Scientific Annals, School of Geology, Aristotle University of Thessaloniki Proceedings of the XIX CBGA Congress, Thessaloniki, Greece	Special volume 100	231-240	Thessaloniki 2010

CALCAREOUS NANNOPLANKTON BIOSTRATIGRAPHY OF THE TERMINAL SEDIMENTS OF THE MAGURA BASIN – A CASE STUDY OF THE POLISH SECTOR (OUTER WESTERN CARPATHIANS)

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Abstract: The Oligocene to Early Miocene closing of the northern sector of the Outer Carpathian sedimentary area is manifested by deposition of the Krosno synorogenic lithofacies in the Grybów-Dukla-Silesian/Sub-Silesian/Skole and Boryslav-Pokuttya basin system. The analogous Malcov synorogenic lithofacies is typical for the Pieniny Klippen Belt and Magura Basin. These lithofacies comprise the fining and thinning upwards sequences. Towards the top, the sedimentary sequences are dominated by marly pelites. In the Pieniny Klippen Belt, as well as in the Krynica and Rača zones of the Magura Basin, the deposition of the Malcov lithofacies was initiated during the NP24 and persisted to NP25 Zone. In the northern part of the Magura Basin (Siary Zone) the youngest deposits (so called Supra-Magura beds) belong to the NP24 Zone. The most important species to determine the NP24 zone in the region is *Cyclicargolithus abisectus*, and for NP25 – *Sphenolithus conicus*. During the Late Oligocene (NP25/NN1) the frontal part of Magura Nappe were thrust northwards onto the terminal Krosno flysch basin. The clastic material derived from eroded front of the Magura Nappe has been found in the Krosno shally facies of the Silesian Basin. The northwards thrusting of the Magura Nappe was also accompanied by formation of the piggy-back basin on the Magura Nappe, filled with synrogenic turbidites of the Zawada and Kremná formations – NN1 and NN2 zones. These nannofossil associations are characterised by the presence of *Sphenolithus delphix* (NN1) and *Sphenolithus disbelemnos* (NN2) while the species of *Dictyococcites bisectus* is absent. At the same time the level of reworked species is high.

Keywords: litho-and biostratigraphy, calcareous nannofossils, Late Oligocene, Early Miocene, Magura Nappe, Outer Western Carpathians

1. Introduction

History of the stratigraphic studies of the Magura Nappe has more than 100 years (Fig. 1A). The first information (beginning of XXth Century) about the Eocene age of the youngest deposits of the Magura Nappe was based on a few determinations of large foraminifera. This point of view has persisted until the mid-50ties of the last century, when the first analyses of small foraminifers were made. These investigations conducted in the northern, marginal part of the Magura Nappe in the Gorlice area (Fig. 1B) revealed the presence of assemblages of small globigerinas, characteristic for the Submenilite Globigerina Marls (SMGM). This datum level marks the Eocene-Oligocene boundary in the more external units (Krosno Zone or Moldavides) of the Outer Carpathians. Few years later, the Malcov Beds (Oligocene) were discovered in the Nowy Sącz area (for references see Osczypko-Clowes, 2001) over the Magura sandstones, regarded as the youngest deposits of the Magura Nappe at that time. For a long time, the SE part of the Magura Nappe, dominated by thick-bedded, turbiditic sandstones, devoid of fauna and microfauna, had a weaker stratigraphic recognition.

A significant qualitative change in biostratigraphic studies took place after application of calcareous nannoplankton. This resulted in the introduction of formal stratigraphic schemes in the Krynica and Bystrica zones (for references see Osczypko-Clowes, 2001). Contemporary research of calcareous nannoplankton from the Krynica and Bystrica zones suggested mainly early-middle Eocene age of formations, while the younger data were found in the outer zones, mainly in the Siary Zone. Such biostratigraphical framework strongly affected the palaeogeographic and palaeotectonic reconstruction not only for the Magura Nappe, but also for the entire outer Carpathians.

The aim of this paper is to summarize biostratigraphical data on the final Oligocene to Early Miocene stages of sedimentation in the Magura Basin. This is based on the author's latest research and recently published papers by Oszczypko-Clowes (2001), Oszczypko and Oszczypko-Clowes (2002; 2009, submitted) and Oszczypko et al. (1999, 2005).

cies differentiations with regards to the Palaeogene deposits, the Magura Nappe has been subdivided into four facies-tectonic zones, namely the Krynica (Orava), Bystrica (Nowy Sącz), Rača and Siary (Figs. 1B, 2, see also Koszarski et al. 1974). From the South, the Magura Nappe is in contact with the PKB along a sub-vertical Miocene strike-slip fault, and at the same time it is flatly overthrust northward over the For-Magura Group of Nappes and the Silesian Nappe by at least 50 km. During the

