 %**	**131**	**41.5 %**	**128**	**40.9 %**	**155**	**49.1 %**	**157**	**49.7 %**	**139**	**44.0 %**

Table 3: Nominal and percentage distribution of calcareous nannoplankton in Poręba Mala section. x — species too rare to be included in count.

Lithostratigraphy	**Zawada Formation**																					
Age	**MIOCENE**																					
Calcareous nannofossil Zones Martini (1971)	**NN1**		**NN1**		**NN1**		**NN1**		**NN2**		**NN2**		**NN2**		**NN2**		**NN2**		**NN2**		**NN2**	
Sample Nos.	**18/00/N**		**17/00/N**		**16/00/N**		**15/00/N**		**25/00/N**		**24/00/N**		**23/00/N**		**22/00/N**		**21/00/N**		**20/00/N**		**19/00/N**	
Sample abundance	**H**		**M**		**H**		**M**		**H**		**M**		**M**		**H**		**M**		**H**		**H**	
Nannofossil preservation	**M**		**P**		**M**		**M**		**M**		**P**		**P**		**M**		**P**		**M**		**M**	
Chiasmolithus altus	4	1.3		0	14	4.4		0		0		0		0		0		0	4	1.3	7	2.2
Chiasmolithus bidens		0		0		0		0	6	1.9	2	0.63	2	0.6		0		0		0		0
Chiasmolithus expansus		0	5	1.6		0		0		0	1	0.3		0		0		0		0		0
Chiasmolithus gigas		0	2	0.6		0		0		0		0		0		0	3	1.0		0		0
Chiasmolithus grandis		0	11	3.5	X		1	0.3	1	0.3	1	0.3	2	0.6	4	1.3	2	0.6	2	0.6	4	1.3
Chiasmolithus medius		0		0		0	2	0.6		0		0		0		0		0		0		0
Chiasmolithus oamaruensis		0	2	0.6		0	6	1.9	2	0.6	2	0.6		0		0		0	1	0.3		0
Chiasmolithus solitus	2	0.6	11	3.5	11	3.5	9	2.9	4	1.3	4	1.3	13	4.1	9	2.9	9	2.9	11	3.5	10	3.2
Discoaster adamanteus		0		0		0		0	3	1.0	1	0.3	1	0.3		0		0		0	1	0.3
Discoaster barbadiensis	1	0.3	11	3.5	20	6.3	3	1.0	5	1.6	11	3.5	5	1.6		0	9	2.9	2	0.6	10	3.2
Discoaster binodosus	1	0.3	1	0.3	1	0.3		0	2	0.6		0	2	0.6		0		0		0		0
Discoaster distinctus	1	0.3	2	0.6		0		0	2	0.6		0	2	0.6	1	0.3		0	1	0.3	4	1.3
Discoaster kuepperi		0	2	0.6		0		0		0		0		0		0		0		0		0
Discoaster lodoensis		0	3	1.0	1	0.3		0	1	0.3		0	3	1.0		0		0	2	0.6	4	1.3
Discoaster mediosus		0		0		0		0		0		0		0	X			0		0		0
Discoaster multiradiatus		0	X			0		0		0		0	1	0.3		0		0		0		0
Discoaster saipanensis		0	5	1.6	3	1.0		0	4	1.3		0	6	1.9		0		0		0		0
Discoaster sp.	X		X			0		0		0		0		0		0		0		0		0
Discoaster tanii	3	1.0	2	0.6	7	2.2	3	1.0	3	1.0	3	1.0	5	1.6	1	0.3		0	1	0.3	1	0.3
Discoaster tanii nodifer		0	2	0.6	X			0	1	0.3		0		0		0		0		0		0
Ericsonia fenestrata	4	1.3		0	X			0	1	0.3		0	4	1.3		0	X		1	0.3		0
