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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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 (Porosonion 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 interval, a unique fresh- to oligohaline fauna characterizes a few layers in less than 1 m thickness. This fauna consists of mainly euryhaline foraminifera and freshwater to oligohaline ostracod assemblages, indicating a...
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 (ROGL 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 (FLIPESCU & SYLVE 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 palaeoecological and biostratigraphical interpretation of foraminiferal 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 foraminiferal fauna 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 (SÉBÉ et al. 2015, 2019; SÉBÉ et al. 2021). These are capped by upper
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 (SÁFTIĆ 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 corallineacean algae, echinoids, abundant molluscs, and sporadic fish remains (DULAI et al. 2021, SEBE et al. 2021, SZÁBO 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 acetylation following a protocol originally worked out by LETHERS & 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 determined 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 carapaaces 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, Milolinella selene, and Quinqueloculina hauerna). The ostracod fauna is characterized by the dominance of marine neritic taxa, such as Aurila cicatricosa, Callistoclythere canaliculata, and Phylpeonophora arcuata. Urocyclammina kystelsis, Loxocaenochata punctatella, Loxocorniculina hastata, Xestoleberis dispar, and Polycyopa 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., Callistoclythere sp., Polycyopa 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-
sum, and E. crisps) 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 tundrum 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 Fabaeformiscadona 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 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.

Figure 5

Layer D36 belongs to the upper Badenian based on the co-evolution of Pyrgo subsphaerica (upper Badenian to recent) and Miliolinella selene (Badenian) among the foraminifera (Luczkowska 1974). Some ostracods in these layers, such as Urocythereis kostelensis and Phylactophora 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 “Bulimalina/Bolvina 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 (Rogl 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-
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, Loxocoroniculum hastatum, Euxinocythere (Euxinocythere) praebosqueti, E. (E.) naca, and Amnicythere tenuis occur. In contrast, sample D35 is dominated by Candonina and Herpetocyprilla 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., Köváry 1974, Bardoč 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 (Harriss & 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—I well, Hungary, Jambor 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.

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Table:

| Layers (NN6) | 72 | 71 | 70 | 64 | 57 | 54 | 52 | 50 | 47 | 41 | 40 | 39 | 38 | 37 | 36 |
|-------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Methods | TS, AA | HP | HP | HP | HP | HP | HP | HP | AA, TS | AA, TS | TS, HP | TS, AA | HP |
| Root traces | – | – | + | + | – | – | – | – | – | – | – | – | – | – | – |
| Organic matter | – | – | – | – | + | – | – | – | – | – | – | – | – | – | – |
| Calcisphaera | – | – | – | – | + | + | – | + | – | – | – | – | – | – | – |
| Red algae & diatoms (bry) | + | – | – | – | – | – | – | + | – | – | – | – | – | – | – |
| Pteropods & Echinodermata (Einz) | + | – | – | – | + | + | – | – | + | – | – | – | – | – | – |
| Fish remains | – | + | – | – | – | + | + | + | + | – | – | + | – | – | – |
| Molluscs (Gastropoda) | + | + | G | – | + | + | – | + | – | – | – | – | – | – | – |
| Ostracoda | + | + | – | – | – | + | + | + | + | + | + | + | + | + | + |
| Foraminifera | + | + | – | – | + | + | + | + | + | + | + | + | + | + | + |
| Age | late Badenian | late Badenian? or early Sarmatian | late Sarmatian |
| Facies | Normal marine, high-energy conditions | Very shallow-water, palustral conditions | Brackish-water, littoral, well-ventilated conditions |
| Interval | 1a | 1b | 2 | 3a | 3b | 3c |

Legend:

- **TS**: thin section
- **AA**: acetic acid preparation
- **HP**: hydrogen-peroxide preparation
- **+** indicates the presence of a fossil group
- **+** indicates some frequency
- **+** indicates several frequency
- **–** indicates none

