

# OLIGOCENE-LOWER MIOCENE CALCAREOUS NANNOFOSSILS FROM BĂBENI AREA (CENTRAL-WESTERN GETIC DEPRESSION, ROMANIA)

DANIELA GHIȚĂ<sup>1,2</sup>, MIHAELA MELINTE-DOBRINESCU<sup>2,3</sup>

<sup>1</sup>OMV Petrom S.A. – I.C.P.T. Câmpina, Formation Characterization and Geochemistry Laboratory, 29 Culturii Blvd., Câmpina, Romania,  
e-mail: daniela.ghita@petrom.com

<sup>2</sup>Doctoral School of Geology, University of Bucharest, 1 Nicolae Bălcescu Blvd., 010041, Bucharest, Romania

<sup>3</sup>National Institute of Marine Geology and Geo-Ecology (GeoEcoMar), 23-25 Dimitrie Onciul St., 024053 Bucharest, Romania  
e-mail: melinte@geoecomar.ro

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**Abstract.** This work presents the calcareous nannofossils assemblages identified in samples recovered from 5 boreholes, drilled on the western side of the Olt River, in the Băbeni area. These boreholes crossed the Lower Oligocene–Lower Miocene sedimentary successions. The identified assemblages were included in the following intervals: (i) upper part of NP21 calcareous nannofossil zone to the lower part of NP23 biozone, corresponding to the early Rupelian, (ii) upper part of NP23 biozone up to NP25 biozone, spanning the late Rupelian–Chattian interval, and (iii) NN1 up to NN3 biozones, covering the Aquitanian and Burdigalian stages. The diversity and abundance of the identified nannofossil assemblages allow paleoenvironmental reconstructions.

**Key words:** Rupelian–Burdigalian interval, calcareous nannoplankton biostratigraphy, paleoecology.

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## 1. INTRODUCTION

Within the Eocene–Oligocene boundary interval, significant modifications occur in the European Tethyan Realm, mirroring the first isolation of the Paratethyan Domain from the Mediterranean and its development in the Central and Eastern Europe, including in nowadays Romanian territory (Rusu, 1988; Rögl, 1998, 1999). The new palaeogeographical setting and the related paleoenvironmental changes implied the modifications in abundance and diversity of various groups of organisms in general, and especially of planktonic marine ones, very sensitive at surface water modifications. Therefore, the calcareous nannofossils show in the Paratethyan Realm a pronounced shift at the Eocene and Oligocene boundary, scarce assemblages during the Oligocene and a renewal of genera and species since the Lower Miocene, when connections with the Mediterranean and Indo-Pacific realms established again connection (Báldi-Beke, 1984; Micu & Gheța, 1986; Mészáros & Ianoliu, 1989;

Mészáros, 1991; Mărunțeanu, 1992, 1999; Chira, 2004; Chira *et al.*, 2011; Melinte, 2005; Melinte-Dobrinescu & Brustur, 2008; Oszczypko-Clowes & Žydek, 2012, among many others).

The Oligocene is a time of global deterioration of the climate and significant temperature decrease linked to the occurrence of permanent ice caps in the Antarctic region and a significant sea-level fall (Haq *et al.*, 1987; Zachos *et al.*, 2001). Hence, a regress in the calcareous nannoplankton development was globally remarked (Aubry, 1992; Dunkley Jones *et al.*, 2008). This feature, along with the regional paleogeography, largely contributed to the shift of the calcareous nannofossils in the Central Paratethys, including the studied area, from the Eocene–Oligocene boundary upwards.

This paper is focused on the Oligocene–Lower Miocene biostratigraphy of the Getic Depression, a foredeep region, which is delimited by the Pericarpethian Fault from the

Moesian Platform towards S, and the Intra-Moesian Fault from the South Carpathians in the N (Săndulescu, 1984; Mutihac *et al.*, 2004). The Getic Depression sedimentation is characterized by three stages: (i) latest Cretaceous to Paleogene, (ii) Early Miocene (Early Burdigalian) to Late Miocene (Late Sarmatian), and, (iii) latest Sarmatian to Late Pliocene (Late Romanian), according to Săndulescu (1984) and Mațenco *et al.* (1997).

The Paleogene of the Getic Depression is cropping out mainly in the Olt and Argeș river basins, being characterized, according to Mihăilă *et al.* (1967) and Popescu *et al.* (1996) by the following lithostratigraphic units (oldest first): (1) the Călimănești Conglomerates, (2) the Cheia Conglomerates, (3) the Pucioasa Marls, and (4) the Muierasca Sandstone. In addition, massive sandstones (the Corbi Sandstone) are exposed in the Argeș River basin.

Several calcareous nannoplankton studies were published regarding the Oligocene-Early Miocene interval of the aforementioned region, based on investigations of the outcrops placed in the northern part of the Getic Depression. Gheța (in Bombiță *et al.*, 1980) mentioned the presence of the Oligocene, *i.e.*, the NP24 biozone of Martini (1971) in the lower part of Pucioasa Formation and of the Aquitanian-Burdigalian NN2 biozone of Martini (1971) towards the upper part of the above-mentioned lithological unit. Gheța (in Bombiță *et al.*, 1980) reported the presence of NN3 biozone, in the lithological unit of Mățău Conglomerates.

The Eocene-Oligocene boundary was studied in the Getic Depression from a calcareous nannoplankton point of view by Micu & Gheța (1986). The authors placed this boundary between NP21 and NP22 biozones, in the lower part of Cheia Formation (= Cheia Conglomerates). Roban & Melinte (2005) renamed the Pucioasa Formation (= Pucioasa Marls) as the Brăduleț Formation, mentioning that this unit covers a large interval, such as Rupelian to Burdigalian, *i.e.*, between NP22 and NN2 calcareous nanofossil zones. The authors stated that the Brăduleț Formation includes the depositional interval of the Cheia Formation (occurring W of the Olt River) and the Corbi Formation (= Corbi Sandstone) that crops out in the eastern part of the Getic Depression, in the Vâlsan and Râul Doamnei river basins.

