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Hátsó borító: Deformed upper Miocene sand layers in the western wall of the sand pit in 2018 (photo: Gábor Csillag)

Budapest, 2021 ISSN 0015-542X

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i) Következtetések Az új következtetések tézisszerű, rövid ismertetése az eredmények és a diszkusszió ismétlése nélkül.

j) Köszönetnyilvánítás

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m) Ábra-, táblázat- és fényképmagyarázatok (magyarul és angolul) Az illusztrációk rövid, összefogott, tartalmában érdemi magyarázata.

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Csontos, L., Nagymarosy, A., Horváth, F. & Kovác, M. 1992: Tertiary evolution of the intra-Carpathian area: A model. — *Tectonophysics* **208,** 221–241. http://dx.doi.org/10.1016/0040-1951(92)90346-8

Jámbor Á. 1998: A Tiszai nagyszerkezeti egység karbon üledékes képződményei rétegtanának ismertetése. — In: Bérczi I. & Jámbor Á. (szerk.): *Magyarország geológiai képződményeinek rétegtana.* MOL Rt. — MÁFI kiadvány, Budapest, 173–185.

Varga A. 2009: A dél-dunántúli paleozoos–alsó-triász sziliciklasztos kőzetek kőzettani és geokémiai vizsgálatának eredményei. — PhD értekezés, ELTE Kőzettan–Geokémiai Tanszék, Budapest, 150 p.

Weaver, C. E. 1989: *Clays, Muds, and Shales.* — Developments in Sedimentology 44, Elsevier, Amsterdam, 819 p. http://dx.doi.org/10.1016/s0070-4571(08)×7036-0

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Magyarhoni Földtani Társulat
Földtani Közlöny
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151/3, 233–234., Budapest, 2021

Stratigraphy and tectonics of the Neogene succession at the southern foothills of the Mecsek Mountains: Investigation of the Pécs–Danitzpuszta outcrop

Preface

The Pannonian Stage of the Central Paratethys comprises sediments that were deposited in Lake Pannon and in the coeval fluvial environments during the late Miocene and Pliocene. These deposits are usually deeply buried under Quaternary formations in the plains of the Pannonian Basin, and are exposed only along the basin margins and around mountains located within the basin as a consequence of the latest Miocene to recent basin inversion.

The Mecsek Mountains in SW Hungary represent a Mesozoic basement high that initially emerged from Lake Pannon as an island (11.6–8 Ma), later it was flooded by the lake (8–7 Ma), and finally it was uplifted due to the basin inversion. The sedimentary „apron" that formed around the Mecsek during the 8–7 Ma transgression and the following regression of Lake Pannon is exposed in many outcrops and includes some classical palaeontological sites, such as Árpád (today Pécs-Nagyárpád), Hidas, and Bükkösd. The older Pannonian beds, however, are known only in a few outcrops, among which the sand pit of Pécs–Danitzpuszta is by far the largest and most spectacular.

The Danitzpuszta outcrop in the eastern outskirts of the city of Pécs was first mentioned in the literature in 1937 by I. Ferenczi, and became widely known in 1953 when the Hungarian text-book „Geology of Hungary" by E. Vadász was published. Pannonian lacustrine layers tilted into vertical position and a plethora of middle to late Miocene vertebrate remains made the outcrop well-known for structural geologists and paleontologists. The lack of biostratigraphic investigations and age data from the lacustrine deposits, however, hindered the temporal interpretation of both the structural and fossil reworking processes. Therefore, we decided to launch a project for the detailed description and paleontological investigation of the section. Following our request in 2018, the owners of the sand pit made a trench excavated across the crest of the tilted layers, which uncovered the lowermost part of the Pannonian stage as well as the underlying Sarmatian and Badenian stages. The trench, together with the succession exposed in the sand pit, opened an exceptional opportunity not only to solve structural problems, but to conduct detailed sedimentological and paleontological investigations along the thick Neogene sediment succession. A composite sedimentary log, representing 220 m stratigraphic thickness across the Badenian, Sarmatian and Pannonian stages, was assembled and sampled for biostratigraphic studies. The results of this research are presented here, in the 3rd and 4th issues of Földtani Közlöny Volume 151.

In the first paper, Sebe et al. (2021) give a description of the outcrop and of the composite log with the interpretation of the depositional environments. Stratigraphically important algal remnants from the succession are presented in two papers. Ćorić (2021) divides the Sarmatian–Pannonian calcareous nannofossil record into three units and seven subintervals based on the last occurrence of marine forms and appearance of endemic lacustrine species. Krizmanić et al. (2021) identified a few stratigraphic marker fossils in the largely endemic Pannonian dinoflagellate cyst assemblages. The microfossils of the succession are also treated in two papers. Szuromi-Korecz et al. (2021) investigated the middle Miocene (Badenian and Sarmatian) foraminifers and ostracods, and described a freshwater or oligohaline interval within the upper part of the Sarmatian. Csoma et al. (2021) established the Pannonian ostracod stratigraphy of the succession, and attempted a correlation to the biozones of the magnetostratigraphically dated Beočin succession. Invertebrate macrofossils of the outcrop are presented in the following two papers. Dulai et al. (2021) evaluate the small coral and mollusk fauna of the normal marine Badenien layers. Botka et al. (2021) demonstrate that the Pannonian mollusk assemblages follow each other in a unique order within the succession. In the last paleontological paper, SZABÓ et al. (2021) present results on the origin of the mixed vertebrate assemblage by studying Badenian to Pannonian fish remains. The volume is closed by a structural geological paper (SEBE 2021), which integrates the biostratigraphic results into the tectonic studies to date the deformation events.

By all these investigations, the Pécs–Danitzpuszta outcrop qualifies as one of the best-studied Neogene successions in Hungary. Our research identified some specific phenomena, like controversy in marking the Sarmatian/Pannonian boundary when traced by different fossil groups, or the presence of freshwater environments during the late Sarmatian, which well deserve the attention of the international scientific community. The outcrop, one of the rare continuous middle–upper Miocene sections in the Pannonian Basin, offers a unique opportunity for further studies focused on these issues.

The research was mainly funded by NKFIH project PD104937 and the Hungarian– Croatian bilateral project TÉT_16-1-2016-0004 (both with K. SEBE as Principal Investigator) and by NKFIH 116618 (with I. MAGYAR as PI). The owner of the sandpit, Quartz Kft., and personally Béla MOLNÁR, Ernő BÜKI and Gyöngyi SZŐLŐSI are thanked for kindly permitting and actively supporting our work in the large outcrop.

Pécs – Budapest, October 2021.

Krisztina SEBE and *Imre MAGYAR*
project leaders

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An exceptional surface occurrence: the middle to upper Miocene succession of Pécs-Danitzpuszta (SW Hungary)

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Egy kivételes feltárás: a pécs-danitzpusztai homokbánya középső–felső miocén rétegsora

Összefoglalás

A pécs-danitzpusztai homokbánya az idős pannóniai (felső miocén) üledékek legfontosabb feltárása Magyarország déli felén. 2018-ban árkolás tárta fel az ismert pannon-tavi összlet feküjét egészen a felső badeniig, ezzel mintegy 220 m valódi vastagságban folyamatos rétegsor lett hozzáférhető. Szerkezeti mozgások hatására a középső miocén üledékek és a pannóniai mészmárga nagy része átbuktatott, a mészmárga-homok határ környéke függőleges, majd a pannóniai homokban folyamatosan csökken a rétegdőlés. A feltárt rétegsor 5 m felső badeni (valamikor 13,8-12,6 millió év között lerakódott) mészmárgával és homokos mészkővel (Lajtai Mészkő) kezdődik, amely a Középső-Paratethys normál sótartalmú vizében halmozódott fel, és szublitorális, majd litorális környezetet jelző puhatestűeket tartalmaz. Ezt 8 m vastag, túlnyomórészt ősmaradványmentes homok, kőzetliszt és kavics követi, melynek kora bizonytalan, csak a legalsó aleuritréteg tartalmaz feltehetőleg áthalmozott badeni mikrofaunát. Ez az egység szárazföldi hordalékkúpon vagy annak vízbe nyúló alsó részén rakódhatott le gravitációs üledékfolyásokból. A rákövetkező 7,5 m vastag, mészkő, márga és agyag vékony rétegeinek váltakozásából álló szakasz szublitorális ősmaradványokat tartalmaz, gyors elöntésre utalva. A benne található foraminiferák, ostracodák, puhatestűek és mészvázú nannoplankton alapján az üledéklerakódás a késő szarmatában (valamikor 12,1 és 11,6 millió év között, Kozárdi Formáció), a brakkvízű Paratethysben történt, majd a pannóniai elején folytatódott. Az egyes ősmaradványcsoportok által jelzett határok ugyanakkor nem esnek egybe. A szarmata vége felé néhány rétegben időszakosan csökkent a sótartalom, valószínűleg édesvíz-beáramlás miatt. A pannóniaiban fölfelé a mészmárga válik uralkodóvá, amelybe agyag-, valamint gradált vagy szerkezet nélküli kavics és homok(kő) rétegek települnek. Ezek a kőzetek nyílt, valószínűleg több száz méter mély vízben rakódtak le. Az összesen 64 m vastag mészmárga sorozat a Pannon-medencében fúrások ezreiből ismert Endrődi Formáció ritka, jól feltárt felszíni előfordulását képviseli. A következő 6–7 m vastag, kőzetlisztes márgából és homokból álló átmeneti szakasszal együtt a pannóniai korai szakaszában, kb. 11,62 és 10,2 Ma közt keletkezett. Ezután kb. 140 m vastag limonitos, kavicsos homok következik, amely a Békési Formáció Kállai Tagozatával rokonítható. Osztályozottsága és a szemcsék koptatottsága jellemzően gyenge vagy közepes, rétegei méteres vastagságúak, szerkezetmentesek, határukat leginkább a cementáció és a mállás változása mutatja. Nagy mennyiségű, idősebb miocén összletekből áthalmozott ősmaradványt és kavicsot, valamint valószínűleg sekélyebb vízből származó pannóniai fosszíliákat tartalmaz. Kb. 10,2 és 10,0 Ma közt rakódhatott le durva hordalékú delták gravitációs üledékfolyások által táplált mélyvízi alsó részén.

Kulcsszavak: Pannon-tó, Paratethys, Mecsek, badeni, szarmata, pannóniai, Endrődi Formáció

Abstract

The Pécs-Danitzpuszta sand pit is the most important outcrop of the oldest Pannonian (upper Miocene, Tortonian) deposits in southern Hungary. A trench excavated in 2018 exposed Lake Pannon deposits and underlying Paratethys strata down to the upper Badenian (Serravallian), and together with the sand pit they make up a continuous sedimentary succession with a true thickness of ~220 m. Due to tectonic deformation, middle Miocene deposits and carbonates in the lowermost Pannonian are overturned. Layers become vertical close to the marl-sand boundary, then the dip changes to normal, with continuously decreasing dip angles. The exposed succession starts with 5 m of upper Badenian (13.8-12.6 Ma old) calcareous marls and sandy limestones with sublittoral, then littoral mollusks, which were deposited in the normal salinity seawater of the Central Paratethys. The overlying 8 m of sand, silt, sandy breccia and conglomerate are fossil-free; only the lowermost silt layer contains reworked Badenian microfauna. This unit probably accumulated from gravity-driven flows in a fan-like, presumably terrestrial depositional setting. The next 7.5 m of frequently alternating thin-bedded limestones, marls and clays with sublittoral biota represent rapid transgression. Foraminifers, ostracods, mollusks and calcareous nannoplankton indicate late Sarmatian, then Pannonian age for this interval. However, the locations of the boundaries indicated by the various groups are not consistent, making the position of the Sarmatian/Pannonian boundary uncertain. The Sarmatian beds with marine fossils still accumulated in the Paratethys, between ~12.1–11.6 Ma, under varying salinities due among others to temporary freshwater input. The Pannonian strata already represent sediments of the brackish Lake Pannon. Above these beds, uniform calcareous marl becomes dominant with some clay layers and graded or structureless conglomerate to sandstone interbeds. The deposition of the overall 64 m thick Pannonian calcareous marl section took place in the open, probably few hundred metres deep water of the lake. It may represent a rare, well-exposed surface occurrence of the Endrőd Formation, which is known from thousands of wells in the Pannonian Basin. Together with the overlying 6–7 m thick transitional interval of silty marls and sands they were deposited between ~11.62 and 10.2 Ma. They are followed by ~140 m of limonitic, pebbly sands. The sands have poor to moderate sorting and rounding, metre-thick beds with transitional boundaries and abundant fossils and clasts reworked from older Miocene units. Their accumulation may have occurred between 10.2 and 10,0 Ma by gravity flows connected to deep-water portions of fan deltas.

Keywords: Lake Pannon, Paratethys, Mecsek Mts, Badenian, Sarmatian, Pannonian, Endrőd Formation

Introduction

In southern Hungary sediments from the early phase of the late Miocene Lake Pannon and the preceding middle Miocene Paratethys sea crop out only in the Mecsek Mts. The Pécs-Danitzpuszta sand pit along the SE margin of the mountains is the most important and best-known outcrop of the oldest Pannonian (upper Miocene, Tortonian) deposits, dominated by calcareous marls and limonitic sands. It has long been known for the deformations visible in the sands (VADÁSZ 1960), and is a type locality of Lake Pannon sediments in the Mecsek area (KLEB 1973). The sand pit is a well-known fossil site as well, with abundant vertebrate remains in the sands, including fishes, amphibians, reptiles as well as terrestrial and marine mammals (KAZÁR et al. 2007, KONRÁD et al. 2010a, SEBE et al. 2015, SZENTESI et al. 2020, SZABÓ et al. 2021). Since the 1990s intense excavation created newer and newer outcrop profiles. By now works have reached the edge of the concession area and sand extraction is nearing its end. Thanks to the support of the mining company with excavating a trench for research purposes in the northern margin of the sand pit in 2018, it was possible to significantly extend our knowledge on the Miocene evolution of the area. The trench not only reached the base of the upper Miocene succession, but also exposed the underlying middle Miocene units.

Here we present the observations gathered during the past decades on the sedimentary succession exposed by the sand pit and the trench. Investigations focused on lithology and stratigraphy, with the aim of describing the building blocks of the succession, constraining their depositional environment and the factors influencing sedimentation.

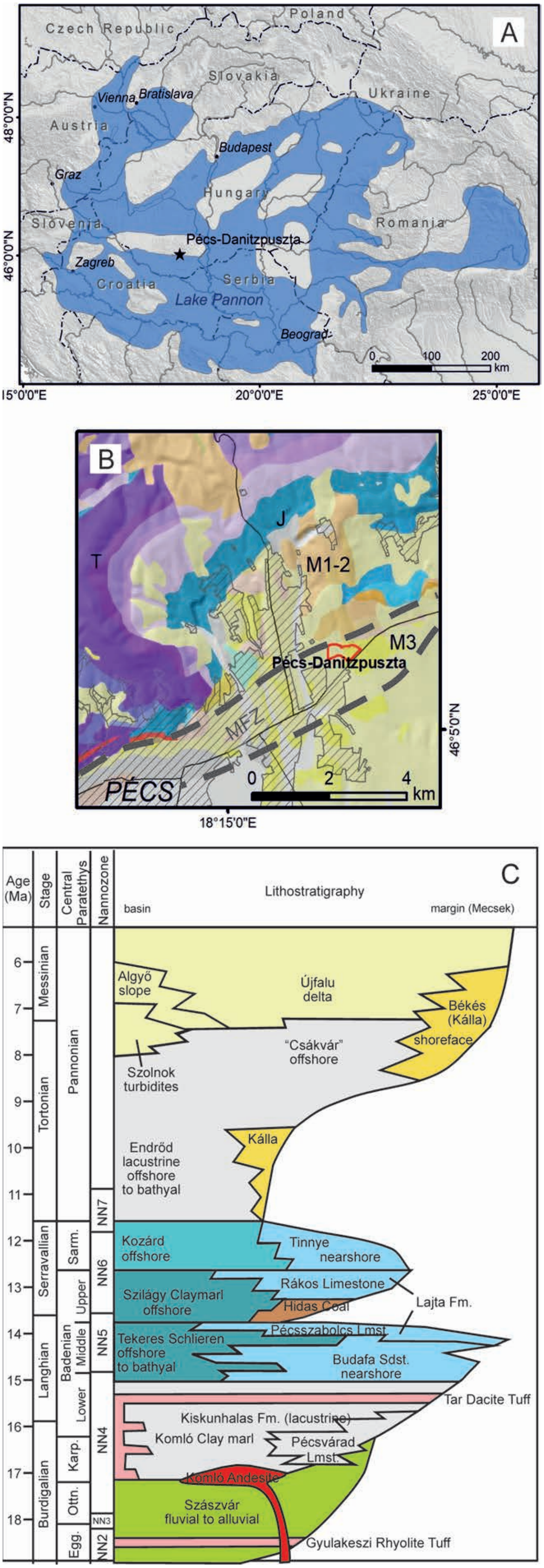
Geological setting

The Pécs-Danitzpuszta sand pit lies on the eastern edge of the city of Pécs, at the foot of the Mecsek Mts (*Figure 1*). Its largest dimensions are approximately 700 m in W-E and 400 m in N-S direction, the latter being roughly parallel with the dip of the succession (*Figure 2*). Deposits crop out mostly along the western and northern walls. The sand pit itself exposes two main lithological units of late Miocene (Pannonian) age: light grey, white or yellowish grey calcareous marls and silts in the northern wall, and the overlying yellowish brown, coarse, limonitic sands in the rest of the area. The mountains directly north of the sand pit are built up of Mesozoic rocks, mostly Lower Jurassic marls and sandstones, which are overlain by lower Miocene terrestrial gravels and sands and middle Miocene marine clastics and carbonates (*Figure 1C*). In the detailed geological map of the area, Pannonian sediments are indicated to have a tectonic contact with the middle Miocene strata north of them (HÁMOR et al. 1966).

The locality lies along a fault zone that borders the Mecsek Mts in the south (Mecsekalja Fault Zone). The exposed succession bears signs of syn-sedimentary deformation (KLEB 1973) and has undergone at least two phases of tectonic deformation related to the activity of this fault zone (KONRÁD & SEBE 2010, SEBE 2021). Syn-sedimentary normal faults and negative flower structures in the lower part of the sand indicate coeval transtension. Tilting and even overturning of the succession from the Badenian beds to the lowermost, faulted Pannonian sand beds refers to strong compression in a later phase. This deformation still occurred during the accumulation of the sand, as shown by the gradual upward decrease of the dip angle. An angular unconformity produced by this event within the sands (*Figure 2B*) was also documented in earlier publications (e.g., BARTHA 1971, KLEB 1973). As a result of the tilting, younging is dominantly towards the south (*Figure 2B*). Early Pannonian compression is probably related to Adria-Europe convergence; however, this event cannot be correlated regionally, it pre-dates basin inversion-related events reported from the region (SEBE 2021, SEBE & MAGYAR submitted).

→ **Figure 1.** Geological setting of the Pécs-Danitzpuszta sand pit. A) Site location relative to the reconstructed outlines of Lake Pannon at 10.8 Ma (from MAGYAR et al. 1999), overlain on the background of modern topography. B) Geological map of the area surrounding the sand pit (modified from CHIKÁN & BUDAI 2005). Legend: T: Triassic; J: Jurassic; M1-2: lower–middle Miocene; M3: upper Miocene rocks; MFZ: Mecsekalja Fault Zone. C) Miocene lithostratigraphic units of the Mecsek region

→ ***1. ábra.** A pécs-danitzpusztai homokbánya földtani környezete. A) A feltárás helyzete a Pannon-tó 10,8 millió évvel ezelőtti kiterjedéséhez képest. A tó körvonala MAGYAR et al. (1999) alapján. B) A szűkebb környék földtani térképe (CHIKÁN & BUDAI 2005 alapján módosítva). T: triász; J: jura; M1-2: alsó–középső miocén; M3: felső miocén (pannóniai) kőzetek; MFZ: Mecsekalja-vetőzóna. C) A Mecsek és környezete miocén litosztratigráfiai egységei*



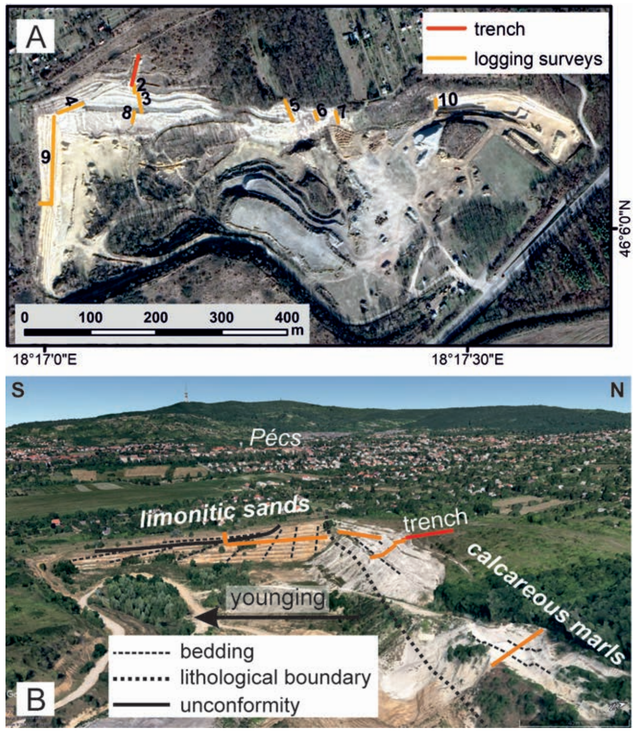


Figure 2. Location of sedimentary sections. A) Map view on an aerial photo from 2004; B) oblique satellite view from the east (image from GoogleEarth, 2019)

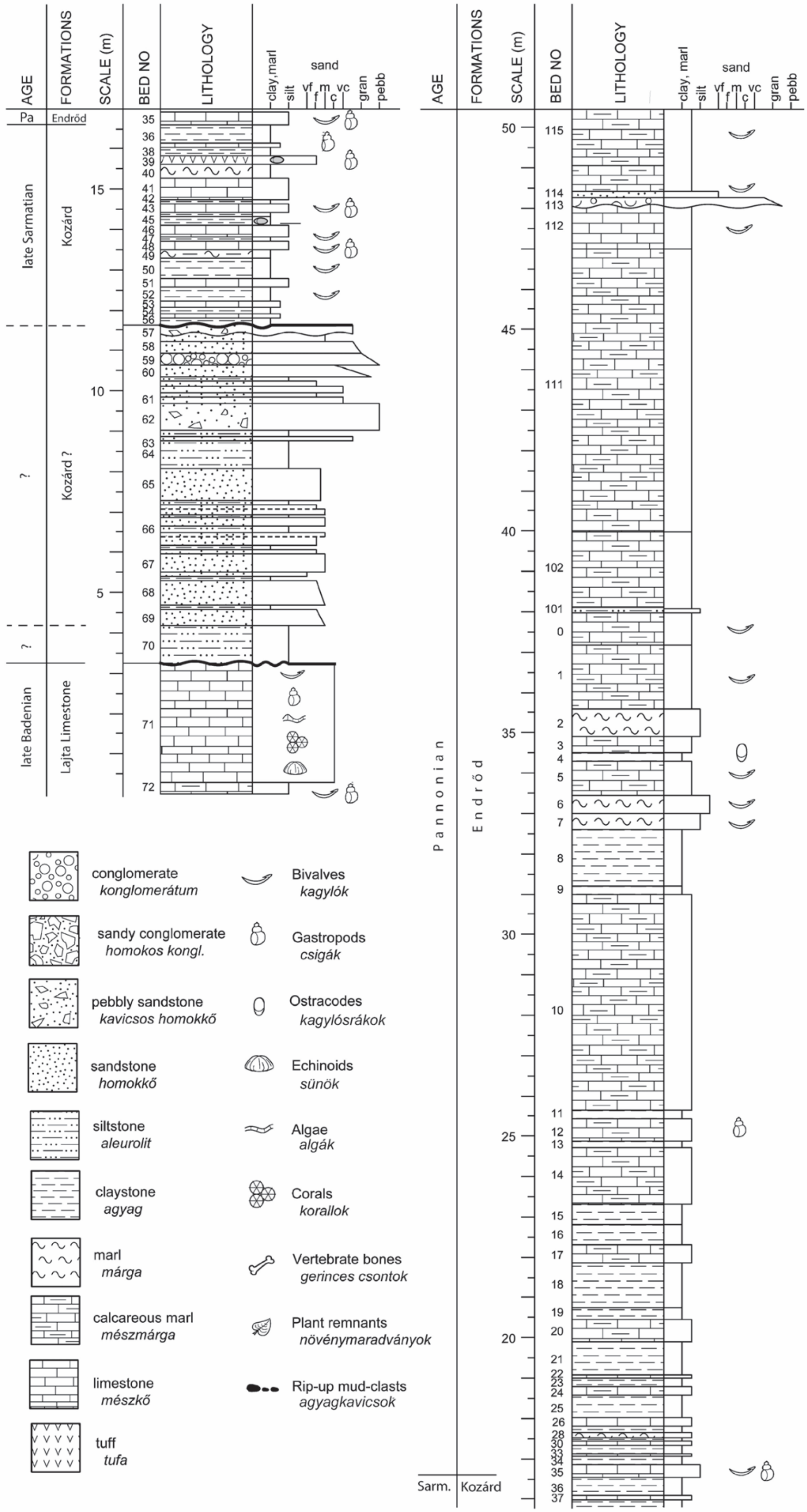
2. ábra. *A rétegsorfelvételek helye A) térképi nézetben, 2004-es légifelvételen és B) kelet felől, ferdén letekintve (GoogleEarth műholdkép, 2019)*

Methods

The deposits and structural features were documented from time to time as the industrial excavation progressed. The sedimentary succession was recorded in multiple logs from the best-exposed sites at the given time (*Figure 2*). The profiles presented in the current paper were selected to cover the entire succession exposed in the sand pit. The trench excavated in September 2018 (*Figure 3*) was 50 m long, elongated NNE–SSW and extended the stratigraphic column downward by a true thickness of 37 m.

Figure 3. Excavation of the trench in September 2018 at the northern margin of the sand pit

3. ábra. *Az árok mélyítése a bánya északi oldalán, 2018 szeptemberében*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late Badenian
Lajta Limestone
Pannonian
Endrőd
Sarm.
Kozárd
conglomerate
konglomerátum
sandy conglomerate
homokos kongl.
pebbly sandstone
kavicsos homokkő
sandstone
homokkő
siltstone
aleurolit
claystone
agyag
marl
márga
calcareous marl
mészmárga
limestone
mészkő
tuff
tufa
Bivalves
kagylók
Gastropods
csigák
Ostracodes
kagylósrákok
Echinoids
sünök
Algae
algák
Corals
korallok
Vertebrate bones
gerinces csontok
Plant remnants
növénymaradványok
Rip-up mud-clasts
agyagkavicsok

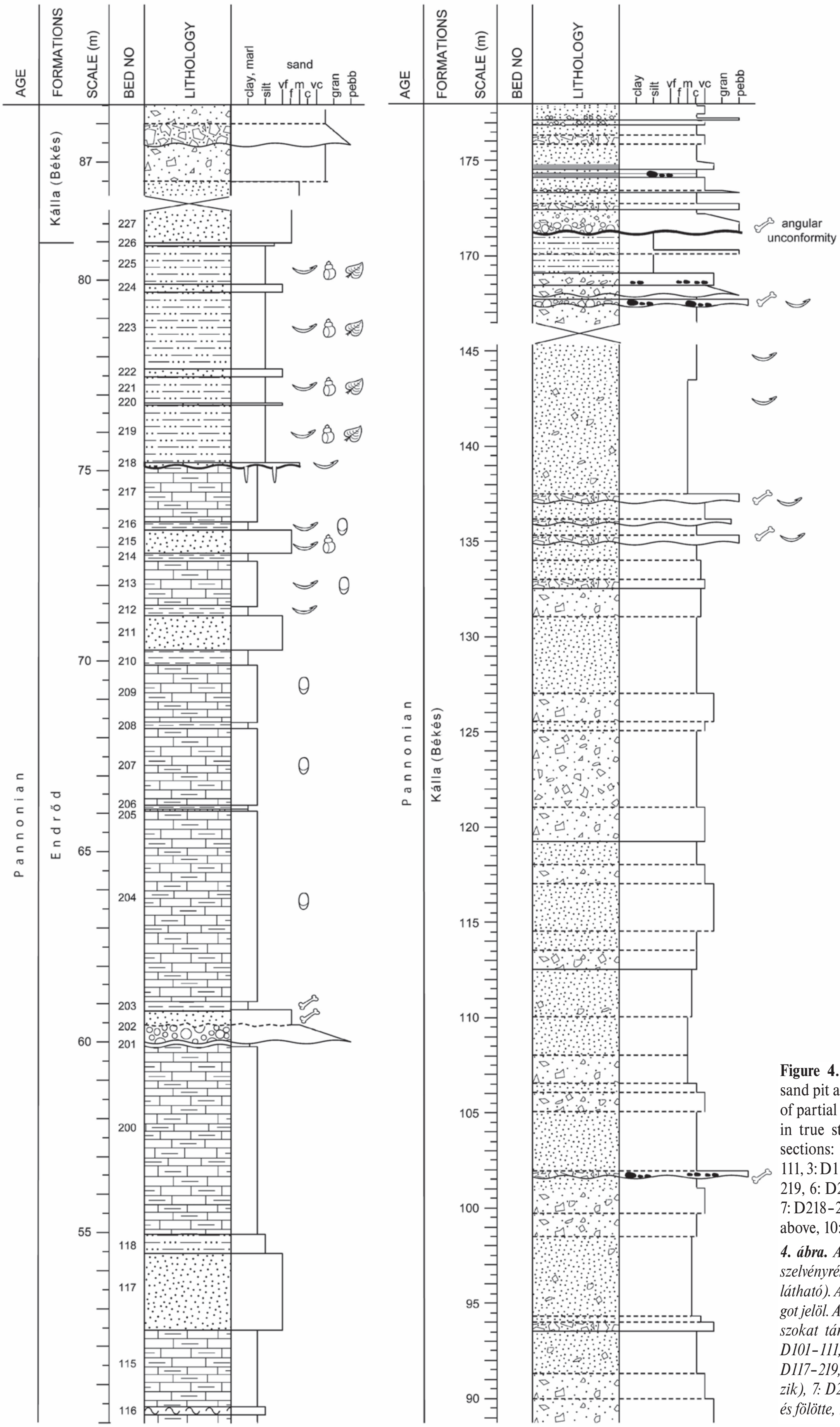


Figure 4. The sedimentary log of the sand pit and the trench (for the location of partial sections see *Figure 2*). Scale is in true stratigraphic thickness. Partial sections: 1 (trench): D72–D1, 2: D101–111, 3: D111–207, 4: D204–227, 5: D117–219, 6: D207–227 (D220–226 missing), 7: D218–227, 8: D207–227, 9: D227 and above, 10: D213–227

***4. ábra.** A bánya és az árok rétegsora (a szelvényrészek elhelyezkedése a 2. ábrán látható). A skála valódi rétegtani vastagságot jelöl. A szelvényrészek az alábbi szakaszokat tárták fel: 1 (árok): D72–D1, 2: D101–111, 3: D111–207, 4: D204–227, 5: D117–219, 6: D207–227 (D220–226 hiányzik), 7: D218–227, 8: D207–227, 9: D227 és fölötte, 10: D213–227*

During the documentation of the sedimentary succession standard field observations were carried out. Lithology, grain size, thickness, types of bedding contacts, sedimentary structures and macrofossil content were recorded with cm-scale accuracy. Since logging was only possible in parts of the succession at a given time, bed numbers of the sedimentary succession are not consecutive and contain gaps, and span from D72 (lowermost Badenian layer) to D227 (start of the limonitic sands). When stratigraphically overlapping sections were logged, some beds occurred in one section and were missing in others. Nevertheless, it was possible to follow several important beds (e.g., tuff, clay with carbonate concretions, clay-sand-clay triplet) for hundreds of metres along the northern wall, allowing us to fit the puzzle pieces of the sedimentary column together.

Systematic sampling was carried out from 83 layers for palynological, nannoplankton, ostracod, foraminifer and mollusc studies (*Figure 4*). Detailed results of the specific investigations are presented in the other papers of this journal volume (BOTKA et al. 2021, CSOMA et al. 2021, ĆORIĆ 2021, DULAI et al. 2021, KRIZMANIĆ et al. 2021, SZABÓ et al. 2021, SZUROMI-KORECZ et al. 2021). In addition, samples were taken for petrographic investigations, authigenic ^{10}Be/^{9}Be-isotope dating, and multiple radiometric dating methods from an upper Miocene tuff layer. Their analysis is underway, therefore they will not yet be discussed here.

Sedimentary succession

A continuous sedimentary succession with a true thickness of ~220 m was documented in the trench and the sand pit (*Figure 4*). Sediments from the bottom of the succession to the top of the Pannonian marls were 80 m thick. The overlying Pannonian limonitic pebbly sands reached a thickness of about 140 m, of which the lower ~60 m plus the succession above the unconformity were logged in detail, where exposure allowed to take a continuous record. The further ~70 m below the unconformity were covered to a large extent during the logging, but point-like observations showed that lithology did not change significantly in this interval. The observed sedimentary facies are listed in *Table 1.*

The oldest part of the succession was exposed in the exploratory trench (*Figure 5*). Due to tectonic deformation, most of this interval is overturned, and the stratigraphically lowest (oldest) layers are located in the north. Overturned beds become steeper towards the south (upsection) until they are vertical close to the southern end of the trench. From there on, they change to normal but steep, southerly dips.

This section describes the main lithological and sedimentological features of the succession, from bottom to top, subdivided into intervals of similar lithologies. The paleontological data justifying the age of the intervals and their lithostratigraphic classification are presented in the discussion section and the papers cited there. The ages of the distinguished sedimentary units provided by biostratigraphic investigations are also used in the titles of the coming sections to help the orientation of the reader.

Badenian marl, bioclastic limestone (D72–71)

The lowermost exposed sediments, up to a thickness of 2 m, are yellowish white, fossiliferous limestone and calcareous marl with a thickness of 2 m, hosting abundant mollusk shells and imprints including *Rissoa*, *Venus* and *Myrtea* species (DULAI et al. 2021). They are overlain by about 3 m of coarse bioclastic limestone, calcarenite with mollusk shells, shell fragments, remains of bryozoans and nodules of corallinacean algae (*Figure 6A*). The macrofauna is dominated by *Cubitostrea* shells (DULAI et al. 2021). A shark tooth (cf. *Araloselachus*, SZABÓ et al. 2021) was found in the calcarenites as well. Bedding is not visible, the rock is rather

Table I. Sedimentary facies and interpretation from the outcrop
I. táblázat*. A feltárt rétegsor litofáciesei és azok értelmezése*

Lithofacies	Grain size	Macrofossils	Bed contacts	Bed thickness (cm)	Depositional processes	Examples, bed no., or metres
Carbonates						
coarse bioclastic limestone	-	diverse marine bivalves, corals, corallinacean algae	-	1	biological, transported in agitate waters	D71
structureless microcrystalline limestone	-	ostracods, bivalves, gastropods	sharp, slightly irregular	3-33	plankton and benthic biomass, quiet suspension settling, bioturbation	D55, D53, D48, D46, D43, D41, D37, D35, D33, D30, D26
laminated microcrystalline limestone	-	gastropods, bivalves	sharp, flat	20	plankton and benthic biomass, quiet suspension settling, dysoxic bottom	D51, D48
gray, structureless, (clayey) marl	-	-	transitional	20-35	biogenic with terrigenous, input, suspension settling	D49, D40,

Table I. continuation

***I. táblázat*.** folytatás

Lithofacies	Grain size	Macrofossils	Bed contacts	Bed thickness (cm)	Depositional processes	Examples, bed no., or metres
gray or white, rarely laminated, mostly structurless, very hard or friable marl, calcareous marl	-	bivalves, gastropods, rare horizontal winding burrows	transitional or sharp	3-100	dominantly biogenic	D32, D28, D24, D22, D20, D17, D14, D12, D10, D6-7, D3-0, D101-
Siliciclastics						
fossiliferous, greenish brown, gray or white structureless clay or silt, rare Mn nodules, rarely bentonitic	clay, silty clay, clayey silt	bivalve shells, gastropods, large ostracods	sharp	8-210	suspension settling, bioturbation; volcanic ash fall	D56, D54, D52, D50, D47, D45, D42, D39, D38, D36, D34, D31, D25, D23, D21, D18, D16-15, D13, D11, D8-9, D203, D210, D212, D214, D216; D219-225; 170m
micaceous, poorly sorted, structureless clay, silt(stone), alternates with gS or Ss	silty clay, sandy silt	lack of macrofossils, some reworked forams and ostracods	sharp, irregular	1-90	low-density gravity flows (slurry flows)	D63, D64, D67-69, D70
structureless sandstone, rare planar lamination, normal gradation, alternates with gS or Fs, polimictic composition	vf-m*	absent	sharp or transitional	10-60	high-density sandy turbidity currents or grain flows	D58, D61, D65, D66-69
mostly structureless sand(stone), rare planar lamination, normal gradation, load structures; moderately to well sorted, quartz-rich composition	vf-vc	mostly absent, rare bivalves	sharp or transitional	10-200	high-density sandy turbidity currents	D113-114, D117, D201-202, D211, D215; D218, D220, D222; D224, D227 and above
poorly sorted, structureless granular, pebbly sand(stone), occasionally normal gradation, ratio of gravel and pebble varies: 10-30%	m-vc, granule, pebble	absent	mostly transitional, rarely sharp	10-400	high-density gravelly turbidity currents or grain flows	D59-61 87m-145m
matrix-supported, poorly sorted, structureless, sandy breccia, non-graded with angular-subangular clast	m-c, pebble	absent	sharp	65	grain flow	D62
clast-supported conglomerate, c-vc sandy matrix, normal gradation	granule, pebble	vertebrate bones, bivalves	sharp, erosional	10-100	high-density gravelly turbidity currents	87.5m, 102m, 135m, 136m, 137m, 168m, 172m, 173.5m, 176m
clast-supported mud-clast conglomerate, c-vc sandy matrix	pebble–cobble	vertebrates	sharp, erosional	20-40	high-density sandy debris flow	167.5m, 169 m

vf: very fine-, f: fine-, m: medium-, c: coarse-; vc: very coarse-grained sand

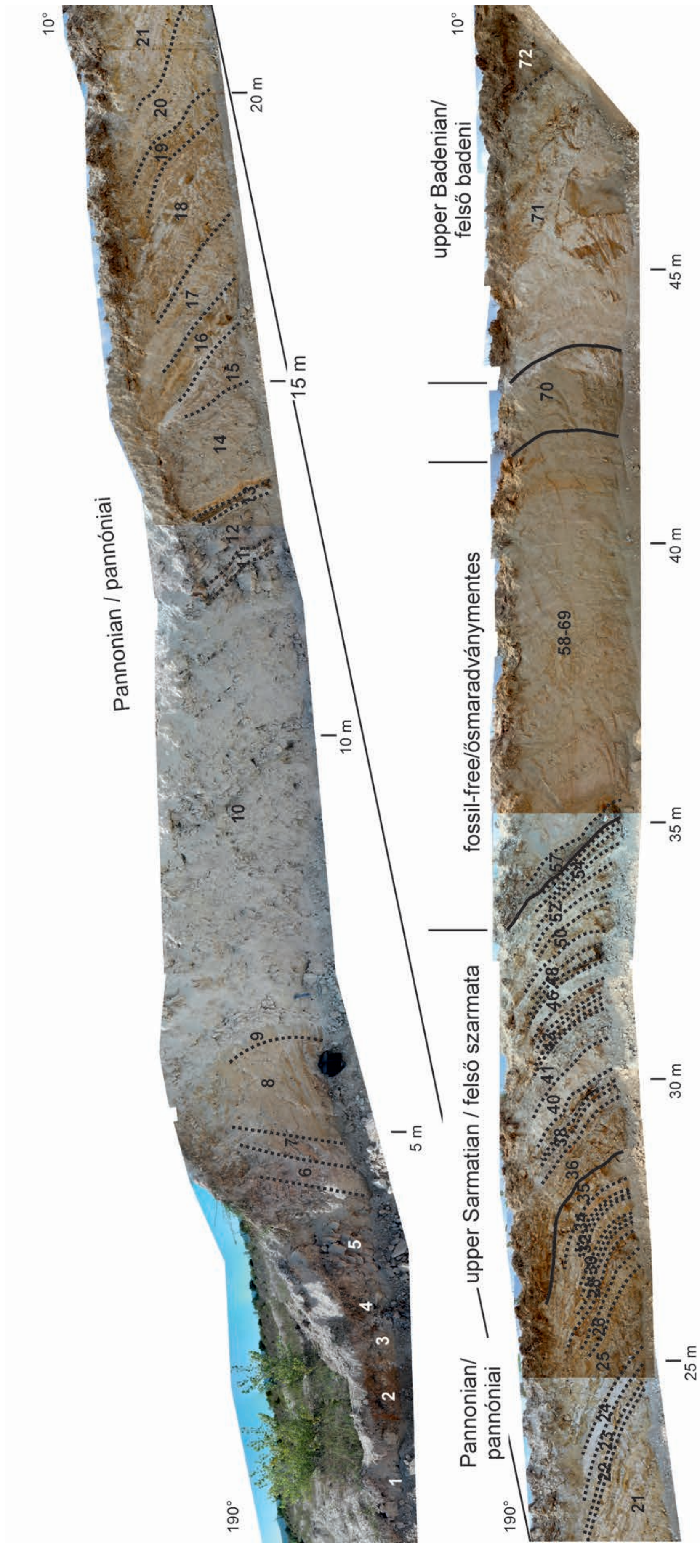


Figure 5. The western wall of the exploratory trench with layer numbers (2018). Metres indicate length along the trench (uneven because of perspective views). For trench location see *Figure 2*

5. ábra. *A kutatóárok nyugati oldala rétegszámokkal (2018). A méterek az árok menti távolságot jelölik, a fényképek torzítása miatt egyenetlenek. Az árok elhelyezkedését a 2. ábra mutatja*

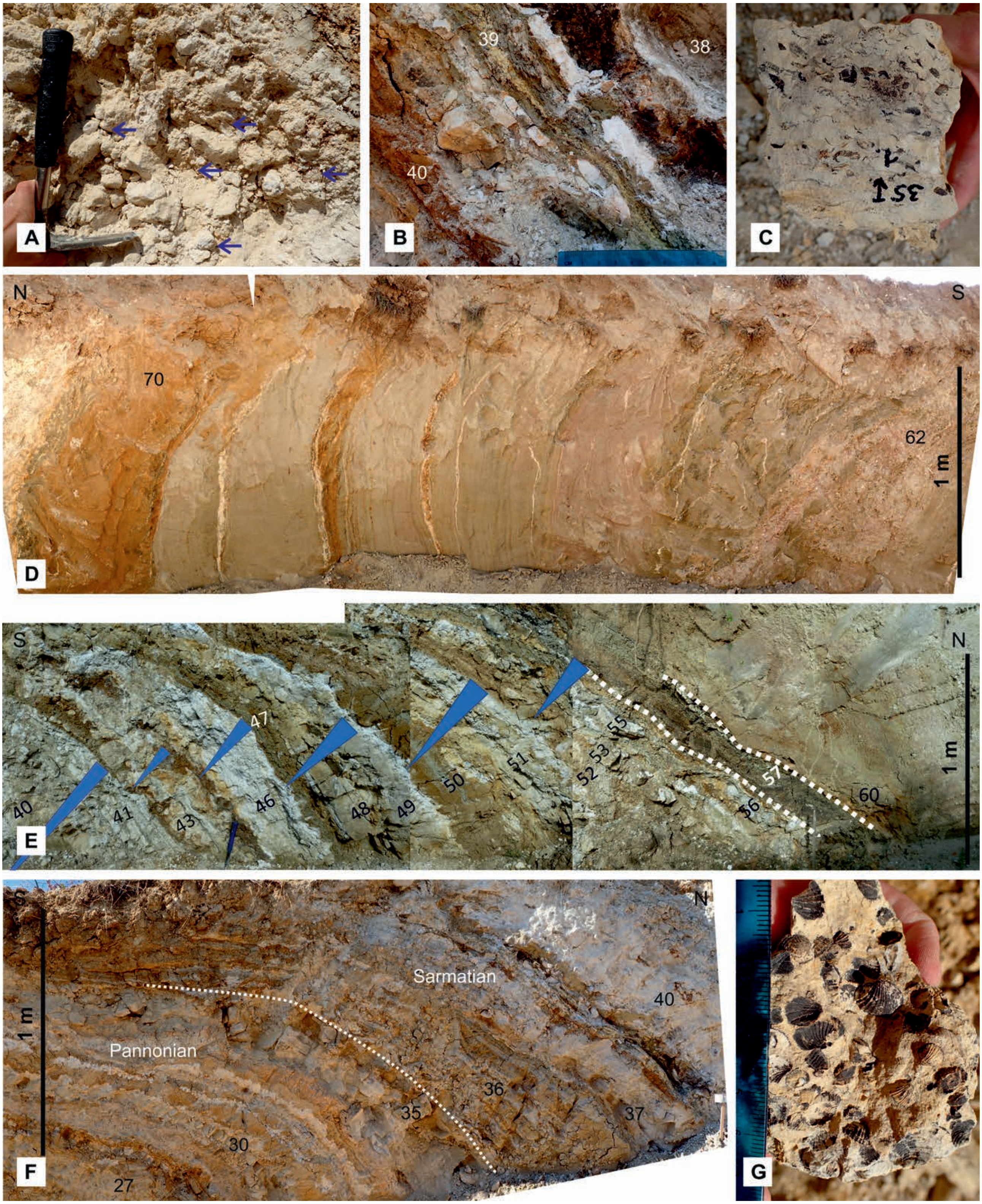


Figure 6. Typical lithofacies of the middle Miocene (Badenian and Sarmatian) and lowermost Pannonian sediments. A) Bed D71, Badenian sandy limestone, with some *Cubitostrea* specimens indicated by arrows; B) Sarmatian greenish yellow tuffitic clay (D39); C and G) Limestone with small Lymnocardiinae specimens, D35, base of the Pannonian succession; D) fossil-free clastics, mostly sands, with silt (e.g., D70) and gravel (D62) interbeds; E) small-scale limestone- marl-to-clay cycles in the upper Sarmatian deposits; F) the Sarmatian/Pannonian boundary within alternating clay, marl and limestone beds, as indicated by microfossils (Szuromi-Korecz et al. 2021)

6. ábra. *A középső miocén (badeni és szarmata) és legalsó pannóniai üledékek jellemző litofáciesei. A) D71, badeni homokos mészkő; néhány* Cubitostrea *maradványt nyíl jelöl; B) szarmata zöldessárga tufás agyag (D39); C és G) mészkő apró Lymnocardiinae-maradványokkal, D35, a pannóniai összlet kezdete; D) ősmaradványmentes törmelékes összlet, uralkodóan homok, kőzetliszttel (pl. D70) és kaviccsal (D62); E) mészkő-márga-agyag ciklusok a szarmata összlet felső részében; F) a mikrofosszíliák által kijelölt szarmata-pannóniai határ a váltakozó mészkő-, márga- és agyagrétegeken belül (Szuromi-Korecz et al. 2021)* fragmented by irregular fractures. Particularly near the stratigraphic top the interval consists of in situ carbonate fragmented by fractures into 40 cm large blocks. The rich microfauna indicated a late Badenian (early Serravallian) age (SZUROMI-KORECZ et al. 2021).

