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Oligocene palaeoenvironmental changes in the Romanian Carpathians, revealed by calcareous nannofossils

(Figs 1–6)

Abstract. Calcareous nannofossils from five sections from the Eastern Carpathians (Romania) have been investigated to identify palaeoenvironmental and palaeoclimatic changes during the Oligocene. Both qualitative and quantitative analysis hade been performed. The nannofloral assemblages reflect cool surface water conditions during Early Oligocene (corresponding to the upper part of NP21 through lower part of NP24 nannofossil zones) and warm water conditions during Late Oligocene (upper part of the NP24 and lower part of the NP25 nannofosil zones). A cooling interval was assumed for the latest Oligocene–basal Miocene (upper part of the NP25 and base of NN1 nannofossil zones), followed by a restoration of a warmer climatic mode in the earliest Miocene. A sea-level fall characterized the early Rupelian, interval when the salinity strongly decreases. These palaeoenvironmental conditions are reflected by the bloom of endemic nannofloras. A sea-level rise characterized the late Rupelian as well as the early Chattian. The deposition of coccolithic limestones, containing bloom of cosmopolitan nannofloral species (within the NP24 Nannofosil Zone) could indicate the Late Oligocene Warming Event in the Romanian Carpathians. The sea-level dropped again in the late Chattian, followed by a new transgression within the latest Chattian–earliest Aquitanian interval.

Key words: calcareous nannofossils, Oligocene, Romanian Carpathians, palaeoenvironment, palaeoclimate.

INTRODUCTION

The Oligocene was a relatively short time-span, but one that was characterized by major geological changes. A dynamic geological evolution of the Tethyan Realm led to the main structuring of the thrust-and-fold belts of the Alpine chain. The tectonic movements changed the paleogeographical pattern of Europe. The Tethys Ocean was divided into the Mediterranean Sea in the southern and western Europe (Dercourt *et al.*, 1993) and the Paratethys Sea, in its central and eastern part

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(Báldi, 1980; Rusu, 1988). The cooling trend prevailing throughout the Oligocene (Aubry, 1992) modified the life and the habitat of many organisms, the marine ones being especially affected. The marine biotic provinces became more fragmented and the appearance of endemic taxa marked the occurrence of several (semi) isolated basins in Europe.

The distribution pattern of the calcareous nannofossils, marine plankton that are very sensitive to palaeoenvironmental fluctuations (e.g., salinity, temperature, nutrients), may be helpful in reconstructing major palaeoecological changes that took place during the Oligocene.

This paper presents the results of qualitative and quantitative analysis of Oligocene calcareous nannofossils from Eastern Carpathian sections (Romania, Central Paratethys). An interpretation including such palaeoenvironmental factors as sea surface temperature, salinity and nutrient availability is provided.

GEOLOGICAL SETTING

Oligocene deposits crop out in large areas within the Tarcau Nappe and the Marginal Fold Nappe (Outer Flysch Zone of the East Carpathians), belonging to the sedimentary cover of the Outer Moldavides (*sensu* Săndulescu, 1984). In Romania, the Oligocene successions are represented by two lithofacies (Fig. 1): Pucioasa-Fusaru (inner – westernmost), having the source of the detritics in the Carpathian area and the Kliwa (outer – easternmost) sourced in the Foreland (Săndulescu & Micu, 1989).

The Lower Oligocene (the Rupelian stage) is characterized in both lithofacies by the occurrence of the Lower Dysodilic Shale Formation, containing bituminous shales with frequent sulphur and disarticulated fish remains. Within this formation, thin laminated coccolithic limestones, similar to the Lower Oligocene Tylawa Limestone from the Western Outer Carpathians of Poland (*cf.* Haczewski, 1989), can be found (Ştefănescu *et al.*, 1993; Melinte, 1995; Rusu *et al.*, 1996). In the eastern (outermost) facies, the base of the Oligocene is represented by the Lower Menilitic Formation, consisting of cherts and bituminous marls (Fig. 1).

