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Dinoflagellate cysts from the Pannonian (late Miocene) "white marls" in Pécs-Danitzpuszta, southern Hungary

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Dinoflagelláta ciszták Pécs-Danitzpuszta pannóniai „fehér márgájából"

Összefoglalás

A késő neogén Pannon-tó üledékeinek rétegtani tagolásában és korrelációjában fontos szerepet játszanak a szerves vázú mikroplanktonhoz tartozó dinoflagelláták cisztái. A pécs-danitzpusztai homokbánya pannóniai mészmárga rétegsorából 66 palinológiai preparátumot vizsgáltunk az üledékek rétegtani helyzetének és korának megállapítása céljából. E fontos feltárásból korábbi vizsgálatok sikertelenül próbáltak dinoflagelláta cisztákat kinyerni. Az új gyűjtésből 6 minta tartalmazott jó megtartású palinomorfákat. A rétegsor aljából vett mintában (D25) valószínűleg áthalmozott középső miocén együttes volt. A középső szakasz mintái (D3, D2, D1) a *Pontiadinium pecsvaradensis* zónát jelezték (kb. 10,8–10,6 M év). A márgák felső részéből vett minták (D219, D221) nem adtak további rétegtani információt, a *Pontiadinium pecsvaradensis* zónába tartoznak vagy annál fiatalabbak. A középső és felső szakasz mintáinak palinofáciese (D3-tól D221-ig) a szárazföldi behordástól távoli, nyugodt, alkalmanként oxigénszegény, valószínűleg mélyvízi üledékképződési környezetet jelez.

Kulcsszavak: Mecsek, pannóniai, palinológia, dinoflagelláta ciszta, biosztratigráfia

Abstract

Dinoflagellate-cyst based biostratigraphy is an important tool in the stratigraphical subdivision and correlation of the Neogene Lake Pannon deposits. A total of 66 palynological samples were investigated from the Pannonian (upper Miocene) marl succession exposed in the Pécs-Danitzpuszta sand pit in order to evaluate the biostratigraphical assignment and constrain the age of the strata. Earlier attempts to recover dinoflagellate cysts from this important reference section had failed. In our material, six samples contained well-preserved palynomorphs. One sample from the lower part of the succession (D25) contained a probably reworked middle Miocene assemblage. Samples from the middle segment of the succession (D3, D2, D1) indicate the *Pontiadinium pecsvaradensis* Zone (ca. 10.8 to 10.6 Ma). Samples from the top of the marl (D219, D221) did not give additional stratigraphic information (*P. pecsvaradensis* Zone or younger). The palynofacies of samples D3 to D221 indicates a relatively distal, calm, occasionally oxygen-deficient, probably deep depositional environment.

Keywords: Mecsek Mts, Pannonian, palynology, dinoflagellate cysts, biostratigraphy

Introduction

Pannonian (late Miocene) "white marls", deposited in regions sheltered from siliciclastic sediment input in Lake Pannon, are widely distributed in the southern part of the Pannonian Basin. Having accumulated in an isolated water body, their stratigraphic subdivision is problematic and relies on a few groups of the endemic biota. Their fossil molluscs have been studied and utilized for biostratigraphy for over a century (e.g., GORJANOVIĆ-KRAMBERGER 1890, 1899; KOCH 1902; SREMAC 1981; VRSALJKO 1999; TER BORGH et al. 2013). The organic-walled microplankton, first of all dinoflagellate cysts and prasinophytes (green algae), also provide good stratigraphic markers in Lake Pannon deposits, but they are scarcely known from the "white marls." A rich dinoflagellate cyst assemblage was reported from the

Našice outcrop in Slavonia, northeast Croatia, by BAKRAČ (2005) and BAKRAČ in VASILIEV et al. (2007), and some dinoflagellate cysts were presented from boreholes in SE Hungary by SÜTŐ-SZENTAI in MAGYAR et al. (2004). Apart from these data, we are not aware of published dinoflagellate cyst assemblages from the Pannonian “white marls.”

The objective of this paper is the investigation of dinoflagellate cysts from the largest surface exposure of these rocks in Hungary, Pécs-Danitzpuszta, in order to provide biostratigraphic and additional paleoenvironmental data for the integrated stratigraphic evaluation of the section. Earlier attempts to recover dinoflagellate cysts from the layers of this outcrop all failed, but as our pilot samples gave promising results, a large set of samples was collected and investigated. Earlier dinoflagellate studies from drill cores in the neighbouring regions of SW Hungary (SÜTŐ-SZENTAI 1982, 1989, 1994, 2000a, 2002) and the Drava basin (INA industrial reports by K. KRIZMANIĆ) provided a firm basis for the biostratigraphic evaluation of the dinoflagellate assemblages.

