

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

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Mészvázú nannofossziliák Pécs-Danitzpuszta középső/felső miocén képződményeiből

Összefoglalás

A pécs-danitzpusztai homokbányában feltárt középső és késő miocén (szarmata és pannóniai) rétegsor 109 mintáján végeztük el mésvázú nannofossziliák mennyiségi vizsgálatát. A feltárás alsó része, amely a szarmatába sorolható, alacsony diverzitású, normál tengeri együttest tartalmaz, melyben a *Calcidiscus leptoporus*, *Reticulofenestra pseudumbilicus*, *Sphenolithus moriformis* és a *Syracosphaera* spp. voltak az uralkodó formák, és amelyben a Didemniidae családba tartozó előgerinchúros zsákállatok (aszcidíák) tői (*Perforocalcinela fusiformis*) is előfordulnak. A középső és késő miocén határa, azaz a szarmata/pannóniai határ a normál tengeri mésvázú nannofossziliák utolsó előfordulásánál húzható meg. A feltárás felső részében az endemikus *Isolithus* spp. monospecifikus előfordulásával, illetve aszcidiákkal jellemzett intervallumok váltakoznak. A feltárás tetején egy rövid szakaszon gyakoriak a Noelaerhabdaceae családba tartozó endemikus kokkolitok (*Bekelithella echinata*, *Noelaerhabdus bozinovicae*, *N. jerkovici*, *Praenoelaerhabdus banatensis*). A nannofosszilia-együttesek drasztikus változását a szarmata/pannóniai határon a Középső-Paratethys lefűződésének következtében kialakult környezeti stressz okozta.

Kulcsszavak: szarmata, pannóniai, Pannon-tó, mésvázú nannofosszília, biosztratigráfia, paleoökológia

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 pseudumbilicus*, *Sphenolithus moriformis* and *Syracosphaera* spp. accompanied by didemnid ascidian spicules (*Perforocalcinela 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 nannoplankton as photosynthetic haptophyte algae, which live in the upper euphotic zone of oceans (WINTER & SIESSER 1994). Generally, nannoplankton flourish in warm, well-stratified, oligotrophic, mid-ocean environments, although numerous species have a broad ecological tolerance (BOWN & 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. BÓNA (1964) and BÓNA & 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 (BÓNA & GÁL 1985). Pannonian sediments with *Bekelithella echinata*, *Noelaerhabdus bozinovicae*, *N. bekei* and *N. jerkovici* from the south-western part of the South Carpathians (Caransebeş-Mehadia Basin, Romania) were assigned to nannoplankton zones NN10/NN11 by MĂRUNŢEANU et al. (1994).

Calcareous nannoplankton 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 (Ćorić 2004, 2005a).

Calcareous nannofossils from Sarmatian and Pannonian deposits of various localities in the North Croatian Basin were investigated by GALOVIĆ & YOUNG (2012) and GALOVIĆ (2017). MĂRUNŢEANU et al. (1994) and MĂRUNŢEANU (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 chronostratigraphy (RÖGL 1998, 1999), the middle Miocene is subdivided into the marine Badenian and Sarmatian Stages, which comprise nannoplankton 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