As the Oligocene-Lower Miocene successions of the central and western areas of the Getic Depression contain hydrocarbons, the aforementioned interval has been extensively drilled (Motaș *et al.*, 1995). The Oligocene-Lower Miocene sediments have been intercepted in several areas of the Getic Depression.

The main aim of this paper is pointing out the modifications in the nanofossil assemblages during the latest Eocene-earliest Miocene interval, in sediments retrieved by five drillings located in SW of Romania, in the Băbeni area, westwards the Olt River. Besides the biostratigraphy based on calcareous nanofossil investigations, a paleoecological approach is also presented.

## 2. METHODOLOGY

To achieve calcareous nannoplankton analyses, 40 cores from five boreholes have been investigated. The area where the drillings are placed is situated west of the Olt River and north of the confluence between Luncavăț and Olt rivers (Fig. 1).

The nanofossil analyses have been realized according to the I.C.P.T. Câmpina Geological Laboratory procedures. For making smear slides, the broken samples were boiled with hydrogen peroxide (30% concentration) to remove the organic matter. The resulted sediment was filtered and washed with distillate water. Afterwards, it was placed in a Berzelius glass with distillate water and exposed to ultrasounds. A few drops of this solution were put on a glass slide and dried on a hot plate. The fixed smear slides were obtained by using Canada Baum.

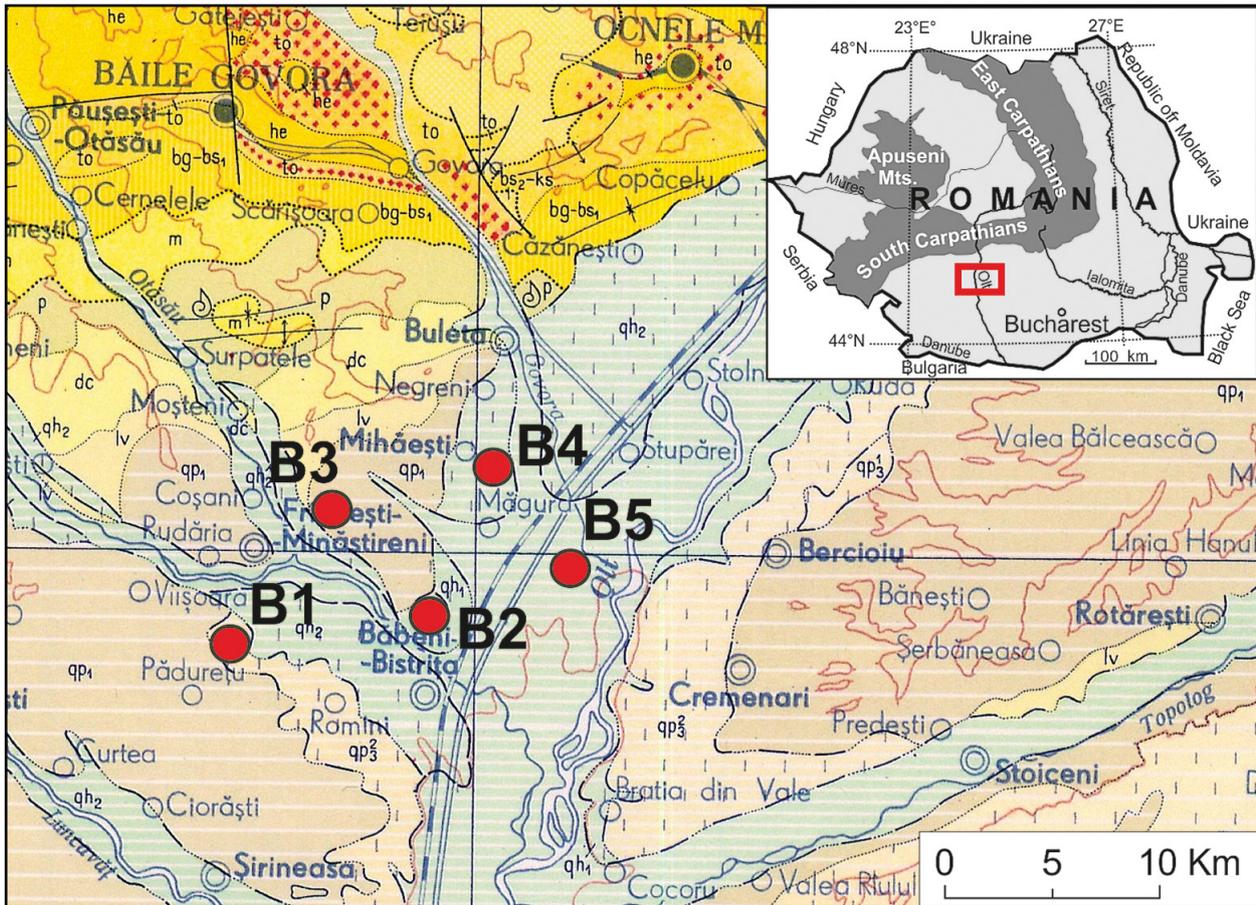
The identification and the photos of the taxa were performed under an Olympus BX 51 polarized microscope (x1000 or x1200 magnifications), with gypsum plate and using QuickPhoto Micro 2.2 software.

## 3. RESULTS

The Oligocene deposits were crossed by all five studied boreholes. The Oligocene sedimentation is representing by two distinct facies: a pelitic one, similar to the Brăduleț Formation and a detrital facies, similar to the Cheia Formation. The pelitic facies is represented by gray, dark gray or blackish clays, interbedded with calcareous clays and sandstones. The detrital facies is made by thick conglomerate beds, alternating with sandstones and thin calcareous clays (Fig. 2).

The B1, B2 and B3 drillings crossed the lower Rupelian deposits. In B1, these deposits are mainly calcareous clays, similar to the ones described by Roban & Melinte (2005) in the Brăduleț Formation. In these sediments, assemblages with *Clausicoccus subdistichus*, *Coccolithus eopelagicus*, *Coccolithus formosus*, *Coccolithus pelagicus*, *Discoaster deflandrei*, *Discoaster tanii*, *Pontosphaera latoculata*, *Reticulofenestra bisecta*, *Reticulofenestra minuta*, *Reticulofenestra umbilicus*, *Sphenolithus moriformis*, *Sphenolithus pseudoradians* and *Zygrhablithus bijugatus* have been identified (Plate 1).

