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Pannonian ostracods from the southwestern Transylvanian basin

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Abstract

Pannonian (Late Miocene) ostracods were investigated from 7 outcrops, exposing deep-water lacustrine sediments along the western margin of the Transylvanian Basin. Sedimentological patterns in the outcrops indicate deposition in sublittoral to profundal environments where fine-grained, suspension fall-out sediments are intercalated with various types of mass transport deposits, most commonly turbidites. The ostracod fauna, consisting of 30 taxa, is dominated by endemic species of the brackish Lake Pannon. The assemblages indicate a mixture of deep-water (sublittoral to profundal) species, such as Paratethyan *Candoninae,* and shallow-water (littoral) species, belonging to *Cyprideis, Loxoconcha, Amnicythere* and *Hemicytheria*. The mixed character of the assemblages is most probably a consequence of the reworking of littoral specimens into deeper environments, a phenomenon also observed in the molluscan fauna from some of the investigated outcrops. Alternatively, some endemic and extinct species of the littoral genera might have adapted to the deep-water environment. A significant decrease in the abundance and diversity of ostracods from west to east is interpreted reflecting increasingly distal environments. The ostracod fauna indicates the *Hemicytheria hungarica* (2 outcrops), *Hemicytheria tenuistriata* (3 outcrops), and *Propontoniella candeo* Zones (2 outcrops) of the lower Pannonian Slavonian Substage.

Keywords: Ostracoda, biostratigraphy, Late Miocene, Pannonian, Transylvanian Basin

1. INTRODUCTION

Study of ostracods of the Neogene Paratethys has substantially contributed to the stratigraphic, environmental, and palaeogeographic understanding of this huge and complex marine to lacustrine depositional system (DANIELOPOL et al., 2008a). Of the large brackish lakes that repeatedly formed during the history of the Paratethys, the Late Miocene-Early Pliocene Lake Pannon was probably the longest-lived (MÜLLER et al., 1999; HARZHAUSER & MANDIC, 2008). As a consequence, this lake was inhabited by an astonishingly diverse lacustrine biota (e.g. PAPP et al., 1985; STEVANOVIĆ et al., 1990).

The dominantly endemic ostracods of Lake Pannon have been studied and described by generations of palaeontologists, starting with REUSS (1850), and leading to the introduction of ca. 500 new species. The taxonomy, environmental requirements, and palaeogeographic distribution of these ostracods, however, is far from being well understood, and needs further study (DANIELOPOL et al., 2008a). In particular, the Transylvanian Basin (TB), representing the easternmost part of the early Lake Pannon, lacks modern and well-illustrated documentation of the endemic ostracod taxa. The objective of this paper is to present the Late Miocene (Pannonian) ostracod faunas from several outcrops of the southwestern TB, and to explore their palaeoecological, palaeobiogeographic and biostratigraphic context.

2. NEOGENE EVOLUTION OF THE TRANSYLVANIAN BASIN

The TB is bordered by the Eastern and Southern Carpathians, and the Apuseni Mountains (Fig. 1). The basin fill can be divided into several tectono-stratigraphic megasequences (KRÉZSEK, 2005; KRÉZSEK & BALLY, 2006), the uppermost one of which comprises the Middle and Upper Miocene (Badenian, Sarmatian and Pannonian Central-Paratethys stages). The Middle Miocene to Quaternary evolution of the TB is related to the Carpathian orogene (ROYDEN, 1988; SCHMID et al., 2008). During this period it evolved as a compressional back-arc basin (DE BROUCKER et al., 1998; CIULAVU, 1999; SANDERS et al., 1999; KRÉZSEK et al., 2010), and its sedimentary history was connected to the subduction along the Carpathian arc. Although a very high rate of subsidence is encountered during this period, no major extensional faults are reported; instead, most structures are related to salt-tectonics (KRÉZSEK & BALLY, 2006). Middle Badenian evaporites are widespread in the subsurface of the entire TB (GHERGARI et al., 1991; KOVÁČ et al., 2007), and salt tectonics was most effective from the Sarmatian to the Pliocene (KRÉZSEK & BALLY, 2006).

Following the fully marine conditions of the Badenian and restricted marine environment in the Sarmatian, the uplift of the Carpathians closed the gateways between the Central and Eastern Paratethys at the end of the Middle Miocene and thus isolated the intra-Carpathian region from the rest of the Paratethys (TER BORGH et al., 2013). With the onset of the Late Miocene Pannonian age, the TB became part of the large brackish Lake Pannon (MAGYAR et al., 1999). The Sarmatian–Pannonian boundary in the TB was traced in a large outcrop of marls and turbiditic sandstones in Oarba de Mureş (SZTANÓ et al., 2005), on the basis of dinoflagellate biostratigraphy (SÜTŐ-SZENTAI & SZEGŐ, 2008), magnetostratigraphy and radiometric dating (VASILIEV et al., 2010), and foraminifer and ostracod biostratigraphy (FILIPESCU et al., 2011). The boundary was unanimously marked on the basis of microfossils. Although the magnetostratigraphic interpretation of the measured polarity pattern is contradictory, high-precision radiometric dating of a volcanic ash deposit from the very top of the one-km-thick Sarmatian sequence (VASILIEV et al., 2010) indicates that the Sarmatian-Pannonian boundary is about 11.6 Ma old, in accordance with recent magnetostratigraphic interpretations from the Vienna basin (PAULISSEN et al., 2011) and the Pannonian basin proper (TER BORGH et al., 2013).

After the isolation event, the water level of Lake Pannon gradually rose, controlled both by increased precipitation and subsidence all over the Pannonian Basin system (MAGYAR et al., 1999; GARCIA-CASTELLANOS, 2006; HARZHAUSER et al., 2008). Pulses of tectonic uplift with short wave lengths are recorded by coarse-grained fan delta systems along the basin margins (MAȚENCO et al., 2010). These fan deltas prograding from the Carpathians and from the Apuseni Mts. toward the basin centre fed the deep-lacustrine turbidite systems interfingering with hemipelagics/profundal marls. Sedimentary facies of the Pannonian deposits thus reflect deposition in a deep lacustrine setting, including lacustrine deep-water fans (KRÉZSEK & FILIPESCU, 2005; SZTANÓ et al., 2005; KRÉZSEK et al., 2010). Shallow-water deposits are subordinate and were preserved mostly in the eastern part of the basin. The final infill of the basin did not take place until the end of the Miocene, but these deposits are seldom preserved, except where covered by back-arc volcanics (KRÉZSEK and FILIPESCU, 2005; MAȚENCO et al., 2010; KRÉZSEK et al., 2010).

Apart from Pliocene lacustrine sediments in the southeastern corner of the TB (for a modern review see HARZHAUSER & MANDIĆ, 2008), Late Miocene Lake Pannon sediments are the youngest deposits in the basin fill succession. Their present-day thickness is usually less than 500 m (KRÉZSEK et al., 2010). Due to Pliocene to Quaternary uplift, more than 500 m of sediments have been eroded particularly in the northernmost part of the TB (DE BROUCKER et al., 1998; KRÉZSEK & FILIPESCU, 2005). Erosion is still active today in the basin, where the altitude varies between 300 and 600 m above sea level (MAȚENCO et al., 2010).

3. PANNONIAN OSTRACODS FROM THE TRANSYLVANIAN BASIN

The first contribution to the knowledge of Pannonian ostracods of the TB was provided by HÉJJAS (1894), who considered this fauna special and isolated. His observation that the ostracod fauna indicates deep water environment was ahead of his time (WANEK, 1992a). CHINTĂUAN (1971) investigated Pannonian ostracods from the western part of Munții Bârgăului. CLICHICI (1980) described an ostracod association from near the Aiud River. This fauna, representing the C-D-E zones of the Pannonian (FILIPESCU, 1999) included: *Erpetocypris abscissa* (POKORNÝ), *Candona trapezoidea* (MÉHES), *Candona* sp., *Loxoconcha granifera* (REUSS) and *Leptocythere auriculata* (MÉHES).

WANEK (1992b) investigated the Sarmatian and Pannonian ostracod fauna of the TB and compared his results with the data of HÉJJAS (1894). He concluded that the complete Sarmatian and the Slavonian Substage of the Pannonian could be identified in the TB.

OLTEANU (in POPESCU, 1995) mentioned some „upper Pannonian–Pontian" ostracod taxa from Lopadea Veche: *Amplocypris abscissa* (REUSS), *A. recta* (REUSS), *Pannonocypris auriculata* [=*Herpetocyprella auriculata*] (REUSS), *Lineocypris trapezoidea* (ZALÁNYI), *Hemicytheria josephinae (*KOLLMANN), *Caspiocypris pontica* (SOKAĈ), *Cyprideis pannonica* (MÉHES).

WANEK & FILIPESCU (1994) reported an upper Slavonian ostracod assemblage from Moldovenești. A diverse lower Pannonian ostracod fauna was described from Ormeniş by WANEK (in FILIPESCU, 1996); the fauna was composed of *Hungarocypris auriculata* [=*Herpetocyprella auriculata*] (REUSS), *Amplocypris reticulata* (HÉJJAS), *Candona (Typhlocypris)* cf. *redunca* (ZALÁNYI), *C. (Caspiocypris) transilvanica* HÉJJAS, *C. (Caspiocypris) improba* KRSTIĆ, *Leptocythere (Amnicythere) paralella* (MÉHES), *Leptocythere (Amnicythere) rodrigera* (POKORNÝ), *Leptocythere (Amnicythere) servica* KRSTIĆ, *Loxoconcha rhombovalis* POKORNÝ, *L. porosa* (MÉHES), *Loxocorniculina hodonica* POKORNÝ, *Graptocythere loerentheyi* MÉHES, *Hemicytheria folliculosa* (REUSS), and *Limnocythere* aff. *aquaensis* CARBONNEL. At Oarba de Mureş (section A), FILIPESCU et al. (2011) marked the Sarmatian–Pannonian boundary at the first occurrence of ostracod assemblages containing deep-water species of the *Amplocypris-Candona* group.