Sarmatian(?) silt, sand(stone), sandy breccia and conglomerate (beds D70–57)

The following ca. 8 m thick interval is comprised of friable to moderately cemented clastic rocks (*Figure 6D*) barren of macrofossils. Micropaleontological investigation of silt layer D70 revealed some poorly preserved tests and fragments, which are most likely redeposited from older (Badenian) marine marls (SZUROMI-KORECZ et al. 2021). The next ca. 5 m is made up of 0.7–0.9 m thick yellow, structureless, micaceous beds of sandy silt and 1–7 cm thick clay beds, alternating with thick medium-, fine- and very fine-grained micaceous, quartz-rich sandstones. Bed contacts can be sharp or transitional. Beds are structureless or faintly laminated, normal gradation up to a thickness of 60 cm also occurs. The uppermost 2.5 m is somewhat coarser, as normally graded beds of coarse-grained granular sandstone and medium to coarse breccia with granular sandy matrix appear. The clasts are angular or subangular and immature; sorting is variable but generally poor. The uppermost, 25 cm thick bed (*Figure 6E*) consists of clayey, granular, coarse sandstone; it is variegated with dark brown manganese-limonite cementation and is capped by an unconformity.

Upper Sarmatian to Pannonian clay, limestone, calcareous marl (D56–22)

Lithologically, the Upper Sarmatian deposits and the lower part of the Pannonian ones are composed of a frequent alternation of 2–10 cm thick limestone, marl and clay beds (*Figure 6F*). There are several changes in the fossil faunas (BOTKA et al. 2021, SZUROMI-KORECZ et al. 2021, ĆORIĆ 2021) in this part of the succession, however, their positions are different for each fossil group. Therefore, an attempt was made to establish independent, physical criteria to subdivide the interval. The grain size variation is not significant; however, the bed thickness and carbonate content can be taken into consideration. The lower part shows the alternation of limestone and clay beds with an average thickness of ~0.2 m (ranging from 6 to 50 cm). The proportion of clay is slightly higher than that of carbonate (55 vs. 45%). Limestones have a sharp base and become marly upwards, with a gradual and irregular transition to clay. This small-scale cyclicity is relatively well-developed in beds 55–52, 51–50, 49–47 or 46–43 (*Figure 6E*). Greenish or yellowish brown clay beds are structureless, occasionally tuffaceous (?44 and 39, *Figure 6B*), others contain mollusk (e.g., cardiid, dreissenid) shells (beds 52, 50, 47). Very hard, micritic limestone beds mostly lack any sedimentary structures except for the finely laminated beds 51 and 48, the latter with very small bivalve and gastropod shells. Other limestone layers yielded abundant mollusks, mostly gastropods (e.g., *Radix*, *Gyraulus* in beds 43 and 37), or mass occurrences of small, delicately ornamented bivalve shells together with Hydrobiidae snails buried in life position (bed 35) (*Figure 6C, G*). The overall carbonate content slightly decreases upwards, thus the number of friable, structureless (49, 40, 24, 22) or laminated calcareous marl beds (32, 28) increases towards the younger strata.

Pannonian calcareous marl and clay (D21–2)

In the following interval the characteristic thickness of clay interbeds increases to 0.5 m, while that of carbonate beds to up to 6 m, with an average around 1 m. The overall ratio of carbonate beds increases to about 75%. Clays are still greenish or yellowish brown and structureless. Occasionally clay is smeared into the fractures of brecciated limestone due to post-sedimentary deformation (D19). Bedding is rather indistinct in the calcareous marl, though the variation in the carbonate content is shown by varying hardness. Mollusk shells (e.g., *Radix*) were found only in bed 12 (*Figure 7A*).

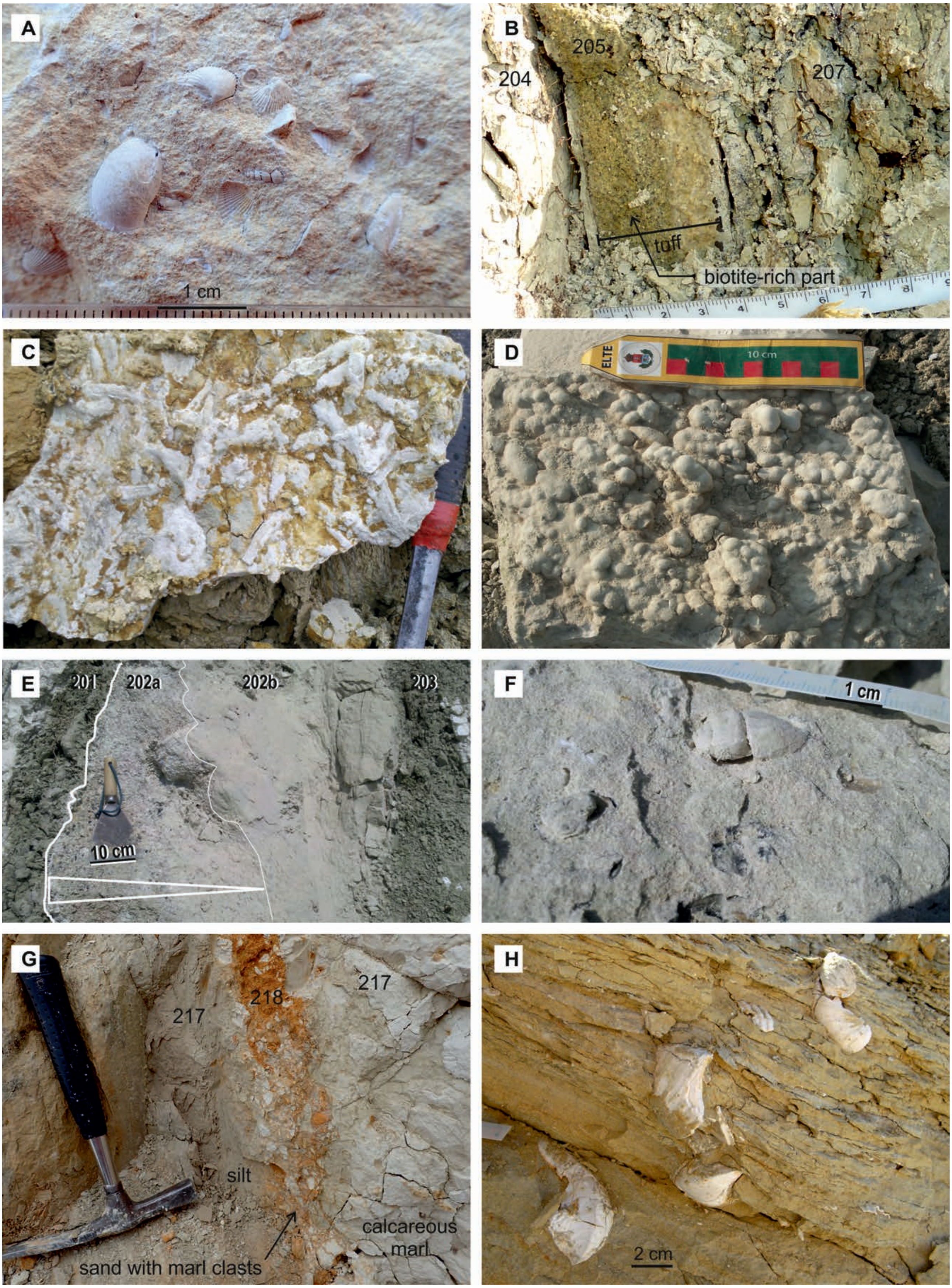
Pannonian calcareous marl with sandstone interbeds (D1–217)

In this section the dominant lithology is light grey to white calcareous marl, with bed thicknesses of 10–30 cm (*Figure 8*). The carbonate content slightly fluctuates, otherwise the rock is mostly structureless. Carbonate concretions occur on the sole of some beds (*Figure 7D*) and along some fractures. Elsewhere bedding-parallel 1-2 cm diameter burrows were observed, filled with calcareous mudstone (*Figure 7C*). Some of the beds host abundant mollusk shells, bivalves and gastropods (BOTKA et al. 2021), and large ostracod carapaxes are also fairly common (CSOMA et al. 2021).

Higher up in the succession intercalations of greyish green clays, grey siltstones, and friable, weakly cemented very fine to medium-grained sandstone and conglomerate beds occur. Their thickness increases upwards (from 20 cm to 1 m), and so does their frequency, hence the proportion of carbonate beds decreases to ca. 70% in the uppermost 10 m (see beds in *Figure 4*). Conglomerates have a sharp erosive base and they are normally graded from medium-grained

→ **Figure 7.** Lithofacies of the upper Miocene calcareous marl succession. A) calcareous marl with mollusks (e.g., *Radix croatica*, *Gyraulus tenuistriatus*, "*Lymnocardium*" cf. *praeponticum*) (D12); B) tuff in calcareous marl (D205); C) bedding-parallel burrows from the upper part of the marl; D) concretions along a bedding plane of the calcareous marl; E) clay and normally graded gravelly sand and sandstone within the calcareous marl succession; F) moulds of littoral gastropods in sandstone (D215); G) the boundary of the calcareous marls and the transitional silt-sand unit; H) large *Congeria partschi* and *Lymnocardium schedelianum* shells in the transitional silts (D219)

→ ***7. ábra.*** *A felső miocén mészmárgasorozat jellemző litofáciesei. A) mészmárga puhatestűekkel (pl.* Radix croatica*,* Gyraulus tenuistriatus*, "*Lymnocardium*" cf.* praeponticum*) (D12); B) tufa mészmárgában (D205); C) réteglappal párhuzamos ásásnyomok a mészmárga felső részéből; D) konkréciók mészmárga réteglapján; E) agyag- és gradált kavicsos homok-betelepülés mészmárgában; F) sekélyvízi csigák lenyomatai homokkőben (D215); G) a mészmárga és az átmeneti aleurithomok egység határa; H)* Congeria partschi *és* Lymnocardium schedelianum *kagylóhéjak aleuritban az átmeneti egységben (D219)*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204
207
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C
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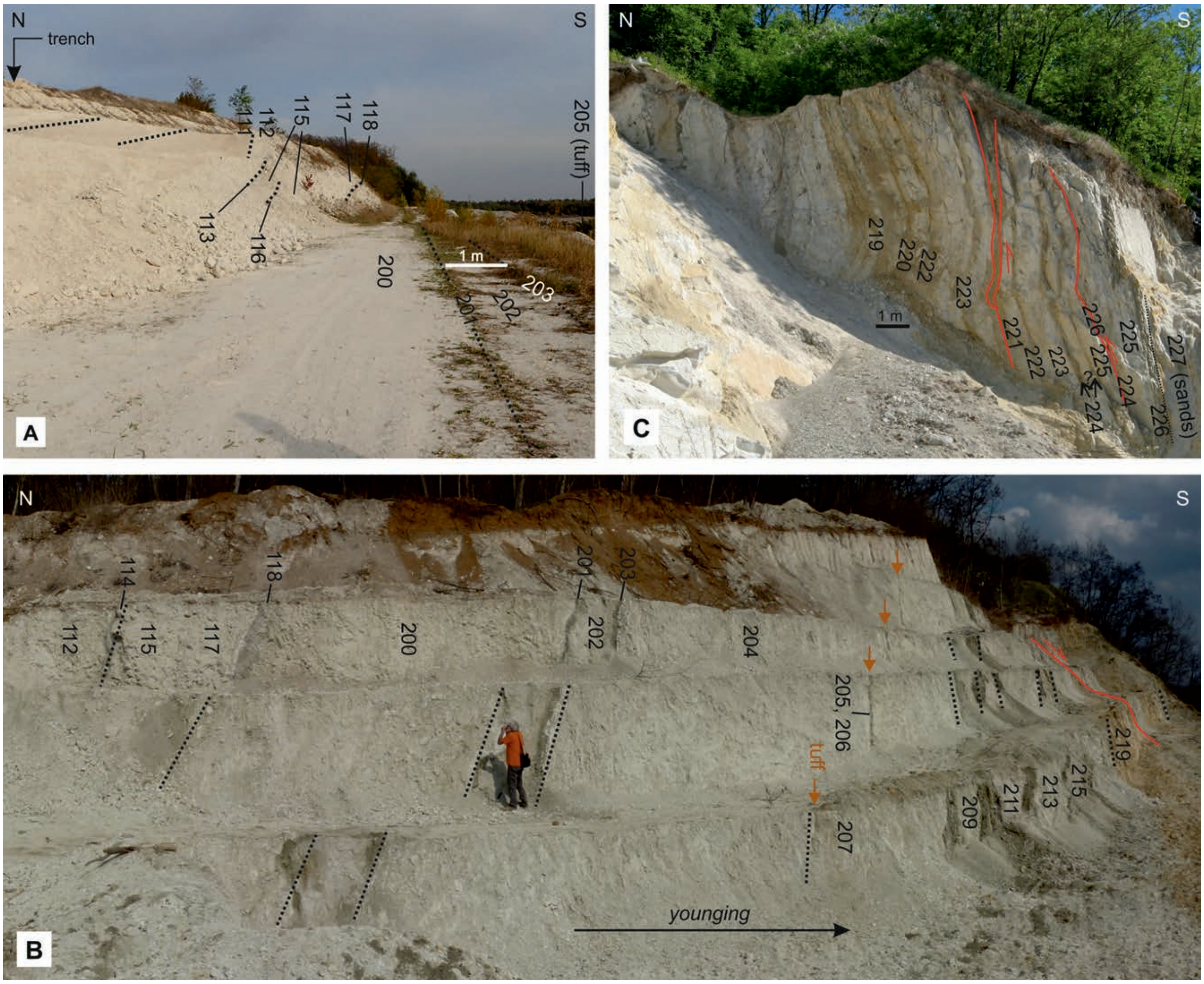


Figure 8. The upper part of the Pannonian carbonate-dominated succession in the northern part of the sand pit, with layer numbers. A) Sections 2–3 immediately south of the trench pictured in 2018; B) section 5 in 2012; C) section 7 in 2015. For section locations see *Figure 2*

8. ábra. *A pannóniai mészmárgarétegsor felső része a bánya északi oldalán, rétegszámokkal. A) 2. és 3. szelvény közvetlenül az ároktól délre, 2018-ban; B) 5. szelvény 2012-ben; C) 7. szelvény 2015-ben. A szelvények elhelyezkedése a* 2. ábrán *látható*

gravel to granular sand. Most sandstones are well-sorted, oligomictic, quartz-rich and structureless; their boundaries are sharp, erosive, or might show ball and flame structures. They occasionally contain vertebrate remains, e.g., fish teeth and bones and turtle shell fragments. D215 contains compressed gastropods and bivalve shells (*Figure 7F*). A greyish green clay bed (D205) contains abundant euhedral biotites and volcanic glass pointing to an ashfall tuff (SEBE et al. 2016); preliminary investigations identified it as an alkaline trachyte tuff (*Figure 7B*). Poorly preserved mollusks are present in D216 and 212.

Pannonian sandstone, silty clay, siltstone: transitional beds between the marls and the limonitic, pebbly sandstone (D218–226)

The topmost ca. 6 m of the fine-grained succession consists of alternations of yellow fossiliferous silty marl, clayey siltstone, siltstone and friable, quartz-rich very fine to medium-grained structureless sandstone, representing a transition towards the overlying sandstone unit. These beds contain abundant macrofloral remains, mostly leaves and branch fragments and some fruits (HABLY & SEBE 2016). The top of the youngest marl bed is irregular with a few cm deep, cylindrical or funnel-shaped burrows filled with the overlying sand. This sand bed (D218) also contains cm-sized rip-up marl clasts and large amounts of mollusk shell fragments (*Figure 7G*). The interval contained a rich profundal mollusk assemblage (BOTKA et al. 2021) (*Figure 7H*).

Pannonian limonitic, pebbly sand(stone) (D227–)

The next ca. 140 m thick succession is divided into two parts by an angular unconformity (*Figure 2B, 9A*) in the western wall of the sand pit; in the NE wall only the portion below the unconformity is exposed. The lower, relatively steeply dipping series is further subdivided by a grey, ca.

0.4-0.5 m thick clayey silt bed (at 170 m in *Figure 4*). The majority of the succession is built up of alternating layers of coarse to very coarse, partly pebbly sand and granule to pebble sized gravel. The deposits are sandstones and conglomerates cemented by limonite and are friable to loosely cemented. As the majority of the rock crumbles easily, for the sake of simplicity the term 'limonitic sand' is used for the entire section hereafter. Beds are parallel, with thickness ranging from a few tens of cm-s to a few metres, they are marked by minor fluctuations of grain size and sorting, i.e. the ratio of sand to gravel. Metre-scale beds can be differentiated mostly by limonite colouring, otherwise it is difficult to distinguish layers, as bed contacts commonly are transitional. Gravel intervals are poorly sorted, consisting mostly of subangular to moderately rounded granules and medium to coarse pebbles. In the pebbly sand beds the ratio of gravel varies between 5 and 50% (*Figure 9C*). The clasts have a polimictic composition with the dominance of quartzite. Lithics and some feldspars are possibly – perhaps indirectly – derived from a granitoid source area, others come from the reworking of older Miocene clastics (mostly from Szászvár and Budafa Formations). Locally, rip-up mud clasts up to a diameter of cobble are dispersed in the pebbly sand (*Figure 9D*). The sand body contains limonite-cemented moulds of Lake Pannon mollusks. Vertebrate remains, among them marine fish and mammal fossils reworked from middle Miocene deposits, are also common.

In the lower part of the pebbly sand succession (*Figure 4*) 1 m wide and 10–15 cm deep scours or lenses appear. Although well-developed grading is rarely present, in many cases the low-relief rough erosional surfaces are often overlain by the coarsest fraction or the largest concentration of gravel. Some irregular, slightly elongated patches of fine, medium and coarse-grained sand appear, without forming distinct burrows. Somewhat below the silt layer at 170 m (*Figure 4*), a ca. 30 cm thick, clast- supported coarse pebble- to cobble mud-clast conglomerate occurs with coarse, very coarse sand matrix and sharp erosional base (*Figure 9D*). The erosional base of another bed at 168.5 m is also paved by small mud-clasts (*Figure 9E*). These beds cut into the "regular" pebbly sand, which is directly overlain by the thick silt marker bed at 170 m within a 20–30 m distance.

Above the angular unconformity at 171 m mostly parallel beds occur without pronounced changes of the lithology, average grain size, clast shape or sorting with respect to the sediments below. The first bed is a normally graded coarse conglomerate with a thickness of ~1 m. It contains exceptionally well-rounded Paleozoic granite and Permian rhyolite cobbles of up to 15 cm diameter, which originate from the lower and middle Miocene Szászvár and Budafa Formations (*Figure 9C*). The graded conglomerate bed interfingers with well-sorted arcosic coarse grained sandstone, which can be followed for several tens of metres above the unconformity. A few limonite cemented marker beds also help to correlate the succession. The youngest part of the succession consists of metre-thick beds of coarse and very coarse sandstone as well as poorly sorted pebbly sandstone, with angular quartzite clasts. The topmost bed contains well-rounded pebbles made up of rhyolite tuff. The lack of traction-induced primary sedimentary structures (such as cross-bedding) in the sandstones and gravelly sandstones is evident both below and above the unconformity.

Interpretation

Lithostratigraphy and depositional environments

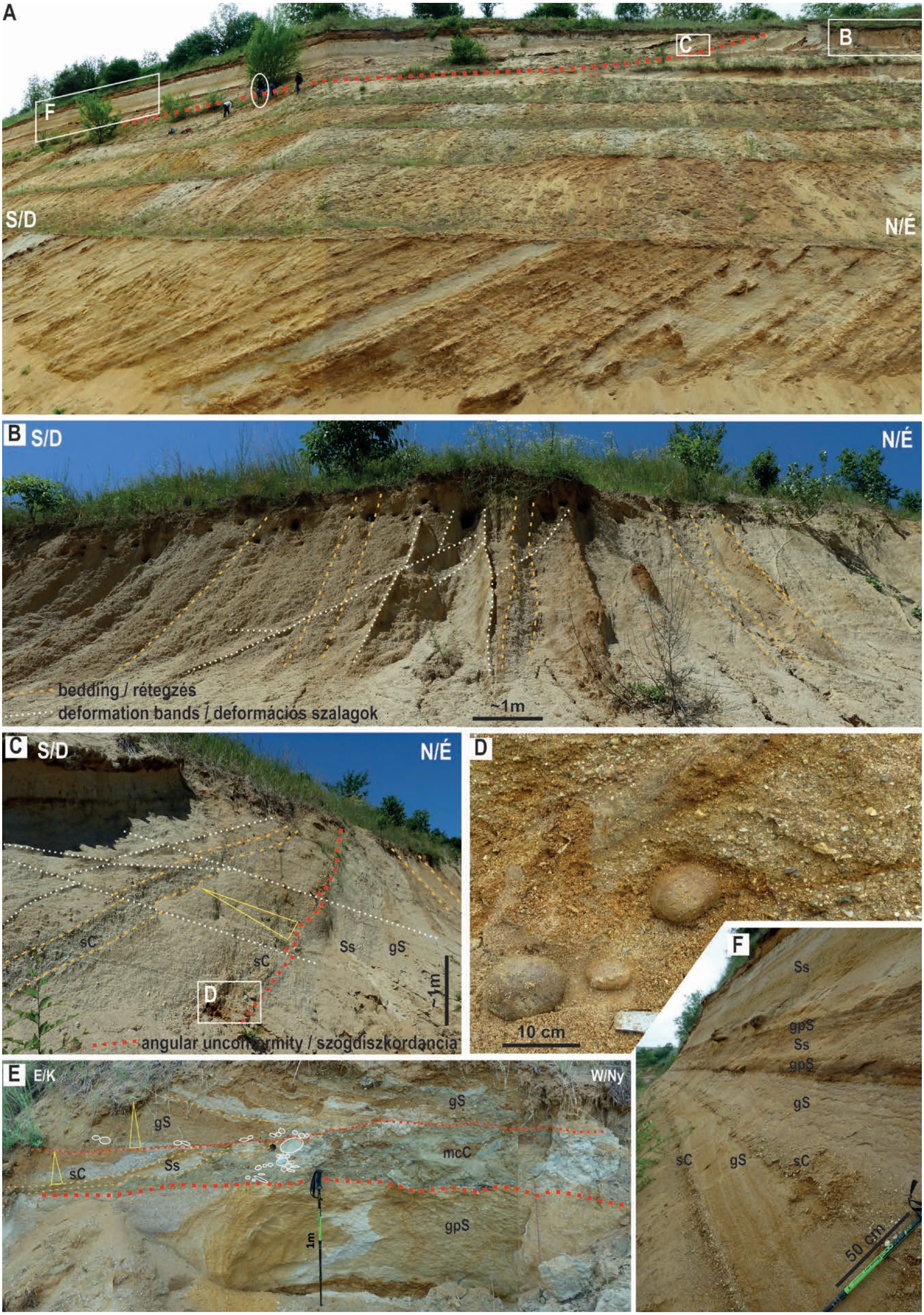
The classification of the exposed sediments into lithostratigraphic units is not straightforward. Several of the Miocene formations previously reported from the area include various lithologies, thus paleontological data are necessary to identify them. However, our studies showed that different fossil groups may show pronounced changes asynchronously in the sedimentary succession. This phenomenon has also been reported from the Paratethys, e.g., in the Vienna Basin, around the Badenian/Sarmatian boundary (Hyžný et al. 2012). The identification of chrono- and lithostratigraphic units, therefore, remains somewhat ambiguous. Hereby, we suggest a sub-division of the studied deposits into stratigraphic units based on the integration of the observed lithofacies variations and fossil assemblages.

Szilágy Clay marl Member of the Baden Formation or Rákos Member of Lajta Limestone Formation (upper Badenian)

The topmost part of the unit was exposed in the northern end of the trench and is represented by the yellowish white calcareous marl of layer D72. The rock contains a typical Badenian mollusk fauna, where all bivalves are inbenthos species in fine-grained deposits, referring to several tens of metres of water depth (Dulai et al. 2021). The microfauna belongs to the upper Badenian Bolivina-Bulimina Zone (13.82–12.65 Ma) and indicates agitated, relatively shallow water with normal salinity (Szuromi-Korecz et al. 2021); it must have been reworked into water depths below wave base. The sediments exposed in the trench, similarly to those in the surrounding area (Hámor et al. 1968), contain more carbonate than the typical Szilágy Clay marl. Therefore, this unit can be classified as Szilágy Clay marl if the carbonate content, the sublittoral depositional environment and the existing stratigraphy of the region is considered, but can also be regarded as a deeper water interval of the overlying Lajta Limestone Fm. The depositional environment might have been located close to the nearshore.

Rákos Member of the Lajta Limestone Formation (upper Badenian)

The ~3 m thick sandy limestone and calcarenite of layer D71 in the trench shows the typical features of the "Leitha limestone": carbonate-rich sediment with a rich macro- and microfauna pointing to shallow and agitated water (Dulai et al. 2021, Szuromi-Korecz et al. 2021). The microfauna indicates a late Badenian age. Based on its stratigraphic posi-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tion (above and/or interfingering with the Szilágy Clay marl and directly below the Sarmatian rocks) and because of the late Badenian age, these layers can be identified as the upper part (Rákos Member) of the Lajta Limestone Formation. In the Mecsek mountains Hámor et al. (1968) and Hámor (1970) defined the Szilágy Clay marl to include the "upper Leitha limestone", adding that the limestone represents a nearshore environment and interfingers with the open-water clay marl. However, in the surroundings of Danitzpuszta, the limestone occurs in a well-defined, narrow belt including the exposure of the trench. Therefore, it is more informative to differentiate these two stratigraphic units.

Kozárd Formation (Sarmatian)

The interval between layers D70 to D36 is sharply divided into two different units: the lower, ca. 7–8 m thick part from D70 to D57 includes silt, sand(stone) and conglomerate, whereas the overlying ca. 5 m show cyclic alternation of thin clay, marl and limestone (D57–D36). The yellowish brown silt of D70 has a reworked microfauna with Badenian elements, poorer but similar to D71 (Szuromi- Korecz et al. 2021). Based on its lithological similarity to the overlying interval, we tentatively classify this layer as Sarmatian as well. Beds D69 to D57 sampled for microfauna investigations contained no microfossils, thus their age is uncertain. The lack of normal salinity marine microfauna points either to terrestrial exposure, or to deposition under variable salinity conditions during the Sarmatian. The age of beds D54 to D36 is indicated by the microfauna as late Sarmatian, ~12.1–11.6 Ma (Szuromi-Korecz et al. 2021). The variable salinity of the otherwise brackish Sarmatian sea is supported by the biota of layers D37–40, which show the influence of freshwater inflow as demonstrated by the microfauna, the nannoplankton and the mollusks as well (Szuromi-Korecz et al. 2021, Ćorić 2021, Botka et al. 2021).

In the clastic succession there are no sedimentary structures pointing to traction currents. Poor sorting, angular clasts, erosive bed contacts and few graded beds may point to rapid deposition from small-volume, either subaerial or subaqueous gravity-driven flows. Considering the lack of fossils, an alluvial or lacustrine fan-like depositional setting is likely. The Fe–Mn encrusted unconformity on top of layer D57, the appearance of clays, marls and limestones above, together with the appearance of fossils denote a sharp change in the depositional environment, probably from terrestrial to (brackish) marine. The overlying mudstones, regardless of their carbonate content, indicate deposition in quiet waters, devoid of wave agitation or intermittent currents, which could have transported sand into the system. The microfauna also supports sublittoral water depths (Szuromi-Korecz et al. 2021). Based on these, a rapid transgression, resulting in a water depth below storm wave base (few tens of meters) and/or large distance to the source area and/or a palaeogeography preventing coarse clastic input is inferred. Based on the high proportion of fine-grained sediments – clays and marls –, this interval is assigned to the Kozárd Formation. The Sarmatian interval exposed in the trench is significantly thinner than the thickness considered typical of the area from borehole data (120–150 m in the Pécsbánya Basin west of the sand pit; Hámor et al. 1968) or that inferred from dips and areal distributions indicated in maps (Hámor et al. 1966, Hetényi et al. 1982).

←Figure 9. Typical lithofacies of the upper Miocene sands. A) alternating coarse and granular very coarse sands with varying limonite cementation. People for scale. The locations of other inserts are indicated. B) steep beds with deformation bands in the upper part of the western wall of the sand pit; C) close-up of the angular unconformity and some reverse faults; for facies codes see *Table I*; D) poorly sorted sandy gravel with well-rounded cobbles above the unconformity; E) granular, pebbly coarse sand (gPcS) overlain erosively by a mud-clast conglomerate (MCC) and granular coarse sand (GcS) beds in the middle of the succession (beds at 168 m of *Figure 4*); F) parallel beds of structureless coarse sand and coarse pebble gravel above the unconformity

←9. ábra. *A felső miocén homokösszlet jellemző litofáciesei. A) nagyszemű és darakavicsos durvaszemű homok váltakozása, változó mértékű limonitos cementációval, a részletfotók helyének jelölésével; B) Meredeken dőlő rétegek a bánya nyugati falának fölső részében; C) a diszkordanciafelszín közelképe néhány feltolódással; a litofácies-kódok magyarázatát az* I. táblázat *tartalmazza; D) rosszul osztályozott homokos kavics a diszkordanciafelszín fölött, jól koptatott hömpölyökkel; E) kavicsos nagyszemű homok (gPcS), fölötte eróziós felszín fölött agyagkavics-konglomerátum (MCC) és darakavicsos nagyszemű homok (GcS) a homokösszlet közepe táján (168 m körüli rétegek a* 4. ábra *rétegsorán); F) szerkezetmentes nagyszemű homok és nagyszemű kavics párhuzamos rétegei a diszkordanciafelszín fölött*

Endrőd Formation (Pannonian)

The layers D35 to D225, with a total thickness of 64 m are assigned to Endrőd Formation. The lower part of this unit (beds D35–D22) is lithologically very similar to the upper part of the underlying Kozárd Fm., hence the boundary was defined based on micropaleontological results: the last occurrence of the typical Sarmatian marine foraminifers was found in layer D36 (Szuromi-Korecz et al. 2021), whereas the first occurrence of typical Lake Pannon ostracods is located in layer D35 (Csoma et al. 2021). In addition, the cyclic lithological pattern becomes less evident upwards, though the alternation of limestone and clay beds persists. Upsection from D14, gradually thickening, homogeneous marl intervals become dominant with some graded or structureless conglomerate to sandstone interbeds. Their deposition took place in open, probably a few hundred metres deep waters, most likely below or on a slope. This can be deduced from the occurrence of 0.5–2 m thick coarse pebbly to sandy turbidite beds, in accordance with the palynofacies and the appearance of profundal mollusks (Krizmanić et al. 2021, Botka et al. 2021). The material of clastic interbeds originated from the dryland in the north. This could have been an island at that time, as shown by the areal distribution of coeval sediments (Kleb 1973, Magyar et al. 1999). The island was elongated in the WSW–ENE direction and had dimensions of 10–15 km × 30–40 km. Both the size of the dryland and the sediment types are comparable to those of the Battonya High in the E Pannonian Basin (Magyar et al. 2004).

Within the Endrőd Fm. most of the Danitzpuszta section (up to D217) represents the Tótkomlós Calcareous marl Member. The sand pit is a rare surface occurrence of this unit known from thousands of wells in the subsurface of the Pannonian Basin. The few other studied outcrops of these deposits are located in Croatia (e.g., Našice, Kovačić et al.

2017, Sebe et al. 2020) and Serbia (Beočin, ter Borgh et al. 2013). The uppermost 6–7 metres, between layers D218 and D226, show a transition towards the overlying sands, with the increase of siliciclastic compounds and a decrease of carbonate content.

It must also be noted that the outcrop offers a special detailed view on the Sarmatian/Pannonian boundary. The position of this boundary is not obvious, as there are discrepancies between the major changes in the different fossil groups. This highlights an interpretation pitfall, even if almost all beds are investigated. In the mollusk fauna the first appearance of Pannonian lymnocardiids (*Lymnocardium praeponticum*) coincides with the first appearance of Lake Pannon ostracods in layer 35 (Botka et al. 2021, Csoma et al. 2021). However, Sarmatian-type cardiids remain dominant in layers 35–33, and they only disappear completely in bed 12. In the nannoplankton record, the dominance of endemic Lake Pannon taxa only starts in layer 20 (Ćorić 2021), close to the position where calcareous marl becomes dominant against the limestone-marl-clay cycles (layer 22). Discrepancies between the positions of the Sarmatian/Pannonian boundary based on different fossil groups – typically mollusks, foraminifers and ostracods, organic walled microplankton and calcareous nannoplankton – have also been reported from other localities (Halmai et al. 1982, Jámbor et al. 1987, Kókay et al. 1991, Hámor 1992), in a transitional interval of mostly calcareous marls, previously defined as the Zala Member of the Endrőd Formation (Jámbor 1980). This boundary question definitely needs further investigations.

The lowermost part of the calcareous marls (beds D35–D12) contains a mollusk assemblage of the *Lymnocardium praeponticum* sublittoral mollusk biozone (~11.62–11.45 Ma), the lowest zone of Lake Pannon sediments (Botka et al. 2021). Upward the fauna changes into an assemblage representing the *Congeria banatica* profundal mollusk biozone (~11.45–9.6 Ma) without a sharp change in lithology. Within this sediment interval, dinocysts in beds D3–D1 indicate *Pontiadinium pecsvaradensis* dinoflagellate Zone (*ca*. 10.8 to 10.6 Ma) (Krizmanić et al. 2021). The transitional silt-sand unit (D218–226) belongs to the *Lymnocardium schedelianum* sublittoral mollusk Zone (11–10.2 Ma). Within this zone, the morphologies of some bivalve species (e.g., *Lymnocardium schedelianum*, *L.* aff. *boeckhi*) and interregional correlation of the mollusk fauna place the top of the unit between 10.5 and 10.2 Ma (Botka et al. 2021).

Kálla Member of the Békés Formation (Pannonian)

Coarse, gravelly sands from layer 227 upwards were derived from a local source area in the Mecsek Mts. The total thickness of clastic strata exposed in the sand pit exceeds 100 m and may attain 140 m. This unit has been classified into the Kálla Formation (now a member of the Békés Formation) because of its local source. However, the sedimentary features, the large-scale depositional architecture, the depositional system or its stratigraphic position is different from the typical occurrences of the Kálla Member (cf., Sztanó et al. 2010, Csillag et al. 2010, Tóth et al. 2010, Magyar et al. 2016).

Any shallow-water setting with wave or current activity can be excluded based on the absence of bedforms indicative for traction currents. Instead, the relatively large bed thickness (or amalgamation), the parallel bedding planes and the occasional occurrence of graded beds points to large-volume gravity-driven flows. No slide or slump structures indicating a sloping topography at the site of accumulation were observed. Initially, the depositional depth might have been as large as for the marl, providing enough space for the deposition of at least 100–140 m of coarse clastics. Most likely fans or fan deltas could have developed near the source area (the Mecsek Mts), while the studied coarse sands formed as deep-water lobe deposits in their distal continuation. Finally, typical Kálla beds and other members of the Békés Formation are transgressive deposits, being covered by open lacustrine marls, but the strata in Danitzpuszta reflect an opposite trend. Flooding of the area is indicated by the underlying calcareous marl, while the appearance of the coarse clastics reflects regressive processes. The opening of new sediment sources and/or transport routes may have been driven by a local base level fall. The coeval coastal to nearshore deposits, i.e., coarse-grained deltas representing the typical Kálla beds, may be eroded by now, hence the succession can be regarded as an unusual, distal variety of the Kálla Member. The trigger for sand deposition remains unclear. The most obvious candidate to initiate erosion and clastic input in the area is the start of compression and thus the uplift of the mountains. However, it seems to post-date the onset of sand accumulation (Sebe 2021). An increasingly humid climate and the corresponding higher erosion potential has been reconstructed for 9.7–9.2 Ma for the Pannonian Basin (Magyar 2010), at least 0.5 Ma after the onset of sand deposition. The re-arrangement of sediment pathways on the lakefloor due to local tectonic activity might have been a triggering factor; however, no evidence is available at the moment to prove this.

The age of sand deposition is constrained partly by the underlying marls (see above). The mollusk assemblages collected from all parts of the gravelly sands, including those above the unconformity, are identical. They belong to the upper part of the *Lymnocardium conjungens* littoral mollusk biozone (9.6–11.0 Ma); within this interval the sands were probably deposited between 10.2 and 10.0 Ma (Botka et al. 2021).

Evolution history

The Danitzpuszta succession records a complex chain of events from the Badenian Paratethys to Lake Pannon. The succession represents an area in the vicinity of an island surrounded by shallow sea, where calcareous marls and shallow water carbonate sands accumulated during the late Badenian. When fully marine deposition ceased, the area became either subaerially exposed or deposition continued in brackish waters sometime between the latest Badenian and the late Sarmatian, probably with a topographic relief allowing the formation of fans. In the late Sarmatian the area became flooded again. Sedimentation took place in sublittoral brackish water, while the sediment sources were distal or topographically limited. Environmental conditions hardly changed when the Paratethys was replaced by Lake Pannon, but a gradual deepening took place and the deposition of calcareous marls became dominant. The overlying siltstone and sandstone beds indicate a gradual increase of siliciclastic input, revealing the exposure of a nearby source area or a re-arrangement of the sediment feeder system. The accumulation of coarse, pebbly sands commenced from gravity flows on deep-water portions of fan deltas.

Conclusions

The sand pit and the trench in Pécs-Danitzpuszta exposed a continuous sedimentary succession with a true thickness of ca. 220 metres. They offer an exceptional outcrop of late Badenian to early Pannonian marine, terrestrial and lacustrine deposits and give information on more than 4 Ma of changing paleoenvironments in and near the Central Paratethys sea and Lake Pannon. The outcrop provided a surface occurrence of a continuous Sarmatian/Pannonian boundary section, where the deposition appears to have been fairly continuous, and micro- and macrofauna need to be used to locate the boundary. However, there are discrepancies between the potential boundaries indicated by molluscs, foraminifers, ostracods and calcareous nannoplankton, calling attention to the fact that differentiating Sarmatian and Pannonian deposits formed in similar environments can be problematic in the field. The site is also a unique, well-accessible surface exposure of the deep lacustrine Endrőd Marl that formed in a paleogeographic setting analogous to many of its subsurface occurrences.

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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 nannofosszíliák Pécs-Danitzpuszta középső/felső miocén képződményeiből

Összefoglalás

A pécs-danitzpusztai homokbányában feltárt középső és késő miocén (szarmata és pannóniai) rétegsor 109 mintáján végeztük el mészvázú nannofosszíliák mennyiségi vizsgálatát. A feltárás alsó része, amely a szarmatába sorolható, alacsony diverzitású, normál tengeri együttest tartalmaz, melyben a *Calcidiscus leptoporus*, *Reticulofenestra pseudoumbilicus*, *Sphenolithus moriformis* és a *Syracosphaera* spp. voltak az uralkodó formák, és amelyben a Didemnidae családba tartozó előgerinchúros zsákállatok (aszcídiák) tűi (*Perforocalcinela fusiformis*) is előfordulnak. A középső és késő miocén határa, azaz a szarmata/pannóniai határ a normál tengeri mészvázú nannofosszíliák utolsó előfordulásánál húzható meg. A feltárás felső részében az endemikus *Isolithus* spp. monospecifikus előfordulásával, illetve aszcídiákkal 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 nannofosszília-együttesek drasztikus változását a szarmata/pannóniai határon a Középső-Paratethys lefűződésének következtében kialakult környezeti stressz okozta.

