Calcareous nannofossils from the middle/upper Miocene succession of Pécs-Danitzpuszta, southern Hungary: cosmopolitan Paratethys and endemic Lake Pannon assemblages

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Abstract

Quantitative analyses on calcareous nannofossils were carried out on 109 middle/late Miocene (Sarmatian/Pannonian) samples from the section at Pécs-Danitzpuszta sand pit (Hungary). The lower part of the section, which can be assigned to the Sarmatian, contains normal marine low-diversity assemblages dominated by Calcidiscus leptoporus, Reticulofenestra pseudoumbilicus, Sphenolithus moriformis and Syracosphaera spp. accompanied by didemnid ascidian spicules (Perforocalcinella fusiformis). The middle/late Miocene (Sarmatian/Pannonian) boundary is characterized by the last occurrences of normal marine calcareous nannofossils. The upper part of the section (Pannonian) can be subdivided into intervals characterized by monospecific endemic nannofossils Isolithus spp. and ascidians, respectively. A short interval with common endemic coccoliths belonging to the family Noelaerhabdaceae (Bekelithella echinata, Noelaerhabdus bozinovicae, N. jerkovici, Praenoelaerhabdus banatensis) in the upper part of the profile was also documented. The drastic change in nannofossil assemblages at the Sarmatian/Pannonian boundary is a result of paleoenvironmental stress caused by the isolation of the Central Paratethys from the Eastern Paratethys.

Keywords: Sarmatian, Pannonian, Lake Pannon, calcareous nannofossils, biostratigraphy, paleoecology

Introduction

As a consequence of the rise of the Alpine mountain belt at around the Eocene/Oligocene boundary, the Tethys Ocean disappeared and the Mediterranean and Paratethys Seas were established as two different palaeogeographic units in central and southern Europe (RÖGL 1998). This biogeographic differentiation led to the development of the regional Paratethyan chronostratigraphic and geochronologic system (RÖGL 1998, 1999). During the Sarmatian, which spans 12.7–11.6 Ma time interval (HARZHAUSER & PILLER 2007), the Central Paratethys was connected only to the Eastern Paratethys (STEININGER & WESSELY 2000). Subsequent isolation of the Central Paratethys from the Eastern...
Paratethys at the Sarmatian/Pannonian boundary led to the formation of Lake Pannon in the Pannonian Basin system (Harzhauser & Piller 2007, and references therein). During the Pannonian Age (11.6–6.1 Ma, Harzhauser & Piller 2007), brackish conditions prevailed in the basin, which made it impossible to use the standard calcareous nannofossil zonation for the biostratigraphic subdivision of the upper Miocene and Pliocene sediments in the Pannonian Basin.

Coccolithophores are a major group of unicellular marine phytoplankton used worldwide for the biostratigraphic and palaeoecologic interpretation of marine sediments from the Jurassic to the Quaternary. Ecologic factors, such as water temperature, light regime, inorganic nutrient supply (nitrate, phosphate, trace elements and vitamins) and water stratification directly influence the distribution of calcareous nanoplankton as photosynthetic haptophyte algae, which live in the upper euphotic zone of oceans (Winter & Siesser 1994). Generally, nanoplankton flourish in warm, well-stratified, oligotrophic, mid-ocean environments, although numerous species have a broad ecological tolerance (Bow & Young 1998).

Jerković (1970, 1971) introduced a new family (Noelaerhabdaceae) with a new genus (Noelaerhabdus) and new species from the Pannonian of the southern Pannonian Basin. Bôna (1964) and Bôna & Gál (1985) recognized the endemic character of Pannonian calcareous nannofossils by investigation of many localities in Hungary. They described the new genus Bekelithella with a new species, B. echinata, and another new species, Noelaerhabdus jerkovici, from sediments exposed in Pécs-Danitzpuszta (Bôna & Gál 1985). Pannonian sediments with Bekelithella echinata, Noelaerhabdus bozinovicae, N. bekei and N. jerkovici from the south-western part of the South Carpathians (Caransebes-Mehadia Basin, Romania) were assigned to nanoplankton zones NN10/NN11 by Mărunteanu et al. (1994).