DE LEEUW et al. (2013) tried to obtain better age constraints on the Middle to Late Miocene Central Paratethyan regional stages (Badenian, Sarmatian and Pannonian) through integrated magnetostratigraphic, radio-isotopic and biostratigraphic research in Transylvania. At Mediaş, Sighişoara, and Târnăveni, the ostracod assemblages indicated a Pannonian age. In the case of Viforoasa and Șoimuș, 3 ostracod biozones were identified following the zonation of KRSTIĆ (1985): the *Propontoniella candeo* Zone, indicating the uppermost part of the Slavonian Substage, and the *Amplocypris abscissa* and *Hemicytheria croatica* Zones, indicating the lower part of the Serbian Substage.

4. MATERIAL AND METHODS

We have selected 7 outcrops from the southwestern part of the TB, where description of the sedimentary facies and interpretation of the depositional environment was followed by sampling for ostracods, preferably from fine-grained sediments where in situ burial of the shells seemed more probable.

Altogether 10 micropaleontological samples (250 g air-dried material) were collected. These samples were washed in hydrogen peroxide (10%), sieved using a 150 µm sieve and oven dried. After a preliminary observation under stereomicroscope, the ostracods were examined and photographed using a scanning electron microscope. A JEOL JEE 4B vacuum evaporator was used for deposition of gold on the surface of specimens. Pictures were taken with SEM (AMRAY 1830) at an accelerating voltage of 20kV in the SEM laboratory of the Department of Petrology and Geochemistry, Eötvös Loránd University, Budapest.

All the ostracod valves, both adults and juveniles, whole and broken specimens were counted from each sample.

5. THE INVESTIGATED OUTCROPS AND THEIR OSTRACOD FAUNA

5.1. The Lopadea Veche/Oláhlapád locality

This sampled outcrop is located 1 km east of the Lopadea stream valley (46°22'45.36"N, 23°39'55.74"E) (Fig. 1). Lopadea Veche belongs to the best studied Pannonian exposures in the TB (LŐRENTHEY, 1893; KOCH, 1900; PÁVAY-VAJNA, 1910; GILLET, 1943; ILIE, 1952; LUBENESCU & LUBENESCU, 1976; OLTEANU in POPESCU, 1995).

Today several small outcrops can be found in the hilly outskirts of the village. They expose an alternation of argillaceous marl and yellow, fine-medium-grained sands, building a 7–8 m thick succession (Fig. 2). Given the lack of specific sedimentary structures it is difficult to decide if the sand was transported by gravity-driven processes or just currents/waves/storms. Both the marls and the sandstones are friable and the carbonate cementa-

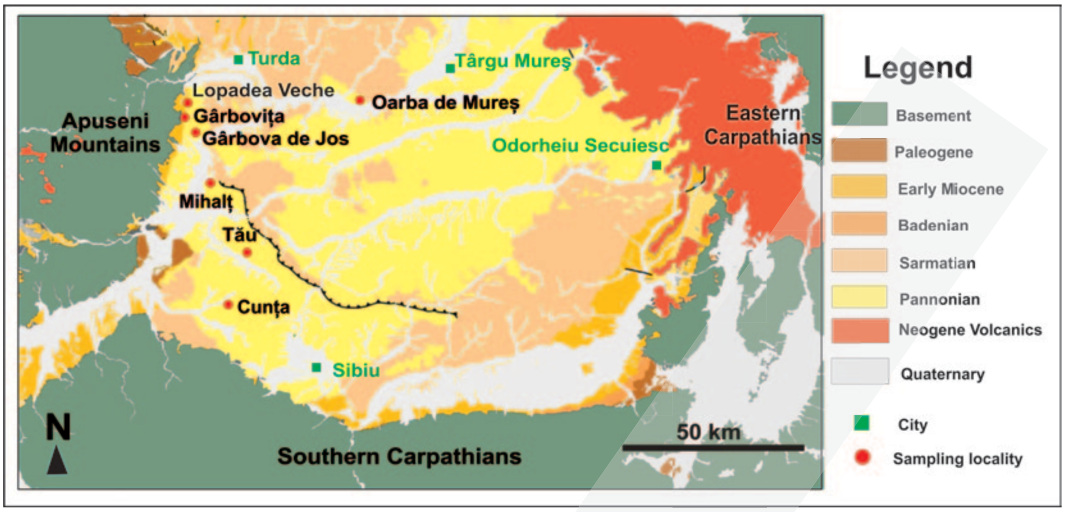

Figure 1. Geological map of the Transylvanian Basin with the distribution of Pannonian sediments and location of the sampled outcrops (adapted from DE LEEUW et al., 2013).

tion is poor. The thickness of sand layers increases upwards from 2–3 cm to 10–15 cm. Along the bedding planes plant fragments, branches, and poorly preserved leaf imprints occur together with a rich mollusc assemblage equally consisting of deep-water (*Congeria banatica* R. HÖRNES, *Paradacna* cf. *lenzi* (R. HÖRNES), *Undulotecha pancici* (BRUSINA)) and shallow-water forms (*Melanopsis vindobonensis* FUCHS). Our sample was collected from a marl bed in the lower part of the outcrop (Fig. 2).

The ostracod association is well preserved and evenly distributed in the argillaceous marl, reflecting autochthonous or al-

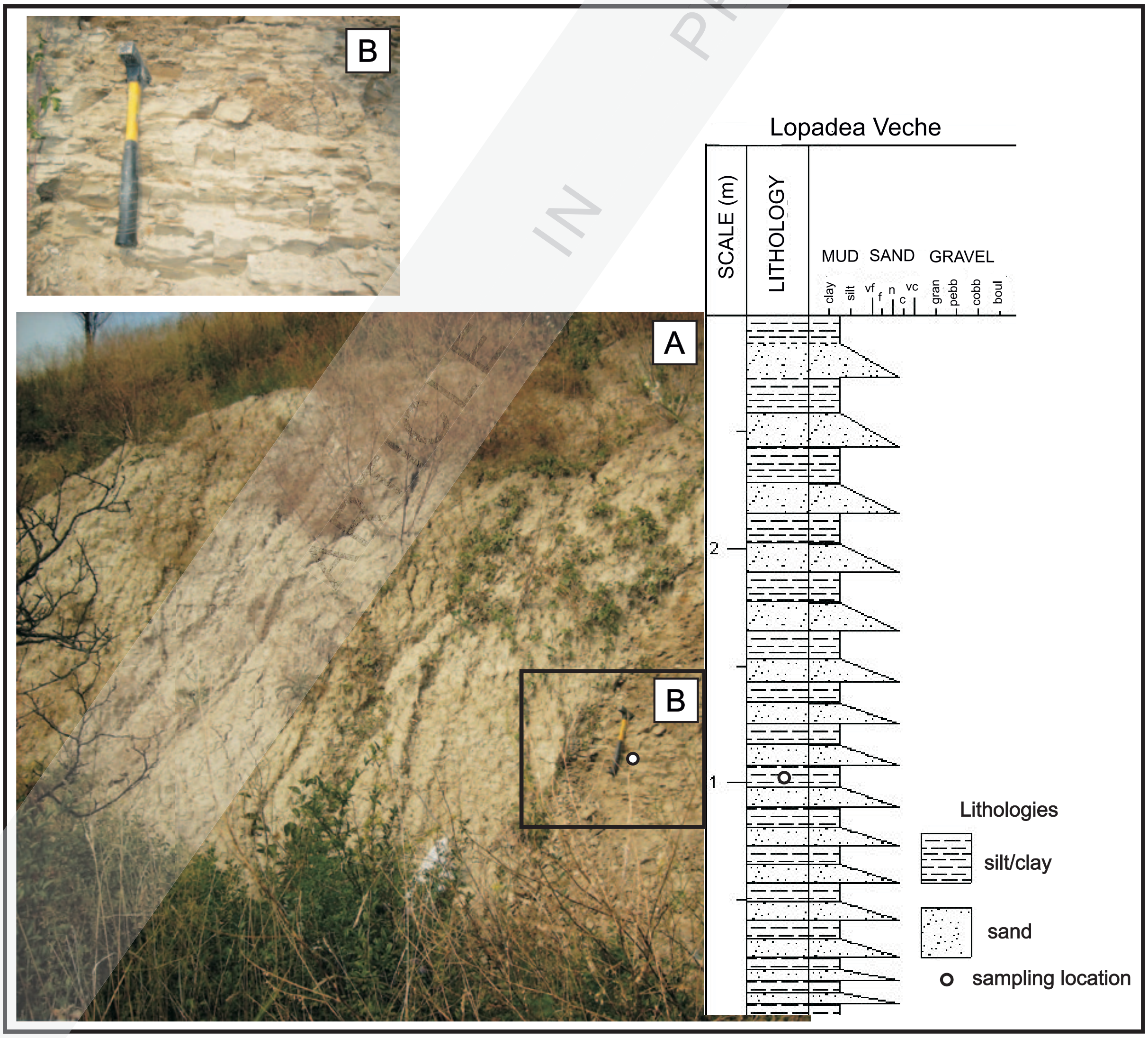

Figure 2. Lopadea Veche; A – alternation of argillaceous marl and yellowish, fine- and medium-grained sand layers, several cm in thickness. White dot indicates sampling location. B – close-up view of the sampled argillaceous marl.