The complex sedimentological and paleontological investigation of the Pécs-Danitzpuszta Neogene sequence was supported by a Croatian–Hungarian bilateral research project; our brief report on the dinoflagellates of the marls is a contribution to this joint effort.

Geological setting

The outcrop is a sand pit, located within the administrative area of Pécs, in the eastern outskirts of the city (*Figure 1*). The pit, together with an exploratory trench excavated in its northwestern margin, expose a strongly tilted Badenian–Sarmatian–Pannonian marl-dominated succession in 80 m stratigraphic thickness, capped by Pannonian sands (SEBE et al. 2021).

Sampling, material and methods

During a field trip in 2017, two pilot samples were taken randomly for palynological analysis from the easily accessible uppermost part of the marl succession (Layers D219 and D221) (*Figure 1*). As the samples yielded a well-preserved dinoflagellate cyst association, the entire section was sampled in two steps. A total of 72 samples (D72 to D1) were taken from the Badenian–Pannonian succession exposed in the exploratory trench, representing the lower 37 m of the section (*Figure 1*). Forty-one samples were chosen for palynological preparation and subsequent palynological and palynofacies analysis. However, only four samples, all belonging to the Pannonian, contained dinoflagellate cysts, and only three were suitable for biostratigraphical and environmental interpretation. The upper part of the Pannonian marl succession (D101 to D226, representing 43 m stratigraphic thickness) was investigated in 23 samples. All slides were barren except sample D225 that contained an impoverished, poorly preserved dinoflagellate cyst assemblage. Due to their poor preservation the biostratigraphic or paleoecological evaluation was not possible.

Processed in the standard way of palynological maceration (MOORE et al. 1991), rock samples were washed in 7% hydrochloric acid (HCl), dried and ground in a laboratory crusher, weighed (100 g) and set for dissolution of carbonates (with 18% HCl) and silicates (with 40% HF). The organic residue

