UPPER BURDIGALIAN-MIDDLE SARMATIAN CALCAREOUS NANNOFOSSILS FROM TOTEA-VĂLENI AREA (GETIC DEPRESSION, ROMANIA)

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Abstract This work presents the calcareous nannofossils identified in samples recovered from 7 boreholes drilled on the western side of the Olt River, in the Totea, Colibași, Rădinești and Văleni areas, within the central-southern part of the Getic Depression. These boreholes crossed upper Burdigalian–middle Sarmatian sediments. The identified assemblages are typical for the following calcareous nannofossil biozones: upper part of NN 3 – lower part of NN 4, corresponding to the late Burdigalian time interval, upper part of NN 4, corresponding to the early Badenian, NN 5, spanning the middle Badenian, and, respectively, NN 6–NN 8, covering the late Badenian – middle Sarmatian interval. The diversity and abundance of the identified nannofossil assemblages allow palaeoenvironmental reconstructions.

Keywords: Lower to Middle Miocene, calcareous nannoplankton, biostratigraphy, Paratethys.

INTRODUCTION

The Getic Depression represents a sedimentary basin that overlaps the contact between the Southern Carpathians and the central-western part of the Moesian Platform, which is a segment of the Vallachian Sector of the platform (Săndulescu, 1984). Its sedimentary deposits are molasses, including limestones, as well as coal and evaporitic (anhydrite and salt) intercalations. The thickness of these successions increases from north to south, where they exceed 4,000 m (Mutihac et al., 2004).

The Getic Depression was part of the Central Paratethys during the Early and Middle Miocene, while from the Late Miocene onwards it belonged to the Eastern Paratethyan domain (Popov et al., 2004). Therefore, in the Getic Depression, part of the larger Dacian Basin of the Paratethys (Jipa & Olariu, 2013), the substages of the Sarmatian *s.l.* (Volhynian, Bessarabian and Kersonian) are used (Marinescu, 1978).

The Miocene sedimentary successions of the southern-central part of the Getic Depression have been extensively drilled for oil and gas accumulations. The upper Burdigalian–Sarmatian sediments were intercepted in the Totea, Colțești, Rădinești and Văleni areas (Diaconescu et al., 2013, Ghiță et al., 2015), situated westwards of the Olt River (Fig. 1).

Several calcareous nannoplankton studies were published regarding the upper Burdigalian–Sarmatian interval based on investigations of outcrops placed in the northern part of the Getic Depression. Bombiță et al. (1980) mentioned the presence of the NN 3 nannofossil zone of Martini (1971), indicative of a late Burdigalian age, in the lithostratigraphic unit of the Mățau Conglomerates. The Badenian–Sarmatian boundary interval was studied by Bartol et al. (2013), from where the authors report a succession of bioevents similar to those described by Mărunțeanu (1999)

in the Outer Moldavide tectonic units of the Eastern Carpathians.

The nannofossil species *Isolithus semenenko*, along with taxa of the genus *Noelaerhabdus*, were considered by Ćorić (2006) as endemic for the Central Paratethyan domain. These taxa were described in Romania, from Pannonian deposits exposed in the southern part of the Pannonian Depression and in the Transylvanian Basin, by Mărunțeanu (1996, 1997), Chira & Mărunțeanu (2000), Chira (2006) and Botka et al. (2019). A few specimens assigned to the genus *Noelaerhabdus* were discovered in the middle Sarmatian *s.l.* (Bessarabian) in a section from the SE extremity of the Moesian Platform, in Southern Dobrogea (Briceag et al., 2018). Based on these data, the later authors indicate a possible connection of Southern Dobrogea (part of the Euxinian–Caspian domain, according to Popov et al., 2004) with the Central Paratethyan domain, during the middle Sarmatian *s.l.*

This paper presents the calcareous nannofossil assemblages of the Lower to Middle Miocene (upper Burdigalian–Sarmatian interval) from the west-central Getic Depression, based on a detailed study to point out cosmopolitan and endemic species. Palaeoecological considerations, based on characteristics of these nannofossil assemblages, are also advanced herein.

METHODOLOGY

To realise the calcareous nannoplankton analysis, 15 cores and 20 cuttings from 7 boreholes have been studied.

The investigated boreholes are located between Gilort River and Olteț River (Fig. 1.)

The nannoplankton analyses were carried out according to the I.C.P.T. Câmpina Geological Laboratory procedures.