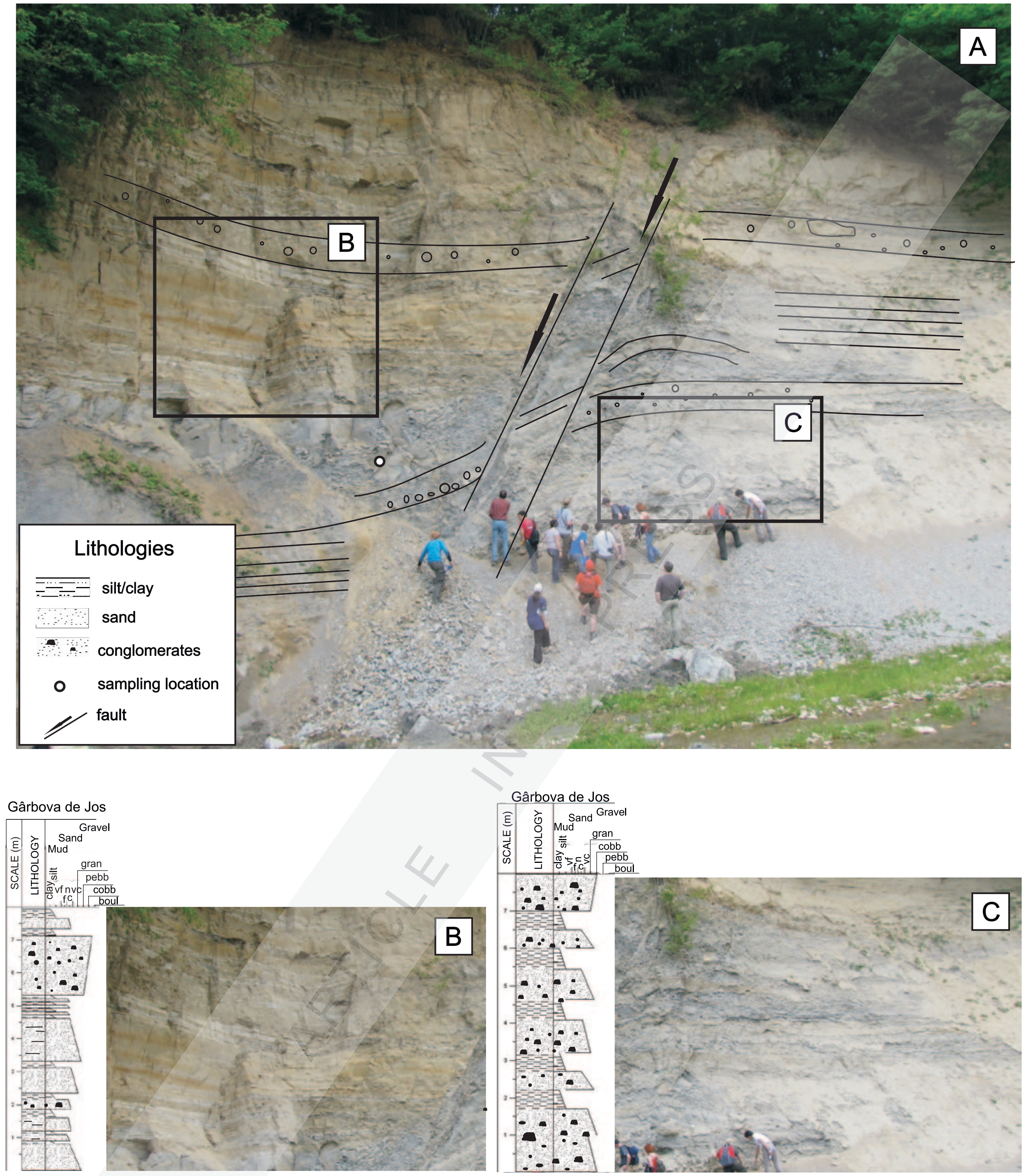

Figure 3. Gârbova de Jos; A – alternation of clast-supported, graded conglomerates, pebbly mudstones, and mud-clast conglomerates; the outcrop is cut by a large normal fault. White dot indicates sampling location. B and C – thin bedded turbidites (fine-grained, graded sandstone beds and mudstone with mud clasts).

most autochthonous burial. This material consists of 173 valves and carapaces, the latter representing 10% of the specimens; juvenile individuals are subordinate in the sample. The assemblage is rich in species, including *Amplocypris* cf. *reticulata* (Pl. 1, Figs. 20–22), *A.* sp., *Herpetocyprella hieroglyphica* (MÉHES), *Candona (Caspiolla) praebalcanica* KRSTIĆ, *Hemicytheria folliculosa*, *Cyprideis pannonica* (Pl. 3, Figs. 5–8), *Loxocorniculina hodonica*, *Candona (Typhlocypris) trigonella* (HÉJJAS) (Pl. 1, Figs. 29–32), *Candona (Propontoniella)* sp., and *Candona (Caspiocypris) transilvanica* (Fig. 8). The most common genera are *Amplocypris* and *Herpetocyprella*.

Species of *Cyprideis, Loxoconcha* and related genera typify marginal ostracod assemblages world-wide (BOOMER & EISENHAUER, 2002; BOOMER et al., 2005). According to KRSTIĆ and STANCHEVA (1990), *Cyprideis* is common in the marginal parts of the Pannonian basin, but missing from the deep basins. *Cyprideis* is therefore an indicator of shallow waters. It inhabits mostly brackish (mesohaline) environments, showing the great-

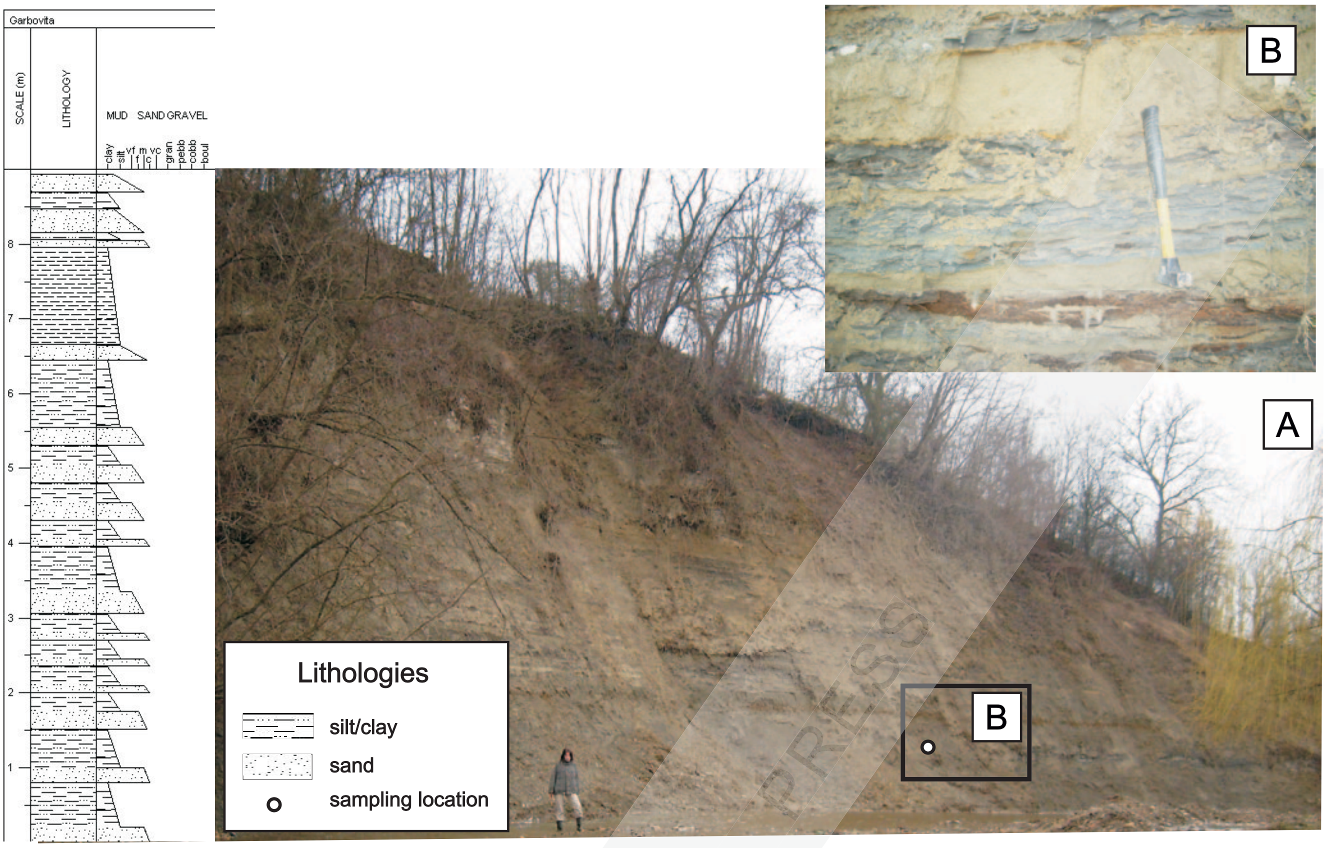

Figure 4. Gârbovița; A – alternation of marl beds and medium- to very fine-grained, graded sandstone layers. B – close-up view of the marl layers, stained by organic matter. White dot indicates sampling location.