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
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 et al. 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 “symbions” 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). Meliolinella 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, bentic 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 Urocyclotheris 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, Kılıç 2000, Aiello et al. 2006, Tanaka 2008). Modern representatives of Aurila, Xestooleberis, and Loxoconcha species mainly live on algae or seagrasses (Puri et al. 1969). Loxoconcha punctatella and Xestooleberis dispar are found in neitic shallow sublittoral, littoral environments in the Mediterranean, Black and Marmara Seas (Perçin-Paçal et al. 2015). In the present-day Mediterranean Sea, Xestooleberis dispar is a phylal marine species, but it also occurs in hypersaline environments (Schiuto et al. 2015, Koehn-Zaninetti & Tétard 1982). Phylactenophora occurs in marginal marine estuaries, gulf and lagoon 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 & Brandão 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-Danitzzpuszta 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 paleoecological 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 miliolid ammonites 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 *Porosonion 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-occurrence 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 *Porosonion*, the specimens of *Ammonia cf. confragiella* became dominant. *Ammonia cf. confragiella* 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. *tosa*, *Fabaeformicandona* 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 cardiods). 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 nanoflora, suggesting increasing nutrient supply in this period (ČORIĆ 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 biofacies. The lower part and the uppermost layer of the upper Sarmatian are characterized by exclusively eurytopic biofacies. 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 Müller, 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: Cycloloria contorta (d’Orbigny), SV, layer D72, scale bar: 500 µm; 12: Affinitrinia ucrainica (Lust), SV, layer D72, scale bar: 500 µm; 13: Nonion commune (d’Orbigny), SV, layer D72, scale bar: 500 µm; 14: Elphidium crispum (Linne), SV, scale bar: 500 µm; 15: Textularia sp., layer D72; 16: Pyrgo subsphaericus (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=carpace, SV=side view, UV=umbilical view

**Plate II – II. tábla**

Sarmatian ostracods from the studied exploratory trench in Pécs-Danitzpuszta: 1: Amnicthea tensis (Reuss), RV in lateral view, layer D50, scale bar: 200 µm; 2–3: Amnicthea cernajesi Stancheva, LV in lateral view, 3: C in left view, layer D38, scale bar: 200 µm; 4–6: Eurixynotheca (Euxinocythere) praebosqueti (Suzin), 4: ephophototype, LV in lateral view, layer D36, scale bar: 250 µm; 5: in lateral view layer D36, scale bar: 200 µm; 6: LV in lateral view, layer D50, scale bar: 200 µm; 7: Eurixynotheca (Euxinocythere) naca (Meheș), RV in lateral view, layer D50, scale bar: 200 µm; 8–9: Cypridopsis pokorny Jiríček, 8: male, RV in lateral view, 9: female, RV in lateral view, layer D38, scale bar: 250 µm; 10: Cypridopsis 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 porosa Meheș, RV in lateral view, layer D54, scale bar: 200 µm; 18: Loxocauda sp., layer D38, scale bar: 250 µm; 19–20: Loxocorculum hastatum (Reuss), RV in lateral view, layer D38, scale bar: 200 µm; 21: Darwinia stevensoni (Brady & Robertson), C in right view, layer D40, 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.), sp., LV in lateral view, layer D38, scale bar: 200 µm; 25: Limnothyrine 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=carpace

**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 saromatica Didekowsky, SV, layer D41, scale bar: 250 µm; 3: Buliminella elegantissima (d’Orbigny), SV, layer D41, scale bar: 500 µm; 4: Ammonia cf. confertista Zheng, UV, layer D41, scale bar: 200 µm; 5: Porosonion granosum (d’Orbigny), SV, layer D54, scale bar: 250 µm; 6: Elasticulina hauerrni (d’Orbigny), SV, layer D54, scale bar: 200 µm; 7–8: Elasticulina aculeatum (d’Orbigny), SV, layer D54, scale bar: 250 µm; 9: Porosonion granosum (d’Orbigny), layer D54; 10: Vaginella affinis (d’Orbigny), layer D38; 11–12: Fabaeformiscandona (?) sp., juv., RN in lateral view, layer D38, scale bar: 200 µm; 13: Cyprideis sp., LV in lateral view, layer D38, scale bar: 200 µm; 26: Heterocypris salina (Brady), C bal oldalnézet, D40 réteg, méretarány: 500 µm

Abbreviations: SV=side view, UV=umbilical view

Rövidítések: LV=bal teknő, RV=jobb teknő, C=kettőstekő, SV=oldalnézet, UV=umbilical view
Plate III – III. tábla
Appendix

Systematic Palaeontology

The specimens of foraminifers and ostracods are reposit-
ed 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 Sarcochina SCHMARD A, 1871
Class Foraminifera J.J. L.
Order Miliolida L., 1885
Family Hauerinidae S., 1839
Subfamily Hauerininae S., 1896
Superfamily Milioloidea E., 1957

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) – TÖTH & GÖRÖG, p. 196,
pl. 1, fig. 1. (cum syn.)
2012 Cycloforina contorta (d’ORBIGNY) – GONERA, fig. 2/M.
2012 Cycloforina contorta (d’ORBIGNY) – MILKER & SCHMIEDEL,
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 & MERİÇ,
fig. 3/8.

