The evolution of the Carpathian Foredeep Basin during the latest Badenian and Sarmatian (Middle Miocene): inferences from micropalaeontological data

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Seven Middle Miocene (Upper Badenian to Lower Sarmatian) sedimentary sections of the Central Paratethys, two from the Polish Carpathian Foredeep Basin (PCFB) and five from the Eastern Carpathian Foreland Basin (ECFB) of Romania and the Republic of Moldova have been analysed micropalaeontologically to better constrain the Badenian–Sarmatian Extinction Event, characterized by significant taxonomic impoverishment of both foraminifers and ostracods. Our studies show significant palaeoenvironmental changes in the basin including depth, salinity, oxygenation, and organic matter flux. The occurrence of moderately diverse planktonic foraminifera (Globigerina, Globigerinita, Globorotalia, Triloculina, Orbulina, Velapertina) in the Upper Badenian deposits of the PCFB as well as in the ECFB and their rarity in the lowermost Sarmatian indicate an almost fully marine environment during the latest Badenian, followed by a significant regression and possible appearance of much more restricted marine conditions across the boundary. The taxonomic composition of the Sarmatian foraminifera, ostracods and calcareous nanofossils indicate that during this interval the salinity fluctuated strongly, with the water regime varying from brackish to normal marine. In addition, the identified micropalaeontological assemblages identified show palaeoenvironmental similarity across different basins of the Central Paratethys. This supports a hypothesis of possible connections during the latest Badenian between different areas of the Central Paratethys, as well as of the existence of a gateway between the Central Paratethys and the Mediterranean realm.

Key words: Middle Miocene, Carpathian Foredeep Basin, foraminifera, ostracods, nanofossils, palaeoenvironment.

INTRODUCTION

The Paratethys Sea was formed in the Early Oligocene as a result of collision between the Afro-Arabian Plate and the Eurasian Plate (Steininger and Rögl, 1985; Seneš, 1988). The Paratethys is subdivided into three basins: the Western Paratethys (Alpine region), the Central Paratethys (Carpathians, Balkans) and the Eastern Paratethys (Euxinian-Caspian) (Seneš, 1960). The strata of the Central Paratethys cover wide areas of the Carpathian Foredeep from Austria, via Poland towards the north and continue along Ukraine, Romania and the Republic of Moldova to the east (Fig. 1).

Variable palaeoenvironmental conditions in the Paratethys resulting in different facies development were strongly influenced by temporary connections with the Mediterranean and the Indo-Pacific realms (Popescu, 1975; Rögl and Steininger, 1984; Paramonova, 1995; Rögl, 1998, 1999; Ilijina, 2000; Kovác, 2000; Popov et al., 2004, 2005; Nevesskaja et al., 2006; Harzhauser and Piller, 2007; Harzhauser et al., 2007; Studencka and Jasonowski, 2011; Maisuradze et al., 2014; Kovác et al., 2017). Moreover, changes in palaeoclimate, stratification of the water column, nutrient supply, as well as bottom-water oxygen have been recognized in different areas of the Central Paratethys (Gonera et al., 2000; Cicchi et al., 2003; Hudáková et al., 2003, 2018; Filippescu et al., 2005; Baldi, 2006; Kovác et al., 2007, 2017; Kováčová and Hudáková, 2009; Kováčová et al., 2009; Perut et al., 2014). The connection between the Central Paratethys and Mediterranean regions is believed to have closed at some point in the Middle Miocene.

During the mid-Badenian, large-scale evaporitic sedimentation (known also as the Badenian salinity crisis; de Leeuw et al., 2010), was widespread in a large part of the Central Paratethys, namely in the Carpathian Foredeep, from south-east Poland to Romania (Peryt, 2006). Afterwards, a transgression took place across the whole of the Central and Eastern Paratethys during the Late Badenian (= the Konkian stage in the Eastern Paratethys) (Rögl and Müller, 1976; Rögl, 1999; Krzywiec, 2001;
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Fig. 1. Map of the study areas (modified after Dumitriu et al., 2017)
A – simplified geological sketch map of the Carpathian Foredeep and Carpathian Orogen (modified after Pawlewicz, 2006); B – simplified geological sketch map of northeastern Romania and the northwestern Republic of Moldova (modified after the geological maps of Romania and Moldova, scale 1:200,000); location of the Romanian (FH₃P, Rânduți, Bilca 1, Domenești and Ripiceni) and Moldovian (Costești) sections studied; C – location of the Polish sections studied (Machów and Jamnica M-83 core) and the extension of the Miocene deposits into extra-Carpathian Poland (modified after Ney et al., 1974).
Polish Carpathian Foredeep Basin

The Polish Carpathian Foredeep Basin is filled with Middle Miocene (Badenian and Sarmatian) marine deposits, which range from a few hundred metres thick in its northern-marginal part, up to 3000 m in the southeastern zone (more central part of the basin; Ney et al., 1974). The Machów section is represented mostly by clays with marl intercalations in the lower part, which are followed by sandstones, and clays with mudstone intercalations, in the upper part. Similar lithologies are encountered in the Janma M-83 core with the exception of sandstones which are not present in this borehole. All these deposits belong to the Machów Formation, which includes three sub-units: the Pecten Beds, Syndesmias Beds and Krakowiec Clays (Alexandrowicz et al., 1982).

The Pecten Beds have been dated as Upper Badenian by Odrzywolska-Bierkowa (1986) based on microfaunal assemblages of Hanzawa crassiseptata (Luchkowska), Sphaerodina bulloides d’Orbigny, Bulimina aculeata d’Orbigny, B. insignis Luchkowska and numerous specimens of Spiralis (Luchkowska, 1964). Based on micropalaeontological analyses, the Krakowiec Clays have been assigned to the foraminiferal Anomalinoideas dividers and Elphidium hauernium zones (Odrzywolska-Bierkowa, 1972; Luchkowska, 1972, Olszewska, 1999; Krzywcie et al., 2008; Lelek et al., 2010; Dumitriu et al., 2017) as well as the B-E Assemblages Zones sensu Dumitriu et al. (2017) indicating the Lower Sarmatian. This stratigraphic position is supported by studies on calcareous nannofossils by Peryt (1997) and Galecka and Olszewska (2011), who distinguished the upper part of the NN6 Zone and the NN7 zone in the “Krakowiec Clays”.