Figure 5. Mihalț. Decimetre to metre thick, massive or laminated marl layers intercalated with thin sandstone beds. White dot indicates sampling location.

est abundance at salinities of 2–16.5‰ (WAGNER, 1964), but certain species of the genus may adapt to hypersaline environments (MEISCH, 2000). Pannonian assemblages with *Cyprideis, Amplocypris, Amnicythere, Hemicytheria* and *Loxoconcha* were probably highly tolerant of fluctuations in salinity: they occupied estuaries, i.e. semi-enclosed coastal water bodies with a salinity gradient from brackish to freshwater, in the southern part of the Pannonian basin (e.g. Kolubara basin in northwestern Serbia; RUNDIĆ, 2006). *Loxocorniculina* is known from brackish water ostracod assemblages of the Paratethys and the Eastern Mediterranean (PIPÍK & BODERGAT, 2004). According to KORECZ (1991), *Candona (Caspiolla) praebalcanica* inhabited plio- mesohaline environments, with 15–80 m water depth, and *Candona (Caspiocypris) transilvanica* inhabited shallow but calm environments.

The entire ostracod assemblage shows a mixture of shallow- and deep-water species, probably as a result of redeposition of littoral forms into deeper parts of the basin. *Candona (Caspiolla) praebalcanica* appears in our material with complete carapaces filled with sediment, a phenomenon indicating rapid burial (HOLMES, 2001). Otoliths and fish teeth also occur in the microfauna (Pl. 3, Figs. 9–16).

5.2. The Gârbova de Jos/Alsóorbó locality

The 20 m high outcrop is located near the village of Gârbova de Jos (46°27'25.58"N, 24°17'10.57"E) (Fig. 1). The outcropping succession is cut by a large normal fault of several metres offset, therefore a relatively thick sedimentary succession can be studied (Fig. 3). It comprises clast-supported, graded conglomerates, thick pebbly mudstones, mud-clast conglomerate, pebbly sandstones, and coarse- to medium-grained and medium- to fine-grained graded sandstone beds intercalated with mudstones. Individual beds are 1–50 cm thick. Poor normal grading and plane- to cross-lamination were recognized. Clast size occasionally attains 50 cm in diameter. These boulders are covered by horizontally laminated, deformed mudstone layers. Higher up, mudstone with a few centimetre thick graded sandstone intercalations becomes dominant. The top of the fine-grained sandstones rarely contains small vertical burrows. These beds are the products of sandy-silty turbidity currents, gravelly-sandy turbidity currents, and debris flows. The latter indicates the proximity of the basin-margin slope. This interpretation is supported by the composition of the gravel, indicating the Apuseni Mts. as a source area. According to KRÉZSEK et al. (2010), a shallow marine ramp supplied coarse clastics to the open shelf; the frequent, large-volume mass wasting events, however, may suggest a steeper slope, such as that of a fan-delta, and to deeper water, probably below the „shelf-edge".

The studied sample was collected from the lower part of the outcrop, from the dark grey suspension fall out mudstone, which also contained thin shells of deep-water bivalves (*Paradacna* cf. *lenzi, Congeria* sp.).

The ostracod association is very poorly preserved with thin and translucent valves. In addition to the fragments, only 48 complete valves were observed in our material. The fauna includes *Amplocypris* sp., *Candona (Typhlocypris)* sp., *Candona (Propontoniella)* sp. and *Hemicytheria folliculosa* (Fig. 8).

Except for the small and ornamented valves of *H. folliculosa,* which are well-preserved, the valves are damaged and broken. In general, ostracods with smooth, thin and elongated carapaces suggest a calm, relatively deep environment (DANIELOPOL, 1980; RUNDIĆ, 2006). Specimens of the littoral *Hemicytheria folliculosa* were probably transported into this environment.

5.3. The Gârbovița / Középorbó locality

This 20 m high outcrop is situated on the right bank of the Gârbova stream valley, across from the village (46°16'51.66"N, 23°38'07.26"E) (Fig. 1). The fossils of this outcrop were briefly treated by WANEK & FILIPESCU (1994); they mention fossil leaves of the tropical plant *Daphnogene*, molluscs, and ostracods, the latter indicating the Pannonian „C" zone of PAPP (1951).

The outcrop exposes marl beds and medium- to very fine-grained, graded, planar to cross-laminated sandstone layers of 5–10 cm thickness; the latter are interpreted as turbidites. The marl layers are dark in colour due to plant remains (organic matter) (Fig. 4). The depositional setting can be best understood by comparing this outcrop with the previous one, where the same marls and sandstones crop out together with various types of conglomerate (KRÉZSEK, 2005).

Congeria partschi CZJZEK and *Melanopsis vindobonensis* – molluscs that lived in shallow-water lacustrine environments – are common in the redeposited turbidite layers. The silty marl layers contain a rich sublittoral mollusc assemblage: *Paradacna* cf. *lenzi*, *Lymnocardium* cf. *majeri* (M. HÖRNES), *Lymnocardium* cf. *otiophorum* (BRUSINA), *Congeria banatica*, „*Gyraulus*" *ponticus* (LŐRENTHEY), *Micromelania* sp. occur together with fish teeth and otoliths. Our sample was taken from this deep-water marl facies.

The ostracod assemblage from Gârbovița is abundant and diverse; 225 ostracod valves were picked from the dried material. The fauna includes the following species (Fig. 8): *Amplocypris firmus* KRSTIĆ (Pl. 1, Figs. 15–19), *A. matejici* KRSTIĆ (Pl. 1, Figs. 11–14), *Herpetocyprella auriculata* (REUSS), *H. hieroglyphica*, *Candona (Caspiolla) praebalcanica* (Pl. 1, Figs. 23, 24), *C. (Typhlocypris) trigonella*, *C. (Caspiocypris) transilvanica*, *C. (Propontoniella)* sp., *Hemicytheria folliculosa* (Pl. 2, Figs. 27–32), *Loxocorniculina hodonica* (Pl. 3, Figs. 2, 3), and *Cyprideis* sp.

Three fossil species of *Herpetocyprella* have been recognised in the deposits of Lake Pannon, and they were previously assigned to *Hungarocypris* (DANIELOPOL et al., 2008b). A single extant representative of the genus, *Herpetocyprella mongolica* DADAY, is endemic to Lake Issyk-Kul, Kyrgizistan, Central Asia. It lives together with recent thalassic and athalassic *Cyprideis torosa* and *Tyrrhenocythere amnicola* at salinity of 6‰ (BRONSTEIN, 1947; RICKETTS et al., 2001). Other shallow-water forms, such as *Hemicytheria, Loxoconcha,* and *Cyprideis*, are subordinate in the sample (8, 6 and 3% of the total specimens, respectively).

5.4. The Mihalț/Mihálcfalva locality

The sampled outcrop, approximately 60–80 m high and 200–300 m long, is situated 1 km N of the village, along the road DJ142L, on the left bank of the Mureș river (46°10'35.05"N, 23°42'20.70"E) (Figs. 1, 5). Decimetre to metre thick, massive or laminated marl and calcareous marl comprise the sediment succession with some rare, thin, medium- to fine-grained sandstone intercalations. The marls are mostly suspension fall out deposits accumulated on the basin plain. Thin-shelled deep-water molluscs, such as *Paradacna* cf. *lenzi*, *Congeria banatica*, *Congeria* sp., *Undulotheca pancici*, *Micromelania* sp. are relatively common in the massive marl from which the sample for ostracods was collected.

The material consists of 56 ostracod valves, including different indeterminate species of Paratethyan Candoninae, and *Loxoconcha rhombovalis*, *Hemicytheria folliculosa,* and *Amnicythere miscere* (KRSTIĆ) (Fig. 8; Pl. 2, Figs. 25, 26, Pl. 3, Fig. 1).

Smooth, thin and translucent valves of *Candona* have the most significant role in the association, but they are unidentifiable

Figure 6. Tău. An erosional surface divides the outcrop into a lower unit, dominated by mudstones formed as levee to overbank deposits intercalated with rare overspilling thin-bedded turbidites, and an upper unit with the complex, migrational deep-water channel fill. White dot indicate sampling locations within the lower unit.

Figure 7. Oarba de Mureş, outcrop E. Massive and bioturbated clay marls. White dot indicates sampling location.