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

Stratigraphic range and geographic distribution: Mio-
cene: Carpathian Foredeep and Transcarpathian Basin, Uk-
aine (BOGDANOWICH 1952, DIDKOWSKY & SATANOVSKAJA
1970); Badenian: Carpathian Foredeep, Poland (LUCZKOWSKA
1974; GONERA 2012), Vienna Basin, Austria (d’ORBIGNY
1846); Badenian to Sarmatian: Mece Mts, Hungary (KO-
RECZ-LÁKY 1968); Sarmatian: Zsámbék Basin and Bud-
apest, Hungary (GÖRÖG 1992, TÖTH & 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 & SCHMIEDEL, p. 61,
fig. 16/11–13.
2015. Affinetrina ucrainica (SEROVA) – SÍLYE, p. 111, pl. 1, figs 4–5.

Dimensions: L= 500–550 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 & SATAN-
OVSKAJA 1970); Lower Sarmatian: Vienna Basin, Austria
(SCHÜTZ et al. 2007); Sarmatian: Moesian Platform, Bulga-
ria (STANCHEVA 1960), Transylvanian Basin, Romania (S-
ÍLYE 2015); Zsámbék Basin, Hungary (GÖRÖG 1992). Recent-
ly 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 ex-
amined)

Stratigraphic range and geographic distribution: Upper
Badenian: Carpathian Foredeep, Poland (LUCZKOWSKA
1974). Recently widely distributed in the Mediterranean Sea,
Caribbean Sea and Atlantic Ocean.
Bolivina sarmatica Didkowsky, 1959  
Plate III, fig. 2

1970 *Bolivina sarmatica* Didkowsky – Didkowsky & Satanowskaia, p. 144, pl. 82, fig. 9. (holotype)  
2008 *Bolivina sarmatica* Didkowsky – Tóth & Görgő, p. 198, pl. 1, fig. 12. (cumm syn.)

2011 *Bolivina sarmatica* Didkowsky – Gareck & Olszewska, fig. 6/e.

2011 *Bolivina sarmatica* Didkowsky – Filipske et al., fig. 5/3.

2014 *Bolivina sarmatica* Didkowsky – Filipske et al., fig. 5/19.

2015 *Bolivina sarmatica* Didkowsky – Silye, p. 129, pl. 4, fig. 17.

2017 *Bolivina sarmatica* Didkowsky – Dumitru 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 & Satanowskaia 1970), Transcarpathian Basin, Carpathian Foredeep, Volhynian-Podolian Plateau, Ukraine (Venglinsky 1975), Western Carpathians (Cicha & Zapletalova 1961), easternmost Pannonian and Transylvanian Basins, Romania (Filipescu 1996; Filipescu et al. 2011, 2014), Zsambék Basin and Budapest, Hungary (Görgő 1992, Tóth & Görgő 2008), Carpathian Foredeep, Poland and Romania (Gareck & Olszewska 2011, Dumitru et al. 2017), Vienna Basin, Austria (Harzhauser et al. 2018).

Superfamily Buliminioidea Jones, 1875  
Family Buliminellidae Hofker, 1951  
Genus Buliminella Cushman, 1911

*Buliminella elegansissima* (d’Orbigny, 1839)  
Plate III, fig. 3

1839 *Bulimina elegansissima* n. sp. d’Orbigny, p. 51, pl. 7, figs 13–14.

2004 *Bulimina elegansissima* (d’Orbigny) – Vilela et al., fig. 4/4.

2008 *Bulimina elegansissima* (d’Orbigny) – Tóth & Görgő, pp. 198–199, pl. 2, figs 2–4. (cumm syn.)

2011 *Bulimina elegansissima* (d’Orbigny) – Filipescu et al., fig. 5/10.

2014 *Bulimina elegansissima* (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 & Satanowskaia 1970), Zsambék Basin and Budapest, Hungary (Görgő 1992, Tóth & Görgő 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 *Asterigerinata planorbis* n. sp. d’Orbigny, p. 225, pl. 11, figs 1–3.