Eastern Carpathians Foreland Basin (Romania and Republic of Moldova)

The deposits studied from Romania and the Republic of Moldova belong to the western part of the Eastern European Platform (Ionesi and Ionesi, 1968; Ionesi, 1968; 1994; Ionesi et al., 2005). They are situated in the external part of the Eastern Carpathians (accumulated in the Carpathian Foreland Basin) and belong to the last marine depositional cycle of the Moldavian Platform (Ionesi, 1994). Their geometry is characterized by a significant increase in thickness of the Volynian strata (Lower Sarmatian sensu lato, Barbot de Marny, 1866), as a consequence of the approaching Carpathian orogeny i.e., the deposit thickness is ~500 m between the Moldova and Siret rivers and reaches up to 800 m in front of the Carpathian orogen (Ionesi, 1968, 1994).

The strata of the FH-P; Rădăuți core and the Dornești exposure are assigned to the Lespezi Formation (Ionesi, 2006), being mostly composed of partly compacted and/or laminated ash-grey clays with some thin intercalations of sand, sandstone and coal. An Early Sarmatian age was postulated for these deposits by Ionesi and Ionesi (1968) based on macro-fossils including Inaequicostata inopinata (Grischevich) and Oboletiforma lithopollica (Dubois), as well as microfossil associations with the foraminifers Cycloforina karreri ovata (Serova), Cycloforina karreri karreri (Venglinski), Elphidiella serena (Venglinski) and Elphidium regium (d’Orbigny). The Lower Sarmatian has been additionally indicated by further foraminiferal (Ionesi, 1968; Ionesi and Guevara, 1993; Dumitriu et al., 2017) as well as calcareous nannofossil (Dumitriu et al.,...
2017) studies. The latter authors assigned this succession to the NN7 nanofossil zone (Early Sarmatian).

The Bilca 1 core deposits are composed of clays and sandstones. The lower part of the section belongs to the upper anhydritic unit (Ionesi, 1994) and has been assigned to the Upper Badenian mainly based on a fauna with Spirolias spp. and Davidschvilia intermedia (Andrusov) (Brânziă et al., 2005). The upper part of the Bilca 1 core belongs to the Lespezi Formation and has been dated as Lower Sarmatian s.l., based on the occurrence of Inequicostata cf. inopinata (Grishkevich) and Mohrensternia cf. angulata (Eichwald) (Brânziă et al. 2005) which are considered as marker fossils for the Lower Sarmatian (Ionesi, 1991).

The strata studied at the Ripiceni and Costești exposures belong to two distinct lithostratigraphic units known as the “Darabani-Mitoc Clays” (Ionesi and Ionesi, 1981) and the “Stânca Limestone” (Simionescu, 1902). They are mostly represented by ash-grey clays (partially compacted or laminated) with some thin intercalations of sand, sandstone and limestone. The Ripiceni deposits were initially assigned to the Sarmatian by Simionescu (1903) based on the macrofaunal association with Ervilia podolica Eichwald, Mohrensternia angulata (Eichwald), M. inflata Hörnes and Abrax reflexa (Eichwald), and later by the palaeoentological studies of Paghida-Trelea (1969), Ionesi and Ionesi (1981, 1982), Brânziă (1999), and Dumitriu et al. (2017).

**MATERIALS AND METHODS**

For this study 172 samples were analysed micropalaeontologically: 34 samples from the Machów sulphur mine (Poland), 18 from the Jmania M-83 core (Poland), 29 from the FHP, Răduați core (Romania), 30 samples from the Bilca 1 core (Romania), 26 from the Domești exposure (Romania), 14 samples from Ripiceni exposure (Romania) and 21 samples from the Costești exposure (Republic of Moldova). The separation of microfossils from sediment samples (~200 g weight each sample) followed standard washing methods including crushing, washing through a 63 µm sieve and drying.

Depending on foraminiferal abundances in different samples, all foraminifera (planktic and benthic) up to 300 specimens were picked. The relative abundance of planktonic foraminifera within the foraminiferal assemblages (P/B ratio), as well as the relative abundance of epifaunal (%E) and infaunal (%I) species, and the relative abundance of the most common genera, were calculated (Figs. 2–8). To assess species diversity, the Fisher alpha index was calculated for each section, together with the total number of specimens for each sample (Appendices 1–7*). The environmental requirements of the foraminifera and ostracoda genera recorded in the sections studied are shown in Appendices 8 and 9, and a new dataset of foraminiferal and ostracoda assemblages of the sections studied was generated.

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* Supplementary data associated with this article can be found, in the online version, at doi: 10.7306/gq.1568
The present study also took into consideration previously published papers on other Central Paratethys basins (the Vienna and Pannonian (Hungary, Croatia) basins) and the Mediterranean realm (for details and references see Appendixes 10–12). Several samples (no. 440 from the Dorneşti exposure, 470, 482, 488 from the FH₃P, Rădăuţi core and 491/4, 495/D from the Costeşti exposure) were analysed for calcareous nanofossils. For semiquantitative analysis, 200 specimens were counted in longitudinal transverses, randomly distributed. The material investigated from Romania (FH₃P, Rădăuţi core, Bilca 1 core, Dorneşti and Ripcieni exposures) and the Republic of Moldova (Costeşti exposure) is deposited in the Original Paleontological Collections Museum of the “Alexandru Ioan Cuza” University of Iaşi, Romania. The material from Poland (Machów sulphur mine and Janmica M-83 core) is curated at the Polish Geological Institute – National Research Institute, Warsaw, Poland.