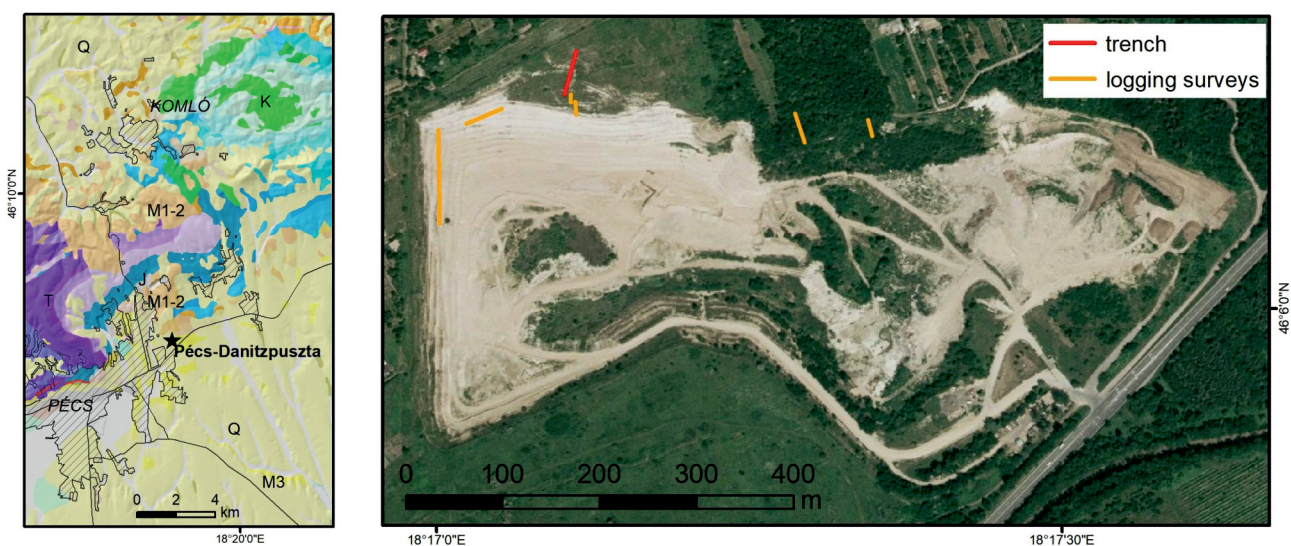


Figure 1. Location of the studied sand pit and the sampled sections

Legend: T (lilac): Triassic; J (blue): Jurassic; K (green): Cretaceous; M1-2: lower–middle Miocene; M3: upper Miocene; Q: Quaternary

1. ábra. A vizsgált feltárás helye a mintázott szelvényekkel

Jelmagyarázat: T (lila): triász; J (kék): jura; K (zöld): kréta; M1-2: alsó és középső miocén; M3: felső miocén; Q: kvarter

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 northernmost 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-Danitzpuszta 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 micropalaeontological 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 1 contains an alphabetically arranged list of autochthonous calcareous nannofossils from the Pécs-Danitzpuszta section.

For the reticulofenestrids, the classification proposed by nannotax3 (<http://www.mikrotax.org/Nannotax3/>) was applied. The following *Reticulofenestra* species were distinguished: *R. minutula* (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. bozinovicae* JERKOVIĆ, 1970, *N. jerkovici* BÓNA & GÁL, 1985, *N. mehadiscus* 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-Danitzpuszta 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 leptoporus* (MURRAY & BLACKMAN, 1898) LOEBLICH & TAPPAN, 1978, *Sphenolithus moriformis* (BRÖNNIMANN & STRADNER, 1960) BRAMLETTE & WILCOXON, 1967, *Syracosphaera* spp., *Braarudosphaera bigelowii* (GRAN & BRAARUD, 1935) DEFLANDRE, 1947 *Braarudosphaera bigelowii* 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 leptoporus* 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 *Perforocalcinella 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