1985 *Asterigerinata planorbis* d’Orbigny – Papp & Schmid, pl. 66, figs 9–11.

1985 *Asterigerinata 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) – Schutz et al., p. 457, pl. 4, fig. 6.

2010 *Asterigerinata 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 *Basterigerinata 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 Mt, 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 (Schutz et al. 2007); Pliocene: Nile Delta, Egypt (Ismail et al. 2010).

Superfamily Nonionioidea 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. Fichtl & Poll, p. 105, pl. 19, figs d–f.

1846 *Nonion commune* d’Orbigny – d’Orbigny, p. 106, pl. 5, figs 7–8.

2008 *Nonion commune* (d’Orbigny) – Tóth & Görgő, pp. 22–203, pl. 2, figs 14–18. (cumm syn.)

2009 *Nonion commune* (d’Orbigny) – Gerhardt et al., pl. 2, fig. 39.

2010 *Nonion commune* (d’Orbigny) – Koubová & Hudačkova, 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) – PEZIEL 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, KOVÁCOVÁ & HUDAČKOVÁ 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 (PEZIEL et al. 2013), Koceljeva area, Western Serbia (JOVANOVIĆ et al. 2019); Badenian to Sarmatian: Mesec Ms, Tokaj Ms and SW-Hungary, Budapest (KOOREC-LAKY 1968, 1973, 1982; BÁLDI 1999; TOTH & GÓRÖG 2008), Appenines, Italy (DIECI 1959); Sarmatian: E-Slovakian Basin, Slovakia (ZLINSKÁ 1997, KOUBOVA & 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 SAIDOV, 1981
Genus Ammonia BRÚNNICH, 1772