The Upper Oligocene (the Chattian stage) of the inner lithofacies is characterized by the occurrence of the Pucioasa Marls with Fusaru Sandstone Formation, composed of bituminous marls interlayered with calcareous sandstones. Within the outer lithofacies, the same interval consists of the Kliwa Sandstone Formation, including white massive, orthoquartzitic sandstones interlayered with thin bituminous shales.

Two distinct nanno-chalk layers (similar to the Jasło and Zagórz coccolithic limestones from the Outer Polish Carpathians – *cf.* Haczewski, 1989; Bąk, 1999) occur within the Upper Oligocene deposits of both Eastern Carpathian facies (Alexandrescu & Brustur, 1985; Ionesi, 1986; Rusu *et al.*, 1996).

The uppermost Oligocene and the lowermost Miocene are characterized by the occurrence of shaly-sandy turbidites with thin tuffs (Ştefănescu *et al.*, 1993; Melinte, 1993; Ionesi *et al.*, 1999).

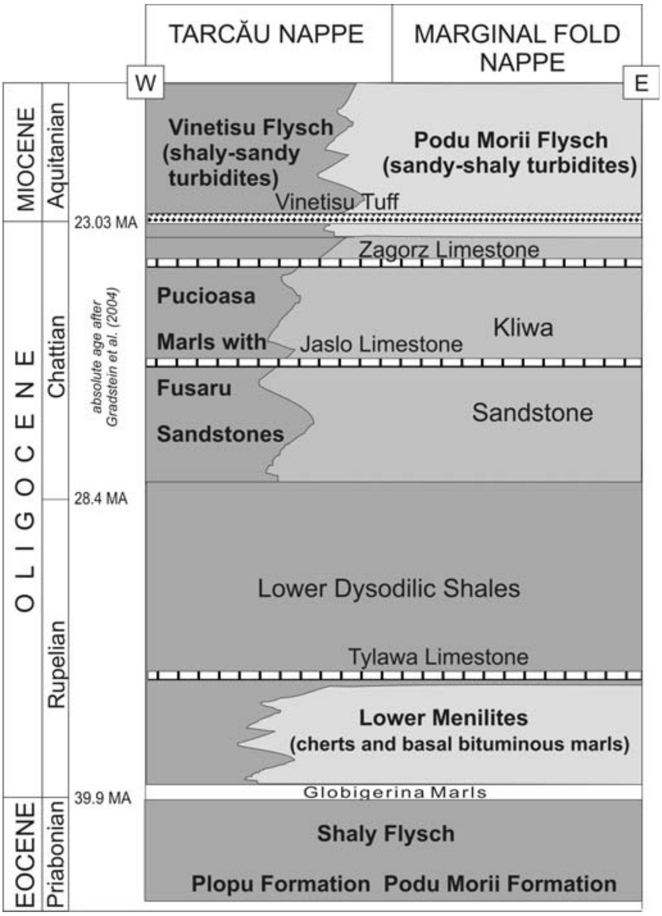

Fig. 1. Oligocene lithofacies of Eastern Carpathians

METHODS AND MATERIAL

Calcareous nannofossils from five Oligocene sections in the Eastern Carpathians were investigated. The sections are located, from north to south, as follows (Fig. 2): 1 – the Târgu-Ocna Section (the right bank of the Trotuş Valley) is situated in the Tarcău Nappe (Kliwa Facies); 2 – the Putna Valley Section (the left bank of the Putna River) is placed in the Marginal Fold Nappe (Vrancea Halfwindow – Kliwa Facies); 3 – the Buzău Valley Section (the left bank of the Buzău River) is situated in the Tarcău Nappe (Kliwa Facies); 4 – the Vinetişu section (in the Buzău Valley Basin) is located in the Tarcău Nappe (Pucioasa-Fusaru Facies); 5 – the Nehoiaşu Section (in the Buzău Valley Basin) is located in the Tarcău Nappe (Pucioasa-Fusaru Facies).

The sediments of the investigated sections cover the whole Oligocene interval, including its lower and upper boundaries (Fig. 3). The Oligocene successions were in detail sampled for nannofloral investigations. Samples were taken every 10 cm.

