

# Early Sarmatian paleoenvironments in the easternmost Pannonian Basin (Borod Depression, Romania) revealed by the micropaleontological data

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(Manuscript received March 13, 2013; accepted in revised form October 16, 2013)

**Abstract:** The Sarmatian sedimentary record of the Borod Depression (eastern Pannonian Basin) consists of a marine sequence with continental influence. The investigated section, located near Vârciorog, was biostratigraphically and paleoenvironmentally analysed. The micro- and macrofossil assemblages include dasycladaceans, characeans, foraminifera, molluscs, polychaetes, ostracods, crabs, bryozoans, fish and vertebrate remains, which are characteristic for a shallow marine setting with local transitions to continental facies. The microfossil assemblages are characteristic for the *Elphidium reginum* Zone and *Mohrensternia* Zone of the early Sarmatian (Serravallian). The succession of populations correlates with the sedimentological trend, allowing the separation of several genetic units. The relative sea-level changes and the progradational trend from the top of the section suggest active tectonics in the hinterland (Apuseni Mountains). The shallow seas surrounding the emerging islands (Apuseni Mountains) provided the connections between the Pannonian and Transylvanian basins during the early Sarmatian.

**Key words:** Sarmatian (late Middle Miocene), Borod Depression (NW-Romania), paleoenvironments, paleogeography, sequence stratigraphy, molluscs, bryozoans, foraminifera, ostracods.

## Introduction

The Borod Depression represents an eastern extension of the larger Pannonian Basin (Fig. 1), developed on the western slopes of the Apuseni Mountains (Istocescu & Istocescu 1974; Györfi & Csontos 1994; Papaianopol & Macaleţ 1998). Its evolution was quite similar to the development of other small basins (Şimleu, Beiuş, and Zarand) near the uplifted structures of the Apuseni Mountains and other older structures in the vicinity (Meseş and Preluca Massifs). The basin's fill consists of Neogene and Quaternary siliciclastic deposits with local intercalations of coal, which unconformably cover the Mesozoic (sedimentary) and Paleozoic (metamorphic) basement. Several studies already highlighted the particular macro- and microfossil contents of the Neogene formations (Givulescu 1957, 1991; Istocescu et al. 1970; Nicorici & Istocescu 1970; Nicorici 1971; Şuraru & Şuraru 1973; Bucur et al. 1993; Popa et al. 1998; Filipescu et al. 2000; Popa 2000; Filipescu & Popa 2001; Miclea et al. 2011). However, paleoenvironmental interpretations and their relation to a wider paleogeographical context are missing until now.

The studied section is located near Vârciorog (Vişinilor Stream, 46°58' 42" N; 22°15' 57" E; Fig. 2) and belongs to the Sarmatian (Middle Miocene) Corniţel Formation (Popa 2000). Nine outcrops (D1–D9) were sampled, but this study refers mainly to outcrop D9, which has been considered as the

most representative. Here, we document the micropaleontological record and discuss the detected paleoenvironmental changes in order to restore a part of the paleogeographical evolution at the eastern border of the Pannonian Basin.

## Material and methods

Forty-three samples were collected from fine-grained siliciclastic intervals along the ~9 m thick section, at distances between 5 to 20 cm (Fig. 2). All the samples were processed by standard micropaleontological methods. The microfossils were recovered from the 63 µm sieve fraction after washing 250 g of dried sediment from each sample. Identification of taxa was followed by quantitative analyses of foraminifera based on percentage distribution of different groups (Fig. 4). Representative taxa are documented by stereomicroscope and the scanning electron microscope (SEM) photographs inserted in Figures 5 to 10.

## Results

The microfossil assemblages were interpreted from the biostratigraphic and paleoecological points of view, trying to point out their relationship to the relative sea-level changes



**Fig. 1.** Position of the investigated area in the Pannonian Basin.

generated by regional events and consequently their potential for stratigraphic dating and correlation.

### Biostratigraphy

The recorded foraminiferal species are characteristic for the early Sarmatian (*Elphidium reginum* Zone — Grill, 1941 — Fig. 3) and are very similar to other assemblages described from the Central Paratethys (Grill 1941; Brestenska 1974; Görög 1992; Popescu 1995; Filipescu et al. 2000; Schütz et al. 2007; Toth & Görög 2008; Koubová & Hudáčková 2010; Toth et al. 2010).

Several ostracod taxa are also indicative for an early Sarmatian age, namely *Cytheridea hungarica*–*Aurila mehesi* Zone (NO11) of the Central Paratethys (Jiříček & Říha 1991): *Callistocythere tokajensis* Pietrzeniuk, 1973, *Callistocythere pantoii* Pietrzeniuk, 1973, *C. maculata* Pietrzeniuk, 1973, *Cytheridea hungarica* Zálányi, 1913, *Aurila mehesi* (Zálányi, 1913), *A. merita* (Zálányi, 1913), *Tenedocythere cruciata* Bonaduce, Ruggieri & Russo, 1986 (e.g. Kollmann 1960; Pietrzeniuk 1973; Jiříček 1974; Zelenka 1990; Fordinál & Zlinská 1994; Szczechura 2000; Tóth 2004, 2008; Fordinál et al. 2006; Gross 2006; Tóth et al. 2010). *Miocyprideis sarmatica* (Zálányi, 1913) is characteristic for the early Sarmatian *Elphidium reginum* Zone but also occurs in the *Elphidium hauerinum* Zone (Jiříček 1974; Tóth 2004, 2008). *Hemicyprideis dacica* (Héjjas, 1895) ranges from the Late Oligocene to the Sarmatian but is frequently found in lower Sarmatian deposits of the Central Paratethys (Kollmann 1960; Jiříček 1974; Gebhardt et al. 2009; Schäfer 2011). *Hemicytheria omphalodes* (Reuss, 1850) is known from the Late Badenian to the Early Pannonian, however, predominantly from the Sarmatian (Cernajsek 1974; Gross 2006; Gross et al. 2007). *Senesia*

*vadaszi* (Zálányi, 1913) is documented from the Karpatian but is particularly common in lower Sarmatian sediments (Jiříček 1974; Zelenka 1990; Gross 2006). *Loxoconcha kochi* Mehes, 1908 (sensu Cernajsek, 1974) occurs during Late Badenian and Sarmatian times (Cernajsek 1974; Gross 2006). Morphotypes resembling *Xestoleberis* aff. *tumida* (Fordinál et al., 2006) and *Xestoleberis* ex gr. *dispar* (Tóth, 2004, 2008) are known from Sarmatian strata. *Heterocypris* sp. seems to be related to *Heterocypris steinheimensis* (Lutz, 1965) of Janz (1994) as well as *Ilyocypris* sp. is close to *Ilyocypris* sp. in Janz (1994), both from Middle Miocene deposits of the South German Steinheim Basin.