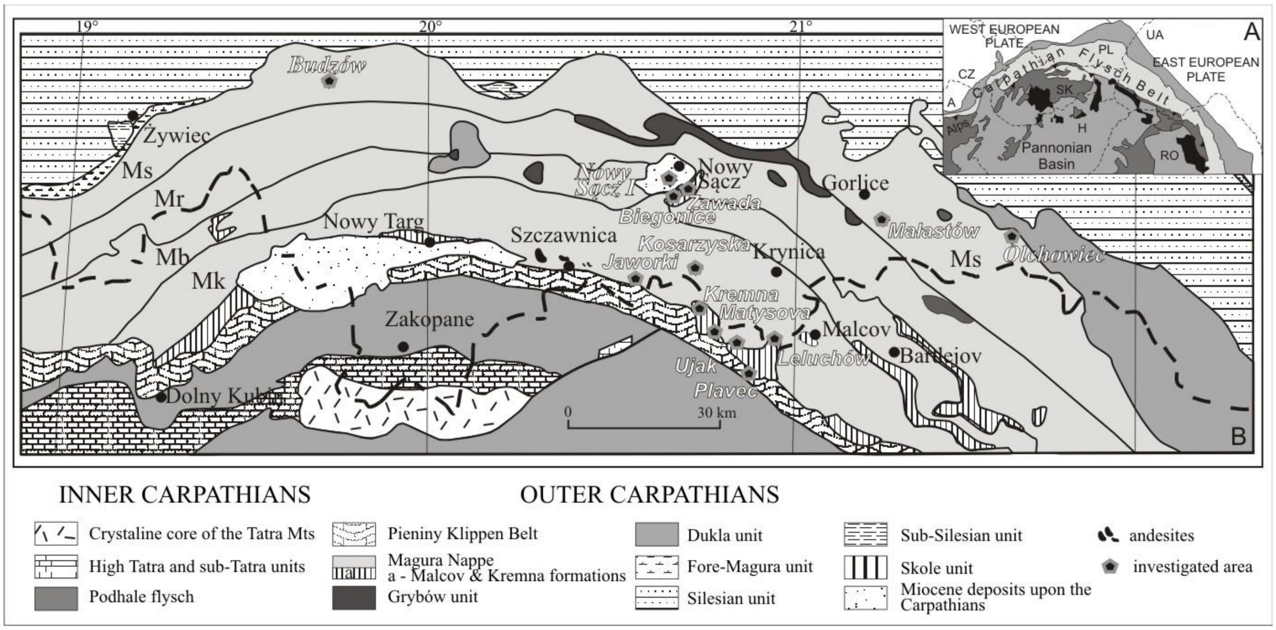

Fig. 1. (A) The geological map of the East Alpine-Carpathian-Pannonian basin system (after Picha et al. 2006), (B) Sketch-map of the Polish Carpathians and their fore-deep (based on Żytko et al. 1989, supplemented). Abbreviations: Su- Siary, Ru- Rača, Bu- Bystrica, and Ku- Krynica facies zones of the Magura Nappe.

2. Geological Setting

The Magura Nappe (Fig.1B) is the largest unit of the Outer Western Carpathians, linked up with the Rheno-Danubian flysch of the Eastern Alps in the west and the Marmarosh Flysch in the east (for references see Oszczypko and Oszczypko-Clowes 2009). The Magura Nappe is mainly composed of Late Cretaceous to the Eocene sediments. The oldest Jurassic – Early Cretaceous rocks are known as Grajcarek Unit from the Peri-Pieniny Klippen Belt (PKB) in Poland and a few localities in Southern Moravia (op.cit.). The youngest (Oligocene to Early Miocene) deposits of the Magura Nappe have been discovered in the Nowy Sącz area (Oszczypko et al., 1999, Oszczypko and Oszczypko-Clowes, 2002), Peri-PKB area (Cieszkowski 1992), and recently in the several other places (Oszczypko et al., 2005; Oszczypko and Oszczypko-Clowes submitted). On the basis of fa-

Late Oligocene – Middle Miocene thrust movements, the Magura nappe has been completely uprooted from its substratum, mainly along ductile Upper Cretaceous rocks (for references see Oszczypko and Oszczypko-Clowes 2009). The Lower Cretaceous (Hauterrivian – Cenomanian) deposits are known only at a few locations in Southern Moravia, whereas the more or less complete sections of the Upper Jurassic – Lower Cretaceous deposits are known only from the Grajcarek thrust sheets from the Peri-PKB area in Poland (for references see Oszczypko and Oszczypko-Clowes 2009).

2.1. Studied sections

For the purpose of this paper the selected profiles from all facies zones of the Magura Nappe and Pieniny Klippen Belt have been used (Fig. 2). This figure shows the synthetic lithostratigraphic profiles of the Palaeogene to Early Miocene deposits, across the Magura Nappe. These profiles are representative of the eastern sector of the Magura Nappe in Poland (Fig. 1B). As the level of correlation we adopted SMGM, or vicariously the top of the variegated shales with the *Reticulophragmium amplectens* (Middle – Late Eocene).