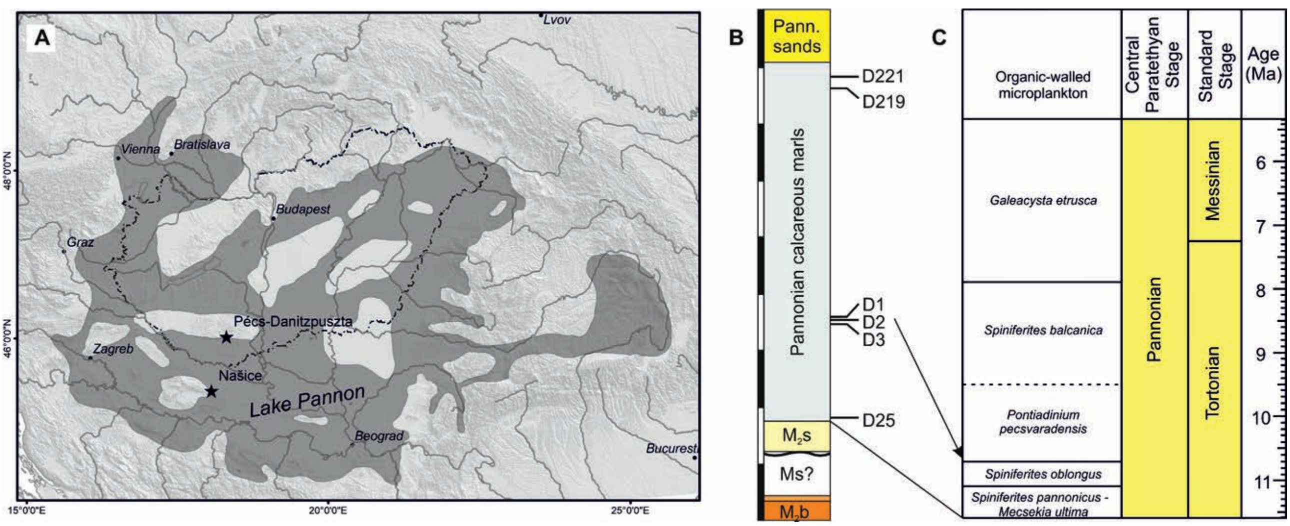

Figure 1. Location of the study area within the Pannonian Basin and stratigraphical position of the palynological samples from Pécs-Danitzpuszta. A: Location of the sand pit; dark patch indicates extent of Lake Pannon at 10.8 Ma after MAGYAR et al. (1999a). B: Simplified stratigraphic log of the sand pit with sample positions. Each segment of the vertical scale represents 10 m (the entire section is 90 m). C: Organic-walled microplankton zonation of Lake Pannon sediments (based on SÜTŐ-SZENTAI 1988, 2000b and BAKRAČ et al. 2012, and modified according to exploration borehole data from Croatia)

1. ábra. *Helyszínrajz és rétegoszlop. A: A pécs-danitzpusztai feltárás helyzete a Pannon-medencében, sötéttel a Pannon-tó elterjedése kb. 10,8 millió évvel ezelőtt (MAGYAR et al. 1999a szerint). B: A feltárás egyszerűsített rétegoszlopa a produktív minták helyével. A függőleges skála minden szegmense 10 métert képvisel, a teljes rétegoszlop 90 m vastag. C: A Pannon-tó üledékeinek szervesvázú mikroplankton zonációja SÜTŐNÉ SZENTAI (1988, 2000b) és BAKRAČ et al. (2012) alapján, a horvátországi szénhidrogén-kutató fúrások adatai alapján módosítva* was separated from undissolved inorganic mixture by treatment with a heavy liquid ($ZnCl_2$, s.g. 2.1 kg/l) and sieved through a 15 mm sieve. Finally, palynological slides were prepared using glycerin gelatin as the mounting medium.

Palynological slides were analysed by a Leitz Aristoplan light microscope and an Olympus DP 25 digital camera with the corresponding Stream Motion software for photography and documentation. An Olympus BX51 fluorescence light microscope was used for palynofacies characterisation and control of reworked palynomorphs.

For each sample, the Thermal Alteration Index (TAI) was determined. This is part of a visual kerogene analysis (Schwab 1990) where the colour of different palynofacies constituents, including sporomorphs, dinoflagellate cysts, acritarchs etc. under the transmitted light is expressed on a ten-step scale (1, 1+, 2–, 2, 2+, 3–, 3, 3+, 4–, 4). The colour is a function of paleotemperature, pressure, and geologic age, as well as that of structure, thickness, chemical composition and weathering of palynomorphs. The degree of thermal maturity is defined by colour change from pale yellow through brown to black (e.g., Staplin 1977).

Palynostratigraphic evaluation of the identified dinoflagellate cysts was based on the relevant literature (e.g., Sütő-Szentai 1988, 2000b; Lučić et al. 2001; Bakrač 2005; Bakrač et al. 2012; Soliman & Riding 2017) and on our own experience (K. K.) from hydrocarbon exploration boreholes in Croatia.

Results

The palynofacies and palynological assemblages of the samples are described in stratigraphic order, from bottom to top. The identified taxa are listed in *Table I.* Palynofacies and selected dinoflagellate cysts are illustrated in *Figures 2* and *3*.

Layer D25

Sample D25 contains abundant sedimentary organic particles in the rock macerate. Amorphous organic matter particles are rare in the palynofacies. Lignohumine clasts are mostly made up of smaller, black, fully oxidized woody fragments (inertinite). Liptinite components are abundant. They include some pollen grains and a lot of various, completely oxidized (transparent) dinoflagellate cysts. In the palynofacies, a significant amount of macerals is composed of bigger, brown, biostructured phytoclasts (vitrinite) and cuticles, both immature (TAI 1–2). The most frequent dinoflagellate cysts are *Lingulodinium machaerophorum* (Deflandre & Cookson, 1955) Wall, 1967 (*Figure 2A*), *Polysphaeridium zoharyi* (Rossignol, 1962) Bujak et al., 1980 (*Figure 2B*), *Spiniferites* sp., *Achomosphaera* sp., *Operculodinium* sp., *Hystrichokolpoma* sp. and *Selenopemphix* sp. (*Table I*).