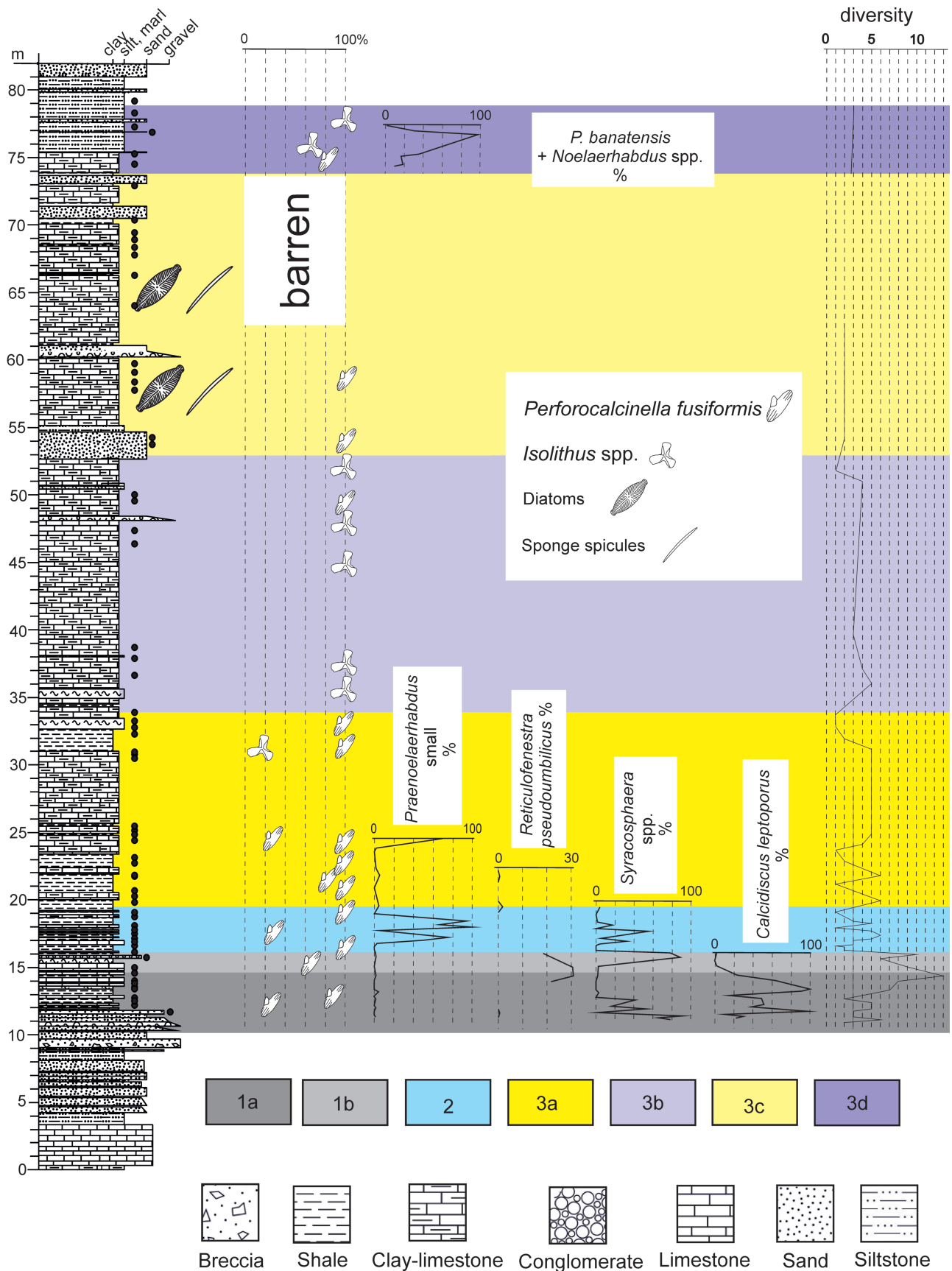


Figure 2. Sample locations and the subdivision of the Pécs-Danitzpuszta section based on calcareous nannofossils (clusters resulting from WARD's method - see Figure 4)

2. ábra. A pécs-danitzpusztai szelvény tagolása mészvázú nannofossziliák alapján (a csoportok elkülönítése WARD módszerével történt, ld. 4. ábra)