Calcareous nanoplankton are thought to contribute substantially to the material of offshore calcareous marls (often mentioned as “white marls,” especially in Croatia and Serbia) of Lake Pannon (Corić 2004, 2005a).

Calcareous nannofossils from Sarmatian and Pannonian deposits of various localities in the North Croatian Basin were investigated by Gálovic & Young (2012) and Gálovic (2017). Mărunteanu et al. (1994) and Mărunteanu (1997) investigated Pannonian calcareous nannofossils from the Pannonian outcrops in the Transylvanian Basin (Romania) and established the evolutionary lineage of the genus Noelaerhabdus. This lineage can be used as a basis for the biostratigraphic subdivision of the Pannonian by calcareous nannofossils.

According to the regional Central Paratethyan chronostatigraphy (Rögl 1998, 1999), the middle Miocene is subdivided into the marine Badenian and Sarmatian Stages, which comprise nanoplankton zones NN4 – lower NN7 (Martini 1971). The Pannonian regional stage includes the entire upper Miocene and can be correlated to zones upper NN7 – NN11.

In this paper a detailed investigation of calcareous nannofossils from the middle–upper Miocene Pécs-Danitzpuszta section (Hungary) is documented. The objective of this study was to infer the stratigraphic position of the exposed succession, and to record and interpret the palaeoecological changes across the profile.

**Geological setting**

The Danitzpuszta outcrop, located in the eastern outskirts of the city of Pécs, is the largest exposure of Pannonian white marls in Hungary (Figure 1). The sand pit itself exposes upper Miocene Lake Pannon sediments: offshore
calcareous marls with clay, clay marl and sand interbeds along the northern wall, and yellowish brown, limonitic coarse sands in the bulk of the pit. Due to tectonic deformation, the succession is tilted, thus the general younging direction of the deposits is towards the south. In 2018 an exploration trench was excavated in the northermmost part of the sand pit, which revealed middle Miocene (Badenian and Sarmatian) layers underlying the upper Miocene ones. For details on the exposed sediments, the reader is referred to Sebe et al. (2021).

Material and methods

In total 109 rock samples were analysed for calcareous nannofossils from the 12 m – 79 m interval of the Pécs-Danítpuszta outcrop, representing a total of 67 m stratigraphic thickness (Figure 2). Sampling covered the whole Sarmatian and Pannonian part of the section where appropriate lithologies – layers with carbonate content – were present. Sampling started with the first carbonate-bearing layer (D56) according to the numbering of Sebe et al. (2021), above the Badenian/Sarmatian boundary, defined by micropaleontological investigations (Szuromi-Korecz et al., 2021).

Smear slides were prepared for all samples using standard procedures described by Perch-Nielsen (1985) and examined under light microscope DMLP Leica using plane- and cross-polarized light with 1000x magnification.

Quantitative data were obtained by counting at least 300 specimens from each smear slide that contained calcareous nannofossils. Further 100 fields of view of each smear slide were checked for important markers for the biostratigraphic and palaeoecologic interpretation of calcareous nannoplankton (Digital annex). Table I contains an alphabetically arranged list of autochthonous calcareous nannofossils from the Pécs-Danítpuszta section.

For the reticulofenestrids, the classification proposed by nannotax3 (http://www.mikrotax.org/Nannotax3/) was applied. The following Reticulofenestra species were distinguished: R. minuta (Gartner, 1967) Haq & Berggren, 1978 (3–5 µm without slits), R. haqii Backman, 1978 (3–5 µm), R. perplexa (Burns, 1975) Wise, 1983, R. cf. rotaria Theodoridis, 1984 (subcircular to circular 5–7 µm), R. pseudoumbilicus (Gartner, 1967) Gartner, 1969 (5–7 µm) and R. pseudoumbilicus (>7 µm).