RESULTS

In all seven sections, we identified 127 species of calcareous and agglutinated benthic foraminifera, 16 species of planktonic foraminifera, 46 species of ostracod and 16 species of calcareous nanofossil (Appendixes 1–7). In general, microfossils are abundant and very well preserved except in the uppermost part of Bilca 1 core, where the specimens are of low diversity (Fisher alpha index is from 0.43 to 10.71), small and strongly abraded.

The most abundant benthic taxa comprise miolids (Affine-trina, Articularia, Articulinia, Cycloloborina, Miliolinella, Psuedotriloculina, Quinqueloculina, Sigmillinita, Triloculina, Varidentella), elphidids (Elphidium, Cribroelphidium, Porosonion), nonionids, bolivinids, buliminids, uvigerinids and lagenids (Favulina and Fissurina). Planktonic foraminifera are represented by Globigerina, Trilobatus, Globigerinoides, Globorotalia, Orbculina and Velaiperlina. Among the agglutinated taxa, Nothia, Haplophragmoides, Reticulophragnium and Textularia species have been recorded. Futhermore, the values of the Fisher alpha index suggest higher species diversity in the Polish Carpathian Foredeep Basin (PCFB) sections studied than in the Eastern Carpathians Foreland Basin (ECFB) (for details see Appendixes 1–7).

In total, integrating our data with the published literature, 24 Badenian planktonic foraminiferal species have been identified in the PCFB and ECFB of which 11 species are common (~45%) to both regions (Appendix 10) while 19 (~80%) and nine species (~38%) are common to the area studied (both PCFB and ECFB) and the Vienna Basin and Pannonian Basin, respectively (see Appendix 10).

In the case of Badenian benthic foraminifera, we compared the micropaleontological assemblages of the PCFB and ECFB. Of 81 species of benthic foraminifera identified in the PCFB 51 species, meaning 62%, are common with those of the ECFB (Appendix 10). Correlating benthic foraminifera from the areas studied with those from the Vienna Basin and Pannonian Basin, 47 (57%) and 38 (46%) species respectively are in common (Appendix 10). In the Lower Sarmatian deposits, in total eight planktonic foraminiferal species have been recorded in the PCFB and 25 species in the ECFB, of which five species (~63%) are common to these regions (Appendix 10). Benthic foraminifera are represented by 80 species in the PCFB and 83 species in the ECFB; 67 species (~80%) are common to both regions (Appendix 10). Among the benthic species, 47 and 32 species (constituting ~59% and respectively 40%) are in common with the Vienna Basin and the Pannonian Basin (Appendix 10).

FORAMINIFERAL ASSEMBLAGES

Qualitative and quantitative studies of the foraminiferal associations recorded in the sections studied have identified twelve different foraminiferal assemblages labelled from I to XII. One assemblage (Assemblage VII) has been described from the Badenian deposits and eleven from the Sarmatian. These assemblages are based on specific characteristics including the occurrence of specific taxa, the clear dominance of one or a few characteristic taxa, or the specific taxonomic composition of the assemblage (for detailed description of the foraminiferal assemblages see Appendix 13).

In the samples analysed, ostracods are generally well-preserved; 53 species have been indentified of which 10 are left in open nomenclature. The most abundant species belong to the genera Callistocythere, Aurila, Cytheris and Loxoconcha.

MICROFOSSIL CHARACTERISTICS OF THE SECTIONS STUDIED

MACHÓW

In the lowermost part of the section (the depth interval 67–75 m; Upper Badenian) the foraminiferal assemblages are highly diverse (Fisher alpha index is 0.80 to 6.33) and composed of benthic epifaunal as well as infaunal morphgroups accompanied by planktonic forms. The epifaunal morphotypes (see e.g., Corliss and Chen, 1988; Rathburn and Corliss, 1994) are represented by Cibicides, Heterolepa, Cibicidoides, Milio linella and Sigmillina, and the infaunal by Bolivina and Buliminina which are the most common in sample 1 (75 m depth) and sample 7 (68 m depth) representing 60% of the benthic foraminiferal assemblages. The planktonic genus Globigerina is very abundant in sample 2 (73 m depth) composing ~50%. Ostracods are relatively rare, only a few specimens of Henry-howella aspermina have been identified. In the uppermost part of the Badenian succession three more ostracod species, Callistocythere incostata, C. sp. and Aurila sp. were encountered. In the upper interval representing the lowermost Sarmatian (67–56.5 m depth) planktonic forms are absent. The foraminiferal assemblages here are composed almost entirely of the epifaunal species Anomalinoïdæ divisæ which comprises 90%. Minor components of these assemblages are Cibicioides, Quinqueloculina and Varidentella. From 67 m depth upwards, the ostracod assemblage becomes more diverse. The most frequent species are Cytherois sarmatica, Callistocythere canaliculata, C. incostata, Aurila mehesi, Polycope orbicularis as well as some representatives of Leptocythere. These ostracod taxa remain abundant until 45 m core depth.

Continuing the section upwards, in the interval 45–56 m in depth (samples 15–19), the genus Anomalinoïdæ totally disappears. The most abundant forms are infaunal non-keeled elphidiids (Porosonion subgranulosus, Elphidiella serena, Elphidium hauerinum), epifaunal mioloids (Cycloforina, Miliolinella, Pseudotriloculina, Quinqueloculina and Varidentella) and
keeled elphidiids (*Elphidium aculeatum, E. joukovi, E. macellum*). In the depth interval 30–43 m (samples 20–25), the foraminiferal associations are equally composed of epifaunal (miliolids and keeled elphidiids) and infaunal morphogroups (lagenids and non-keeled elphidiids). Some planktonic forms (*Globigerina*) were also encountered in sample 23. In the upper interval (samples 26–34) at 2–25 m in depth, the most abundant species belong mostly to the infaunal genera *Elphidialla, Bolivina, Bulimina, Nonion, Porsononion* and non-keeled *Elphidium*, which together constitute 70% of the assemblage. Epifaunal keeled *Elphidium, Cyclolforina, Neoeponides, Rosalina, Varidentella* are also quite common (30%) (Fig. 2). From 45 m upwards, in the Machów section, only scarce *Xestoleberis dispar* represents the ostracod fauna.