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Fig. 1 a Geological Map of Romania, scale 1: 1,000,000. Printed by the Geological Institute of Romania (1978), showing the location of the investigated area; **b** Location of the studied drillings on the scale 1:200,000 Pitești Sheet (Mihăilă et al., 1967) of the Geological Map of Romania, printed by the Geological Institute of Romania.

For making smear slides, the samples were broken up and the resulting fragments were boiled with hydrogen peroxide (30% concentration) to remove the organic matter. The resulted material was filtered and washed with distilled water. The washed mud was placed in a Berzelius glass with distilled water and exposed to ultrasounds. A few drops of this solution were transferred to a glass slide and dried on a hot plate. The fixed smear slides were mounted by using Canada Baum adhesive. The identification and the microphotographs of the taxa were performed using an Olympus BX 51 polarized microscope (x1000 or x1200 magnifications), with gypsum plate and QuickPhoto Micro 2.2 software.

RESULTS

The oldest studied deposits of boreholes TO-2, CO-1, VA-2 and RA-1 are composed of gray and reddish-brown marls and clays with argillaceous limestone intercalations. Gray, siliceous fine-grained sandstones with mixed binder or calcareous cement also occur (Fig. 2).

Their late Burdigalian age is justified by the co-occurrence of *Calcidiscus macintyreii* and *Sphenolithus heteromorphus*, corresponding to the interval between the upper part of the NN3 and the lower part of the NN4 biozone of Martini (1971). In addition, the nannoplankton assemblage

contains Miocene species such as (Fig. 3): *Calcidiscus leptoporus*, *Coccolithus miopelagicus*, *Cyclicargolithus floridanus*, *Helicosphaera ampliaptera*, *H. carteri*, *H. intermedia*, *Pontosphaera multipora*, *Reticulofenestra pseudumbilicus*, and *R. haqii*, besides reworked Cretaceous–Paleogene nannofossils. Noteworthy is the low frequency, or even absence, of *Helicosphaera ampliaptera* in these assemblages. The aforementioned assemblages prove the presence of the NN4 Biozone, spanning the Burdigalian, whereas the NN5 Biozone with *Sphenolithus heteromorphus* already indicates the presence of the Langhian (respectively that of the Paratethyan Badenian stage). In the studied boreholes, the Lower Miocene (Burdigalian) deposits are covered by Middle Miocene ones (Badenian and Sarmatian). Samples from this interval were recovered from all of these boreholes.

The typical Badenian stage sedimentary succession of the Central Paratethys includes four distinct lithological units in the extra-Carpathian regions of Romania (listed from older to younger): (i) The Slănic Formation (= the Slănic Tuff), which is composed of interbedded volcanic tuffs, claystones and marlstones; levels very rich in foraminifera, described as the ‘Globigerina Marls’, occur mainly in the lower part of the unit; (ii) The ‘Evaporitic’ Formation, which consists mainly of salt breccias, bedded or lenticular gypsum bodies, salt accumulations, and very thin, cm to

Period	Epoch (TGS 2012)	Stage	Substage	Standard Nannoplankton Scale (Martini, 1971)	Lithological column	Lithostratigraphy	
NEOGENE	MIOCENE	Sarmatian	Bess.	NN 9		Gray marls and clays with sandstones intercalations	
				NN 8			
			Volh.	NN 7			
		Badenian	Late	NN 6		Spiratella Marls	
				NN 5		Radiolaria Shale	
			Middle			Salt Formation	
			Burdigalian	Early		NN 4	
		Late		Redish and gray mals			
		Early		NN 3		Redish argillaceous limestones	
			Gray clays				

Legend

clay
marl
argillaceous limestone
fine calcareous sandstone
salt

Fig. 2 Lithology and biostratigraphy of the upper Burdigalian-middle Sarmatian deposits of the Totea - Colțești - Rădinești - Văleni area.

dm thick, silty clay beds; (iii) The ‘Radiolarian Shale’ Formation that is composed of argillaceous shales, rich in radiolarians, as well as sands and sandstones (Fig. 3); and (iv) The ‘*Spiralis* Marls’ Formation, which is developed in a predominantly pelitic facies (Popescu, 1951; Ștefănescu et al., 1978; Mutihac et al., 2004; Melinte-Dobrinescu & Stoica, 2013). The boreholes studied by us from the Getic Depression, in the Totea and Rădinești areas, intercepted all of the aforementioned units.