Palaeogene Basin) and PKB suture zone (Údol section, fig. 2). In the southern part of the Krynica Zone, the youngest deposits belong to the Malcov and Kremná formations (Figs. 2, 3). So far, the only site of Malcov Formation on the Polish side was found in the Leluchów section (for reference

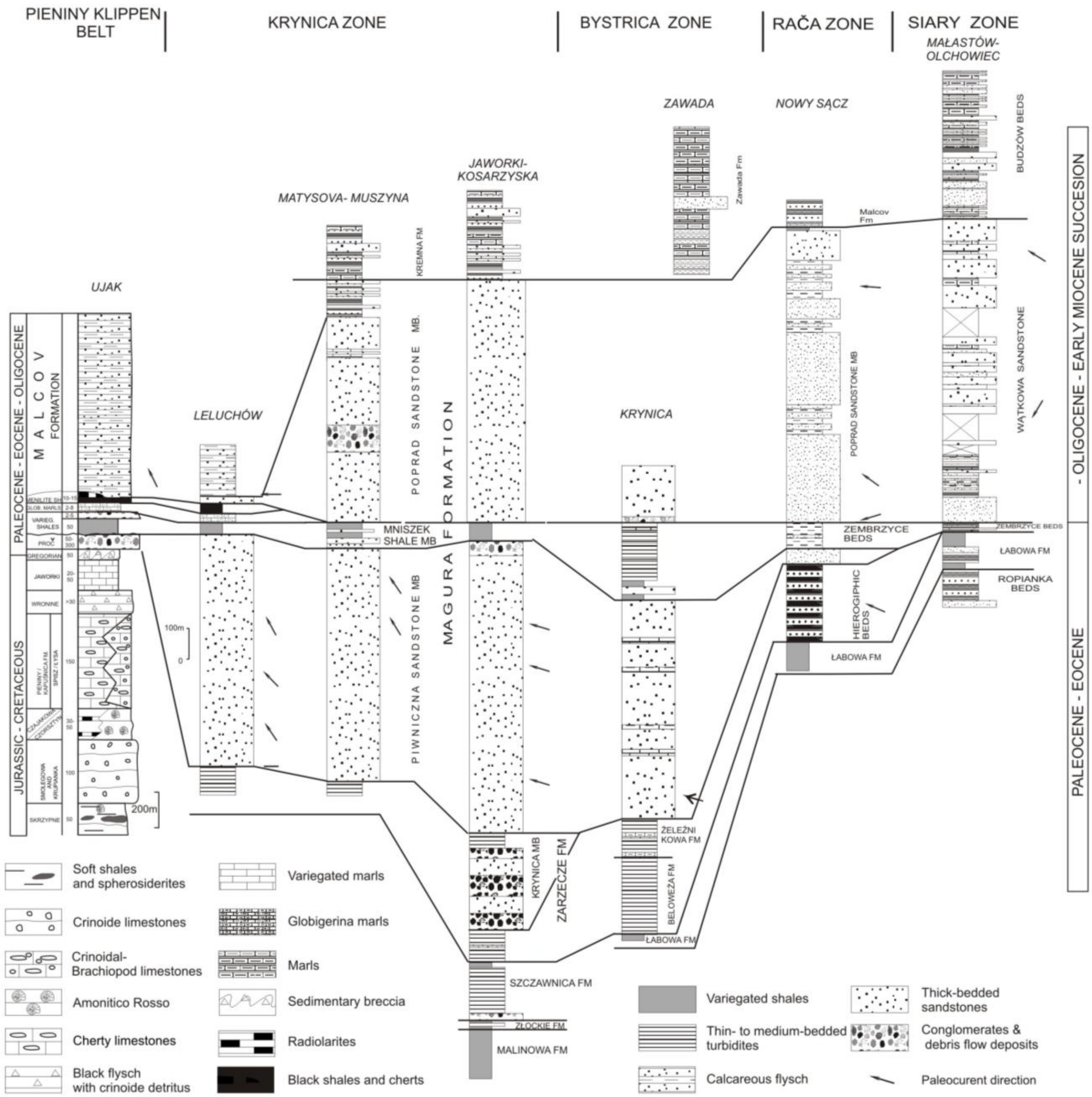

Fig 2. The lithostratigraphic logs of the Magura Nappe (after Oszczypko-Clowes 2001; Oszczypko and Oszczypko-Clowes 2009).

2.2. Krynica Zone

The Krynica facies zone provides an important insight for our understating of terminal history of the Magura Basin. This zone records facies links with post-nappe – Late Eocene to Oligocene basins of the Central Carpathians (Central Carpathian

see Oszczypko-Clowes, 2001). This section is situated close to the Polish-Slovak border, and is directly linked with the Ujak section of the PKB (Oszczypko et al., 2005). In the Leluchów profile, the Malcov Formation is composed of the following, Late Eocene to Oligocene lithostratigraphic units: the Leluchów Marls Member, Smereczek Shale Member and Malcov Formation s.s. The Leluchów Marl Member (see SMGM) consists of green and grey marly shales with numerous calcite veins covered by a 4 m thick unit of red, greyish-green, greenish and olive marls. The Smereczek Shale Member is represented by dark, silicified, Menilite-like shales (for references see Oszczypko-Clowes 2001). The lowermost portion of this member reveals a marly development with a few tuffite intercalations, and a thin (2-5 cm) intercalation of hornstones at the top. The upper portion of the Menilite Shales consists of black non-calcareous, bituminous shales with a few layers of coarse-grained, thick-bedded sandstone. In the uppermost part of the Leluchów section occur thin-bedded turbidites – dark-grey marly shales with intercalations of thin bedded (10-12 cm), cross-laminated calcareous sandstones. These flat-lying, south dipping strata belong to the Malcov Formation ss.