Kulcsszavak: szarmata, pannóniai, Pannon-tó, mészvázú 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 pseudoumbilicus, 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 uppert 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

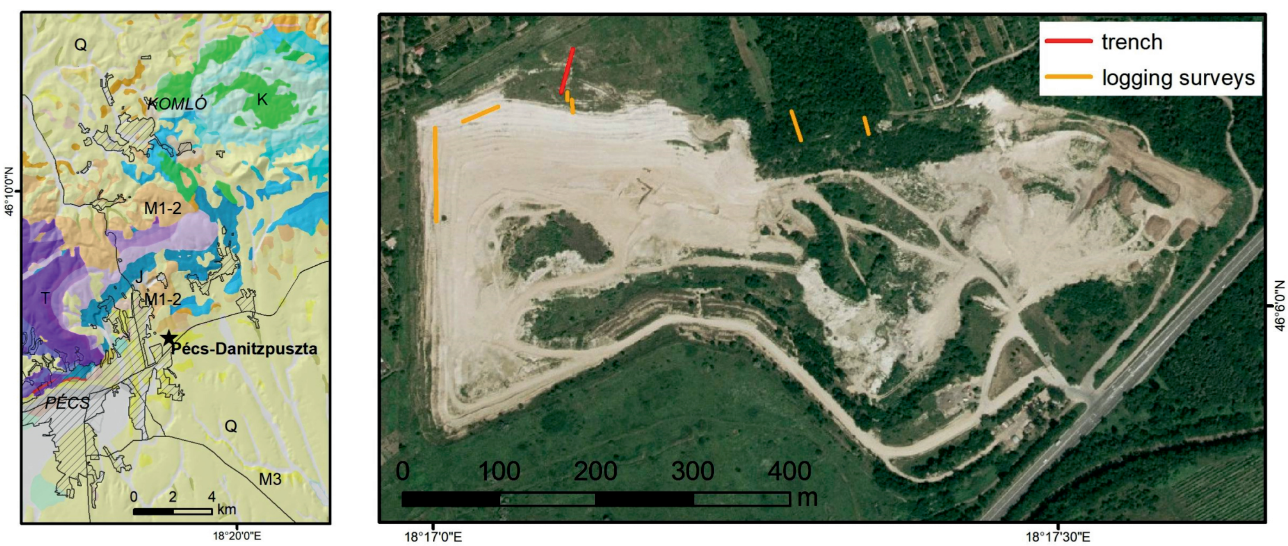


Figure 1. Location of the studied sand pit and the sampled sections

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 I* 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 *Noelaerhabus* 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 bigelowi* 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

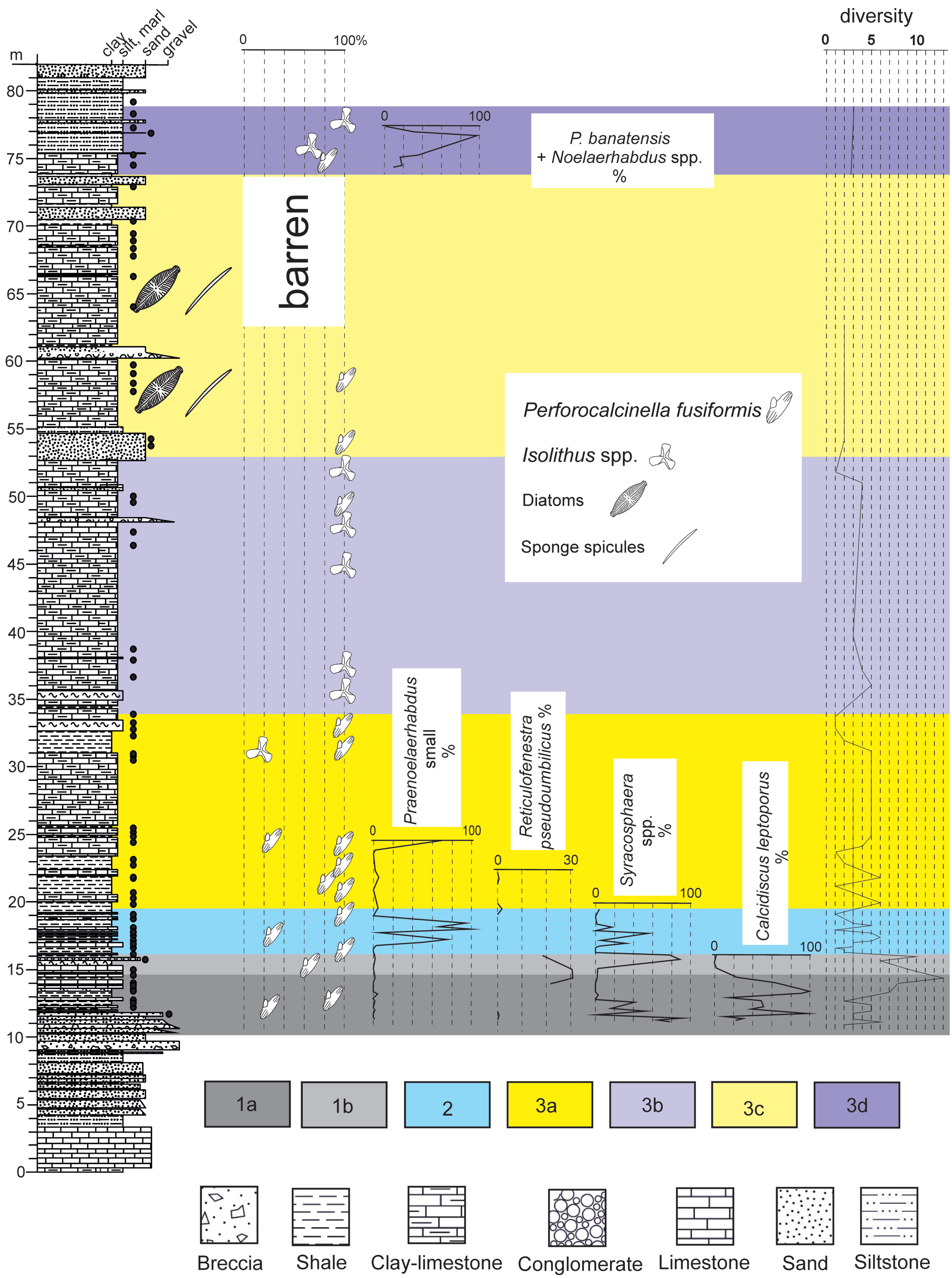


Figure 2. Sample locations and the subdivision of the Pécs-Danitzpuszta section based on calcareous nannofossils (clusters resulting from WARD's method – see *Figure 4*)

2. ábra. *A pécs-danitzpusztai szelvény tagolása mészvázú nannofosszíliák 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

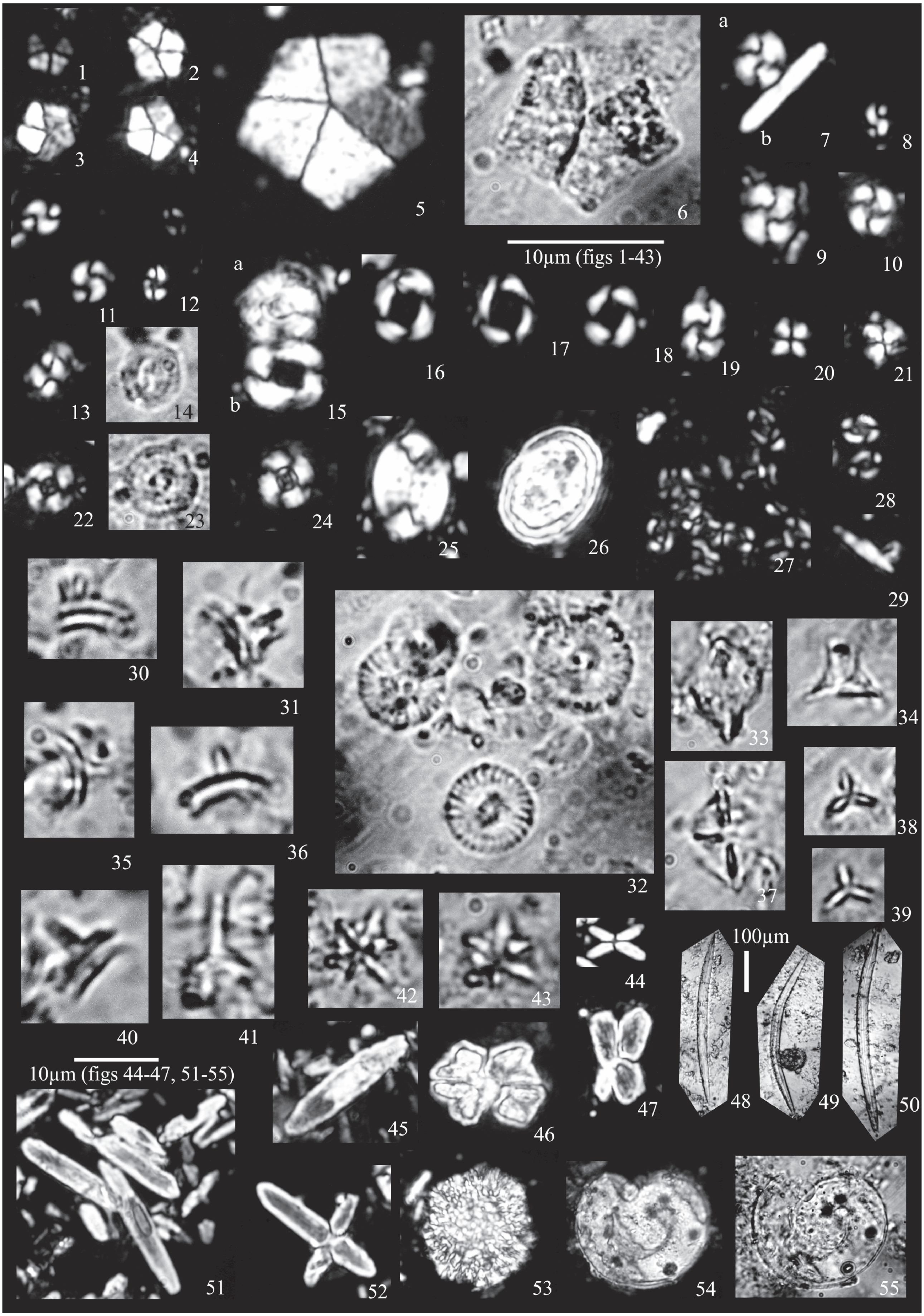
I. tábla. *Az autochton mészvázú nannofosszíliák eloszlása a pécs-danitzpusztai szelvény mintáiban (ábécésorrendben)*

Species	Specimen number	Number of samples
Acanthoica cohenii (JERKOVIĆ, 1971) AUBRY, 1999	42	5
Bekelithella echinata BÓNA & GÁL, 1985	11	5
Braarudosphaera bigelowii (GRAN & BRAARUD 1935) DEFLANDRE, 1947	2	2
Braarudosphaera bigelowi subsp. *parvula* STRADNER, 1960	13	5
Calcidiscus leptoporus (MURRAY & BLACKMAN, 1898) LOEBLICH & TAPPAN, 1978	1777	15
Calcidiscus pataecus (GARTNER, 1967) DE KAENEL & VILLA, 1996	2	2
Calciosolenia brasiliensis (LOHMANN, 1919) YOUNG in YOUNG et al., 2003	7	2
Catinaster cf. *calyculus* 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 pavelici ĆORIĆ , 2008	2582	25
Isolithus semenenko LYUL'EVA, 1989	2092	22
Isolithus spp.	89	13
Lithostromation perdurum DEFLANDRE, 1942	1	1
Praenoelaerhabdus banatensis MIHAJLOVIĆ 1993, *Noelaerhabdus* spp.	625	7
Praenoelaerhabdus small (<3 μm)	1475	22
Perforocalcinella fusiformis BÓNA 1964	7691	49
Pontosphaera discopora SCHILLER, 1925	1	1
Pontosphaera multipora (KAMPTNER, 1948 ex DEFLANDRE in DEFLANDRE & FERT, 1954) ROTH, 1970	2	2
Pontoshaera sp.	2	2
Reticulofenestra haqii 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 moriformis (BRÖNNIMANN & STRADNER, 1960) BRAMLETTE & WILCOXON, 1967	144	5
Sphenolithus sp.	2	1
Syracosphaera spp.	1945	24
Thoracosphaera 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-


10µm (figs 1-43)
100µm
10µm (figs 44-47, 51-55)

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. pseudoumbilicus* 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 nannofosszíliák a pécs-danitzpusztai szelvényből*

1–4. *Braarudosphaera bigelowi* 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 pseudoumbilicus* (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* ĆORIĆ, 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* LULJEWA, 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. pseudoumbilicus* and *Praenoelorhabdus* small. This cluster contains samples from Subintervals 1a (11 samples), 1b (2 samples), Interval 2 (6 samples), Subinterval 3d (with *B. echinatta, 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 leptoroporus*, *Reticulofenestra pseudoumbilicus*, *Syracosphaera* spp. and *Praenoelaerhabdus* small as

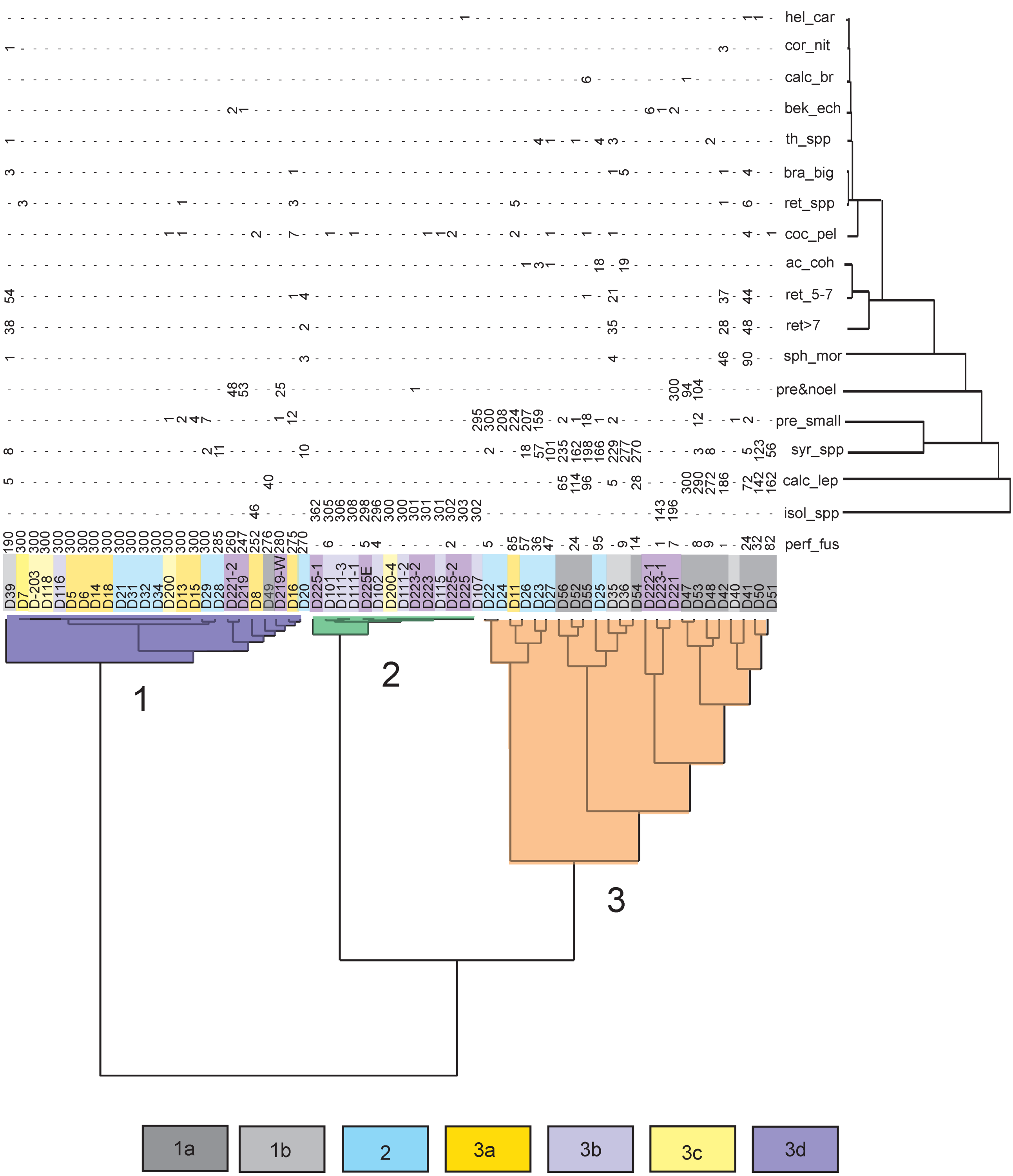


Figure 4. Dendrogram of sample clusters resulting from WARD's method

4. ábra. *A vizsgált minták dendrogramja (WARD módszere alapján)*

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)

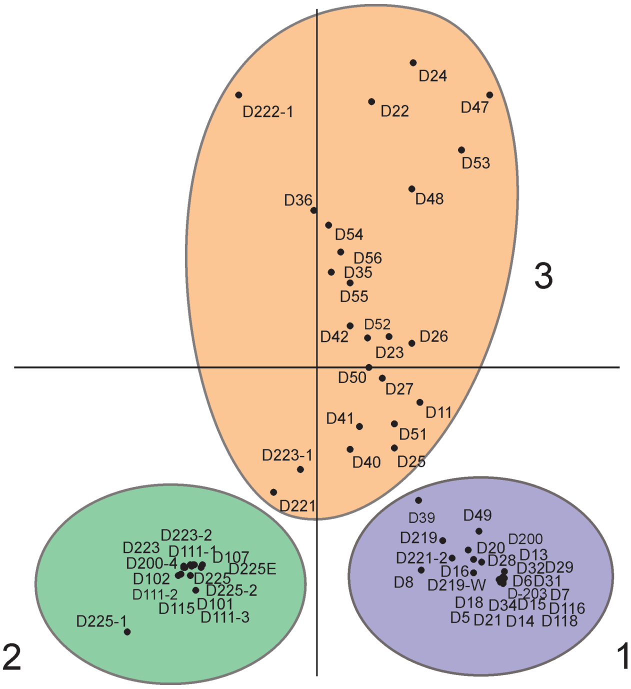


Figure 5. Nonmetrical Multidimensional Scaling (nMDS) of samples

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 palaeoconditions 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. *pseudoumbilicus* (>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 (Dubrovicza) and Romania (Kevna Bremia) 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 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 jerkovici* and only sporadic occurrences of normal marine species; thus, it can be attributed to the Pannonian. Mărunţeanu (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 Mărunţeanu 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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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

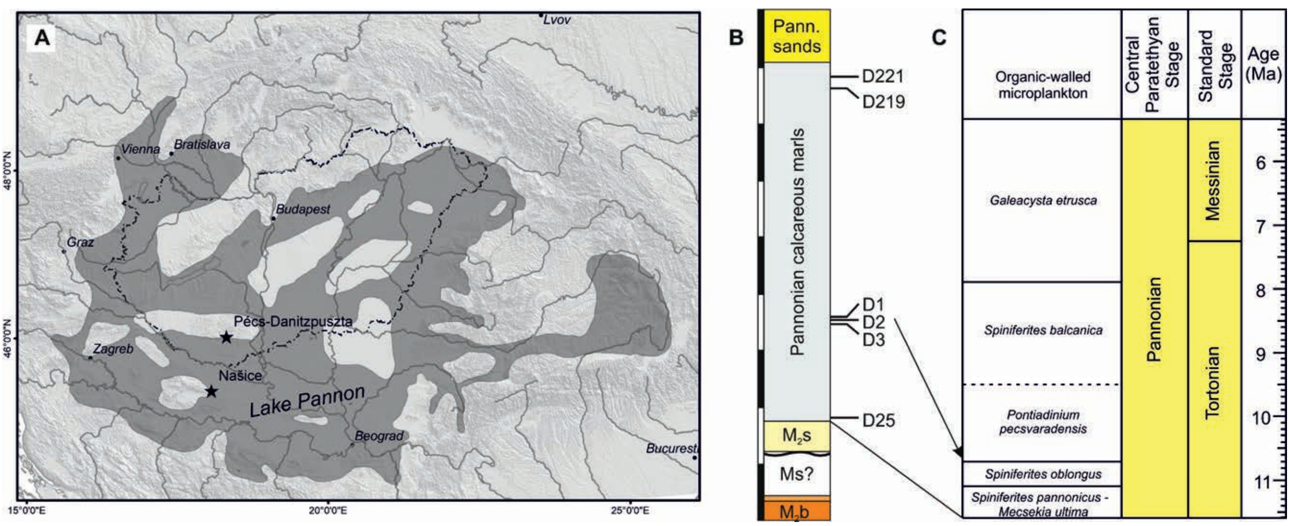

Figure 1. Location of the study area within the Pannonian Basin and stratigraphical position of the palynological samples from Pécs-Danitzpuszta. A: Location of the sand pit; dark patch indicates extent of Lake Pannon at 10.8 Ma after MAGYAR et al. (1999a). B: Simplified stratigraphic log of the sand 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

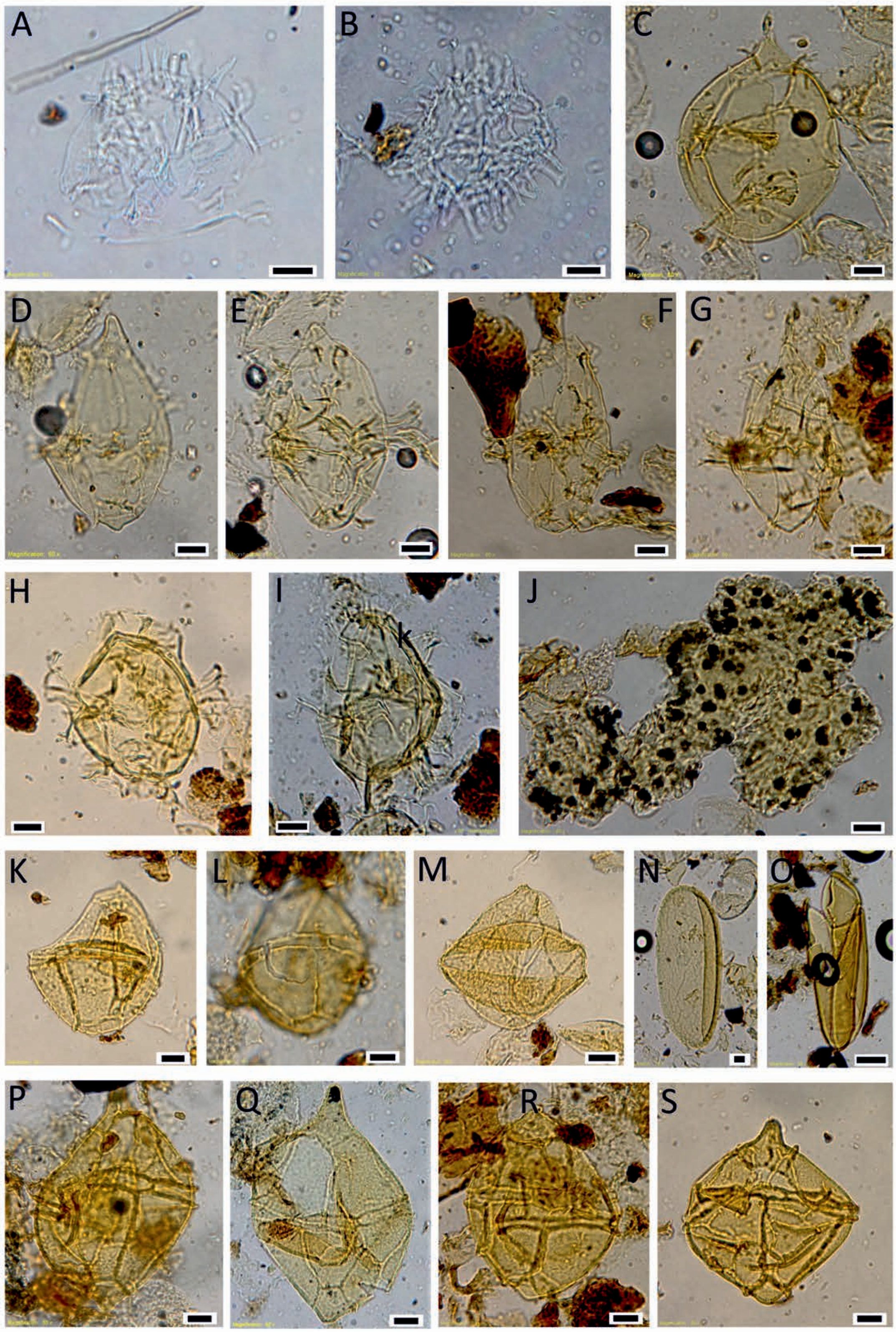

Figure 2. Selected Pannonian dinoflagellate cysts and green algae from the Pécs-Danitzpuszta outcrop. The black scale bars represent 10 μm for each figure.

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*).

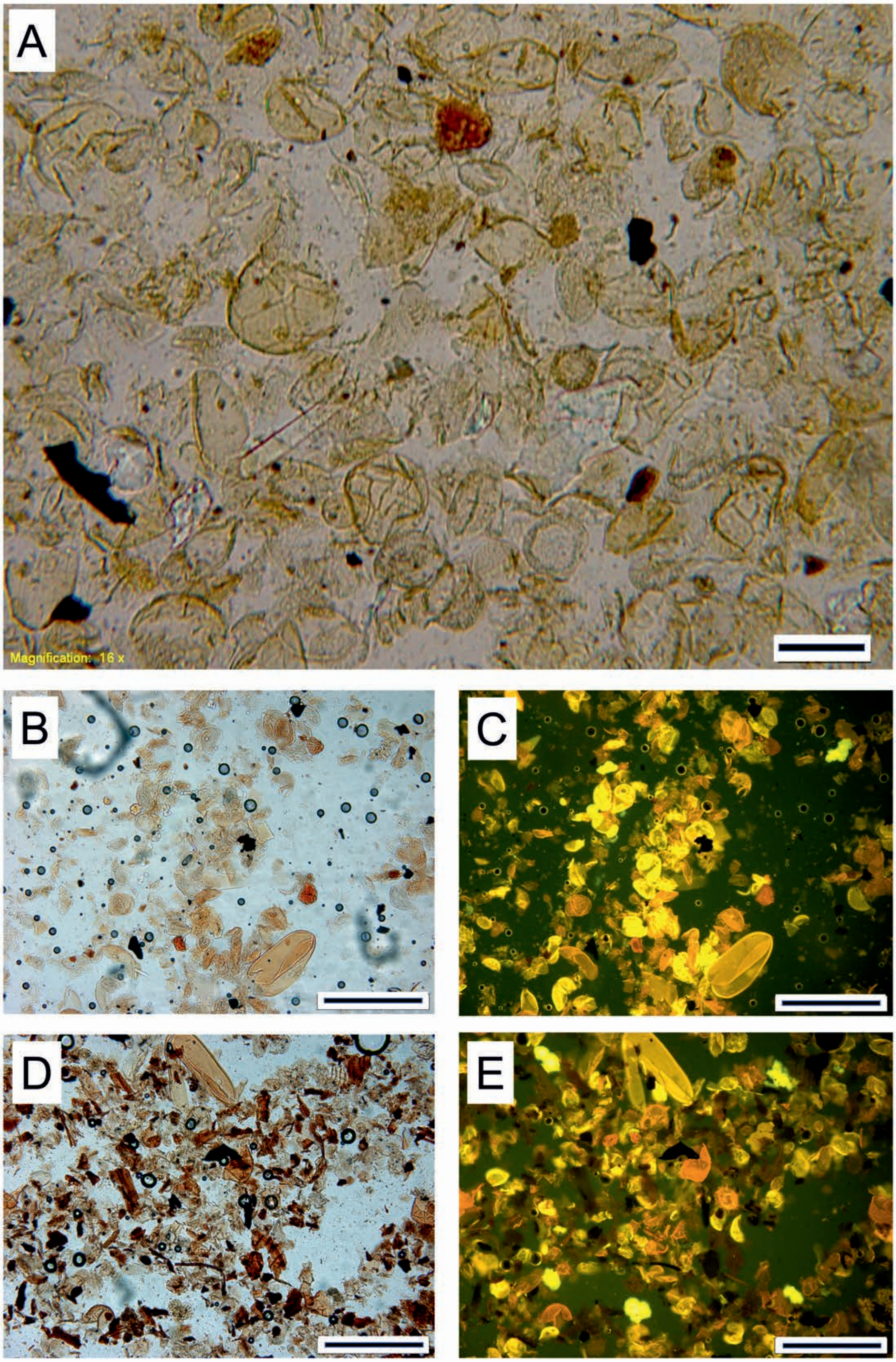

Figure 3. Palynofacies of the samples. A: Very rich macerate from D2 with predominance of amorphous organic matter (ca. 50%) and liptinite kerogen components (ca. 40%); scale bar 50 μm; B: Palynofacies with abundant sedimentary organic matter in D219 in transmitted light; scale bar 200 μm; C: Same in 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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Various marginal marine environments in the Central Paratethys: Late Badenian and Sarmatian (middle Miocene) marine and non-marine microfossils from Pécs-Danitzpuszta, southern Hungary

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Késő badeni és szarmata (középső miocén) mikrofosszíliák Pécs-Danitzpusztáról

Összefoglalás

A Középső-Paratethys középső miocén foraminifera és kagylósrák együttesei általában stabil normál tengeri viszonyokat tükröznek a badeniben, míg térben és időben változatosabb, mozaikos környezeteket a szarmatában. A pécs-danitzpusztai homokbányában kiásott kutatóárokban 17 méter vastagságban tárult fel a tektonikusan kibillentett középső miocén rétegsor, amely jelentős környezeti változásokról tanúskodik a késő badeni és a pannóniai között. A rétegsor alján normál tengeri, sekélyvízi, meleg, jól szellőzött, aránylag nagy energiájú, mikrobaszőnyeges aljzatú környezetre utalnak a mészkő-, márgarétegek mikrofosszíliái. A foraminiferák alapján ezek a rétegek a késő badeniben (13,82 és 12,65 millió év között) rakódtak le. A szelvény középső szakaszán a tengeri rétegeket mikrofosszília-mentes, gravitációsan áthalmozott durva homok-breccsa, aleurolit váltakozásából álló sorozat követi, amelyben valószínűleg szárazföldi kitettségre utaló gyökérbekérgezéseket is találtunk. A következő tengerelöntés éles kőzettani váltás mellett a szelvény felső részéből kinyert mikrofosszíliák alapján a késő szarmatában történt, kb. 12 és 11,6 millió év között. Ezek a rétegek a felső szarmata *Porosononion granosum* zónát (foraminiferák) és *Aurila notata* zónát (kagylósrákok) képviselik. Az együttesek kizárólag tágtűrésű fajokból állnak, és változó só-, oxigén- és tápanyagtartalmú, növényzettel rendelkező, brakkvízi tengeri környezetet jeleznek. Az 5 m vastag felső szarmata egységben néhány rétegből, amelyek együttesen egy métert képviselnek, édesvízi vagy legfeljebb oligohalin kagylósrákfauna és kivételesen tág sótűrésű foraminiferák kerültek elő. Az együttesek megváltozását nem kíséri jelentős litológiai váltás, nincs jele megnövekedett szárazföldi eredetű behordásnak, amely egy közeli folyótorkolatot jelezne. Sem a késő szarmata geomorfológiai viszonyok, sem a kőzetminőség nem utal a tengertől részben elzárt környezet (lagúna, parti mocsár) kialakulására. A helyi viszonyokon túlmutató tényezők (pl. az éghajlat változása) nagyobb területen is megfigyelhető lenne, ilyen adatokkal azonban nem rendelkezünk. A tágtűrésű foraminiferák és édesvízi-oligohalin kagylósrákok megjelenése mindenesetre helyben vagy a közelben élő közösségre utal, és így a helyi alacsony (5–10 ‰) sótartalmat jelzi. Ilyen közösséget más szarmata szelvényből a Középső-Paratethys területén eddig nem ismertünk. A szelvény tetején a foraminiferák hirtelen eltűnése és ezzel egy időben a kagylósrákfauna teljes kicserélődése a szarmata és pannóniai emeletek határát jelöli ki (11,6 millió év).

Kulcsszavak: Középső-Paratethys, Mecsek, foraminifera, kagylósrák, taxonómia, biosztratigráfia, paleoökológia

Abstract

The middle Miocene foraminifera and ostracod record of the Central Paratethys usually reflects stable normal marine depositional environments for the Badenian and more patchy, less stable restricted marine environments for the Sarmatian. A 17 m thick outcrop at Pécs-Danitzpuszta, Mecsek Mts, SW Hungary exposed an upper Badenian to Pannonian succession where foraminifers and ostracods document significant environmental changes. The basal layers of the section contain micro- and macrofossils indicating normal marine, shallow, warm, well-oxygenated habitat with relatively high-energy conditions and algal vegetation on the bottom, and represent the upper Badenian (13.82 to 12.65 Ma). The marine deposits are followed by coarse sandstone, breccia and siltstone layers barren of microfossils but containing rhizoliths. The sediments were probably subaerially exposed for some time. The following marine inundation, marked by the appearance of clays and limestones as well as fossils, was dated to the late Sarmatian (ca. 12 to 11.6 Ma) on the basis of the restricted marine microfossil assemblages from the upper part of the succession (*Porosononion granosum* Zone, *Aurila notata* Zone). This community is characterized by exclusively eurytopic forms indicating an unstable and vegetated marginal marine environment with fluctuations in salinity, as well as oxygen and food availability. Within the 5 m thick upper Sarmatian marine interval, a unique fresh- to oligohaline fauna characterizes a few layers in less than 1 m thickness. This fauna consists of highly euryhaline foraminifera and freshwater to oligohaline ostracod assemblages, indicating a temporary salinity reduction to 5–10 ‰. No similar freshwater fauna has been reported from the Sarmatian of the Central Partethys so far. The eventual disappearance of the foraminifera from the paleontological record coupled with a complete turnover in the ostracod fauna indicates the transition from the marginal marine Sarmatian Sea to the brackish Lake Pannon, marking the Sarmatian/Pannonian boundary (11.6 Ma).

Keywords: Central Paratethys, Mecsek Mts, Foraminifera, Ostracoda, taxonomy, biostratigraphy, paleoecology

Introduction

The distribution of marine microorganisms in an epicontinental sea is driven by the local and regional changes of environmental conditions such as salinity, water temperature, oxygen-level, food availability, substrates, and water depth. These environmental conditions and the evolution of the microfauna were controlled by the openings and closures of the seaways towards the adjacent seas and the world ocean in the Paratethys, an epicontinental sea of central and eastern Europe during the Oligocene and Miocene (RÖGL 1998, POPOV et al. 2004). The connection toward the Mediterranean Sea was terminated due to the uplift of the Dinarides at the Badenian/Sarmatian boundary, triggering an endemic evolution of the marine faunas in the Paratethys (e.g., PALCU et al. 2015). The seaway towards the Indopacific was closed in the late Sarmatian, eliminating the last Indo-Pacific planktonic elements that were detected in the Transylvanian Basin (FILIPESCU & SILYE 2008). All of these changes might have influenced the biota at the study area in SW Hungary.

The present study focuses on the taxonomy and paleoecological and biostratigraphical interpretation of foraminifer and ostracod communities from a middle Miocene succession exposed in an exploratory trench in the Pécs-Danitzpuszta sand pit, Mecsek Mts, SW Hungary. Earlier studies of middle Miocene foraminifera in Hungary (BÁLDI 1999, 2006; BÁLDI et al. 2002; BÁLDI 2006; GÖRÖG 1992; KORECZ-LAKY 1964, 1965, 1968, 1973, 1982; KORECZ-LAKY & NAGY-GELLAI 1985; TÓTH & GÖRÖG 2008) showed the wide distribution of the normal marine Badenian and restricted marine (brackish and hypersaline) Sarmatian faunas, which are well-known in the entire Central Paratethys. The study of Sarmatian ostracods resulted in a biostratigraphic system for the entire Pannonian Basin (TÓTH 2004, 2008), whereas Badenian ostracods from Hungary have not been studied yet. By investigating the Pécs-Danitzpuszta micropaleontological record, we give the first documentation of Badenian ostracods from Hungary and also describe a so far unknown upper Sarmatian non-marine ostracod assemblage.

Geological setting

The Pécs-Danitzpuszta sand pit lies in the eastern outskirts of Pécs, at the foot of the Mecsek Mts (*Figure 1*). The region north of the sand pit is built up of Mesozoic rocks, mostly Lower Jurassic marls and sandstones, overlain by a succession of lower to middle Miocene terrestrial clastics and middle Miocene marine clastics and carbonates (SEBE et al. 2015, 2019; SEBE et al. 2021). These are capped by upper

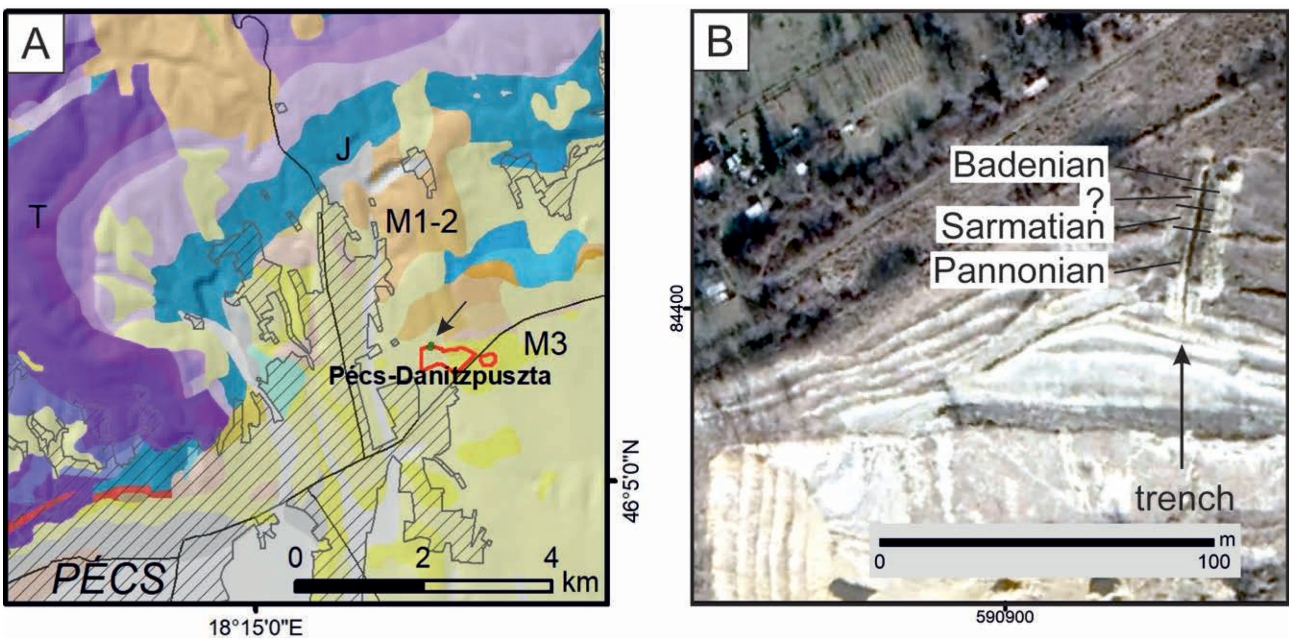


Figure 1. Location of the Pécs-Danitzpuszta sand pit (A) and the exploratory trench (B)
1. ábra. *A pécs-danitzpusztai homokbánya (A) és a kutatóárok (B) elhelyezkedése*

Miocene (Pannonian) marls and sands, exposed in many outcrops around the Mecsek. The boundary between Sarmatian and Pannonian deposits is continuous in (sub)basin centres, while they are separated by an unconformity with increasing hiatus towards the margins. Similar, but several km thick Neogene successions were reported from the Drava Basin to the south and southwest (SAFTIĆ et al. 2003; SEBE et al. 2020) reflecting the opening and evolution of the Pannonian Basin, flooding by the Paratethys sea and later by the brackish Lake Pannon.

Material and methods

Studied section of Pécs-Danitzpuszta sand pit

The sand pit exposes strongly tilted upper Miocene (Pannonian) calcareous marls and sands. In 2018, an exploratory trench was excavated in the northwestern part of the sand pit across the tilted beds that underlie the exposed Pannonian marl (*Figure 1*). The trench revealed the lowermost part of the Pannonian succession and the underlying Sarmatian and Badenian deposits. Due to tectonic deformation, most of the exposed succession is overturned, and the stratigraphically lowest (oldest) layers are located in the north (SEBE 2021). Overturned beds become steeper towards the south (upsection) and they are almost vertical close to the southern end of the trench. The oldest part of the studied section is represented by yellowish white calcareous marl (Layer D72) in the northern end of the trench (*Figures 2, 3*). It contains a typical Badenian mollusk fauna and belongs to the Lajta Formation (SEBE et al. 2021, DULAI et al. 2021). D71 also shows features typical of the Lajta Limestones: it is a sandy limestone with corallinacean algae, echinoids, abundant molluscs, and sporadic fish remains (DULAI et al. 2021, SEBE et al. 2021, SZABÓ et al. 2021). The following beds (D70 to D57) did not provide stratigraphically valuable fossils; thus, their age is uncertain (*Figure 2*). These are unconformably overlain by a ca. 5 m thick unit of alternating thin clay, marl and limestone beds (layers D56–D36), identified as the Sarmatian Kozárd Formation based on its fossil content and lithology (SEBE et al. 2021).

Micropaleontological samples and methods

Fifteen middle Miocene samples from the trench were studied for their foraminiferal and ostracod content (*Figures 2, 3*). The samples derived from soft sediments (about 200 g of air-dried clayey, sandy and marly sediments) were processed with hydrogen-peroxide (10%). Hard limestones and calcareous marls were examined in thin sections, or the samples were treated by acetolysis following a protocol originally worked out by LETHIERS & CRASQUIN-SOLEAU (1988) to extract the isolated carbonate skeletal microfauna. The applied extraction methods and the frequency of the extracted fossil groups from the studied layers are summarized in *Figure 4*.

Thirteen samples yielded interpretable microfossil content; D57 and D69 were free of microfossils (*Appendix*). The microfossils were determinated using a Zeiss SteREO Discovery.V12 modular binocular stereo microscope in the Laboratory of MOL Plc., Budapest. Thin sections were prepared in the Laboratory of MOL Plc., Budapest and they were investigated with a Zeiss Axio Imager.A1 polarizing microscope. Microscopic images were taken by a Zeiss AxioCam MRc 5 camera, mounted on the Zeiss microscope, using the AxioVision 40×64 v.4.9.1.0 software. The SEM images were taken at the Botanical Department of the Hungarian Natural History Museum in Budapest.