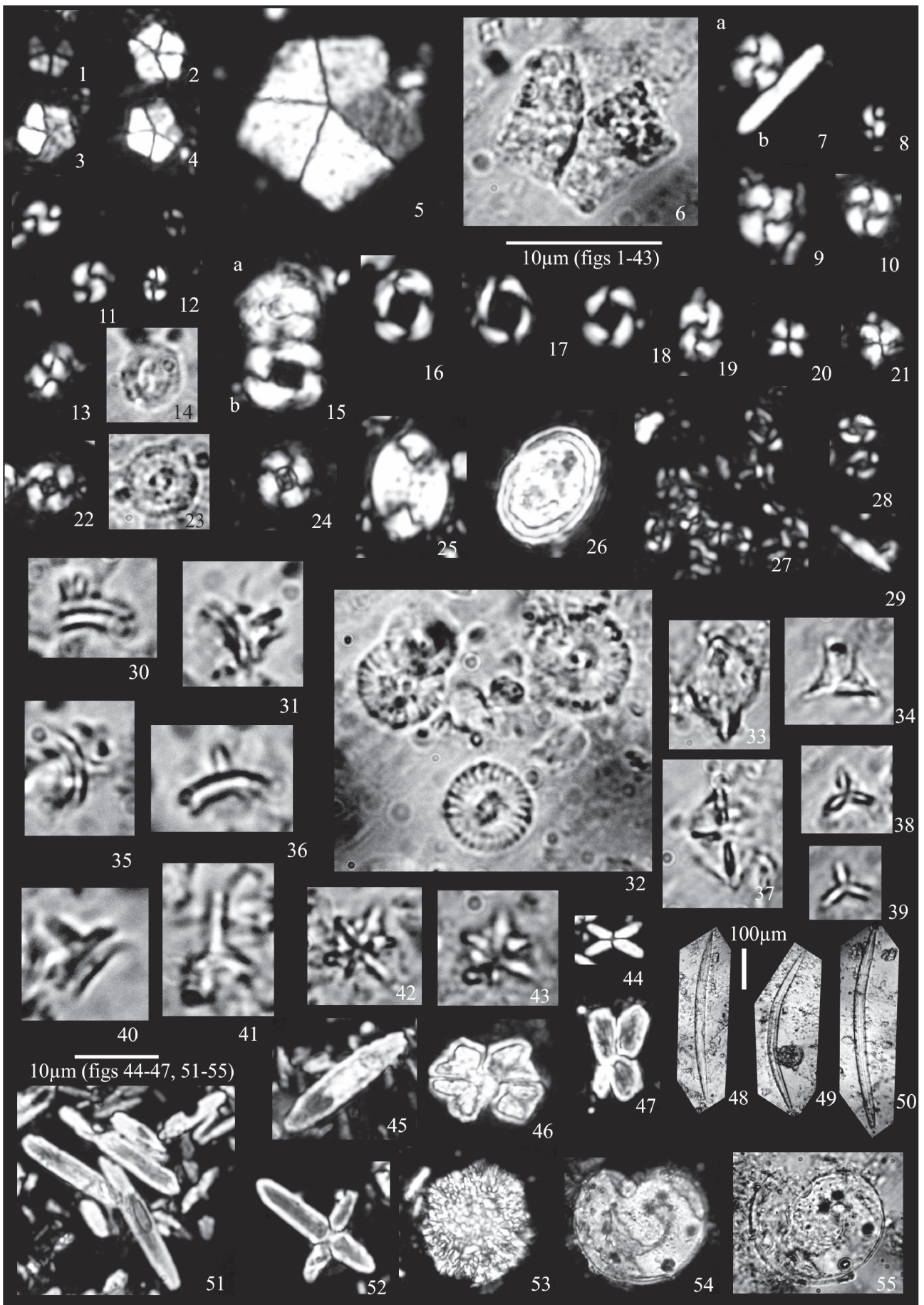
Table I. Distribution of autochthonous calcareous nannofossils in samples from the Pécs-Danitzpuszta section. The list is arranged in an alphabetical order**I. tábla.** Az autochton mészvázú nannofossziliák eloszlása a pécs-danitzpusztai szelvény mintáiban (ábécésorrendben)