Fig. 2. Location of studied sections

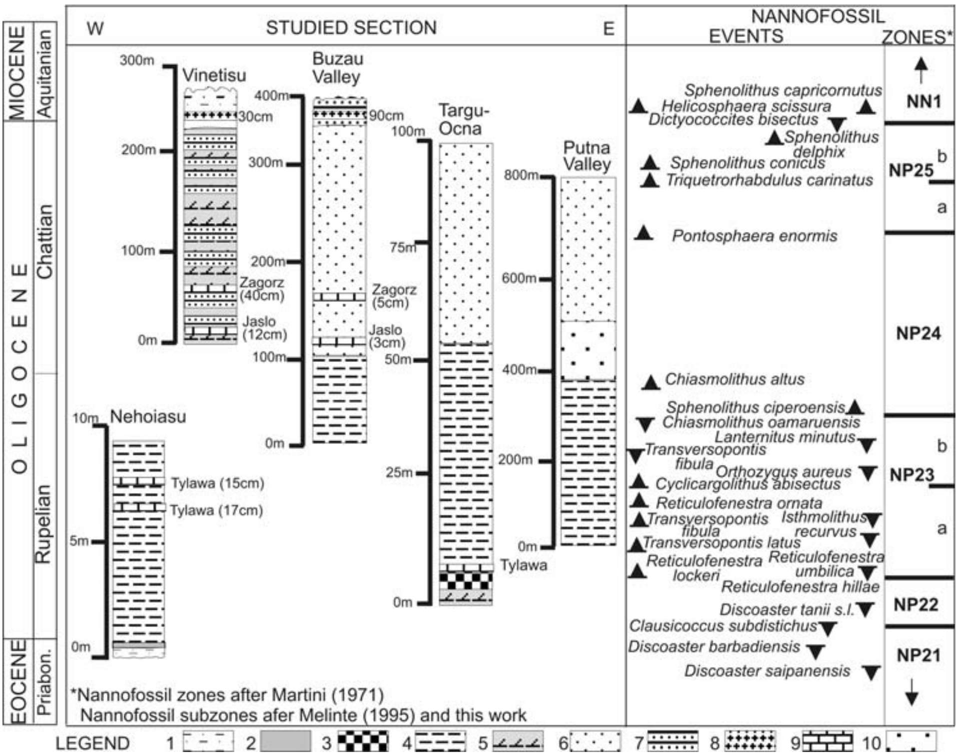

Fig. 3. Lithology of studied sections from Eastern Carpathians and main nannofossil events. Legend: *1* – shally turbidites; *2* – marls with globigerinids; *3* – cherts; *4* – bituminous shales; *5* – bituminous marls; *6* – sandstones; *7* – sandy turbidites; *8* – tuffs; *9* – coccolithic limestones; *10* – conglomerates

To achieve quantitative analyses, at least 500 specimens were counted in each smear-slide, in longitudinal transverses randomly distributed. The individual taxonomical diversity, in percentage, was considered from the total counted taxa.

Four taxonomical groups of calcareous nannofossils were considered for palaeoecological investigations, as follows:

– *Sphenolithus* spp., taxa confined to warm well oxygenated surface waters and to open marine environments (Aubry *et al.*, 1992; Fornaciari *et al.*, 1996);

– *Helicosphaera* spp., nannofossils more related to warm surface waters and near-shore environment (Bukry *et al.*, 1971; Krhovský *et al.*, 1993);

– *Dictyococcites bisectus* and *Zygrhablithus bijugatus*, cosmopolitan species, more frequent in near-shore environments (Krhovský *et al.*, 1992), blooming when nutrient input increased (Melinte, 1993);

– *Pontosphaera* spp., euthrophic taxa (Aubry, 1992), which proliferated under stable marine conditions and tolerated only slight salinity fluctuations (Nagymarosy & Voronina, 1992).

RESULTS

In the studied Oligocene sediments, 38 species were identified (Figs 4, 5). Similar results were obtained in all the Oligocene investigated successions. The nannofloral distribution and fluctuation pattern given in Figure 4 summarized the data of all the studied sections.