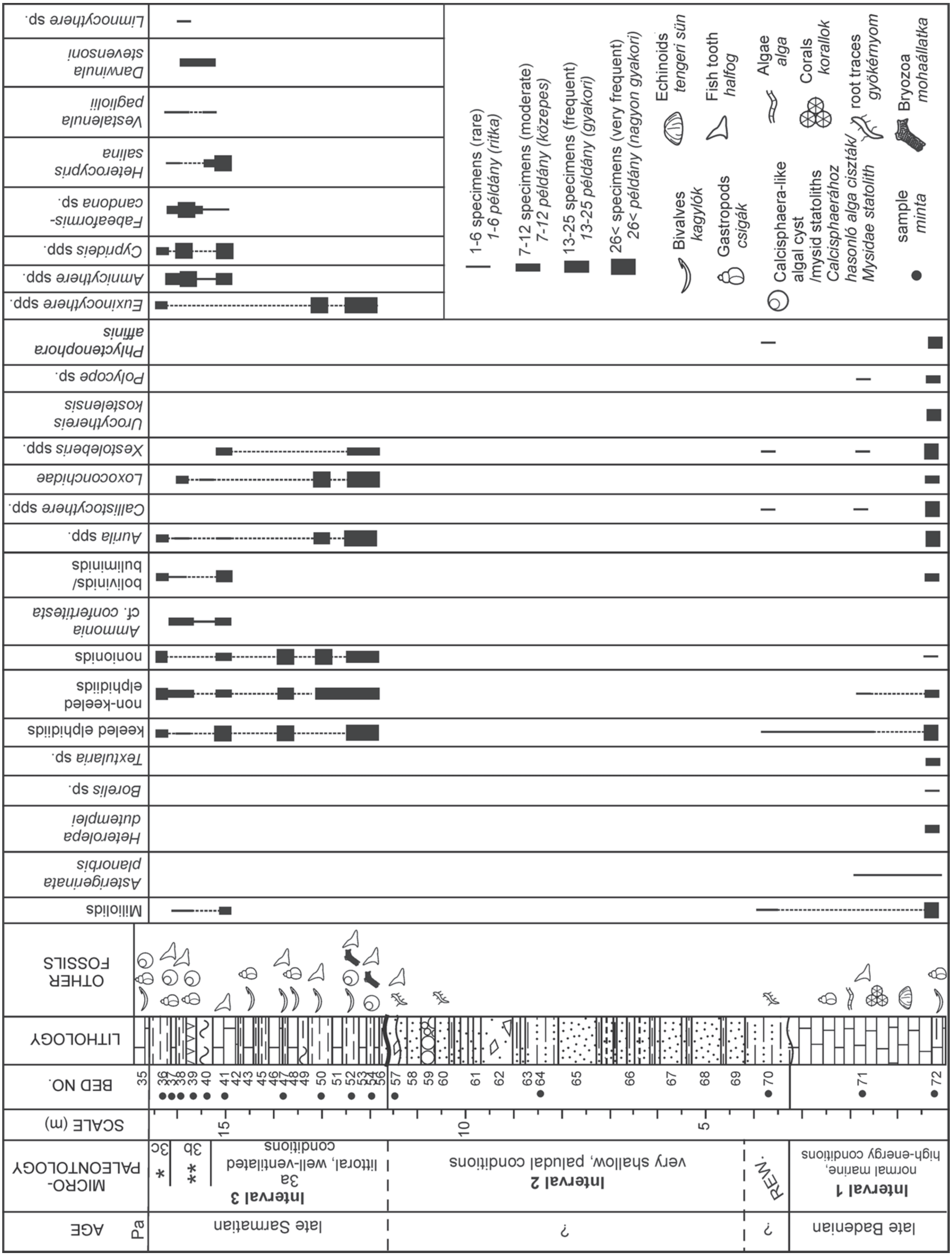
Results

Relatively diverse and well-preserved benthic foraminiferal and ostracod assemblages were found in the studied middle Miocene beds. Altogether, 30 foraminifer and 32 ostracod taxa were identified (see *Appendix* and *Digital annex*). The foraminifera specimens are moderately to well-preserved, except for layers D70 and D71, where they were probably affected by transport of the tests and/or diagenetic processes. The ostracod specimens are disarticulated valves in most cases; however, a few carapaces also occur. The ostracod material is characterized by both adult and juvenile forms.

The oldest layer (D72) yielded the most diverse and abundant microfossil assemblage. Twenty-one foraminifera and 11 ostracod taxa were identified (*Figure 2, Plate I*). The foraminiferal assemblage was dominated by eurytopic taxa of keeled elphidiids (*Elphidium aculeatum, E. crispum,* and *E. macellum*) and miliolids (*Borelis* sp., *Cycloforina contorta*, *Affinetrina ucrainica, Miliolinella selene,* and *Quinqueloculina hauerina*). The ostracod fauna is characterized by the dominance of marine neritic taxa, such as *Aurila cicatricosa, Callistocythere canaliculata,* and *Phlyctenophora arcuata. Urocythereis kostelensis*, *Loxoconcha punctatella, Loxocorniculina hastata, Xestoleberis dispar*, and *Polycope* sp. also occur in low abundance. Besides foraminifers and ostracods, sample D72 also yielded significant amounts of echinoderm skeletal and spike fragments.

The microfossil assemblages of layers D70 and D71 were similar to, but significantly poorer than, that of D72. Poor preservation of the carbonate skeletons allowed only genus level determination in most cases (*Xestoleberis* sp., *Callistocythere* sp., *Polycope* sp., and *Elphidium* sp.). Echinoderm fragments were also more sporadic than in sample D72. The microfossils of layer D70 are probably reworked based on the scarcity and poor preservation of the specimens, although a diagenetic effect cannot be excluded either.

The soft sediments of layers D54 to D41 yielded a less diverse (5–10 taxa), well-preserved foraminifer and ostracoda fauna (*Figure 2, Plates II–III*). Among the foraminifera, exclusively eurytopic forms (taxa with wide environmental tolerance) were present. Keeled elphidiids with an acute periphery, sometimes equipped with spines, were the most common (e.g., *Elphidium aculeatum*, *E. macellum*, *E. obtu-*


AGE
Pa
late Sarmatian
?
?
late Badenian
MICRO-PALEONTOLOGY
Interval 3
3a
littoral, well-ventilated conditions
3b
3c
Interval 2
very shallow, paludal conditions
REW.
Interval 1
normal marine, high-energy conditions
SCALE (m)
BED NO.
LITHOLOGY
OTHER FOSSILS
Miliolids
Asterigerinata planorbis
Heterolepa dutemplei
Borelis sp.
Textularia sp.
keeled elphidiids
non-keeled elphidiids
nonionids
Ammonia cf. confertitesta
bolivinids/buliminids
Aurila spp.
Callistocythere spp.
Loxoconchidae
Xestoleberis spp.
Urocythereis kostelensis
Polycope sp.
Phlyctenophora affinis
Euxinocythere spp.
Amnicythere spp.
Cyprideis spp.
Fabaeformis-candona sp.
Heterocypris salina
Vestalenula pagliolii
Darwinula stevensoni
Limnocythere sp.
1-6 specimens (rare)
1-6 példány (ritka)
7-12 specimens (moderate)
7-12 példány (közepes)
13-25 specimens (frequent)
13-25 példány (gyakori)
26< specimens (very frequent)
26< példány (nagyon gyakori)
Bivalves
kagylók
Echinoids
tengeri sün
Gastropods
csigák
Fish tooth
halfog
Calcisphaera-like algal cyst /mysid statoliths
Calcisphaerához hasonló alga ciszták/ Mysidae statolith
Algae
alga
Corals
korallok
root traces
gyökérnyom
sample
minta
Bryozoa
mohaállatka

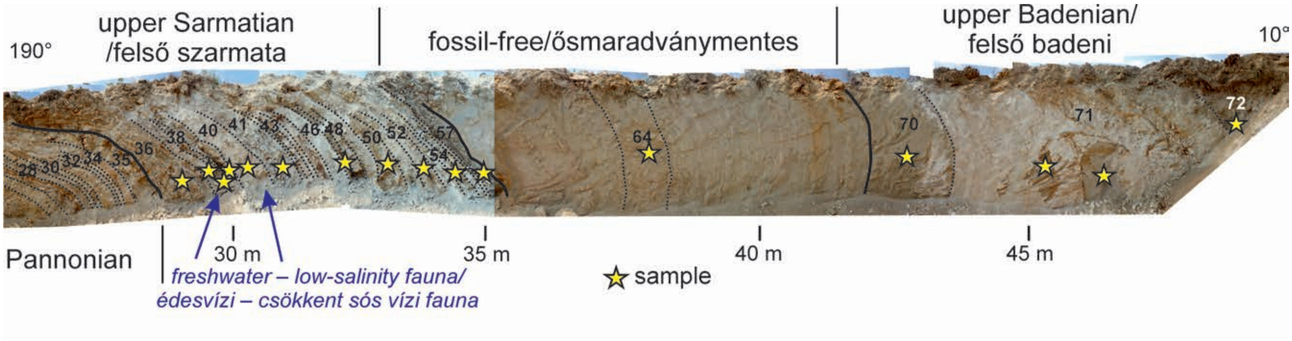


Figure 3. The northern part of the exploratory trench exposes overturned middle Miocene (D72 to D36) and stratigraphically overlying Pannonian (D35 to D28) layers. Sampling locations are indicated by yellow stars

3. ábra. *A kutatóárok északi része, mely az átbuktatott középső miocén (D72 – D26) és a pannóniai rétegeket (D35 – D28) tárja fel. A sárga csillag jelzi a mintavételi helyeket*

sum, and *E. crispum*). Among the non-keeled elphidiids, where the periphery of the tests is rounded or bluntly angular, specimens of *Porosononion granosum* were abundant. The ostracod fauna was characterized by different species of the genera *Aurila*, *Loxoconcha* and *Euxinocythere* (e.g., *Aurila notata, Loxoconcha kochi*, *L. porosa,* and *Euxinocythere [Euxinocythere] praebosqueti*). Specimens of *Xestoleberis tumida* are also present in the samples.

In layers D40 to D37, mainly specimens of the infaunal, non-keeled elphidiid *P. granosum* and *Ammonia* sp. were found (*Figure 2*). Beside the sporadic occurrence of marginal marine ostracods (e.g., *Loxoconcha porosa* and *Aurila* sp.), non-marine, freshwater to oligohaline ostracods, like *Fabaeformiscandona* sp., *Heterocypris salina, Darwinula stevensoni,* and *Vestalenula pagliolii* are present in the recovered assemblages.

Layer D36 is characterized by the dominance of eurytopic non-keeled elphidiids and nonionids and the representatives of leptocytherid *Euxinocythere* (*E. [E.] praebosqueti* and *E. [E.] naca*) (*Plate II*).

Discussion

Biostratigraphy

Benthic foraminifera are instrumental in the biostratigraphy of the middle Miocene sediments of the Central Paratethys, because the best index fossils, such as planktonic foraminifers and nannoplankton, are commonly missing from the fossil record, especially in the coastal regions (*Figure 5*).

← **Figure 2.** Sedimentary log of the middle Miocene part of the Pécs-Danitzpuszta succession, with sample locations, micropaleontological intervals and subintervals based on the stratigraphic distribution and ecological needs of the studied microfossil assemblages and the distribution of the paleoecologically important foraminifer and ostracod taxa and morphogroups in the samples
Abbreviation: Pa= Pannonian

← ***2. ábra.*** *A pécs-danitzpusztai homokbányában kiásott kutatóárok középső miocén szakaszának szelvénye a vizsgált minták feltüntetésével, a mikrofauna biosztratigráfiai és paleoökológiai értékelése alapján elkülönített intervallumokkal, valamint a környezetjelzés szempontjából fontos foraminifera és ostracoda taxonok, illetve morfocsoportok megoszlásával*
Rövidítés: Pa= pannóniai

A commonly used threefold subdivision of the Badenian in the Pannonian, Vienna and Danube basins is partly based on the composition of benthic foraminifers reflecting distinct paleoenvironmental changes (Papp et al. 1978). The lower Badenian is represented by the "Lagenidae Zone," the middle Badenian by the "*Spiroplectammina* Zone," and the upper Badenian by the "*Bulimina*/*Bolivina* Zone" (Grill 1943, Papp et al. 1978). Sarmatian sediments of the Pannonian, Vienna and Danube basins can be divided to four benthic foraminiferal zones: *Anomalinoides dividens*, *Elphidium reginum*, and *Elphidium hauerinum* Zones in the lower Sarmatian, and *Porosononion granosum* Zone in the upper Sarmatian (Grill 1943, Jiřiček 1972, Papp & Seneš 1974). For the Sarmatian of the Pannonian Basin, Tóth (2009) proposed a two-fold ostracod zonation: *Cytheridea hungarica-Aurila mehesi* Zone for the lower Sarmatian and *Aurila notata* Zone for the upper Sarmatian.

Layer D72 belongs to the upper Badenian based on the co-eval occurrence of *Pyrgo subsphaerica* (upper Badenian to recent) and *Miliolinella selene* (Badenian) among the foraminifera (Łuczkowska 1974). Some ostracods in these layers, such as *Urocythereis kostelensis* and *Phlyctenophora affinis,* are restricted to the Badenian (Gross & Piller 2006). Although the microfauna is dominated by eurytopic forms, normal marine taxa (e.g., *Callistocythere canaliculata* and *Heterolepa dutemplei*) also occur in these samples; they disappeared from the Central Paratethys at the end of the Badenian. Thus, the microfossil assemblages of layers D72 to D70 indicate late Badenian age, equivalent of the "*Bulimina*/*Bolivina* Zone" (13.82 to 12.65 Ma, according to Hohenegger et al. 2014 and Raffi et al. 2020), which correlates with the standard nannoplankton Zone NN6 (Rögl et al. 2008).

The presence of *Aurila notata* in layers D54 to D36 suggests correlation with the *Aurila notata* Zone (ca. 12 to 11.6 Ma). Several other taxa, such as *Euxinocythere* (*E.*) *praebosqueti, E.* (*E.*) *naca, Loxoconcha kochi* are also restricted to the upper Sarmatian in the Pannonian Basin (Tóth 2009). The foraminiferal assemblages are characterized by a great abundance of *Porosononion granosum* in almost all samples, indicating the *Porosononion granosum* Zone. This cor-

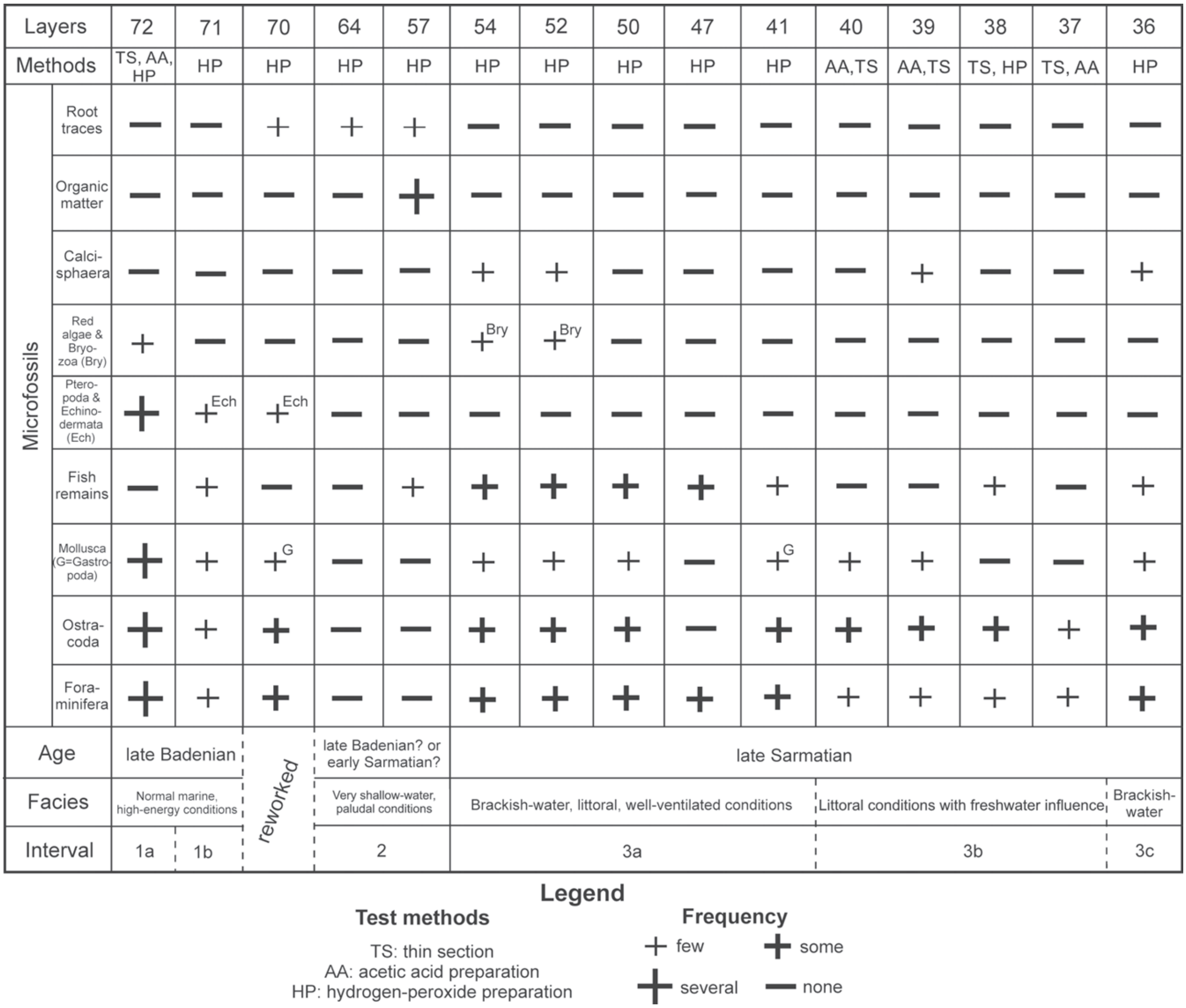


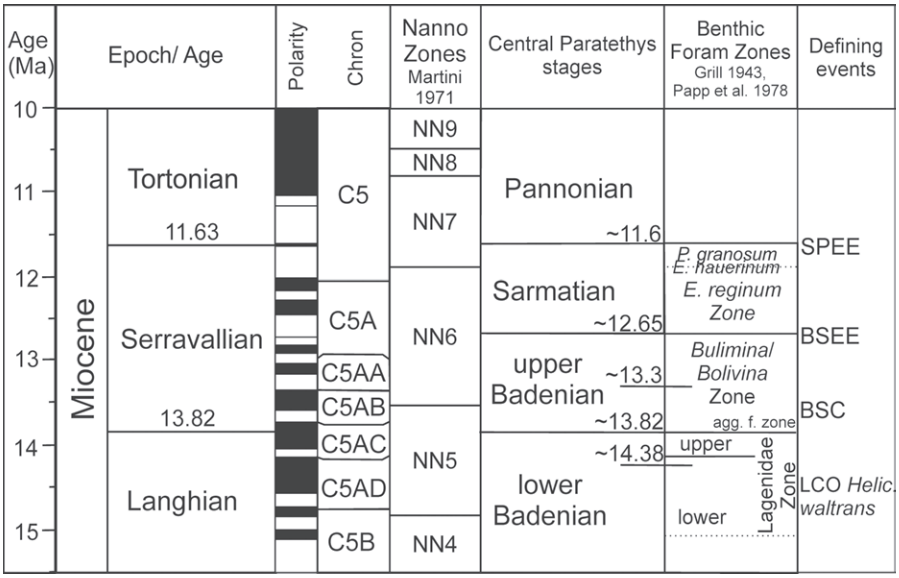
Figure 4. The extraction method of the studied layers and the frequency of the extracted fossil groups from the studied samples

***4. ábra.** Az egyes rétegek mintáinak mikropaleontológiai feltárási módszere, és a kinyert ősmaradványcsoportok gyakorisága a mintákban*

relates with the younger part of the *Aurila notata* Zone (TÓTH 2009). This biostratigraphic interpretation is in accordance with the nannoplankton zonation of the same layers (NN6 or younger, according to ĆORIĆ, 2021).

A sudden change in the microfossil assemblages can be observed between layers D36 and D35, indicating the Sarmatian/Pannonian boundary (11.6 Ma). Foraminifera are entirely missing from sample D35, and the ostracod faunas of the two samples are completely different, without any species in common. In D36, juvenile *Aurila notata* and *Cyprideis* sp. specimens, *Loxocorniculum hastatum*, *Euxinocythere* (*Euxinocythere*) *praebosqueti*, *E.* (*E.*) *naca*, and *Amnicythere tenuis* occur. In contrast, sample D35 is dominated by *Candona* and *Herpetocyprella* species. Calcisphaera-like large algal cysts and mysid statoliths (ballast stones of the shrimplike mysids; following the interpretation of VOICU 1981) are present in sample D35 in low abundance. These are characteristic fossils in strata near the S/P boundary at several locations in Hungary where it was not possible to precisely assign the boundary itself (e.g., KŐVÁRY 1974, BARDÓCZ et al. 1987). Mysids are very common in unanimously Sarmatian layers of the Transylvanian and Dacian Basins (e.g., POPESCU 1995).

Despite the sharp microfaunal change, no major shift can be observed in the lithofacies of the sediment. The mollusc assemblage of sample D35 contains abundant "Sarmatian-type" small-sized cardiids (BOTKA et al. 2021). This fauna, affected by the Lilliput Effect (HARRIES & KNORR 2009), is often related to environmental stress and has been published from the Sarmatian/Pannonian transition by several authors from different parts of the Pannonian Basin (e.g., Zsámbék Basin, Hungary, BOHN-HAVAS 1983; Lajoskomárom–1 well, Hungary, JÁMBOR et al. 1985; Medvednica Mts, Croatia, VRSALJKO 1999). Although the ostracod faunas of layers D36 and D35 are very different, and mollusks are missing from D36 while D35 shows the mass occurrence of tiny cardiid bivalves, it is not obvious if a short gap or continuous sedimentation occurred at the Sarmatian/Pannonian boundary.



Fiure 5. Middle to upper Miocene geochronology, geomagnetic polarity chrons, biozonations of calcareous nannoplankton and benthic foraminifers correlated to regional chronostratigraphy of the Central Paratethys with defining events (modified after HOHENEGGER et al. 2014 and RAFFI et al. 2020).

Abbreviations: BSC= Badenian Salinity Crisis, SPEE = Sarmatian–Pannonian Extinction Event, BSEE=Badenian–Sarmatian Extinction Event (after HARZHAUSER & PILLER 2007)

5. ábra. *Középső miocén rétegtani ábra radiometrikus koradatokkal, magnetosztratigráfiai és biosztratigráfiai (mészvázú nannoplankton, bentosz foraminifera) beosztással, illetve a Középső-Paratethysben lejátszódott meghatározó események feltüntetésével (HOHENEGGER et al. 2014 és RAFFI et al. 2020 után módosítva).*

Rövidítések: BSC= Badeni Sókrízis, SPEE = Szarmata/pannóniai kihalási esemény, BSEE= Badeni/szarmata kihalási esemény (HARZHAUSER & PILLER 2007 után)

Paleoecology

Ecological requirements of the extant relatives of the studied middle Miocene taxa

Extant representatives of keeled elphidiids live in temperate to warm, shallow marine (at water depths up to 50 m) environments (inner shelf) and hypersaline lagoons (MURRAY 1991, 2006). They are mostly epiphytic dwellers (live on plants) and prefer sandy sediment (LANGER 1993, MURRAY 2006). In the Mediterranean Sea, *E. aculeatum* and *E. macellum* live on arborescent algal vegetation (LANGER et al. 1998). They are chromatophore-bearing foraminifera and the "symbionts" may control the phototaxis and the depth distribution of the host organism. The chromatophores are pigment-containing cells that produce color. However, the nature of this symbiosis and the role of the chromatophores in phototaxis – the ability of organisms to move directionally in response to a light source – are poorly known. *E. macellum* is a common member of foraminiferal assemblages in the Black Sea living in the shallow sublittoral zone and coastal pools (down to 20 m depth) (TEMELKOV 2008). *Miliolinella* and *Quinqueloculina* are epiphytic or they cling on hard substrates in the inner shelf or in normal marine to hypersaline lagoons and marshes; they rarely can be found in deep-sea records (MURRAY 2006). Recent miliolids prefer waters rich in calcium carbonate (JORISSEN 1988). *Borelis* is a large, benthic foraminifera with photosynthetic diatom algal symbionts. The recent species are restricted to depths of 5–65 m in, for example, the Gulf of Aqaba, and to minimum sea-surface temperatures greater than 18 °C (REISS & HOTTINGER 1984, LANGER & HOTTINGER 2000). Non-keeled infaunal elphidiids are characteristic species of brackish to hypersaline marshes and lagoons; however, they can also be found in the inner shelf (water depth up to 50 m) (MURRAY 2006). *Ammonia* is widespread in marginal marine environments worldwide and is common in sediments with highly variable mud and organic matter contents, even at low oxygen levels in marsh environments (MURRAY 2006).

Among the ostracods, *Aurila* and *Urocythereis* recently live in great abundance in the infralittoral and uppermost circalittoral zone (water depth up to 40 m) of the Black Sea, the Mediterranean, the Eastern Atlantic, and the Indo-Pacific area (e.g., ATHERSUCH 1977, RUIZ et al. 1997, KILIÇ 2000, AIELLO et al. 2006, TANAKA 2008). Modern representatives of *Aurila*, *Xestoleberis,* and *Loxoconcha* species mainly live on algae or seagrasses (PURI et al. 1969). *Loxoconcha punctatella* and *Xestoleberis dispar* are found in neritic shallow sublittoral, littoral environments in the Mediterranean, Black and Marmara Seas (PERÇIN-PAÇAL et al. 2015). In the present-day Mediterranean Sea, *Xestoleberis dispar* is a phytal marine species, but it also occurs in hypersaline environments (SCIUTO et al. 2015, KOEHN-ZANINETTI & TÉTARD 1982). *Phlyctenophora* occurs in marginal marine estuarine, gulf and lagoonal environments in the Indo-Pacific Realm (WOUTERS 1999, HUSSAIN et al. 2004, MISHRA et al. 2019). Recent polycopids have a nektobenthic lifestyle and are found from abyssal ocean depths (KARANOVIC & BRANDĂO 2012, 2016) to less saline estuarine environments (TANAKA & TSUKAGOSHI 2010).

Recent *Euxinocythere,* similarly to *Aurila* and *Loxoconcha,* occur in shallow marine sublittoral and littoral environments in the Black Sea (PERÇIN-PAÇAL et al. 2015). The extant species *Heterocypris salina* and *Darwinula stevensoni* are cosmopolitan and are known from all continents. *Heterocypris salina* lives in saline coastal and inland water bodies coexisting with other halophilic ostracods and tolerate salinities up to 20‰ (MEISCH 2000). The modern species of *Darwinula* are mostly found in freshwater, although *D. stevensoni* also tolerates stable, brackish conditions in coastal waters (e.g., Baltic Sea) or saline lakes (NEALE 1988, VAN

DONINCK et al. 2003), and is reported to tolerate salinities as high as 15‰ (DE DECKKER 1981). Today, *Vestalenula pagliolii* occurs in Brazil, where it thrives in riverine pools and lakes, semiterrestrial and/or interstitial habitats and occurs in geographically restricted areas (MARTENS et al. 1997).

Paleoenvironments

Three main intervals were differentiated in the studied layers of Pécs-Danitzpuszta trench based on the stratigraphic distribution and ecological needs of the identified foraminifera and ostracod taxa, within which further subintervals were designated (*Figure 2*). The paleocological interpretations are based on the ecology of extant relatives of the studied taxa.

Interval 1 (sample D72) represents the upper Badenian, and it is characterized with the most diverse fossil assemblage within the sedimentary record (*Figure 2*). The dominance of keeled elphidiids and miliolids among the foraminifera and marine neritic genera (*Aurila, Callistocythere, Loxoconcha, Urocythereis, Phlyctenophora,* and *Xestoleberis*) among the ostracods suggests shallow marine, calcium-carbonate rich littoral environment (inner shelf) with water depths up to 50 m. Although several of the identified forms can live today in hypersaline lagoons as well, the high diversity of the microfauna excludes such environmental interpretation. The presence of the large benthic foraminifera *Borelis* in the assemblage indicates warm seawater, with temperatures higher than 18 °C (REISS & HOTTINGER 1984; LANGER & HOTTINGER 2000). Based on the great abundance of epiphytic dweller foraminifera taxa such as *E. aculeatum* and *E. macellum* and phytal ostracods (*Aurila, Loxoconcha* and *Xestoleberis*), a rich arborescent algal vegetation is supposed to have been present on the sea bottom. The keeled elphidiids are cromatophore-bearing foraminifers that must have lived in the euphotic zone with well-ventilated conditions. The abundance of thick-shelled ostracods, often with worn valves, and the abundance of echinoderm fragments indicate high energy conditions in the sea bottom. The red algal and bryozoan fragments also support this environmental interpretation.

Interval 2 (samples D69 and D57) yielded only one fish tooth. Carbonate-cemented cylinders around holes were interpreted as rhizoliths (root traces; *Figure 2*). The Fe-Mn encrusted unconformity on top of bed D57 and the appearance of fossiliferous clays, marls and limestones with upper Sarmatian marine microfossils above the unconformity denote a sharp change in the depositional environment, probably from terrestrial to marine.

Interval 3 (layers D54 to D36) belongs to the upper Sarmatian, suggesting that the area was re-flooded by the sea only during the late Sarmatian.

Subinterval 3a (samples D54 to D41) is characterized by exclusively eurytopic forms and lower diversity than in Interval 1 (*Figure 2*). The impoverishment of the marine faunal elements is explained by the Badenian-Sarmatian Extinction event (BSEE) caused by the final isolation of the Central Paratethys from the Mediterranean and coeval reconnection with the Eastern Paratethys (HARZHAUSER & PILLER 2007). Among the elphidiids, non-keeled forms (mainly the specimens of *Porosononion granosum*) appeared in great abundance due to the unstable environment, e.g., slight fluctuation in salinity or other factors such as food availability. The non-keeled infaunal elphidiids tolerate brackish to hypersaline conditions suggesting marginal marine depositional environments such as a lagoon or a hypersaline marsh. The disappearance of *Phlyctenophora* and *Urocythereis* and the dominance of *Euxinocythere* corroborate the marginal marine conditions. The abundance of the keeled elphidiids and phytal ostracods (*Aurila, Loxoconcha* and *Xestoleberis*) implies a rich vegetation on the substrate. The co-occurence of shallow infaunal non-keeled and epiphytic keeled elphidiids suggests mixed assemblages indicating a very differentiated seafloor.

In Subinterval 3b (samples D40 to D37) the faunal composition radically changed (*Figure 2*). The abundance and diversity of foraminifera and ostracoda decreased. Beside the non-keeled infaunal *Porosononion,* the specimens of *Ammonia* cf. *confertitesta* became dominant. *Ammonia* cf. *confertitesta* tolerates a wide range of salinity (10–50‰) and also occurs in non-marine foraminifera faunas (MURRAY 2006). The ostracod fauna is characterized by non-marine, freshwater to oligohaline ostracods, such as *Darwinula stevensoni*, *Heterocypris salina*, *Vestalenula pagliolii*, *Cyprideis* cf. *torosa*, *Fabaeformiscandona* sp., and *Limnocythere* sp. This microfossil assemblage indicates a sudden decrease in salinity (which is also supported by the mollusk fauna represented by *Radix, Gyraulus* and *Theodoxus* occurring without the brackish *Congeria* and cardiids). The interpretation of this phenomenon, however, remains a hard nut to crack. The lithology does not show any sign of increased terrestrial input that the proximity of a river mouth would cause, and the Sarmatian geomorphological position of the outcrop, reconstructed as a tip of a promontory protruding into a wide basin, does not support the idea of a freshened lagoon or coastal marsh either. A more regional cause of the salinity drop, such as a climate change, would have left its mark on the fossil record of a wider region, but we are not aware of such observations. Thus, what we can conclude is only that the euryhaline foraminifera and freshwater-oligohaline ostracods lived together in a brackish water (5–10 ‰ salinity) habitat.

In Subinterval 3c (sample D36), characteristic Sarmatian eurytopic taxa (non-keeled elphidiids, nonionids, and representatives of the leptocytherid *Euxinocythere)* replace the non-marine, freshwater-oligohaline species. The low diversity microfossil assemblage with the dominance of infaunal foraminifera (non-keeled elphidiids, nonionids, and bolivinids) and thin-shelled ostracods indicates low-oxygenated environment and/or higher organic content. The latter is supported by the nannoflora, suggesting increasing nutrient supply in this period (ĆORIĆ 2021).

Conclusions

The microfossil record of the middle Miocene sedimentary succession of Pécs-Danitzpuszta indicates significant environmental changes through the late Badenian–early Pannonian. The lowermost part of the section belongs to the upper Badenian, with typical Badenian faunal elements indicating stable, normal marine, shallow (inner shelf), warm, well-ventilated environment with relatively high-energy conditions and algal vegetation on the bottom. The overlying layers are devoid of marine microfossils and may indicate terrestrial deposition and subaerial exposure. Following an unconformity, the upper part of the middle Miocene succession belongs to the upper Sarmatian with two distinct biofacies. The lower part and the uppermost layer of the upper Sarmatian are characterized by exclusively eurytopic forms, indicating an unstable and vegetated marginal marine environment with fluctuations in salinity, as well as oxygen and food availability. The middle part of the upper Sarmatian, however, contains highly euryhaline forams and a unique freshwater to oligohaline ostracod fauna, indicating low salinity. Finally, the disappearance of foraminifera taxa and a complete turnover in the ostracod fauna indicates the boundary between the marginal marine Sarmatian and the brackish lacustrine Pannonian stages (11.6 Ma).

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Plate I – I. tábla

Badenian microfossils from the studied exploratory trench in Pécs-Danitzpuszta: 1: *Callistocythere canaliculata* (REUSS), RV in lateral view, layer D72, scale bar: 250 µm; 2–3: *Aurila cicatricosa* (REUSS), 2: LV in lateral view, 3: C in right view, layer D72, scale bar: 250 µm; 4: *Urocythereis kostelensis* (REUSS), LV in lateral view, layer D72, scale bar: 250 µm; 5: *Loxoconcha punctatella* (REUSS), LV in lateral view layer D72, scale bar: 200 µm; 6: *Senesia cinctella* (REUSS), C in right view, layer D72, scale bar: 250 µm; 7: *Xestoleberis tumida* (REUSS), RV in lateral view, layer D72, scale bar: 250 µm; 8: *Xestoleberis dispar* MUELLER, C in left view, layer D72, scale bar: 250 µm; 9: *Borelis* sp., SV, layer D72, scale bar: 200 µm; 10: *Heterolepa dutemplei* (D'ORBIGNY), UV, layer D72, scale bar: 500 µm; 11: *Cycloforina contorta* (D'ORBIGNY), SV, layer D72, scale bar: 200 µm; 12: *Affinetrina ucrainica* (SEROVA), SV, layer D72, scale bar: 500 µm; 13: *Nonion commune* (D'ORBIGNY), SV, layer D72, scale bar: 500 µm; 14: *Elphidium crispum* (LINNÉ), SV, scale bar: 500 µm; 15: *Textularia* sp., layer D72; 16: *Pyrgo subsphaerica* (D'ORBIGNY), layer D72; 17: *Asterigerinata planorbis* (D'ORBIGNY), layer D72; 18: *Heterolepa dutemplei* (D'ORBIGNY), layer D72; 19: echinoid spine, layer D72; 20: sponge spicule, layer D72; 21: red algae fragment, layer D72; 22: serpulid worm burrow, layer D72

Abbreviations: LV= left valve, RV= right valve, C= carapace, SV= side view, UV= umbilical view

Badeni mikrofosszíliák a pécs-danitzpusztai homokbányában ásott kutatóárokból: 1: Callistocythere canaliculata *(REUSS), RV oldalnézetben, D72 réteg, méretarány: 250 µm; 2–3:* Aurila cicatricosa *(REUSS), 2: LV oldalnézetben, 3: C jobb oldali nézetben, D72 réteg, méretarány: 250 µm; 4:* Urocythereis kostelensis *(REUSS), LV oldalnézetben, D72 réteg, méretarány: 250 µm; 5:* Loxoconcha punctatella *(REUSS), LV oldalnézetben, D72 réteg, méretarány: 200 µm; 6:* Senesia cinctella *(REUSS), C jobb oldali nézetben, D72 réteg, méretarány: 250 µm; 7:* Xestoleberis tumida *(REUSS), RV oldalnézetben, D72 réteg, méretarány: 250 µm; 8:* Xestoleberis dispar *MUELLER, C in bal oldali nézetben, D72 réteg, méretarány: 250 µm; 9:* Borelis *sp., SV, D72 réteg, méretarány: 200 µm; 10:* Heterolepa dutemplei *(D'ORBIGNY), UV, D72 réteg, méretarány: 500 µm; 11:* Cycloforina contorta *(D'ORBIGNY), SV, D72 réteg, méretarány: 200 µm; 12:* Affinetrina ucrainica *(SEROVA), SV, D72 réteg, méretarány: 500 µm; 13:* Nonion commune *(D'ORBIGNY), SV, D72 réteg, méretarány: 500 µm; 14:* Elphidium crispum *(LINNÉ), SV, méretarány: 500 µm; 15:* Textularia *sp., D72 réteg; 16:* Pyrgo subsphaerica *(D'ORBIGNY), D72 réteg; 17:* Asterigerinata planorbis *(D'ORBIGNY), D72 réteg; 18:* Heterolepa dutemplei *(D'ORBIGNY), D72 réteg; 19: tengerisüntüske, D72 réteg; 20: szivacstű, D72 réteg; 21: vörösalga-töredék, D72 réteg; 22: féregjárat, D72 réteg*

Rövidítések: LV= bal teknő, RV= jobb teknő, C= kettősteknő, SV= oldalnézet, UV= köldökoldali nézet

Plate II – II. tábla

Sarmatian ostracods from the studied exploratory trench in Pécs-Danitzpuszta: 1: *Amnicythere tenuis* (REUSS), RV in lateral view, layer D50, scale bar: 200 µm; 2–3: *Amnicythere cernajseki* STANCHEVA, 2: LV in lateral view, 3: RV in lateral view, layer D38, scale bar: 200 µm; 4–6: *Euxinocythere* (*Euxinocythere*) *praebosqueti* (SUZIN), 4: ecophenotype, LV in lateral view, layer D36, scale bar: 250 µm; 5: RV in lateral view, layer D36, scale bar: 200 µm; 6: LV in lateral view, layer D50, scale bar: 200 µm; 7: *Euxinocythere* (*Euxinocythere*) *naca* (MÉHES), RV in lateral view, layer D50, scale bar: 200 µm; 8–9: *Cyprideis pokorny* JIŘIČEK, 8: male, RV in lateral view, 9: female, RV in lateral view, layer D38, scale bar: 250 µm; 10: *Cyprideis* sp., layer D38, scale bar: 250 µm; 11: *Hemicytheria omphalodes* (REUSS), juvenile, RV in lateral view, layer D36, scale bar: 200 µm; 12–13: *Aurila notata* (REUSS), 12: RV in lateral view, 13: LV in lateral view, layer D50, scale bar: 500 µm; 14–15: *Loxoconcha kochi* MÉHES, 14: LV in lateral view, 15: RV in lateral view, layer D50, scale bar: 250 µm; 16: *Loxoconcha laeta* STANCHEVA, LV in lateral view, layer D54, scale bar: 200 µm; 17: *Loxoconcha porosa* MÉHES, RV in lateral view, layer D54, scale bar: 200 µm; 18: *Loxocauda* sp., layer D38, scale bar: 250 µm; 19–20: *Loxocorniculum hastatum* (REUSS), 19: LV in lateral view, 20: RV in lateral view, layer D36, scale bar: 250 µm; 21: *Darwinula stevensoni* (BRADY & ROBERTSON), C in right view, layer D 40, scale bar: 250 µm; 22–23: *Vestalenula pagliolii* (PINTO & KOTZIAN), 22: RV in lateral view, 23: C in left view, layer D38, scale bar: 200 µm; 24: *Fabaeformiscandona* ? sp. juv., RV in lateral view, layer D38, scale bar: 200 µm; 25: *Limnocythere* sp., LV in lateral view, layer D38, scale bar: 200 µm; 26: *Heterocypris salina* (BRADY), C in left view, layer D40, scale bar: 500 µm

Abbreviations: LV= left valve, RV= right valve, C= carapace

Szarmata kagylósrákok a pécs-danitzpusztai homokbányában ásott kutatóárokból: 1: Amnicythere tenuis *(REUSS), RV oldalnézetben, D50 réteg, méretarány: 200 µm; 2–3:* Amnicythere cernajseki *STANCHEVA, 2: LV oldalnézetben, 3: RV oldalnézetben, D38 réteg, méretarány: 200 µm; 4–6:* Euxinocythere *(*Euxinocythere*)* praebosqueti *(SUZIN), 4: ökofenotípus, LV oldalnézetben, D36 réteg, méretarány: 250 µm; 5: RV oldalnézetben, D36 réteg, méretarány: 200 µm; 6: LV oldalnézetben, D50 réteg, méretarány: 200 µm; 7:* Euxinocythere *(*Euxinocythere*)* naca *(MÉHES), RV oldalnézetben, D50 réteg, méretarány: 200 µm; 8–9:* Cyprideis pokorny *JIŘIČEK, 8: hím, RV oldalnézetben, 9: nőstény, RV oldalnézetben, D38 réteg, méretarány: 250 µm; 10:* Cyprideis *sp., D38 réteg, méretarány: 250 µm; 11:* Hemicytheria omphalodes *(REUSS), juvenilis, RV oldalnézetben, D36 réteg, méretarány: 200 µm; 12–13:* Aurila notata *(REUSS), 12: RV oldalnézetben, 13: LV oldalnézetben, D50 réteg, méretarány: 500 µm; 14–15:* Loxoconcha kochi *MÉHES, 14: LV oldalnézetben, 15: RV oldalnézetben, D50 réteg, méretarány: 250 µm; 16:* Loxoconcha laeta *STANCHEVA, LV oldalnézetben, D54 réteg, méretarány: 200 µm; 17:* Loxoconcha porosa *MÉHES, RV oldalnézetben, D54 réteg, méretarány: 200 µm; 18:* Loxocauda *sp., D38 réteg, méretarány: 250 µm; 19–20:* Loxocorniculum hastatum *(REUSS), 19: LV oldalnézetben, 20: RV oldalnézetben, D36 réteg, méretarány: 250 µm; 21:* Darwinula stevensoni *(BRADY & ROBERTSON), C jobb oldali, D40 réteg, méretarány: 250 µm; 22–23:* Vestalenula pagliolii *(PINTO & KOTZIAN), 22: RV oldalnézetben, 23: C baloldali nézetben, D38 réteg, méretarány: 200 µm; 24:* Fabaeformiscandona *? sp. juv., RV oldalnézetben, D38 réteg, méretarány: 200 µm; 25:* Limnocythere *sp., LV oldalnézetben, D38 réteg, méretarány: 200 µm; 26:* Heterocypris salina *(BRADY), C bal oldali nézetben, D40 réteg, méretarány: 500 µm*

Rövidítések: LV= bal teknő, RV= jobb teknő, C= carapace

Plate III – III. tábla

Sarmatian foraminifers and other microfossils from the studied exploratory trench in Pécs-Danitzpuszta: 1: *Articulina* sp. indet., fragmented specimen, layer D41, scale bar: 200 µm; 2: *Bolivina sarmatica* DIDKOWSKI, SV, layer D41, scale bar: 250 µm; 3: *Buliminella elegantissima* (D'ORBIGNY), SV, layer D41, scale bar: 500 µm; 4: *Ammonia* cf. *confertitesta* ZHENG, UV, layer D41, scale bar: 200 µm; 5: *Porosononion granosum* (D'ORBIGNY), SV, layer D54, scale bar: 250 µm; 6: *Elphidium hauerinum* (D'ORBIGNY), SV, layer D54, scale bar: 200 µm; 7–8: *Elphidium aculeatum* (D'ORBIGNY), SV, layer D54, scale bar: 250 µm; 9: *Porosononion granosum* (D'ORBIGNY), layer D37; 10: *Vestalenula pagliolii* (PINTO & KOTZIAN), layer D38; 11–12: *Fabaeformiscandona* ? sp. juv., layer D38; 13: *Calcisphaera*-like large algal cyst, layer D35; 14: Mysid statolith, layer D35.