Most of the aforementioned taxa are long-ranging, covering in general the Eocene-Oligocene interval, while a few nanofossils, such as *Clausicoccus subdistichus*, *Coccolithus formosus*, *Discoaster tanii* and *Reticulofenestra umbilicus* have their last occurrence (LO) in the Lower Oligocene, *i.e.*, the Rupelian stage (Martini, 1971; Perch-Nielsen, 1985; Bown & Dunkley Jones, 2012; Gradstein *et al.*, 2012). Taking into account that *Clausicoccus subdistichus* and *Coccolithus formosus* became extinct in the lower Rupelian (Gradstein *et al.*, 2012), in the NP22 nanofossil zone of Martini (1971) and no species that vanished in the Upper Eocene (such as *Discoaster barbadiensis* and *Discoaster saipanensis*) occur, we



**Fig. 1.** Location of the studied area in S Romania (up right) and of the Getic Depression studied drillings on the Pitesti Sheet, scale 1:200,000, (Mihăilă *et al.*, 1967), printed by the Geological Institute of Romania.

assigned the clayey deposits to the NP22 biozone. To note that *Reticulofenestra minuta* is very frequent.

Above, the samples yielded nanofossil assemblages composed of: *Reticulofenestra lockeri*, *Coccolithus pelagicus*, *Coccolithus eopelagicus*, *Cyclicargolithus floridanus*, *Helicosphaera compacta*, *Lanternithus minutus*, *Reticulofenestra bisecta*, *Reticulofenestra dictyoda*, *Reticulofenestra minuta*, *Reticulofenestra stavensis*, *Pontosphaera latoculata*, *Pontosphaera multipora*, *Sphenolithus moriformis* and rare species of *Orthozygus aureus*, *Reticulofenestra ornata* and *Pontosphaera (=Transversopontis) fibula*. The species *Lanternithus minutus* has its LO in Rupelian, within NP23 biozone (Varol, 1998; Stradner *et al.*, 2010), while *Clausicoccus subdistichus* and *Coccolithus formosus*, knowing to become extinct in NP22, are not present in the assemblages. These findings argue for the presence of the NP23 biozone, Early Oligocene (lower part of the Rupelian) in age.

The overlaying deposits contain calcareous nanofossil assemblages with *Cyclicargolithus abisectus* and without *Lanternithus minutus*, pointing out the presence of NP23 (de Kaenel & Villa, 1996; Melinte, 2005); probably the assemblage belongs to the top of this biozone, which corresponds to

the upper part of the Rupelian. This biozone was identified in all studied boreholes. The nanofossil assemblages of the aforementioned interval are most diversified than the older ones; besides the long-ranging species above-mentioned, a high diversity of *Helicosphaera* genus, represented by *H. bramlettei*, *H. compacta*, *H. intermedia*, *H. recta* and *H. perch-nielseniae*, was observed. Additionally, *Cyclicargolithus floridanus* is present with a high abundance (Plate 1).

The aforementioned biozones, NP21 up to NP23 of Martini (1971) corresponding with the biozones of Melinte (1993, 2005) have been also encountered in B2 and B3 drillings. The lithology of the crossed deposits changed: some thin conglomerate levels are present, interbedded with clays, which contain Rupelian nanofossil assemblages, scarcer than the ones observed in the B1 drilling.

In B3 and B4 drillings, in the assemblages found in the dark gray silty calcareous clays, showing similar lithological aspects to the Brăduleț Formation, *Sphenolithus ciproensis* has been observed. As the range of this nanofossil covers biozones NP24 and NP25 of Martini (1971), a late Rupelian to Chattian age is assumed.