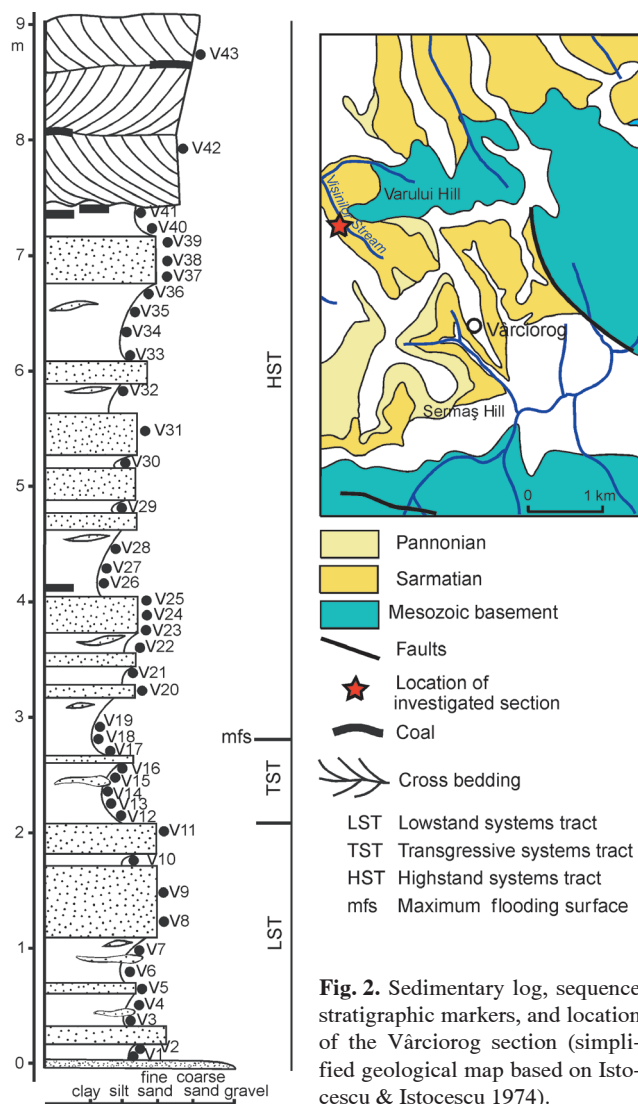
The presence of the genus *Mohrensternia* allows a clear correlation of the mollusc fauna with the early Sarmatian *Mohrensternia* Zone (Papp, 1956), equivalent to the foraminiferal zonation.

The bryozoan assemblages display a low diversity (5–7 taxa) and are dominated by opportunistic cyclostomatous “*Tubulipora*” and *Crisia*. Other species of *Cryptosula* and *Schizoporella* are typical for Sarmatian assemblages (Ghiurcă & Stancu 1974; Vávra 1977; Zágöršek 2007).

### Microfossil assemblages and paleoenvironments

Microfossil assemblages along the sampled section provided valuable information on the paleoenvironmental evolution. Our interpretations are based on the estimated autecology of several taxa:

a. Among foraminifera (Figs. 5–7), the opportunistic *Ammonia* species are detritivorous and able to dwell in very unstable nearshore environments with fluctuating salinities (Zaninetti 1982; Walton & Sloan 1990), eutrophic conditions, and short term dysoxia (Murray 2006). *Elphidium* spe-



**Fig. 2.** Sedimentary log, sequence stratigraphic markers, and location of the Vărciorog section (simplified geological map based on Istocescu & Istocescu 1974).

cies (keeled epifaunal herbivorous and rounded infaunal detritivorous morphotypes — Murray 1991; Langer 1993) are indicators of almost normal marine conditions and quite stable environments. Miliolid foraminifera (epifaunal detritivorous and/or herbivorous) are characteristic for very shallow waters with normal marine to hypersaline conditions (Łuczowska 1972, 1974; Murray 1991). The rotaliids are represented by opportunistic epifaunal or infaunal dwellers, while buliminids document deeper and less oxygenated environments (Corliss 1985; Corliss & Fois 1990; Murray 1991; Jorissen et al. 1995).

b. Ostracod assemblages (Table 1, Fig. 8), which are dominated by *Miocyprideis* and *Hemicyprideis*, refer to highly fluctuating salinities, as suggested by the comparison with modern *Cyprideis*. Frequently these dominate in marginal marine, brackish waters (Kollmann 1960; Morkhoven 1963; Gebhardt et al. 2009; Pirkenseer & Berger 2011; Schäfer 2011). *Hemicytheria omphalodes* (Reuss, 1850) is frequently found in sandy, brackish water deposits (Cernajsek 1974). The euryhaline *Aurila* occurs preferably in epineritic, sandy coastal settings (Hartmann 1975). Xestoleberidids with well

Age		Chronos	Mollusc zones	Foraminifera zones
Middle Miocene	late	C5r.3r	Sarmatimactra vitaliana	Porosonion granosum
		C5An.1n	upper Ervilia	
	early	C5An.1r		
		C5An.2n	lower Ervilia	Elphidium hauerinum
		C5Ar.1r	Mohrensternia	Elphidium reginum
				Anomalinoidea

**Fig. 3.** Chrono- and biostratigraphic correlation table for the Middle Miocene (after Harzhauser et al. 2008).

developed eyespots dwell typically in littoral to sublittoral, sandy and phytal habitats of marine and brackish waters (Athersuch 1976; Bonaduce & Danielopol 1988). *Senesia* and *Loxoconcha* are considered as marginal marine taxa (Morkhoven, 1963; Gross, 2006), while *Ilyocypris* and *Heterocypris* are typical freshwater dwellers. A deepening trend in the euphotic zone can be documented by *Cytherella* (a littoral to epibathyal, marine filter feeder; Gross 2006, cum Lit.) and by *Tenedocythere* (an infralittoral element of warm seas; Breman 1976; Bonaduce et al. 1976).

c. Poorly preserved Bryozoa (Fig. 9), are dominated by cyclostomatous colonies of “*Tubulipora*” (possibly belonging to genus *Oncosoezia*) and *Crisia*, which prefer unstable (shallow, high energy) environments and usually belong to pioneer assemblages. This is also supported by the few specimens of *Nelia*. The identified “*Tubulipora*” specimens are very similar to *Tubulipora cumulus* (Sinzow, 1892) as described by Zágoršek & Fordinál (2006). At least two species of *Crisia* were identified: *Crisia haueri* Reuss, 1847 and *Crisia romanica* Zágoršek, Silye & Szabó, 2008. Among cheilostomes, which are common in more stable conditions, *Schizoporella tetragona* (Reuss, 1848) and/or *S. dunkeri* (Reuss, 1848) and *Hippopleurifera* cf. *semicristata* (Reuss, 1848) and/or *Cryptosula terebrata* (Sinzow, 1892) are present. Better preserved specimens are needed for more detailed determination. The assemblages are similar to those described from the Danube Basin (Zágoršek & Fordinál 2006) with elements from Cerna-Strei Depression (Zágoršek et al. 2008).

d. Among molluscs (Table 2, Fig. 10), *Tropidomphalus* sp. and clausiliids derived from the adjacent woodland. The coastal mudflats were inhabited by large populations of *Agapilia picta* (Ferussac, 1825), *Granulolabium bicinctum* (Brocchi, 1814) and *Cerithium rubiginosum* (Eichwald, 1830). Harzhauser & Kowalke (2002) and Lukeneder et al. (2011) described comparable mudflat assemblages throughout the Sarmatian Paratethys Sea. Various species of *Mohrensternia*, the carnivorous *Clavatulula dodderleini* (Hörnes, 1856) and the byssate bivalve *Musculus sarmaticus* (Gatujev, 1916) might have preferred the transition towards the very shallow sublittoral zone. *Duplicata duplicata* (Sowerby, 1832) represented a scavenging nassariid.