The ‘*Globigerina* Marls’ are pointed out in the Totea area by microfaunal assemblages rich in *Globigerina* species. The samples from the basal part of this unit, collected from the TO-2 and TO-3 boreholes, contain nannoplankton assemblages consisting of *Sphenolithus heteromorphus*,

Pontosphaera discopora (with high frequency), *Umbilicosphaera rotula*, *Helicosphaera ampliaperta* and *H. walbersdorfensis* (Figs. 3, 4). These assemblages characterize the upper part of the NN 4 zone (Martini, 1971). Stratigraphically higher, the samples from the TO-2 well contain an assemblage showing a low frequency of *Helicosphaera ampliaperta* associated with a high frequency of *Pontosphaera discopora*. A similar assemblage was also observed in the sediments of the same lithostratigraphic units in the TO-3 borehole. A nannoplankton assemblage containing *Helicosphaera wallichi*, *H. walbersdorfensis*, *Sphenolithus heteromorphus*, *Pontosphaera discopora* and *Umbilicosphaera rotula* (Fig. 4), specific for the NN 5 biozone (Martini, 1971), was identified in the samples

Fig. 3 Upper Burdigalian calcareous nannofossils: **a, b** *Calcidiscus leptoporus* (Murray & Bramlette) Loeblich & Tappan (VA-1 borehole; a – N+ with λ compensator, b – NII with λ compensator); **c** *Calcidiscus macintyre* (Bukry & Bramlette) Loeblich & Tappan (CO-1 borehole, N+); **d** *Coccolithus miopelagicus* Bukry (TO-2 borehole, NII); **e** *Cyclicargolithus floridanus* (Roth & Hay) Bukry (TO-2 borehole, NII); **f, g** *Helicosphaera ampliaperta* Bramlette & Wilcoxon (TO-1 borehole, f – N+, 7 – gNII); **h** *Helicosphaera intermedia* Martini (CO-1 borehole, N+); **i, j** *Pontosphaera multipora* (Kamptner) Roth (TO-3 borehole, i – N+, j – N+ with λ compensator); **k, l** *Sphenolithus heteromorphus* Deflandre (TO-3 borehole, k – N+, 0°, l – N+, 45°).

from the TO-1 and TO-3 boreholes. In the assemblages found in the samples recovered just below the salt layers of the Evaporitic unit (TO-2 borehole), the occurrence, with a high frequency, of *Umbilicosphaera rotula* and *Umbilicosphaera jafari* has been observed.

The ‘Radiolarian Shale’ unit has been identified in the samples from RA-1 and TO-3 boreholes, based on a microfaunal assemblage rich in radiolarian taxa. These samples do not contain any nannofossils.

The occurrence of *Limacina* (= *Spirialis*) taxa, identified in the microfaunal associations derived from borehole TO-1, argues the presence of the ‘*Spirialis* Marls’. For these samples, the nannoplankton assemblages indicate the occurrence of the NN 6 zone of Martini (1971), based on the presence of the index taxon *Discoaster exilis*. In addition, the assemblages contain *Calcidiscus macintyre*, *Coccolithus miopelagicus*, *Discoaster musicus*, *Helicosphaera carteri*, *H. wallichii*, *H. walsbersdorfensis*, *Reticulofenestra perplexa*, *R. haqii* and *R. pseudoumbilicus* (Fig. 4).

In the sedimentary succession of the TO-1 borehole, gray marls with sandstone and sand intercalations represent the lower Sarmatian (Volhynian substage) depositional interval, dated by a microfauna with *Anomalinoidea dividens*

and *Elphidium hauerinum* (Ghiță et al., 2017). In this interval, the samples yielded nannofossil assemblages with a large number of small-sized reticulofenestrids, along with small-sized *Braarudosphaera bigelowii* (< 5 μ m), *Calcidiscus leptoporus*, *Calcidiscus macintyre*, *Coccolithus miopelagicus*, *Helicosphaera carteri*, *H. walsbersdorfensis*, *Umbilicosphaera jafari* and *Syracosphaera pulchra* (Fig. 5). An assemblage with predominantly small-sized reticulofenestrids was also identified in the samples from the VA-1 borehole. Mărunțeanu (1999) studied extra-Carpathian sections and described similar assemblages which she assigned to the NN 7 biozone (Martini, 1971), crossing the Badenian-Sarmatian boundary.