Ericsonia formosa	28	8.9	16	5.1	15	4.8	22	7.0	20	6.3	16	5.07	9	2.9	19	6.0	16	5.1	11	3.5	15	4.8
Ericsonia subdisticha	5	1.6	1	0.3		0		0		0		0		0		0		0		0		0
Helicosphaera bramlettei	9	2.9	14	4.4	6	1.9		0		0	6	1.9	11	3.5	9	2.9	14	4.4	13	4.1	3	1.0
Helicosphaera elongata		0		0	1	0.3		0		0		0		0		0		0		0		0
Helicosphaera lophota		0		0		0		0		0	2	0.6	1	0.3	2	0.6	8	2.5		0		0
Holodiscolithus macroporus		0	1	0.3		0		0		0		0		0		0		0		0		0
Lanternithus minutus		0		0		0		0		0	3	1.0	1	0.3	2	0.6	1	0.3		0		0
Neococcolithes dubius		0	10	3.2	5	1.6	1	0.3		0	4	1.3	5	1.6	3	1.0	9	2.9	1	0.3	3	1.0
Pontosphaera lateliptica	4	1.3		0	2	0.6	5	1.6	1	0.3		0		0		0		0		0		0
Reticulofenestra dictyoda	5	1.6	10	3.2	11	3.5	26	8.2	11	3.5	6	1.9	10	3.2	12	3.8	10	3.2	8	2.5	16	5.1
Reticulofenestra hillae	2	0.6	3	1.0	7	2.2	7	2.2		0	3	1.0	1	0.3		0	4	1.3		0	1	0.3
Reticulofenestra umbilica		0	1	0.3		0		0		0		0		0		0		0		0		0
Rhabdosphaera clavigera		0	2	0.6		0		0		0	1	0.3	4	1.3		0	3	1.0	1	0.3		0
Rhabdosphaera inflata		0		0		0		0	8	2.5		0		0		0		0		0		0
Semihololithus kerabyi		0		0		0		0	1	0.3	6	1.9	6	1.9		0	4	1.3	1	0.3	2	0.6
Sphenolithus calyculus		0		0		0		0	1	0.3	1	0.3		0		0		0		0	X	
Sphenolithus capricornutus		0		0		0		0		0	1	0.3	1	0.3		0		0		0		0
Sphenolithus delphix		0	1	0.3		0		0		0		0	1	0.3		0		0		0		0
Sphenolithus editus		0		0		0	2	0.6	X		1	0.3	2	0.6		0		0	1	0.3	1	0.3
Sphenolithus radians		0	1	0.3	2	0.6		0	4	1.3	2	0.6	2	0.6		0	2	0.6		0	2	0.6
Sphenolithus spiniger		0	2	0.6	1	0.3		0		0	1	0.3		0	1	0.3	2	0.6		0		0
Transersopontis fibula	2	0.6	3	1.0		0		0		0		0	3	1.0	2	0.6	1	0.3	3	1.0	1	0.3
Tribrachiatus orthostylus		0		0		0	1	0.3		0		0		0		0		0		0		0
undivided Cretaceous species	25	7.9	10	3.2	7	2.2	6	1.9	10	3.2	5	1.6	7	2.2	14	4.4	7	2.2	18	5.7	9	2.9
REWORKED SPECIES	**96**	**30.4 %**	**134**	**42.4 %**	**114**	**36.1 %**	**94**	**29.8 %**	**91**	**28.8 %**	**83**	**26.3 %**	**110**	**34.8 %**	**79**	**25.0 %**	**104**	**32.9 %**	**82**	**26.0 %**	**94**	**29.8 %**
Braarudosphaera bigelowii		0		0	5	1.6		0		0		0		0		0		0		0		0
Calcidiscus leptoporus		0		0		0		0		0		0	2	0.6	2	0.6	5	1.6		0		0
Coccolithus pelagicus	79	25.0	34	10.8	26	8.2	50	15.8	44	13.9	44	13.9	35	11.1	55	17.4	38	12.0	52	16.47	47	14.88
Coronocyclus nitescens	5	1.6	3	1.0	2	0.6		0	7	2.2	3	1.0	4	1.3	5	1.6	1	0.3		0	22	7.0
Cyclicargolithus abisectus	3	1.0	7	2.2	5	1.6	5	1.6	23	7.3	9	2.9	5	1.6	14	4.4	9	2.9	6	1.9	1	0.3