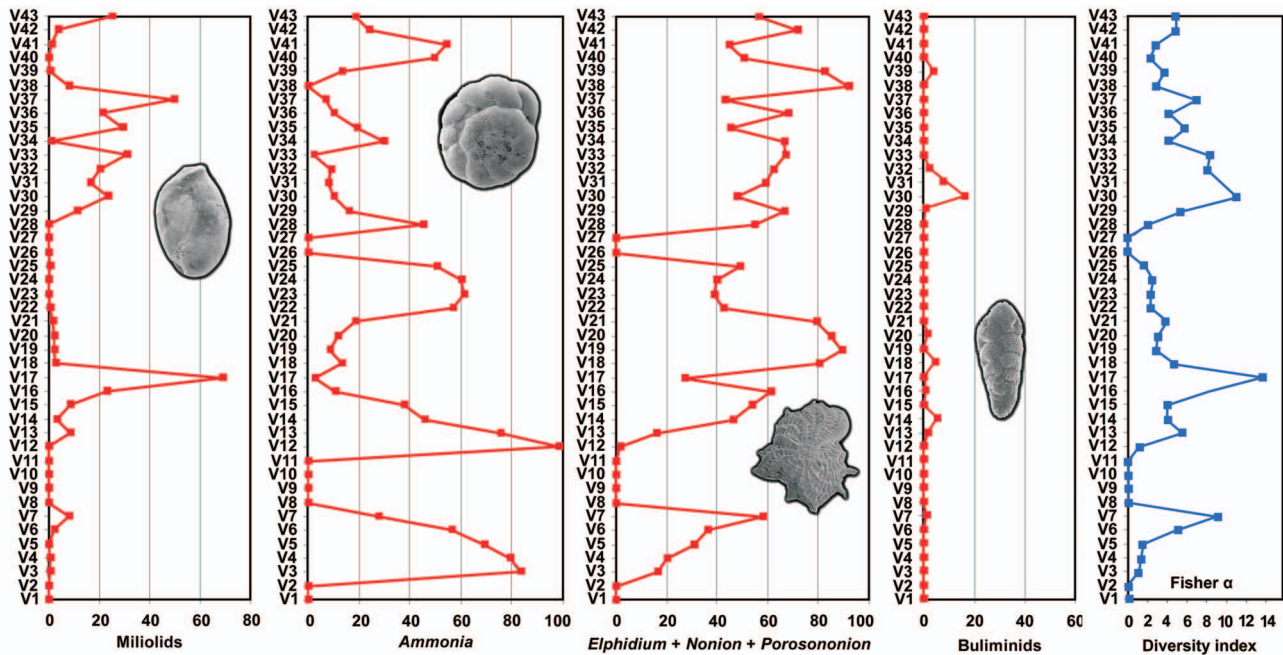


Fig. 4. Quantitative distribution (no. of specimens per sample) of the main foraminiferal groups identified at Vărciorog. Particular abundances of taxa characteristic to low salinity (*Ammonia*), normal salinity (*Elphidium*, *Nonion*, *Porosonion*), high salinity/shallow environments (Miliolids), and lower oxygenation/deeper environments (Buliminids) can be observed. Highest diversities (Fisher  $\alpha$  index) are related to normal marine conditions.

e. Fragments of fossil tetrapods indicate the proximity of continental environments. The most representative groups are the rodents (Muridae), insectivores (Gliridae), and omnivores (Erinaceidae) — Molnar (2011).

The lowermost part of the section (samples V1-2 in Fig. 2) was deposited under continental influence. This was suggested by the presence of terrestrial gastropods, such as apex fragments of unidentified clausiliids and fragments of the helioid *Tropidomphalus* sp. The latter indicates moist woodland and wetlands (Binder 2004; Harzhauser et al. 2008), which is consistent with the amphibian and mammal remains occurring in the same samples. Likewise, abundant plant debris document significant terrestrial input.

Coastal marine conditions established with samples V3-4, which are moderately abundant in the gastropods *Agapilia picta*, *Granulolabium nodosoplicatum* (Hörnnes, 1856), *Stajatholisa* (Jekelius, 1944), *Cornirostra moesiensis* (Jekelius, 1944) and the bivalve *Loripes niveus* (Eichwald, 1853). Ostracods are rare in V3-4 and dominated by *Miocyprideis sarmatica* (Zalányi, 1913), which is accompanied by *Hemicyprideis dacica* (Héjjas, 1895), *Hemicytheria omphalodes*, and a few *Aurila mehesi* (Zalányi, 1913), and *Xestoleberis* aff. *tumida* (Reuss, 1850). The dominant foraminifera (Fig. 4) are *Ammonia beccarii* (Linné, 1758), *A. tepida* (Cushman, 1926), associated with rare specimens of *Elphidium crispum* (Linné, 1758) and *E. flexuosum* (d'Orbigny, 1846), which are able to tolerate low and fluctuating salinities (Walton & Sloan 1990; Murray 1991). Accordingly, shallow, marginal marine (brackish) depositional environments with considerable fluctuations in salinity are indicated for the interval V3-4.

Conditions change with sample V5, which yielded more diverse microfossil assemblages. The foraminifera reach a relatively high diversity (Fisher  $\alpha=9$ ) in V7: *Elphidium crispum*, *E. aculeatum* (d'Orbigny, 1846), *E. grilli* Papp, 1963, *E. reginum* (d'Orbigny, 1846), *E. josephinum* (d'Orbigny, 1846), *E. fichtelianum* (d'Orbigny, 1846) — more than 60 % of the assemblage — *Nonion commune* (d'Orbigny, 1825), *N. bogdanowiczii* Voloshinova, 1952, *Porosonion granosum* (d'Orbigny, 1846), *Lobatula lobatula* (Walker & Jacob, 1798), *Rosalina brady* (Cushman, 1915), and rare miliolids: *Varidentella reussi* (Bogdanowich, 1952), *Quinqueloculina hauerina* (d'Orbigny, 1846), *Q. seminula* (Linné, 1758), *Pseudotriloculina consobrina* (d'Orbigny, 1846), *Articulina problema* Bogdanowich 1952, *A. sarmatica* (Karrer, 1877). The ostracods diversified as well, but are still dominated by *Miocyprideis sarmatica*. *Hemicytheria omphalodes* and *Senesia vadaszi* (Zalányi, 1913) which co-occur with some specimens of *Aurila merita* (Zalányi, 1913), *Loxoconcha* sp. 1, and a few valves of *Ilyocypris* sp. and *Heterocypris* sp. The faunal spectrum is quite similar to the previous one (V3-4), but several marginal marine taxa such as *Senesia* and *Loxoconcha* are also present. Nevertheless, the occurrence of rare freshwater ostracods (*Ilyocypris*, *Heterocypris*) documents some terrestrial (fluvial) input. Probably, the dominance of *Aurila* in V7 indicates somewhat more stable (salinity) conditions and a slight transgressive trend. *Cytheridea hungarica* Zalányi, 1913, another epineritic, brackish to normal marine mussel shrimp (Gross 2006, cum Lit.) was found only in V7, associated with *M. sarmatica*. Subordinately *H. dacica*, *H. omphalodes*, *S. vadaszi* and rare specimens *Loxoconcha* and *Xestoleberis* occur. The mollusc assemblage is also diverse