Ammonia cf. conferitesta ZHENG, 1978
Plate III, fig. 4

Dimensions: D= 250–450 µm
Remarks: 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) – BRANZILĂ, pl. 4, fig. 5.
2004 Elphidium aculeatum (d’ORBIGNY) – MERCI et al., pl. 32, figs 5–8.
2005 Elphidium aculeatum (d’ORBIGNY) – GOLDRECK et al., pl. 1, fig. 12.
2008 Elphidium aculeatum (d’ORBIGNY) – TOTH & GÓRÖG, pp. 204–205, pl. 3, figs 5–6. (cum syn.)
2010 Elphidium josephinum (d’ORBIGNY) – KOUBOVA & HUDAČKOVÁ, pl. 1, fig. 26.
2011 Elphidium aculeatum (d’ORBIGNY) – GEDL & PERYT, pl. 1, fig. 9/F, I–K.
2012 Elphidium aculeatum (d’ORBIGNY) – ALCOLOU ET AL., pl. 1, fig. 13.
2012 Elphidium aculeatum (d’ORBIGNY) – MILKER & SCHMIDL, 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 & JASONOWSKI, fig. 4/C, D, L, M.
2012 Elphidium aculeatum (d’ORBIGNY) – JASONOWSKI et al., fig. 12/A, B, D, E.
2013 Elphidium aculeatum (d’ORBIGNY) – TER BORGH et al., fig. 6, 8–9.
2014 Elphidium josephinum (d’ORBIGNY) – FILIPESCU et al., fig. 7/10.
2014 Elphidium aculeatum (d’ORBIGNY) – MELIS et al., fig. 11/8.
2015 Elphidium aculeatum (d’ORBIGNY) – SYLVE, 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, BRANZILĂ 2004), Crimea-Caucasus region, South-Caspian Depression, Russia and Azerbaijan (VOLOSHINOVA 1952); Sarmatian: Carpathian Foredeep, Poland, Romania and Ukraine (SZCZECHURA 1982, 2000; JASONOWSKI et al. 2012; DUMITRIU et al. 2017), Vienna Basin, Austria and Slovakia (MARKS 1951, PAPP 1963; SCHÜTZ et al. 2007; KOUBOVA & HUDAČKOVÁ 2010), Danube Basin and East-Slovakian Basin, Slovakia (BRESTENSKA 1974; ZLINSKÁ 1997), Tokaj Ms, Mesec Ms, Zsámbsék Basin and Budapest, Hungary (KOREC-LAKY 1973, 1968, 1964, 1965, 1982; GÓRÖG 1992; TOTH & GÓRÖG 2008), easternmost Pannonian and Transylvanian basins, Romania (KOVÁCS 2001, SUCHU 2005, FILIPESCU et al. 2014, SYLVE 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 (LINNÉ, 1758)
Plate I, fig. 14
1758 Nautilus crispus n. sp. LINNAEUS, p. 709, pl. 1, figs 2d–e.
1888 Elphidium crispum (LINNÉ) – JORISSSEN, p. 120, pl. 3, figs 8–9, pl. 24, figs 1–2.
2004 Elphidium crispum (LINNE) – MERCI et al., pl. 1, figs 16–18.
2004 Elphidium crispum (LINNE) – MENDES et al., pl. 1, fig. 6.
2004 Elphidium crispum (LINNE) – BRANZILÁ, pl. 4, fig. 11.
2005 Elphidium crispum (LINNE) – MORIGI et al., pl. 2, fig. 9a–c.
2008 Elphidium crispum (LINNE) – TÖTH & GÖRÖG, pp. 205–206, pl. 3, figs 7–8. (cum syn.)
2009 Elphidium crispum (LINNE) – FREZZA & CARBONI, pl. 1, fig. 16.
2010 Elphidium crispum (LINNE) – KOUBOVA & HUĐÁČKOVÁ, pl. 1, fig. 24.
2011 Elphidium crispum (LINNE) – GLED & PERYT, fig. 9/C, R.
2012 Elphidium crispum (LINNE) – FERRER GARCÍA & BLÁZQUEZ MORA, pl. 4, fig. 12.
2012 Elphidium crispum (LINNE) – GONERA, figs 4f.
2012 Elphidium crispum (LINNE) – MILKER & SCHMID, p. 120, fig. 27/13–14.
2012 Elphidium crispum (LINNE) – MELIS et al., pl. 1, fig. 4.
2012 Elphidium crispum (LINNE) – ALÇOLOU et al., pl. 1, fig. 15.
2014 Elphidium crispum (LINNE) – FILIPESCU et al., fig. 7/3.
2014 Elphidium crispum (LINNE) – YOKES et al., figs 11/10–11.
2014 Elphidium crispum (LINNE) – TER BORGH et al., fig. 6/8.
2016 Elphidium crispum (LINNE) – LEI & LI, p. 361, fig. 84.
2016 Elphidium crispum (LINNE) – DIMIZA et al., pl. 4, fig. 20.
2019 Elphidium crispum (LINNE) – PEZELJ et al., fig. 5/D, I.
2019 Elphidium crispum (LINNE) – JOVANOVIC et al., pl. 1, figs f/3, g/7.
2019 Elphidium crispum (LINNE) – 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: Dacic Basin, Romania and Serbia (TER BORGH et al. 2014), Carpathian Foredeep, Poland and Ukraine (GLED & PERYT 2011, GONERA 2012), Vienna Basin, Austria (PAPP 1963), Apennines, Italy (DIECI 1959), Koceljeva area, Western Serbia (JOVANOVIC 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 (SZCZECHU A 1982), Mecsek Mts, Zsáméb Basin and Budapest, Hungary (KORECZ-LAKY 1964, 1968; GÖRÖG 1992; TÖTH & GÖRÖG 2008), Vienna Basin, Slovakia (KOUBOVA & HUĐÁČKOVÁ 2010); Moldavian Plateau, Moldavia (BRANZILÁ 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: Mediterranean 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) – TÖTH & GÖRÖG, pl. 3, figs 10–12. (cum syn.)
2010 Elphidium hauerinum (d’ORBIGNY) – KOUBOVA & HUĐÁČKOVÁ, pl. 1, fig. 18.
2011 Elphidium hauerinum (d’ORBIGNY) – FILIPESCU et al., fig. 4/3.
2011 Elphidium hauerinum (d’ORBIGNY) – IONESI & PASCAI, 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 & PASCAI 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, Zsáméb Basin, Mecsek Mts and Budapest, Hungary (KORECZ-LAKY 1964, 1965, 1968, 1973, 1982; GÖRÖG 1992; TÖTH & GÖRÖG 2008); Danube Basin and East-Slovakian Basin, Slovakia (BRINSTENSKÁ 1974, ZLINSKA 1997, KOUBOVA & HUĐÁČKOVÁ 2010), Carpathian Foredeep, Poland (SZCZECHURA 1982, 2000).