**JAMNICA M-83**

In the Jamnica M-83 core succession, the lowermost interval, the Upper Badenian (225–235 m in depth, samples 19, 17, 16), is characterized by abundant planktonic species especially belonging to the genus *Globigerina* (sample 16). Among the benthic forms 43% are represented by infaunal *Bolivina, Bulimina, Favulina, Pappina, Nonion, Textularia* and *Uvigerina* while 57% are represented by epifaunal taxa such as *Heterolepa, Cibicidoides* and *Cibicides*. Sample 16 yielded many (50 specimens) agglutinated forms belonging to the following genera: *Netitha, Rhizammina, Reticulophragnum, Reophax, Haplophragmoides, Cyclamina, Budašhevaella*. The next interval, the lowermost Sarmatian (202–220 m depth, samples 15–10) is characterized mainly by epifaunal species of the genera *Anomalinoëides, Articularia, Miliolæa, Neoeponides, Pseudotriluculina, Quïqueloculina, Triloculina* and *Varidentella*. Upwards in the section (132–202 m depth) the foraminiferal assemblage is clearly dominated by infaunal *Bolivina, Fissurina* and *Nonion*, which together comprise ~90% of the benthic assemblages. Minor components of this association are *Neoeponides* and *Varidentella*. The interval between 35–75 m in depth is dominated by epifaunal forms such as *Articulina, Cibicides, Pseudotriluculina*, and *Varidentella* while infaunal non-keeled elphidiids occur in much lower numbers. Representatives of planktonic foraminifer *Globigerina* appear again in this part of the section, comprising 50% in samples 1 and 3 (Fig. 3).

In the Jamnica M-83 borehole, 20 ostracod species were recorded (*Appendix 2*). In the lowermost part of the succession (samples 16, 19), the typical Badenian ostracod taxa *Cnestytheria truncata, Henryhowellia asperimma, Cytheropteron vespertilio, Loxocorniculum hastatum, Xestoleberis tumida* were found. Upwards in the section (175–220 m depth), ostracods are mostly represented by *Cytheris sarmatica, Phlyctocythere pellucida, Callistocythere incostata* and *Aurila mehesi* while in the interval 50–75 m only *Callistocythere postvallata* and *Xestoleberis tumida* were identified.

**BILCA 1**

Planktonic foraminifera mostly dominate the lower part of the section (704–806 m depth, samples 1–4): *Globigerina praebulloides, G. bulloides, Trilobatus bisphericus, T. trilobus* and *Vestaperta indigena*. Other components of the association are *Bulimina, Hansenisca, Heterolepa, Sphaeroidina, Textularia* and
Uvigerina, though samples 9 (950 m) and 27 (120 m) are entirely composed of Globigerina sp. Globorotalia sp. appears in samples 4 (704 m), 23 (240 m) and 28 (90 m) (Fig. 4). The upper interval (360–704 m depth) is composed of both epifaunal (Ammonia, keeled Elphidium and Cibicidoides) and infaunal morphotypes (non-keeled Elphidium, Nonion and Porosononion). Upwards in the section, the 30–360 m interval is mostly dominated by Ammonia, keeled and non-keeled Elphidium. Cycloforina and Quinqueloculina. Planktonic foraminifera were also recorded in these intervals. Only one ostracod species, Cytheridea acuminata, was recorded in the section.

FHşP; RĂDĂUŢI

In the lower part of the section (239 and 174 m depth, samples 467 and 473 respectively), the foraminiferal assemblages are entirely composed of planktonic foraminifera (Globigerina and Globorotalia). Upwards in the succession (175–200 m depth, samples 472, 481, 471, 470, 474), the foraminiferal associations are characterized mostly by benthic epifaunal morphotypes: e.g., Ammonia, Cycloforina, keeled Elphidium, Cibicidoides, Milolina, Pseudotriquilocula. The next interval (90–175 m) has yielded calcareous epifaunal genera such as Ammonia which represents 100% of the foraminiferal assemblage in sample 485 and 97% in sample 484. Cycloforina (100% in sample 476), keeled Elphidium (60% in sample 475) and Pseudotriquilocula (60% in sample 479). Minor components of this interval are the genera Articularia, Elphidiella, Nodo-baculariella, Nonion, Porosononion and Varidentella. Planktonic species of Globigerina occur in samples 477 (40% of the assemblage) and 483 (50% of the assemblage). The upper part of the succession (27–90 m depth) is mainly characterized by Cycloforina and keeled Elphidium. Ammonia, Articulalia, Elphidiella and Nonion species also occur in this interval. Globigerina represents 25% of the assemblage in sample 487 (Fig. 5).

In total, 25 ostracod species were found in the FHşP, Rădăuţ borehole material. In the lower part of the section two samples 470, 474 (170–180 m depth) include a significant number of ostracod species. Although ostracod abundance is low, dominant species were distinguished as Cytheridea hungarica, Aunla mehesi, Callistocythere canaliculata, C. egregia, C. incostata and Euxinocythere praebosqueti, accompanied by Loxocomiculum schmidtii, Senesia vadaszi and Xestoleberis fusata. The ostracods are relatively scarce in the upper part of the section (25–155 m). The most representative species are Loxococoncha minima, L. impressa, Hemiptyrides dacica dacica and Callistocythere spp.