Subdivision of genus Noelaerhabdus on the species level (Noelaerhabdus bekei Jerković, 1971, N. bozjinovicae Jerković, 1970, N. jerkovici Bóna & Gál, 1985, N. mehadicus Marunteanu, 1996 and N. bonagali Marunteanu, 1995) is based on the shape and length of the central spine. During the preparation, the central spine usually became damaged or broken and, therefore, species of this genus can be easily confused with Praenoelaerhabdus banatensis that does not possess the central spine. Therefore, P. banatensis and Noelaerhabdus spp. were counted together for statistical treatment. Coccoliths with diameter smaller than 3 µm with closed central area were assigned to Praenoelaerhabdus small.

Simple statistical analyses were calculated with EXCEL, whereas complex analyses were performed using the program PAST 4.03.

Clustering of samples was performed by Ward’s method based on standardized Euclidean distances with a subsequent determination of species that are indicative for the obtained clusters (see later Figure 4). Nonmetrical Multidimensional Scaling (nMDS), also based on standardized Euclidean distances, was used for the representation of the relationships between samples in a low-dimensional space (see later Figure 5). The grade of changes in nannofossil composition along the section was measured as distances between subsequent samples in the low dimensional character space gained by nMDS. Large distances indicate a strong turnover in floral composition, and longer intervals of large distances are typical for intensive environmental oscillations.

Results

Thirty-six of the 109 investigated smear slides were barren of calcareous nannofossils (Figure 2, Digital annex). Eleven samples contained too low amount of fossils; these were unsuitable for quantitative investigations. The rest of the samples (62 in total) contained generally common to abundant, well preserved calcareous nannofossils (Figure 3). All assemblages from the investigated section are characterized by low diversities, with a maximum value of 13 species in sample D41 (Figure 2).

According to the first and last occurrences of characteristic nannofossil species and based on their quantitative distribution patterns, the Pécs-Danítpuszta section can be subdivided into three main intervals, which are further divided into subintervals (Figure 2, Digital annex).

Interval 1): from the lowermost sample to the last occurrence of Reticulofenestra pseudoumbilicus (Gartner, 1967) Gartner, 1969 (D56 to D35). This interval contains assemblages with normal marine nannofossils: Acanthoica cohenii (Jerković, 1971) Aubry, 1999, Calcidiscus leptopus (Murray & Blackman, 1898) Loeblich & Tappan, 1978, Sphenolithus moriformis (Bronnimann & Stradner, 1960) Bramlette & Wilcoxon, 1967, Syracosphaera spp., Braarudosphaera bigelovii (Gras & Brasud, 1935) Deflandre, 1947 Braarudosphaera bigelovii subsp. parvula Stradner, 1960, and Coccolithus pelagicus (Wallich, 1877) Schiller, 1930. Barren samples from this interval probably point to short freshwater input. Interval 1 can be subdivided into two subintervals, each characterized by its own assemblage:

– Subinterval 1a): from the lowermost sample (D56) to D41 with the last common occurrence of Calcidiscus leptopus as the upper boundary of this subinterval. Assemblages are rich in well-preserved nannofossils, accompanied by Syracosphaera spp. and didemnid ascidian spicules (sea squirts) assigned to Perforocalciniella fusiformis Bóna, 1964. The uppermost two samples (D42, D41) contain high amounts of Sphenolithus moriformis and Reticulofenestra pseudoumbilicus. Sediments from the upper part (D46 to
Figure 2. Sample locations and the subdivision of the Pécs-Danitzpuszta section based on calcareous nannofossils (clusters resulting from Ward’s method – see Figure 4)

2. ábra. A pécs-danitzpuszta szélvény tagolása mészvázú nannofosszíliák alapján (a csoportok elkülönítése Ward módszerével történt, ld. 4. ábra)
D41) are characterized by decrease in abundance of nannofossils.