The maximum diversity (22 calcareous nannofossil species) was recorded within the lowermost Rupelian (upper part of NP21 Nannofossil Zone) and in the upper Chattian (uppermost part of NP25 Nannofossil Zone). The minimum diversity of nannofloral assemblages (14 species) was observed within the upper Rupelian, at the boundary between the NP23 and NP24 nannofossil zones – Fig. 4. Five nannofloral extinction events, of *Discoaster saipanens* Bramlette & Riedel, *D. barbadienis* Tan, *Clausicoccus subdistichus* (Roth & Hay) Prins, *Discoaster tanii* (Bramlette & Riedel) Bukry and *Helicosphaera reticulata* Bramlette & Wilcoxon), were identified within the Eocene/Oligocene boundary interval and in the lower Rupelian (upper part of NP21 and in the NP22 nannofossil zones). A more pronounced extinction was noted within the upper Rupelian (NP23 Nannofossil Zone), where seven nannofossil species, *Isthmolithus recurvus* Deflandre, *Reticulofenestra hillae* Bukry & Percival, *R. umbilica* (Levin) Martin & Ritzowski, *Orthozygus aureus* (Strdaner) Brameltte & Wilcoxon, *Lanternitus minutus* Stradner, *Chiasmolithus oamaruensis* (Deflandre) Hay, Mohler & Wade and *Transversopontis fibula* Gheta have their highest occurrence.

An important speciation of coccolithophores took pace at the end of the early Rupelian (NP23a Nannofossil Subzone), when *Reticulofenestra lockeri* Müller, *R. ornata* Müller, *Transversopontis fibula* and *T. latus* Müller appeared (Fig. 4). Another interval of accelerated nannofloral radiation within the Romanian Carpathians was recorded within the Oligocene/Miocene boundary interval (NP25b and NN1), when seven species (*Helicosphaera paleocarteri* Theodoridis, *Triquetror-*