Cyclicargolithus floridanus	66	20.9	19	6.0	36	11.4	56	17.7	58	18.4	42	13.3	33	10.5	80	25.3	39	12.4	57	18.1	51	16.2
Cyclicargolithus luminis		0	1	0.3	4	1.3	1	0.3	1	0.3	4	1.3	4	1.3	14	4.4	3	1.0	2	0.6	3	1.0
Discoaster deflandrei	4	1.3	16	5.1	20	6.3	10	3.2	4	1.3	7	2.2	12	3.8	2	0.6	5	1.6	7	2.2	12	3.8
Discoaster druggi		0		0		0		0	1	0.3	6	1.9	3	1.0		0	2	0.6	3	1.0	3	1.0
Helicosphaera ampliaperta		0		0		0		0		0		0	X			0		0		0		0
Helicosphaera euphratis	2	0.6	2	0.6		0	X	0	3	1.0	X		1	0.3	1	0.3	1	0.3	3	1.0	1	0.3
Helicosphaera intermedia		0	1	0.3		0		0		0		0		0		0		0		0		0
Reticulofenestra sp. *small*	17	5.4	9	2.9	11	3.5	14	4.4	24	7.6	15	4.8	18	5.7	13	4.1	21	6.7		0	12	3.8
Neococcolithes minutus		0		0		0		0		0	1	0.3		0		0		0		0		0
Pontosphaera discopora	1	0.3	2	0.6		0		0		0		0	1	0.3	1	0.3	1	0.3	2	0.6		0
Pontosphaera multipora		0	2	0.6		0		0		0		0	5	1.6		0	4	1.3	9	2.9	1	0.3
Pontosphaera plana	1	0.3	4	1.3	1	0.3		0	2	0.6	3	1.0	3	1.0	1	0.3	2	0.6	4	1.3	3	1.0
Pontosphaera rothi		0	X	0		0		0		0		0		0		0		0		0		0
Reticulofenestra daviesii		0		0		0		0	4	1.3		0	4	1.3		0		0	X	0		0
Reticulofenestra pseudoumbilica		0		0	0	0		0	X	0		0		0		0		0		0		0
Sphenolithus conicus	3	1.0	4	1.3	13	4.1	2	0.6	4	1.3	17	5.4	10	3.2	4	1.3	12	3.8	8	2.5	14	4.4
Sphenolithus disbelemnos		0		0		0		0		0	4	1.3		0		0	X	0	X	0		0
Sphenolithus dissimilis		0	1	0.3	1	0.3		0	1	0.3	3	1.0	1	0.3		0	1	0.3	X	0	X	0
Sphenolithus moriformis	6	1.9	20	6.3	22	7.0	21	6.7	23	7.3	25	7.9	19	6.0	9	2.9	24	7.6	9	2.9	21	6.7
Transversopontis obliquipons		0	2	0.6		0		0		0		0		0		0		0		0		0
Transversopontis pulcher	12	3.8	7	2.2	3	1.0	4	1.3	1	0.3	2	0.6	13	4.1	13	4.1	11	3.5	24	7.6	1	0.3
Transversopontis pulcheroides	1	0.3	11	3.5	7	2.2	4	1.3	1	0.3	12	3.8	6	1.9	2	0.6	8	2.5	15	4.8	5	1.6
Triquetrorhabdulus carinatus		0	2	0.6	X	0		0	2	0.6	2	0.6	3	1.0		0	3	1.0	4	1.3		0
Triquetrorhabdulus milowii		0		0		0		0		0		0		0		0	X			0		0
Umbilicosphaera rotula		0		0		0		0	2	0.6	1	0.3	3	1.0		0		0		0		0
Zygrhablithus bijugatus	4	1.3	15	4.8	30	9.5	39	12.4	4	1.3	17	5.4	4	1.3	3	1.0	5	1.6	12	3.8	8	2.5
AUTOCHTONOUS SPECIES	**204**	**64.6 %**	**162**	**51.3 %**	**186**	**58.9 %**	**206**	**65.2 %**	**209**	**66.2 %**	**217**	**68.7 %**	**189**	**59.9 %**	**219**	**69.4 %**	**195**	**61.8 %**	**217**	**68.7 %**	**205**	**64.9 %**