Abbreviations: SV= side view, UV= umbilical view

S*zarmata foraminiferák és egyéb mikrofosszíliák a pécs-danitzpusztai homokbányában ásott kutatóárokból: 1:* Articulina *sp. indet., töredékes példány, D41 réteg, méretarány: 200 µm; 2:* Bolivina sarmatica *DIDKOWSKI, SV, D41 réteg, méretarány: 250 µm; 3:* Buliminella elegantissima *(D'ORBIGNY), SV, D41 réteg, méretarány: 500 µm; 4:* Ammonia *cf.* confertitesta *ZHENG, UV, D41 réteg, méretarány: 200 µm; 5:* Porosononion granosum *(D'ORBIGNY), SV, D54 réteg, méretarány: 250 µm; 6:* Elphidium hauerinum *(D'ORBIGNY), SV, D54 réteg, méretarány: 200 µm; 7–8:* Elphidium aculeatum *(D'ORBIGNY), SV, D54 réteg, méretarány: 250 µm; 9:* Porosononion granosum *(D'ORBIGNY), D37 réteg; 10:* Vestalenula pagliolii *(PINTO & KOTZIAN), D38 réteg; 11–12:* Fabaeformiscandona *? sp. juv., D38 réteg; 13:* Calcisphaerá*hoz hasonló nagyméretű alga ciszta, D35 réteg; 14: Misidae statolith, D35 réteg.*

Rövidítések: SV= oldalnézet, UV= köldökoldali nézet

Plate I – I. tábla

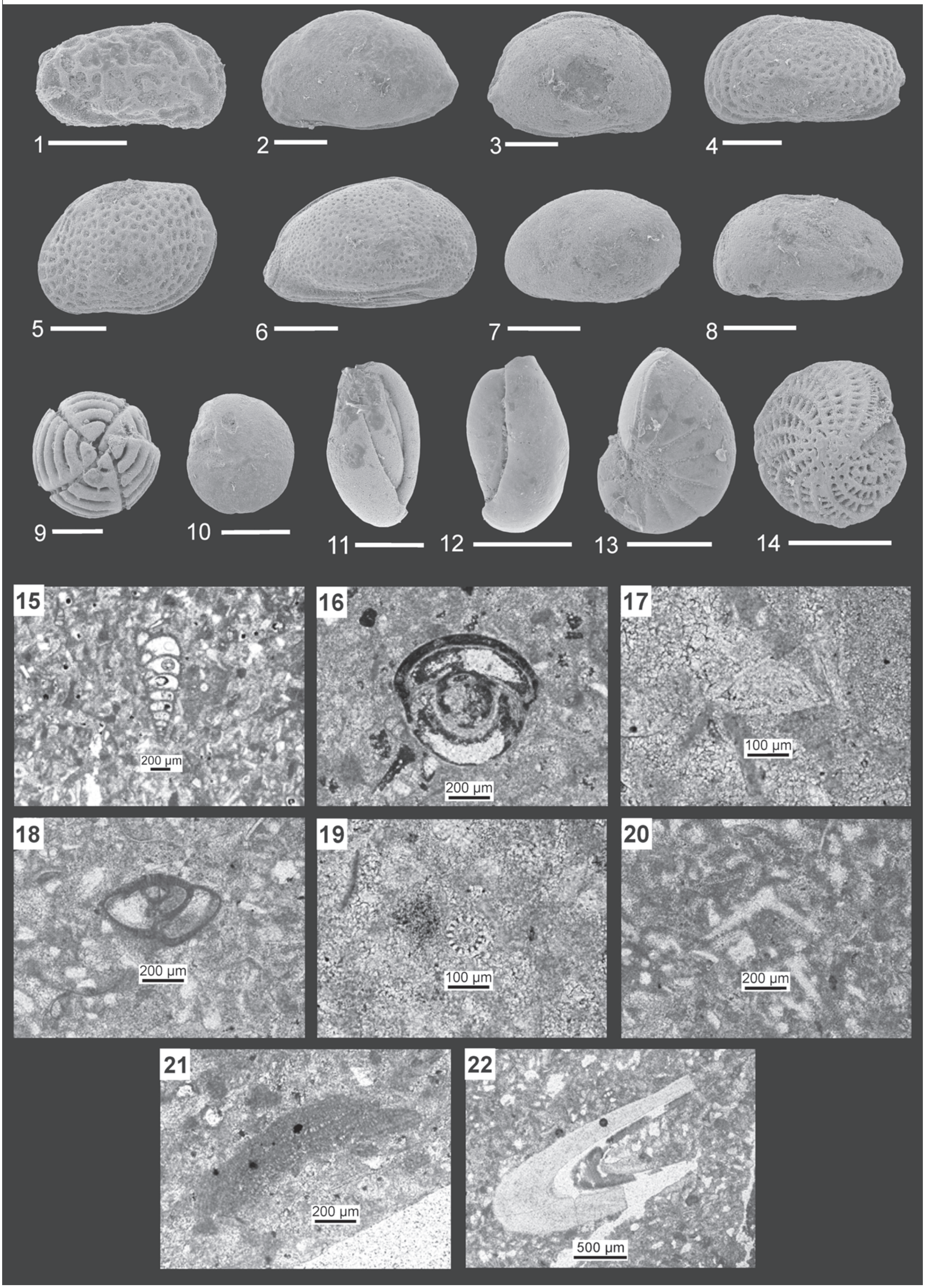


Plate II – II. tábla

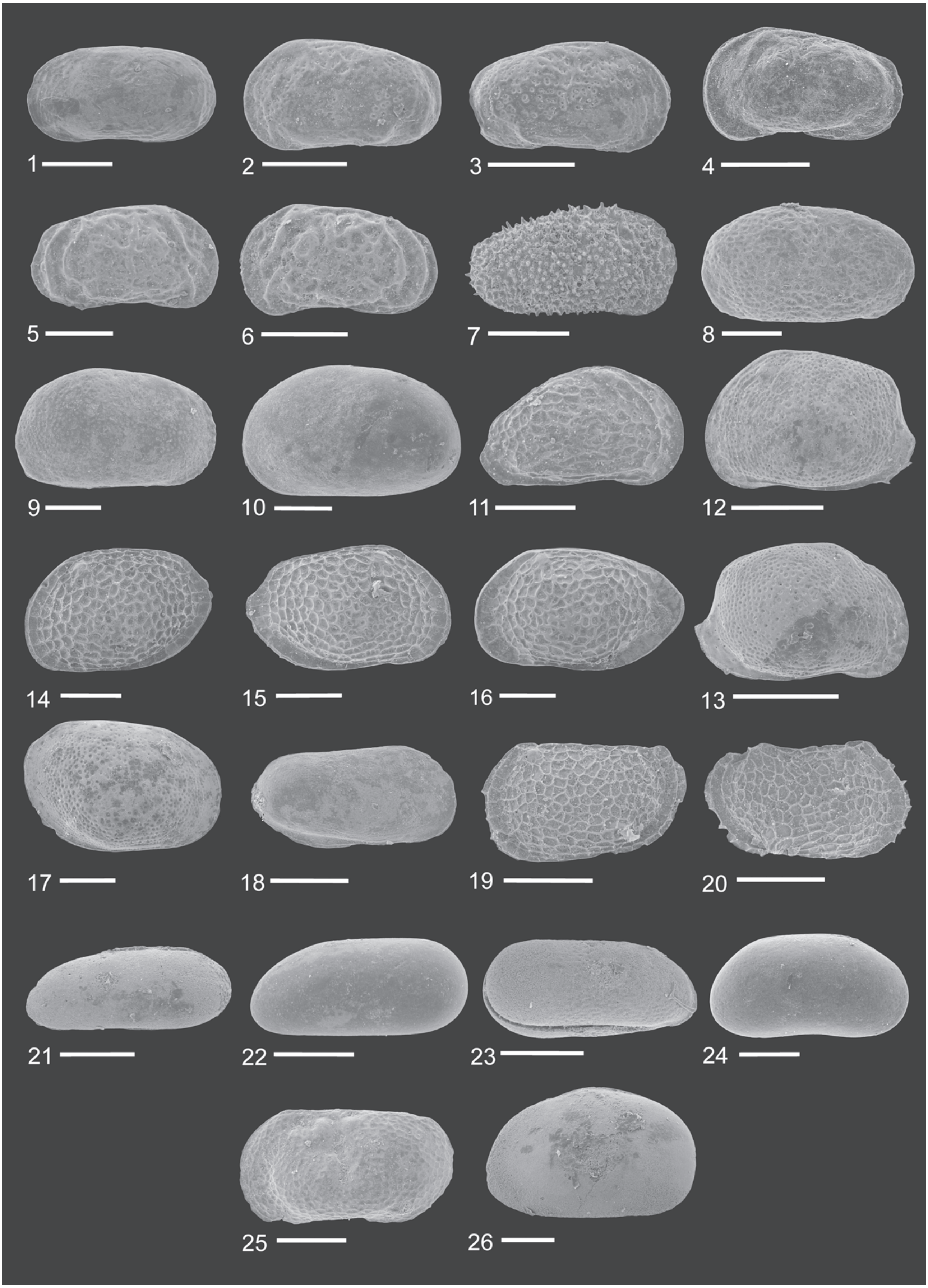
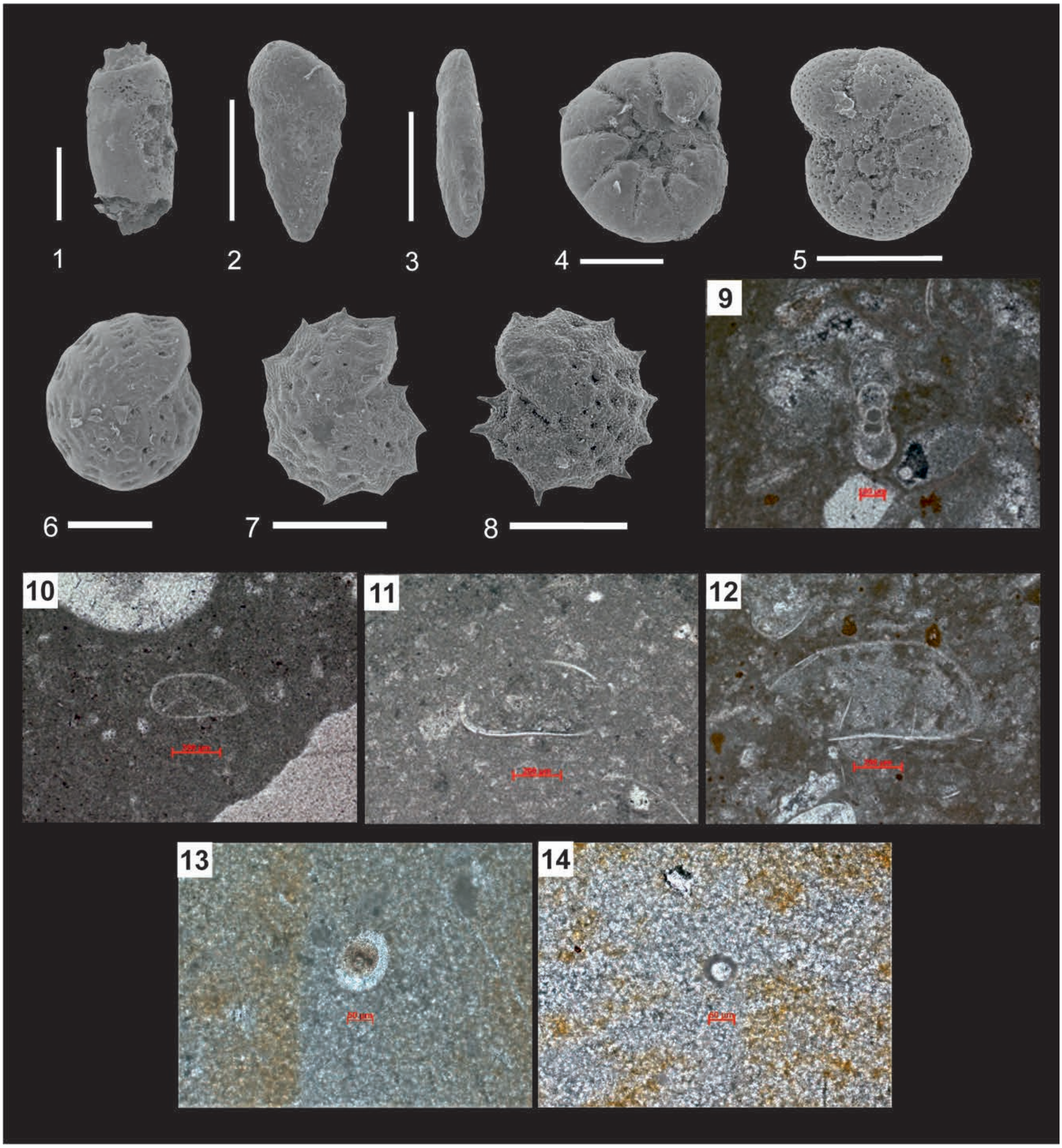


Plate III – III. tábla



Appendix

Systematic Palaeontology

The specimens of foraminifers and ostracods are reposited in the Laboratory of MOL Plc., Exploration and Production Division (Budapest, Hungary).

Foraminifera

Higher classification of the foraminifera follows that of LOEBLICH & TAPPAN (1992). Abbreviations: L: length, B: breadth, D: diameter and Th: thickness.

Phylum Protista
Subphylum Sarcodina SCHMARDA, 1871
Class Foraminifera J.J. LEE, 1990
Order Miliolida LANKESTER, 1885
Suborder Miliolina DELAGE & HERUARD, 1896
Superfamily Milioloidea EHRENBERG, 1839
Family Hauerinidae SCHWAGER, 1876
Subfamily Haueríninae SCHWAGER, 1876
Genus *Cycloforina* LUCZKOWSKA, 1972

Cycloforina contorta (D'ORBIGNY, 1846)
Plate I, fig. 11

1846 *Quinqueloculina contorta* n. sp. D'ORBIGNY, p. 298, pl. 20, figs 4–6.
2008 *Cycloforina contorta* (D'ORBIGNY) – TÓTH & GÖRÖG, p. 196, pl. 1, fig. 1. (cum syn.)
2012 *Cycloforina contorta* (D'ORBIGNY) – GONERA, fig. 2/M.
2012 *Cycloforina contorta* (D'ORBIGNY) – MILKER & SCHMIEDL, pp. 53–54, fig. 14/6.
2014 *Cycloforina contorta* (D'ORBIGNY) – YOKES et al., fig. 8/2.
2016 *Cycloforina contorta* (D'ORBIGNY) – LEI & LI, pp. 98–99, fig. 6.
2016 *Cycloforina contorta* (D'ORBIGNY) – KIRCI-ELMAS & MERIÇ, fig. 3/8.

Dimensions: L= 530–540 µm, B=400–410 µm, Th= 220–240 µm

Stratigraphic range and geographic distribution: Miocene: Carpathian Foredeep and Transcarpathian Basin, Ukraine (BOGDANOWICH 1952, DIDKOWSKY & SATANOVSKAJA 1970); Badenian: Carpathian Foredeep, Poland (LUCZKOWSKA 1974; GONERA 2012), Vienna Basin, Austria (D'ORBIGNY 1846); Badenian to Sarmatian: Mecsek Mts, Hungary (KORECZ-LAKY 1968); Sarmatian: Zsámbék Basin and Budapest, Hungary (GÖRÖG 1992, TÓTH & GÖRÖG 2008). Recently widely distributed over the world.

Subfamily Miliollinellinae VELLA, 1957
Genus *Affinetrina* LUCZKOWSKA, 1972

Affinetrina ucrainica (SEROVA, 1952)
Plate I, fig. 12

1952 *Miliolina ucrainica* n. sp. SEROVA in BOGDANOWICH, p. 104, pl. 8, fig. 2.
1992 *Affinetrina ucrainica* (SEROVA) – GÖRÖG, pp. 79-80, pl. 6, figs 1–3. (cum syn.)
2007 *Affinetrina ucrainica* (SEROVA) – SCHÜTZ et al., p. 453, pl. 2, fig. 2.
2012 *Affinetrina ucrainica* (SEROVA) – MILKER & SCHMIEDL, p. 61, fig. 16/11–13.
2015. *Affinetrina ucrainica* (SEROVA) – SILYE, p. 111, pl. 1, figs 4–5.

Dimensions: L= 500–530 µm, B=200–300 µm, Th= 160–220 µm

Stratigraphic range and geographic distribution: Upper Badenian: Carpathian Foredeep, Poland (LUCZKOWSKA 1974); Upper Badenian – Sarmatian: Transcarpathian Basin and Carpathian Foredeep, Ukraine (DIDKOWSKY & SATANOVSKAJA 1970); Lower Sarmatian: Vienna Basin, Austria (SCHÜTZ et al. 2007); Sarmatian: Moesian Platform, Bulgaria (STANCHEVA 1960), Transylvanian Basin, Romania (SILYE 2015); Zsámbék Basin, Hungary (GÖRÖG 1992). Recently widely distributed in the Mediterranean Sea.

Genus *Pyrgo* DEFRANCE, 1824

Pyrgo subsphaerica (D'ORBIGNY, 1839)
Plate I, fig. 16 (thin section)

1839 *Biloculina subsphaerica* n. sp. D'ORBIGNY, p. 162, pl. 8, figs 25–27.
1974 *Pyrgo subsphaerica* (D'ORBIGNY) – LUCZKOWSKA, pp. 118–119, pl. 22, figs 4a, b.
2008 *Pyrgo subsphaerica* (D'ORBIGNY) – DE ARAÚJO & MACHADO, pl. 1, fig. 3.

Dimensions: B= 660 µm (other dimensions are not examined)

Stratigraphic range and geographic distribution: Upper Badenian: Carpathian Foredeep, Poland (LUCZKOWSKA 1974). Recently widely distributed in the Mediterraen Sea, Caribbean Sea and Atlantic Ocean.

Order Buliminida FURSENKO, 1958
Superfamily Bolivinoidea GLAESSNER, 1937
Family Bolivinidae GLAESSNER, 1937
Genus *Bolivina* D'ORBIGNY, 1839

Bolivina sarmatica DIDKOWSKY, 1959
Plate III, fig. 2

1970 *Bolivina sarmatica* DIDKOWSKY – DIDKOWSKY & SATANOVSKAJA, p. 144, pl. 82, fig. 9. (holotype)
2008 *Bolivina sarmatica* DIDKOWSKY – TÓTH & GÖRÖG, p. 198, pl. 1, fig. 12. (cum syn.)
2011 *Bolivina sarmatica* DIDKOWSKY – GARECKA & OLSZEWSZKA, fig. 6/e.
2011 *Bolivina sarmatica* DIDKOWSKY – FILIPESCU et al., fig. 5/3.
2014 *Bolivina sarmatica* DIDKOWSKY – FILIPESCU et al., fig. 5/19.
2015 *Bolivina sarmatica* DIDKOWSKY – SILYE, p. 129, pl. 4, fig. 17.
2017 *Bolivina sarmatica* DIDKOWSKY – DUMITRIU et al., fig. 13/p.
2018 *Bolivina sarmatica* DIDKOWSKY – HARZHAUSER et al., fig. 5/10.

Dimensions: L= 150–160 µm, B= 90–95 µm

Stratigraphic range and geographic distribution: Sarmatian: Moldavian Plateau (DIDKOWSKY & SATANOVSKAJA 1970), Transcarpathian Basin, Carpathian Foredeep, Volhynian-Podolian Plateau, Ukraine (VENGLINSKY 1975), Western Carpathians (CICHA & ZAPLETALOVÁ 1961), easternmost Pannonian and Transylvanian Basins, Romania (FILIPESCU 1996; FILIPESCU et al. 2011, 2014), Zsámbék Basin and Budapest, Hungary (GÖRÖG 1992, TÓTH & GÖRÖG 2008), Carpathian Foredeep, Poland and Romania (GARECKA & OLSZEWSZKA 2011, DUMITRIU et al. 2017), Vienna Basin, Austria (HARZHAUSER et al. 2018).

Superfamily Buliminoidea JONES, 1875
Family Buliminellidae HOFKER, 1951
Genus *Buliminella* CUSHMAN, 1911

Buliminella elegantissima (D'ORBIGNY, 1839)
Plate III, fig. 3

1839 *Bulimina elegantissima* n. sp. D'ORBIGNY, p. 51, pl. 7, figs 13–14.
2004 *Buliminella elegantissima* (D'ORBIGNY) – VILELA et al., fig. 4/4.
2008 *Buliminella elegantissima* (D'ORBIGNY) – TÓTH & GÖRÖG, pp. 198-199, pl. 2, figs 2–4. (cum syn.)
2011 *Buliminella elegantissima* (D'ORBIGNY) – FILIPESCU et al., fig. 5/10.
2014 *Buliminella elegantissima* (D'ORBIGNY) – FILIPESCU et al., fig. 6/13.

Dimensions: L= 230–320 µm, D= 90–100 µm

Stratigraphic range and geographic distribution: Sarmatian: Black Sea Depression, Ukraine, Moldavian Plateau (DIDKOWSKY & SATANOVSKAJA 1970), Zsámbék Basin and Budapest, Hungary (GÖRÖG 1992, TÓTH & GÖRÖG 2008), easternmost Pannonian and Transylvanian Basins, Romania (FILIPESCU et al. 2011, 2014). Recently widely distributed over the world.

Superfamily Asterigerinoidea D'ORBIGNY, 1839
Family Asterigerinatidae REISS, 1963
Genus *Asterigerinata* REISS, 1963

Asterigerinata planorbis (D'ORBIGNY, 1846)
Plate I, fig. 17 (thin-section)

1846 *Asterigerina planorbis* n. sp. D'ORBIGNY, p. 225, pl. 11, figs 1–3.
1985 *Asterigerina planorbis* D'ORBIGNY – PAPP & SCHMID, pl. 66, figs 9–14.
1985 *Asterigerina planorbis* D'ORBIGNY – KORECZ-LAKY & NAGY-GELLAI, pl. 158, figs 1–4.
1998 *Asterigerinata planorbis* (D'ORBIGNY) – CICHA et al., pl. 64, figs 8–10.
1998 *Asterigerinata planorbis* (D'ORBIGNY) - ZLINSKÁ, pl. 8, figs 10–11.
2007 *Asterigerinata planorbis* (D'ORBIGNY) – SCHÜTZ et al., p. 457, pl. 4, fig. 6.
2010 *Asterigerina planorbis* D'ORBIGNY – ISMAIL et al., pl. 4, figs 4–5.
2012 *Asterigerinata planorbis* (D'ORBIGNY) – GONERA, fig. 4/c.
2013 *Asterigerinata planorbis* (D'ORBIGNY) – PEZELJ et al., fig. 6/17.
2016 *Asterigerinata planorbis* (D'ORBIGNY) – PEZELJ et al., fig. 5/A–H.
2014 *Biasterigerina planorbis* (D'ORBIGNY) – TER BORGH et al., fig. 5/31–32.
2019 *Asterigerinata planorbis* (D'ORBIGNY) – JOVANOVIĆ et al., pl. 1, figs f/6, g/5, h/6.
2020 *Asterigerinata planorbis* (D'ORBIGNY) – PERYT et al., fig. 4/h.

Dimensions: D= 250–350 µm

Stratigraphic range and geographic distribution: Kiscellian: Börzsöny Mts, Hungary (KORECZ-LAKY & NAGY-GELLAI 1985); Badenian: Vienna Basin, Austria (D'ORBIGNY 1846), East-Slovakian Basin (ZLINSKÁ 1998), Dacian Basin, Romania (TER BORGH et al. 2014), Mt Majevica, Bosnia and Herzegovina (PEZELJ et al. 2013, 2016); Koceljeva area, Western Serbia (JOVANOVIĆ et al. 2019); Carpathian Foredeep, Poland (GONERA 2012, PERYT et al. 2020), North-Croatian Basin, Croatia (PEZELJ et al. 2016); Lower Sarmatian: Vienna Basin, Austria (SCHÜTZ et al. 2007); Pliocene: Nile Delta, Egypt (ISMAIL et al. 2010).

Superfamily Nonionoidea SCHULTZE, 1854
Family Nonionidae SCHULTZE, 1854
Subfamily Nonioninae SCHULTZE, 1854
Genus *Nonion* MONTFORT, 1808

Nonion commune (D'ORBIGNY, 1846)
Plate I, fig. 13

1798 *Nautilus scapha* n. sp. FICHTEL & MOLL, p. 105, pl. 19, figs d–f.
1846 *Nonionina communis* D'ORBIGNY – D'ORBIGNY, p. 106, pl. 5, figs 7–8.
2008 *Nonion commune* (D'ORBIGNY) – TÓTH & GÖRÖG, pp. 22–203, pl. 2, figs 14–18. (cum syn.)
2009 *Nonion commune* (D'ORBIGNY) – GEBHARDT et al., pl. 2, fig. 39.
2010 *Nonion commune* (D'ORBIGNY) – KOUBOVÁ & HUDAČKOVÁ, pl. 1, fig. 15.
2012 *Nonion commune* (D'ORBIGNY) – FERRER GARCÍA & BLÁZQUEZ MORILLA, fig. 4/6.

2012 *Nonion commune* (D'ORBIGNY) – GONERA, fig. 4/e.
2013 *Nonion commune* (D'ORBIGNY) – PERYT, fig. 4/F.
2013 *Nonion commune* (D'ORBIGNY) – PEZELJ et al., fig. 6/18.
2014 *Nonion commune* (D'ORBIGNY) – FILIPESCU et al., fig. 6/7.
2019 *Nonion commune* (D'ORBIGNY) – JOVANOVIĆ et al., pl. 1, figs f/14, g/6, h/3.
2019 *Nonion commune* (D'ORBIGNY) – ROSLIM et al., fig. 4/33–36.

Dimensions: D= 350–370 μm, Th= 130–160 μm

Stratigraphic range and geographic distribution: Karpatian: Molasse Basin, Austria (RÖGL 1969); Badenian: Vienna Basin, Austria and Slovakia (D'ORBIGNY 1846, KOVÁČOVÁ & HUDÁČKOVÁ 2005), Carpathian Foredeep, Poland (SZCZECHURA 1982, PERYT 2013); Volhynian-Podolian Plateau, Carpathian Foredeep, Transcarpathian Basin, Crimea-Caucasus region and Kuban Lowland, Ukraine and Russia (VOLOSHINOVA 1952, DIDKOWSKY & SATANOVSKAJA 1970), Slovenia (OBLAK 2007), Mt Majevica, Bosnia and Herzegovina (PEZELJ et al. 2013), Koceljeva area, Western Serbia (JOVANOVIĆ et al. 2019); Badenian to Sarmatian: Mecsek Mts, Tokaj Mts and SW-Hungary, Budapest (KORECZ-LAKY 1968, 1973, 1982; BÁLDI 1999; TÓTH & GÖRÖG 2008), Appenines, Italy (DIECI 1959); Sarmatian: E-Slovakian Basin, Slovakia (ZLINSKÁ 1997, KOUBOVÁ & HUDAČKOVÁ, 2010), Vienna Basin, Austria (SCHÜTZ et al. 2007, GEBHARDT et al. 2009), easternmost Pannonian Basin, Romania (FILIPESCU et al. 2014); Upper Miocene: Ambug Hill, Borneo (ROSLIM et al. 2019). Recently widely distributed over the world.

Superfamily Rotalioidea EHRENBERG, 1839
Family Rotaliidae EHRENBERG, 1839
Subfamily Ammoniinae SAIDOVA, 1981
Genus *Ammonia* BRÜNNICH, 1772

Ammonia cf. *confertitesta* ZHENG, 1978
Plate III, fig. 4

Dimensions: D= 250–450 μm

Remaks: The studied specimens are very similar (mainly the spiral side of the test) to the holotype described by ZHENG (1978) however the last chamber of the studied specimens in most cases is missing.

Family Elphidiidae GALLOWAY, 1933
Subfamily Elphidiinae GALLOWAY, 1933
Genus *Elphidium* MONTFORT, 1808

Elphidium aculeatum (D'ORBIGNY, 1846)
Plate III, figs 7–8

1846 *Polystomella josephina* n. sp. D'ORBIGNY, p. 130, pl. 6, figs 25–26.
1846 *Polystomella aculeata* n. sp. – D'ORBIGNY, p. 131, pl. 6, figs 27–28.
1995.*Elphidium aculeatum* (D'ORBIGNY) – POPESCU, p. 94, pl. 7, figs 4–7.
2004 *Elphidium aculeatum* (D'ORBIGNY) – BRÂNZILĂ, pl. 4, fig. 5.
2004 *Elphidium aculeatum* (D'ORBIGNY) – MERIÇ et al., pl. 32, figs 5–8.
2005 *Elphidium aculeatum* (D'ORBIGNY) – GOLDBECK et al., pl. 1, fig. 12.
2008 *Elphidium aculeatum* (D'ORBIGNY) – TÓTH & GÖRÖG, pp. 204–205, pl. 3, figs 5–6. (cum syn.)
2010 *Elphidium josephinum* (D'ORBIGNY) – KOUBOVA & HUDAČKOVA, pl. 1, fig. 26.
2011 *Elphidium aculeatum* (D'ORBIGNY) – GEDL & PERYT, pl. 1, fig. 9/F, I–K.
2012 *Elphidium aculeatum* (D'ORBIGNY) – ALOULOU et al., pl. 1, fig. 13.
2012 *Elphidium aculeatum* (D'ORBIGNY) – MILKER & SCHMIEDL, p. 119, fig. 27/5–6.
2012 *Elphidium aculeatum* (D'ORBIGNY) – GONERA et al., fig. 4/K.
2012 *Elphidium aculeatum* (D'ORBIGNY) – MELIS et al., pl. 1, fig. 1.
2012 *Elphidium aculeatum* (D'ORBIGNY) – PERYT & JASIONOWSKI, fig. 4/C, D, L, M.
2012 *Elphidium aculeatum* (D'ORBIGNY) – JASIONOWSKI et al., fig. 12/A, B, D, E.
2013 *Elphidium aculeatum* (D'ORBIGNY) – TER BORGH et al., fig. 6, 8–9.
2014 *Elphidium josephium* (D'ORBIGNY) – FILIPESCU et al., fig. 7/10.
2014 *Elphidium aculeatum* (D'ORBIGNY) – YOKES et al., fig. 11/8.
2015 *Elphidium aculeatum* (D'ORBIGNY) – SILYE, p. 150, pl. 8, figs 1–2, 4.
2017 *Elphidium aculeatum* (D'ORBIGNY) – DUMITRIU et al., fig. 11/Q, R.
2020 *Elphidium aculeatum* (D'ORBIGNY) – PERYT et al., fig. 3/h.

Dimensions: D= 450–600 μm, Th= 200–350 μm.

Stratigraphic range and geographic distribution: Badenian: Carpathian Foredeep, Poland and Ukraine (GEDL & PERYT 2011, GONERA et al. 2012, PERYT et al. 2020); Late Badenian to Sarmatian: Volhynian–Podolian Plateau, Moldavian Plateau, Moldavia and Carpathian Foredeep, Ukraine (VENGLINSKY 1958; DIDKOWSKY & SATANOVSKAJA 1970, BRÂNZILĂ 2004), Crimea-Caucasus region, South-Caspian Depression, Russia and Azerbaijan (VOLOSHINOVA 1952); Sarmatian: Carpathian Foredeep, Poland, Romania and Ukraine (SZCZECHURA 1982, 2000; JASIONOWSKI et al. 2012; DUMITRIU et al. 2017), Vienna Basin, Austria and Slovakia (MARKS 1951, PAPP 1963; SCHÜTZ et al. 2007; KOUBOVA & HUDAČKOVA 2010), Danube Basin and East-Slovakian Basin, Slovakia (BRESTENSKÁ 1974; ZLINSKÁ 1997), Tokaj Mts, Mecsek Mts, Zsámbék Basin and Budapest, Hungary (KORECZ-LAKY 1973, 1968, 1964, 1965, 1982; GÖRÖG 1992; TÓTH & GÖRÖG 2008), easternmost Pannonian and Transylvanian basins, Romania (KOVÁCS 2001, SUCIU 2005, FILIPESCU et al. 2014, SILYE 2015); Romanian Plain, Romania (POPESCU 1995), Moesian Platform, Bulgaria (STANCHEVA 1960); Pannonian Basin, Serbia (TER BORGH et al. 2013); Holocene: Mediterranean Sea, Italy (MELIS et al. 2012, YOKES et al. 2014). Recently widely distributed over the world.

Remarks: The number and size of spines are variable, it seems to be intraspecific variability. Making the species *Elphidium josephinum* described by D'ORBIGNY the junior synonym of *E. aculeatum*, thus an invalid name.

Elphidium crispum (LINNE, 1758)
Plate I, fig. 14

1758 *Nautilus crispus* n. sp. LINNAEUS, p. 709, pl. 1, figs 2d–e.
1988 *Elphidium crispum* (LINNÉ) – JORISSEN, p. 120, pl. 3, figs 8–9, pl. 24, figs 1–2.

2004 *Elphidium crispum* (LINNÉ) – MERIÇ et al., pl. 1, figs 16–18.
2004 *Elphidium crispum* (LINNÉ) – MENDES et al., pl. 1, fig. 6.
2004 *Elphidium crispum* (LINNÉ) – BRÂNZILĂ, pl. 4, fig. 11.
2005 *Elphidium crispum* (LINNÉ) – MORIGI et al., pl. 2, fig. 9a–c.
2008 *Elphidium crispum* (LINNÉ) – TÓTH & GÖRÖG, pp. 205–206, pl. 3, figs 7–8. (cum syn.)
2009 *Elphidium crispum* (LINNÉ) – FREZZA & CARBONI, pl. 1, fig. 16.
2010 *Elphidium crispum* (LINNÉ) – KOUBOVA & HUDAČKOVA, pl. 1, fig. 24.
2011 *Elphidium crispum* (LINNÉ) – GEDL & PERYT, fig. 9/C, R.
2012 *Elphidium crispum* (LINNÉ) – FERRER GARCÍA & BLÁZQUEZ MORILLA, pl. 4, fig. 12.
2012 *Elphidium crispum* (LINNÉ) – GONERA, fig. 4/j.
2012 *Elphidium crispum* (LINNÉ) – MILKER & SCHMIEDL, p. 120, fig. 27/13–14.
2012 *Elphidium crispum* (LINNÉ) – MELIS et al., pl. 1, fig. 4.
2012 *Elphidium crispum* (LINNÉ) – ALOULOU et al., pl. 1, fig. 15.
2014 *Elphidium crispum* (LINNÉ) – FILIPESCU et al., fig.7/3.
2014 *Elphidium crispum* (LINNÉ) – YOKES et al., fig. 11/10–11.
2014 *Elphidium crispum* (LINNÉ) – TER BORGH et al., fig. 6/8.
2016 *Elphidium crispum* (LINNÉ) – LEI & LI, p. 361, fig. 84.
2016 *Elphidium crispum* (LINNÉ) – DIMIZA et al., pl. 4, fig. 20.
2016 *Elphidium crispum* (LINNÉ) – PEZELJ et al., fig. 5/ D, I.
2019 *Elphidium crispum* (LINNÉ) – JOVANOVIĆ et al., pl. 1, figs f/3, g/7.
2019 *Elphidium crispum* (LINNÉ) – ROSLIM et al., fig. 4/25.

Dimensions: D= 450–1200 µm, Th=330–350 µm

Stratigraphic range and geographic distribution: Langhian: Aquitaine Basin, France (CAHUZAC & POIGNANT 2000); Karpatian-Badenian: East-Mecsek Mts, Hungary (KORECZ-LAKY 1968); Badenian: Dacian Basin, Romania and Serbia (TER BORGH et al. 2014), Carpathian Foredeep, Poland and Ukraine (GEDL & PERYT 2011, GONERA 2012), Vienna Basin, Austria (PAPP 1963), Apennines, Italy (DIECI 1959), Koceljeva area, Western Serbia (JOVANOVIĆ et al. 2019); Badenian: North-Croatian Basin, Croatia (PEZELJ et al. 2016), Karpatian–Sarmatian: Transcarpathian Basin, Volhynian-Podolian Plateau and Caucasus, Ukraine and Russia (VENGLINSKY 1958, DIDKOWSKY & SATANOVSKAJA 1970); Sarmatian: Carpathian Foredeep, Poland (SZCZECHURA 1982), Mecsek Mts, Zsámbék Basin and Budapest, Hungary (KORECZ-LAKY 1964, 1968; GÖRÖG 1992; TÓTH & GÖRÖG 2008), Vienna Basin, Slovakia (KOUBOVA & HUDAČKOVA 2010); Moldavian Plateau, Moldavia (BRÂNZILĂ 2004); Lower Sarmatian: easternmost Pannonian Basin, Romania (FILIPESCU et al. 2014); Upper Miocene: Ambug Hill, Borneo (ROSLIM et al. 2019); Pliocene: Toscana, Italy (FICHTEL & MOLL 1798); Holocene: Meditterranean Sea, Italy (MORIGI et al, 2005, MELIS et al. 2012). Recently widely distributed over the world.

Elphidium hauerinum (D'ORBIGNY, 1846)
Plate III, fig. 6

1846 *Polystomella Hauerina* n. sp. D'ORBIGNY, p.122, pl. 6, figs 5–10.
1995 *Elphidium hauerinum* (D'ORBIGNY) – POPESCU, p. 95, pl. 8, fig. 10.
2005 *Elphidium hauerinum* (D'ORBIGNY) – FILIPESCU et al., pl. 2, figs 4–5.
2008 *Elphidium hauerinum* (D'ORBIGNY) – TÓTH & GÖRÖG, pl. 3, figs 10–12. (cum syn.)
2010 *Elphidium hauerinum* (D'ORBIGNY) – KOUBOVÁ & HUDAČKOVÁ, pl. 1, fig. 18.
2011 *Elphidium hauerinum* (D'ORBIGNY) – FILIPESCU et al., fig. 4/3.
2011 *Elphidium hauerinum* (D'ORBIGNY) – IONESI & PASCARIU, pl. 1, fig. 29.
2012 *Elphidium hauerinum* (D'ORBIGNY) – JASIONOWSKI et al., fig. 14/E, H, I, M.
2014 *Elphidium hauerinum* (D'ORBIGNY) – FILIPESCU et al., figs 7–9.
2015 *Elphidium hauerinum* (D'ORBIGNY) – SILYE, p. 152, pl. 8, figs 5–7.
2017 *Elphidium hauerinum* (D'ORBIGNY) – DUMITRIU et al., fig. 12/G, H.

Dimensions: D=240–430 µm, Th= 100–150 µm

Stratigraphic range and geographic distribution: Badenian?: Vienna Basin, Austria (D'ORBIGNY 1846); Badenian-Sarmatian: Transcarpathian Basin, Carpathian Foredeep, Ukraine (VENGLINSKY 1958, DIDKOWSKY & SATANOVSKAJA 1970); Sarmatian: Carpathian Foredeep, Ukraine, Poland and Romania (JASIONOWSKI et al. 2012, DUMITRIU et al. 2017), Moldavian Plateau, Romania (IONESI & PASCARIU 2011), N-Caucasus, Russia (VOLOSHINOVA 1952); Moesian Platform, Bulgaria (STANCHEVA 1960), easternmost Pannonian and Transylvanian basins, Romania (FILIPESCU 1996; KOVÁCS 2001; SUCIU 2005; FILIPESCU et al. 2005, 2011, 2014), Romanian Plain, Romania (POPESCU 1995), Vienna Basin, Austria (D'ORBIGNY 1846, PAPP 1963, SCHÜTZ et al. 2007), Tokaj Mts, Zsámbék Basin, Mecsek Mts and Budapest, Hungary (KORECZ-LAKY 1964, 1965, 1968, 1973, 1982; GÖRÖG 1992; TÓTH & GÖRÖG 2008); Danube Basin and East-Slovakian Basin, Slovakia (BRESTENSKÁ 1974, ZLINSKÁ 1997, KOUBOVÁ & HUDAČKOVÁ 2010), Carpathian Foredeep, Poland (SZCZECHURA 1982, 2000).

Genus *Porosononion* PUTRYA in VOLOSHINOVA, 1958

Porosononion granosum (D'ORBIGNY, 1846)
Plate III, figs 5, 9 (thin section)

1846 *Nonionina granosa* n. sp. D'ORBIGNY, p. 110, pl. 5, figs 19–20.
1988 *Elphidium granosum* (D'ORBIGNY) – JORISSEN, p. 104, pl. 2, figs 1–3, pl. 16–19.
1992 *Porosononion granosum* (D'ORBIGNY) – GÖRÖG, pp. 112–113, pl. 11. fig. 5. (cum syn.)
2000 *Porosononion granosum* (D'ORBIGNY) – POIGNANT et al., pp. 400–401, pl. 1, figs 13–14. (cum syn.)
2000 *Porosononion granosum* (D'ORBIGNY) – SZCZECHURA, pl. 5, figs 3, 6.
2000 *Elphidium granosum* (D'ORBIGNY) – CARBONI et al., fig. 10.
2001 *Porosononion granosum* (D'ORBIGNY) – FILIPESCU et al., pl. 3, fig. 11.
2004 *Porosononion subgranosus monogranulata* GERKE – BRÂNZILĂ, pl. 2, figs 7–9.
2007 *Porosononion* ex gr. *granosum* (D'ORBIGNY) – SCHÜTZ et al., pl. 6, fig.6.
2007 *Porosononion granosum* (D'ORBIGNY) – GROSS et al., pp. 210–211, fig. 4 a–e, h–i.
2008 *Cribroelphidium* ex gr. *granosum* (D'ORBIGNY) – TÓTH & GÖRÖG, p. 204, pl. 3., figs 3–4.
non 2010 *Porosononion granosum* (D'ORBIGNY) – KOUBOVÁ & HUDAČKOVÁ, pl. 1, fig. 20.

2011 *Porosononion granosum* (D'ORBIGNY) – FILIPESCU et al., fig. 4/9.
2012 *Elphidium granosum* (D'ORBIGNY) – MILKER & SCHMIEDL, p. 121, fig. 27/17–18.
2013 *Porosononion granosum* (D'ORBIGNY) – TER BORGH et al., fig. 6/4–5.
2015 *Porosononion granosum* (D'ORBIGNY) – SILYE, p. 147, pl. 7, figs 4–5.
2018 *Porosononion granosum* (D'ORBIGNY) – HARZHAUSER et al., fig. 5/1–2.
2019 *Porosononion granosum* (D'ORBIGNY) – NÁÑEZ & MALUMIÁN, pp. 197–201, figs 5–6.

Dimensions: D= 200–500 µm

Stratigraphic range and geographic distribution: Middle Miocene: Atlantic Ocean, Argentina (NÁÑEZ & MALUMIÁN 2019); Badenian: Transylvanian Basin, Romania (FILIPESCU 2001); Badenian–Sarmatian: Vienna Basin, Austria (D'ORBIGNY 1846); Sarmatian: Vienna Basin and Styrian Basin, Austria (GROSS et al. 2007, SCHÜTZ et al. 2007, HARZHAUSER et al. 2018), Zsámbék Basin and Budapest, Hungary (GÖRÖG 1992, TÓTH & GÖRÖG 2008), Transcarpathian Basin, Ukraine (VOLOSHINOVA 1952, VENGLINSKY 1958), Carpathian Foredeep, Poland (SZCZECHURA 2000), Transylvanian Basin, Romania (FILIPESCU et al. 2011, SILYE 2015), Moldavian Plateau (BRÂNZILĂ 2004); Pliocene: Mediterranean Sea, Spain (CARBONNEL & MAGNÉ 1977) and Greece (HAGEMAN 1979). Recently widely distributed over the world.