Table I. Dinoflagellate cysts and green algae identified in the Pécs-Danitzpuszta samples

I. táblázat. *A pécs-danitzpusztai szelvény mintáiból meghatározott dinoflagelláta ciszták és zöldalgák*

	D25	D3	D2	D1	D219	D221
Lingulodinium machaerophorum	X					
Polysphaeridium zoharyi	X					
Spiniferites pannonicus		X	X	X	X	X
Spiniferites oblongus		X	X	X	X	X
Spiniferites hennersdorfensis		X	X	X	X	X
Spiniferites maisensis						X
Spiniferites bentorii granulatus					X	
Spiniferites sp.	X		X	X		
"*Virgodinium asymmetricum*"		X	X	X	X	X
"*Virgodinium foveolatum*"			X			X
"*Virgodinium*" sp.			X			
Pontiadinium pecsvaradensis		X	X	X		X
Pontiadinium obesum						X
Pontiadinium sp.			X			
Impagidinium globosum			X			
Impagidinium spongianum			X			
Impagidinium sp.		X	X	X	X	X
Selenopemphix sp.	X					X
Nematosphaeropsis sp.				X		X
Achomosphaera sp.	X			X		
Operculodinium sp.	X			X		
Hystrichokolpoma sp.	X					
Chytroeisphaeridia sp.			X			
Spirogyra sp.		X	X	X	X	X
Botryococcus braunii		X	X	X	X	X