The similar type of the Malcov Formation is known from exposures in the Údol village near Stará Ľubovňa and Plaveč (Figs. 1B, 2). The upper part of the Malcov Formation is represented by dark grey marly shales with intercalations of thin to medium-bedded muscovite sandstones.

The Kremná Formation has been established by Oszczypko *et* al. (2005). The thickness of the for-

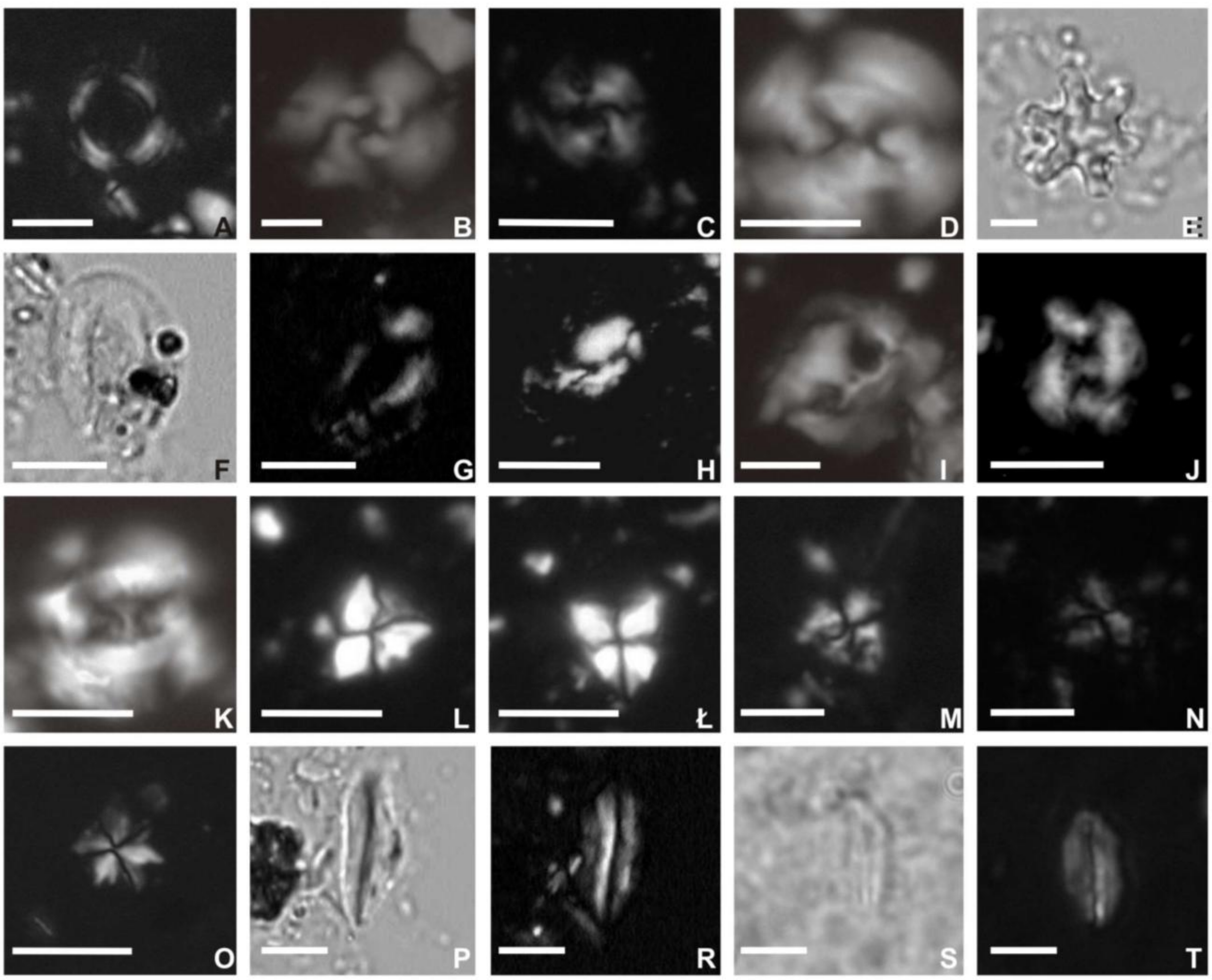

Fig. 3. Light microscope photographs of index nannofossil form Magura Kremná and Zawada formations (for the sample localities see Oszczypko and Oszczypko-Clowes 2002 and Oszczypko et al. 1999, 2005). The length of the scale bar is 5μm. A - *Coronocyclus nitescens*, Kremná Formation, B - *Cyclicargolithus abisectus*, Magura Formation, C - *Cyclicargolithus floridanus*, Magura Formation, D - *Dictyococcites bisectus*, Magura Formation, E - *Discoaster* cf. D. *druggii*, Zawada Formation, F, G - *Helicosphaera ampliaperta*, Zawada Formation, H - *Helicosphaera carterii*, Kremná Formation, I - *Helicosphaera recta*, Magura Formation, J, K -*Reticulofenestra lockeri*, Magura Formation, L, Ł- *Sphenolithus conicus*, Magura Formation, M, N - *Sphenolithus disbelemnos*, Kremná Formation, O - *Sphenolithus dissimilis*, Magura Formation, P, R -*Triquetrorhabdulus milowii*, Zawada Formation, S, T - *Triquetrorhabdulus rugosus*, Kremná Formation.