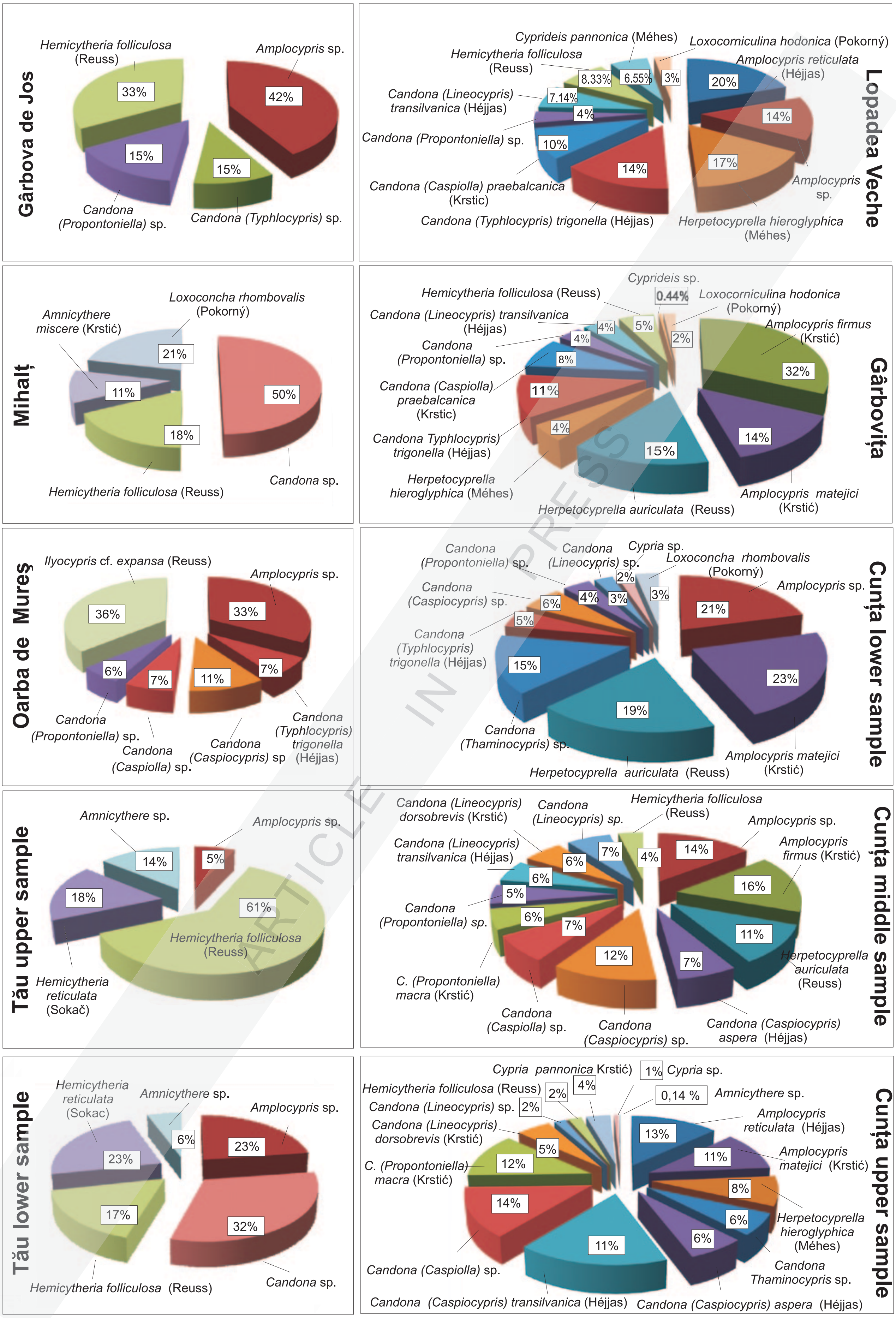

Figure 8. Pie charts of species distribution in each sample (percentage of specimens in all specimens from 250 g sediment).

to species level due to their very poor preservation. The small and ornamented valves of the other taxa are well preserved. *Loxoconcha* occurs in meso- to euhaline, littoral environments (MORKHOVEN, 1963). Numerous *Amnicythere* species live in the littoral and sublittoral zones of the Black and Caspian Seas at brackish salinity, but some species have been observed in freshwater bays and estuaries. *Amnicythere multituberculata* (LIVENTAL) lives today in the central and southern Caspian Basins at salinities of 11.5–13.5‰. It is missing in the northern Caspian Basin, where freshwater input from Volga River effectively lowers salinity (SCHORNIKOV, 1964). The freshwater Lake Ohrid, however, also hosts some endemic species of the genus, such as *Amnicythere karamani* (KLIE) (NAMIOTKO et al., 2012).

5.5. The Tău/Székástóhát locality

The outcrop is almost 1 km wide, where a 12–15 m high continuous succession can be followed over a distance of 300 m. It occurs along road DC203 (46°5'20.14"N, 23°50'33.36"E) (Fig. 1).

The central part of the outcrop can be divided into two units (Fig. 6). The lower unit consists of thin beds of mudstone intercalating with very thin, fine- or medium-grained sandstone beds. This unit contains a deep-water mollusc association with *Paradacna* cf. *lenzi*, *P.* cf. *abichi* (R. HÖRNES), *Lymnocardium* sp., *Congeria czjzeki* M. HÖRNES, *C.* sp., *Velutinopsis* sp., *Undulotheca pancici*, *Micromelania* sp. The upper unit starts with a wide erosional scour and is composed up of thick, often amalgamated, massive beds of medium- to very coarse-grained, granular sandstone. Rip-up mud clasts and water-escape structures are common. Shallow and laterally stepping erosional surfaces are also characteristic.

Sand beds in both units are the products of turbidity currents. The lower unit dominated by mudstones was formed as levee to overbank deposits with rare overspilling thin-bedded turbidites. The upper sandstone represents a complex, laterally migrating deep-water channel fill (KRÉZSEK et al., 2010; TŐKÉS, 2013) (Fig. 5). As a whole, a major isolated channel-levee system in a deep, profundal environment can be reconstructed in the outcrop.

Two samples were taken for ostracods; one from the lower part and another from the upper part of the fine-grained overbank sediments (lower unit).

The assemblage from the lower part of the marl unit is poorly preserved and consists of 88 ostracod valves (Fig. 8). The fauna includes *Amplocypris* sp., *Candona* sp., *Hemicytheria folliculosa*, *H. reticulata* (SOKAČ) (Pl. 2, Fig. 24), and *Amnicythere* sp. The assemblage from the upper part of the marl unit is poor in species and individuals (the sample consists of 57 ostracod valves; Fig. 8). The fauna includes *Hemicytheria folliculosa*, *H. reticulata*, *Amnicythere* sp., and *Amplocypris* sp.

Candona is rare in the lower sample and completely missing from the upper one. *Hemicytheria* and *Amplocypris* are dominant in the upper marl bed. *Amnicythere* occurs in both samples, but it is more abundant in the upper one. *Hemicytheria,* a representative of the littoral environment, indicates resedimentation processes.

5.6. The Cunța/Konca locality

The sampling location is about 1 km west of the village of Cunța at the western border of its administrative area (45°92'63.63"N, 23°70'21. 23"E) (Fig. 1). LŐRENTHEY (1893) published a list of molluscs from Cunța (at that time spelled as Koncza), including *Melanopsis fossilis* (GMELIN), *M. pygmaea* HÖRNES, *M. bouei* FÉRUSSAC, *Plagiodacna carinata* (DESHAYES), *Congeria subglobosa* PARTSCH, *C. partschi, Congeria sp., Unio* sp., and *Theodoxus crenulatus* (KLEIN). LŐRENTHEY (1893) thought that this fauna represented the „*Lyrcaea*-horizon", the uppermost stratigraphic unit out of the three ones that he recognized in the Transylvanian basin. The exact location where fossils of these shallow-water species were collected, however, remains unknown.

The sampled outcrop displays decimetre to metre thick coarse-grained sandstone and pebbly sandstone beds, up to cobble-sized clasts. These are mostly well sorted with horizontal lamination. The sandstones alternate with bluish grey, bioturbated marls. Some marl layers are laminated. Fish remnants (otoliths, teeth) are common in the studied beds. Gravity mass flows and suspension settling alternated in the depositional environment. Three samples were collected from different levels of the bluish grey marl layers.

The sample from the lower part of the outcrop consists of 154 well-preserved ostracod valves. The most frequent genera are *Amplocypris* and *Herpetocyprella*. The fauna includes the following species (Fig. 8): *Amplocypris matejici*, *A.* sp., *Herpetocyprella auriculata* (Pl. 1, Figs. 6–10), *Candona (Thaminocypris)* sp., *C. (Caspiocypris)* sp., *C. (Propontoniella)* sp., *C. (Typhlocypris) trigonella*, *C. (Lineocypris)* sp., *Cypria* sp. and *Loxoconcha rhombovalis* (Pl. 3, Fig. 4).

The ostracod fauna from the middle part of the outcrop comprises a rich and well-preserved association. We found 344 juvenile and adult ostracod valves, representing the following species: *Candona (Lineocypris) dorsobrevis* KRSTIĆ (Pl. 1, Figs. 25–28), *C. (Caspiocypris)* sp., *C. (Lineocypris)* sp., *C. (Propontoniella) macra*, *C. (Propontoniella)* sp., *C. (Caspiocypris) transilvanica*, *C. (Caspiolla)* sp., *C. (Thaminocypris)* sp., *Amplocypris* sp., *A. firmus, Herpetocyprella auriculata, C. (Caspiocypris) aspera* (HÉJJAS), and *Hemicytheria folliculosa* (Fig. 8).

The ostracod fauna from the upper part of the Cunța outcrop is the richest and most diverse association in this study; we found 665 well-preserved ostracod valves in the material. The association includes *Amplocypris reticulata*, *A. matejici*, *Herpetocyprella hieroglyphica* (Pl. 1, Figs. 1–5), *Candona (Caspiocypris) transilvanica* (Pl. 2, Figs. 5–8, 13–15), *C. (Propontoniella) macra* (Pl. 2, Figs. 9–12), *C. (Caspiolla)* sp., *C. (Caspiocypris)* cf. *aspera* (Pl. 2, Figs. 1–4), *C. (Lineocypris)* sp., *C. (Lineocypris) dorsobrevis*, *Hemicytheria folliculosa*, *Cypria pannonica* (KRSTIĆ) (Pl. 2, Figs. 20–23), *Cypria* sp., and *Amnicythere* sp. (Fig. 8).

The Cunța assemblages, especially from the middle and upper parts of the section, differ from our other samples in the diversity and dominance of various Paratethyan Candoninae species. In general, the majority of *Candona* species are freshwater, tolerating a slight increase of salinity, but the endemic Lake Pannon Candoninae adapted to brackish water (MEISCH, 2000; CZICZER et al., 2008). Typically trapezoid-shaped species of the subgenus *Lineocypris* occur predominantly in the deep parts of large lakes (MORKHOVEN, 1963).

The appearance of *Cypria* in both the lower and upper samples is also a unique feature of the Cunța outcrop. Most species of *Cypria* live in freshwater (lakes, pools) preferring environments with abundant vegetation, although they tolerate mesohaline conditions as well (MEISCH, 2000). The appearance of this genus therefore may indicate freshwater influence, probably proximity of a deltaic environment, in accord with the presence of *Unio* in the Cunța mollusc fauna (LŐRENTHEY, 1893).