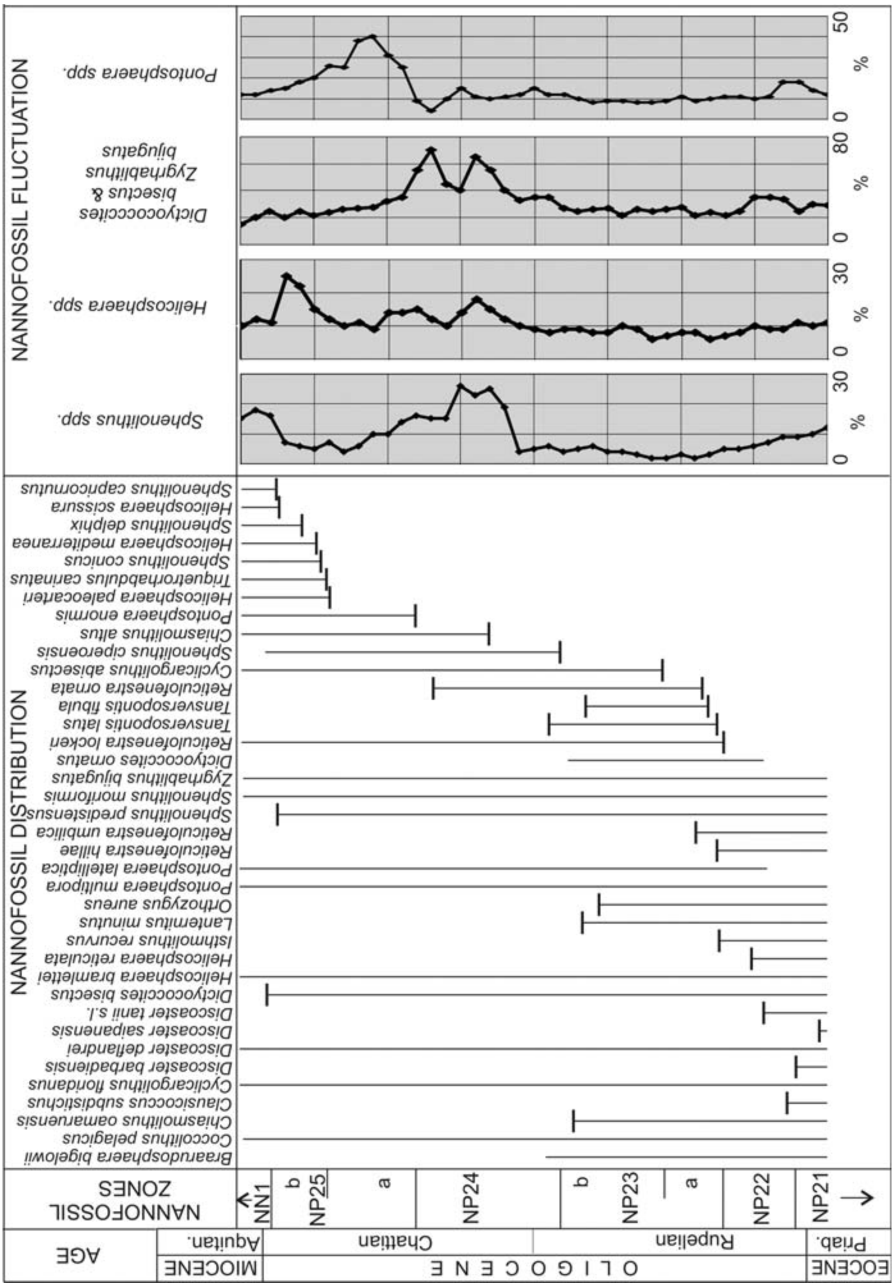

Fig. 4. Synthetic chart of the distribution and fluctuation of selected nannofossils in the Eastern Carpathians