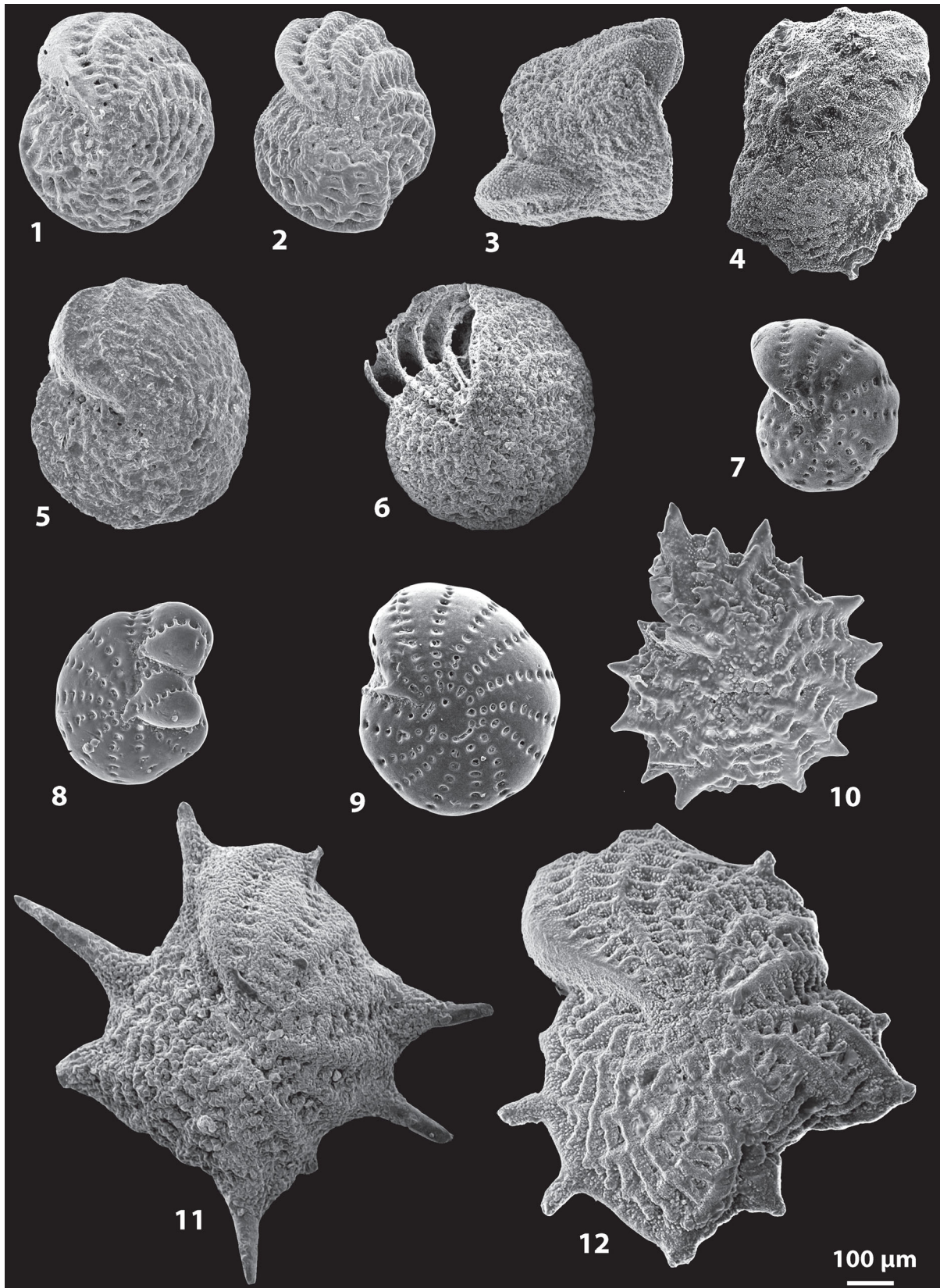
**Fig. 5.** Foraminifera from Vârciorog (SEM pictures): **1** — *Cycloforina badenensis* (d'Orbigny, 1846), sample V7; **2-3** — *Quinqueloculina hauerina* d'Orbigny, 1846, sample V16; **4** — *Pseudotriloculina consobrina* (d'Orbigny, 1846), sample V22; **5** — *Varidentella reussi* (Bogdanowicz, 1952), sample V21; **6** — *Quinqueloculina akneriana* d'Orbigny, 1846, sample V16; **7** — *Quinqueloculina bogdanowiczi* (Serova, 1955), sample V16; **8** — *Quinqueloculina buchiana* d'Orbigny, 1846, sample V17; **9** — *Varidentella latelacunata* (Vengliniski, 1953), sample V43; **10-11** — *Articulina sarmatica* (Karrer, 1877), sample V36; **12** — *Articularia articulinoidea* Gerke & Issaeva, 1952, sample V32; **13** — *Articulina problema* Bogdanowicz, 1952, sample V31; **14-15** — *Bolivina moldavica* Didkowski, 1959, sample V30; **16-17** — *Bolivina nisporonica* Maissuradze, 1988, samples V14 and V16; **18** — *Bolivina pseudoplicata* Heron-Allen & Earland, 1930, sample V14; **19** — *Bolivina sarmatica* Didkowski, 1959, sample V30.





**Fig. 6.** Foraminifera from Vărciorog (SEM pictures): 1-2 — *Ammonia beccarii* (Linné, 1758), sample V5; 3 — *Ammonia tepida* (Cushman, 1926), sample V16; 4 — *Ammonia beccarii* (Linné, 1758), twin test, sample V4; 5-6 — *Lobatula lobatula* (Walker & Jacob, 1798), sample V7; 7 — *Nonion commune* (d'Orbigny, 1825), sample V19; 8 — *Eponides* sp.(?), sample V34; 9 — *Rosalina bradyi* (Cushman, 1915), sample V34; 10 — *Caucasina schichkinskye* (Samoylova, 1947), sample V7; 11 — *Fursenkoina sarmatica* (Vengliniski, 1958), sample V32; 12 — *Fursenkoina pontoni* (Cushman, 1932), sample V31; 13 — *Buliminella elegantissima* (d'Orbigny, 1839), sample V31; 14-15 — *Schackoinella imperatoria* (d'Orbigny, 1846), sample V17.





**Fig. 7.** Foraminifera from Várciorog (SEM pictures): 1–2 — *Elphidium grilli* Papp, 1963, sample V4; 3 — *Elphidium crispum* (Linné, 1758), sample V13; 4, 5 — *Elphidium crispum* (Linné, 1758), sample V24; 6 — *Elphidium fichtelianum* (d'Orbigny, 1846), sample V7; 7 — *Elphidium obtusum* (d'Orbigny, 1846), sample V15; 8, 9 — *Elphidium hauerinum* (d'Orbigny, 1846), sample V17; 10 — *Elphidium josephinum* (d'Orbigny, 1846), sample V28); 11–12 — *Elphidium reginum* (d'Orbigny, 1846), sample V23.