5.7. The Oarba de Mureş/Marosorbó locality

The investigated outcrop is on the right bank of the river Mureş near Oarba de Mureş village (46°27'25.58"N, 24°17'10.57"E)

Table 1. Occurrences of Pannonian ostracod species in the investigated outcrops and the stratigraphic distribution of each species according to the literature (POKORNÝ, 1944; KRSTIĆ, 1971, 1972a, b, 1973a, b, 1985; SOKAČ, 1972, 1990; JIŘIČEK, 1985; WANEK, 1992a; FILIPESCU, 1996; RUNDIĆ, 1998, 2006; RUNDIĆ et al., 2011; FILIPESCU et al., 2011).

Regional Chronostratigraphy	PANNONIAN							
	Slavonian Substage				Serbian Substage			
Age	11.6 Ma							ca. 9 Ma
OSTRACODA BIOZONES – POKORNÝ, 1944	α		β		γ		δ	
PAPP, 1951	A	B	C	D	E			
KOLLMANN, 1960	A	B	C	D	E		F	G, H
JIŘIČEK, 1985	A	B		C	D	E1	E2	E3
KRSTIĆ, 1985	Hemicytheria lőrentheyi	Hemicytheria hungarica	Hemicytheria tenuistriata	Propontoniella candeo	Amplocypris abscissa	Hemicytheria croatica	Serbiella sagittosa	Typhlocyprella lineocypriformis

Ostracod species	Lopadea Veche	Gârbovița	Gârbova de Jos	Mihalț	Oarba de Mureș	Tău upper sample	Tău lower sample	Cunța lower sample	Cunța middle sample	Cunța upper sample
Amplocypris reticulata (HÉJJAS, 1894)	○									●
Amplocypris firmus KRSTIĆ, 1973		●							●	
Amplocypris matejici KRSTIĆ, 1973		●						●		
Amlpocypris sp.	○		○		●	∘	○	●	●	
Herpetocyprella auriculata (REUSS, 1850)		●						●	●	
Herpetocyprella hieroglyphica (MÉHES, 1907)	●	◌								●
Candona (Thaminocypris) sp.								●		●
Candona (Typhlocypris) trigonella (HÉJJAS, 1894)	●	●			○			◌		
Candona (Typhlocypris) sp.			◌							
Candona (Caspiocypris) aspera (HÉJJAS, 1894)									●	○
Candona (Caspiocypris) transilvanica (HÉJJAS, 1894)	○	○							○	●
Candona (Caspiocypris) sp.					○			◌	●	
Candona (Caspiolla) praebalcanica (KRSTIĆ, 1972)	○	○			○					
Candona (Caspiolla) sp.					∘				○	●
Candona (Propontoniella) macra (KRSTIĆ, 1972)									○	●
Candona (Propontoniella) sp.	◌	◌	○		◌			∘	○	
Candona (Lineocyris) dorsobrevis (KRSTIĆ, 1972)									○	●
Candona (Lineocyris) sp								∘	○	◌
Candona sp.				●			●			
Hemicytheria folliculosa (REUSS, 1850)	○	○	●	◌		●	○		○	○
Hemicytheria reticulata (SOKAČ, 1972)						○	○			
Cyprideis pannonica (MÉHES, 1908)	○									
Cyprideis sp.		∘								
Cypria pannonica (KRSTIĆ, 1973)										○
Cypria sp.								∘		∘
Ilyocypris cf. expansa (REUSS, 1850)					●					
Amnicythere miscere (KRSTIĆ, 1973)				◌						
Amnicythere sp.						◌	◌			∘
Loxocorniculina hodonica (POKORNÝ, 1952)	∘	∘								
Loxoconcha rhombovalis (POKORNÝ, 1952)				○				∘		

Outcrops

● > 26
○ 13-25
◌ 7-12
∘ 1-6
specimens in 250 g dried material
[shaded] - stratigraphic range of the species in literature data

(Figs. 1, 7). The Upper Sarmatian to Lower Pannonian outcrops at Oarba de Mureș received much attention recently (SZTANÓ et al., 2005; SÜTŐ-SZENTAI & SZEGŐ, 2008; VASILIEV et al., 2010; FILIPESCU et al., 2011). The outcrop sampled (and designated as outcrop „E") is located in the horizontal continuation of outcrop D of SZTANÓ et al. (2005), exposing massive and bioturbated clay marl with up to 0.5–1 m thick beds, and with intercalations of a few cm thick calcareous marls (Fig. 7). In this part of the succession sediments indicate deep basin-floor environment without mass-flow events. In one of the calcareous marl layers, molluscs („*Lymnocardium*" *undatum* (REUSS), *Congeria* cf. *banatica*) were preserved as moulds. The sample was collected from a massive clay marl bed from the lower part of the outcrop.

The investigated ostracod fauna, consisting of 100 valves, has low diversity (Fig. 8). The assemblage includes the following brackish water ostracods: *Amplocypris* sp., *Candona (Caspiocypris)* sp., *C. (Caspiolla)* sp., *C. (Propontoniella)* sp., *C. (Typhlocypris) trigonella,* and *Ilyocypris* cf. *expansa* (REUSS) (Pl. 2, Figs. 16–19).

The most common species in the assemblage belong to *Amplocypris* and *Candona*. Their valves are thin, translucid and often broken. The oblong and elongated carapace shape may indicate benthic dwellers (DE DECKKER, 2002).

Ilyocypris cf. *expansa* seems to be an exotic element in the assemblage, because *Ilyocypris* is known to live in freshwater, tolerating slowly running water (MEISCH, 2000). Valves of the modern species *Ilyocypris lacustris* KAUFMANN, 1900 were recorded from freshwater lakes at depths of 35–139 m, but the presence of living specimens in deep water environment is uncertain (MEISCH, 2000). Its presence in this deep-water assemblage is probably due to reworking from a shallow, freshwater-influenced environment.

6. DISCUSSION AND CONCLUSIONS

6.1. Palaeoenvironment and palaeogeography

The overall palaeoecological interpretation of the investigated ostracod faunas is difficult; probably much more samples would be required to understand the ecological significance of these endemic species. In general, the assemblages indicate a mixture of deep-water and shallow-water species. Thin-shelled, smooth Paratethyan Candoninae occupied the sublittoral to profundal zones of Lake Pannon, from the wave base down to the foot of the slope. The littoral zone was inhabited by forms with thicker and ornamented shells, such as, for instance, *Cyprideis, Loxoconcha, Amnicythere,* and *Hemicytheria*. In our samples, the deep-water and littoral taxa occur in various ratio.

Interestingly, the mollusc fauna shows similar characteristics across some of the investigated outcrops (Lopadea Veche, Gârbovița, and, according to the literature, Cunța). Thin-shelled bivalves, known to be confined to deep water environments elsewhere (e.g. *Paradacna abichi, Congeria banatica, Undulotheca pancici*), occur together (or in very close proximity to) typical littoral, herbivorous snails, such as *Melanopsis*. Sedimentological patterns in all the outcrops indicate various kinds of mass transport deposits, most commonly interpreted as turbidites. Although the ostracod samples were taken from fine-grained, suspension fall-out sediments, reworking and re-deposition of littoral ostracod valves into the deep-water environment is the most plausible explanation for the mixed character of the ostracod (and mollusc) faunas. In this case, the actual ostracod assemblages from the investigated part of the TB highly depend on local taphonomic factors. Alternatively, some species of the otherwise littoral ostracod genera may have adapted to living at greater depths; such examples are recorded from the Caspian Sea (BOOMER et al. 2005).

In terms of the abundance and diversity of ostracods, these outcrops can be divided into two distinct groups: Lopadea, Gârbovița, and Cunța (all the three samples) yielded more than 100 specimens (154 to 665) and at least 10 species (10 to 14), whereas Gârbova de Jos, Mihalț, Tau (both samples), and Oarba de Mureş yielded consistently fewer specimens (48–100) and species (4–6) from the same amount of sediment (Fig. 8). In addition, reworked littoral molluscs occur in the first group, but they were not observed in the second. The first group of outcrops lie closer to the basin margin, directly on the foothills of the Apuseni Mts, whereas the second group is located in a more basinward position (although the distance between Gârbovița and Gârbova de Jos is only a few kilometres). We hypothesize that these differences in abundance and diversity of the ostracods reflect environmental differences, such as deeper water and/or decreasing levels of oxygen and nutrients, i.e. more distal environments towards the basin interior.

In the Caspian Sea (a Paratethyan remnant) which is the best modern analogue of Lake Pannon, BOOMER et al. (2005) reported a steep gradient in ostracod diversity with increasing water depth within the deep water realm. They found that the number of ostracod species decreased from 17 to 3 between 315 and 479 m. In addition, their samples showed that total specimen abundance declined exponentially with increasing water depth. We speculate that these patterns may be analogous with the diversity and abundance drop that we observed in our samples, although there are no means of estimating the absolute water depth in the early Pannonian TB.

6.2. Biostratigraphic interpretation and age

Various ostracod biostratigraphic systems have been erected in different parts of the Pannonian Basin System, but they usually reflect local characteristics and significantly differ from each other (e.g. POKORNÝ, 1944; KOLLMANN, 1960; SOKAČ, 1972; KRSTIĆ, 1973a, b, 1985; JIŘIČEK, 1985; RUNDIĆ, 1998, 2002, 2006; RUNDIĆ et al., 2011). GANIĆ et al. (2010) and TER BORGH et al. (2013) came to the conclusion that the „classical" Lake Pannon ostracod biozones are difficult to identify in the otherwise diverse and abundant ostracod record of the Beočin claypit (Fruška Gora, Serbia), which is roughly coeval with these Transylvanian samples, possibly because earlier biostratigraphic research underestimated the role of palaeoecological conditions in the occurrence and distribution of ostracods. A similar view was expressed by OLTEANU (2011).