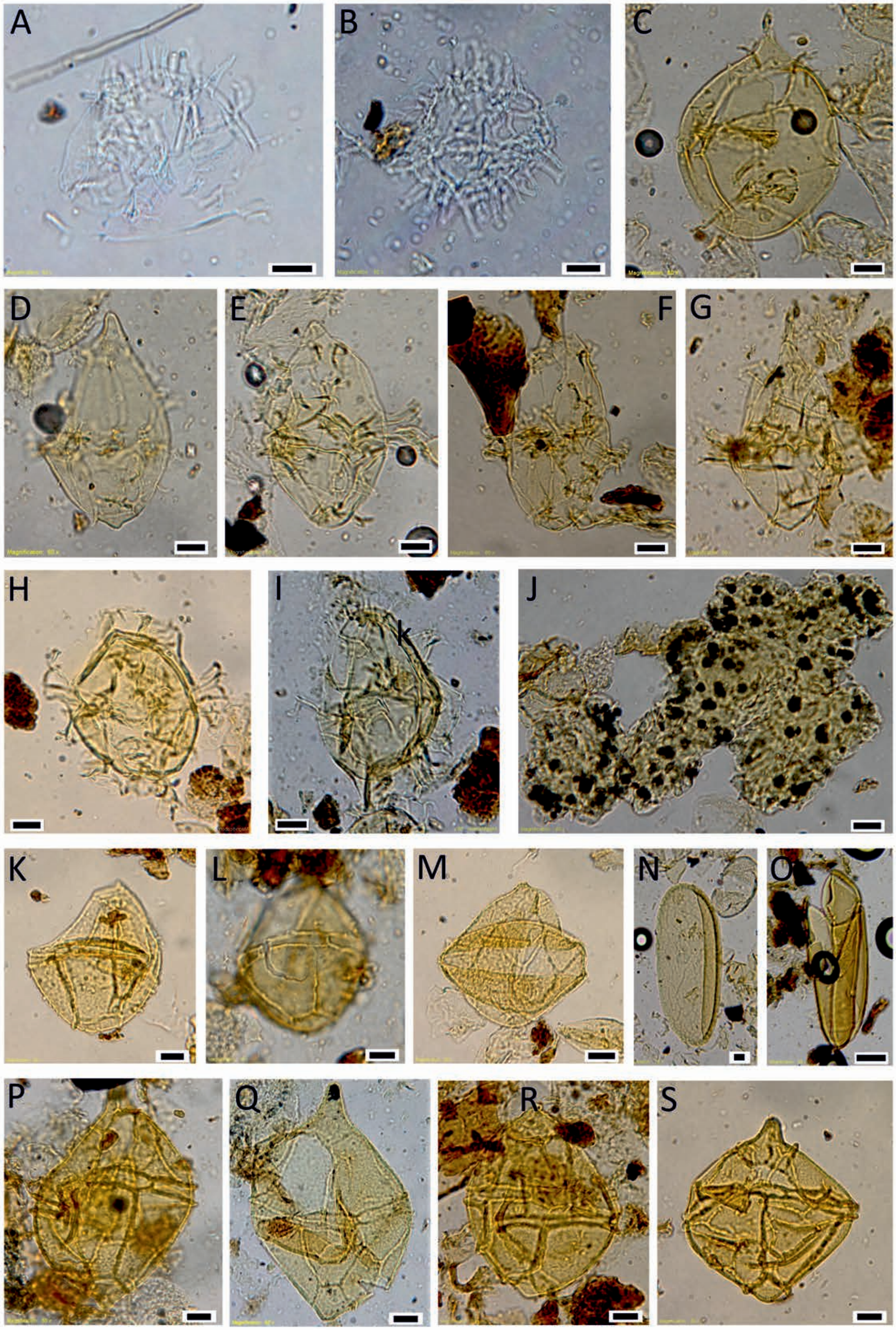

Figure 2. Selected Pannonian dinoflagellate cysts and green algae from the Pécs-Danitzpuszta outcrop. The black scale bars represent 10 µm for each figure.

A: *Lingulodinium machaerophorum* (DEFLANDRE & COOKSON, 1955) WALL 1967, D25; B: *Polysphaeridium zoharyi* (ROSSIGNOL, 1962) BUJAK et al. 1980, D25; C: *Spiniferites pannonicus* (SÜTŐ-SZENTAI, 1986), SOLIMAN & RIDING 2017 (D219); D–G: *Spiniferites oblongus* (SÜTŐ-SZENTAI, 1986) SOLIMAN & RIDING 2017 (D, E: D219; F: D221; G: D3); H, I: *Spiniferites hennersdorfensis* SOLIMAN & RIDING, 2017 (H: D221; I: D1); J: *Botryococcus braunii* KÜTZING, 1849 (D221); K, L: "*Virgodinium asymmetricum*" SÜTŐ-SZENTAI, 2010 (D221); M: "*Virgodinium foveolatum*" SÜTŐ-SZENTAI, 1982 (D221); N: *Spirogyra* sp. Type II (D219); O: *Spirogyra* sp. Type I (D221); P–R: *Pontiadinium pecsvaradensis* SÜTŐ-SZENTAI, 1982 (P: D221; Q: D1; R: D3); S *Pontiadinium obesum* SÜTŐ-SZENTAI, 1982 (D221)

2. ábra. *Pannóniai dinoflagelláta ciszták és zöldalgák a pécs-danitzpusztai feltárásból. A fekete aránymérték mindegyik képen 10 µm-nek felel meg*

Layer D3

The macerate of the rock sample is very rich in sedimentary organic matter. About 50% of the palynofacies is composed of amorphous organic matter. Lignohumine clasts make up about 20% of the organic residue composed mostly of brown, bigger, biostructured phytoclasts (vitrinite) and fewer black (inertinite) kerogen clasts. About 30% of the palynofacies is liptinite component made up of dinoflagellate cysts, green algae remnants (*Spirogyra* sp. and *Botryococcus braunii* KÜTZING, 1849) and different spores and pollen grains. Macerals are immature (TAI 2). The most frequent dinoflagellate cysts are *Spiniferites pannonicus* (SÜTŐ-SZENTAI, 1986), SOLIMAN & RIDING, 2017, *Spiniferites oblongus* (SÜTŐ-SZENTAI, 1986) SOLIMAN & RIDING, 2017 (*Figure 2G*), *Spiniferites hennersdorfensis* SOLIMAN & RIDING, 2017, *Impagidinium* sp., "*Virgodinium asymmetricum"* SÜTŐ-SZENTAI, 2010 and *Pontiadinium pecsvaradensis* SÜTŐ-SZENTAI, 1982 (*Figure 2R*) (*Table I*).

Layer D2

The sample is very rich in sedimentary organic matter (*Figure 3A*). Amorphous organic matter particles are predominant (ca. 50%). Lignohumine clasts make up ca. 10% of the palynofacies and they are mostly composed of black (inertinite) clasts. The liptinite component represents about 40% of the visible organic residue and it is made up of diverse chorate and proximate (dominant) dinoflagellate cysts, green algae remnants (abundant *Spirogyra* sp., *Botryococcus braunii* KÜTZING, 1849), spores and assorted pollen grains (mostly bisaccate conifer pollen). Macerals are immature (TAI 1-2).