**Table 1:** Distribution of ostracods along the Vărciorog section.

Sample	Species														Remarks on the assemblage						
	<i>Cytherella</i> sp.	<i>Ilyocypris</i> sp.	<i>Heterocypris</i> sp.	<i>Callistocythere tokajensis</i> Pietrzenuk, 1973	<i>Callistocythere pantoi</i> Pietrzenuk, 1973	<i>Callistocythere maculata</i> Pietrzenuk, 1973	<i>Cytheridea hungarica</i> Zálányi, 1913	<i>Hemicyprideis dacica</i> (Héjjas, 1895)	<i>Miocyprideis sarmatica</i> (Zálányi, 1913)	<i>Hemicytheria omphalodes</i> (Reuss, 1850)	<i>Aurila melhesi</i> (Zálányi, 1913)	<i>Aurila merita</i> (Zálányi, 1913)	<i>Senesia vadaszi</i> (Zálányi, 1913)	<i>Tenedocythere cruciata</i> Bonaduce, Ruggieri & Russo, 1986		<i>Loxococoncha kochi</i> Méhes, 1908 (sensu Cernajsek, 1974)	<i>Loxococoncha</i> sp. 1	<i>Loxococoncha</i> sp. 2	<i>Xestoleberis</i> aff. <i>tumida</i> (Reuss, 1850)	<i>Xestoleberis</i> ex gr. <i>dispar</i> Müller, 1894	
V43	-										x	x	x	x					x	rare, badly preserved	
V42											x	x							x	rare, badly preserved	
V41												x			x	x			x	rare, badly preserved	
V39	x			-	-	-					+	+	+	x	x	x			x	moderately rich	
V38	-										x	x	x						-	rare	
V37	x										+	-	+	x	x					+	moderately rich, badly preserved
V36	x			-							+				x				x	x	moderately rich, very badly preserved
V33	-										x			-	x				-		rare
V32	x			x	x						x			+	-	x	x			x	moderately rich
V31	x			x	x				x			+	+	+	x		x	x	x	x	rich
V30	x			x							+	+	+	+	x	x			-		moderately rich
V29	x			x							+	+	+		x	x				x	moderately rich
V28											x										rare
V22											-	-									very rare
V21											+	+	x	x	x			x			rich
V20											+	+		x	+				x	x	rich, very badly preserved
V19											-	-									very rare
V18															x						rare, badly preserved
V17											+	+	+	+		x	x		x		rich
V16											x	+	+	+			+		x	x	moderately rich
V15											-	+	x		+			x	x	x	rich, badly preserved
V14												+	+	+							very rich, well preserved
V13																					very rare
V12																					rare
V7											x	x	x								rare
V5											+	+		x	+						rich
V4											-	x	-	-							rare
V3											-	x	-	-							rare

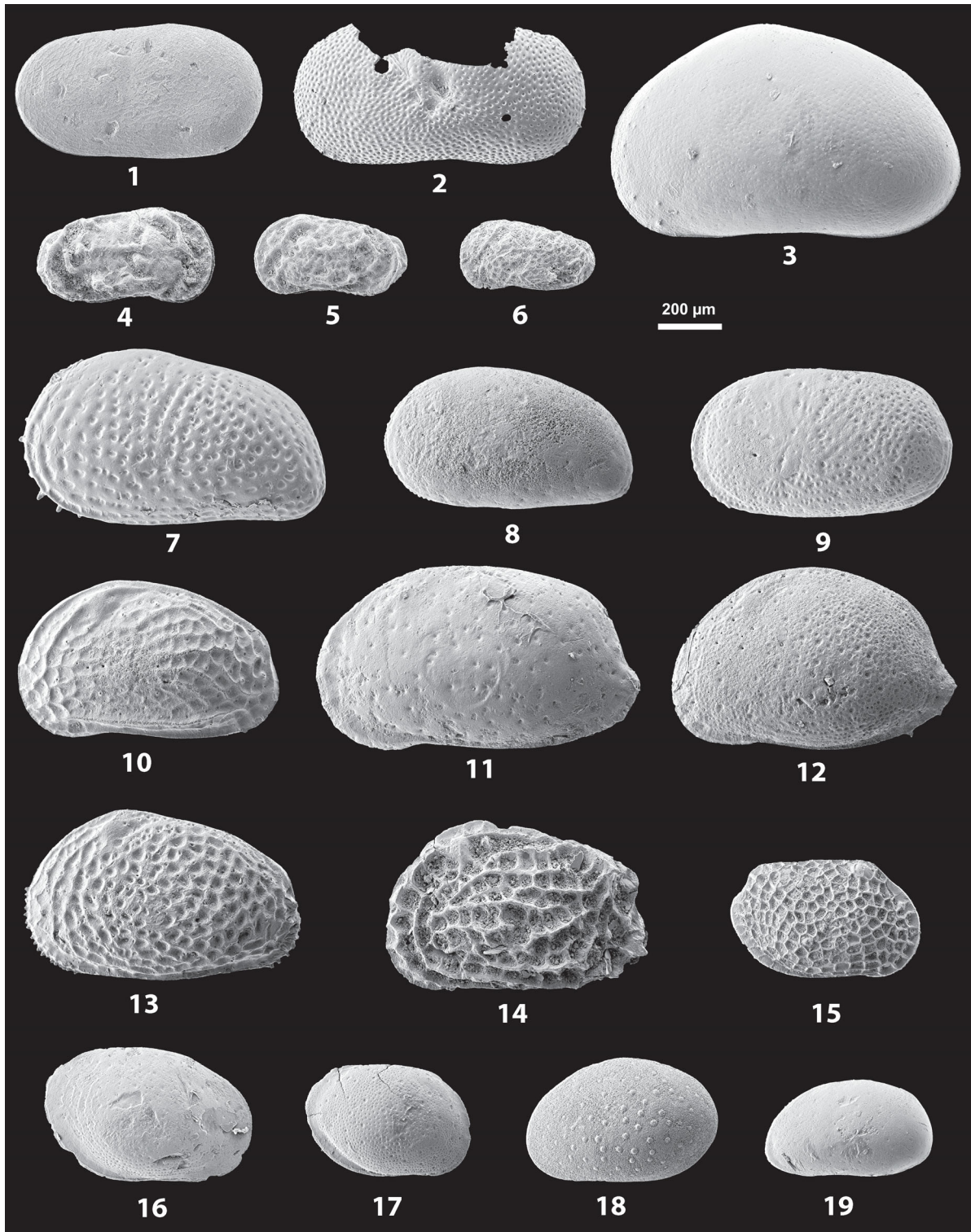
and suggests a mixture of different habitats: coastal mudflats (large populations of *Agapilia picta*, *Granulolabium bicinctum*, and *Cerithium rubiginosum*) and transition to the very shallow sublittoral zone (*Mohrensternia angulata* (Eichwald, 1830), *Clavatulina doderleini* (Hörnes, 1856), *Musculus sarmaticus* (Gatujev, 1916), and *Duplicata duplicata* (Sowerby, 1832)). Pioneer bryozoans with *Tubulipora* and *Crisia* can be observed in V7. The assemblage became more diverse afterwards. Microfossil assemblages identified in samples V5-7 and relatively high values of diversity point to water salinities, close to normal marine values.

The gradual disappearance of typical marine taxa and a coarsening of the sediment in samples V8-9 suggests an alteration of the marine environment due to a higher terrestrial influence.

The re-establishment of marine conditions is documented in sample V12 by the presence of shallow marine foraminifera (*Ammonia beccarii* and *Elphidium hauerinum* (d'Orbigny, 1846)), molluscs (outstanding predominance of *Duplicata duplicata*, occurring along with *Granulolabium bicinctum* and *Agapilia picta*), and rare ostracods (*Miocyprideis sarmatica*, *Hemicytheria omphalodes*, *Aurila merita*).