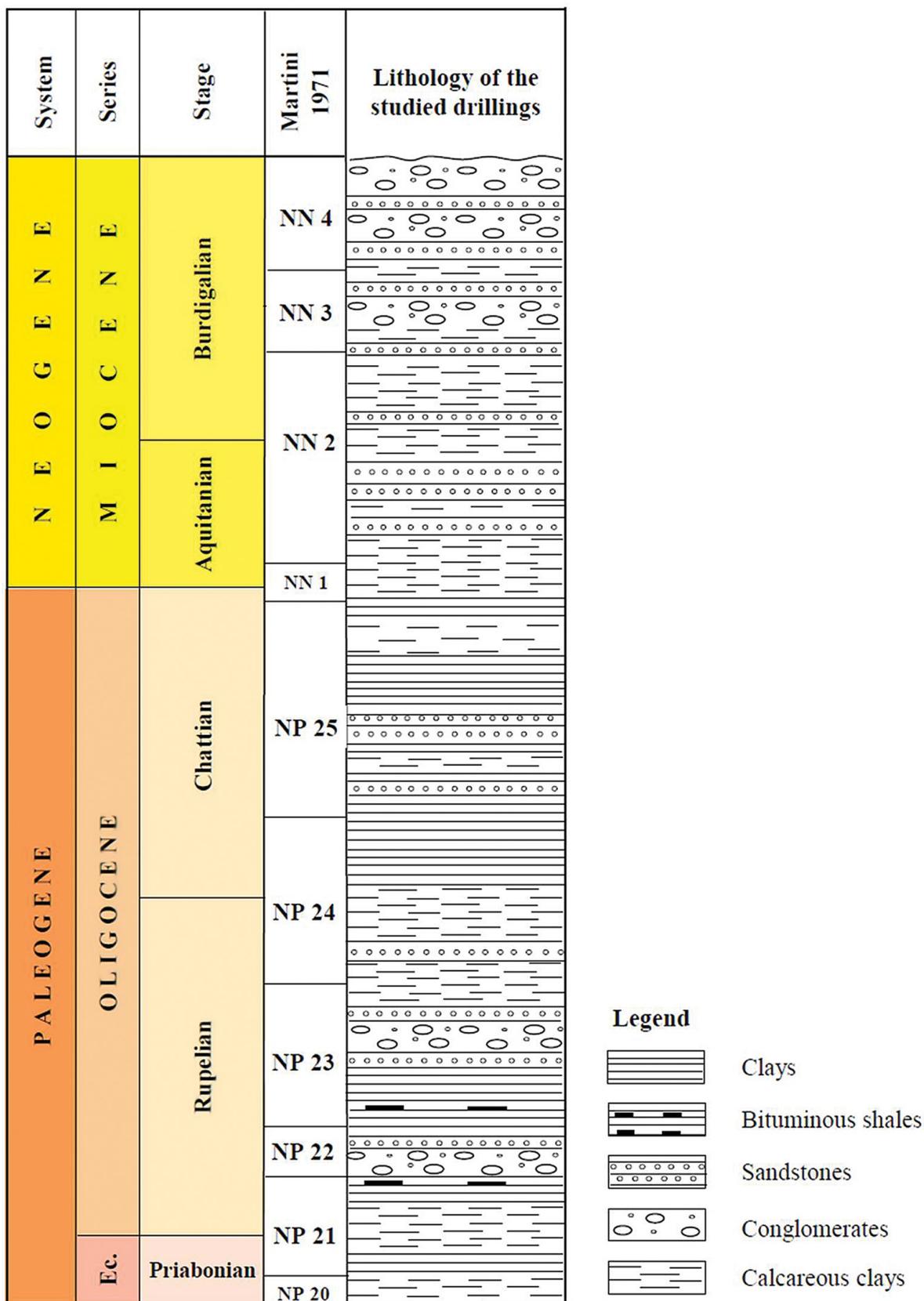
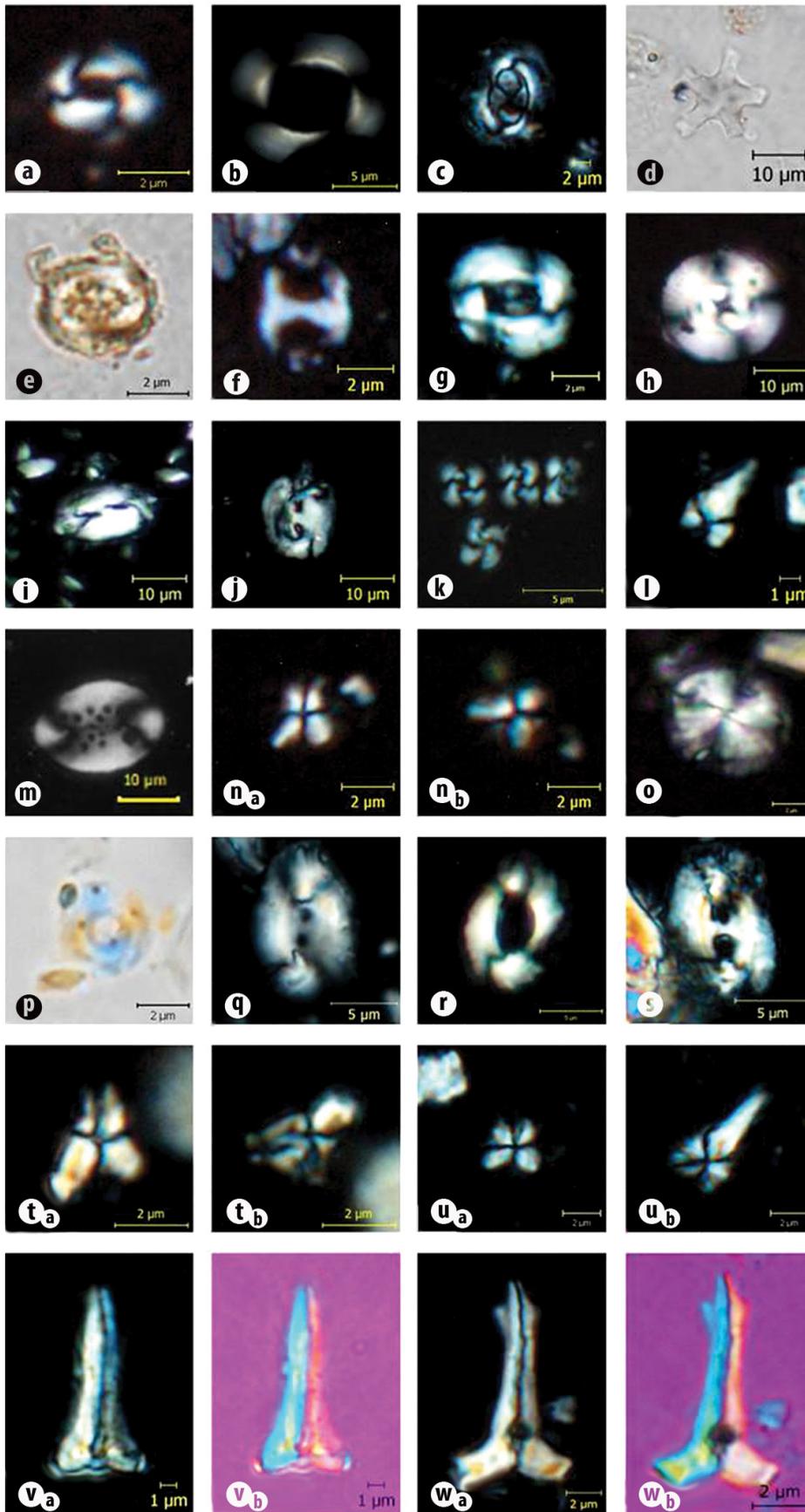


Fig. 2. Synthetic lithological column of the sediments traversed by the studied drillings of the Băbeni area (Getic Depression) and the corresponding Oligocene-Lower Miocene NP and NN calcareous nannofossil zones of Martini (1971).

**PLATE 1.** Oligocene-Lower Miocene identified calcareous nanofossils; microphotographs taken at LM (light microscope); N+ crossed nicols; NII light polarized light; scale bar in microns.