Dinoflagellate cysts are represented mainly by *Spiniferites pannonicus* (SÜTŐ-SZENTAI, 1986), SOLIMAN & RIDING, 2017, *Spiniferites oblongus* (SÜTŐ-SZENTAI, 1986) SOLIMAN & RIDING, 2017, *Spiniferites hennersdorfensis* SOLIMAN & RIDING, 2017, *Spiniferites* sp., *Impagidinium globosum* SÜTŐ-SZENTAI, 1985, *Impagidinium spongianum* SÜTŐ-SZENTAI, 1985, *Impagidinium* sp., *Chytroeisphaeridia* sp., "*Virgodinium foveolatum"* SÜTŐ-SZENTAI 1982, "*Virgodinium"* sp., "*Virgodinium asymmetricum"* SÜTŐ-SZENTAI, 2010, *Pontiadinium pecsvaradensis* SÜTŐ-SZENTAI, 1982 and *Pontiadinium* sp. (*Table I*).

Layer D1

The sample is very rich in sedimentary organic matter. Amorphous organic matter makes up about 50% and lignohumine clasts about 20% of the palynofacies. The liptinite component is abundant and comprises 30% of the visible organic residue. The palynological assemblage is composed of diverse chorate and proximate (predominant) dinoflagellate cysts, green algae remnants (*Spirogyra* sp., *Botryococcus braunii* KÜTZING, 1849), spores and various pollen grains (mainly bisaccate). Pyrite inclusions in palynomorphs are common. Macerals are mechanically damaged and immature (TAI 1-2). The most frequent dinoflagellate cysts are *Spiniferites pannonicus* (SÜTŐ-SZENTAI, 1986), SOLIMAN & RIDING, 2017, *Spiniferites oblongus* SÜTŐ-SZENTAI, 1986, *Spiniferites hennersdorfensis* SOLIMAN & RIDING, 2017 (*Figure 2I*), *Spiniferites* sp., *Achomosphaera* sp., *Nematosphaeropsis* sp., *Operculodinium* sp., *Impagidinium* sp., "*Virgodinium asymmetricum"* SÜTŐ-SZENTAI, 2010 and *Pontiadinium pecsvaradensis* SÜTŐ-SZENTAI, 1982 (*Figure 2Q*) (*Table I*).

Layer D219

The rock sample is very rich in sedimentary organic matter (*Figure 3B, C*). About 50% of the organic particles are represented by amorphous organic matter. Lignohumine clasts make up about 40% of the organic residue and it is composed mostly of smaller, black, opaque, completely oxidized woody tissue (inertinite). About 10% of the palynofacies is liptinite component made of diverse chorate and proximate dinoflagellate cysts, green algae remnants e.g., *Spirogyra* sp. Type II (*Figure 2N*) and *Botryococcus braunii* KÜTZING, 1849, various spores and abundant pollen grains. Macerals are mechanically damaged and contain no pyrite inclusions. The most numerous dinoflagellate cysts are *Spiniferites pannonicus* (SÜTŐ-SZENTAI, 1986), SOLIMAN & RIDING, 2017 (*Figure 2C*), *Spiniferites bentorii granulatus* FUCHS & SÜTŐ-SZENTAI, 1991, *Spiniferites oblongus* (SÜTŐ-SZENTAI, 1986) SOLIMAN & RIDING, 2017 (*Figure 2D, E*), *Spiniferites hennersdorfensis* SOLIMAN & RIDING, 2017, "*Virgodinium asymmetricum"* SÜTŐ-SZENTAI 2010 and *Impagidinium* sp. (*Table I*).

This sample is colloquially referred to as the Myrtle facies because of the abundant *Myrica* leaves found in this layer (HABLY & SEBE 2016).

Layer D221

The sample is very rich in sedimentary organic matter (*Figure 3D, E*). Amorphous organic matter particles make up about 50%, and lignohumine kerogene clasts form 20% of the palynofacies. Lignohumine clasts are mainly large-sized brown, biostructured phytoclasts (vitrinite) and smaller black clasts (inertinite). About 30% of the organic residue is liptinite kerogen component composed of diverse chorate and proximate dinoflagellate cysts, green algae remnants *Spirogyra* sp. Type I (*Figure 2O*) and *Botryococcus braunii* KÜTZING, 1849 (*Figure 2J*), and rare spores and pollen grains (mostly bissacate).