The proportions of *Elphidium* become higher in samples V13-16 (*E. grilli*, *E. flexuosum*, *E. crispum*, *E. rugosum* (d'Orbigny, 1846), *E. obtusum* (d'Orbigny, 1846)). Miliolids are particularly abundant in sample V17 (*Varidentella reussi*, *Quinqueloculina akneriana* d'Orbigny, 1846, *Q. bogdanowiczii* (Serova, 1955), *Q. seminula* (Linné, 1758), *Cycloforina contorta* (d'Orbigny, 1846), *C. badensis* (d'Orbigny, 1846), *Pseudotriloculina consobrina*, *Miliolonella* sp., *Sinu-*





**Fig. 8.** Ostracoda from Várciorog (SEM pictures — all in external view; L=left, R=right valve): **1** — *Cytherella* sp. (L), sample 39; **2** — *Ilyocypris* sp. (L), sample 5; **3** — *Heterocypris* sp. (L), sample 5; **4** — *Callistocythere tokajensis* Pietrzeniuk, 1973 (R), sample 39; **5** — *Callistocythere pantoi* Pietrzeniuk, 1973 (L), sample 39; **6** — *Callistocythere maculata* Pietrzeniuk, 1973 (L), sample 39; **7** — *Cytheridea hungarica* Zálányi, 1913 (L), sample 7; **8** — *Hemicyprideis dacica* (Héjjas, 1895) (L), sample 7; **9** — *Miocyprideis sarmatica* (Zálányi, 1913) (L), sample 21; **10** — *Hemicytheria omphalodes* (Reuss, 1850) (L), sample 21; **11** — *Aurila mehesi* (Zálányi, 1913) (L), sample 7; **12** — *Aurila merita* (Zálányi, 1913) (L), sample 5; **13** — *Senesia vadaszi* (Zálányi, 1913) (L), sample 5; **14** — *Tenedocythere cruciata* Bonaduce, Ruggieri & Russo, 1986 (L), sample 39; **15** — *Loxoconcha kochi* Méhes, 1908 (sensu Cernajsek, 1974) (R), sample 39; **16** — *Loxoconcha* sp. 1 (R), sample 39; **17** — *Loxoconcha* sp. 2 (R), sample 21; **18** — *Xestoleberis* aff. *tumida* (Reuss, 1850) (L), sample 5; **19** — *Xestoleberis* ex gr. *dispar* Müller, 1894 (L), sample 7.



**Fig. 9.** Bryozoa from Vârciorog (SEM pictures): **1** — *Oncousoecia* cf. *biloba* (Reuss, 1847) from \*sample showing large gonozoecium with small oeciopore (left margin of the colony); the specimen differs from Reuss species in having much larger pseudopores on gonozoecium (sample V7); **2** — *Annectocyma* sp. — large gonozoecium with centrally situated oeciopore on short peristome; very similar is Recent species *A. arcuata* (Harmelin, 1976) growing, however, in narrower colonies (sample D2-30); **3** — *Cryptosula*? sp. — enlarged \*peristomial part of each zoecium carrying small oral avicularia; the development of avicularia on each zoecium is uncommon in true *Cryptosula* (sample D7-31); **4** — Inner view of *Cryptosula*? showing perforation of the frontal shield and large condyles in the aperture (sample D7-02); **5** — *Crisia romanica* Zăgoršek, Silye & Szabó, 2008 showing well developed gonozoecium; note the longitudinal pseudopores and dented proximal of the gonozoecium (sample D7-30); **6** — encrusting base of *Schizoporella* indicate algal meadow on the spot (sample D8-11); **7** — *Schizoporella* sp. — encrusting colony with ovicells and avicularia; the specimen is similar to *Schizoporella dunkeri* (Reuss, 1847) but differs in having much wider sinus and larger avicularia (sample D8-11); **8** — *Nelia* sp. showing only one avicularium on the gymnocyst of each zoecium; the specimen is similar to Recent *Nelia tenella* (Lamarck, 1816), which however usually has two avicularia on gymnocyst of entire zoecium (sample V7).



**Table 2:** Distribution of diagnostic gastropods along the Várciorog section.

Environment	Family	Taxon	Specimens per sample																
			V1	V2	V3	V4	V5	V7	V12	V15	V16	V17	V18	V21	V26	V29	V37	V42	
Mar. — Paratethys Sea	Acmaeidae	<i>Tectura</i> aff. <i>zboroviensis</i> Friedberg, 1928 (sp. nov.)	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Mar. — Paratethys Sea	Neritidae	<i>Agapilia picta</i> (Ferussac, 1825)	0	1	18	1	718	0	40	1	1	1	0	0	0	4	0	0	0
Mar. — Paratethys Sea	Trochidae	<i>Gibbula</i> cf. <i>gutenbergi</i> (Hilber, 1897)	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Mar. — Paratethys Sea	Batillariidae	<i>Granulolabium bicinctum</i> (Brocchi, 1814)	0	0	1	7	350	2	59	1	1	1	3	1	0	0	0	0	0
Mar. — Paratethys Sea	Batillariidae	<i>Thericium rubiginosum</i> (Eichwald, 1830)	0	0	0	1	50	0	8	0	0	0	0	0	0	0	0	0	0
Mar. — Paratethys Sea	Batillariidae	<i>Potamides nodosoplicatum</i> (Hörnes, 1855)	0	0	27	1	5	0	11	0	0	0	0	0	0	0	0	0	0
Mar. — Paratethys Sea	Hydrobiidae	<i>Hydrobia</i> sp. 1	0	0	1	1	5	0	0	0	0	0	0	0	0	0	0	0	0
Mar. — Paratethys Sea	Hydrobiidae	<i>Hydrobia soceni</i> Jekelius, 1944	0	0	0	0	4	1	2	0	0	0	0	0	0	0	0	0	0
Mar. — Paratethys Sea	Hydrobiidae	<i>Hydrobia</i> cf. <i>subprotractra</i> Jekelius, 1944	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0
Mar. — Paratethys Sea	Hydrobiidae	<i>Staja tholsa</i> (Jekelius, 1944)	0	0	78	2	1	1	22	0	0	0	0	0	0	0	0	0	0
Mar. — Paratethys Sea	Hydrobiidae	<i>Staja immutata</i> (Hoernes, 1856)	0	0	17	0	2	0	2	0	0	0	0	0	0	0	0	0	0
Mar. — Paratethys Sea	Hydrobiidae	<i>Staja depressa</i> (Jekelius, 1944)	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Mar. — Paratethys Sea	Rissoidae	<i>Rissoa banatica</i> Jekelius, 1944	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
Mar. — Paratethys Sea	Rissoidae	<i>Mohrensternia hydrobioides</i> Hilber, 1897	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
Mar. — Paratethys Sea	Rissoidae	<i>Mohrensternia angulata</i> (Eichwald, 1830)	0	0	0	1	38	2	0	0	0	0	0	0	0	0	0	0	0
Mar. — Paratethys Sea	Rissoidae	<i>Mohrensternia pseudoangulata</i> Hilber, 1897	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Mar. — Paratethys Sea	Rissoidae	<i>Mohrensternia inflata</i> (Andzejowski, 1835)	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0
Mar. — Paratethys Sea	Rissoidae	<i>Mohrensternia sarmatica</i> Friedberg, 1923	0	0	0	0	7	1	0	0	0	0	0	0	0	0	0	0	0
Freshwater	Bithyniidae	<i>Bithynia</i> sp. (operculum)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Terrestrial	Pomatiidae	<i>Pomatias</i> cf. <i>conicus</i> (Klein, 1853) (operculum)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Mar. — Paratethys Sea	Nassariidae	<i>Duplicata duplicata</i> (Sowerby, 1832)	0	0	0	0	32	0	89	0	0	0	0	0	0	0	0	0	0
Mar. — Paratethys Sea	Clavatulidae	<i>Clavatula doederleini</i> (Hörnes, 1856)	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0
Mar. — Paratethys Sea	Acteonidae	<i>Acteocina lajonkairieana</i> (Basterot, 1825)	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1
Mar. — Paratethys Sea	Cornirostridae	<i>Cornirostra moesiensis</i> (Jekelius, 1944)	0	0	6	2	10	2	0	0	0	0	0	0	0	0	0	0	0
Terrestrial	Clausiliidae	Clausiliidae indet.	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Terrestrial	Helicidae	<i>Tropidomphalus</i> sp.	2	3	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Mar. — Paratethys Sea	Mytilidae	<i>Musculus sarmaticus</i> (Gatujev, 1916)	0	0	0	0	17	0	0	0	0	0	0	0	0	0	0	0	0
Mar. — Paratethys Sea	Lucinidae	<i>Loripes niveus</i> (Eichwald, 1853)	0	0	2	3	33	0	0	0	0	0	0	1	0	0	0	0	0
Mar. — Paratethys Sea	Semelidae	<i>Ervilia dissita</i> (Eichwald, 1830)	0	0	0	0	0	1	0	0	0	1	0	0	1	0	1	2	0
Mar. — Paratethys Sea	Cardiidae	Cardiidae indet.	0	0	0	0	1	1	0	0	0	0	0	0	1	0	0	0	0