— **Subinterval 1b):** from D40 to D35, between the last occurrence of *Cd. leptoporus* and the last continuous occurrence of *Reticulofenestra pseudoumbilicus*. Assemblages of this subinterval contain rare but well-preserved nannofossils dominated by *R. pseudoumbilicus*, *Syracosphaera* spp., and *P. fusiformis*.

### Table 1. Distribution of autochthonous calcareous nannofossils in samples from the Pécs-Danitzpusza section. The list is arranged in an alphabetical order.

| Species                                           | Specimen number | Number of samples |
|---------------------------------------------------|-----------------|-------------------|
| *Acanthoica cohenii* (JERKOVIĆ, 1971) AUBRY, 1999| 42              | 5                 |
| *Bekelithella echinata* BONA & GAL., 1985        | 11              | 5                 |
| *Braurudosphaera bigelowii* (GRAN & BRAAUR 1935) DEFLANDRE, 1947| 2               | 2                 |
| *Braurudosphaera bigelowi subsp. parvula* STRADNER, 1960| 13              | 5                 |
| *Calciscus leptoporus* (MURRAY & BLACKMAN, 1898) LOEBLICH & TAPPAN, 1978| 1777            | 15                |
| *Calciscus pataeus* (GARTNER, 1967) DE KAENEL & VILLA, 1996| 2               | 2                 |
| *Calciosolenia brasiliensis* (LOHMAN, 1919) YOUNG in YOUNG et al., 2003| 7               | 2                 |
| *Catnaster cf. calycus* MARTINI & BRAMLETTE, 1963| 1               | 1                 |
| *Coccolithus pelagicus* (WALLICH 1877) SCHILLER, 1930| 27              | 15                |
| *Coronocyclus nitescens* (KAMPTNER, 1963) BRAMLETTE & WILCOXON, 1967| 4               | 2                 |
| *Helicosphaera carteri* (WALLICH 1877) KAMPTNER, 1954| 3               | 3                 |
| *Isolithus pavlici* ŐRiC, 2008                    | 2582            | 25                |
| *Isolithus semenenko* LYUL’EVA, 1989              | 2092            | 22                |
| *Isolithus* spp.                                  | 89              | 13                |
| *Lithostromation perdurnum* DEFLANDRE, 1942       | 1               | 1                 |
| *Prænoolerhabdus banatensis* MIHAILOVIC 1993, *Noelaerhabdus* spp. | 625            | 7                 |
| *Prænoolerhabdus* small (<3 µm)                   | 1475            | 22                |
| *Perforocinella fusiformis* BONA 1964              | 7691            | 49                |
| *Pontosphera discopora* SCHILLER, 1925            | 1               | 1                 |
| *Pontosphera multipora* (KAMPTNER, 1948 ex DEFLANDRE & FERT, 1954) ROTH, 1970| 2               | 2                 |
| *Pontosphaera* sp.                               | 2               | 2                 |
| *Reticulofenestra hqiil* BACKMAN, 1978            | 5               | 3                 |
| *Reticulofenestra minutula* (GARTNER, 1967) HAQ & BERGGREN, 1978| 4               | 2                 |
| *Reticulofenestra perplexa* (BURNS, 1975) WISE,1983| 4              | 2                 |
| *Reticulofenestra pseudoumbilicus* >7 µm (GARTNER, 1967) GARTNER, 1969| 153            | 7                 |
| *Reticulofenestra pseudoumbilicus* 5–7 µm (GARTNER, 1967) GARTNER, 1969| 164            | 7                 |
| *Reticulofenestra cf. rotaria* THEODORIDIS, 1984 | 7               | 2                 |
| *Sphenolithus moniformis* (BRÖNNIMANN & STRADNER, 1960) BRAMLETTE & WILCOXON, 1967| 144            | 5                 |
| *Sphenolithus* sp.                               | 2               | 1                 |
| *Syracosphaera* spp.                             | 1945            | 24                |
| *Thoracosphaera* spp.                            | 16              | 7                 |