(a) *Reticulofenestra minuta* Roth (N+), Rupelian, borehole B1; (b) *Reticulofenestra umbilicus* (Levin) Martini & Ritzkowski (N+), Rupelian, borehole B1; (c) *Clausicoccus subdistichus* (Roth & Hay) Prins (N+), Rupelian, borehole B2; (d) *Discoaster tanii* Bramlette & Riedel (NII), Rupelian, borehole B2; (e) *Reticulofenestra ornata* Müller (NII), Rupelian, borehole B2; (f) *Pontosphaera* (= *Transversopontis*) *fibula* (Gheța) (N+), Rupelian, borehole B2; (g) *Reticulofenestra lockeri* Müller (N+), Rupelian, borehole B3; (h) *Cyclargolithus abisectus* (Müller) Wise (N+), Chattian, borehole B3; (i) *Helicosphaera perch-nielsenae* Haq (N+), Rupelian, borehole B1; (j) *Helicosphaera recta* Haq (N+), Chattian, borehole B3; (k) *Cyclargolithus floridanus* (Roth & Hay) Bukry (N+), borehole B3; (l) *Sphenolithus ciperoensis* Bramlette & Wilcoxon (N+, 45°), borehole B2; (m) *Pontosphaera enormis* (Locker) Perch-Nielsen (N+), Chattian, borehole B3; (n<sub>a,b</sub>) *Sphenolithus delphix* Bukry (n<sub>a</sub>: N+ 0°, n<sub>b</sub>: N+ 45°), Burdigalian, borehole B5; (o) *Calcidiscus leptoporus* (Murray & Bramlette) Loeblich & Tappan (N+), Aquitanian, borehole B4; (p) *Umbilicosphaera jafari* Müller (NII with  $\lambda$  compensator), Aquitanian, borehole B4; (q) *Helicosphaera carteri* (Wallich) Kamptner (N+), Aquitanian, borehole B4; (r) *Helicosphaera ampliaperta* Bramlette & Wilcoxon (N+), Burdigalian, borehole B5; (s) *Helicosphaera mediterranea* Müller (N+), Aquitanian, borehole B4; (t<sub>a,b</sub>) *Sphenolithus belemnus* Bramlette & Wilcoxon (t<sub>a</sub>: N+ 0°, t<sub>b</sub>: N+ 45°), Burdigalian, borehole B5; (u<sub>a,b</sub>) *Sphenolithus heteromorphus* Deflandre (u<sub>a</sub>: N+ 0°, u<sub>b</sub>: N+ 45°), Burdigalian, borehole B5; (v<sub>a,b</sub>) *Zygrhablithus bijugatus bijugatus* Deflandre (v<sub>a</sub>: N+, v<sub>b</sub>: N+ with  $\lambda$  compensator), Rupelian, borehole B3; (w<sub>a,b</sub>) *Zygrhablithus bijugatus cornutus* Bown (w<sub>a</sub>: N+, w<sub>b</sub>: N+ with  $\lambda$  compensator), Chattian, borehole B3.

System	Series	Stage	Martini, 1971		Melinte 2005	This paper	Bio-events
NEOGENE	MIOCENE	AQUITANIAN	NN 1	<i>Triquetrorhabdulus carinatus</i>	NN 1	<i>Calcidiscus leptoporus</i>	
PALEOGENE	OLIGOCENE	CHATTIAN	NP 25	<i>Sphenolithus ciperoensis</i>	NP 25	<i>Pontosphaera enormis</i>	<ul style="list-style-type: none"> <li>▲ FO <i>Sphenolithus delphix</i></li> <li>→ Bloom of <i>Cyclicargolithus floridanus</i></li> <li>▲ FO <i>Pontosphaera enormis</i></li> </ul>
			NP 24	<i>Sphenolithus distentus</i>	NP 24	<i>Sphenolithus ciperoensis</i>	<ul style="list-style-type: none"> <li>▲ FO <i>Sphenolithus ciperoensis</i></li> </ul>
			NP 23	<i>Sphenolithus predistentus</i>	NP 23	<i>Cyclicargolithus abisectus</i>	<ul style="list-style-type: none"> <li>→ Bloom of <i>Cyclicargolithus floridanus</i></li> <li>▲ FO <i>Cyclicargolithus abisectus</i></li> </ul>
		NP 22	<i>Helicosphaera reticulata</i>		<i>Reticulofenestra lockeri</i>	<ul style="list-style-type: none"> <li>▲ FO <i>Reticulofenestra lockeri</i></li> </ul>	
		NP 21	<i>Clausicoccus subdistichus</i>		<i>Reticulofenestra minuta</i>	<ul style="list-style-type: none"> <li>→ Bloom of <i>Reticulofenestra minuta</i></li> </ul>	
		NP 20	<i>Sphenolithus pseudoradians</i>				
		EC.	PRIABONIAN				

Fig. 3. Correlation of the Oligocene calcareous nannofossil biozones and biotical events recorded in the Băbeni area (Getic Depression, S Romania) and comparison with the global zonation of Martini (1971) and Carpathian region of Romania (Melinte, 2005).

In the nannofossil assemblages *Coccolithus pelagicus*, *Cyclicargolithus abisectus*, *Cyclicargolithus floridanus*, *Discoaster deflandrei*, *Helicosphaera euphratis*, *Helicosphaera recta*, *Pontosphaera multipora*, *Reticulofenestra bisecta* and *Zygrhablithus bijugatus* are also present.

The youngest Oligocene biozone recognized is the *Pontosphaera enormis* biozone (Melinte 1993, 2005; Melinte-Dobrinescu & Brustur 2008), corresponding to NP25 standard zone (Martini, 1971). Two samples recovered from the B1 well, made by dark-gray calcareous clays, contain the above-mentioned species. The presence of *Pontosphaera enormis* along with *Cyclicargolithus abisectus* indicated an early Chattian age - the lower part of NP25 biozone (Martini, 1971). In addition, the assemblage contains the nannofossils: *Coccolithus pelagicus*, *Cyclicargolithus floridanus*, *Discoaster deflandrei*, *Helicosphaera euphratis*, *Reticulofenestra bisecta*, *Reticulofenestra dictyoda*, *Reticulofenestra lockeri*, *Sphenolithus moriformis* and *Zygrhablithus bijugatus*. It is to remark the bloom of *Cyclicargolithus floridanus* in the above-mentioned depositional interval. Upwards, the co-occurrence of *Pontosphaera enormis* and *Sphenolithus delphix* argued the presence of NP25 biozone; several authors indicate that the first occurrence of *Pontosphaera enormis* is placed in the Paratethyan Realm towards the upper part of the Chattian (Melinte 1993, 2005; Melinte-Dobrinescu & Brustur, 2008 Ozdínová & Soták 2014).