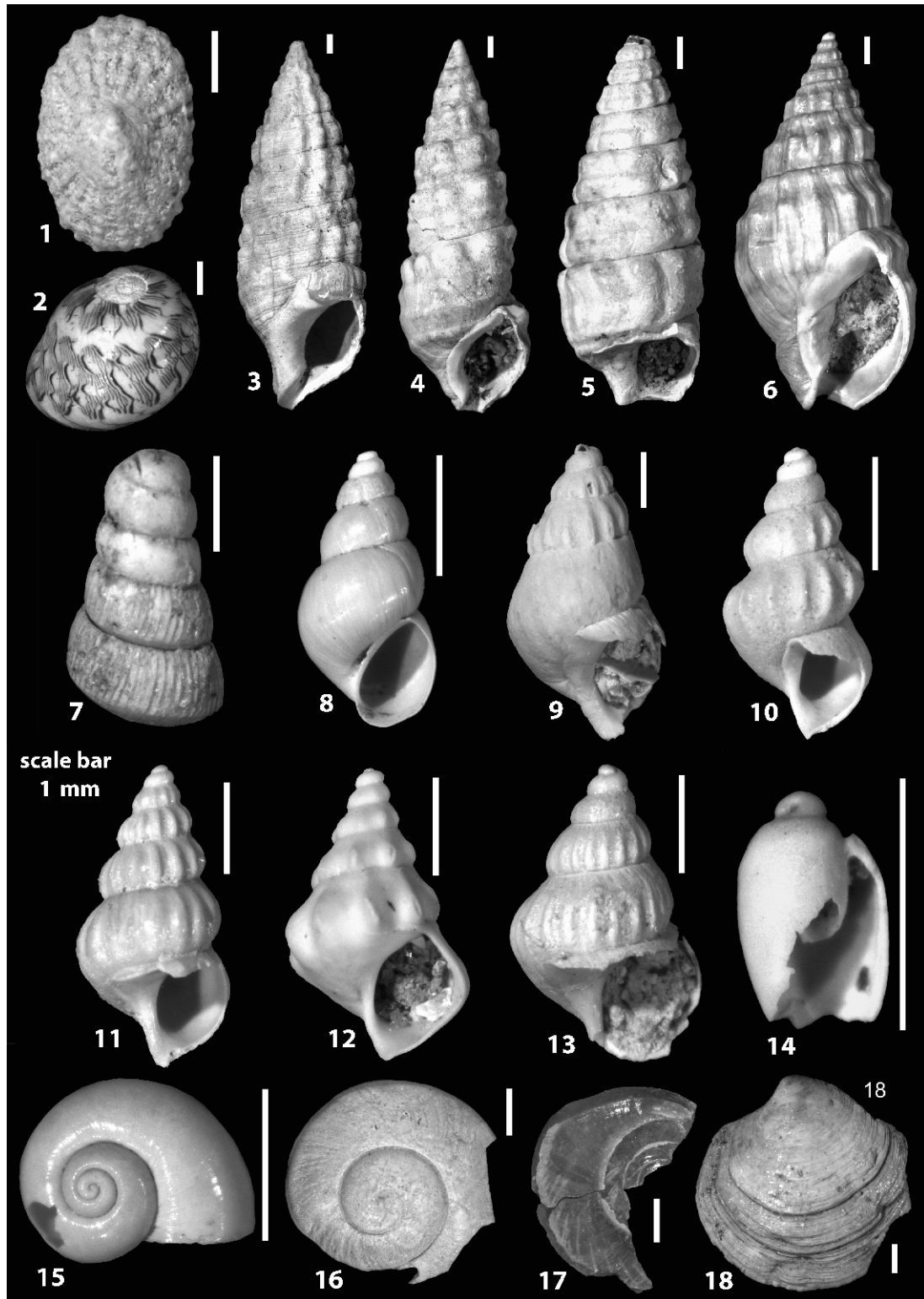
*loculina consobrina* (d'Orbigny, 1846)) occurring together with buliminids (*Bolivina sarmatica* Didkovski, 1959, *B. moldavica* Didkovski, 1959, *B. pseudoplicata* Heron-Allen & Earland, 1930, *B. nisporonica* Maissuradze, 1988, *Caucasina schichkinskye* (Samoylova, 1947), *Buliminella elegantissima* (d'Orbigny, 1839), *Fursenkoina sarmatica* (Venglinski, 1958), *F. pontoni* Döderlein, 1884) and rotaliids (*Rosalina bradyi*, *Nonion commune*, *Schackoinella imperatoria* (d'Orbigny, 1846)). At the level of sample V17, the diversity reaches the highest value of the section (Fisher  $\alpha$  = 13.63). Together with the composition of the foraminiferal assemblage, this points to more stable salinity conditions and probably slightly deeper environments. Less stressful conditions are also suggested by increasing ostracod abundances within samples V14–17 (*Hemicytheria omphalodes*, *Aurila* spp. and *Senesia vadaszi* became important elements, while the amounts of *Miocyprideis sarmatica* relatively decrease). The presence of *Nelia* and *Crisia* together with rich assemblages of cyclostote bryozoan “*Tubulipora*” may indicate a normal saline environment.

*Ammonia* specimens (*A. beccarii*, *A. tepida*) are associated with keeled *Elphidium* (*E. crispum*, *E. aculeatum*, *E. fichtelianum*, *E. grilli*), *Nonion*, *Porosonion* and very rare *Bolivina* in the shallow environments documented by samples V18–22. The trend continues up to sample V25, with assemblages containing varying proportions of foraminifera, ostracods (abundant only in samples V20 and V21), and fish remains, suggesting unstable shallow marine environments. This change is also suggested by the decreasing diversity of

foraminifera (Fisher  $\alpha$ : 1.74–4.77 in Fig. 4) between samples V18 to V25.