Genus Porosonion Putrya in VOLOSHINOVA, 1958

Porosonion granosum (d’ORBIGNY, 1846)

Plate III, figs 5, 9 (thin section)
1846 Nonionina granosus n. sp. d’ORBIGNY, p. 110, pl. 5, figs 19–20.
1888 Elphidium granosum (d’ORBIGNY) – JORISSEN, p. 104, pl. 2, figs 1–3, pl. 16–19.
1992 Porosonion granosum (d’ORBIGNY) – GÖRÖG, pp. 112–113, pl. 11, fig. 5. (cum syn.)
2000 Porosonion granosum (d’ORBIGNY) – POPESCU et al., pp. 400–401, pl. 1, figs 13–14. (cum syn.)
2000 Porosonion granosum (d’ORBIGNY) – SZCZECHURA, pl. 5, figs 3, 6.
2000 Elphidium granosum (d’ORBIGNY) – CARBONI et al., fig. 10.
2001 Porosonion granosum (d’ORBIGNY) – FILIPESCU et al., pl. 3, fig. 11.
2004 Porosonion subgranosus monogranulata GERKE – BRANZILÁ, pl. 2, figs 7–9.
2007 Porosonion ex gr. granosum (d’ORBIGNY) – SCHÜTZ et al., pl. 6, fig.6.
2007 Porosonion granosum (d’ORBIGNY) – GROSS et al., pp. 210–211, fig. 4 a–e, h–i.
2008 Crichelphilidium ex gr. granosum (d’ORBIGNY) – TÖTH & GÖRÖG, p. 204, pl. 3, figs 3–4.
2010 Porosonion granosum (d’ORBIGNY) – KOUBOVA & HUĐÁČKOVÁ, pl. 1, fig. 20.
2011 Porosononion granosum (d’ORBIGNY) – FILIPESCU et al., fig. 4/9.
2012 Elphidium granosum (d’ORBIGNY) – MILKER & SCHMIDT, p. 121, fig. 27/17–18.
2013 Porosononion granosum (d’ORBIGNY) – ter BORGH et al., figs 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), Zsámébék Basin and Budapest, Hungary (GÖRÖG 1992, TÖTH & GÖRÖG 2008), Transcarpathian Basin, Ukraine (VOLOSHINOVA 1952, VENGILINSKY 1958), Carpathian Foredeep, Poland (SZCZECHURA 2000), Transylvanian Basin, Romania (FILIPESCU et al. 2011, SILYE 2015), Moldavian Plateau (BRANZILĂ 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 & SCHMIDT, 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) – PEZELJ, figs 4/V, W, 7/Y
2014 Heterolepa dutemplei (d’ORBIGNY) – ter BORGH et al., fig. 5/41–42.

Dimensions: D=450–600 µm, Th= 200–350 µm
Stratigraphic range and geographic distribution: Middle to Upper Eocene: Paleogene Basin, Hungary (ŐZSVÁRT 2007); Upper Eocene – Lower Oligocene: Vandelov-Geygelia Basin, Republic of Macedonia (STOJANOVA & PETROV 2014; VALCHEV & STOJANOVA 2016); Kiscellian to Badenian: Börzsöny Mts, Hungary (KORECZ-LAKY & NAGY-GELLAI 1985); SW-Hungary (BALDI 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; PÉRYT 2013; DUMITRIU et al. 2017), Upper Miocene: Ambug Hill, Borneo (ROSİM et al. 2019).

Ostracoda

Classification of the ostracods follows that of HARTMANN & PURI (1974) and HÖRNER 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 Cytherocopia BARD, 1850
Superfamily Cytheroidea BARD, 1850
Family Cytherideidae SARS, 1925
Subfamily Cytherideinae SARS, 1925
Genus Cyprideis JONES, 1857