mation varies from 200-300 m in the Matysová and Dubne section up to 500–600 m in the Kremná and Jaworki-Kosarzyska section (Figs. 1B, 2). The Kremná Formation is composed of thin-to medium-bedded turbidites (T_{bc}) with intercalations of thick-bedded (1.0-2.0 m) massive sandstones. The upper part is dominated by thin-bedded turbidites. The calcareous sandstones are intercalated by gray marly shales.

2.3. Bystrica Zone

The youngest deposits of this zone belong to the Zawada Formation (Figs. 2, 4) which has been 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 the Zawada, Biegonice (Oszczypko et al., 1999; Oszczypko-Clowes, 2001) and Poręba Mała sections (Oszczypko and 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 (Fig. 2).

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 lack of exposures, the relationship between the Malcov Formation of the Rača Subunit and the Zawada Formation is not clear yet.

2.4. Rača Zone

In the Rača Zone, above the Poprad Sandstone Member of the Magura Formation, marls and shally lithofacies of Krosno-like facies were found in borehole Nowy Sącz I (Figs. 1B, 2, 4). These sediments are at least 100 m thick and were included into the Malcov Formation (see Oszczypko-Clowes et al. 2009).

In the Nowy Sącz 1 borehole, the Malcov Formation was pierced beneath the Late Badenian freshwater deposits (Oszczypko-Clowes et al., 2009) to a depth up to 540 m. Below this depth, folded deposits of the Magura Nappe were reached. The depth interval 540-602 m is dominated by dark-greyish, mainly non-calcareous claystones with sporadic intercalations of mudstones and very fine muscovite sandstones. At a depth of 569-571 m, light marly claystones with sideritic concretions were found. Further down (602.0-606.5 m), fragments of light-yellowish marls occurred. Beneath