The nannofossil content identified in samples from this section consists of long-ranging species such as Reticulofenestra pseudoumbilicus, R. minuta, R. minutula, Coccolithus pelagicus, Co. miopelagicus, Helicosphaera carteri, Pontosphaera japonica, Sphenolithus abies and Calcidiscus leptopus. Reticulofenestra taxa represent ~25% of the total assemblage, while Discosaster and Sphenolithus species comprise ~20%. The rest of the in situ assemblage is composed of Helicosphaera, Calcidicus, Pontosphaera and Coccolithus.

*Fig. 4. The relative abundance of the most common foraminiferal genera, P/B ratio, epifaunal/infaunal ratio and foraminiferal assemblages in the Bilca 1 core*

a – chronostratigraphy; b – lithostratigraphy; c – biostratigraphy after Ionesi (1991); d – biostratigraphy after Dumitriu et al. (2017); for other explanations see Figure 2
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Foraminiferal assemblages of the Dornești locality are composed of epifaunal (Ammonia, Articulata, Cycloforina, keeled Elphidium and Quinqueloculina) as well as infaunal representatives (Bolivina, Buliminata, Elphidiella, non-keeled Elphidium and Nonion). Planktonic forms of Globigerina occur in samples 101–103, 108, 110 and 165 and constitute 10–78% of all foraminifera (Fig. 6). Ostracods are scarce and were found only in two samples (samples 440 and 146), and are represented by six species, the most abundant being Cytheridea hungarica and Euxinocythere praebosqueti.

The calcareous nannofossils identified in the lower part of the section contain diverse assemblages with discoasterid taxa, i.e., Discoaster kugleri and D. deflandrei which along with Sphenolithus abies represent ~35% of the total assemblage. The rest of the in situ taxa are represented by reticulofenestrids and species of Helicosphaera, Calcidiscus, Pontosphaera and Coccolithus.

RIPICENI

35 species of calcareous benthic foraminifera were identified in the Ripiceni exposure. Agglutinated and planktonic foraminifera are absent. Excepting samples a and g, all the samples yielded foraminiferal assemblages entirely composed of epifaunal morphotypes. Ammonia, Cycloforina, Cibicides, Cibicidoides and Quinqueloculina are the most abundant genera in the lower part of the section (samples i, k, m; Fig. 7). The most numerous ostracod taxa are Cytheroïdes sarmaticus, Cytheroïdes hungarica, Aurila mehesi and Callistocythere canaliculata alongside C. maculata, C. inconstata, Aurila merita, Phlyctocythere pellucida, Loxoconcha, and Xestoleberis species.

COSTEȘTI

The foraminiferal assemblage of the Costești section is clearly dominated by benthic epifaunal morphotypes belonging to Articulata, Articulina, Cycloforina, Pseudotriloculina and Quinqueloculina in its lower part, and by infaunal forms (Fissurina and Porosonion) in the upper part (Fig. 8). Planktonic foraminifera are absent. The ostracod fauna is rather scarce and only found in three samples (495/D, 491/1 and 491/5); the most common species are Loxoconchium schmidtii and Lo. hastatum. The calcareous nannofossil content identified in this section comprised only one barren sample (495/D) and another one (sample 491/4) containing only reworked taxa from older Cretaceous and Paleogene deposits.

DISCUSSION

PALAEOENVIRONMENTAL CHANGES ACROSS THE BADENIAN-SARMATIAN EXTINCTION EVENT

The Badenian/Sarmatian boundary is commonly associated with the regional Badenian–Sarmatian Extinction Event (BSEE) (Harzhauser and Piller, 2007) interpreted as a cata-
Fig. 6. The relative abundance of the most common foraminiferal genera, P/B ratio, epifaunal/infaunal ratio and foraminiferal assemblages in the Dornești section

a – chronostratigraphy; b – lithostratigraphy; c – biostratigraphy after Ionesi (1991); d – biostratigraphy after Dumitriu et al. (2017); for other explanations see Figure 2

Fig. 7. The relative abundance of the most common foraminiferal genera, P/B ratio, epifaunal/infaunal ratio and foraminiferal assemblages in the Ripiceni section

a – chronostratigraphy; b – lithostratigraphy; c – biostratigraphy after Ionesi (1991); d – biostratigraphy after Dumitriu et al. (2017); for other explanations see Figure 2
Fig. 8. The relative abundance of the most common foraminiferal genera, P/B ratio, epifaunal/infaunal ratio and foraminiferal assemblages in the Costești section

a – chronostratigraphy; b – lithostratigraphy; c – biostratigraphy after Ionesi (1991); d – biostratigraphy after Dumitru et al. (2017); for other explanations see Figure 2

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The sea level fall during the Badenian-Sarmatian transition may be additionally supported by a decrease across the boundary of the proportion of planktonic foraminifera within the total foraminiferal assemblages in Machów (from ~60 to ~2%) and Jamnica M-83 (from ~56 to 0%) sections (Figs. 2 and 3). This ratio, however, must be treated with caution since it strongly depends on the salinity as well as on the abundance of benthic foraminifera, which may be related to factors such as oxygenation or food supply. A more reliable method seems to be analysis of the planktonic foraminiferal depth-morphogroup model (Keller, 1985), which is based on modern analogues such the depth stratification of recent species composition (Bé and Hamlin, 1967; Bé, 1977; Schiebel and Hemleben, 2005). According to this model, simple Globigerina-like or Globigerinoïdes-like morphotypes live near the water surface (up to tens of metres) while more complex, Globorotalia show preferences for deeper/intermediate habitats. Consequently, the common occurrence of these forms in the Late Badenian of the PCFB and their rarity in the Sarmatian (see also Szczepura, 2000; Garecka, 2004) suggests a evidence of a sea level fall during the Badenian-Sarmatian transition.