Remarks: The umbilical region is very variable in this group. Due to the large morphological variation, the taxonomic status of fossil specimens is uncertain. The studied specimen is identical (including umbilical region) to the holotype described by D'ORBIGNY (1846).

Family Cibicididae CUSHMAN, 1927
Subfamily Cibicidinae CUSHMAN, 1927
Genus *Heterolepa* FRANZENAU, 1884

Heterolepa dutemplei (D'ORBIGNY, 1846)
Plate I, figs 10, 18 (thin section)

1846 *Rotalia dutemplei* n. sp. D'ORBIGNY, p. 157, pl. 8, figs 19–21.
1982 *Heterolepa dutemplei* (D'ORBIGNY) – SZCZECHURA, pl. 16, figs 8–9.
1985 *Heterolepa dutemplei* (D'ORBIGNY) – PAPP & SCHMID, p. 59, pl. 50, figs 1–3.
1985 *Heterolepa dutemplei* (D'ORBIGNY) – KORECZ-LAKY & NAGY-GELLAI, pl. 20, fig. 4a–b.
1998 *Heterolepa dutemplei* (D'ORBIGNY) – CICHA et al., pp.107–108, pl. 71, figs 1–3.
1999 *Heterolepa dutemplei* (D'ORBIGNY) – BÁLDI, pp. 209–210, pl. 9, figs 1–6, pl. 10, figs 1–2.
2000 *Heterolepa dutemplei* (D'ORBIGNY) – SZCZECHURA, pl. 1, figs 6, 13.
2001 *Heterolepa dutemplei* (D'ORBIGNY) – FILIPESCU, pl. 3, figs 12–13.
2007 *Heterolepa dutemplei* (D'ORBIGNY) – OZSVÁRT, pp. 84–85, pl. 11, figs 11–13. (cum syn.)
2013 *Heterolepa dutemplei* (D'ORBIGNY) – PERYT, figs 4/V, W, 7/Y
2013 *Heterolepa dutemplei* (D'ORBIGNY) – PEZELJ et al., fig. 6/20.
2014 *Heterolepa dutemplei* (D'ORBIGNY) – TER BORGH et al., fig. 5/41–42.
2014 *Heterolepa dutemplei* (D'ORBIGNY) – STOJANOVA & PETROV, pl. 1, fig. 11.
2016 *Heterolepa dutemplei* (D'ORBIGNY) – VALCHEV & STOJANOVA, pl. 2, figs 3–4.
2016 *Heterolepa dutemplei* (D'ORBIGNY) – PEZELJ et al., fig. 5/M
2017 *Heterolepa dutemplei* (D'ORBIGNY) – HARZHAUSER et al., pl. 2, fig. 13.
2017 *Heterolepa dutemplei* (D'ORBIGNY) – DUMITRIU et al., fig. 9/I, J.
2019 *Heterolepa dutemplei* (D'ORBIGNY) – JOVANOVIĆ et al., pl. 1, fig. h/1.
2019 *Heterolepa dutemplei* (D'ORBIGNY) – ROSLIM et al., fig. 4/8–13.

Dimensions: D=450–600 µm, Th= 200–350 µm

Stratigraphic range and geographic distribution: Middle to Upper Eocene: Paleogene Basin, Hungary (OZSVÁRT 2007); Upper Eocene – Lower Oligocene: Valandovo-Gevgelia Basin, Republic of Macedonia (STOJANOVA & PETROV 2014; VALCHEV & STOJANOVA 2016); Kiscellian to Badenian: Börzsöny Mts, Hungary (KORECZ-LAKY & NAGY-GELLAI 1985); SW-Hungary (BÁLDI 1999); Ottnangian: Austria, Vienna Basin (HARZHAUSER et al. 2017); Badenian: Koceljeva area, Western Serbia (JOVANOVIĆ et al. 2019); Mt Majevica, Bosnia and Herzegovina (PEZELJ et al. 2013); North-Croatian Basin, Croatia (PEZELJ et al. 2016), Austria, Vienna Basin (D'ORBIGNY 1846), Dacian and Transylvanian basins, Serbia and Romania (FILIPESCU 2001, TER BORGH et al. 2014); Carpathian Foredeep, Poland (SZCZECHURA 1982, 2000; PERYT 2013; DUMITRIU et al. 2017), Upper Miocene: Ambug Hill, Borneo (ROSLIM et al. 2019).

Ostracoda

Classification of the ostracods follows that of HARTMANN & PURI (1974) and HORNE et al. (2002). Abbreviations: L: length, H: height.

Phylum Arthropoda SIEBOLD, STANNIUS, 1845
Subphylum Crustacea PENNANT, 1777
Class Ostracoda LATREILLE, 1802
Order Podocopida MÜLLER, 1894
Suborder Cytherocopina BAIRD, 1850
Superfamily Cytheroidea BAIRD, 1850
Family Cytherideidae SARS, 1925
Subfamily Cytherideinae SARS, 1925
Genus *Cyprideis* JONES, 1857

Cyprideis pokorny JIŘIČEK, 1974
Plate II, figs 8–9

1974 *Cyprideis pokorny* n. sp. JIŘIČEK, p. 439, pl. 2, figs 1–4.
2009 *Cyprideis pokorny* JIŘIČEK – TÓTH, p. 87, pl. 4, figs 3,6.

Dimensions: L= 660–720 µm, H= 350–410 µm, L/H= 1.6–1.8.

Stratigraphic range and geographic distribution: Upper Sarmatian: Vienna Basin, Slovakia (JIŘIČEK 1974); Vértes Hill, Hungary (TÓTH 2009).

Family Hemicytheridae PURI, 1953
Subfamily Hemicytherinae PURI, 1953
Genus *Aurila* POKORNÝ, 1955

Aurila cicatricosa (REUSS, 1850)
Plate I, figs 2–3

1850 *Cypridina cicatricosa* n. sp. REUSS, pp. 67–68, pl. 9, fig. 21.
1962 *Mutilus (Aurila) cicatricosa* (REUSS) – STANCHEVA, p. 32, pl. 4, fig. 8.
1971 *Aurila cicatricosa* (REUSS) – CERNAJSEK, pp. 65–69, pl. 6, figs 7–14, pl. 14, fig. 7, pl. 17, fig. 4 a–b. [partim, pl. 14, fig. 8]
1978 *Aurila cicatricosa* (REUSS) – BRESTENSKÁ & JIŘIČEK, p. 409, 432, pl. 6, fig. 1.
2008 *Aurila cicatricosa* (REUSS) – FARANDA et al., pl. 2, figs 4–5.
2004 *Aurila cicatricosa* (REUSS) – AIELLO & SZCZECHURA, pp. 28–30, pl. 5, fig. 2.
2006 *Aurila cicatricosa* (REUSS) – GROSS & PILLER, pp. 47–48, text-fig. 6/1, pl. 21, figs 1-12, pl. 22, figs 8–10.
2006 *Aurila cicatricosa* (REUSS) – SZCZECHURA, fig. 9/9–10.
2012 *Aurila cicatricosa* (REUSS) – SEKO et al., fig.8/P.
2014 *Aurila (Aurila) cicatricosa* (REUSS) – TER BORGH et al., fig.7/16.

Dimensions: L= 900–950 µm, H= 530–580 µm, L/H= 1.6–1.7.

Stratigraphic range and geographic distribution: Badenian: Vienna Basin, Austria (CERNAJSEK 1971, GROSS & PILLER 2006); Carpathian Foredeep, Czech Republic, Poland (BRESTENSKÁ & JIŘIČEK 1978, AIELLO & SZCZECHURA 2004, SZCZECHURA 2006, SEKO et al. 2012); Dacian Basin, Romania (TER BORGH et al. 2014); Late Miocene: Mediterranean, Greece (FARANDA et al. 2008).

Aurila notata (REUSS, 1850)
Plate II, figs 12–13.

1850 *Cypridina notata* n. sp. REUSS, p. 66, pl. 9, fig. 16.
2006 *Aurila (Euaurila?) notata* (REUSS) – GROSS & PILLER, p. 83–84, pl. 29, figs 1–9.
2008 *Aurila notata* (Reuss) – TÓTH, pp. 122–123, pl.8. figs 3–7. (cum syn.)
2017 *Aurila notata* (Reuss) – DUMITRIU et al., fig. 12/Q.
2018 *Aurila notata* (Reuss) – HARZHAUSER et al., fig. 7/10.

Dimensions: L= 900–950 µm, H= 530–580 µm, L/H= 1.6–1.7.

Stratigraphic range and geographic distribution: Upper Sarmatian: Vienna Basin, Austria and Slovakia (CERNAJSEK 1974, JIŘIČEK 1983, ZELENKA 1990, JANZ & VENNEMANN 2005, GROSS & PILLER 2006, HARZHAUSER et al. 2018); Zsámbék Basin, Hungary (TÓTH 2008); Caucasus, Russia (SUZIN 1956); Lower Sarmatian: Moldovian Plateau. Romania (DUMITRIU et al. 2017).

Genus *Hemicytheria* POKORNÝ, 1952

Hemicytheria omphalodes (REUSS, 1850)
Plate II, fig. 11

1850 *Cypridina omphalodes* n. sp. REUSS, p. 75, pl. 10, fig. 7.
2008 *Hemicytheria omphalodes* (REUSS) – TÓTH, pl. 6, figs 2–6. (cum syn.)
2011 *Hemicytheria omphalodes* (REUSS) – OLTEANU, pl. 18, fig. 8.
2014 *Hemicytheria omphalodes* (REUSS) – FILIPESCU et al., fig. 8/10.

Dimensions: L= 810–820 µm, H= 470–480 µm, L/H= 1.7–1.75.

Stratigraphic range and geographic distribution: Upper Badenian: Transylvanian Basin, Romania (OLTEANU 2001); Sarmatian: Vienna Basin, Slovakia (JIŘIČEK 1974, ZELENKA 1990); Zsámbék Basin, Hungary (TÓTH 2008); Lower Sarmatian: Danube Basin and the eastern region, Slovakia (FORDINÁL et al. 2006, FORDINÁL & ZLINSKÁ 1994); Upper Sarmatian: Vienna Basin, Austria (CERNAJSEK 1974); Pannonian: easternmost Pannonian Basin, Transylvanian Basin, Romania (OLTEANU 2001, 2011; FILIPESCU et al. 2014), Pannonian Basin, Croatia (SOKAČ 1972).

Genus *Senesia* JIŘIČEK, 1974

Senesia cinctella (REUSS, 1850)
Plate I, fig. 6

1850 *Cypridina cinctella* n. sp. REUSS, p. 67, pl. 9, fig. 19.
1962 *Mutilus (Aurila) cinctella* (REUSS) – STANCHEVA, p. 35, pl. 4, fig. 9.
1979 *Aurila (Aurila) cinctella* n. ssp. – BASSIOUNI, pp. 118–119, pl. 19, figs 7–8.
2006 *Senesia cinctella* (REUSS) – GROSS & PILLER, pp. 57–58, pl. 31, figs 1–5.

Dimensions: L= 750–760 µm, H= 410–420 µm, L/H= 1.8–1.82

Stratigraphic range and geographic distribution: Lower Miocene: Black Sea Depression, Turkey (BASSIOUNI 1979); Badenian: Vienna Basin, Austria and Slovakia (REUSS 1850, CERNAJSEK 1971, BRESTENSKÁ & JIŘIČEK 1978, GROSS & PILLER 2006); Moesian Plateau, Bulgaria (STANCHEVA 1962).

Subfamily Urocythereidinae HARTMANN & PURI, 1974
Genus *Urocythereis* RUGGIERI, 1950

Urocythereis kostelensis (REUSS, 1850)
Plate I, fig. 4

1850 *Cypridina kostelenis* n. sp. REUSS, p. 68, pl. 9, fig. 22.
1978 *Urocythereis kostelensis* (REUSS) – BRESTENSKÁ & JIŘIČEK, p. 410, 432, pl. 6, fig. 12.
1985 *Urocythereis kostelenis* (REUSS) – ZELENKA, p. 246, pl. 3, fig. 2.
2004 *Urocythereis kostelenis* (REUSS) – ZORN, p. 180, fig. 4/10–11.
2006 *Urocythereis kostelenis* (REUSS) – GROSS & PILLER, pp. 106–108, pl. 38, figs 1–5,9,11–12.

Dimensions: L= 820–835 µm, H= 410–420 µm, L/H= 1.9–2.

Stratigraphic range and geographic distribution: Badenian: Carpathian Foredeep, Poland (REUSS 1850), Vienna and Molasse basins, Austria and Slovakia (REUSS 1850, BRESTENSKÁ & JIŘIČEK 1978, ZELENKA 1985, ZORN 2004; GROSS & PILLER 2006).

Family Leptocytheridae Hanai, 1957
Subfamily Leptocytherinae Hanai, 1957
Genus *Amnicythere* Devoto, 1965

Amnicythere cernajseki Stancheva, 1984
Plate II, figs 2–3

1963 *Leptocythere modesta* n. sp. Stancheva, p. 22, pl. 3, fig. 8.
1974 *Leptocythere* sp. – Cernajsek, p. 476, pl. 2, fig. 7.
1984 *Amnicythere cernajseki* nom. nov. – Stancheva, p. 39, pl. 1, fig. 5.
1998 *Amnicyther* aff. *plana* (Schneider) – Olteanu, p. 153, pl. 8, fig. 7.
2008 *Amnicythere* (?) sp.– Tóth, p. 110, pl. 2, figs 5–6.
2011 *Amnicythere cernajseki* Stancheva – Filipescu et al., fig. 5/20.

Dimensions: L= 570–600 µm, H= 260–300 µm, L/H= 2–2.19.

Stratigraphic range and geographic distribution: Sarmatian: Vienna Basin, Austria (Cernajsek 1974); Lower Sarmatian: Transylvanian Basin, Romania (Olteanu 1998); Upper Sarmatian: Zsámbék Basin, Hungary (Tóth 2008); Transylvanian Basin, Romania (Filipescu et al. 2011).

Amnicythere tenuis (Reuss, 1850)
Plate II, fig. 1

1850 *Cytherina tenuis* n. sp. Reuss, p. 53, pl. 8, fig. 14.
2008 *Amnicythere tenuis* (Reuss) – Tóth, p. 109–110, pl. 2, figs 1–3, 5. (cum syn.)
2013 *Amnicythere tenuis* (Reuss) – ter Borgh et al., fig. 6/14–15.
2014 *Amnicythere tenuis* (Reuss) – ter Borgh et al., fig. 8/27–28.
2015 *Amnicythere tenuis* (Reuss) – Silye, pl. 10, figs 1–3.
2018 *Amnicythere tenuis* (Reuss) – Harzhauser et al., fig. 7/3.

Dimensions: L= 510–550 µm, H= 250–290 µm, L/H= 1.96–2.3.

Stratigraphic range and geographic distribution: Sarmatian: Vienna Basin, Austria (Cernajsek 1974, Harzhauser et al. 2018); Carpathian Foredeep, Poland (Szczechura 2000); Zsámbék Basin and Budapest, Hungary (Tóth 2004, 2008); Lower Sarmatian: East-Slovakian Basin, Slovakia (Zlinská & Fordinál 1995); Transylvanian Basin, Romania (Olteanu 1998, Silye 2015); Pannonian and Dacian basins, Serbia and Romania (ter Borgh et al. 2013, 2014); Bessarabian: Moesian Plate, Bulgaria (Stancheva 1963, 1990); Pannonian: Pannonian Basin, Hungary (Méhes 1908); Pontian: Dacian Basin, Romania (Hanganu 1974).

Genus *Callistocythere* Ruggieri, 1953

Callistocythere canaliculata (Reuss, 1850)
Plate I, fig. 1

1850 *Cypridina canaliculata* n. sp. Reuss, p. 76, pl. 9, fig. 12.
2006 *Callistocythere canaliculata* (Reuss) – Gross & Piller, pp. 25–26, pl. 8, figs 1–4, 8–9, pl. 10, figs 1–2. (cum syn.)
2011 *Callistocythere* aff. *canaliculata* (Reuss) – Hajek-Tadesse & Prtoljan, figs 4, 9.
2019 *Callistocythere canaliculata* (Reuss) – Brinkmann et al., fig. 4/P.

Dimensions: L= 570–600 µm, H= 260–300 µm, L/H= 2–2.19.

Stratigraphic range and geographic distribution: Ottnangian: North Alpine Foreland Basin, Germany (Brinkmann et al. 2019); Karpatian: Molasse Basin, Austria (Zorn 2003, 2004); Badenian: Vienna Basin and Danube Basin, Slovakia (Brestenská & Jiřiček 1978, Gross & Piller 2006); Transylvanian Basin, Romania (Olteanu 1998); Carpathian Foredeep, Poland (Paruch-Kulczycka 1992; Paruch-Kulczycka & Szczechura 1996, Aiello & Szczechura 2004); Sarmatian: Tokaj Mts, Hungary (Pietrzeniuk 1973); North-Croatian Basin, Croatia (Hajek-Tadesse & Prtoljan 2011).

Genus *Euxinocythere* Stancheva, 1968

Euxinocythere (Euxinocythere) naca (Méhes, 1908)
Plate II, fig. 7

1908 *Cythere naca* n. sp. Méhes, p. 548–549, pl. 10, figs 8–12.
1989 *Leptocythere naca* (Méhes) – Sokač, p. 687, pl. 8, fig 10.
1989 *Leptocythere (Amnicythere) naca* (Méhes) – Olteanu, pl. 8, fig. 6.
1989 *Euxinocythere (Euxinocythere)* cf. *naca* (Méhes) – Krstić & Stancheva, p. 778, pl. 11, fig. 3.
2008 *Euxinocythere (Euxinocythere) naca* (Méhes) – Tóth, pp. 112–113, pl. 1, fig.7. (cum syn.)
2009 *Euxinocythere (Euxinocythere) naca* (Méhes) – Tóth, p. 84, pl. 3, fig. 3.
2011 *Leptocythere (Euxinocythere) naca* (Méhes) – Olteanu, pl. 19, fig. 1.
2013 *Euxinocythere naca* (Méhes) – ter Borgh et al., fig. 8/10.

Dimensions: L= 470–510 µm, H= 235–260 µm, L/H= 1.88–1.95.

Stratigraphic range and geographic distribution: Sarmatian: Vienna and Danube basins, Austria and Slovakia (Cernajsek 1974, Zelenka 1990); Moldavian Plateau, Romania (Ionesi & Chintăuan 1975, 1985); Carpathian Foredeep, Poland (Szczechura 2000); Volhynian: Moesian Plate, Northern Bulgaria (Stancheva 1990); Zsámbék Basin, Hungary (Tóth 2008, 2009); Pannonian-Pontian: Pannonian Basin, Hungary and Serbia (Krstić 1973, Méhes 1908, Széles 1982, Krstić & Stancheva 1989; ter Borgh et al. 2013); North-Croatian Basin, Croatia (Sokač 1967, 1972, 1989); Transylvanian Basin, Romania (Olteanu 2011); Pontian: Dacian Basin, Romania (Olteanu 1989); South Caspian Basin, Azerbaijan (Agalarova 1967).

Euxinocythere (Euxinocythere) praebosqueti (Suzin, 1956)
Plate II, figs 4–6

1956 *Leptocythere praebosqueti* n. sp. Suzin, p. 83, pl. 3, figs 2–4.
2008 *Euxinocythere (Euxinocythere) praebosqueti* (Suzin) – Tóth, p. 114, pl. 3, figs 2–5. (cum syn.)
2013 *Euxinocythere (Euxinocythere) praebosqueti* (Suzin) – Van Baak et al., fig. 4/13.

Dimensions: L= 490–510 µm, H= 200–260 µm, L/H= 1.9–2.1.

Stratigraphic range and geographic distribution: Sarmatian: Moesian Plate, Northern Bulgaria (STANCHEVA 1972, 1990); Upper Sarmatian: Zsámbék Basin, Hungary (TÓTH 2008); Bessarabian: Caucasus, Russia (SUZIN 1956); Plio-Pleistocene: South Caspian Basin, Azerbaijan (VAN BAAK et al. 2013).

Family Loxoconchidae SARS, 1925
Subfamily Loxoconchinae SARS, 1925
Genus *Loxoconcha* SARS, 1866

Loxoconcha kochi MÉHES, 1908
Plate II, figs 14–15

1908 *Loxoconcha kochi* n. sp. MÉHES, pp. 543–544, pl. 9, figs 5–9.
2005 *Loxoconcha kochi* MÉHES – FILIPESCU et al., pl. 3, fig. 6.
2006 *Loxoconcha kochi*? MÉHES – GROSS & PILLER, pp. 112–113, pl. 40, figs 1–7,9.
2008 *Loxoconcha kochi* MÉHES – TÓTH, p. 124, pl. 9, fig. 6. (cum syn.)
2013 *Loxoconcha kochi* MÉHES – TER BORGH et al., fig. 8/24–25.
2014 *Loxoconcha kochi* MÉHES - TER BORGH et al., fig. 7/23.
2014 *Loxoconcha kochi* MÉHES – FILIPESCU et al., fig.8/15.
2018 *Loxoconcha kochi* MÉHES – HARZHAUSER et al., fig.7/12.

Dimensions: L= 640–835 µm, H= 400–520 µm, L/H= 1.6–1.75.

Stratigraphic range and geographic distribution: Upper Badenian: Vienna Basin, Austria (GROSS & PILLER 2006); Dacian Basin, Romania (TER BORGH et al. 2014); Sarmatian: Vienna Basin, Austria (CERNAJSEK 1974, GROSS & PILLER 2006, HARZHAUSER et al. 2018); easternmost Pannonian and Transylvanian basins, Blacks Sea Depression, Romania (IONESI & CHINTĂUAN 1985; FILIPESCU et al. 2005, 2014); Upper Sarmatian: Zsámbék Basin, Hungary (TÓTH 2008); Pannonian Basin, Serbia (TER BORGH et al. 2013); Lower Pannonian (?): Pannonian Basin, Hungary (MÉHES 1908); Messinian and Pliocene (?): Rhône Valley, France (CARBONNEL 1978).

Loxoconcha laeta STANCHEVA, 1963
Plate II, fig. 16

1963 *Loxoconcha laeta* n.sp. STANCHEVA, pp. 34–35, pl.6, fig 9.
1990 *Loxoconcha laeta* STANCHEVA – STANCHEVA, pp. 88–89, pl. 31, figs 5–6.
2009 *Loxoconcha laeta* STANCHEVA – TÓTH, pp. 91–92, pl. 7, fig. 12.

Dimensions: L= 720–750 µm, H= 390–410 µm, L/H= 1.8–1.83.

Stratigraphic range and geographic distribution: Lower Sarmatian: Moesian Plate, Bulgaria (STANCHEVA 1963, 1990); Upper Sarmatian: Zsámbék Basin, Hungary (TÓTH 2009).

Loxoconcha porosa MÉHES, 1908
Plate II, fig. 17

1908 *Loxoconcha porosa* n. sp. MÉHES, pp. 542–543, pl. 8, figs 10–14.
2008 *Loxoconcha porosa* MÉHES – TÓTH, pp. 124–125, pl. 9, figs 3–5. (cum syn.)

Dimensions: L= 620–700 µm, H= 420–470 µm, L/H= 1.45–1.55.

Stratigraphic range and geographic distribution: Sarmatian: Pannonian Basin, Serbia (KRSTIĆ 1972); Black Sea Depression, Romania (IONESI & CHINTĂUAN 1985); Upper Sarmatian: Vienna Basin, Slovakia (ZELENKA 1990); Zsámbék Basin, Hungary (TÓTH 2008); Pannonian: Pannonian Basin, Hungary and Croatia (MÉHES 1908, SOKAČ 1972).

Loxoconcha punctatella (REUSS, 1850)
Plate I, fig. 5

1850 *Cypridina punctatella* n. sp. REUSS, pp. 65–66, pl. 9, fig. 15 a–b.
1978 *Loxoconcha punctatella* (REUSS) – BRESTENSKÁ & JIŘIČEK, pl. 2, figs 12–13.
1985 *Loxoconcha punctatella* (REUSS) – ZELENKA, pl. 3, figs 10–11.
2004 *Loxoconcha* ex. gr. *punctatella* (REUSS) – TÓTH, pp. 140–141, pl. 6, figs 1–2.
2006 *Loxoconcha punctatella* (REUSS) – GROSS & PILLER, pp. 73–74, pl. 40, figs 8,11, pl. 41, figs 1–10. (cum syn.)
2006 *Loxocorniculum* cf. *punctatella* (REUSS) – SZCZECHURA, fig. 10/3.
2008 *Loxoconcha* ex. gr. *punctatella* (REUSS) – TÓTH, p. 125, pl. 10, figs 1–2.
2011 *Loxoconcha punctatella* (REUSS) – HAJEK-TADESSE & PRTOLJAN, fig. 4/16.
2012 *Loxoconcha punctatella* (REUSS) – SEKO et al., fig. 8/D.
2013 *Loxoconcha punctatella* (REUSS) – TER BORGH et al., fig. 6/28.
2019 *Loxoconcha punctatella* (REUSS) – BRINKMANN et al., fig. 8/N–O.

Dimensions: L= 540–670 µm, H= 400–450 µm, L/H= 1.4–1.54.

Stratigraphic range and geographic distribution: Burdigalian: Molasse Basin, Austria (BRINKMANN et al. 2019); Karpatian: Molasse Basin, Austria (ZORN 1998); Badenian: Danube Basin and Vienna Basin, Slovakia (BRESTENSKÁ & JIŘIČEK 1978, ZELENKA 1985); Molasse Basin, Austria (ZORN 2004); Carpathian Foredeep, Czech Republic and Poland (PARUCH-KULCZYCKA 1992, SZCZECHURA 2006, SEKO et al. 2012); North-Croatian Basin, Croatia (HAJEK-TADESSE & PRTOLJAN 2011); Badenian to Sarmatian: Vienna Basin, Austria (GROSS & PILLER 2006); Lower Sarmatian: Zsámbék Basin, Hungary (TÓTH 2004, 2008); Pannonian Basin, Serbia (TER BORGH et al. 2013).

Genus *Loxocorniculum* BENSON & COLEMAN, 1963

Loxocorniculum hastatum (REUSS, 1850)
Plate II, figs 19–20

1850 *Cytherina hastata* REUSS sensu CERNAJSEK – REUSS, pl. 9, fig. 26.
2008 *Loxocorniculum hastatum* (REUSS) – TÓTH, pp.125–126, pl. 9, figs 1–2. (cum syn.)
2012 *Loxocorniculum hastatum* (REUSS) – SEKO et al., fig. 8/F.
2014 *Loxocorniculum hastatum* (REUSS) – TER BORGH et al., fig.7/22.
2017 *Loxocorniculum hastatum* (REUSS) – DUMITRIU et al., fig. 13/I–J.
2019 *Loxocorniculum hastatum* (REUSS) – BRINKMANN et al., p. 84, fig. 8/M.

Dimensions: L= 620–630 µm, H= 390–410 µm, L/H= 1.5–1.6.

Stratigraphic range and geographic distribution: Oligocene to Miocene (Aquitanian, Burdigalian, Langhian): Aquitaine Basin, France (DUCASSE et al. 1991, BEKAERT et al. 1991, DUCASSE & CAHUZAC 1996); Burdigalian: Molasse Basin, Austria (BRINKMANN et al. 2019); Rhône Basin, France (CARBONNEL 1969); Eggenburgian: Molasse Basin, Austria (KOLLMANN 1971); Karpatian: Vienna Basin, Czech Republic (KHEIL 1967); Molasse Basin, Austria (ZORN 1998, 2003, 2004); Badenian: Molasse Basin, Austria (ZORN 1998, 2004); Carpathian Foredeep, Poland and Czech Republic (PARUCH-KULCZYCKA 1992, SZCZECHURA 2006, SEKO et al. 2012); Vienna Basin, Austria and Czech Republic (CERNAJSEK 1974, BRESTENSKÁ & JIŘIČEK 1978, JANZ & VENNEMANN 2005, ZELENKA 1985); Moesian Platform, Bulgaria (STANCHEVA 1962); Dacian Basin, Romania (TER BORGH et al. 2014); Carpathian Foredeep, Poland (AIELLO & SZCZECHURA 2004); Sarmatian: Mecsek Mts and Zsámbék Basin, Hungary (SZUROMI-KORECZ & SZEGŐ 2001, TÓTH 2008); Carpathian Foredeep, Poland (DUMITRIU et al. 2017).

Family Xestoleberididae SARS, 1928
Genus *Xestoleberis* SARS, 1866

Xestoleberis dispar MUELLER, 1894
Plate I, fig. 8

1894 *Xestoleberis dispar* n. sp. MÜLLER, p. 334, pl. 25, figs 2, 3, 9, 35.
1982 *Xestoleberis dispar* MÜLLER – FARANDA et al., pl. 2, figs 16–17.
1986 *Xestoleberis* sp. – MOSTAFAWI, pl. 3, fig. 33.
2006 *Xestoleberis* aff. *dispar* MÜLLER – GROSS & PILLER, pp. 137–138, pl. 2, fig. 4.
2008 *Xestoleberis dispar* MÜLLER – KOEHN-ZANINETTI & TÉTARD, fig. 4/10.
2014 *Xestoleberis dispar* (MUELLER) – TER BORGH et al., fig.7/26–27.
2015 *Xestoleberis dispar* MUELLER – SCIUTO et al., pl. 2, fig. 6.
2016 *Xestoleberis dispar* MUELLER – PARLAK & NAZIK, pl. 3, fig. 14.
2017 *Xestoleberis fuscata* SCHNEIDER – DUMITRIU et al., fig. 13/H.

Dimensions: L= 660–665 µm, H= 350–370 µm, L/H= 1.80–1.88.

Stratigraphic range and geographic distribution: Badenian: Dacian Basin, Romania (TER BORGH et al. 2014); upper Badenian to lower Sarmatian: Vienna Basin, Austria (GROSS & PILLER 2006); lower Sarmatian: Carpathian Foredeep, Poland (DUMITRIU et al. 2017); Tortonian, Pleistocene: Mediterranean Sea, Greece (FARANDA et al. 2008, MOSTAFAWI 1986); Recently widely distributed in the Mediterranean Sea.

Xestoleberis tumida (REUSS, 1850)
Plate I, fig. 7

1850 *Cytherina tumida* n. sp. REUSS, pp. 57–58, pl.8, fig. 29.
2006 *Xestoleberis tumida* (REUSS) – GROSS & PILLER, pp. 134–137. pl. 48, figs 1–10, pl. 49, figs 1–5, pl. 51, fig. 7. (cum syn.)
2006 *Xestoleberis* cf. *tumida* (REUSS) – SZCZECHURA, fig. 10/2,4.

Dimensions: L= 510–540 µm, H= 320–330 µm, L/H= 1.6–1.8.

Stratigraphic range and geographic distribution: Karpatian: Molasse Basin, Austria (ZORN 1998); Badenian: Carpathian Foredeep, Poland (SZCZECHURA 2006); Austria (ZORN 1998; GROSS & PILLER 2006).

Suborder Cypridocopina BAIRD, 1845
Superfamily Cypridoidea BAIRD, 1845
Family Cyprididae BAIRD, 1845
Subfamily Cyprinotinae BRONSHTEIN, 1947
Genus *Heterocypris* CLAUS, 1892

Heterocypris salina (BRADY, 1868)
Plate II, fig. 26

1868 *Cypris salina* n. sp. BRADY, p. 368; pl. 28, figs 8–13.
1980 *Heterocypris salina salina* (BRADY) – FREELS, p.28. pl. 3, figs 1–6. cum syn.
2000 *Heterocypris salina* (BRADY) – MEISCH, pp. 349–352, fig. 135.
2003 *Heterocypris salina* (BRADY) – MISCHKE et al., fig. 1/7.
2004 *Heterocypris salina* (BRADY) – PIPÍK, p.227, pl. 1, figs 6–7.
2005 *Heterocypris salina* (BRADY) – MATZKE-KARASZ, p. 126, pl. 3, fig. 4.
2005 *Heterocypris salina* (BRADY) – SCHARF et al., pl. 2, figs 17–20.
2008 *Heterocypris salina* (BRADY) – NAZIK et al., pl. 1, fig. 15.
2008 *Heterocypris salina* (BRADY) – POQUET et al., fig. 6/I.
2012 *Heterocypris salina* (BRADY) – MISCHKE et al., pl. 1, figs 7–10, 18.
2014 *Heterocypris salina* (BRADY) – SCHARF & MEISCH, fig. 3/I–K.
2014 *Heterocypris salina* (BRADY) – MISCHKE et al., fig. 7/2.
2016 *Heterocypris salina* (BRADY) – SALEL et al., pl. 4, figs 4–6.
2019 *Heterocypris salina* (BRADY) – TUNCER et al., pl. 1, figs 1–3.

Dimensions: L= 945–955 µm, H= 565–590 µm, L/H= 1.61–1.67.

Stratigraphic range and geographic distribution: Widely distributed in upper Miocene to Holocene freshwater to saline habitats (riverine pools and lakes) in Europe (MEISCH 2000) and recently over the world.

Suborder Darwinulocopina BRADY & NORMAN, 1889
Superfamily Darwinuloidea BRADY & NORMAN, 1889
Family Darwinulidae BRADY & NORMAN, 1889
Genus *Darwinula* BRADY & NORMAN, 1889

Darwinula stevensoni (BRADY & ROBERTSON, 1870)
Plate II, fig. 21

1870 *Polycheles stevensoni* m. BRADY & ROBERTSON, pp. 25–26, pl. 7, figs 1–7, pl. 10, figs 4–14.
2000 *Darwinula stevensoni* (BRADY & ROBERTSON) – MEISCH, p. 49, fig. 16/A–E.
2004 *Darwinula stevensoni* (BRADY & ROBERTSON) – PIPÍK et al., pl. 1, fig. 10.
2005 *Darwinula stevensoni* (BRADY & ROBERTSON) – CABRAL et al., pp. 53–55, pl. 1, figs 1–6. (cum syn.)
2012 *Darwinula stevensoni* (BRADY & ROBERTSON) – FUHRMANN, pl. 1, figs 1 a–f.

Dimensions: L= 670–680 µm, H= 420–425 µm, L/H= 1.59–1.6.

Stratigraphic range and geographic distribution: Widely distributed in Oligocene to Holocene lacustrine environments in Europe (MEISCH 2000) and recently over the world.

Genus *Vestalenula* ROSSETTI & MARTENS, 1998

Vestalenula pagliolii (PINTO & KOTZIAN, 1961)
Plate II, figs 22–23; Plate III, fig. 10 (thin-section)

1961 *Darwinula pagliolii* n. sp. PINTO & KOTZIAN, p. 27, pl. 1, figs 1–5, pl. 3, figs 1–4, pl. 5, figs 1–9, pl. 6, figs 1–9, pl. 9, figs 1–9.
2003 *Vestalenula pagliolii* (PINTO & KOTZIAN) – PIPÍK & BODERGAT, p. 348, pl. 1, figs 5–10, fig. 24. (cum syn.)
2004 *Vestalenula pagliolii* (PINTO & KOTZIAN) – PIPÍK et al., pl. 1, fig. 11.
2005 *Vestalenula pagliolii* (PINTO & KOTZIAN) – CABRAL et al., pp. 59–60, pl. 3, figs 5–16.

Dimensions: L= 455–470 µm, H= 210–220 µm, L/H= 2.16–2.18.

Stratigraphic range and geographic distribution: Widely distributed in Oligocene to Holocene freshwater to oligohaline habitats (riverine pools and lakes) in Europe (MEISCH 2000) and recently in Brazil (MARTENS et al. 1997).

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Pannonian (late Miocene) ostracod fauna from Pécs-Danitzpuszta in Southern Hungary

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Pannóniai kagylósrák fauna Pécs-Danitzpusztáról

Összefoglalás

A pécs-danitzpusztai homokbányában, a kitermelt homok feküjében egy tektonikailag erősen kibillentett pannóniai márga rétegsor tárul fel. Az összlet vastagsága 65 m a szarmata–pannóniai határtól a fedő homokig. Ez a bányaudvar a pannóniai emelet aljának legjobb, rétegtanilag legteljesebb felszíni feltárása Magyarországon, ezért komplex őslénytani, rétegtani feldolgozása nemzetközi jelentőségű. Tanulmányunk a rétegsor kagylósrák-maradványainak vizsgálatáról szól. 45 preparált kőzetmintából 29 tartalmazott értékelhető, jó megtartású kagylósrák faunát, összesen 39 taxont, amelyek 9 nemet képviselnek.

A ma is élő, tengeri eredetű nemek (*Loxoconcha, Cyprideis, Amnicythere*) élőhelyeit figyelembe véve a vizsgált együttesek aránylag sekély, de hullámbázis alatti, alacsony energiájú, csendes környezetben, pliohalin (9–16‰) sótartalmú vízben élhettek. Az édesvízi eredetű bevándorlók közül a *Candona*-nem különböző alnemei nyilvánvalóan elviselték a brakkvizet is, ahogy azt a ma is élő *Typhlocypris* subgenus esetében látjuk. Ugyanez igaz lehetett arra a néhány *Cypria* fajra is, amelyek nagyon elterjedtek voltak a Pannon-tóban. A *Herpetocyprella*-nem, amelynek csak egyetlen élő faját ismerjük, de amely szintén igen elterjedt volt a Pannon-tóban, a bezáró kőzetek fáciesei alapján erősen tágtűrésű lehetett. A kihalt nemek (*Hemicytheria, Loxocorniculina, Amplocypris*) mind brakkvízi környezetben (a szarmata Paratethysben vagy brakkvízi tavakban) éltek.

Biosztratigráfiailag négy egységre osztottuk a rétegsort. Az intervallum zónák alját minden esetben egy-egy marker faj első előfordulása (vélelmezett első megjelenése) jelöli ki. A *Hemicytheria lorentheyi* zóna a pannóniai rétegsor alsó 5,5 méterét fogja át. A *Hemicytheria tenuistriata* zóna 29 m, a *Candona (Propontoniella) candeo* zóna 18 m vastag. Az *Amplocypris abscissa* zóna mintázott vastagsága 6,5 méter. A hasonló fáciesű, bár homogénebb beocsini rétegsorban, amely a Fruska Gorában található mintegy 150 km-re délkeletre Pécstől, magnetosztratigráfiai adatok alapján a szarmata-pannóniai határ kora 11,6 millió év, a *Hemicytheria tenuistriata* első megjelenésének kora 11,23 millió év, a Danitzpusztán az *Amplocypris abscissa* zónában megjelenő *Candona (Reticulocandona) reticulata* első előfordulásának kora pedig 10,2 millió év. Ezek alapján feltételezzük, hogy feltárásunkban a pannóniai márga rétegsor a 11,6 – 10 millió évek közti intervallumot képviseli.

A feltárás kagylósrák- és puhatestű zonációjának összevetése azt mutatja, hogy a *Hemicytheria lorentheyi* zóna egésze és a *H. tenuistriata* zóna legalsó része korrelálható a *Lymnocardium praeponticum – Radix croatica* zónával, míg a feltárás felső részén az *Amplocypris abscissa* zóna ad átfedést a *Lymnocardium schedelianum* zónával.

Keywords: késő Miocén, Pannon-tó, osztrakodák, őskörnyezet, biosztratigráfia, Mecsek

Abstract

The large outcrop at Pécs-Danitzpuszta, southern Hungary, exposes a 65-meter-thick succession of calcareous marls, clay marls and calcareous sands that were deposited during the early history of Lake Pannon, a vast, Caspian-type lake in Central Europe in the late Miocene. Within the framework of the complex stratigraphic investigation of this succession, well preserved, relatively diverse benthic ostracod assemblages containing 39 taxa were recovered from 29 samples (16 samples were barren). Palaeoecological interpretation of the ostracod genera suggests that deposition took place in a low-energy environment, in the shallow sublittoral zone of Lake Pannon, in pliohaline (9–16‰ salinity) water. The entire succession was divided into four interval zones based on the first occurrences of assumedly useful marker fossils: *Hemicytheria lorentheyi* Zone (from sample D29), *Hemicytheria tenuistriata* Zone (from sample D17), *Propontoniella candeo* Zone (from sample D115) and *Amplocypris abscissa* Zone (from sample D209). Based on comparison to the Beočin section 150 km to the SE, where a lithologically and stratigraphically similar section was dated magnetostratigraphically by an international team, we tentatively assume that the Pannonian marl succession of the Pécs-Danitzpuszta outcrop represents the time interval of 11.6 to ca. 10 Ma.

Keywords: late Miocene, Lake Pannon, ostracods, palaeoenvironment, biostratigraphy, Mecsek Mts

Introduction

In the large sand pit of Pécs-Danitzpuszta, which is famous for its unique middle to late Miocene reworked terrestrial and marine vertebrate remains (Szabó et al. this volume), a 65-meter-thick, tectonically tilted succession is exposed that consists of calcareous marls, clay marls and calcareous sands (Sebe et al. 2021). This Pannonian (upper Miocene, Tortonian) succession represents fairly continuous sedimentation from the Sarmatian/Pannonian boundary to the top of the marl. The marl is overlain by a thick sand body that is exploited in the pit. This succession, deposited in Lake Pannon, offers a unique opportunity to investigate various fossil groups and to establish correlation between the biostratigraphic systems.

This study focuses on the ostracod fauna of the Pannonian marls. The primary objective of this work is the documentation of the ostracod assemblages along the profile in order to determine their biostratigraphic and palaeoecological significance. Early Pannonian ostracod records are poorly known in SW Hungary (Széles 1982; Szuromi-Korecz 1991, 1992), but they were extensively studied in other parts of the southern Pannonian Basin where the lithology and thus the inferred palaeoenvironment was similar to that in Danitzpuszta, such as the areas in the vicinity of Zagreb (Sokač 1972) and Belgrade (Krstić 1960, 1985; Rundić et al. 2011). Most recently, the ostracod record from the 120-meter-thick calcareous marl succession of Beočin (near Novi Sad, Serbia) was investigated and published by Stoica & Rundić in ter Borgh et al. (2013). The Beočin outcrop was also subject to magnetostratigraphic investigations, which dated the marl succession between 11.6 Ma (Sarmatian/Pannonian boundary) and ca. 9.9 Ma (ter Borgh et al. 2013). These papers, as well as some other modern, well-documented ostracod studies on thoroughly investigated lower Pannonian outcrops from the entire area of Lake Pannon (e.g., Gross 2004, Filipescu et al. 2011, Olteanu 2011, Botka et al. 2020) offer a good opportunity to place the Danitzpuszta ostracod record into a biostratigraphic and palaeoecological framework.

Geological setting and stratigraphy

The Pécs-Danitzpuszta sand pit is the best outcrop of the oldest Pannonian (upper Miocene) strata in the Mecsek area (Kleb 1973). The pit is located at the eastern boundary of Pécs, on the north side of Highway 6 (*Figure 1*). Sand has been produced here since the beginning of the 20th century.