The most common dinoflagellate cysts are *Spiniferites pannonicus* (SÜTŐ-SZENTAI, 1986), SOLIMAN & RIDING, 2017, *Spiniferites oblongus* (SÜTŐ-SZENTAI, 1986) SOLIMAN & RIDING, 2017 (*Figure 2F*), *Spiniferites hennersdorfensis* SOLIMAN & RIDING, 2017 (*Figure 2H*), *Spiniferites maisensis* SÜTŐ-SZENTAI, 1994, *Selenopemphix* sp, *Nematosphaeropsis* sp., "*Virgodinium asymmetricum"* SÜTŐ-SZENTAI, 2010 (*Figure 2K, L*), *Impagidinium* sp., "*Virgodinium foveolatum"* SÜTŐ-SZENTAI, 1982 (*Figure 2M*), *Pontiadinium obesum* SÜTŐ-SZENTAI, 1982 (*Figure 2S*) and *Pontiadinium pecsvaradensis* SÜTŐ-SZENTAI, 1982 (*Figure 2P*) (*Table I*).

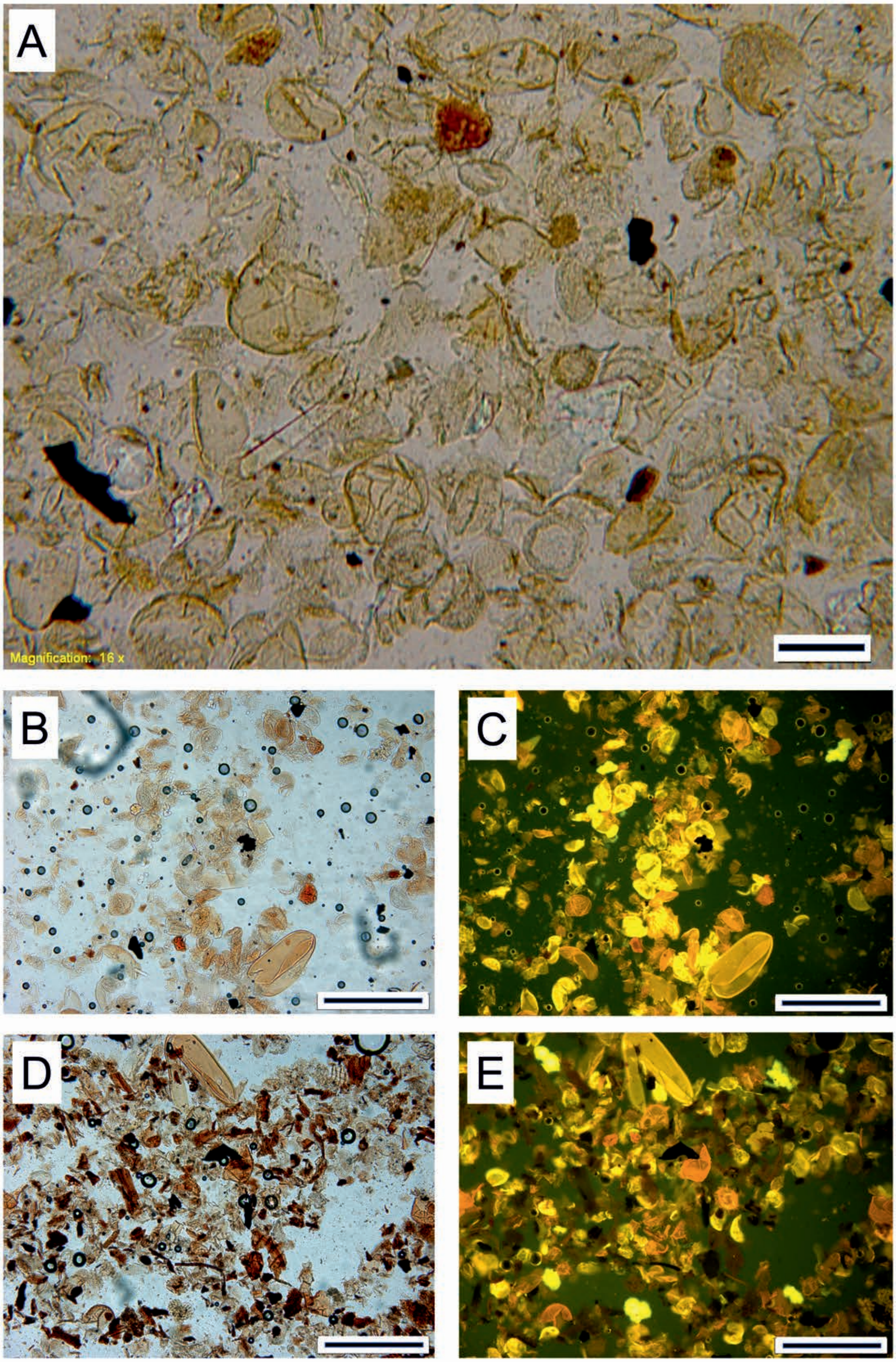

Figure 3. Palynofacies of the samples. A: Very rich macerate from D2 with predominance of amorphous organic matter (ca. 50%) and liptinite kerogen components (ca. 40%); scale bar 50 µm; B: Palynofacies with abundant sedimentary organic matter in D219 in transmitted light; scale bar 200 µm; C: Same in fluorescent light; D: Palynofacies very rich in organic matter from D221 in transmitted light; scale bar 200 µm; E: Same in fluorescent light

3. ábra. *A vizsgált minták palinofáciese. A: Nagyon gazdag macerátum a D2 rétegből jelentős mennyiségű amorf szerves anyaggal (kb. 50%) és liptinittel (kb. 40%); az aránymérték 50 µm; B: A D219 réteg palinofáciese sok üledékes szerves anyaggal, áteső fényben; az aránymérték 200 µm; C: Ugyanaz fluoreszkáló fényben; D: A D221 réteg palinofáciese nagyon sok szerves anyaggal áteső fényben; az aránymérték 200 µm; E: Ugyanaz fluoreszkáló fényben*

Discussion

Paleoenvironmental interpretation

Samples D3, D2, D1, D219 and D221 share a series of common features, including a high proportion of amorphous matter, lower lignohumine content, pyrite inclusions, mostly bissacate forms of pollen grains, and an abundance of dinoflagellates with a predominance of proximate dinoflagellate cysts. Thus, their palynofacies indicates a relatively distal, calm, occasionally oxygen-deficient, probably deep depositional environment (STEFFEN & GORIN 1993, TYSON 1995, SLUIJS et al. 2005).

Biostratigraphic interpretation