Interval 2 (clay-marl-limestone alternation): From the last occurrence of *R. pseudoumbilicus* to the last occurrence of *Syracosphaera* spp. (D34 to D20). Assemblages from this interval are dominated by small-sized noelaerhabdaceae (with a diameter of 3µm or less) assigned to *Prænoolerhabdus* small, *P. fusiformis*, and *Syracosphaera* spp. This assemblage is accompanied by very rare *A. cohenii*, *C. pelagicus* and *R. pseudoumbilicus*. Spora-
dically, occurrences of these species can be a result of reworking.

**Interval 3:** the upper part of the section in a thickness of ca. 61 m (D19 to D225E). This interval is characterized by blooms of diademid ascidian spicules (P. fusiformis) and endemic nannofossils belonging to the genus *Isolithus* (*Isolithus pavelici*, *Isolithus semenenko*, *Isolithus spp.*). Samples D219W to D223–2 contain endemic *Prænoelaerhabdus banatensis Miha uljovic*, 1993 (taxa without central spine), *Noelaerhabdus bekei Jerković*, 1971 (short spine in the central area), *N. jerkovici Böna & Gál*, 1985 (longer spine) and *Bekelithella echinata Böna & Gál*, 1985. Normal marine nannofossils (A. cohenii, *Catineras* cf. coalitus, *C. pelagicus*, *R. perplexa*, *R. haqii*, *R. pseudoambilicus* etc.) are very rare in this interval. Interval 3 can be subdivided into the following four subintervals based on the alternating pre dominance of ascidians and *Isolithus spp.*, respectively.

- **Subinterval 3a:** from sample D19 to D5 (between the last occurrence of *Syracosphaera* spp. and first common occurrence of *Isolithus* spp.) is characterized by blooms of ascidians, whereas the dominance of *Prænoelaerhabdus* small was observed only in sample D11, and by the very scarce presence of normal marine taxa (*C. pelagicus*, *R. haqii*, *R. minutula*, *R. perplexa*).

- **Subinterval 3b:** from sample D1 to D17W contains assemblages with the blooms of *Isolithus* spp. with sporadically abundant ascidians (sample D116).

- **Subinterval 3c:** from sample D118 to D217. In the lower part of this interval (D118 to D207) ascidians occur accompanied by diatoms and sponge spicules, whereas the upper part is barren and does not contain any fossils (D209–D217).

**Figure 3.** Calcareous nannofossils from the Pécs-Danitzpuszta section. 3. a. *P. fusiformis* of the Pécs-Danitzpuszta section. 3. b. *R. perplexa* occurring with ascidians. Subinterval 3a ends with samples containing *Isolithus* spp. (Samples D223 and D225).

**Discussion**

**Palaeoecology**

The interpretation of the palaeoecosystem is based on the changes in abundance patterns of nannofossils within assemblages. All samples contain very low diversity assemblages with higher values in the lower part of the section (Intervals 1 and 2 with a maximum value of 13 taxa in D41, Figure 4). Dense assemblages from the middle and upper part of the section (Intervals 3a – d) consist mostly of only one or two species. Calcareous nannofossil assemblages from the lower part of the section (Intervals 1 and 2) are defined by *Calcidiscus leptoroporus*, *Reticulofenestra pseudoumbilicus*, *Syroncphaera* spp. and *Prænoelaerhabdus* small as
main components. *Isolithus* spp. and didemnid ascidians are dominating components in the upper part of the section in Interval 3.