We found that the pelitic facies of the Brăduleț Formation, mainly composed of dark gray calcareous clays, crossed by all studied boreholes, continues in the Early Miocene interval (Aquitanian to lower Burdigalian). The nannoplankton assemblages encloses *Cyclicargolithus abisectus* with its LO towards the base of the Aquitanian stage (Gradstein *et al.*, 2012), in NN1 zone of Martini (1971), but lack *Sphenolithus ciperoensis*, which disappears towards

the top of the Oligocene (Bergen *et al.*, 2017). Significant biostratigraphical nannofossils in the NN1 biozone include *Calcidiscus leptoporus*, *Helicosphaera carteri* and *Sphenolithus conicus*.

In the investigated boreholes B1, B2, B3, B4 and B5, above the assemblages marking the base of the Miocene, assemblages that characterize the NN2 zone of Martini (1971), late Aquitanian to early Burdigalian age (Young, 1998) are present. *Discoaster druggii*, which the first occurrence (FO) marks the base of NN2 zone, is rarely encountered in the studied drillings, in a few samples. Species of the genus *Umbilicosphaera*, such as *U. jafari* and *U. rotula* that have the FO in NN2 (Young, 1998), appear in NN2 biozone, along with *Reticulofenestra pseudoumbilicus* and long-ranging taxa.

Above the depositional interval covered by the lower part of NN2, the lithology of drilled deposits changes. The sediments overlaying the brownish clays of the Brăduleț Formation are included in a detritic facies, represented by the Muierasca Formation (=Muierasca Sandstones) and Mățău Formation (=Mățău Conglomerates) units. The Muierasca Formation consists of microconglomerates, interbedded with sandstones, clays and marls. The Mățău Formation is mainly composed of reddish to brownish conglomerates, alternating with calcareous clays and calcareous sandstones (Bombiță *et al.*, 1980). The aforementioned lithological units were recovered in the boreholes B1, B2, B3, B4 and B5.

In the marly and clayey layers of Muierasca unit, the FO of *Helicosphaera ampliapertura* was remarked. This occurrence is placed towards the top of NN2, within the lower part of the Burdigalian (Young, 1998). The nannofossil assemblages are dominated by *Reticulofenestra pseudoumbilicus* and *Reticulofenestra haqii*, both species showing a high frequency.

System	Series	Stage	Martini, 1971		Mărușeanu, 1999		This paper	Bio-events
NEOGENE MIOCENE	BURDIGALIAN	NN 4	Helicosphaera ampliaperata	H. ampliaperata	b Calcidiscus leptoporus		Sphenolithus heteromorphus	
		NN 3	Sphenolithus belemnus		a Discoaster adamanteus		Sphenolithus belemnus	FO Sphenolithus heteromorphus FO Sphenolithus belemnus
		NN 2	Discoaster druggii	Discoaster druggii	b Helicosphaera carteri		b Helicosphaera ampliaperata	FO Helicosphaera ampliaperata
				a Sphenolithus dissimilis		a Umbilicosphaera jafari		FO Discoaster druggii FO Reticulofenestra pseudoumbilicus FO Umbilicosphaera jafari FO Calcidiscus leptoporus
	AQUITANIAN	NN 1	Triquetrorhabdulus carinatus		Triquetrorhabdulus carinatus		Calcidiscus leptoporus	

**Fig. 4.** Correlation of the Lower Miocene calcareous nannoplankton biozones and the biotical events recorded in the Băbeni area (Getic Depression, S Romania) and comparison with the global zonation of Martini (1971) and Carpathian region of Romania (Mărușeanu, 1999).

In the reddish-brown silty calcareous clays interlayered in the conglomerate levels of Mățău Formation of the borehole B5, *Sphenolithus belemnus* occurs. The FO of this nannofossil marks the base of NN3 zone of Martini (1971), being placed in the Burdigalian (Raffi *et al.*, 2006). The assemblages of NN3 are diversified and contain, besides long-ranging taxa, typical Miocene nannofossils, such as: *Coccolithus miopelagicus*, *Cyclicargolithus floridanus*, *Helicosphaera ampliaperata*, *Helicosphaera carteri*, *Helicosphaera intermedia*, *Helicosphaera mediterranea*, *Reticulofenestra haqii*, *Reticulofenestra pseudoumbilicus*, *Sphenolithus dissimilis* and *Sphenolithus moriformis*. The species *Helicosphaera ampliaperata*, *Umbilicosphaera jafari* and *Umbilicosphaera rotula* are present, but with a low abundance.

Upwards, in the Mățău Formation, the assemblages are characteristic for the interval covered by NN3 to lower part of NN 4 biozones of Martini (1971), of a late Burdigalian age (Young, 1998; Raffi *et al.*, 2006). The age is argued by the co-occurrence of *Calcidiscus premacintyreii* and *Sphenolithus heteromorphus*, the later with a low frequency. In addition, the assemblages contain *Calcidiscus leptoporus*, *Coccolithus miopelagicus*, *Cyclicargolithus floridanus*, *Helicosphaera ampliaperata*, *Helicosphaera carteri*, *Pontosphaera multipora*, *Reticulofenestra haqii* and *Reticulofenestra pseudoumbilicus*.

#### 4. DISCUSSION

The depositional interval studied from the calcareous nannofossil point of view belongs to the Oligocene-Lower Miocene. In general, the calcareous nannofossil biostratigraphy of this interval follows the zonation of Martini (1971), made on pelagic sediments of low latitudes. In his biozonation many biozones were defined based on the last occurrence of the nannofossils, but in sediments containing several reworkings, as the orogenic areas, such events are difficult to identify. Moreover, most of the Oligocene and Lower Miocene defined biozones are largely based on the

occurrence of *Sphenolithus* species, which are more related to the warm-water surface of lower- to mid-paleolatitudes (Perch-Nielsen, 1985; Aubry, 1992; Villa *et al.*, 2008).