Cyprideis pokornyi Jiriček, 1974
Plate II, figs 8–9

1974 Cyprideis pokornyi n. sp. Jiriček, p. 439, pl. 2, figs 1–4.
2009 Cyprideis pokornyi Jiriček – 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 (JIRIČEK 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) – CERNIAJEK, 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 & JIRIČEK, p. 409, 432, pl. 6, fig. 1.
2008 Aurila cicatricosa (REUSS) – FARAIDA 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: Bade-
nian: Vienna Basin, Austria (CERNIAJEK 1971, GROSS & PIL-
LER 2006); Carpathian Foredeep, Czech Republic, Poland
(BRESTENSKÁ & JIRIČEK 1978, AIELLO & SZCZECHURA 2004,
SZCZECHURA 2006, SEKO et al. 2012); Dacian Basin, Ro-
mania (TER BORGH et al. 2014); Late Miocene: Mediterranean,
Greece (FARAIDA 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 (Exaurila?) notata (REUSS) – GROSS & PILLER, p. 83–84, pl. 29, figs 1–9.
2008 Aurila notata (REUSS) – TÖTH, 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 Sar-
matian: Vienna Basin, Austria and Slovakia (CERNIAJEK
1974, JIRIČEK 1983, ZELENKA 1990, JANZ & VENNEMANN
2005, GROSS & PILLER 2006, HARZHAUSER et al. 2018); Zsám-
bék Basin, Hungary (TÖTH 2008); Caucasus, Russia
(SUZIN 1956); Lower Sarmatian: Moldovan Plateau, Ro-
mania (DUMITRIU et al. 2017).

Genus Hemicytheria Pokorný, 1952

Hemicytheria omphalodes (REUSS, 1850)
Plate II, fig. 11
1850 Cypridina omphalodes n. sp. REUSS, pp. 75, pl. 10, fig. 7.
2008 Hemicytheria omphalodes (REUSS) – TÖTH, 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); Sar-
matian: Vienna Basin, Slovakia (JIRIČEK 1974, ZELENKA
1990); Zsámőbek Basin, Hungary (TÖTH 2008); Lower Sar-
matian: Danube Basin and the eastern region, Slovakia
(FORDINÁL et al. 2006, FORDINÁL & ZLINSKÁ 1994); Upper Sar-
matian: Vienna Basin, Austria (CERNIAJEK 1974); Pan-
nonian: easternmost Pannonian Basin, Transylvanian Ba-
sin, Romania (OLTEANU 2001, 2011; FILIPESCU et al. 2014), Pannonian Basin, Croatia (SOKAČ 1972).

Genus Senesia JIRIČEK, 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. sp. – BASSOUNI, 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 (BASSOUNI 1979); Badenian: Vienna Basin, Austria and Slovakia (REUSS 1850, CERNIAJEK 1971, BRESTENSKÁ & JIRIČEK 1978, GROSS & PILLER 2006); Moesian Plateau, Bulgaria (STANCHEVA 1962).

Subfamily Urocythereidinae HARTMANN & PURI, 1974
Genus Urocythereis RUGGERI, 1950

Urocythereis kostelenis (REUSS, 1850)
Plate I, fig. 4
1850 Cypridina kostelenis n. sp. REUSS, p. 68, pl. 9, fig. 22.
1978 Urocythereis kostelenis (REUSS) – BRESTENSKÁ & JIRIČEK, 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: Baden-
ian: Carpathian Foredeep, Poland (REUSS 1850), Vienna
and Molasse basins, Austria and Slovakia (REUSS 1850, BRESTENSKÁ & JIRIČEK 1978, ZELENKA 1985, ZORN 2004,
GROSS & PILLER 2006).
Family Leptocytheridae HANAI, 1957
Subfamily Leptocytherinae HANAI, 1957
Genus Amnicythere DEVOTO, 1965

Amnicythere cernaijeki STANCHEVA, 1984
Plate II, figs 2–3
1963 Leptocythere modesta n. sp. STANCHEVA, p. 22, pl. 3, fig. 8.
1974 Leptocythere sp. – CERNAIJSEK, p. 476, pl. 2, fig. 7.
1984 Amnicythere cernaijeki 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 cernaijeki 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 (CERNAIJSEK 1974); Lower Sarmatian: Transylvanian Basin, Romania (OLTEANU 1998); Upper Sarmatian: Zsámbék Basin, Hungary (TÓTH 2008); Transylvanian Basin, Romania (FILIPESCU et al. 2011).