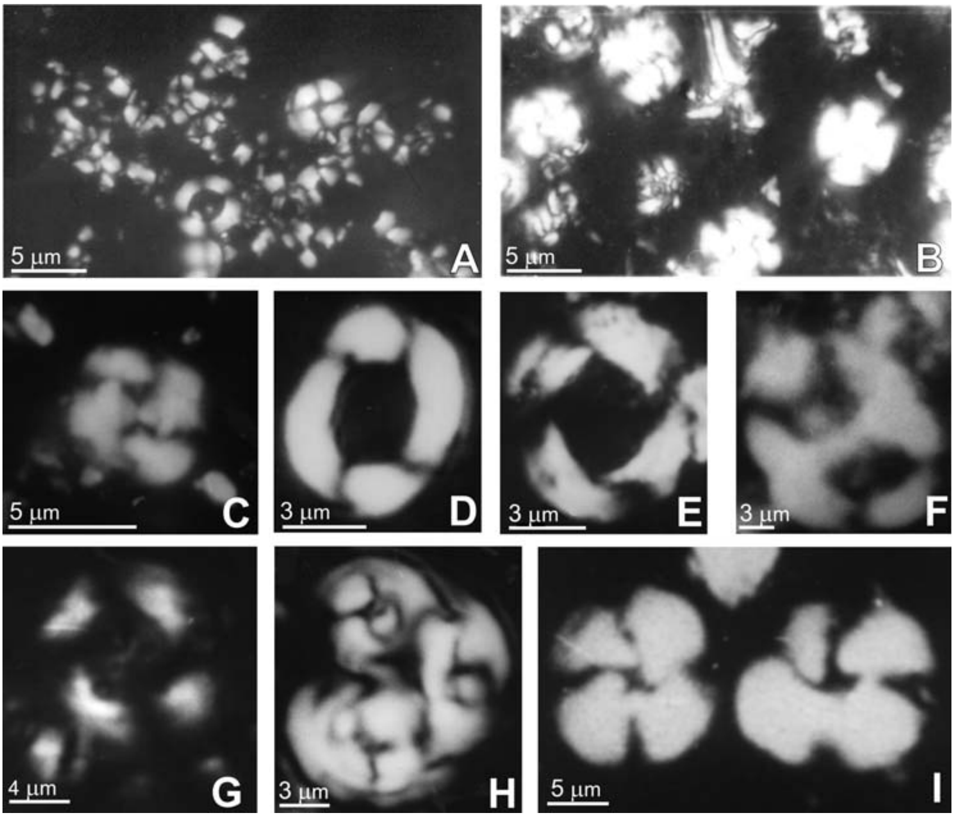

Fig. 5. Microphotographs of nannofosil species from Eastern Carpathians, LM, N+. **A** – Bloom of *Reticulofenestra ornata* Müller, NP24, Jasło Limestone, Buzau Valley Section. **B** – Blooms of *Dictyococcites bisectus* (Hay *et al.*) Bukry & Percival and *Zygrhablithus bijugatus* (Deflandre), NP24, Zagórz Limestone, Vinetişu Section. **C** – *Reticulofenestra lockeri* Müller, NP23, Lower Dysodilic Shale Formation, Târgu-Ocna Section. **D** – *Pontosphaera latelliptica* (Baldi-Beke & Baldi) Perch-Nielsen, NP25, Pucioasa Formation with Fusaru Sandstone, Vinetişu Section. **E** – *Reticulofenestra hillae* Bukry & Percival, NP22, Lower Dysodilic Shale Formation, Târgu-Ocna Section. **F** – *Transversopontis fibula* Gheta, NP23, Lower Dysodilic Shales, Târgu-Ocna Section. **G** – *Dictyococcites ornatus* (Müller) Bistrická, NP23, Tylawa Limestone, Nehoiaşu Section. **H** – Coccosphere of *Dictyococcites bisectus*, Jasło Limestone, Vinetişu Section. **I** – Bloom of *Cyclicargolithus floridanus* (Roth & Hay) Bukry, Jasło Limestone, Vinetişu Section

habdulus carinatus Martini, *Sphenolithus conicus* Bukry, *Helicosphaera mediterranea* Müller, *Sphenolithus delphix* Bukry, *Helicosphaera scissura* Müller and *Sphenolithus capricornutus* Bukry & Percival first appeared.

In the studied sections, the genus *Sphenolithus* represents from 2 up to 26% of the total nannofloral assemblages (Fig. 4). The highest abundance of sphenoliths was observed in the lower Chattian (NP24 Nannofossil Zone), while the lowest one was recorded in the lower Rupelian (uppermost NP22 and lowermost NP23 nannofossil zones). The total abundance of *Sphenolithus* significantly drops to 4%, in the upper Chattian (NP25), but it increases to 18% within the Oligocene/Miocene boundary interval (NN1 Nannofossil Zone). *Helicosphaera* spp. makes 6 to 30% of calcareous nannoplankton assemblages in the studied Romanian sections, with its maximum evidenced in the uppermost Chattian, NP25b Subzone, and the minimum in the Rupelian, NP23b Nannofossil Subzone (Fig. 4). In general, low frequencies of *Helicosphaera* spp. were observed in the lower Oligocene (6 to 11%) and more consistent ones (11 to 25%) in the upper Oligocene. *Dictyococcites bisectus* (Hay *et al.*) Bukry & Percival and *Zygrhablithus bijugatus* (Deflandre) represent together an important component of the Oligocene nannofloras from the investigated successions. The abundance of these species strongly fluctuates, from 20% (in the lower Rupelian – NP23 Nannofossil Zone) to 70% in the lower Chattian (NP24 Nannofossil Zone), the maximum being recorded within the Zagórz coccolithic limestone laminae. The lowest abundance (6%) of *Pontosphaera* spp. was also observed in the lower Oligocene (NP23 Nannofossil Zone), while the highest proportion (40%) was recorded in the upper Oligocene (NP25 Nannofossil Zone). A low abundance of this genus was noted in the upper Rupelian and lower Chattian deposits and a higher one in the lower Rupelian and upper Chattian studied successions.