The stratigraphically lower part of the exposed Pannonian succession belongs to the Endrőd Formation (*Figure 2*; Sebe et al. 2015; Sebe et al. 2020). It consists of massive, greyish white calcareous marls, clay marls, sand, and even fine gravel, altogether amounting to 65 meters of stratigraphic thickness. The marls contain plant remains, a rich mollusk fauna and vertebrate fossils. Plant remains indicate a thermophilous flora with taxa suggesting extensive lakeshore swamp forests (Hably & Sebe 2016). Based on the mollusk fauna, the bottom of the succession belongs to the *Lymnocardium praeponticum* Zone, whereas the top of the marl is assigned into the *Lymnocardium schedelianum* Zone (11.6–11.4 Ma and 11–10.2 Ma respectively, according to Magyar & Geary 2012, Botka et al. 2021). The overlying limonitic, coarse-grained sands contain reworked middle Miocene (Badenian and Sarmatian) and Pannonian aquatic and terrestrial vertebrate fossils (Kazár et al. 2001, 2007; Kazár 2003; Cserpák 2018; Szabó et al. 2021), where the youngest terrestrial mammals, including the early form of *Hippotherium primigenium,* indicate the MN9/10 mammal zones (Vallesian, 11.1–8.7 Ma; Kordos in Kazár et al. 2001, 2007; Kazár 2003; Gasparik in Sebe et al. 2015).

The marl succession and partly the overlying sand and gravel beds were tilted into a near-vertical position by structural movements (Konrád & Sebe 2010). We sampled the calcareous marl succession from two measured profiles. The upper part of the marl (D114 to D219) was sampled in 2015 in the eastern part of the northern wall of the sand pit, whereas the lower part (D35 to D1) was sampled in 2018, when a new trench was digged on the top of the northern wall across the almost vertical marl layers, exposing the oldest Pannonian, Sarmatian, and Badenian deposits (*Figures 1, 2*; Sebe et al. 2021).

Material and methods

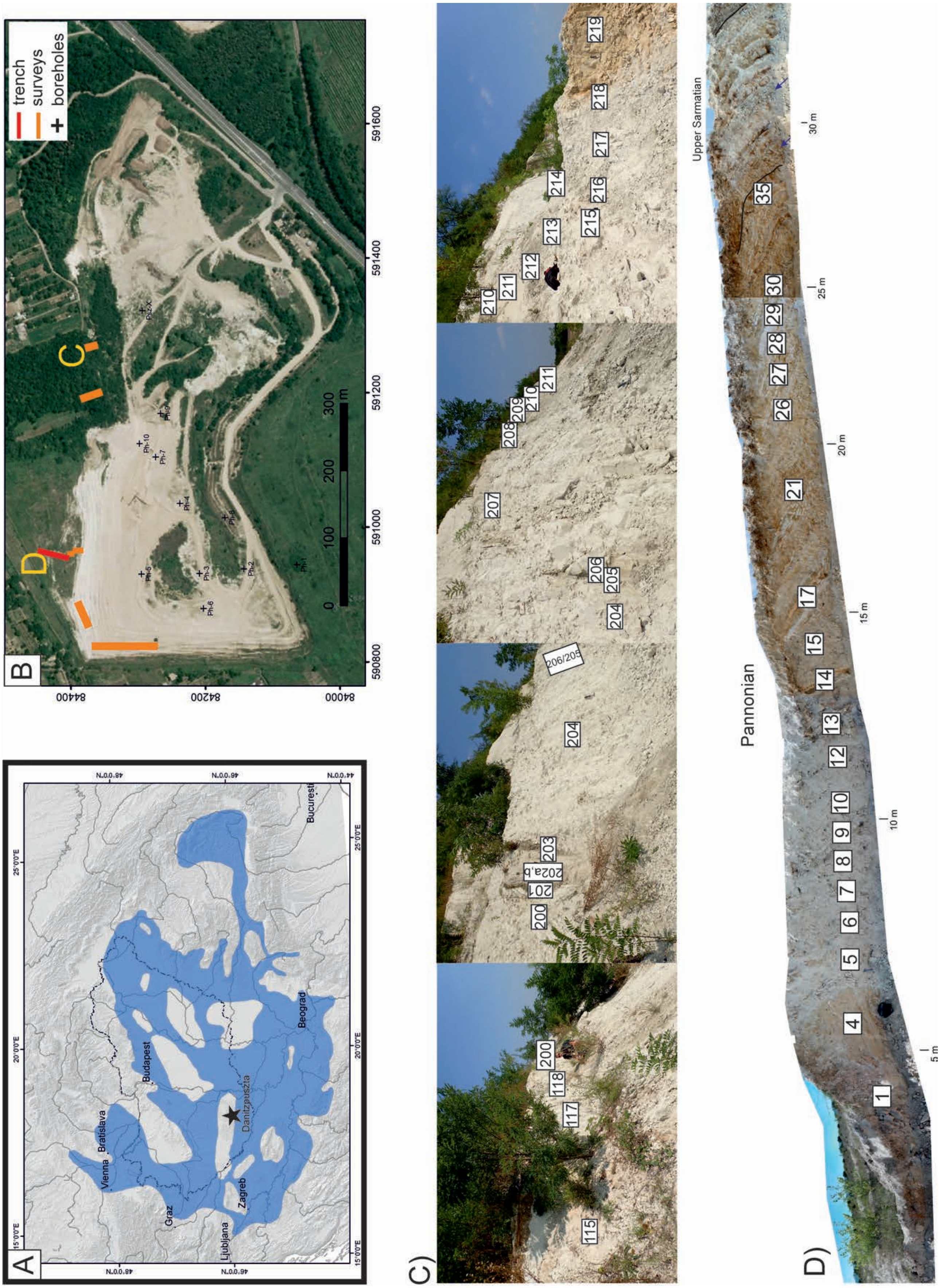
Forty-five samples were examined from the 65-meter-thick Pannonian marl succession: 20 from its lower part, exposed in the trench at the northern wall of the pit, and 25 from the upper part of the succession, in the eastern part of the outcrop (*Figure 1*). Twenty-nine samples contained ostracod carapaces and single valves, the others were free of ostracods (*Figure 3*). The carbonate skeletal microfauna was processed with hydrogen-peroxide (10%) from about 500 g of air-dried sediments. The ostracod valves were selected under stereomicroscope. Hitachi S-2600N scanning electron microscope was used for SEM investigation. SEM images were taken at the Department of Botany of the Hungarian Natural History Museum in Budapest.

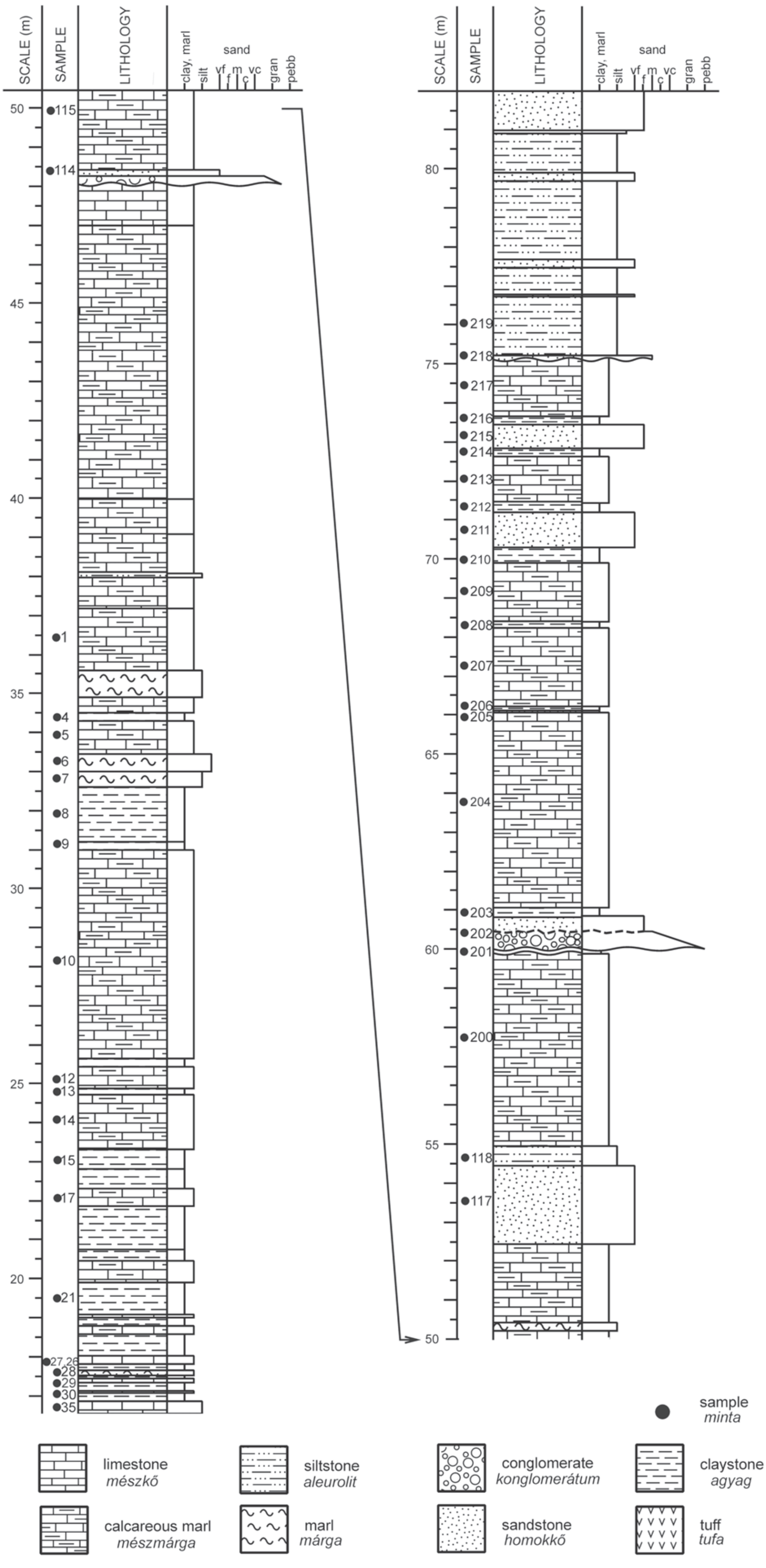
Ostracod assemblages and palaeoenvironments

The Danitzpuszta succession yielded a relatively diverse benthic ostracod material made up of 39 taxa with generally well-preserved valves (*Appendix*). Shed valves of juvenile specimens and valves of dead individuals can be preserved depending on delicacy of the valves and "valve-remains transport" (Zhai et al. 2015).

→ **Figure 1**. A) Lake Pannon within the Pannonian Basin at ca. 10.8 Ma (after Magyar et al. 1999). B) Aerial view of the Pécs-Danitzpuszta sand pit with the collection sites (C: pit, D: trench). C–D) Logged strata with the sample locations (C: pit, D: trench)

→ ***1. ábra.*** *A) A Pannon-tó kiterjedése a Pannon-medencében kb. 10,8 millió évvel ezelőtt (Magyar et al. 1999 alapján). B) A pécs-danitzpusztai homokbánya a gyűjtési helyekkel (C: bányafal, D: kutatóárok). C–D) A bányafal (C) és a kutatóárok (D) rétegsora a mintavételi helyekkel*


A
Vienna
Bratislava
Budapest
Graz
Ljubljana
Zagreb
Danitzpuszta
Beograd
Bucuresti
B
trench
surveys
boreholes
C
D
0 100 200 300 m
590800
591000
591200
591400
591600
84000
84200
84400
C)
D)
Pannonian
Upper Sarmatian
5 m
10 m
15 m
20 m
25 m
30 m

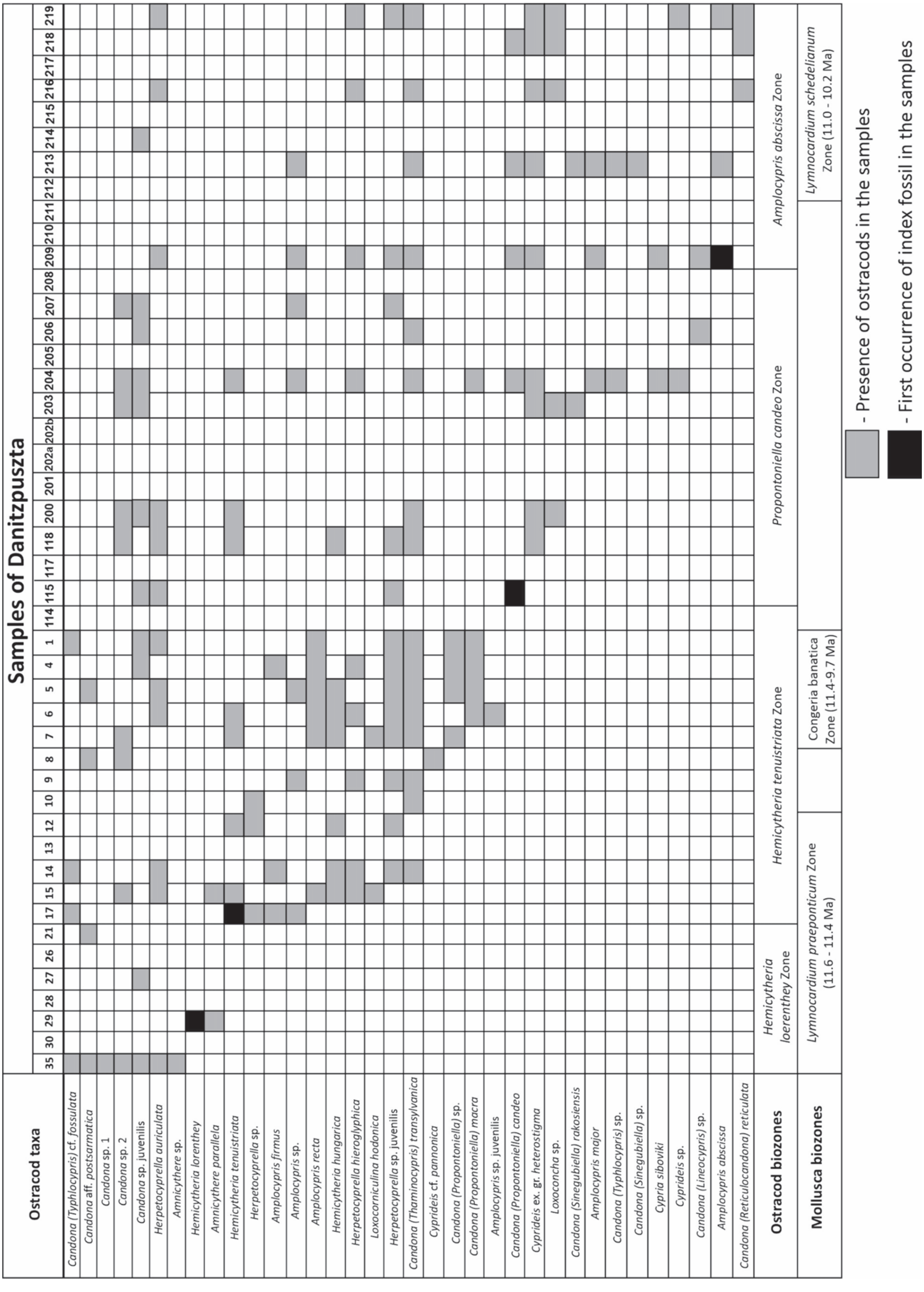


← **Figure 2.** Composite sedimentary log of the Pannonian marl with the sampled layers

← ***2. ábra.*** *A feltárt pannóniai rétegsor finomszemű (uralkodóan mészmárgából álló) részének kompozit szelvénye a mintázott rétegek számának feltüntetésével*

→ **Figure 3.** Distribution of Pannonian ostracod species across the investigated succession. First occurences of biostratigraphic marker species (according to KRSTIĆ 1985) in black. The mollusk biozones are from BOTKA et al., 2021

→ ***3. ábra.*** *A pannóniai kagylósrákok előfordulása a vizsgált szelvényben. Azoknak a fajoknak az első előfordulását, amelyeket KRSTIĆ (1985) biosztratigráfiai zónajelzőknek használt, fekete téglalapok jelzik. A puhatestű biozonációt BOTKA et al. (2021) alapján tüntettük fel*


Samples of Danitzpuszta
Ostracod taxa
35 30 29 28 27 26 21 17 15 14 13 12 10 9 8 7 6 5 4 1 114 115 117 118 200 201 202a 202b 203 204 205 206 207 208 209 210 211 212 213 214 215 216 217 218 219
Candona (Typhlocypris) cf. fossulata
Candona aff. postsarmatica
Candona sp. 1
Candona sp. 2
Candona sp. juvenilis
Herpetocyprella auriculata
Amnicythere sp.
Hemicytheria lorenthey
Amnicythere parallela
Hemicytheria tenuistriata
Herpetocyprella sp.
Amplocypris firmus
Amplocypris sp.
Amplocypris recta
Hemicytheria hungarica
Herpetocyprella hieroglyphica
Loxocorniculina hodonica
Herpetocyprella sp. juvenilis
Candona (Thaminocypris) transylvanica
Cyprideis cf. pannonica
Candona (Propontoniella) sp.
Candona (Propontoniella) macra
Amplocypris sp. juvenilis
Candona (Propontoniella) candeo
Cyprideis ex. gr. heterostigma
Loxoconcha sp.
Candona (Sinegubiella) rakosiensis
Amplocypris major
Candona (Typhlocypris) sp.
Candona (Sinegubiella) sp.
Cypria siboviki
Cyprideis sp.
Candona (Lineocypris) sp.
Amplocypris abscissa
Candona (Reticulocandona) reticulata
Ostracod biozones
Hemicytheria loerenthey Zone
Hemicytheria tenuistriata Zone
Propontoniella candeo Zone
Amplocypris abscissa Zone
Mollusca biozones
Lymnocardium praeponticum Zone (11.6 - 11.4 Ma)
Congeria banatica Zone (11.4-9.7 Ma)
Lymnocardium schedelianum Zone (11.0 - 10.2 Ma)
- Presence of ostracods in the samples
- First occurrence of index fossil in the samples

Sixteen samples were free of ostracods (*Figure 3*). No correlation was found between lithology and the barren samples; the presence or absence of benthic ostracods did not depend on the grain size of the sediments. Where ostracods were found, we did not see any indication of decreased oxygen levels. Changes in nutrient availability might have been a control on ostracod distribution, but this environmental factor is difficult to identify.

The composition of the ostracod fauna does not show any significant change across the section. Some of the identified genera (members of the Cytheroidea superfamily) are survivors of marine origin (*Amnicythere, Loxoconcha, Loxocorniculina, Cyprideis, Hemicytheria*), whereas others (members of the Cypridoidea superfamily) are considered freshwater and brackish immigrants (*Candona, Cypria, Herpetocyprella, Amplocypris*). In the following we briefly review the known habitat and (palaeo)ecological demand of each genus in order to create a basis for the environmental interpretation of our assemblages.

Amnicythere occurs in the lowermost part of the section (*Figure 3*). This genus appeared in the brackish marine Sarmatian and has radiated in the Paratethys. In addition to some sporadic occurrences in the Tortonian and lower Messinian of the Mediterranean, as many as 19 species were reported from the upper Messinian Lago-Mare deposits (GLIOZZI et al. 2005). The genus has 10 living representatives, all inhabiting fresh to oligo – mesohaline waters of the Black-Azov, Caspian and Aral Seas (GLIOZZI & GROSSI 2008, NAMIOTKO et al. 2011).

Representatives of genus *Loxoconcha* occur in the upper part of the section (*Figure 3*). This genus first appeared in the Cretaceous (MOORE 1961) or in the Palaeocene (MORKHOVEN 1963). According to SAVATENALINTON & MARTENS (2009), family Loxoconchidae includes 22 extant genera, most of them living in marine and brackish environments; only six species are known from freshwater ecosystems (KARANOVIC 2012). In the modern ostracod fauna of the Caspian Sea, *Loxoconcha* is the most eurytopic genus, hence its high density on the shelf of the South Caspian basin (GOFMAN 1966). It can be equally found on algae, on the bottom, or within the substrate (ELOFSON 1941, PURI et al. 1969). Some species dwell in the profundal zone of the Caspian (down to 875 m; BOOMER et al. 2005), but only a few species live in the agitated littoral zone with freshwater influence (GOFMAN 1966).

Loxocorniculina, an extinct genus of the family Loxoconchidae, was found in the lower part of the section (*Figure 3*). It is a typical Paratethyan form, which first appeared in the Sarmatian and spread into the Palaeo-Mediterranean during the late Messinian Lago-Mare event (FARANDA et al. 2007). The fossil *Loxocorniculina djafarovi* indicates oligohaline to mesohaline water of variable depth (IACCARINO et al. 2008).

Cyprideis occurs in the outcrop upsection from sample D8 (*Figure 3*). It first appeared at the end of the Palaeogene and spread across Eurasia and America in the Miocene. Its relatively few extant species can be found worldwide, especially in brackish and hypersaline (or otherwise chemically extreme), shallow-water environments (MORKHOVEN 1963, VAN HARTEN 1990). In the Caspian Sea, *Cyprideis torosa* was found in abundance in a sample from 13 m water depth, whereas it was completely missing from samples taken from 62 m depth and below (BOOMER et al. 2005). The phenotype (including size, shape, pores and ornaments of the valves) is influenced by environmental factors such as salinity (SANDBERG 1964; VAN HARTEN 1975, 2000; SCHWEITZER & LOHMANN 1990; BOWLES 2013). The widespread *Cyprideis pannonica*, occurring in sample D8, was observed to be characteristic for shallow, hypersaline or alkaline waters (BENSON 1973, 1978).

The extinct genus *Hemicytheria*, occurring throughout the outcrop (*Figure 3*), is mostly known from the Sarmatian and Pannonian layers of the Pannonian Basin System. It is interpreted to have lived in brackish (oligo- to pliohaline) waters, although less typically it has also been found in freshwater layers (SOKAČ 1972).

Of the genera that immigrated into Lake Pannon from freshwater and athalassic waterbodies, *Candona* is widespread throughout the outcrop (*Figure 3*). The nominal subgenus *Candona* is known to have populated freshwater lakes of the Northern Hemisphere since the Eocene (KRSTIĆ 1972b), although a few species tolerate oligo- and miohaline environments as well. BOOMER et al. (2005) reported specimens from 62 to 405 m water depth from the Caspian. Most *Candona (Candona)* species are infaunal (MORKHOVEN 1963). Subgenus *Propontoniella*, a probable ancestor of subgenus *Serbiella* (KRSTIĆ 1972b), is known exclusively from the older Pannonian deposits. The extant subgenus *Lineocypris* entered the palaeontological record in the Late Cretaceous. Today it lives in freshwater, especially in deep lakes (MORKHOVEN 1963). Subgenus *Reticulocandona* was originally endemic to Lake Pannon, but its fossils were recovered from the Pontian of Azerbaijan as well (KRSTIĆ 1972b). Subgenera *Sinegubiella* and *Thaminocypris* were endemic to Lake Pannon, although the latter was also found in the Mio-Pliocene of the Dacian basin. The first appearance of subgenus *Typhlocypris* was recorded in Lake Pannon. Its extant species are living in fresh- and athalassic waters of Europe (SOKAČ 1972).

The genus *Cypria* occurs in samples D204 and D209 (*Figure 3*). This genus is known from the Tertiary to the present day. Most of the extant species are active swimmers and prefer a freshwater, plant-rich environment (MORKHOVEN 1963; SOKAČ 1972). For instance, *Cypria ophtalmica* occurs in springs of five regions: Northern Italy, Eastern Iberia, Upper Danube, Southern Anatolia and Central and Western Europe (ROSATI et al. 2014).

The species *Herpetocyprella auriculata* and *H. hieroglyphica* occur throughout the succession (*Figure 3*). The only extant *Herpetocyprella* species, *H. mongolica* lives in the saline lake of Issyk-Kul, Kyrgyzstan (KARANOVIC 2012), while fossil species were reported from the freshwater Pliocene deposits of Central Asia (MANDELSHTAM & SHNEIDER 1963). Based on this distribution, DANIELOPOL et al. (2008) erected two hypotheses concerning the palaeoecology and palaeobiogeography of *Herpetocyprella*. According to the first hypothesis, it originally habitated shallow freshwaters, and its valves were transported into Lake Pannon. The second hypothesis claims that it was probably present in marginal environments of the Sarmatian Paratethys sea, and later it formed autochthonous populations in Lake Pannon. In the first case, adaptation of the originally freshwater genus to saline waters took place repeatedly and independently in Central Europe and later in Central Asia, whereas in the latter case a salt-tolerating species migrated from Lake Pannon to Central Asia in a stepping-stone manner, from lake to lake (Danielopol et al. 2008). We think that the common occurrence and wide geographical distribution of *Herpetocyprella* in Lake Pannon deposits (see above), with our Danitzpuszta data added, favors the second model. Rundić (2006) found that *Herpetocyprella* species ("*Hungarocypris*" in that paper) were typical nearshore dwellers, preferring sandy substrates, and that they rarely occur in fine-grained sediments. In our material, however, both *Herpetocyprella* species were found in offshore clays and silts, similarly to the Transylvanian Basin samples of Kovács et al. (2016) and Botka et al. (2020), and to the Kisalföld ("Danube") Basin samples of Cziczer et al. (2009). *Herpetocyprella auriculata* and *H. hieroglyphica* thus appear to have been rather ubiquitous species that inhabited the littoral to sublittoral and perhaps even the profundal zones of the early Lake Pannon.

The extinct genus *Amplocypris*, occurring throughout the section (*Figure 3*), is represented by at least four species in the outcrop. This genus was apparently endemic to Lake Pannon and later migrated to the Dacian Basin.

Based on the modern distribution and environmental demand of *Loxoconcha*, *Cyprideis* and *Amnicythere*, the investigated assemblages probably lived in relatively shallow but low-energy, pliohaline (9–16‰ salinity) waters in the sublittoral zone of Lake Pannon. Various subgenera of *Candona* obviously tolerated brackish water, as it is evidenced by the extant *Typhlocypris*. Probably the same applies to the few *Cypria* species that are widespread in the deposits of Lake Pannon. *Herpetocyprella* seems to have been a highly eurytopic genus. The other extinct genera, i.e., *Loxocorniculina, Hemicytheria* and *Amplocypris* were all brackish-water (oligo- to pliohaline) dwellers.

Biostratigraphy

Pannonian ostracod biostratigraphic systems are numerous (e.g. Sokač 1972, 1990; Jiřiček 1983, 1985; Krstić 1974, 1985, 1990; Szuromi-Korecz 1992; *Figure 4*). The most detailed, highest-resolution system was elaborated by Krstić (1985, 1990), based primarily on densely collected samples from outcrops in the area of the former Yugoslavia. Recently, however, several authors emphasized that the influence of the palaeoenvironmental changes on the distribution of ostracods had been underestimated, and that a reconsideration of the biozonation is needed (e.g., Gross 2004, Olteanu 2011, Stoica & Rundić in Ter Borgh et al. 2013).

Keeping the difficulties and uncertainties of Pannonian ostracod biostratigraphy in mind, we based the evaluation of the Danitzpuszta material on the stratigraphic system of Krstić (1985). However, instead of her rather vaguely defined zones, we looked for first occurrences of species, and defined our zones as interval zones between those first occurrences. We also compared our results with the ostracod record from Beočin in Serbia (Stoica & Rundić in Ter Borgh et al. 2013), where the lithology of the investigated succession and thus the inferred depositional environment is similar to that of Danitzpuszta, and where the first occurrences of ostracod species had been dated by magnetostratigraphic method (ter Borgh et al. 2013). (The correlation between the micropalaeontologically and the magnetostratigraphically investigated sections of the Beočin outcrop is missing from ter Borgh et al. 2013, but is available in the PhD thesis of ter Borgh 2013). We are confident that the relatively uniform lithology and depositional environment throughout the section lends credit to our biostratigraphic evaluation.

Based on consecutive first occurrences, we distinguished four stratigraphic intervals (interval zones) in the Danitzpuszta succession: *Hemicytheria lorentheyi* Zone (D35 to D21), *Hemicytheria tenuistriata* Zone (D17 to D114), *Propontoniella candeo* Zone (D115 to D208), and *Amplocypris abscissa* Zone (D209 to D219) (*Figure 3*).

Hemicytheria lorentheyi occurs in only one sample (D29), but this species is known to be characteristic of the lowermost Pannonian interval in other sections (e.g., Méhes 1908, Gross 2004). Other species occurring in the *Hemicytheria lorentheyi* Zone in our material include *Amnicythere parallela, Amnicythere* sp., *Herpetocyprella auriculata, Candona (Typhlocypris)* cf. *fossulata* and *C.* aff. *postsarmatica* (*Figure 3*). *Candona postsarmatica* is also considered a very basal Pannonian species, a contemporary of *Hemicytheria lorentheyi*; Szuromi-Korecz (1992) identified it in the Nagykozár–2 borehole, 4 km S of the Danitzpuszta outcrop, where it occurred in the lowermost Pannonian *Spiniferites pannonicus* Zone of the dinoflagellate biostratigraphy (Sütőné Szentai 2012).

Hemicytheria tenuistriata first occurs in sample D17 (*Figure 3*). The stratigraphic range of this species is known to overlap with that of *Hemicytheria lorentheyi*, but it has not been reported so far from the lowermost Pannonian layers. In Beočin, *H. tenuistriata* first occurs in a reversed polarity interval, interpreted to be between C5r1n and C5r.2r-1n, and thus dated at 11.23 Ma (inferred by us from data available in ter Borgh 2013). The *Hemicytheria tenuistriata* Zone in Danitzpuszta contains the following species: *Amplocypris firmus, A. recta, Amplocypris* sp., *Candona (Thaminocypris) transylvanica, C. (Typhlocypris)* cf. *fossulata, C. (Propontoniella) macra, C. (Propontoniella)* sp., *C.* aff. *postsarmatica, Candona* sp., *Cyprideis* cf. *pannonica, Hemicytheria hungarica, Herpetocyprella*

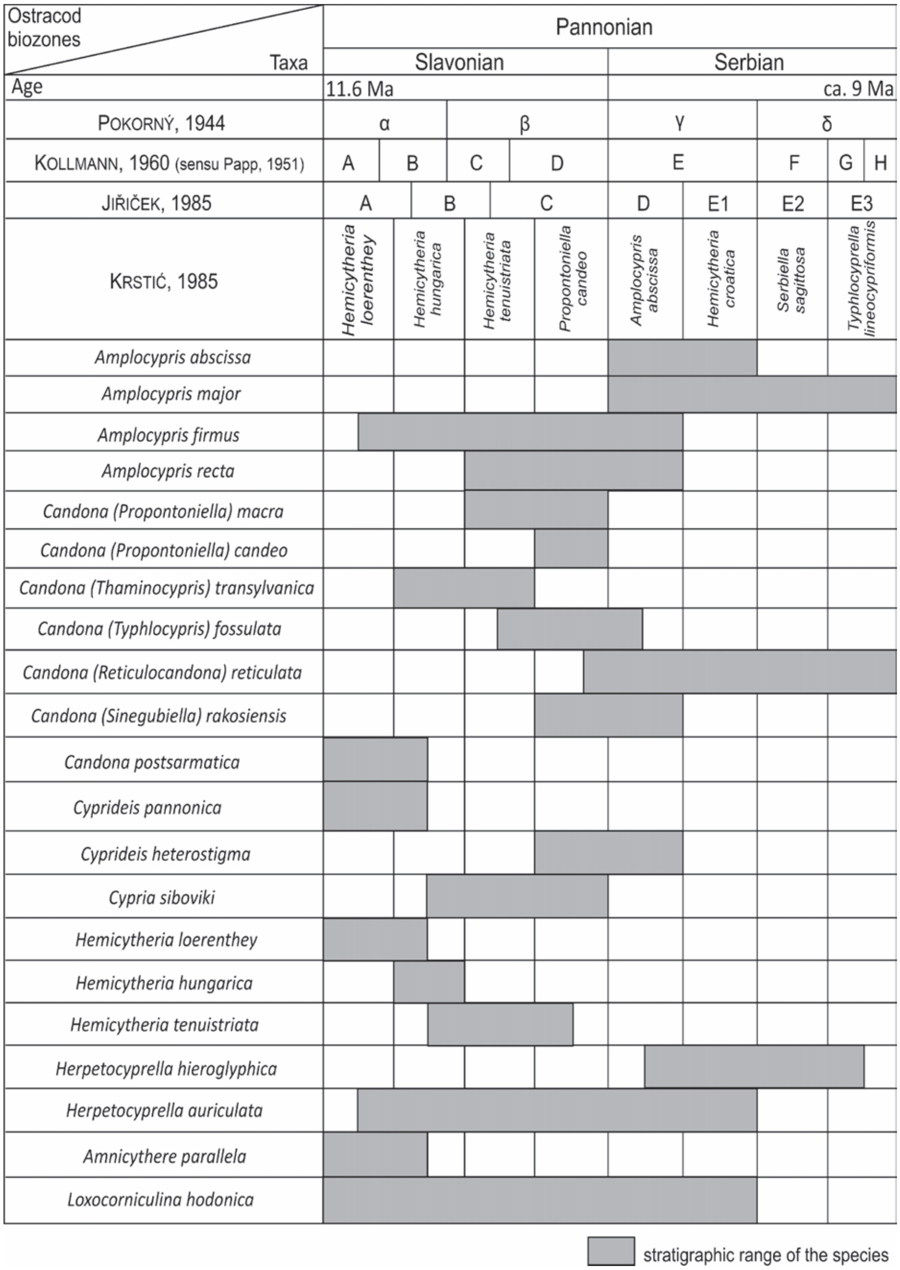


Figure 4. Literature-based stratigraphic distribution of the ostracod species identified in the Pécs-Danitzpuszta outcrop, according to POKORNY (1944), KOLLMANN (1960), JIŘIČEK (1985) and KRSTIĆ (1985). Compilation is based on KOVÁCS et al. (2016)

4. ábra. *A pécs-danitzpusztai feltárásban azonosított pannóniai kagylósrák fajok rétegtani elterjedése* POKORNÝ *(1944),* KOLLMANN *(1960),* JIŘIČEK *(1985) és* KRSTIĆ *(1985) alapján. A korreláció* KOVÁCS *et al. (2016) munkáját követi*

hieroglyphica, H. auriculata, Herpetocyprella sp., *Amnicythere parallela* and *Loxocorniculina hodonica* (*Figure 3*). *Amplocypris firmus* and *Loxocorniculina hodonica* share their first occurrence with *Hemicytheria tenuistriata* both in the Danitzpuszta and Beočin records.

Candona (Propontoniella) candeo first occurs in sample D115 (*Figure 3*). This species is missing from the Beočin record, but it was recorded in the stratigraphically thoroughly investigated succession of Guşteriţa (Sibiu, Transylvanian Basin, Romania; BOTKA et al. 2020). In that outcrop, the first occurrence of *Candona (Propontoniella) candeo* was coeval with the first occurrence of the dinoflagellate species *Pontiadinium pecsvaradense*, and the age of their first occurrence was speculated to be about 10.75 Ma. In the Danitzpuszta outcrop, however, an occurrence of *Pontiadinium pecsvaradense* is known from D1–3 (KRIZMANIĆ et al., 2021), 14–15 m below the first occurrence of *Candona (Propontoniella) candeo* in sample D115. (In fact, specimens of subgenus *Propontoniella* from samples D1, D4, D5 and D7 might belong to *Candona (Propontoniella) candeo*, but their poor preservation hindered species-level identification.) The following species occur in our *Candona*

(Propontoniella) candeo Zone: *Candona (Propontoniella) macra, C. (Sinegubiella) rakosiensis, C. (Thaminocypris) transylvanica, C. (Typhlocypris)* sp., *Cypria siboviki, Cyprideis* ex. gr. *heterostigma, Hemicytheria tenuistriata, H. hungarica, Herpetocyprella auriculata*, and *H. hieroglyphica* (*Figure 3*).

Amplocypris abscissa first occurs in sample D209 (*Figure 3*). This species was not recorded in Beočin (although a taxonomically questionable form designated „*Amplocypris* ex gr. *abscissa*" is present throughout the section, from the Sarmatian/Pannonian boundary up to the highest sample, covering the time interval of 11.6–9.9 Ma; TER BORGH et al. 2013). Other species in our *Amplocypris abscissa* Zone include *Amplocypris major, Candona (Propontoniella) candeo, C. (Reticulocandona) reticulata, C. (Sinegubiella) rakosiensis, C. (Thaminocypris) transylvanica, Cypria siboviki, Cyprideis* ex. gr. *heterostigma, Herpetocyprella auriculata, H. hieroglyphica* (*Figure 3*). *Candona (Reticulocandona) reticulata*, first occurring in sample D216, is one of the latest appearing species in the Beočin section as well; its first occurrence corresponds to ca. 10.25 Ma (assuming a constant depositional rate throughout C5n.2n in the Beočin succession).

Comparing the ostracod and mollusk zonations in the Danitzpuszta outcrop, we found that the *Hemicytheria lorentheyi* Zone and the lowermost part of the *Hemicytheria tenuistriata* Zone overlap with the *Lymnocardium praeponticum – Radix croatica* Zone. In the upper part of the section, the *Amplocypris abscissa* Zone overlaps with the *Lymnocardium schedelianum* Zone. This latter relationship is similar to that reported from the Hennersdorf section (cf., HARZHAUSER & MANDIC 2004 and DANIELOPOL et al. 2011).

Conclusions

The Pécs-Danitzpuszta outcrop yielded a characteristic limno-brackish Lake Pannon benthic ostracod fauna with well-preserved valves from 29 samples collected from the 65 meter thick Pannonian Endrőd Marl succession. Thirty-nine ostracod taxa, which belong to 9 genera, 8 families and 1 order (*Podocopida*), were identified.

Based on the ecology of extant genera and palaeoecological interpretation of the extinct ones, the studied ostracod assemblages probably lived in relatively shallow but low-energy, pliohaline (9–16‰ salinity) waters in the sublittoral zone of Lake Pannon.

Biostratigraphically, we divided the succession into four interval zones based on the first occurrence (supposed first appearance) of four species. The *Hemicytheria lorentheyi* Zone is 5.5 m thick, and represents the basal part of the Pannonian succession (from 11.6 Ma onwards). The overlying *Hemicytheria tenuistriata* Zone is 29 m thick; the first occurrence of *H. tenuistriata* in the Beočin outcrop was magnetostratigraphically dated as 11.23 Ma. The following *Candona (Propontoniella) candeo* Zone is 18 m thick. The overlying *Amplocypris abscissa* Zone was sampled in 6.5 m thickness. Because *Candona (Reticulocandona) reticulata,* first appearing in the Beočin succession at ca. 10.2 Ma, has its first occurrence in the upper part of this 6.5 m interval, we tentatively suggest that the age of the investigated Pannonian interval is 11.6–10 Ma.

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Plate I – I. tábla

The depicted specimens are adult individuals. LV = left valve, RV = right valve / *Az ábrákon felnőtt egyedek szerepelnek oldalnézetben. LV = bal teknő, RV = jobb teknő*

1 – *Amnicythere parallela* (MÉHES 1908), RV in lateral view, scale: 200 µm, D29

2 – *Cyprideis pannonica* (MÉHES 1908), RV in lateral view, scale: 500 µm, D8

3 – *Cyprideis* ex gr. *heterostigma* POKORNÝ 1952, RV in lateral view, scale: 500 µm, D219

4 – *Hemicytheria tenustriata* (MÉHES 1908), LV in lateral view, juvenile specimen, scale: 200 µm, D15.