Similarly to foraminifera, ostracods also suffered a strong decrease across the BSEE in the sections studied. Of >100 known ostracod genera, the common ostracod taxa still typical of shallower waters (from up to tens of metres) include Heterolepa hungarica, Henryhowella asperrima, Xestoconculum hastatum, Senesia vadaszi, and Xestoleberis fuscata. Badenian species are mostly represented by deeper, sublittoral to epibathyal forms such as Henryhowella asperrima, and Sarmatian species by endemic, much shallower forms, such as Callistothe care incostata, Cnestocyclis truncata, Euxinocythere praebogesi, Cytheridea hungarica, Aurila merita, and Aurila mehesi (Tóth et al., 2010). In addition to these endemic Sarmatian forms, many common ostracod taxa still typical of shallower waters (from up to tens of metres) have been recorded — Cymacytheridea, Loxoconcha, Loxoconculum and Xestoleberis (Hartmann, 1975; ter Borgh et al., 2014). Accordingly, the occurrence of deeper water ostracods in the Badenian deposits and the appearance of shallower water species in the Sarmatian provide additional evidence of a sea level fall across the Bis boundary.

Benthic foraminiferal assemblages from the uppermost Badenian of Poland and Romania (Blica 1) include a large number of buliminations, bolivinoids, uvigerinids, and representatives of Cibicides, Heterolepa, Hanzawaia, and Cibicoidcides, enrolled or partly uncoiled milolids such as Milolina, Pseudotriloculina, and Sigmolina as well as agglutinated foraminifera. The large number of epifaunal (cibicidids, anomalids and milolids) together with diverse and abundant relatively deep infraunal taxa (buliminids, bolivinids and uvigerinids) indicate a relatively large organic matter supply (see Bálti, 2006; Kováčová et al., 2009; Kováčová and Hudačková, 2009) and relatively good/moderate oxygenation at the sea floor (mesotrophic conditions) (see Jorissen et al., 1995) with the expected decrease in oxygenation and increase in organic matter deeper in the sediment.

High bottom-water oxygen concentrations are also supported by the presence of large oxygen-consuming cytheracean ostracods (Whithey, 1985) e.g., Callistothe care, Aurila and Cytherides spp. Fully marine conditions are also indicated by the Badenian calcareous nonplankton assemblages, which are characterized in the Central Paratethys by high abundance and diversity. Furthermore, in the intra- and extra-Carpathian regions of Romania, the biostratigraphy based on nannofossil distribution (Meszaros, 1992; Mărunțeanu, 1999; Melinte-Dobrinescu and Stoica, 2013) allowed the identification of all biozones established for the Mediterranean realm and the open-ocean Indo-Pacific realm.

The Badenian is often regarded as the last fully marine interval in the Central Paratethys (Papp, 1954, 1956) with connections between the Central and Eastern Paratethys through the Bělrad Straits (Palcu et al., 2017) and between the Paratethys Sea and the Mediterranean realm through the Slovenian Corridor (Bartol et al., 2014) or through the Axios (Vardar) Trench (Studencka et al., 1996). However, Kováč et al. (2017) considered that the Slovenian corridor was probably closed during this time interval. By contrast, the Sarmatian of the Central Paratethys is commonly viewed as more restricted with mostly shallow-water conditions (Papp, 1954, 1956; Papp et al., 1974). However, some authors (Filipescu et al., 1999, 2014; Piller and Harzhauser, 2005; Comèe et al., 2009) suggest the existence of normal salinity during the Sarmatian.

Consequently, the planktonic foraminifera recorded in some intervals of the Lower Sarmatian of Poland and Romania have been interpreted as reworked from Badenian sediments (Ionesi, 1968; Paghida-Trelea, 1969; Brânziilă, 1999, 2004; Brânziilă and Chira, 2005; Ionesi, 2006; Brânziilă et al., 2011) or having been introduced (Lucczkowska, 1964; Odrywolska-Bierkova, 1974), probably due to an influx of marine water into the Carpathian Foredeep from the Mediterranean Basin (Szczepura, 2000) or Indo-Pacific region (Filipescu and Silye, 2008; Stoica et al., 2013; Silye, 2015). Planktonic foraminifera recorded (Figs. 3–6) in the Lower Sarmatian deposits (Assemblage V) of the area studied are, however, very well-preserved, abundant, and taxonomically diverse (representatives of Globigerina bulloides, G. praebulloides, Triloculina trilobus, T. bisphericus and Globorotalia miocenica), indicating rather an in situ occurrence. Accordingly, some short-lived transgressions and some periods of temporary nearly normal marine conditions during the Sarmatian, with very high diversity (Filipescu et al., 1999; Latal et al., 2004; Piller and Harzhauser, 2005) have been postulated. Moreover, in this foraminiferan assemblage (V) planktonic foraminifera co-occur with benthic taxa such as Bolivina and Bulimina, which also suggests slightly deeper conditions with generally normal salinity (Murray, 2006; Tóth et al., 2010; Peryt, 2013). Additionally, the ostracod species of the lowermost part of the Sarmatian deposits of the PCFB sections, such as Henryhowella asperrima, Callistothe care spp., Loxoconculum hastatum and Xestoleberis tumida support the occurrence of almost fully marine water (see ter Borgh et al., 2014). Similarly, in the lowermost part of the FH3-P4 Rădăuţii borehole (ECFB) the occurring ostracod assemblages are characteristic of fully marine waters (ter Borgh et al., 2014).