Didemnid ascidian spicules are generally common and well-preserved in basins characterised by high bottom water temperature, rapid sedimentation rate and low water circulation (Varol & Houghton 1996). *Perforocalcinella fusiformis* that belongs to this group was described from the lower Pannonian of the Mecsek Mountains (borehole Hidas), Hungary (Bóna 1964). Blooms of *P. fusiformis* were also documented from the upper Sarmatian in different parts of the Central Paratethys (Galović 2017, Ćorić et al. 2017).
and, as sporadic occurrences, from the Badenian (KOVAČ et al. 2005, 2008). The changes in occurrences of *P. fusiformis* are strongly influenced ecologically by changes in palaeo-conditions and cannot be used for biostratigraphic subdivision.

**Interval 1** with the highest diversity throughout the section (average value 5.12 taxa/sample) contains assemblages with normal marine nannofossils.

**Subinterval 1a** is dominated by *Calcidiscus leptoporus*, an extant taxon with the first occurrence within NN2 (lowermost Aquitanian) and still present in recent oceans. Ecological preferences of *C. leptoporus* were investigated in Portuguese coastal water by ŠILVA et al. (2009). This opportunistic cosmopolitan coccolithophore species points to warmer, low turbulent, normal salinity, oligotrophic waters. High occurrences of warm oligotrophic *S. moriformis* on the top of Subinterval 1a (samples D42 and D41) point to a short interval of increased salinity during Sarmatian. The absence or only sporadic occurrence of *Coccolithus pelagicus*, which is well-known as a marker of nutrient-rich cold water (OKADA & McINNRE 1979, WINTER & SIESSER 1994), and those of helicoliths with ecological preference for upwelling and reticuloenestrids accompanied with ascidians were also reported from the upper Sarmatian sediments from other parts of the Central Paratethys (GALOVIĆ 2017, ŠARINOVA et al. 2018), and are interpreted as a consequence of decreasing water depth at the end of the middle Miocene (as documented by e.g., PILLER et al. 2007).

Samples from Interval 1 are grouped into Cluster 3 (Figure 4) occupying the central and the upper part of nMDS, and biostratigraphically can be attributed into the Sarmatian.

**Interval 2** represents a thickness of ca. 3 m and contains very low diversity assemblages with an average value of 3.14 taxa/sample. The lower part of this interval (D34 to D28) is dominated by ascidians, whereas in the upper part (D27 to D23) *Praenoelaerhabdus small* and *Syracosphaera* spp. prevail. *Acanthochaeta cohenii* and ascidians are also common.

Genus *Praenoelaerhabdus* with *P. banatensis* is an endemic taxon described from Pannonian deposits of Serbia (MIHAILOVIĆ 1993). Small *Praenoelaerhabdus* with a diameter less than 2 µm were documented from the Sarmatian and Pannonian of Croatia (ČORIĆ et al. 2017). Blooms of small *Praenoelaerhabdus* together with *Syracosphaera* spp. during Interval 2 can be interpreted as a period of strongly reduced salinity. It represents a transitional interval containing normal marine (*A. cohenii* and *Syracosphaera* spp.) and endemic forms (*Praenoelaerhabdus* small) in a low diversity association. Samples of Interval 2 containing ascidians are grouped into Cluster 1, whereas samples with coccoliths (*Syracosphaera* spp. and *Praenoelaerhabdus* small) were statistically grouped into Cluster 3.

The longest part of the section (ca. 61 m) belongs to **Interval 3**, which is subdivided into four subintervals according to the predominance of *P. fusiformis* (Subintervals 3a and 3c), *Isolithus* spp. (3b and 3d) or *P. banatensis* and *Noelaerhabdus* spp., respectively. *Isolithus sememenko* LULJEWA, 1989 was originally described from the lower Pliocene marls of the Eastern Paratethys (Taman region, Russia). The occurrences of this genus were documented in the uppermost Sarmatian and Pannonian sediments of the Central Paratethys in Croatia, Serbia and Romania (ČORIĆ et al. 2017, GALOVIĆ 2017), CHIRA & MALACU (2008) reported about the abundance of various *Isolithus* species in the Pannonian of Transylvania (Romania). ČORIĆ (2004, 2005a, b) investigated quantitatively the calcareous nannofossils from the Pannonian of Croatia (Našice) and found periodically repeated blooms of *Isolithus* spp. alternating with periods of blooms of *P. fusiformis*. Periods with blooms of ascidian spicules (3a and 3c) can be interpreted as periods of shallowing whereas intervals with abundant *Isolithus* spp. (3b and 3d) can point to the opposite trend. Results of quantitative analyses can be used for the correlation
between various locations and sub-basins within the Pannonian Basin.