Species	Specimen number	Number of samples
<i>Acanthoica cohenii</i> (JERKOVIĆ, 1971) AUBRY, 1999	42	5
<i>Bekelithella echinata</i> BÓNA & GÁL, 1985	11	5
<i>Braarudosphaera bigelowii</i> (GRAN & BRAARUD 1935) DEFLANDRE, 1947	2	2
<i>Braarudosphaera bigelowii</i> subsp. <i>parvula</i> STRADNER, 1960	13	5
<i>Calcidiscus leptoporus</i> (MURRAY & BLACKMAN, 1898) LOEBLICH & TAPPAN, 1978	1777	15
<i>Calcidiscus pataecus</i> (GARTNER, 1967) DE KAENEL & VILLA, 1996	2	2
<i>Calciosolenia brasiliensis</i> (LOHMANN, 1919) YOUNG in YOUNG et al., 2003	7	2
<i>Catinaster</i> cf. <i>calyculus</i> MARTINI & BRAMLETTE, 1963	1	1
<i>Coccolithus pelagicus</i> (WALLICH 1877) SCHILLER, 1930	27	15
<i>Coronocyclus nitescens</i> (KAMPTNER, 1963) BRAMLETTE & WILCOXON, 1967	4	2
<i>Helicosphaera carteri</i> (WALLICH 1877) KAMPTNER, 1954	3	3
<i>Isolithus pavelici</i> ĆORIĆ, 2008	2582	25
<i>Isolithus semenenko</i> LYUL'EVA, 1989	2092	22
<i>Isolithus</i> spp.	89	13
<i>Lithostromation perdurum</i> DEFLANDRE, 1942	1	1
<i>Praenoelaerhabdus banatensis</i> MIHAJLOVIĆ 1993, <i>Noelaerhabdus</i> spp.	625	7
<i>Praenoelaerhabdus</i> small (<3 µm)	1475	22
<i>Perforocalcinella fusiformis</i> BÓNA 1964	7691	49
<i>Pontosphaera discopora</i> SCHILLER, 1925	1	1
<i>Pontosphaera multipora</i> (KAMPTNER, 1948 ex DEFLANDRE in DEFLANDRE & FERT, 1954) ROTH, 1970	2	2
<i>Pontosphaera</i> sp.	2	2
<i>Reticulofenestra haqii</i> BACKMAN, 1978	5	3
<i>Reticulofenestra minutula</i> (GARTNER, 1967) HAQ & BERGGREN, 1978	4	2
<i>Reticulofenestra perplexa</i> (BURNS, 1975) WISE, 1983	4	2
<i>Reticulofenestra pseudoumbilicus</i> >7 µm (GARTNER, 1967) GARTNER, 1969	153	7
<i>Reticulofenestra pseudoumbilicus</i> 5–7 µm (GARTNER, 1967) GARTNER, 1969	164	7
<i>Reticulofenestra</i> cf. <i>rotaria</i> THEODORIDIS, 1984	7	2
<i>Sphenolithus moriformis</i> (BRÖNNIMANN & STRADNER, 1960) BRAMLETTE & WILCOXON, 1967	144	5
<i>Sphenolithus</i> sp.	2	1
<i>Syracosphaera</i> spp.	1945	24
<i>Thoracosphaera</i> spp.	16	7

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*.

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 *Praenoelaerhabdus* 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 didemnid 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 *Praenoelaerhabdus banatensis* MIHAJLOVIĆ, 1993 (taxa without central spine), *Noelaerhabdus bekei* JERKOVIĆ, 1971 (short spine in the central area), *N. jerkovici* BÓNA & GÁL, 1985 (longer spine) and *Bekelithella echinata* BÓNA & GÁL, 1985. Normal marine nannofossils (*A. cohenii*, *Catinaster* cf. *coalitus*, *C. pelagicus*, *R. perplexa*, *R. haqii*, *R. pseudoubilicus* etc.) are very rare in this interval. Interval 3 can be subdivided into the following four subintervals based on the alternating predominance 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 *Praenoelaerhabdus* small was observed only in sample D11, and by the very scarce presence of normal marine taxa (*C. pelagicus*, *R. haqi*, *R. minutula*, *R. perplexa*).