Another flooding event is documented in the marshy environments from samples V26–27. Opportunistic shallow marine foraminifera assemblages with *Elphidium* and *Ammonia* occur in sample V28. Stable environments, indicated by relatively high values of diversity in samples V29–32 (Fisher  $\alpha$  = 5.48–9.48), allowed the diversification of assemblages, which contain rotaliids (*Elphidium grilli*, *E. reginum*, *E. crispum*, *Ammonia beccarii*, *Nonion commune*), miliolids (*Varidentella reussi*, *Cycloforina badensis*, *Articulina problema*, *Sinuloculina consobrina*), and buliminids (*Bolivina moravica*, *B. sarmatica*, *Buliminella elegantissima*, *Fursenkoina sarmatica*). A deepening trend, but still within the euphotic zone, can also be documented by the first occurrence of the ostracod *Cytherella* in V29 and by *Tenedocythere* in V30, followed by the last occurrence of *Miocyprideis sarmatica* in V31. Bryozoans show another acme in V32, which may suggest salinity levels close to normal marine values.

Diversity decreases gradually in samples V33–43 (Fisher  $\alpha$  = 8.26–4.83) due to the shallowing trend and progradation of tide-influenced deltas, as shown by foraminifera (rare and poorly preserved miliolids and rotaliids), ostracods (*Aurila* spp., *Senesia vadaszi* and *Tenedocythere sulcata*, which prefer sandy substrates), and fish remains. Molluscs are only represented by rare and poorly preserved remains of *Agapilia picta* and by *Acteocina lajonkairieana* (Basterot, 1825) in the uppermost sample V42. The topmost part of the section con-



**Fig. 10.** Molluscs from Várciorog (stereomicroscope pictures): **1** — *Tectura* aff. *zboroviensis* Friedberg, 1928 (sp. nov.), sample V5; **2** — *Agapilia picta* (Férussac, 1825), sample V12; **3** — *Therithium rubiginosum* (Eichwald, 1830), sample V5; **4** — *Granulolabium bicinctum* (Brocchi, 1814), sample V5; **5** — *Potamides nodosoplicatus* (Hörnes, 1855), sample V3; **6** — *Duplicata duplicata* (Sowerby, 1832), sample V12; **7** — Clausiliidae indet., sample V5; **8** — *Hydrobia soceni* Jekelius, 1944, sample V5; **9** — *Mohrensternia hydrobioides* Hilber, 1897, sample V7; **10** — *Mohrensternia angulata* (Eichwald, 1830), sample V5; **11** — *Mohrensternia sarmatica* Friedberg, 1923, sample V7; **12** — *Mohrensternia inflata* (Andzejowski, 1835), sample V7; **13** — *Rissoa banatica* Jekelius, 1944, sample V7; **14** — *Acteocina lajonkaireana* (Basterot, 1825), sample V42; **15** — *Cornirostra moesiensis* (Jekelius, 1944), sample V7; **16** — *Tropidomphalus* sp., sample V5; **17** — *Pomatias* cf. *conicus* (Klein, 1853), sample V29; **18** — *Loripes niveus* (Eichwald, 1853), sample V5.



tains frequently reworked microfossils, due to the stronger erosion driven by the fluvial incision.

### Sea-level changes and regional paleogeography

A transgressive trend was observed throughout the Paratethys during the *Elphidium reginum* Zone of the Sarmatian. It caused flooding of incised valleys in the North Alpine Foredeep (Mandic et al. 2008) and of marginal areas in the Vienna and Styrian Basins (Harzhauser & Piller 2004a,b; Kováč et al. 2008), as well as the Transylvanian Basin (Krezsek & Filipescu 2005).

At Vârciorog, the sea-level trend is recorded by the parasequences (Fig. 2) formed mainly in shallow marine, with relatively high-energy environments (beach to shoreface). Changes in sedimentary facies correlate with changes in the diversity and taxonomic composition of the microfossil assemblages (Fig. 4); very shallow unstable settings were characterized by opportunistic taxa (e.g. *Ammonia*) while diverse assemblages (with rotaliids, buliminids, and miliolids) inhabited deeper and more stable environments.

The lower parasequences (samples V1–11 in Fig. 2) probably represent the early stage of a sea-level rise, when the sedimentary input was still higher than the accommodation space (lowstand systems tract — LST in Fig. 2). The microfossils identified in this interval show a continental influence in the beginning, but turn gradually into marine assemblages.

The main phase of sea-level rise (transgressive systems tract — TST) was recorded in the following interval (samples V12–18), based on the sedimentological trend and on the deeper and more diversified microfossil assemblages (the offshore taxa suggest the maximum flooding in sample V18).

The highstand systems tract (HST), related to the late stage of the relative sea-level rise can be documented by samples V19–43. Dominant aggradation (V29–31), which created quite stable conditions on the substrate, stimulated diversification. Subsequent progradation of delta systems developed tide influenced channels and coal marshes (samples V32–43).

The progradational trend from the top of the section is related to the high sediment input from the hinterland, which produced regression and diversity decrease.

Regional tectonics was probably the cause for the sequence development. This is supported by the biostratigraphic position of the Vârciorog section relative to the global cycles chart of Haq et al. (1988), sequences described from the Transylvanian Basin (Krezsek & Filipescu 2005), and by the particular paleogeography in the Paratethyan area. Beside the relative sea-level changes, the active tectonics generated a chain of islands during the early Sarmatian, populated in the marginal areas by shallow marine assemblages. Such shallow marine assemblages were described from other sites on the eastern margin of the Pannonian Basin and in the vicinity of the Apuseni Mountains (Paučá 1954; Istocescu et al. 1965; Clichici 1971, 1972; Istocescu & Gheorghian 1971; Nicorici 1971; Rado 1972; Chintăuan & Nicorici 1976; Chintăuan 1977; Popa 1998, 2000; Filipescu et al. 2000; Zágöršek et al. 2008). This paleoenvironmental setting demonstrates that, during the Sarmatian, the shallow seas in the vicinity of the rising Apuseni Mountains repre-

sented the connections between the Pannonian Basin and the deep areas of the Transylvanian Basin.

### Conclusions

The microfossil assemblages identified at Vârciorog are characteristic for the early part of the Sarmatian (*Elphidium reginum* Zone). These are similar to other assemblages identified in the Pannonian Basin and on the border of the Apuseni Mountains.

Paleoenvironments suggested by the micropaleontological assemblages are mainly marginal to shallow marine, with fairly high energy and fluctuating salinity. Specific microvertebrates, molluscs, and ostracods demonstrate the proximity of continental paleoenvironments. Cyclic successions of microfossil assemblages follow the sedimentological trend in the parasequences and fit into the characteristic systems tracts of almost an entire stratigraphic sequence.

Shallow marine paleoenvironments on the borders of the Apuseni Mountains (easternmost Pannonian Basin), as described herein, document marine seaways between the Pannonian Basin and the Transylvanian Basin. Our paleoenvironmental interpretation demonstrated repeated sea-level changes and a progradational trend suggesting an uplifting in the source area. This could be the early stage of an important uplift in the Apuseni Mountains during the late Sarmatian (Krezsek & Filipescu 2005).

**Acknowledgments:** This work was funded by the Sectorial Operational Program for Human Resources Development 2007–2013, co-financed by the European Social Fund, under the Project POSDRU/107/1.5/S/76841 entitled “Modern Doctoral Studies: Internationalization and Interdisciplinarity”. Part of the work was supported by the Project GAČR 205/09/0103. Authors are grateful to Prof. Johann Hohenegger, Dr. Natália Hudáčková, Prof. Michal Kováč, and Dr. Jozef Michalík for their valuable suggestions during the review process.

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