The biocoenosis and the detected dinoflagellate cysts of D25 bear resemblance to those of the late Sarmatian *Polysphaeridium zoharyi–Lingulodinium machaerophorum Zone* (BAKRAČ 2005, BAKRAČ et al. 2012), although both species may occur sporadically in the Pannonian. The thermal heterogeneity of the macerals as well as the completely oxidized dinoflagellate cysts may indicate reworking from Sarmatian or upper Badenian sediments. Forams, ostracods and mollusks all argue for a Pannonian age of D25.

The rest of the samples contained typical endemic Pannonian assemblages. Based on the presence of *Pontiadinium pecsvaradensis* and the lack of any younger zone markers, the D3 to D1 interval belongs to the *P. pecsvaradensis Zone* (e.g., SÜTŐ-SZENTAI 1988, BAKRAČ et al. 2012) (*Figure 1*). In Croatia, this zone is traditionally assigned into the upper (younger) part of the upper Pannonian (s. str.), and is correlated with the so-called “Banatica layers” (*Congeria banatica* bearing marls; see in LUČIĆ et al. 2001). MAGYAR et al. (1999b) argued that the *P. pecsvaradensis* Zone correlates with the older part of C5n magnetic polarity zone in several wells, and its age was estimated as 10.6-10.8 Ma (MAGYAR & GEARY 2012) or 10.65-10.75 Ma (BOTKA et al. 2020).

Samples D219 and D221 did not yield any species unambiguously marking a zone younger than the *P. pecsvaradensis Zone*; even *P. pecsvaradensis* itself was missing in D219. Although *Pontiadinium obesum* and *Spiniferites maisensis*, both occurring in D221, are more common in the younger zones (traditionally correlated with the Pontian in Croatia, see BAKRAČ et al. 2012), they first appear in the *Spiniferites oblongus* Zone that underlies the *P. pecsvaradensis* Zone. Thus, the biostratigraphic position of these layers can be given as “*P. pecsvaradensis* Zone or younger”.

Conclusions

Six samples (out of the investigated 66) from the Pannonian marl succession of Pécs-Danitzpuszta contained well-preserved palynomorph assemblages. Samples D1 to D3 in the middle part of the succession yielded, among others, the dinoflagellate cyst *Pontiadinium pecsvaradensis*, a biostratigraphic marker species (*P. pecsvaradensis Zone*). Well-preserved material from the top of the succession failed to contain any species exclusively characterizing biozones younger than the *P. pecsvaradensis Zone*, thus these samples either belong to the *P. pecsvaradensis Zone* or they are younger.

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