Consequently, it is difficult to employ the zonation of Martini (1971) in deep-marine basins, where turbidite deposits occur; this type of lithology contains frequently reworked calcareous nannofossils (Wagreich & Krenmayr, 1993). This problem is known to occur in the Romanian Carpathian Paleogene-Miocene depositional interval. Besides, due to the appearance of the Paratethyan Domain since the Oligocene (Rusu, 1988; Rögl, 1999) on large areas from the Central and Eastern Europe (Popov *et al.*, 2004), including the present-day Romanian territory, the paleogeographic setting led to the occurrence, in the semi-isolated basins, of endemic taxa. In such Paleogene-Miocene semi-isolated basins the proliferation of warm-water nannofossils, such as *Sphenolithus* spp. and *Discoaster* spp., was limited. For solving these issues, several biostratigraphic schemes have been proposed for the Oligocene-Miocene interval of the Romanian Extra-Carpathian (Melinte, 1993, 2005; Mărușeanu, 1999). The afore-mentioned zonations have been used herein (Figs. 3 and 4) and correlated with the Martini (1971) biozones.

The boundary between Eocene and Oligocene could not be pointed out based on the nannofossil biostratigraphy of Martini (1971), *i.e.*, the extinction of *Discoaster barbadiensis* and *Discoaster saipanensis*, species that were observed as reworked up to the Lower Miocene sediments of the studied boreholes. The Eocene-Oligocene boundary was approximately based on the high frequency of small reticulofenestrids, such as *Reticulofenestra minuta* and *Reticulofenestra minutula*. A significant bloom of *Reticulofenestra minuta* was encountered, along with a high frequency of *Reticulofenestra minutula*. The high frequency of the small reticulofenestrids is coincident, in the studied boreholes, with a pronounced lithological change. The

dominant marly lithology of the Eocene is sharply replaced by an anoxic deposition, *i.e.*, mainly dark-grey to black clays, which characterize the Oligocene of the Getic Depression (Bombiță *et al.*, 1980, Motaș *et al.*, 1995, Boroși *et al.*, 2003). Previous studies indicate that *Reticulofenestra minuta* occur with a high frequency in a shallow marine setting (Haq, 1980) and in stressful conditions, related to rapid environmental changes (Wade & Bown, 2006). Additionally, several blooms of *Reticulofenestra minuta* were reported from the Central Paratethys within the Early Miocene and lower part of the Middle Miocene (Švábenická, 2002; Ćorić & Hohenegger, 2008; Holcová, 2013), possibly reflecting a paleoenvironmental stress.

The identification of the Oligocene biozones (NP22 up to NP25) are defined by Martini (1971) based on the distribution of *Sphenolithus* taxa, which are very rare or are missing in the investigated sediments. In the Băbeni area, in the Lower Oligocene samples, the assemblages are mainly made by *Coccolithus pelagicus*, *Reticulofenestra bisecta*, *Reticulofenestra umbilicus*, *Lanternithus minutus* and *Zygrhablithus bijugatus*, nanofossils mostly associated with cooler-water surface and a shallow marine setting (Perch-Nielsen, 1985; Haq *et al.*, 1987; Krhovský *et al.*, 1992; Nagymarosy, 2002; Melinte, 2005; Oszczytko-Clowes & Żydek, 2012). The interval corresponding to the Lower Oligocene NP23 biozone contains several successive first occurrences (FO), such as those of *Reticulofenestra lockeri*, *Cyclicargolithus abisectus* and *Sphenolithus ciperoensis*, the later event marking the top of NP23.

The nanofossils *Reticulofenestra ornata* and *Pontosphaera (=Transversopontis) fibula*, identified in the studied samples, have their FO in the lower part of NP23 biozone (Melinte, 2005). The species are endemic taxa of the Central Paratethys; they were reported in Romania, within the Carpathians and Transylvanian Basin, as well as in Ukraine, Czech Republic, Hungary and Slovakia (Gheța *et al.*, 1976; Mészáros & Ianoliu, 1989; Krhovský *et al.*, 1992; Nagymarosy & Voronina, 1992; Melinte, 2005; Melinte-Dobrinescu & Brustur, 2008; Garecka, 2012; Kallanxhi *et al.*, 2018).

The base of NP24 biozone, late Rupelian-early Chattian in age (Melinte, 2005) was recognized based on the FO of *Sphenolithus ciperoensis*. From the aforementioned interval, the calcareous nanofossils show a higher diversity and abundance than in the lower Rupelian. Possibly, this change mirrors the connection of the Central Paratethys with other realms, *i.e.*, the Indio-Pacific one (Rögl, 1998, Popov *et al.*, 2004).

As the LO of *Sphenolithus distensus* was not identified, because the lack of this taxon, the NP24/NP25 boundary was approximated based on *Pontosphaera enormis* FO (Fig. 3). The *Pontosphaera enormis* biozone was defined herein, as the interval between the FO *Pontosphaera enormis* and the FO of *Calcidiscus leptoporus* and was correlated with NP25 of Martini (1971). Melinte (2005) divided NP25 into two

biozones, based on the FO of *Sphenolithus delphix* (Fig. 3). In the subzone NP25a biozone, a bloom of *Cyclicargolithus floridanus* was observed in the studied samples of the Getic Depression. In this interval, *Cyclicargolithus abisectus* and *Pontosphaera enormis* co-occur. Previously, blooms of *Cyclicargolithus floridanus* were reported in this interval in the Eastern Carpathian outer structures and in the Transylvanian Basin, related to the occurrence of coccolithic limestones (Melinte, 2005; Melinte-Dobrinescu & Brustur, 2008). In the Outer Polish Carpathians, coccolithic limestones (namely Jaslo and Zagórz) are known to occur in the Late Oligocene, *i.e.*, Chattian (Haczewski, 1989; Bağ, 1999). Most probably, this event is related to a warmer surface waters and reconnection with the open ocean of the Central Paratethys.