5 – *Hemicytheria tenustriata* (MÉHES 1908), RV in lateral view, scale: 200 µm, D12

6 – *Hemicytheria lorenthey* (MÉHES 1908), RV in lateral view, scale: 500 µm, D29

7 – *Hemicytheria hungarica* (MÉHES 1908), LV in lateral view, scale: 200 µm, D15

8 – *Hemicytheria hungarica* (MÉHES 1908), RV in lateral view, scale: 250 µm, D7

9 – *Loxocorniculina hodonica* POKORNÝ 1952, RV in lateral view, scale: 250 µm, D15

10 – *Candona (Candona)* aff. *postsarmatica* KRSTIĆ 1972, LV in lateral view, scale: 500 µm, D8

11 – *Candona (Candona)* aff. *postsarmatica* KRSTIĆ 1972, RV in lateral view, scale: 500 µm, D8

12 – *Candona (Propontoniella) macra* KRSTIĆ 1972, RV in lateral view, scale: 250 µm, D4

13 – *Candona (Propontoniella) candeo* KRSTIĆ 1972, RV in lateral view, scale: 200 µm, D213

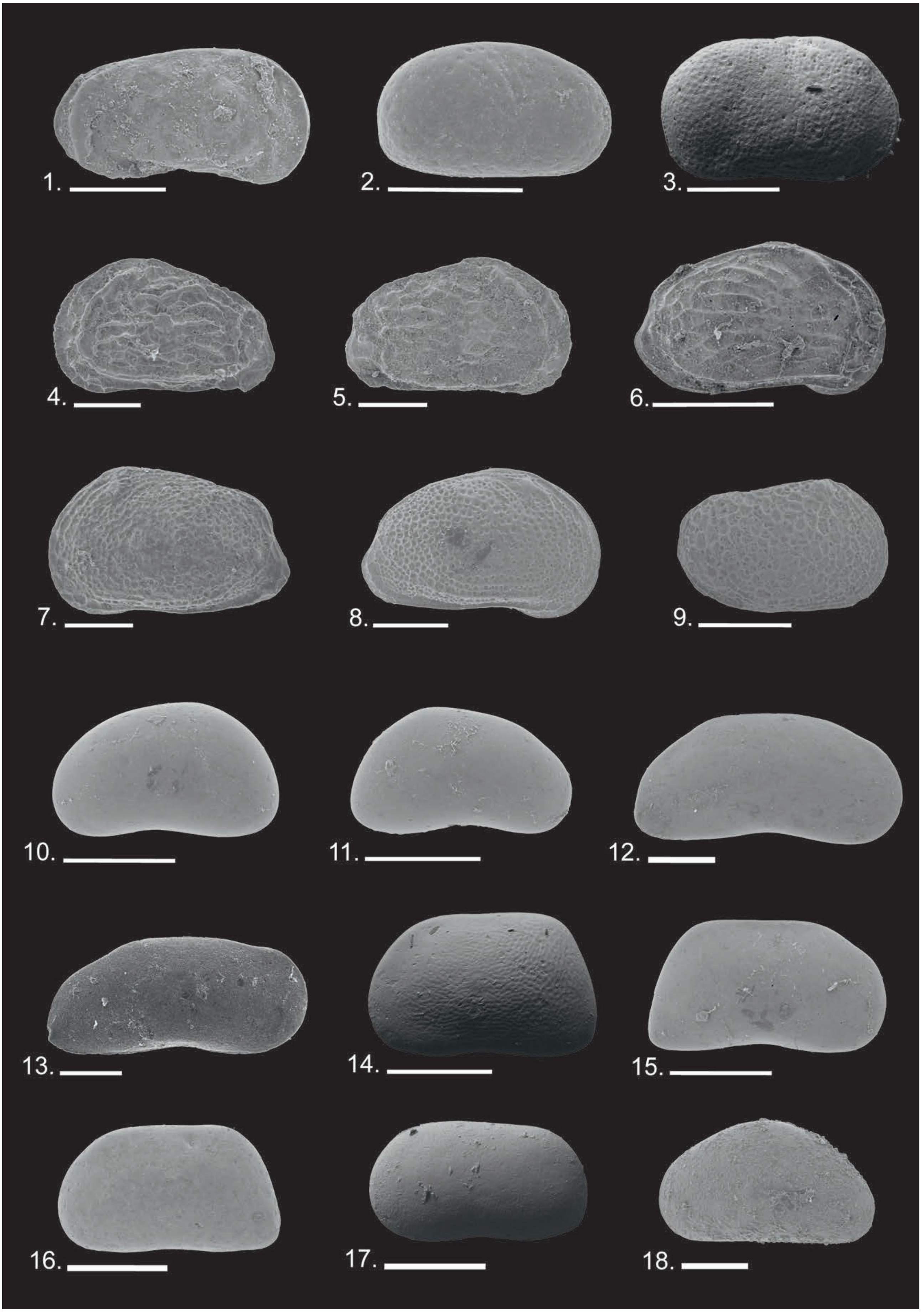
14 – *Candona (Reticulocandona) reticulata* (MÉHES 1908), LV in lateral view, scale: 500 µm, D216

15 – *Candona (Thaminocypris) transylvanica* (HÉJJAS 1894), RV in lateral view, scale: 500 µm, D4

16 – *Candona (Thaminocypris) transylvanica* (HÉJJAS 1894), LV in lateral view, scale: 500 µm, D7

17 – *Candona (Sinegubiella) rakosiensis* (MÉHES 1907), LV in lateral view, scale: 200 µm, D213

18 – *Candona (Thyphlocypris)* cf. *fossulata* POKORNÝ 1952, RV in lateral view, scale: 250 µm, D14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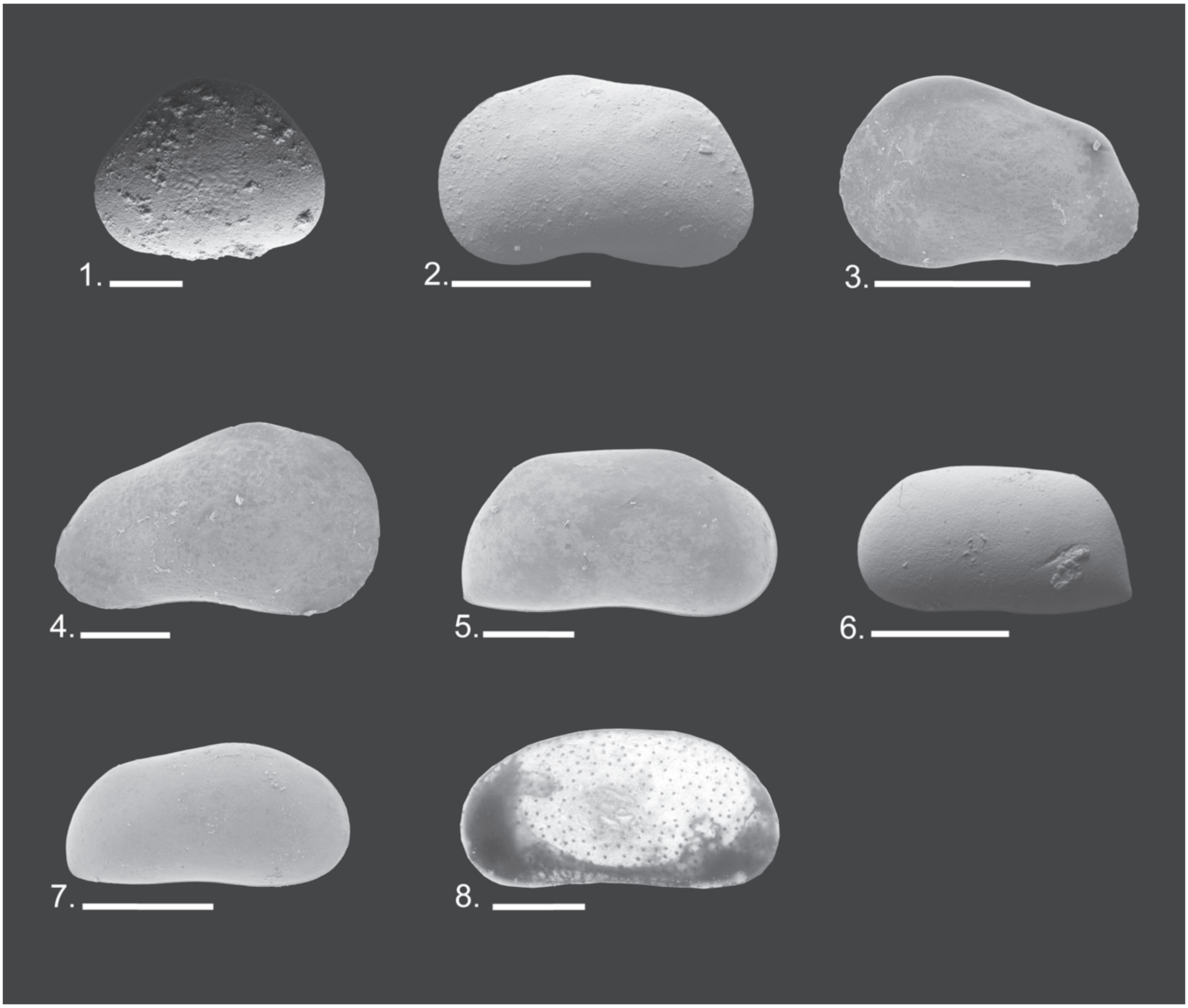

Plate II – II. tábla

Where not indicated otherwise, the depicted specimens are adult individuals. LV = left valve, RV = right valve / *A 3, 4, 6. ábrán juvenilis, a többin felnőtt egyedek szerepelnek oldalnézetben. LV = bal teknő, RV = jobb teknő*

1 – *Cypria siboviki* KRSTIĆ 1968, LV in lateral view, scale: 200 µm, D209

2 – *Herpetocyprella auriculata* (REUSS 1850), LV in lateral view, scale: 500 µm, D200

3 – *Herpetocyprella hieroglyphica* (MÉHES 1907), juvenile LV in lateral view, scale: 500 µm, D9

4 – *Herpetocyprella hieroglyphica* (MÉHES 1907), juvenile RV in lateral view, scale: 250 µm, D9

5 – *Amplocypris abscissa* (REUSS 1850), RV in lateral view, scale: 500 µm, D213

6 – *Amplocypris major* KRSTIĆ 1973, juvenile LV in lateral view, scale: 250 µm, D213

7 – *Amplocypris firmus* KRSTIĆ 1973, RV in lateral view, scale: 500 µm, D4

8 – *Amplocypris recta* (REUSS 1850), LV in lateral view, scale: 500 µm, D15

Appendix

Systematic Palaeontology

Here we follow the classification of HORNE et al. (2002) and HARTMANN & PURI (1974). The lists of synonyms and the *Stratigraphic range and geographic distribution* sections contain items which were published with proper illustrations of specimens. The Pécs-Danitzpuszta specimens are deposited in the Department of Palaeontology, Eötvös Loránd University, Budapest. Abbreviations: L: length, H: height.

Phylum Arthropoda SIEBOLD & STANNIUS 1845
Subphylum Crustacea PENNANT 1777
Class Ostracoda LATREILLE 1802
Order Podocopida MÜLLER 1894
Suborder Cytherocopina BAIRD, 1850
Superfamily Cytheroidea BAIRD, 1850
Family Leptocytheridae HANAI 1957
Genus *Amnicythere* DEVOTO 1965

Amnicythere parallela (MÉHES, 1908)
Plate I, fig. 1

1908 *Krithe parallela* n. sp. – MÉHES, pp. 550–551, pl. 10, figs 1–3.
1960 *Leptocythere parallela* (MÉHES) – KRSTIĆ, p. 279, pl. 1, figs 19–20; pl. 2, figs 22–33; pl. 3, figs 16–17; pl. 4, figs 6, 7, 10–16.
1972 *Leptocythere parallela* (MÉHES) – SOKAČ, p. 66, pl. 30, figs 4, 7–10.
1973a *Leptocythere* (*Amnicythere*) *parallela* (MÉHES) – KRSTIĆ, pp. 57–58, figs 4–11; pl. 5, figs 1–3; pl. 6, fig. 5.
1973a *Leptocythere* (*Amnicythere*) aff. *parallela* (MÉHES) – KRSTIĆ, pp. 58–59, figs 12–16; pl. 1, fig. 6.
1980 *Leptocythere parallela* (MÉHES) – IONESI & CHINTAUAN, pl. 1, fig. 3.
1982 *Leptocythere parallela* (MÉHES) – SZÉLES, p. 252, fig.12.
1985 *Leptocythere* (*Amnicythere*) aff. *parallela* (MÉHES) – KRSTIĆ, pl. 11, fig. 4.
1986 *Leptocythere parallela* (MÉHES) – IONESI & CHINTAUAN, pl. 1, fig. 8.

Material: Danitzpuszta trench (4 valves)
Dimensions: L = 485.930–583.422 µm, H = 242.577–288.425 µm, L/H = 2.003–2,23 µm
Stratigraphic range and geographic distribution: lower Sarmatian (Volhynian) and Maeotian of the Euxinian Basin and lower Pannonian of the Pannonian Basin: Sarmatian (upper Volhynian) of Southern Dobrogea (IONESI & CHINTAUAN 1986); Maeotian of Moldova (IONESI & CHINTAUAN, 1980); Pannonian of the Vienna Basin in the Czech Republic and Mt. Medvednica in Croatia (SOKAČ 1972), Sopron (Darufalva) (MÉHES 1908) and Tengelic (SZÉLES 1982) in Hungary, Prnjavor in Bosnia (KRSTIĆ 1985), and Malo Bučje, Velika Moštanica, Sibovik–5, Vrčin in Serbia (KRSTIĆ 1960, 1973a).

Family Cytherideidae SARS 1925
Subfamily Cytherideinae SARS 1925
Genus *Cyprideis* JONES 1857

Cyprideis pannonica (MÉHES, 1908)
Plate I, fig. 2

1908 *Cytheridea pannonica* n. sp. – MÉHES, pp. 553–555, pl. 11, figs 6–14.
1929 *Cytheridea pannonica* MÉHES – ZALÁNYI, p. 73, textfig 351: 10, 361: 6.
1944 *Cytheridea pannonica* MÉHES – ZALÁNYI, p. 90, p. 172.
1944 *Cyprideis pannonica* (MÉHES) – POKORNÝ, pp. 292–293, pl. 1, figs 3–4.
1960 *Cyprideis pannonica* (MÉHES) – KOLLMANN, p. 163, pl. 13, figs 1–4.
1959 *Cyprideis pannonica* (MÉHES) – ZALÁNYI, p. 213.
1963 *Cyprideis pannonica* (MÉHES) – SZÉLES, pl. 6, figs 1–2.
1966 *Cyprideis pannonica* (MÉHES) – HANGANU, pl. 40. fig. 2.
1968a. *Cyprideis* (*Cyprideis*) cf. *pannonica* (MÉHES) – KRSTIĆ, p. 111, pl. 1, figs 2–3.
1970 *Cyprideis pannonica* (MÉHES) – TRELEA et al. pp. 111–112, pl. 3, figs 10 a–c.
1973 *Cyprideis pannonica* (MÉHES) – BENSON, text–fig. 2, E–F.
1974 *Cyprideis pannonica* (MÉHES) – CERNAJSEK, pp. 473–474, pl. 2, fig. 5.
1975 *Cyprideis pannonica* (MÉHES) – IONESI & CHINTAUAN, pl. 1, fig. 3.
1976 *Cyprideis pannonica* (MÉHES) – CHINTAUAN & NICORICI, p. 12, pl. 1, figs 5–7.
1978 *Cyprideis pannonica* (MÉHES) – CARBONNEL, pl. 1, figs 11–13.
1978 *Cyprideis pannonica* (MÉHES) – BENSON, pl. 2, figs 4–8.
1979 *Cyprideis* (*Cyprideis*) *pannonica* (MÉHES) – BASSIOUNI, pp. 84–85, pl. 1, figs 1–6.
1980 *Cyprideis pannonica* (MÉHES) – IONESI & CHINTAUAN, pl. 1, fig. 2.
1983 *Cyprideis pannonica* (MÉHES) – JIŘIČEK, pl. 6, fig. 32.
1985 *Cyprideis pannonica* (MÉHES) – IONESI & CHINTAUAN, pl. 1, fig. 2.
1985 *Cyprideis pannonica* (MÉHES) – JIŘIČEK, p. 396, pl. 53, figs 1–4.
1990 *Cyprideis* (*Cyprideis*) ex. gr. *pannonica* – KRSTIĆ & STANCHEVA, pl. 9, fig. 10.

1996 *Cyprideis pannonica* (MÉHES) – ÜNAL, p. 92, pl. 1, fig. 9–11.
1998 *Cyprideis pannonica* (MÉHES) – KOVÁČ et al., pl. 4, figs 5–6.
2000 *Cyprideis pannonica* (MÉHES) – CHINTAUAN, pl. 1, fig. 7.
2001 *Cyprideis pannonica* (MÉHES) – TUNOĞLU & ÜNAL, p. 171, pl. 1, fig. 8.
2005 *Cyprideis pannonica* (MÉHES) – RADU & STOICA, pl. 2, figs 9–11.
2008 *Cyprideis pannonica* (MÉHES) – NAZIK et al., pl. 1, figs 8–9.
2008 *Cyprideis pannonica* (MÉHES) – BEKER et al., p. 9, pl. 1, figs 1–3.
2011 *Cyprideis pannonica* (MÉHES, 1908) – WITT, pl. 1, fig. 1.
2011 *Cyprideis pannonica* (MÉHES) – FILIPESCU et al., text-fig. 5, fig. 15.
2013 *Cyprideis pannonica* (MÉHES) – STOICA et al., pl. 2, fig. 1.

Material: Danitzpuszta trench (4 valves)

Dimensions: L = 851.243–875 μm H = 475.02–501.493 μm, L/H = 1.745–1.792

Stratigraphic range and geographic distribution: Sarmatian to Pannonian of the Pannonian Basin system, Sarmatian to Meotian of the Dacian Basin, Sarmatian of the Euxinian Basin, upper Miocene of the Aegean Basin, Messinian of the Eastern Mediterranean Basin, upper Miocene to Plio-Pleistocene of continental Turkey: Sarmatian in Nexing in Austria (CERNAJSEK 1974); Tusa (CHINTAUAN & NICORICI 1976), Livezile (CHINTAUAN 2000), and Oarba de Mureş (FILIPESCU et al. 2011) in Transylvania, Romania; Pannonian in Malacky M–16 borehole in Slovakia (KOVÁČ et al. 1998); Hodonín (POKORNÝ 1944; JIŘIČEK 1983, 1985) and Svatobořice–Mistřín (CARBONNEL 1978) in the Czech Republic; Drassburg in Austria (KOLLMANN 1960); Sopron, Peremarton, Budapest–Kőbánya, Tiszttaberek, Duna–Tisza Interfluve (MÉHES, 1908, ZALÁNYI 1944, SZÉLES 1963) and Tihany (ZALÁNYI 1959) in Hungary; Badnjevac, Varovnica in Serbia (ZALÁNYI 1929, KRSTIĆ 1968a); Krško in Slovenia (KRSTIĆ & STANCHEVA 1990); Szócsán/Soceni in Transylvania, Romania (MÉHES 1908); Sarmatian in Hârlău (TRELEA et al. 1970, RADU & STOICA 2005), Siret and Moldova valleys (IONESI & CHINTAUAN 1975, 1980) in Romania; Meotian at Teleajen river, Prahova, Brăteşti (HANGANU 1966, IONESI & CHINTAUAN, 1980) and Rămnicu Sărat (STOICA et al. 2013) in Romania; Sarmatian in Pinarhisar in Turkey (WITT 2011) and Văleni (Dobrogea) in Romania (IONESI & CHINTAUAN 1985); ?upper Miocene („Pannonian and Pontian") in Gelibolu BE–18 in Turkey (ÜNAL 1996; TUNOĞLU & ÜNAL 2001); Messinian in DSDP Leg 42A, Site 376, Florence Rise, W of Cyprus (BENSON 1978) and DSDP Leg 13, Site 129, Hole 129A, Levantine Basin (BENSON 1973); upper Miocene in Arguvan, Malatya in Turkey (BASSIOUNI 1979; NAZIK et al. 2008); Plio-Pleistocene in Karapınar-Konya in Turkey (BEKER et al. 2008).

Cyprideis ex gr. *heterostigma* POKORNÝ, 1952
Plate I, fig. 3

Material: Danitzpuszta pit (256 valves, 1 carapace)

Dimensions: L = 570.382–1130 μm, H = 309.585–663 μm, L/H = 1.704–1.842

Remarks: The anterodorsal outline shows a variability in convexity, maybe due to sexual dimorphism. There is significant variability in the convexity of the valves as well; it is difficult to decide whether it reflects intraspecific variation or higher convexity is a diagnostic morphological character of another species. There are more adults than juveniles.

Family Hemicytheridae PURI 1953
Subfamily Hemicytherinae PURI 1953
Genus *Hemicytheria* POKORNÝ 1952

Hemicytheria tenuistriata (MÉHES, 1908)
Plate I, figs 4–5

1908 *Cythereis tenuistriata* n. sp. – MÉHES, pp. 559–561, text-figs 5–10.
1985 *Graptocythere (Hemicytheria) tenuistriata* (MÉHES) – KRSTIĆ, pl. 13, fig. 5.
2011 *Hemicytheria tenuistriata* (MÉHES) – OLTEANU, pl. 26, fig. 8.
2013 *Hemicytheria tenuistriata* (MÉHES) – TER BORGH et al., pl. 8, fig. 5.

Material: Danitzpuszta pit (13 valves); Danitzpuszta trench (19 valves)

Dimensions: L = 399–802.624 μm H = 247–476.447 μm, L/H = 1.615–1.685

Stratigraphic range and geographic distribution: lower Pannonian in the Pannonian Basin: Sopron in Hungary (MÉHES 1908); Velika Moštanica (KRSTIĆ 1985) and Beočin (TER BORGH et al. 2013) in Serbia.

Hemicytheria lorentheyi (MÉHES, 1908)
Plate I, fig. 6

1908 *Cythereis Lőrentheyi* n. sp. – MÉHES, pp. 561–562, pl. 8, figs 1–6.
1960 *Hemicytheria lőrentheyi* (MÉHES) – KRSTIĆ, p.280, pl. 1, fig. 23; pl. 3, fig. 20; pl. 4, fig. 5.
1969 *Hemicytheria* cf. *loerenthei* (MÉHES) – GRAMANN, pp. 501, pl. 35, fig. 4.
1972 *Hemicytheria lőrentheyi* (MÉHES) – IONESI & CHINTAUAN, pp. 101–102, pl. 5, fig. 4.
1983 *Hemicytheria lorentheyi* (MÉHES) – JIŘIČEK, pl. 6, fig. 31.
1985 *Hemicytheria lorentheyi* (MÉHES) – JIŘIČEK, p. 405, pl. 56, figs 4–6.
2004 *Hemicytheria lorentheyi* (MÉHES) – GROSS, p. 86, pl. 13, figs 5–6; pl. 14 fig. 9.

Material: Danitzpuszta trench (1 valve)

Dimensions: L = 1003.76 μm H = 591.47 μm, L/H = 1.697

Stratigraphic range and geographic distribution: Sarmatian of the Euxinian Basin, lower Pannonian of the Pannonian Basin, and Messinian (Meotian–Pontian) of the Aegean (Strymon) Basin: Sarmatian of Moldova (IONESI & CHINTAUAN, 1972); lower Pannonian of Sopron, Budapest–Kőbánya, Peremarton, Hungary (MÉHES 1908); Belgrade, Serbia (KRSTIĆ 1960); Mataschen, Austria (GROSS 2004); Bučany–48, Slovakia (JIŘIČEK 1983); Mutěnice, Czech Republic (JIŘIČEK, 1985); Messinian (Meotian–Pontian) of Strymon Basin (GRAMANN 1969).

Hemicytheria hungarica (Méhes, 1908)
Plate I. figs 7–8

1908 *Cythereis hungarica* n. sp. – Méhes, pp. 562–563, pl. 8, figs 7–9.
2009 *Hemicytheria hungarica* (Méhes) – Tóth, p. 89, pl. 5, figs 4–5 cum. syn.
2010 *Hemicytheria hungarica* (Méhes) – Zorn, p. 266, pl. 1, fig. 13.

Material: Danitzpuszta pit (6 valves); Danitzpuszta trench (27 valves)

Dimensions: L = 531.444–823.895 µm H = 301.321–483.859 µm, L/H =1.703–1.763

Stratigraphic range and geographic distribution: Sarmatian of the Euxinian Basin, Sarmatian and lower Pannonian of the Pannonian Basin system: Sarmatian of the Caucasus region (Schneider, 1953); Sarmatian of the Danube Basin, Slovakia (Dornič & Kheil 1963) and Csákvár, Hungary (Tóth 2009); lower Pannonian of Sopron (Darufalva) and Budapest–Kőbánya in Hungary (Méhes 1908); Prnjavor in Bosnia (Krstić 1985); Drassburg in Austria (Zorn 2010).

Family Loxoconchidae Sars 1925
Genus *Loxocorniculina* Krstić 1972

Loxocorniculina hodonica Pokorný, 1952
Plate I, fig. 9

1952 *Loxoconcha hodonica* n. sp. – Pokorný, pp. 308–309, pl. 5, figs 1, 2, 9, figs 36–37.
1960 *Loxoconcha hodonica* Pokorný – Krstić, p. 281, pl. 2, fig. 28.
1963 *Loxoconcha hodonica* Pokorný – Grekoff & molinari, p. 5, pl.2, figs 5–6.
1966 *Loxoconcha hodonica* Pokorný – Hanganu, pl. 43, fig. 3.
1969 *Loxoconcha* cf. *hodonica* Pokorný – Gramann, pp. 509–510, pl. 34, figs 1–2.
1972 *Loxoconcha hodonica* Pokorný – Sokač, pp. 84–85, pl. 44, figs 6–7.
1972a. *Loxoconcha* (*Loxocorniculina*) *hodonica* Pokorný – Krstić, p. 253, pl. 4, fig. 7; pl. 6, figs 4–6.
1972 *Loxoconcha hodonica* Pokorný – Sissingh, p. 133, pl. 10, figs 15–16.
1985 *Loxoconcha* (*Loxocorniculina*) *hodonica* Pokorný – Krstić, pl. 12, fig. 10.
2013 *Loxocorniculina hodonica* (Pokorný) – ter Borgh et al., text-fig. 8, 30.
2016 *Loxocorniculina hodonica* Pokorný – Kovács et al., pl. 3, figs 2–3.

Material: Danitzpuszta trench (4 valves)

Dimensions: L = 475–535.852 µm H = 322.242–325 µm, L/H= 1.474–1.648

Stratigraphic range and geographic distribution: lower Pannonian of the Pannonian Basin system, Meotian of the Dacian Basin, Messinian of the Mediterranean Basin: lower Pannonian of Hodonín in the Czech Republic (Pokorný 1952); Mt. Medvednica in Croatia (Sokač 1972); Velika Moštanica, Sibovik–2a, Velika Plana, Vrčin, Belgrade, Makiš, and Beočin in Serbia (Krstić 1960, 1972a, 1985; ter Borgh et al. 2013); Lopadea Veche and Gârboviţa in Transylvania, Romania (Kovács et al. 2016); Maeotian of Teleajen River valley, Prahova in Romania (Hanganu 1966); Messinian (Meotian–Pontian) of the Strymon Basin (Gramann 1969); Messinian (?) of Crete (Sissingh 1972); Messinian of Reggio Emilia in Italy (Grekoff & Molinari 1963).

Superfamily Cypridoidea Baird 1845
Family Candonidae Kaufmann 1900
Subfamily Candoninae Kaufmann 1900
Genus *Candona* Baird 1845

Candona (Candona) aff. *postsarmatica* Krstić, 1972
Plate I, figs 10–11

1972b. *Candona* (*Candona*) *postsarmatica* n. sp. – Krstić, pp. 9–11, pl. 2, figs 4–6; p. 113.
1972b. *Candona* aff. *postsarmatica* n. sp. – Krstić, pl. 4, fig. 2.
1980a. *Candona (Candona)* aff. *postsarmatica* Krstić – Krstić, fig. 10.
1985 *Candona (Candona) postsarmatica* Krstić – Krstić, pl. 3, fig. 2.
2011 *Candona (Caspiocypris) postsarmatica* – Olteanu, pl. 2, fig. 1.
2013 *Candona (Caspiocypris) postsarmatica* – Mazzini et al., pl. 2, fig. e.

Material: Danitzpuszta trench (10 valves)

Dimensions: L = 971.880–1000.739 µm H = 511.266–554.633 µm, L/H = 1.804–1.9

Remark: In her original publication Krstić depicted only females, without giving their size. Our specimens have more rounded outline, but it is difficult to decide if this difference is due to sexual dimorphism, ontogenetic state, or our material represents a different species.

Stratigraphic range and geographic distribution of C. postsarmatica: lower Pannonian of the Pannonian Basin system, Tortonian of Turkey: lower Pannonian of Belgrade and Aleksinac in Serbia (Krstić 1972b, 1980a, 1985); Carand in Transylvania, Romania (Olteanu 2011); Tortonian of Çankiri Basin, Tuğlu, in Turkey (Mazzini et al. 2013).

Candona (Propontoniella) macra Krstić, 1972
Plate I, fig. 12

1972b. *Candona (Propontoniella) macra* – Krstić, pp. 35–36, pl. 11, figs 15–18, p. 123.
1985 *Candona (Propontoniella) macra* – Krstić, pl. 1, fig. 9.
2016 *Candona (Propontoniella) macra* Krstić – Kovács et al., pl. 2, figs 9–12.
2019 *Propontoniella macra* – Spadi et al., text–fig 3, I; text–fig 16, F–I.

Material: Danitzpuszta pit (2 valves); Danitzpuszta trench (15 valves)

Dimensions: L = 725–984.157 µm H = 350–442.223 µm, L/H = 2.071–2.225

Stratigraphic range and geographic distribution: lower Pannonian of the Pannonian Basin system: Vranović–1, Mt.

Krndija, Croatia (SPADI et al. 2019); Velika Moštanica, Sibovik (Belgrade) in Serbia (KRSTIĆ 1972b, 1985); Cunța in Transylvania, Romania (KOVÁCS et al. 2016).

Candona (Propontoniella) candeo KRSTIĆ, 1972
Plate I, fig. 13

1972b. *Candona (Propontoniella) candeo* – KRSTIĆ, pp. 36–37, pl. 4, fig. 10; pl. 11, figs 1–4, figs 29–32; p. 124.
1985 *Candona (Propontoniella) candeo* – KRSTIĆ, pl. 2, fig. 3–6.

Material: Danitzpuszta pit (29 valves)
Dimensions: L = 736.87–827.2 µm H = 339.65–359.49 µm L/H = 2.3–2.44
Stratigraphic range and geographic distribution: lower Pannonian of the Pannonian Basin: Velika Moštanica, Sibovik creek in Serbia (KRSTIĆ 1972b, 1985).

Candona (Reticulocandona) reticulata (MÉHES, 1907)
Plate I, fig. 14

1907 *Aglaia reticulata* n. sp. – MÉHES, pp. 442–443, pl. 3, figs 10–14.
1962 *Candona (Lineocypris) reticulata* (MÉHES) – SOKAČ, pl. 1, fig. 6.
1963 *Candona (Lineocypris) reticulata* MÉHES – SZÉLES, pl. 5, fig. 5.
1971 *Candona (Lineocypris) reticulata* (MÉHES) – OLTEANU, p. 91, pl. 3, fig. 3.
1972b. *Candona (Reticulocandona) reticulata* (MÉHES) – KRSTIĆ, pp. 59–60, pl. 17, figs 1–2, 6–7; pl. 24, fig. 7; figs 48–49.
1972 *Candona (Lineocypris) reticulata* (MÉHES) – SOKAČ, pp. 53–54, pl. 23, figs 12–16.
1980b. *Candona (Reticulocandona) reticulata* (MÉHES) – KRSTIĆ, pl. 2, figs 4–6.
1982 *Candona (Lineocypris) reticulata* MÉHES – SZÉLES, p. 241, pl. 4, figs 2, 4–5.
2011 *Candona (Reticulocandona) reticulata* (MÉHES) – OLTEANU, pl. 9, fig. 4.
2011 *Reticulocandona reticulata* (MÉHES) – RUNDIĆ et al., pl. 9, figs 9–10.

Material: Danitzpuszta pit (10 valves)
Dimensions: L = 476.585–530.056 µm, H = 276.246–333.957 µm, L/H = 1.587–1.725
Remark: Although the the posterodorsal rim is variable, each individual has a diagnostic fine reticulation on the valve surface.
Stratigraphic range and geographic distribution: Pannonian of the Pannonian Basin: Szócsán/Soceni in Transylvania, Romania (MÉHES 1907); Budapest–Kőbánya, Danube–Tisza Interfluve, Tengelic in Hungary (MÉHES 1907; SZÉLES 1963, 1982); Mt. Medvednica in Croatia (SOKAČ 1962, 1972); Beočin, Belgrade (ZV–3) in Serbia (KRSTIĆ 1972b, 1980b; RUNDIĆ et al. 2011); Groşi, Rieni in Transylvania, Romania (OLTEANU 1971, 2011).

Candona (Thaminocypris) transylvanica (HÉJJAS, 1894)
Plate I, figs 15–16

1894 *Candona reticulata* n. sp. – HÉJJAS, p. 63, pl. 4, figs 14 a, b, c.
1972b. *Candona* (*Thaminocypris*) cf. *transylvanica* (HÉJJAS) – KRSTIĆ, pp. 63–64, pl. 18, fig. 8.
2016 *Candona* (*Caspiocypris*) *transilvanica* (HÉJJAS) – KOVÁCS et al., pl. 2, figs 5–8, 13–15.

Material: Danitzpuszta pit (18 valves); Danitzpuszta trench (40 valves)
Dimensions: L = 1035.667–1128.067 µm H = 558.371–669.064 µm, L/H = 1.686–1.854
Stratigraphic range and geographic distribution: lower Pannonian of the Pannonian Basin: Belgrade ("London" C–2) in Serbia (KRSTIĆ 1972b); Târgu Mureş, Băgău, Miercurea Nirajului, Lopadea Veche, Gârbovița, Cunța in Transylvania, Romania (HÉJJAS 1894, KOVÁCS et al. 2016).

Candona (Sinegubiella) rakosiensis (MÉHES, 1907)
Plate I, fig. 17

1907 *Aglaia rákosiensis* n. sp. – MÉHES, pp. 513–514, pl. 6, figs 8–13.
1972b. *Candona* (*Sinegubiella*) *rakosiensis* (MÉHES) – KRSTIĆ, p. 80, pl. 25, figs 8–11, pl. 30, fig. 1.
1972 *Candona* (*Caspiocypris*) *rakosiensis* (MÉHES) – SOKAČ, p. 39, pl. 15, figs 1–3.

Material: Danitzpuszta pit (4 valves)
Dimensions: L = 440–549.131 µm H = 230–289.469 µm, L/H = 1.897–1.913
Stratigraphic range and geographic distribution: lower Pannonian of the Pannonian Basin: Sopron, Budapest–Kőbánya in Hungary (MÉHES 1907); Mt. Medvednica in Croatia (SOKAČ 1972); Đurinci in Serbia (KRSTIĆ 1972b).

Candona (Typhlocypris) cf. *fossulata* POKORNÝ, 1952
Plate I, fig. 18

1952 *Candona fossulata* n. sp. – POKORNÝ, pp. 264–266, text–fig. 11, 12; pl. 2 fig. 1.
1972 *Candona (Typhlocypris) fossulata* POKORNÝ – SOKAČ, pp. 59–60, pl. 28, fig. 1.
1972b. *Candona (Typhlocypris)* aff. *fossulata* POKORNÝ – KRSTIĆ, p. 84, pl. 24, fig. 12; pl. 27, figs 4–7.
1980 *Candona (Typhlocypris)* ex. gr. *fossulata* POKORNÝ – FREELS, pp. 63–64, pl. 9, figs 21–26.

Material: Danitzpuszta trench (10 valves)
Dimensions: L = 828.630–1025 µm H = 460.177–550 µm, L/H = 1.801–1.863
Remark: The postero-dorsal and the ventral margin is more rounded than in the holotype.
Stratigraphic range and geographic distribution of C. fossulata: lower Pannonian of the Pannonian Basin, upper Miocene of Turkey: lower Pannonian in Hodonín in Czech Republic (POKORNÝ 1952); Mt. Medvednica in Croatia (SOKAČ 1972); Karagača creek in Serbia (KRSTIĆ 1972b); upper Miocene of Denizli basin in Turkey (FREELS 1980).

Subfamily *Cyclocypridinae* KAUFMANN 1900
Genus *Cypria* FISCHER 1855

Cypria siboviki KRSTIĆ, 1968
Plate II, fig 1

1968b. *Cypria siboviki* n. sp. – KRSTIĆ, p. 247–248, pl. 66, figs 1–2.
1972 *Cypria siboviki* KRSTIĆ – SOKAČ, pp. 64, pl. 24, figs 15–16, 19.
1975 *Cypria siboviki* KRSTIĆ – KRSTIĆ, p. 195–196, pl. 1, figs 1–2.
1975 *Cypria* aff. *siboviki* KRSTIĆ – KRSTIĆ, pl. 1, fig. 3.

Material: Danitzpuszta pit (2 valves)

Dimensions: L = 485–500.1 µm, H = 350–373.215 µm, L/H = 1.340–1,386

Stratigraphic range and geographic distribution: lower Pannonian of the Pannonian Basin: Mt. Medvednica in Croatia (SOKAČ 1972); Velika Moštanica, Sibovik 7/2 in Serbia (KRSTIĆ 1968b, 1975).

Family *Cyprididae* BAIRD 1845
Genus *Herpetocyprella* DADAY 1909

Herpetocyprella auriculata (REUSS, 1850)
Plate II, fig. 2

1850 *Cypridina auriculata* n. sp. – REUSS, p. 51, pl. 8, fig. 8.
1991 *Hungarocypris auriculata* (REUSS) – SZUROMI-KORECZ, pp. 225–228, pl. 17, figs 1–8, cum syn.
2008 *Herpetocyprella auriculata* (REUSS) – DANIELOPOL et al., p. 152, text-figs 2 C, D; 3A, C; 4 A–C, 10 D, E.
2011 *Hungarocypris auriculata* (REUSS) – OLTEANU, pl. 1, figs 2, 4–7, 9–10.
2016 *Herpetocyprella auriculata* (REUSS) – KOVÁCS et al., pl. 1, figs 6–10.

Materials: Danitzpuszta pit (35 valves); Danitzpuszta trench (22 valves)

Dimensions: L = 1166–675 µm H = 646–875 µm, L/H = 1.805–1.914

Stratigraphic range and geographic distribution: Pannonian of the Pannonian Basin system: Vienna (REUSS 1850) and Sankt Margarethen (DANIELOPOL et al. 2008) in Austria; Muteniče, Svatoborice, Hodonín, Stavěšice in the Czech Republic (POKORNÝ 1944, 1952; JIŘIČEK 1983, 1985; DANIELOPOL et al. 2008); Sopron, Tengelic, Nagykozárd, Máriakéménd, Tisztaberek in Hungary (MÉHES 1907, ZALÁNYI 1944, SZÉLES 1982, SZUROMI-KORECZ 1991); Mt. Medvednica in Croatia (SOKAČ 1972); Belgrade, Velika Moštanica, Sibovik 9, Đurinci in Serbia (KRSTIĆ 1973b, 1985); Holod, Şoimi (OLTEANU 2011), Gârboviţa, and Cunţa (KOVÁCS et al. 2016) in Transylvania, Romania.

Herpetocyprella hieroglyphica (MÉHES, 1907)
Plate II, fig. 3–4

1907 *Cypris hieroglyphica* n. sp. – MÉHES, p. 508, pl. 3, figs 15–19.
1991 *Hungarocypris hieroglyphica* (MÉHES) – SZUROMI-KORECZ, pp. 228–230, pl. 18, figs 1–2, cum syn.
2008 *Herpetocyprella hieroglyphica* (MÉHES) – DANIELOPOL et al., p. 153, text-fig. 11.
2011 *Hungarocypris hieroglyphica* (MÉHES) – OLTEANU, pl. 1, figs 1, 3, 8.
2016 *Herpetocyprella hieroglyphica* (MÉHES) – KOVÁCS et al., pl. 1, figs 1–5.

Materials: Danitzpuszta pit (25 valves); Danitzpuszta trench (13 valves)

Dimensions: L = 950.438–1807.306 µm H = 561.818–909.175 µm, L/H = 1,691 –1,987

Stratigraphic range and geographic distribution: lower Pannonian of the Pannonian Basin system: Danube–Tisza Interfluve in Hungary (SZÉLES 1963); Hodonín (JIŘIČEK 1985) and Stavěšice (DANIELOPOL et al. 2008) in the Czech Republic; Mt. Medvednica in Croatia (SOKAČ 1967, 1972); Vrčin, Karagača creek in Serbia (KRSTIĆ 1960, 1973b, 1985); Szócsán/Soceni (MÉHES 1907, DANIELOPOL et al. 2008), Şoimi, Holod (OLTEANU 1971, 2011), Lopadea, Gârboviţa, Cunţa (KOVÁCS et al. 2016) in Transylvania, Romania.

Subfamily Cypridopsinae BRONSTEIN 1947
Genus *Amplocypris* ZALÁNYI 1944

Amplocypris abscissa (REUSS, 1850)
Plate II, fig. 5

1972 *Amplocypris abscissa* (REUSS) – SOKAČ, p. 36, pl. 11, figs 2, 4, 6; pl. 13, figs 2, 4, 5–6.
1973c. *Amplocypris abscissa* (REUSS) – KRSTIĆ, pp. 102–103, pl. 1 fig. 4; pl. 4, figs 3–4, pl. 8, fig. 1.
1983 *Amplocypris abscissa* (REUSS) – JIŘIČEK, pl. 6, fig. 36.
1985 *Amplocypris abscissa* (REUSS) – JIŘIČEK, p. 393, pl. 51, figs 13–15.
1989 *Amplocypris abscissa* (REUSS) – OLTEANU, pl. 1, fig. 16.
2011 *Amplocypris abscissa* (REUSS) – DANIELOPOL et al., text-figs 1 A–B, 2, 3, 7–10.
2011 *Amplocypris* aff. *abscissa* (REUSS) – OLTEANU, pl. 5, fig. 5; pl. 22, fig. 5.

Material: Danitzpuszta pit (22 valves)

Dimensions: L = 726.027–1082.241 µm H = 356.025–553.896 µm, L/H = 1.954–2.039

Stratigraphic range and geographic distribution: lower Pannonian of the Pannonian Basin: Hodonín in the Czech Republic (JIŘIČEK 1983, 1985); Sankt Margarethen, Hennersdorf in Austria (DANIELOPOL et al. 2011); Mt. Medvednica in Croatia (SOKAČ 1972); Belgrade in Serbia (KRSTIĆ 1973c); Sinteşti in Transylvania, Romania (OLTEANU 1989, 2011).

Amplocypris major KRSTIĆ, 1973
Plate II, fig. 6

1972 *Amplocypris major* KRSTIĆ – SOKAČ, p. 36, pl. 13, figs 1–3.
1973c. *Amplocypris major* – KRSTIĆ, pp. 100–102, figs 61–65; pl. 5, figs 1–2.
1985 *Amplocypris major* KRSTIĆ – KRSTIĆ, pl. 5, figs 6–8.
2011 *Amplocypris major* KRSTIĆ – OLTEANU, pl. 4, fig. 3.

Material: Danitzpuszta pit (5 valves)

Dimensions: L = 964.906–1331 µm H = 516.333–653 µm, L/H = 1.869–2.038

Stratigraphic range and geographic distribution: Pannonian of the Pannonian Basin: Mt. Medvednica in Croatia (SOKAČ 1972); Belgrade in Serbia (KRSTIĆ 1973c, 1985); Soceni in Transylvania, Romania (OLTEANU 2011).

Amplocypris firmus KRSTIĆ, 1973
Plate II, fig. 7

1973c. *Amplocypris firmus* n. sp. – KRSTIĆ, pp. 103–104, pl. 1, fig. 1; pl. 3, fig. 2; pl. 10 figs 1–3.
1973c. *Amplocypris* cf. *firmus* KRSTIĆ – KRSTIĆ, pl. 8, fig. 4.
1985 *Amplocypris firmus* – KRSTIĆ, pl. 6, fig. 4.
2013 *Amplocypris* ex. gr. *firmus* KRSTIĆ – TER BORGH et al., fig. 7/1.
2016 *Amplocypris firmus* KRSTIĆ – KOVÁCS et al., pl. 1, figs 15–19.

Material: Danitzpuszta trench (7 valves)

Dimensions: L = 825–1082.267 µm H = 375–540.935 µm, L/H = 2.001–2.2

Stratigraphic range and geographic distribution: lower Pannonian of the Pannonian Basin system: Velika Moštanica, Sibovik 7/2, Beočin, Đurinci in Serbia (KRSTIĆ 1973c; TER BORGH et al. 2013); Gârbovița, Cunța in Transylvania, Romania (KOVÁCS et al. 2016).

Amplocypris recta (REUSS, 1850)
Plate II, fig. 8

1850 *Cytherina recta* n. sp. – REUSS, p. 52, pl. 8, fig. 11.
1972 *Amplocypris recta* (REUSS) – SOKAČ, p. 35, pl. 11, figs 5, 7–8.
1973c. *Amplocypris recta* (RSS.) – KRSTIĆ, p. 113, pl. 3, fig. 1; pl. 16, figs 6–7.
1973c. *Amplocypris* ex. gr. *recta* (RSS.) – KRSTIĆ, p. 113, pl. 16 figs 4–5.
1982 *Amplocypris recta* REUSS – SZÉLES, p. 246, pl. 7, figs 4–5.
1982 *Amplocypris* aff. *recta* REUSS – SZÉLES, pp. 246–247, pl. 7, fig. 6; pl. 7, figs 1, 3.
1983 *Amplocypris recta* (REUSS) – JIŘIČEK, pl. 6, fig. 35.
1985 *Amplocypris* aff. *recta* (REUSS) – JIŘIČEK, p.392, pl. 51, figs 10–12.
1985 *Amplocypris recta* (REUSS) – KRSTIĆ, pl. 15, fig. 1.
1998 *Amplocypris recta* (REUSS) – KOVAČ et al., pl. 4, fig. 9.
1998 *Amplocypris recta* (REUSS) – PIPÍK & HOLEC, pl. 1, figs 1–2.
2004 *Amplocypris recta* (REUSS) – PIPÍK et al., pl. 1, fig. 14.
2011 *Amplocypris recta* – DANIELOPOL et al., fig. 4.
2011 *Amplocypris recta* (REUSS) – OLTEANU, pl. 22, fig. 7.

Materials: Danitzpuszta pit (3 valves); Danitzpuszta trench (34 valves)

Diemensions: L= 631,410 – 1717,526 µm, H= 331,675 – 867,911 µm, L/H= 1,904 –1,979

Stratigraphic range and geographic distribution: Pannonian of the Pannonian Basin system: Moosbrunn (REUSS 1850) and Sankt Margarethen (DANIELOPOL et al. 2011) in Austria; Studienka (PIPÍK et al. 2004), Borský Svätý Jur (PIPÍK & HOLEC 1998), and boreholes in the Vienna Basin (KOVAČ et al. 1998) in Slovakia; Hodonín in the Czech Republic (JIŘIČEK 1983, 1985); Tengelic in Hungary (SZÉLES 1982); Mt. Medvednica in Croatia (SOKAČ 1972); Đurinci in Serbia (KRSTIĆ 1973c, 1985); Şoimi in Transylvania, Romania (OLTEANU 2011).

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Tartalom — Contents

Nemzeti Kulturális Alap
A kiadvány a Magyar Tudományos Akadémia támogatásával készült.