The NN 8 zone of Martini (1971) was identified in the samples from borehole VA-1 due to the occurrence of the index nannofossil *Catinaster coalitus*. The assemblages are characterized by the presence of *Isolithus semenko* and *Noelaerhabdus bozinovicae*, endemic taxa of the Central Paratethys basin (Bona & Gal, 1985; Mărunțeanu, 1998; Ćorić, 2006; Galović & Young, 2012) that occur with a very low frequency in our samples. Alongside these taxa, small-sized reticulofenestrids, *Calcidiscus macintyre*, *Coccolithus miopelagicus*, *Helicosphaera carteri*,

Fig. 4 Lower to middle Badenian calcareous nannofossils: **a** *Discoaster variabilis* Martini & Bramlette (TO-2 borehole, NII); **b** *Helicosphaera wallichii* (Lohmann) Boudreaux & Hay (TO-2 borehole, N+); **c, d** *Sphenolithus heteromorphus* Deflandre (RA-1 borehole, c – N+, 0°, d – N+, 45°); **e, f** *Pontosphaera discopora* Schiller (RA-1 borehole, e – N+, f – NII); **g** *Reticulofenestra haqii* Backman (CO-1 borehole, N+); **h** *Reticulofenestra pseudumbilicus* (Gartner) Gartner (CO-1 borehole, N+); **i** *Umbilicosphaera jafari* Müller (TO-2 borehole, NII); **j** *Umbilicosphaera rotula* (Kamptner) Varol (TO-2 borehole, NII).

very rare *H. stalis* and reworked Cretaceous–Early Miocene species make up the assemblage.

DISCUSSION

The composition of late Burdigalian nannoplankton assemblages is similar throughout the studied area in the investigated boreholes. *Sphenolithus heteromorphus*, *Calcidiscus macintyreii*, *C. leptoporus*, commonly present, indicate warm water-surface and an oligotrophic environment (Roth, 1994). The low nutrient input into the basin is reflected by the decrease in abundance of the taxa that are more dependant on high nutrient levels, such as: *Coccolithus pelagicus*, *Cyclicargolithus floridanus*, *Helicosphaera carteri* and *Reticulofenestra pseudumbilicus* (Auer et al., 2014).

Major changes in the composition of the nannoplankton assemblages have been observed starting with the early Badenian interval. A significant increase in the abundance of warm-water species, along with the ones that prefer shelf areas, such as *Pontosphaera discopora*, *P. multipora* and *Helicosphaera carteri* (Auer et al., 2014), can be noticed. The low percentage, or lack altogether, of discoasterids is interpreted as an indicator of a nearshore sedimentation (Ćorić & Hohenegger, 2008). In addition, the significant increase of species that support variations

in salinity (such as small and medium-sized reticulofenestrids alongside *Braarudosphaera bigelowii*) is another indicator of a nearshore sedimentation (Melinte, 2004; Ćorić & Hohenegger, 2008; Melinte-Dobrinescu & Stoica, 2013).

Umbilicosphaera jafari and *Umbilicosphaera rotula* show an increase in frequency in the middle Badenian samples recovered from below the salt level. It is possible that this bio-event marks the beginning of the isolation of the Central Paratethys, announcing the salinity crisis at the end of the middle Badenian. The two above-mentioned species were found in association in the Polemi Basin of Cyprus and in Vienna Basin, Austria, and their presence has been interpreted as an indicator for an increased salinity (Wade & Bown, 2006; Ćorić & Hohenegger, 2008).

The late Badenian coincides with the latest Late Miocene marine transgression in the Dacian Basin, marked in the nannoplankton assemblages by the presence of cosmopolitan taxa. The low percentage of warm-water species such as *Discoaster variabilis*, *D. musicus*, *Calcidiscus leptoporus* and *C. macintyreii* probably indicates the renewal of the Indo-Pacific Ocean connections, interrupted during the middle Badenian (Popov et al., 2004). *Discoaster exilis* and *D. deflandrei*, found in small amounts in the nannoplankton associations, are both considered to have preferred colder waters (Lelek et al., 2016). Meanwhile,