The Oligocene-Miocene boundary is placed at the base NN 1 (Berggren *et al.*, 1995). The base of this biozone is marked by the LOs of *Reticulofenestra bisecta*, *Sphenolithus ciperoensis* and *Zygrhablithus bijugatus* (Martini, 1971). At the GSSP (Global Section and Stratotype Point) of the Aquitanian, defined in the Lemme-Carrosio Section (Italy), *Sphenolithus delphix* firstly occurs below the Oligocene-Miocene boundary, while just above the boundary the FO and LO of *Sphenolithus capricornutus* were recorded, followed by the LO of *Sphenolithus delphix* (Steiniger *et al.*, 1997). In the studied boreholes, *Sphenolithus capricornutus* was not identified, while *Sphenolithus delphix* is very rare, its LO being not observed. Therefore, we use for approximating the Oligocene-Miocene boundary the FO of *Calcidiscus leptoporus* (Fig. 4), nanofossil which firstly appear towards the base of the Aquitanian (Young, 1998) and pointed the top of *Pontosphaera enormis* biozone defined in this work

The NN2 biozone of Martini (1971) is Aquitanian-earliest Burdigalian in age (Berggren *et al.*, 1995). The marker species, *Discoaster druggii*, which the FO is dated 23.2 Ma (Berggren *et al.*, 1995), was rarely encountered in the studied boreholes. In the Paratethys, this event corresponds to the Egerian-Eggerburgian boundary (Mărunțeanu, 1992; Holcová, 2002). The FO of *Discoaster druggii* was found to be synchronous in the analyzed cores with the FO of *Reticulofenestra pseudoumbilicus* and that of *Umbilicosphaera jafari*. In the present paper we divided the NN2 – *Discoaster druggii* biozone into two subzones: NN2a – *Umbilicosphaera jafari* and NN2b – *Helicosphaera ampliapertura* (Fig.4), based on the FO of *Helicosphaera ampliapertura*, which approximates the base of the Burdigalian stage (Raffi *et al.*, 2006). This bioevent was found to occur in the earliest Burdigalian of the Romanian Carpathians and in the same time interval in the Transylvanian Basin (Mărunțeanu 1992, 1999; Chira, 2004; Melinte-Dobrinescu & Brustur, 2008; Chira *et al.*, 2011). The FO of *Discoaster druggii* is an earliest Burdigalian event in the Mediterranean areas as well (Theodoridis, 1984, Bossio *et al.*, 2005).

In the Romanian Carpathians and their foreland regions, both NN1 and NN2 biozones are characterized by the

occurrence of high percentage of reworked nanofossils, mainly of Cretaceous and Paleogene age. This feature was used in Romania, in the hydrocarbon exploration, to point out the lowermost Miocene depositional interval (Boroși *et al.*, 2003). The presence of a significant amount of reworking is possibly linked to the particular sedimentation regime of the Getic Depression foredeep and Early Miocene active tectonics of the Romanian Carpathians and adjacent areas (Săndulescu, 1984; Maženco *et al.*, 1997). We hypothesize also that in the Getic Depression, a high nutrient input existed during Aquitanian-Burdigalian interval, as *Coccolithus pelagicus*, *Cyclicargolithus floridanus* and small reticulofenestrids, taxa known to have a preference for this feature (Holcová, 2013; Auer *et al.*, 2014), are commonly present.

The occurrence of *Sphenolithus belemnus*, along with *Sphenolithus heteromorphus* and *Helicosphaera ampliaperata* in sediments showing a similar lithology with the Mățău Formation argued for a late Burdigalian age, corresponding to the interval spans by NN3 up to the lower part of NN4 biozones of Martini (1971). Similar assemblages were described from the outer structures of the Eastern Carpathians (Dicea & Dicea, 1979, Mărunțeanu, 1992, 1999).

## 5. CONCLUSIONS

The lithology recovered by the five boreholes situated in the Băbeni region is similar to that observed in the lithological units cropping out in the Getic Depression, such as Brăduleț, Cheia, Muierasca and Mățău, previously described by Roban & Melinte (2005). The calcareous nanoplankton assemblages identified in the Brăduleț Formation point out that this unit covers a large interval, from the Lower Oligocene up to the Lower Miocene, respectively NP21 to lower part of NN2 biozones of Martini (1971).

The Rupelian age of the Cheia Formation, which is interfingering with the Brăduleț Formation, is argued by the occurrence of nanofossils that characterized the NP21 – lower part of NP23 biozone interval. The Muierasca Formation is late Aquitanian to early Burdigalian in age, belonging to the NN2 biozone. The NN3 up to the lower part of NN 4 biozones were identified in samples with lithology assigned to the Mățău Formation.

In the studied sediments of Getic Depression drillings, several calcareous nanofossil events have been highlighted in the Oligocene-Early Miocene interval:

- A high frequency of *Reticulofenestra minuta*, in the Lower Oligocene sediments, *e.g.*, lower Rupelian. As this event is placed at the base of the Oligocene, it could be useful for assigning the Eocene-Oligocene boundary in areas where, due to the reworking processes, the last occurrence of *Discoaster barbadiensis* and *Discoaster saipanensis*, species that vanished at the top of the Eocene, could not be recognized.
- The first occurrence, in the lower part of NP23 biozone, of the endemic Paratethyan species, such as *Pontosphaera fibula* and *Reticulofenestra ornata*. This event was formerly observed by several authors in the Intra- and Extra-Carpathian areas and corresponds to a mainly anoxic depositional interval.
- Two blooms of *Cyclicargolithus floridanus* were highlighted. The oldest bloom is placed in the Lower Oligocene, upper part of NP23, *i.e.*, late Rupelian, where in the assemblages *Cyclicargolithus abisectus* occurs. The youngest bloom is situated in the Upper Oligocene (Chattian), within the NP25 biozone, in the assemblages where *Cyclicargolithus abisectus* and *Pontosphaera enormis* are present.
- Within the Lower Miocene studied deposits, in the Aquitanian-Burdigalian interval, several successive first occurrences have been pointed out (oldest first): *Calcidiscus leptoporus*, *Umbilicosphaera jafari*, *Reticulofenestra pseudoumbilicus*, *Discoaster druggii*, *Helicosphaera ampliaperata*, *Sphenolithus belemnus* and *Sphenolithus heteromorphus*.

Based on the identified bio-events, we have presented herein new biozones for the Oligocene and Lower Miocene investigated depositional intervals. These biozones are defined based on the first occurrence of the nanofossils observed in the studied boreholes.

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