The moderately common occurrence of planktonic foraminifera (Globigerina), which constitutes up to 90%, in the lower Volhynian (=Lower Sarmatian) of the northwestern part of the Moldavian Platform (the area of the FH1-P3 Rădăuţi, Blica 1 and Dorneşti sections) as well as short-lived appearances of the relatively deeper-dwelling Globorotalia, suggest the occurrence of a deeper basin during the Early Volhynian in this area than in the northeast part of the ECFB (the area of the Ripiceni and Costeşti sections) where planktonic foraminifera are sparcadic. These data follow the general scheme of facies development of the ECFB (Grasu et al., 2002; Miclaus et al., 2011), namely, the deeper foredeep depocentre for the FH1-P3 Rădăuţi, Blica 1 cores.
and Domenghi section and the much shallower subaqueous depozone for the Ripiceni and Costești sections (Fig. 1B). This foraminiferal data also indicates that during the Early Sarmatian, this area was possibly slightly deeper than the area of the Machów and Jannica M-83 sections, where planktonic foraminifera are significantly less frequent. Following the scheme of planktonic foraminiferal morpho-groups (e.g., Leckie, 1987), the occurrence of relatively shallow-dwelling forms (Globigerina), and the sporadic occurrence of deeper-dwelling foraminifera with a pseudokel or acute periphrphy, indicates that the general water depth of the forereef depozone area during the Early Volhynian is estimated to be up to a few tens of metres but much <100 m. This assumption is supported by the presence in the same interval of benthic foraminifera (see Figs. 2–6) and by the ostracod fauna (Callistocythere, Cytheridea, Aurila and Xestoleberis), which have been described as characteristic of the upper infralittoral environment (Bremen, 1975) and the epi-nerritic facies (Lietbou, 1975). Additionally, Callistocythere flavidosusca (Ruggieri, 1959) (which is similar in C. canaliculata, does not exceed 100 m water depth, being very abundant near 70 m (Bonaduce et al., 1976). The occurrence of Hemicyprideais dacica dacica, the counterpart of a Cyprideis species, in the upper part of the FH3-P, Răďauți section, may indicate highly fluctuating salinities in the basin.

Interestingly, the relatively deeper-dwelling foraminfer Globorotalia of the Upper Badenian strata from the areas studied of the ECFB is represented by a single species i.e., Globorotalia mayeri. By contrast, the Sarmatian globorotaliids are much more taxonomically diverse, represented by Globorotalia mayeri, G. bykovae, G. michonca, G. cosovensis, G. margino-decata and Globorotalia sp. (for details and references see Appendix 10). This might argue against the hypothesis of a general sea level drop during the Badenian-Sarmatian transition in this part of the ECFB, but alternatively it may indicate a record of stronger subsidence during the Sarmatian than in the Badenian, possibly resulting from movement of the Carpathian fold.

The depocenter was possibly moving eastwards (Ionesi, 1994), resulting in more rapid subsidence and the occurrence of a slightly deeper basin in the NW part of the ECFB during the Early Sarmatian than in the Badenian.

In general, the Sarmatian salinity of the Central Paratethys has been considered as being brackish, transition between the normal marine conditions of the Badenian to the very brackish to fresh conditions of the Pannonian (Báldi et al., 2017). Our studies indicate that during the Early Sarmatian, the part of the Central Paratethys studied was not totally brackish but rather the salinity was variable, oscillating from brackish, through normal marine to slightly elevated, probably due to some minor transgressions when short-lived near-f Ally marine conditions were re-established both in the PCFB and in the ECFB. The two clearly demarcated foraminifer assemblages identified in the Sarmatian deposits studied indicate changing environmental conditions of the parts of the PCFB and ECFB studied, which are as follows. A brackish and shallow environment, up to 50 m depth (Murray, 2006; Pérez-Asensio et al., 2012), can be assigned to foraminiferan Assemblage III, which is clearly dominated by the species Ammonia beccari, and which has been observed only in the eastern part of the Paratethys (the FH3-P, Răďauți and Bilia 1 sections). In general, Ammonia beccari is commonly regarded as an opportunistic species which can tolerate salinities from 10–30‰ (Murray, 2006), being able to adapt to hyposaline conditions (Murray, 1968). Its predominance or the low diversity association marked by the dominance of this species usually indicates shallow and brackish environments (Cimerman and Langer, 1991; Hayward and Hollis, 1994; Filipescu et al., 2014). In the brackish Holocene deposits of the NW Black Sea, as in the coastal regions, where the salinity is 7–8‰, Ammonia beccari is the dominant species, producing monospecific assemblages (Bricca and Ion, 2014). Still very shallow but, almost normal marine salinity conditions are associated with Assemblage I, recorded in the Romanian and Moldavian parts studied of the ECFB, which is characterized by the presence of elphidiids [especially the large-keeled Elphidium species (E. ruminum and E. crenulatum)], characterizing depths of 0–50 m (Murray, 2006; Gedi et al., 2016). Moreover, this assemblage may indicate generally oligotrophic conditions and a rich sea-grass vegetation substrate (Langer, 1993; Tóth and Görög, 2008; Koubová and Hudáčková, 2010; Ionesi et al., 2010; Filipescu et al., 2014). Shallow, euphotic conditions of a normal marine salinity environment (Murray, 2006; Pyryt and Jasionowski, 2012) are also correlated with foraminifer Assemblage VI, identified in the FH3-P, Răďauți, Domenghi and Ripiceni sections. Normal marine salinity but deeper conditions are also supported by the presence of planktonic foraminifera (Assemblage V) (Hemleben et al., 1989) in the Jannica M-83, FH3-P, Răďauți, Bilia 1 and Domenghi sections.

Several intervals with slightly higher salinity have been identified in all the sections studied (Figs. 2–4) and correspond to Assemblages II and IV, dominated by milolids. This group of foraminifera is peculiar to shallow waters with salinities varying from normal to hypersaline (Luczowska, 1974; Murray, 2006; Filipescu et al., 2014) and cannot live in hyposaline conditions (Murray, 1968). Accordingly, the presence of these assemblages in the sections studied indicates episodes of slightly higher salinity during the Early Sarmatian, both in PCFB and in the ECFB, which is against the traditional opinion that the Sarmatian was in general a brackish period in the Paratethys (Papp, 1956; Czepiec and Kotarba, 1998; Fordín et al., 2006; Ionesi, 2006; Vršaljk et al., 2006; Maaríusradze and Koiaia, 2011).