As no special zonation for the TB has been currently produced, the biostratigraphic zonation of KRSTIĆ (1971, 1972a, b, 1973a, b, 1985) and SOKAČ (1972, 1990) originally elaborated for the southern parts of the Pannonian Basin is applied here. Recent stratigraphic observations from the TB (WANEK, 1992a; FILIPESCU, 1996; FILIPESCU et al., 2011) were also taken into account. For instance, WANEK (1992b) found that *Amplocypris reticulata* is probably an endemic species for the TB, and is present only in the „α phase" of POKORNÝ (1944), corresponding to the lowermost Pannonian, i.e. lower part of the Slavonian Substage; *Loxoconcha rhombovalis* determines the final part of the Slavonian Substage; *Cyprideis pannonica* appears in the uppermost Sarmatian and is present in the „α phase" of the Pannonian.

KRSTIĆ (1985) erected 8 stratigraphic ostracod zones for the Pannonian Stage: four zones in the older Slavonian and four in the younger Serbian Substages. The four Slavonian zones (from bottom to top) are the *Hemicytheria loerentheyi, Hemicytheria hungarica, Hemicytheria tenuistriata*, and *Propontoniella candeo* Zones. Characteristic species of the three latter zones from the present material include:

Hemicytheria hungarica Zone: *Cyprideis pannonica*, *Amplocypris reticulata*, *Amnicythere miscere*, *Herpetocyprella auriculata*, *Candona (Caspiocypris) transilvanica*.

Hemicytheria tenuistriata Zone: *Loxocorniculina hodonica*, *Herpetocyprella auriculata*, *Hemicytheria folliculosa*, *Candona* (*Typhlocypris) trigonella*, *C. (Propontoniella) macra*, *C. (Caspiocypris) transilvanica*, *Ilyocypris* cf. *expansa*.

Propontoniella candeo Zone: *Candona (Propontoniella) macra*, C. (*Thaminocypris)* sp., *Herpetocyprella hieroglyphica*, *Hemicytheria reticulata*, *Loxoconcha rhombovalis.*

The appearance of *Hemicytheria reticulata* in the latter biozone requires some discussion because SOKAČ (1972) and OL-

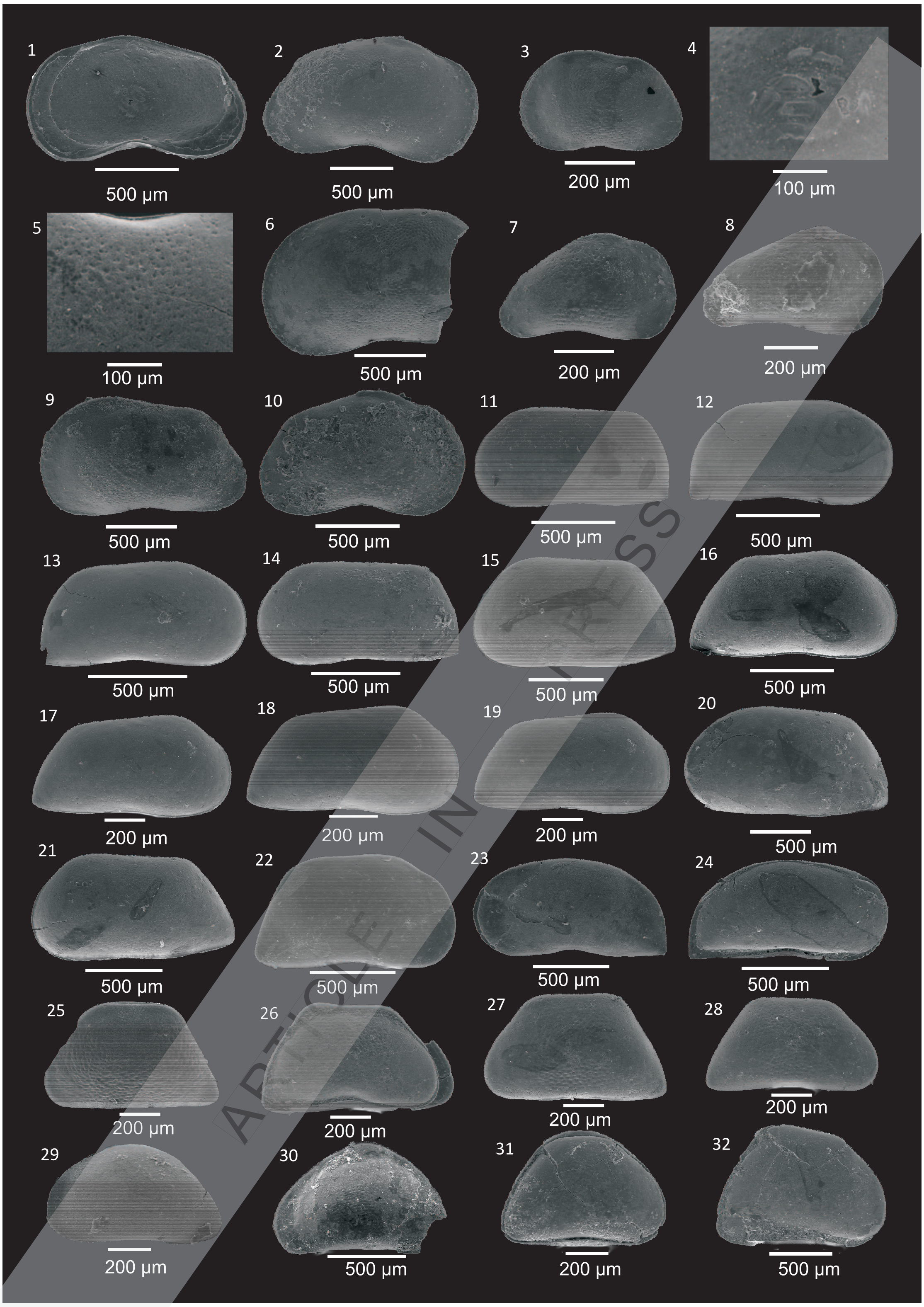

Plate 1. Pannonian ostracod assemblages from the southwestern part of the TB.

1–5 *Herpetocyprella hieroglyphica* (MÉHES), Cunța; right valve (RV), internal lateral view (1), RV, external lateral view (2), left valve (LV), juvenile (juv.) (3), central muscle scars (4), pore canals on the ventral part of the RV (5).

6–10 *Herpetocyprella auriculata* (REUSS), Cunța; LV, fragment (6), RV juv. (7), RV juv. (8), LV juv. (9), RV juv. (10).

11–14 *Amplocypris matejici* KRSTIĆ, Gârbovița; LV (11), RV (12), RV (13), LV (14).

15-19 *Amplocypris firmus* KRSTIĆ, Gârbovița; LV (15), RV (16), RV (17), RV (18), RV (19).

20–22 *Amplocypris* cf. *reticulata* (HÉJJAS), Lopadea Veche; LV (20), LV (21), RV (22).

23, 24 *Candona (Caspiolla) praebalcanica* KRSTIĆ, Gârbovița; carapace, lateral view of LV (23), carapace, lateral view of RV (24).

25–28 *Candona (Lineocypris) dorsobrevis* KRSTIĆ, Cunța; LV (25), carapace, lateral view of RV (26), LV (27), RV (28).

29–32 *Candona (Typhlocypris) trigonella* (HÉJJAS), Lopadea Veche; carapace, lateral view of LV (29), carapace, lateral view of LV (30), carapace, lateral view of RV (31), carapace, lateral view of RV (32).