Samples from Subintervals 3a and 3c (dominated by *P. fusiformis*) are mostly grouped into Cluster 1 together with samples from Intervals 1 and 2, which have similar composition, thus they cannot be separated from each other stratigraphically. On the other hand, samples containing *Isolithus* spp. (Subintervals 3b and 3d) build Cluster 2 (Figure 4), clearly separated in the lower left part of the nMDS diagram (third quadrant).

The middle part of Subinterval 3c (D200-1 to D207) is characterized by the occurrences of well-preserved diatoms and sponge spicules. HAJOS (1985) investigated occurrences of Pannonian diatoms from several localities in Hungary. All occurrences may point to sedimentation in very shallow areas, or lagoons dominated by NW wind. The investigated diatom assemblages are very often accompanied by sponge remains. Occurrences of sponge remains can be a sign of extremely stressing conditions, such as water level variation (MANCONI & PROZANTO 2015, 2016). Therefore, Subinterval 3c in the Pécs-Danitzpuszta section can be interpreted as a period of strong shallowing. Interestingly, freshwater sponge remains (*Ephydatia fossilis*) were first described from the middle/upper Miocene from Hungary (Dubrovicza) and Romania (Kevna Brema) by TRAXLER (1894).

Subinterval 3d contains rich, well-preserved assemblages. The lower part of this Subinterval is dominated by the co-occurrence of ascidians and endemic nannofossils, such as *Bekelithella echinata*, *Praenoelaerhabdus banatensis*, *Noelaerhabdus bekei* and *Noelaerhabdus jekovici*. Occurrences of placoliths from family Noelaerhabdaceae is a sign of short deepening of this part of the basin. Subinterval 3d ends with blooms of *Isolithus* spp.

**Biostratigraphy**

Generally, the Pécs-Danitzpuszta section can be subdivided into a lower part (Intervals 1 and 2 including samples D56 to D20) with normal marine calcareous nannofossils, and an upper part (Interval 3 including samples D18 to D225) characterized by the presence of ascidians and endemic nannofossils and very rare marine nannofossils.

In the lower part of the section, the absence of *Sphenolithus heteromorphus* DEFLANDRE, 1953 points to an age younger than NN5 (MARTINI 1971). Interval 1b contains a high amount of *R. pseudoumbilicus* (up to 30% of total nannofossils and about 90% of all counted reticulofenestrids). FORNACIARI et al. (1996) used common and abundant *R. pseudoumbilicus* to define the *Reticulofenestra pseudoumbilicus* Partial-range Subzone (MNN6b) in the Mediterranean region, which can be correlated with the upper part of standard nannoplankton Zone NN6. RAFFI et al. (2006) dated Highest Occurrence (HO) of *Cyclicargolithus floridanus* (ROTH & HAY in HAY et al. 1967) BUKRY 1971 at 12.1 Ma in the uppermost Serravallian. The absence of *C. floridanus* in all investigated samples allows an attribution of the lower part of the section (D56 to D20) to the upper NN6 or younger, which can be correlated to the upper Sarmatian. The zone marker for NN7, *Discoaster kugleri* MARTINI & Bramlette, 1963, was not observed in the section. The absence of discoasters (open marine taxa) is most probably caused by the shallowing environment during the Sarmatian in this area. According to the last continuous occurrence of marine nannofossils, the Sarmatian–Pannonian boundary can be placed between samples D20 and D19. Sample D36 contains common *Braarudosphaera bigelowi* subsp. *parvula* STRADNER 1960. Bloom of this small pentalith was observed in the upper Sarmatian of the southern Vienna Basin (STRADNER 1960) and was interpreted as the result of a drop in salinity. Occurrences of this species confirm the attribution of this part of the section into the upper Sarmatian.