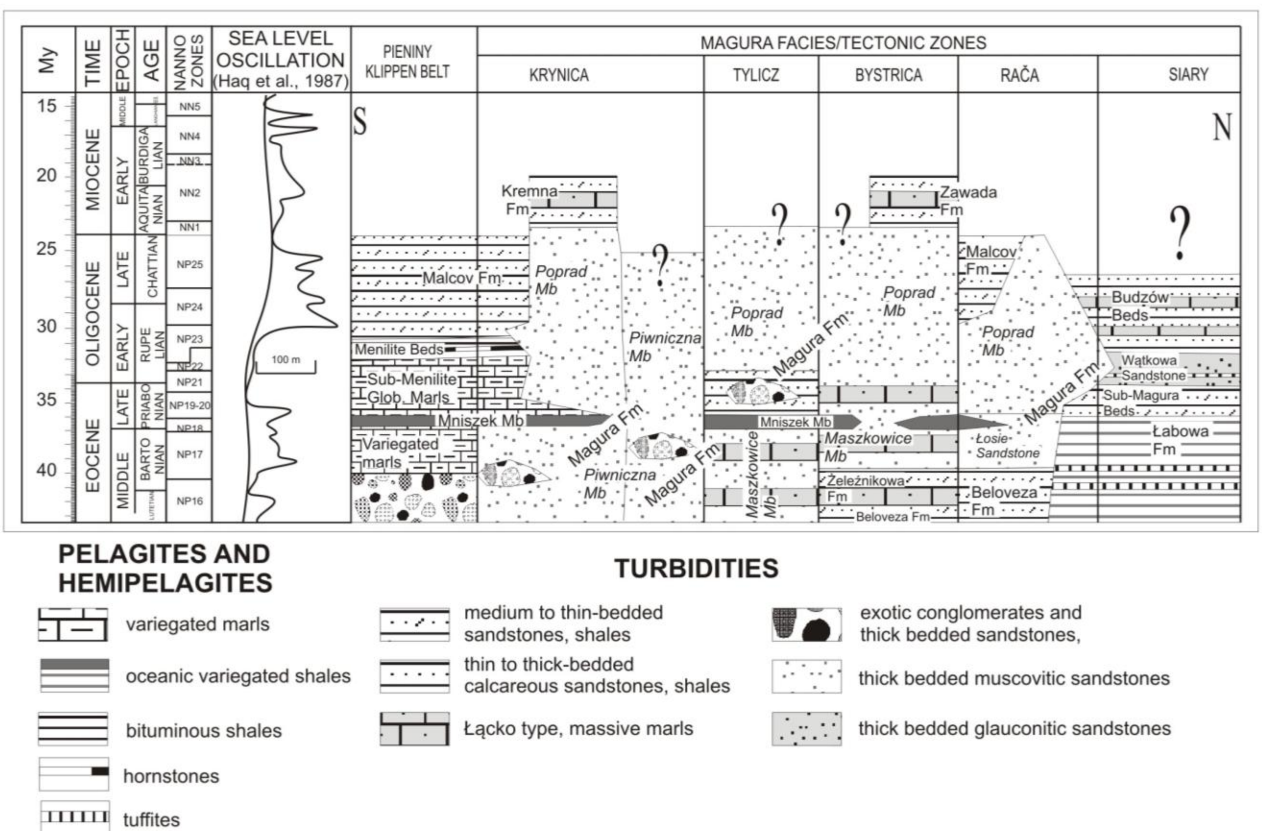

Fig. 4. The lithostratigraphic table of the Palaeogene – Early Miocene deposits of the Magura Nappe and Pieniny Klippen Belt (after Oszczypko and Oszczypko-Clowes, 2009).

the marls, down to a depth of 618.7 m, dark-greyish calcareous claystones and mudstones containing a few thick-bedded intercalations of medium-grained muscovite sandstones were pierced. At depth 618.7-620.8 m a 2 m thick layer of brown-chocolate claystones occurs, followed by dark-greyish claystones. Deeper still, to a terminal depth 704 m, poorly-cemented thick-bedded, muscovite sandstones of the Poprad Sandstone Member of the Magura Formation occur.

2.5. Siary Zone

In the Siary Zone, the Budzów Beds are an equivalent of the Malcov Formationof the Rača and Krynica/PKB zones. In the Małastów and Olchowiec sections (Figs. 1B, 2, 3), these beds occur above the Wątkowa sandstones. Their thickness varies from at least 290 m in Olchowiec, up to 470 m in the Malastów sections. The Budzów Beds are represented by marly claystones, with intercalations of medium to thick-bedded glauconitic sandstones. Subsequently silicified marls and spherosiderites are visible.

3. Material and Methods

A great number of samples (over 100) used for the nannofossil analyses were gathered during the author's field work. The samples were collected from the Malcov Formation in the Leluchów section and Nowy Sącz I borehole (Oszczypko-Clowes, 2001), Zawada Formation (Oszczypko et al., 1999; Oszczypko & Oszczypko-Clowes, 2002) and Kremná Formation (Oszczypko et al., 2005) of the Magura Nappe. Recently, new samples of the Kremná Formation, and Malcov Formation (Údol and Plaveč) have been obtained (Oszczypko and Oszczypko-Clowes, submitted).

All samples were prepared using the standard smear slide technique for light microscope (LM) observations. The investigation was carried out under LM at a magnification of 1000x using phase contrast and crossed nicols. Several of the specimens photographed in LM are illustrated in fig. 3.

The examined samples from the Zawada Formation contain well preserved and diverse calcareous nannoplankton assemblages, highly dominated by the reworked species, especially those of Middle/Late Eocene such as *Chiasmolithus gigas*, *Chiasmolithus grandis, Chiasmolithus oamaruensis, Discoaster barbadiensis*, *Discoaster bifax, Sphenolithus radians*, as well as some Oligocene species. The level of reworking varies from more than 60%, down to approximately 20-30%.

The abundance pattern for the Kremná Formation is different for certain samples, and varies from more than 15 species (per observation field) down to less than 5. Majority of specimens are easily identifiable. The level of reworking is generally not higher than 30%.

4. Biostratigraphy based on the calcareous nannofosils

For the purpose of this work the standard zonation of Martini (1970) and Martini and Worsley (1970) was used. In the case where the index species have not been observed, it was necessary to use the secondary index species.

Sphenolithus distentus Zone (NP24)
Age: Late Oligocene
Remarks: This zone was identified (Figs.1B, 2, 4) in the Budzów Beds from the Małastów and Olchowiec sections (Fig.1B, 2) and the Malcov Formation s.s. from the Leluchów section. The zone assignment is based on the first occurrence (FO) of *Cyclicargolithus abisectus*. The FO of *Cyclicargolithus abisectus* is usually found close to the FO of *Sphenolithus ciperoensis* (zonal marker for the lower boundary of zone NP24) and thus can be used to approximate the boundary of NP23 and NP24 (Martini and Műller 1986). In addition, *Sphenolithus dissimilis* was also observed. The FO of these species is characteristic for zone NP24 (see Perch-Nielsen 1985).

Sphenolithus ciperoensis Zone (NP25)
Age: Late Oligocene
Remarks: This zone was identified in the Malcov Formation from Údol and Plaveč localities, as well as from the borehole Nowy Sącz I (Figs. 1, 2, 4).
The zone assignment is based on the first occurrence of *Sphenolithus capricornutus* and *Sphenolithus conicus* and *Ponthosphaera rothi*. Slightly less abundant are *Cyclicargolithus abisectus*, *Reticulofenestra lockeri*, *Sphenolitus dissimilis* and *Reticulofenestra dictoda*. The species of *Dictyococcites bisectus* is occurring very rare, but it is still present. The (FO) of *Sphenolithus conicus* has been traditionally used as the base of the NN1 zone. However, Bizon and Műller (1979), Biolzi et al. (1981) and Melinte (1995) have observed the FO of these species as low as in the upper part of the zone NP25.