DISCUSSION

The Oligocene nannofloral fluctuation pattern recorded in the East Carpathians reflects the environmental changes of that time. Following the Late Paleocene–Early Eocene nannofloral remarkable diversity (120 species), a sharp decline (up to 39 species) was recorded in the Oligocene (Bown *et al.*, 2004), probably related to the climatic deterioration. Globally, the Oligocene started with an accentuated cooling (Savin, 1977; Aubry, 1992; Jovane *et al.*, 2004), coeval with the first isolation of the Paratethys (Báldi, 1980; Rusu, 1988; Rögl, 1998). The global and regional changes are well reflected in the nannofossil assemblage character and in their fluctuation pattern.

Within the Eocene/Oligocene boundary interval, a significant decline in the abundance of warm water nannofossils (species of *Sphenolithus* and *Discoaster*) or even an almost complete extinction of them was noticed. The genus *Discoaster* is represented throughout the Oligocene deposits of the Romanian Carpathians only by rare specimens of *D. deflandrei* Bramlette & Riedel. The nannofloral turnover (several extinctions, followed by an interval of important speciation), observed in the lower Oligocene deposits of the Eastern Carpathians, suggests an interval of unstable marine environment (fluctuations of salinity, temperature and nutrient input). The Eocene taxa progressively disappeared, being replaced, in the Paratethys region, including the Romanian Carpathian area, by endemic species (*Transversopontis fibula*, *T. latus*, *Reticulofenestra ornata*), adapted for strong salinity fluctuations. Together with these species, monospecific assemblages with *Braarudosphaera bigelowii* (Gran & Braarud) Deflandre, a species characteristic for brackish water environments, occur in the lower Rupelian (NP23a Nannofossil Sub-

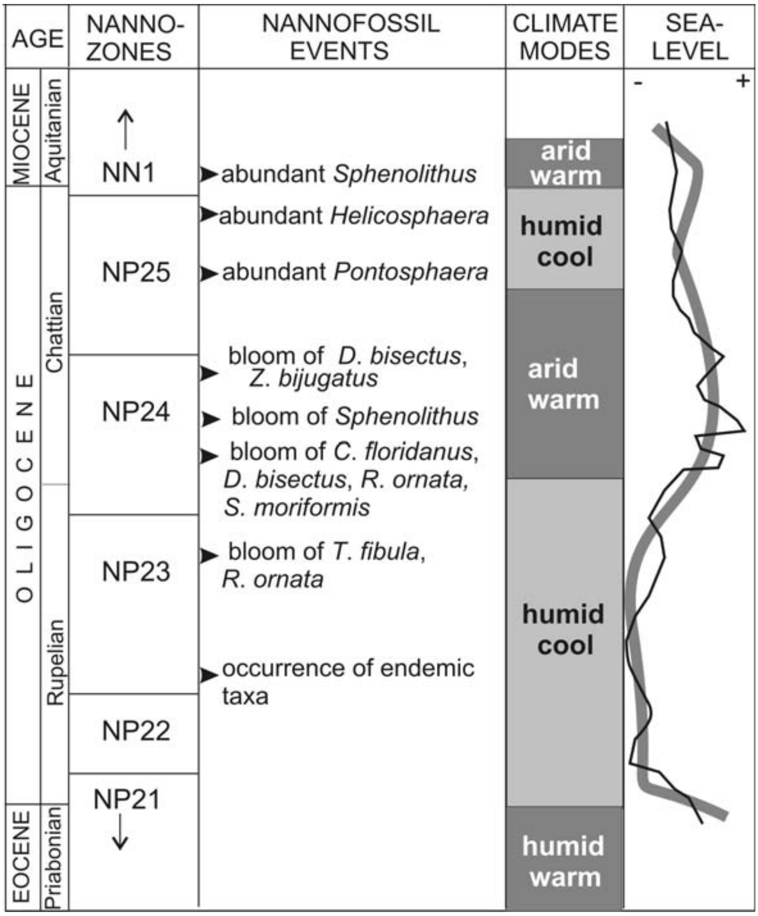

Fig. 6. Oligocene palaeoenvironmental changes in the Eastern Carpathians

zone), both in the Eastern Carpathians and in the Transylvania area (Rusu *et al.*, 1996), indicating also a significant drop of salinity. Blooms of endemic species, e.g., *Transversopontis fibula* and *Reticulofenestra ornata*, which also prefer high nutrient supply (Oszczypko-Clowes, 2001), were recorded from the lower Rupelian coccolithic laminae of the Tylawa Limestone (NP23 Nannofossil Zone).