The lower part of Subinterval 3d (samples D219 to D223) is characterized by high amounts of ascidians, endemic coccoliths *Bekelithella echinata*, *Praenoelaerhabdus banatensis*, *Noelaerhabdus bekei*, *Noelaerhabdus jekovici* and only sporadic occurrences of normal marine species; thus, it can be attributed to the Pannonian. MARUNTEANU (1997) proposed an evolutionary lineage for the endemic *Noelaerhabdus* species in Transylvania. Due to the shallow position of the section, only the nannofossil assemblages from the uppermost part of the Pécs-Danitzpuszta section (Subinterval 3d) fit this proposed model. According to MARUNTEANU et al. (1994), a similar endemic assemblage occurs above marine species that represent the NN9 zone in the Temes Valley, Romania. Thus, the endemic assemblage must be younger than the beginning of NN9 Chron (10.55 Ma). Sample D221 contains the very rare *Catinaster* cf. *calyculus* MARTINI & BRAMLETTE, 1963. This cup-shaped nannofossil has a short stratigraphic range with the first occurrence within NN9 and the last occurrence within NN10. Therefore, this part of the section can be correlated either with NN9 (9.53–10.55 Ma) or with NN10 (8.29–9.53 Ma).

**Conclusions**

All samples from the Pécs-Danitzpuszta outcrop contain low-diversity calcareous nannofossil assemblages. The section can be divided into three intervals that reflect palaeoecological changes during the late Sarmatian and Pannonian period. Interval 1 (samples D56 to D35) is dominated by normal marine nannofossils, such as *C. leptopora*, *R. pseudoumbilicus*, *S. moriformis*, *Syracosphaera* spp., and by didemnid ascidian spicules (sea squirts). This assemblage points to warm, shallow oligotrophic marine conditions. A slight increase in eutrophication in the upper part (Subinterval 1b) is probably caused by enhanced nutrient supply by rivers. Interval 2 (D34 to D20) displays very low diversity. The co-occurrence of endemic *Praenoelaerhabdus* small and normal marine *A. cohenii* and *Syracosphaera* spp. indicates a drop in salinity, which can be interpreted as a stepwise transition from marine to brackish lacustrine conditions. The longest interval, Interval 3 (D18 to D225) is characterized by alternation of monospecific assemblages with either *P. fusiformis* or *Isoli-
Assemblages dominated by ascidians (P. fusiformis) are interpreted as periods of shallowing based on the co-occurrences of diatoms and sponge remains within this interval (3c). On the contrary, the intervals with abundant Isolithus spp. are interpreted as periods of slight deepening. In addition, a short interval (lower part of 3d) with endemic calcareous nannofossils (B. echinata, Noelaehabdas spp.) also indicate a period of deepening of the basin. Changes in the Pannonian assemblages are influenced by changes in environmental circumstances, most probably water depth and salinity.

Based on the abundance of R. pseudoumbilicus and the absence of S. heteromorphus and C. floridanus, Intervals 1 and 2 can be attributed to the upper NN6 (and/or NN7) standard nannoplankton zones (younger than 12.1 Ma), and are interpreted here as belonging to the marine upper Sarmatian, whereas Interval 3 correlates with the brackish lacus - interpreted here as belonging to the marine upper Sarmatian (3c). On the contrary, the intervals with abundant handwriting (3c).

The applied statistical methods document the response of nannofossil assemblages to the rapid environmental and paleoecological changes that took place during the Sarmatian and Pannonian in this part of the Pannonian Basin.

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