Discoaster druggii Zone (NN2)
Age: Early Miocene
Remarks: This zone was identified in the Kremná and Zawada formations (Figs. 2, 4).

The zone assignment of the described section is based on a 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 the association. According to the standard zonation of Martini (1970) and Martini and Worsley (1970), the first occurrence of *Reticulofenestra pseudoumbilica* takes place in the NN5 zone. However, in the Intra- and Outer Carpathian areas of Romania the FO of *Reticulofenestra pseudoumbilica* coincides with the FO *Discoaster druggii* (Marunteanu 1992), which corresponds to the lower limit of NN2. According to Young (1998), the FO of *Sphenolithus disbelemnos* and/or *Umbilicosphaera rotula* is a reliable biostratigraphical event characteristic for the lower limit of NN2 Zone.

Additionally, the nannofossil association from the Zawada Formation contains *Discoaster druggii* and *Helicosphaera ampliaperta.* The presence of *Discoaster druggii* was documented from more than 50% of investigated samples, whereas the occurrence of *Helicosphaera ampliaperta* is extremely rare. The presence of *Helicosphaera ampliaperta* can suggest the upper part of Zone NN2 (see Holcová, 2002; 2005).

5. Palaeoecology

During the Oligocene, drastic changes in palaeography and palaeoecology took place in Southern Europe. This was connected with transformation of the Western Tethys into the Eastern Paratethys. The transformation was initiated in the nannoplankton zones NP21/22 and resulted in the long lasting anoxic bottom conditions and deposition of the black shales (see Schulz et al., 2005). In the Carpathian sedimentary area, this was recorded by replacement of the pelagic Globigerina Marls by the menilite bituminous shales. These palaeoenviromental changes took place mainly in the northern external part of the Carpathian Flysch Basin (Skole, Sub-Silesian/Silesian and Dukla subbasins), in the lower extend in the Transylvanian and Central Carpathian Palaeogene basins, and to a very small extent also in the Magura Basin.

In the Fore-Magura, Ždánice-Subsilesian and Pouzdřany units of the Czech sector of the Outer Carpathians, the microfossils response on the paleoenvironmental changes has been described by Krhovský and Djurasinovič (1993) and Švábenická et al. (2007). These changes display the nannofossil blooms in the upper portion of the Menilite Formation and reflects the freshwater runoff (floods), decreased salinity, high nutrient input, and sea-level fluctuations connected with gradual isolation of the basin during the Oligocene. Simultaneously, the number of autochtonous species decreased and domination of reworked fossils is observed. This study also of confirmed the diachronous onset of the Krosno lithofacies (Švábenická et al., 2007).

In the Magura Basin, the Oligocene palaeoecological changes are manifested mainly in the Malcov Formation, which was paleogeographically connected with the Central Carpathian Palaeogene Basin. These changes are characterized by the distinct decrease of species diversity, drop of salinity and bloom of *Reticulofenestra ornata, Transversopontis fibula* and *Transversopontis latus* (Oszczypko-Clowes, 2001). In the Lower Burdigalian Zawada and Kremná formations, the palaeoecological changes are not so well manifested. This is probably due to domination of reworked nannofossils derived from the intensively eroded accretionary prism.

6. Palaeogeography

At the turn of the Eocene, the fundamental reorganization of the Magura Basin took place. It was probably related to the first manifestations of an eastwards escape of the ALCAPA (Alpine-Carpathian-Pannonian) Mega Unit to its Early Miocene, pre-orogenic position (Figs. 2, 3, 5, see also Ustaszewski et al., 2008; Oszczypko and Oszczypko-Clowes, 2009). As a result, the Oligocene Magura Basin was occupied by three distinct, interfingering turbiditic lithofacies: glauconitic sandstones in the north (Siary Zone), the Magura type muskovitic sandsones in the middle and southern part of the basin (Rača, Bystrica and Krynica zones), and the black shales and calcareous sandstones (Malcov Formation) in the southernmost part of the basin. These facies were supplied from the different source areas. The Malcov lithofacies records a connection with the PKB and Central Carpathians Paleogene Basin (CCPB), post-nappe basins, and locally overlapped with an angular discordance the Magura type sandstones.

The Oligocene – Early Miocene closing of the northern sector of the Outer Carpathian sedimentary area is manifested by deposition of the Krosno synorogenic lithofacies, which occupied the Grybów-Dukla-Silesian/Sub-Silesian/Skole and Boryslav-Pokuttya basin system (Fig. 5). These lithofacies represent the fining and thinning upwards sequences. Towards the top, the sedimentary sequences are dominated by marly pelites. The beginning and termination of these deposits was diachronic and migrated across the basins towards the north.