The higher rate of nannofloral extinction was recorded not in the lower Rupelian (around the NP22/NP23 nannofossil zones boundary), where the maximum Oligocene isolation of the Paratethys was assumed (Krhovský *et al.*, 1992; Rögl, 1998), but in the upper Rupelian (NP23b Nannofossil Zone). This fact is indicative for new palaeoenvironmental changes, caused by the restoration of normal marine conditions in the Romanian Carpathians and connection of this part of the Paratethys with the Mediterranean Sea and North Sea (Rögl, 1998). The endemic species, adapted to survive in the (semi) isolated basins of the Paratethys, with low salinity, low water temperature and high nutrient supply, could not survive in normal marine environment and warmer water.

The uppermost Rupelian–lower Chattian interval (NP24 Nannofossil Zone) is characterized by stable environmental conditions. Almost no change (e.g., extinction, speciation) in the nannofloral assemblages was recorded. The increased percentages of *Sphenolithus* and *Helicosphaera*, genera confined to warm surface water masses, argued for an early Chattian warm interval in the Romanian Carpathians. The deposition of the two episodes of coccolithic limestones (Jasło and Zagórz) from the Eastern Carpathians, containing blooms of cosmopolitan species *Dictyoccoccites bisectus*, *Zygrhablithus bijugatus* and *Cyclicargolithus floridanus* (Roth & Hay) Bukry, argued also for a warmer climate mode during the early Chattian. In the studied Eastern Carpathian sections, a bloom of *Sphenolithus* was recorded between the deposition of Jasło Limestone and Zagórz Limestone, within the NP24 Nannofossil Zone. This bio-event suggests probably the warmest Oligocene interval in the Romanian Carpathian area (Fig. 6). These data are in agreement with the Oligocene palaeoclimatic reconstruction from other European areas. In north-western Europe (Belgium, Germany and North Sea Basin), the Rupelian/Chattian boundary is overlain by transgressive Chattian deposits, which corresponds to a distinct warming event (Van Simaeys *et al.*, 2004). This pulse, as the one assumed in the Eastern Carpathians, could be correlated with the globally detected Late Oligocene Warming Event, which was approximated at 26 Ma (Zachos *et al.*, 2001).

The interval of stable marine conditions extends also over the upper Chattian (NP25 Nannofossil Zone). The significant drop in frequency of *Sphenolithus* indicates a temperature shift during the latest Chattian, while the increasing frequency of the genus *Pontosphaera* probably reflects stable marine conditions and slight salinity fluctuations.

A restoration of a warm climate could be supposed during the earliest Miocene, an interval where the representatives of the genera *Sphenolithus* as well as *Helicosphaera* are again abundant.

CONCLUSIONS

Based on calcareous nannofossil distribution and their fluctuation pattern, several environmental changes are assumed to have taken place during the Oligocene of the Eastern Carpathians. A cool climate started at the beginning of the Oligocene (Krhovský *et al.*, 1992; Aubry, 1992; Jovane *et al.*, 2004), accompanied by a sea-level fall in the Romanian Carpathian area (part of the Paratethys region). These changes correspond to the NP22 and NP23 nannofossil zones. In the Romanian Carpathians, the Rupelian is characterized by strong salinity fluctuations. A sea level rise took place during the late Rupelian (end of NP23 Nannofossil Zone), whereas the climate remained cool. A warm-climate interval was recognized during the early Chattian, accompanied by an important sea-level rise. A cooler climate occurred again in the late Chattian, accompanied by a sea-level fall. Stable marine conditions, with slight salinity fluctuations, characterized the late Rupelian and persisted through the whole late Oligocene. The latest Chattian is characterized by a sea-level rise, but the climate remained cool. The warm climatic mode was restored again in the earliest Aquitanian, when the sea-level significantly increased.

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