– **Subinterval 3b):** from sample D1 to D117W 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. **ábra.** Mészvázú nannofossilizációk a pécs-danitzpusztai szelvényből
 1–4. *Braarudosphaera bigelowii* subsp. *parvula* STRADNER, 1960, D36.
 5, 6 *Braarudosphaera bigelowii* (GRAN & BRAARUD, 1935) DEFLANDRE, 1947, D41.
 7a, 9, 10. *Praenoelaerhabdus banatensis* MIHAJLOVIĆ, 1993, D219.
 7b. Didemnid ascidian spicule, D219.
 8, 11, 12. *Praenoelaerhabdus* small (<3µm), 11: Sample D-219; 8, 12. D11.
 13, 14. *Coccolithus pelagicus* (WALLICH, 1877) SCHILLER 1930, D41.
 15a, 22–24, 32. *Calcidiscus leptoporus* (MURRAY & BLACKMAN, 1898) LOEBLICH & TAPPAN, 1978, 15a: Sample D-39; 22–25, 37: D47.
 15b, 16–18. *Reticulofenestra pseudoubilicus* (GARTNER, 1967) GARTNER, 1969, 15b: Sample D-39, 16, 17: Sample D-35, 18: D41.
 19. *Reticulofenestra perplexa* (BURNS, 1975) WISE, 1983 D41.
 20, 21. *Sphenolithus moriformis* (BRÖNNIMANN & STRADNER, 1960) BRAMLETTE & WILCOXON, 1967, Sample D-25; 28: D41.
 25. *Pontosphaera multipora* (KAMPTNER, 1948 ex DEFLANDRE in DEFLANDRE & FERT, 1954) Roth 1970, D221.
 26. *Pontosphaera discopora* SCHILLER, 1925, D25.
 27, 28. *Syracosphaera* spp., D54.
 29. *Calciosolenia brasiliensis* (LOHMANN, 1919) YOUNG in YOUNG et al. 2003, D55.
 30, 31. *Bekelithella echinata* BÓNA & GÁL, 1985, D221.
 33, 37. *Isolithus pavelici* ČORIĆ, 2005, Figs 33, 45: D107; Figs 33, 44: D102.
 34. *Acanthoica* sp.
 35, 36, 40. *Noelaerhabdus bekei* JERKOVIĆ, 1971, D 221.
 38, 39. *Isolithus semenenko* LULJEVA, 1989, D102.
 41. *Noelaerhabdus jerkovici* BÓNA & GÁL, 1985, D221.
 42, 43. *Catinaster calyculus* MARTINI & BRAMLETTE, 1963, D221.
 44–47, 51, 52. Didemnid ascidian spicules: *Perforocalcinella fusiformis* BÓNA, 1964, 45–47.: D6; 43, 51, 52: D36.
 48–50. Loose demosponge spicules, different types of oxeas, D204–3
 53. Calcifying dinoflagellates (*Thoracosphaera* spp.), D25.
 54, 55. Planktonic gastropods, D25.

– **Subinterval 3d)** includes samples from the top of the section (D219W to D225E). This short interval (ca. 4 m) is characterized by occurrences of endemic calcareous nannofossils belonging to family Noelaerhabdaceae JERKOVIĆ, 1970 emend. YOUNG & BOWN, 1997: *Bekelithella echinata*, *Praenoelaerhabdus banatensis*, *Noelaerhabdus bekei*, *N. bozinovicae*, *N. jerkovici* in samples D219 to D223-1 co-occurring with ascidians. Subinterval 3d ends with samples containing *Isolithus* spp. (Samples D223 and D225).

Thin green clay/silt layers from the top of the profile Pécs-Danitzpuszta (D226, D226E) are barren of calcareous nannofossils.

Very rare occurrences of *Watznaueria barnesiae* (BLACK in BLACK & BARNES, 1959) PERCH-NIELSEN, 1968, *Micula staurophora* (GARDET, 1955) STRADNER, 1963 and *Nannoconus steinmannii* KAMPTNER, 1931 throughout the whole section point to reworking from the Cretaceous.

Species distribution by multivariate analyses

Cluster analysis by the Euclid method differentiated three clusters (Figure 4).

A single species, *Perforocalcinella fusiformis*, is an indicator component for clustering samples into Cluster 1. This cluster includes 25 samples mostly from interval 2 and from subintervals 3a and 3c. All samples from this cluster are grouped in the 4th quadrant of nMDS (Figure 5).

High percentages of endemic genus *Isolithus* spp. characterize Cluster 2, which groups in total 14 samples exclusively from Subintervals 3b and 3d. Samples from Cluster 2 are placed in the 3rd quadrant of nMDS (Figure 5).

Most significant species in Cluster 3 are *Calcidiscus leptoporus*, *Syracosphaera* spp., *Sphenolithus moriformis*, *R. pseudoubilicus* and *Praenoelorbhdus* small. This cluster contains samples from Subintervals 1a (11 samples), 1b (2 samples), Interval 2 (6 samples), Subinterval 3d (with *B. echinata*, *Praenoelaerhabdus banatensis* and *Noelaerhabdus* spp.) and only one sample from Interval 3a. Samples from Cluster 3 are grouped in the central part of nMDS (Figure 5).