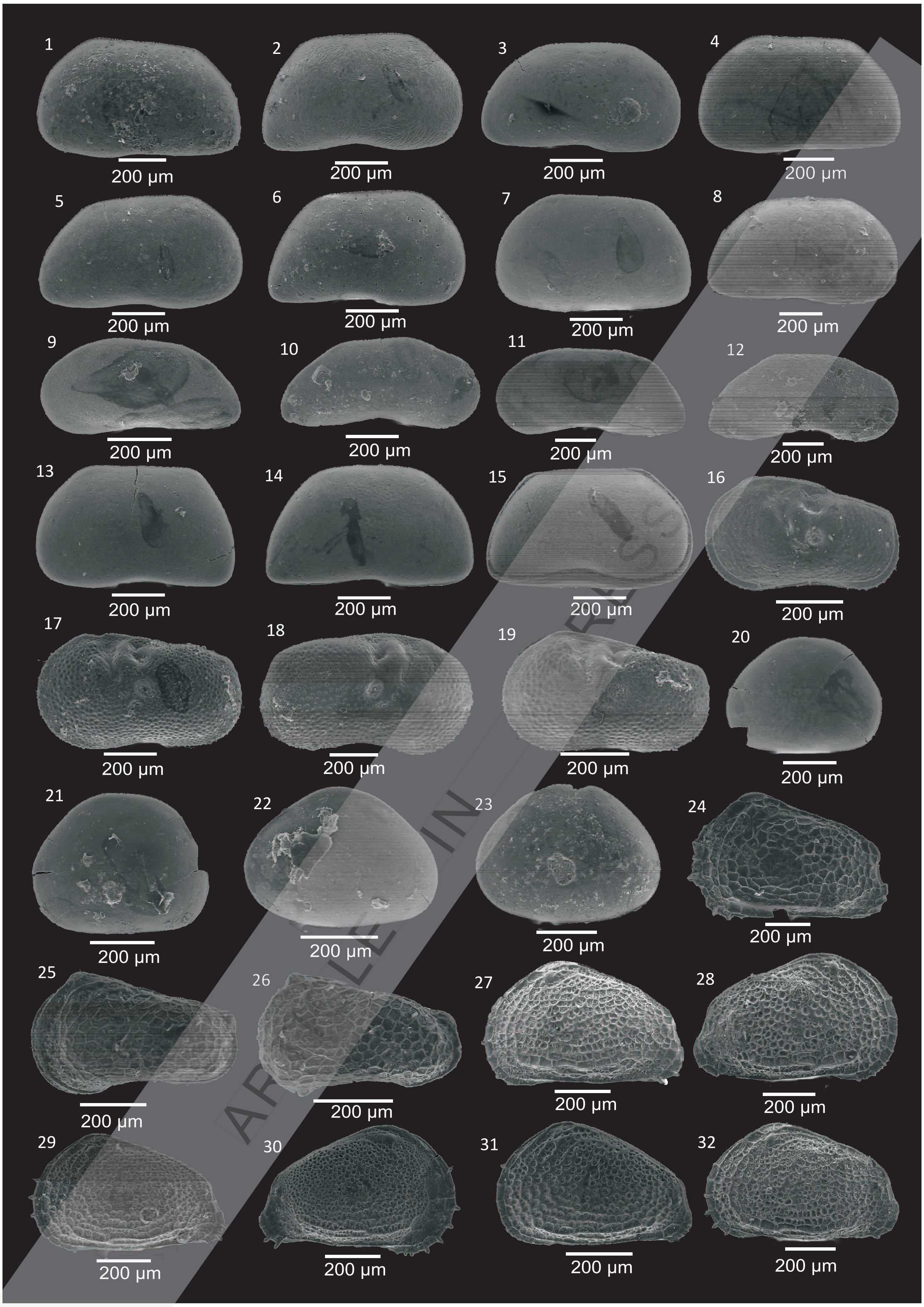

Plate 2. Pannonian ostracod assemblages from the southwestern part of the TB.

1–4 *Candona* (*Caspiocypris)* cf. *aspera* (HÉJJAS), Cunța; LV (1), RV (2), RV (3), LV (4).
5–8 *Candona* (*Caspiocypris) transilvanica* (HÉJJAS), Cunța; RV (5), RV (6), LV (7), RV (8).
9–12 *Candona (Propontoniella) macra* KRSTIĆ, Cunța; LV (9), RV (10), LV (11), RV (12).
13–15 *Candona (Caspiocypris) transilvanica* (HÉJJAS), Cunța; LV (13), RV (14), carapace, lateral view of RV (15).
16–19 *Ilyocypris* cf. *expansa* (REUSS), Oarba de Mureș; internal lateral view of RV (16), LV (17), RV (18), LV (19).
20–23 *Cypria pannonica* KRSTIĆ, Cunța; LV (20), LV (21), RV (22), LV (23).
24 *Hemicytheria reticulata* SOKAČ, Tău; LV.
25, 26 *Amnicythere miscere* (KRSTIĆ), Mihalț; LV (25), LV (26).
27–32 *Hemicytheria folliculosa* (REUSS), Gârbovița; LV juv. (27), RV juv. (28), LV juv. (29), RV juv. (30), LV juv. (31), LV juv (32).

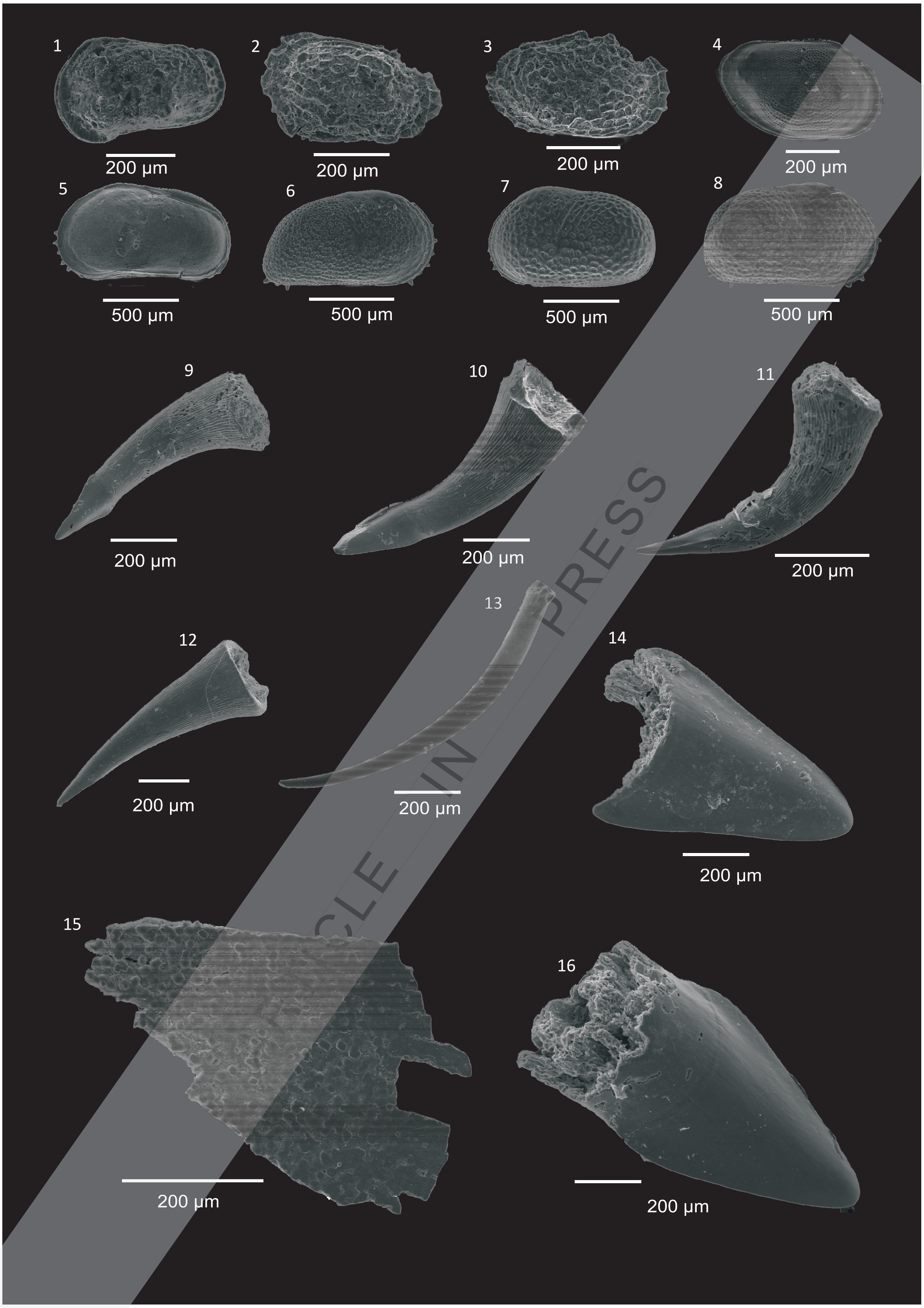

Plate 3. Pannonian micropalaeontological assemblages from the southwestern part of the TB.

1	*Amnicythere miscere* (KRSTIĆ), Mihalţ; LV.
2, 3	*Loxocorniculina hodonica* POKORNỲ, Gârbovița; LV (2), LV (3).
4	*Loxoconcha rhombovalis* POKORNỲ, Cunța; RV.
5–8	*Cyprideis pannonica* (MÉHES), Lopadea Veche; RV, internal lateral view (5), RV, external lateral view (6), LV (7), RV (8).
9–16	Fish skeletal fragments; fish teeth, Gârbovița (9–10), fish tooth, Mihalţ (11), fish teeth, Cunța (12–13), fish teeth, Lopadea Veche (14, 16), fish squama, Lopadea Veche (15).

TEANU (2011) claim that this species occurs only in the Serbian substage „Late Pannonian"). Indeed, the specimens presented here differ from the original description of SOKAČ (1972) in lacking the sharp, high ventral rib and the pronounced posterioventral part. Such differences in the expression of ornamentation have been extensively discussed (for more details see KEEN, 1982), and they can be related to ecological or genetic factors, especially in the brackish environment of Lake Pannon in which ecological conditions were highly variable (PIPÍK, 1998). Lake Pannon is well known for its extensive intralacustrine evolution (e.g. GEARY, 1990; PIPÍK 2007). This discovery of *H. reticulata* may represent an ancestor of *H. reticulata* in the sense of SOKAČ (1972), but this relationship should be demonstrated by detailed morphometric and evolutionary study of the subfamily Hemicytherinae in Lake Pannon.

In conclusion, the three ostracod biozones above are represented in the samples from the southwestern part of the TB (Table 1). Lopadea Veche and Gârbovița belongs to the *Hemicytheria hungarica* Zone. Samples from Gârbova de Jos, Oarba de Mureș, and Mihalț can be assigned into the *Hemicytheria tenuistriata* Zone. Finally, the ostracod fauna from Tău and Cunța indicates the *Propontoniella candeo* Zone. All these zones belong to the lower Pannonian Slavonian Substage, but the oldest Pannonian ostracod biozone, the *Hemicytheria loerentheyi* Zone was not identified in any of the samples. This interpretation is roughly supported by the mollusc fauna. The age of the outcrops is thus approximately between 10 and 11.3 Ma (cf. VASILIEV et al., 2010).

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