Amnicythere tenes (REUSS, 1850)
Plate II, fig. 1
1850 Cytherina tenes n. sp. REUSS, p. 53, pl. 8, fig. 14.
2008 Amnicythere tenes (REUSS) – TÓTH, p. 109–110, pl. 2, figs 1–3, 5, (cum syn.)
2013 Amnicythere tenes (REUSS) – TER BORGH et al., fig. 6/14–15.
2014 Amnicythere tenes (REUSS) – TER BORGH et al., fig. 8/27–28.
2015 Amnicythere tenes (REUSS) – SILYE, pl. 10, figs 1–3.
2018 Amnicythere tenes (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 (CERNAIJSEK 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 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) – SORÁC, 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 (CERNAIJSEK 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-Bosnian Basin, Hungary and Serbia (KRSTIĆ 1973, MÉHES 1908, 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: Zsámébk 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 (CERNAIEK 1974, GROSS & PILLER 2006, HARZHAUSER et al. 2018); easternmost Pannonian and Transylvanian basins, Blacks Sea Depression, Romania (IONESI & CHINTAUAN 1985; FILIPESCU et al. 2005, 2014); Upper Sarmatian: Zsámébk Basin, Hungary (TÓTH 2008); Pannonian Basin, Serbia (TER BORGH et al. 2013); Lower Pannonian (?): Pannonian Basin, Hungary (MÉHES 1908); Messinian and Pliocene (?): Rhôné 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: Zsámébk 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 & CHINTAUAN 1985); Upper Sarmatian: Vienna Basin, Slovakia (ZELENKA 1990); Zsámébk Basin, Hungary (TÓTH 2008); Pannonian: Pannonian Basin, Hungary and Croatia (MÉHES 1908, ŠOKAČ 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) – BREJTSKÁ & JIRIČEK, 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 & PRTOSJAN, 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 (BREJTSKÁ & JIRIČEK 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 & PRTOSJAN 2011); Badenian to Sarmatian: Vienna Basin, Austria (GROSS & PILLER 2006); Lower Sarmatian: Zsámébk 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 CERNAIEK – 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: \( L = 620–630 \, \mu m, H = 390–410 \, \mu m, L/H = 1.5–1.6 \).

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 (KOLLMAU 1971); Karpatainian: Vienna Basin, Czech Republic (KLIEHL 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 (CERNSEK 1974, BRESTENSKÁ & JIRIČEK 1978, JANZ & VENNERMANN 2005, ZELENKA 1985); Moeian Platform, Bulgaria (STANCHEVA 1962); Dacian Basin, Romania (TER BORGH et al. 2014); Carpathian Foredeep, Poland (AIELLO & SZCZECHURA 2004); Sarmatian: Mečsek Mts and Zsámbék Basin, Hungary (SZUROMI-KORECZ & SZEGÓ 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 & PILLET, pp. 137–138, pl. 2, fig. 4.
2008 *Xestoleberis dispar* MÜLLER – KOEHN-ZANINETTI & TÉTARD, fig. 4/10.
2014 *Xestoleberis dispar* (MÜLLER) – TER BORGH et al., fig. 7/26–27.
2015 *Xestoleberis dispar* MÜLLER – SCIUTO et al., pl. 2, fig. 6.
2016 *Xestoleberis dispar* MÜLLER – PARLAK & NAZIK, pl. 3, fig. 14.
2017 *Xestoleberis fuscata* SCHNEIDER – DUMITRIU et al., fig. 13/II.

Dimensions: \( L = 660–665 \, \mu m, H = 350–370 \, \mu m, L/H = 1.80–1.88 \).

Stratigraphic range and geographic distribution: Badeanian: Dacian Basin, Romania (TER BORGH et al. 2014); upper Badenian to lower Sarmatian: Vienna Basin, Austria (GROSS & PILLET 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 & PILLET, 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: \( L = 510–540 \, \mu m, H = 320–330 \, \mu m, L/H = 1.6–1.8 \).

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

Suborder Cypridocopina BAIRD, 1845
Superfamily Cypridoidea BAIRD, 1845
Family Cyprididae BAIRD, 1845
Subfamily Cyprinotinae BRONSTEIN, 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) – PIPIK, 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) – SÁLÉL et al., pl. 4, figs 4–6.
2019 *Heterocypris salina* (BRADY) – TUNCER et al., pl. 1, figs 1–3.

Dimensions: \( L = 945–955 \, \mu m, H = 565–590 \, \mu m, L/H = 1.61–1.67 \).

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) – PIPIK 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) – FURHMANN, pl. 1, figs 1 a–f.

Dimensions: \( L = 670–680 \, \mu m, H = 420–425 \, \mu m, L/H = 1.59–1.6 \).

Stratigraphic range and geographic distribution: Wide-
ly 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) – Pipik & Bodergat, p. 348, pl. 1, figs 5–10, fig. 24. (cum syn.)

2004 *Vestalenula pagliolii* (Pinto & Kotzian) – Pipik 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).