Discussion

Palaeoecology

The interpretation of the palaeoenvironment 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 2). 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 leptoporus*, *Reticulofenestra pseudoubilicus*, *Syracosphaera* spp. and *Praenoelaerhabdus* small as

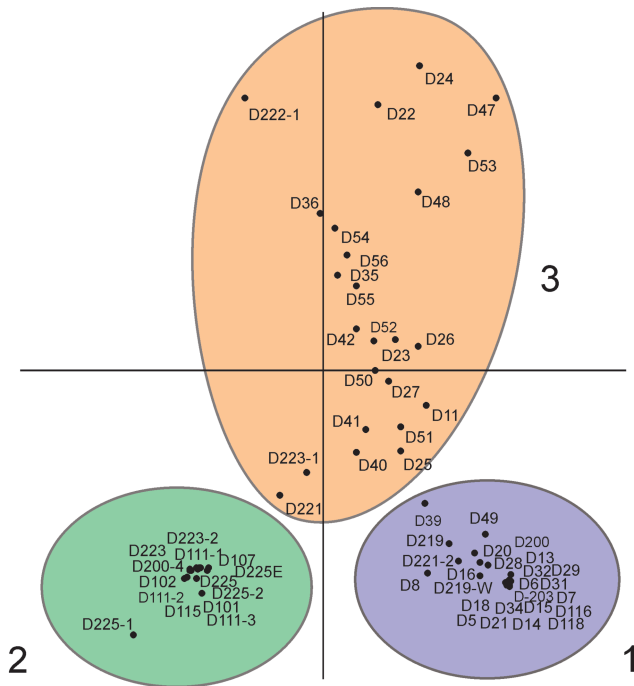


Figure 5. Nonmetrical Multidimensional Scaling (nMDS) of samples 5. *ábra.* A minták eloszlása nem-metrikus többdimenziós skálázási módszerrel (nMDS)

and, as sporadic occurrences, from the Badenian (KOVÁČ 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 SILVA 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 & MCINYRE 1979, WINTER & SIESSER 1994), and those of helicoliths with ecological preference for upwelling (PERCH-NIELSEN 1985, RAHMAN & ROTH 1990) support this interpretation.

In *Subinterval 1b*, *Calcidiscus leptoporus* is replaced by large *R. pseudumbilicus* (>7 µm). The abundance of this species, together with the occurrences of *B. bigelowii* in the top of Subinterval 1a and throughout Subinterval 1b, points to a period of increased eutrophy within the Sarmatian. Increased nutrient supply was probably caused by more intense river runoff. Abundant occurrences of *B. bigelowii* may

point to decreased salinity; however, this species never exceeds 2% in nannofossil assemblages from Pécs-Danitzpuszta outcrop. *Braarudosphaera bigelowii* is predominantly observed in neritic and shelf seas (PERCH-NIELSEN 1985). An increase in species diversity from Subinterval 1a to Subinterval 1b confirms a raise in the nutrient supply in the upper part of Interval 1. Common occurrences of *C. leptoporus*, *Syracosphaera* spp., and reticulofenestrids accompanied with ascidians were also reported from the upper Sarmatian sediments from other parts of the Central Paratethys (GALOVIĆ 2017, ŠARINOVÁ 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. *Acanthoica cohenii* and ascidians are also common.

Genus *Praenoelaerhabdus* with *P. banatensis* is an endemic taxon described from Pannonian deposits of Serbia (MIHAJLOVIĆ 1993). Small *Praenoelaerhabdus* with a diameter less than 2 µm were documented from the Sarmatian and Pannonian of Croatia (ĆORIĆ 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 semenenko* 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 (ĆORIĆ et al. 2017, GALOVIĆ 2017). CHIRA & MALACU (2008) reported about the abundance of various *Isolithus* species in the Pannonian of Transylvania (Romania). ĆORIĆ (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. HAJÓS (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 (Dubrovica) and Romania (Kevna Bremlia) 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 jerkovici*. 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 shallow 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 pentolith 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 jerkovici* and only sporadic occurrences of normal marine species; thus, it can be attributed to the Pannonian. MĂRUNȚEANU (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 MĂRUNȚEANU 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. leptoporus*, *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 *Iso-*

lithus spp. 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*, *Noelaerhabdus* 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 lacustrine Pannonian. Based on the occurrences of *Bekelithella echinata* and species belonging to the genus *Noelaerhabdus*, the upper part of the section is attributed to NN10 nannozone. Our investigations show that quantitative assessment of endemic calcareous nannofossils might be a tool for stratigraphic correlation within the Pannonian.

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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