The Malcov lithofacies, an equivalent of the Krosno one, is 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 NP 24 and persisted to NP25 zone, whereas in the Rača zone in NP24 and NP25 respectively. In the northern part of the Magura Basin (Siary zone) the youngest deposits (so called Supra-Magura beds) belongs to NP24 zone (Oszczypko-Clowes, 2001). In the Grybów-Dukla units, the Krosno shaly facies belongs to NP25.

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

7. Conclusions

1. In the Magura Basin the youngest (terminal) flysch deposits belong to the Supra-Magura Beds, Malcov and Zawada/Kremná formations.

2. The deposition of the Supra-Magura Beds – glauconitic sandstones and massive marly mudstones took place in the deepest, northernmost part of the Magura Basin (Siary facies Zone). During the Late Oligocene (NP24/NP25 zones) this part of the basin was uplifted and transformed in the fron-

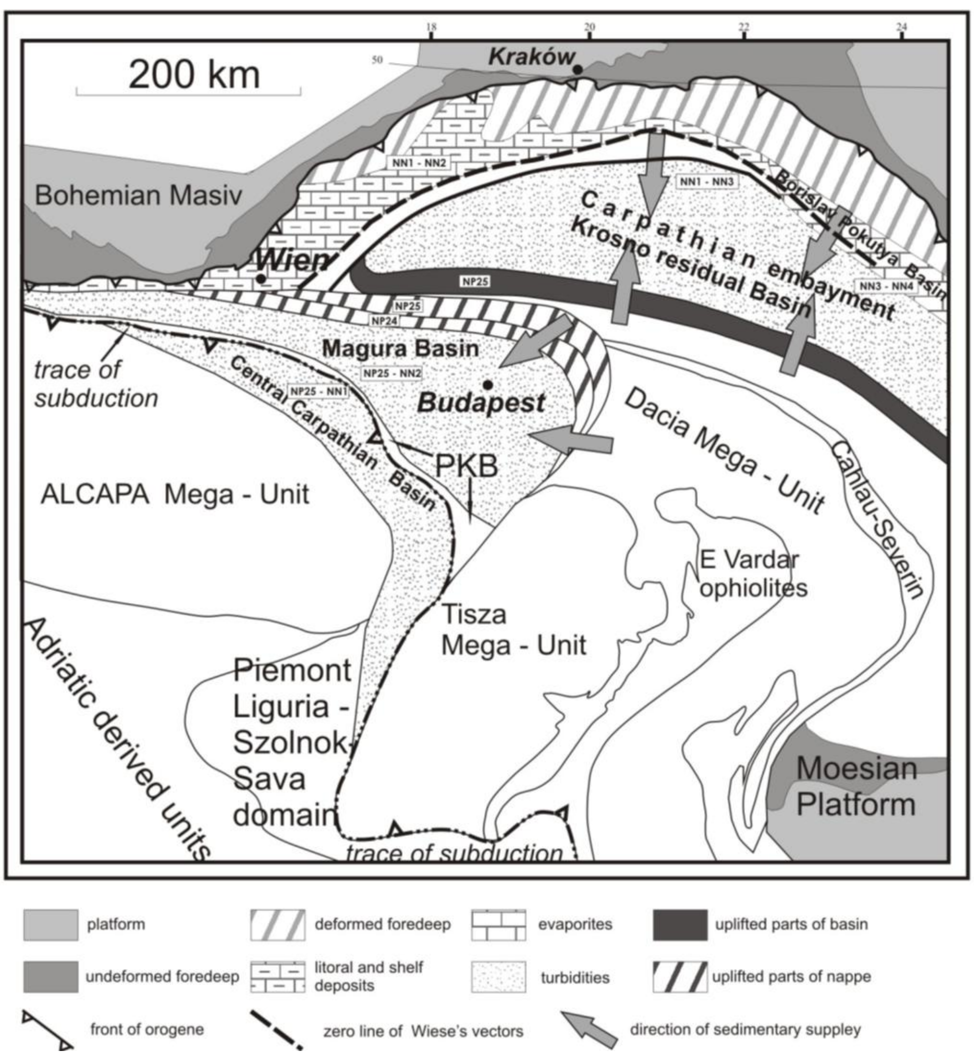

Fig. 5. A map-view restoration of the Alpine-Carpathian-Dinaridic system for the Early Miocene after Ustaszewski et al. (2008).

tal part of the Magura Nappe, overthrust upon the Fore-Magura Basin.

3. The Malcov lithofacies (Rača, ? Bystrica and Krynica facies zones) correspond to the Krosno synorogenic facies and display the same sedimentary development. The termination of the Malcov Formation took place in the Late Oligocene, NP24 and NP25.

4. The youngest deposits of the Magura Basin belong to the Zawada/Kremná formations are of Early Miocene age (NN1, NN2). This synorogenic turbiditic facies, characterized by the high content of carbonate clasts and reworking nanofossils, form the sedimentary infill of a piggy-back basin on the Magura Nappe.

Acknowledgments

The author is gratefully indebted to Dr. Eva Halásová, Dr. Lilian Švábenická and Prof. Dušan Plašienka for their constructive comments which greatly improved this paper.

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