Fig. 5 Upper Badenian-Bessarabian calcareous nannofossils: **a** *Braarudosphaera bigelowii* (Gran & Braarud) Deflandre (TO-1 borehole); **b** *Calcidiscus macintyreii* (Bukry & Bramlette) Loeblich & Tappan (TO-1 borehole); **c** *Catinaster coalitus* Martini & Bramlette (VA-1 borehole); **d, e** *Discoaster exilis* Martini & Bramlette (TO-1 borehole); **f** *Discoaster musicus* Stradner (TO-1 borehole); **g** *Helicosphaera carteri* (Wallich) Kamptner (TO-1 borehole); **h** *Helicosphaera walberdorfensis* Mueller (TO-1 borehole); **i** *Reticulofenestra minuta* Roth (TO-1 borehole); **j** *Reticulofenestra perplexa* (Burns) Wise (VA-1 borehole); **k, l** *Sphenolithus abies* Deflandre (VA-1 borehole); **m** *Syracosphaera pulchra* Lohmann (TO-1 borehole); **n** *Noelaerhabdus bozinovicae tegulatus* Bona & Gal (VA-1 borehole); **o, p** *Isolithus semenenko* Lufjeva (o – VA-1 borehole, p – RA-1 borehole).

the high percentage of taxa such as *Helicosphaera carteri*, *Coccolithus pelagicus* and *Braarudosphaera bigelowii*, indicates that the sedimentation took place in a shallow-water eutrophic environment (Melinte-Dobrinescu & Stoica, 2013).

The composition of the lower Sarmatian (Volhynian substage) nannoplankton assemblages indicates an open marine environment, argued by the presence of the taxa belonging to the *Discoaster*, *Helicosphaera* and *Syracosphaera* genera. At the level of the middle Sarmatian (Bessarabian substage) important changes in the nannoplankton assemblages were observed. The main characteristic of these nannofossil associations is the mixture of endemic taxa, such as *Isolithus semenenko* and *Noelaerhabdus bozinovicae*, in the Central Paratethys. The aforementioned nannofossils are typical for the Central Paratethyan domain, being mostly distributed in the Pannonian Basin

(Hungary, Serbia - Bona & Gal, 1985), but also occurring in the Transylvanian (Romania - Mărunțeanu, 1998; Chira et al., 2000; Chira & Malacu, 2008) and Styrian (Austria - Ćorić & Gross, 2004) ones. Our studies indicate, for the first time, the presence of these endemic taxa in the Getic Depression, south of the Southern Carpathians, within an area included in the Dacian Basin from the Middle Miocene onwards (Jipa & Olariu, 2013). This discovery most probably indicates connections of the Pannonian and Transylvanian basins with the Dacian one during the Middle Miocene (Sarmatian).

The co-existence of the two types of nannofossil associations can be explained by the arrival of the Pannonian species in the western Dacian Basin, where normal salinity existed. However, the Pannonian “intruders” did not manage to adapt to the differing environmental conditions and soon afterwards disappeared from the Dacian fossil record.

CONCLUSIONS

The upper Burdigalian calcareous nannofossil associations identified in the central-western Getic Depression contain species that are more adapted to warm water-surface and oligotrophic environments. These assemblages are indicative for the interval between the NN 3 and the lower part of the NN 4 biozones.

In the Totea area, the Badenian stage shows complete lithological successions, with the development of all of the characteristic units described in the extra-Carpathian region. The lower Badenian nannoplankton assemblages are characterized by an increased number of species that indicate the warming of surface waters and a shallow-marine environment. The common presence of warm-water taxa such as the discoasterids probably reflects/documents Indo-Pacific influences from the Indo-Pacific Ocean in the western part of the Getic Depression (western Dacian Basin) during the late Badenian.

The continuity of the connections with the Indo-Pacific Ocean is also observed during the early Sarmatian (early Volhynian interval), equivalent to the NN 6 nannofossil zone (Piller et al., 2007). Within the upper part of the middle Sarmatian (the upper Volhynian interval, covered by the NN 7 biozone), the assemblage contains small-sized reticulofenestrids and *Braarudosphaera bigelowii*, both of which could mark a short period of decreased salinity in the Getic Depression.

A high-salinity marine environment is assumed during the lower part of the middle Sarmatian (lower Bessarabian, corresponding to the NN 8 nannofossil zone), argued by the presence of cosmopolitan nannofossils. During the aforementioned interval, a connection between the Central Paratethys (i.e., Pannonian and Transylvanian basins) and the Eastern Paratethys (western Dacian Basin) allowed the migration of the endemic nannofossils *Isolithus semenenko* and *Noelaerhabdus bozinovicae*.

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