Assemblage X, which is 98% composed of Nonion species, has been recognized in the Jannica M-83 and Bilia 1 sections while Assemblage XI, composed 100% of Parosonion species, occurs in the Costești section (Figs. 3–4 and 5). These foraminifera are usually associated with environments of brackish to normal marine salinity conditions (Avinam-Katav et al., 2013; Filipescu et al., 2014; Silve, 2015) and decreasing salinity (for low species-richness assemblages) (Culver et al., 2012) and possible increasing in nutrient supply. Assemblage IX (Figs. 2 and 3) of the Upper Sarmatian, composed of high abundant infaunal species belonging to Bulimina and Bolivina, indicates deeper sea depths (middle neritic) with generally normal-salinity and low oxygen-content at the sea-floor (Murray, 1991; Sen Gupta and Machain-Castillo, 1993; Jorissen et al., 1995; Klováčová et al., 2009; Dubicka et al., 2014; Drinia et al., 2016; Pezelj et al., 2016). Similar conditions can be postulated for the deposits of the uppermost part of the Costești section, represented by Assemblage XI, which is entirely composed of representatives of Fissurina (Silve, 2015).

The taxonomic composition of the Sarmatian ostracod assemblages, especially the occurrence of Aurila, Callistocythere, Henryhowella, Xestoleberis, Loxoconcha, Loxococcolum in the sections studied also indicates fluctuations in salinity (van Morkhoven, 1963; Szczezura, 2006; Tóth et al., 2010; ter Borg et al., 2014) both in PCFB and ECFB. The calcareous nanofossilss in the sections studied indicate a fully marine environment, at least for some short periods, since the majority of the species live in waters with salinities higher that 20–22‰ (Tappan, 1980). An exception is the extant species Emiliania huxleyi that may be identified today in waters
with lower salinity, i.e., 11‰ in the Azov Sea and Black Sea (Buky, 1974; Melinte-Dobrinecu and Ion, 2013). Furthermore, the common presence of discoasterids and sphenoliths in the deposits studied from the lower part of the Sarmatian of ECFB also supports an interpretation of intervals with normal marine conditions, since these nannofossils are mostly confined to open marine settings (Backman and Pestieux, 1987).

Fluctuations of salinity during the Sarmatian have also been documented in other parts of the Central Paratethys (e.g., Filipescu et al., 1999, 2014; Piller and Harzhauser, 2005; Ruman et al., 2017).

POSSIBLE CONNECTIONS BETWEEN DIFFERENT BASINS OF THE PARATETHYS

A variety of studies (e.g., Łuczewska, 1964; Ionesi, 1968; Paghida-Trelea, 1969; Popescu, 1975; Dumitrică et al., 1975; Brózda and Chira, 2005; Popescu-Cușă, 2006; Mikuž, 2009; ter Borgh et al., 2014) have noted the similarities between the latest Badenian and/or Early Sarmatian fossils from different basins of the Central Paratethys, and different gateways of communication across the Paratethys have recently been postulated (e.g., Palcu et al., 2017). It is still difficult to assess where the connections between distinctive basins such as the Carpathian Foredeep and Pannonian, Dacian, Transylvanian and Vienna basins were situated. Even more difficult to assess seem to be the factors that influenced the connectivity between different basins of the Central Paratethys (ter Borgh et al., 2013) since isolation of each basin took place at different times.

Our results contribute to these discussions, and suggest that during the latest Badenian and Early Sarmatian there were foraminiferal migratory routes between the northern and eastern parts of the Carpathian Foredeep Basin, since ~45% of planktonic and 62% of benthic foraminiferal species are common to both regions during the latest Badenian while in the Early Sarmatian, 63% of planktonic and 80% of benthic species are the same. Additionally, some ostracod species (14, ~31%) were identified as being in common to these two basins during the Early Sarmatian. A possible connection between the Carpathian Foredeep Basin and the Vienna Basin as well as between the Carpathian Foredeep Basin and the Pannonian Basin during the latest Badenian, which enabled planktonic and benthic foraminiferal migration, is also postulated based on the recently compiled micropalaeontological dataset. Surprisingly, there are more taxa in common between the Carpathian Foredeep Basin and the Vienna Basin (80% of planktonic and 57% of benthic species are in common) than between the Carpathian Foredeep Basin and the Pannonian Basin (38% of planktonic and 46% of benthic species are in common). Based on the common taxa identified in these basins we infer that the connection between the Carpathian Foredeep Basin and the Vienna Basin was more active, the connecting area being in the Eastern Alps and Western Carpathians junction (western Moravia) (Mandic, 2004; Holcová et al., 2015; Kovác et al., 2017). This interpretation seems to be consistent with the data, especially if the latest Badenian is linked with a significant transgression (Kovác et al., 2007).

While the suggested connection between the area studied and the Vienna Basin and the Pannonian Basin during the latest Badenian seemed to have been active, based on the presence of a large share of planktonic species (80% with the Vienna Basin and 38% with Pannonian Basin) we cannot demonstrate the same for the Early Sarmatian. Here, the benthic Sarmatian foraminifera are 47 (59%) and 32 (40%) in common for the area studied and the Vienna Basin and the Pannonian Basin respectively, while the common planktonic foraminifera are missing from the area studied and from the Vienna Basin and Pannonian Basin. Therefore, there was probably no connectivity allowing planktonic foraminiferal migration during the Early Sarmatian. If the connections existed, they must have been quite shallow, allowing free migration of only benthic foraminifera and ostracods [16 (~37%) and 17 (~40%) of species having been recorded as common between the area studied and the VB and PB respectively].

POSSIBLE CONNECTION BETWEEN THE CENTRAL PARATETHYS AND THE MEDITERRANEAN REGION DURING THE LATEST BADENIAN

During the last few decades, several comparative palaeontological studies of various areas of the Central Paratethys and the Mediterranean realm have been carried out to find possible migration routes, though these have led to contradictory interpretations. Based on the presence of common ostracod fauna in the Central Paratethys and the Mediterranean, Szczechura (1996, 1997) postulated a possible connection between these two basins during the Late Badenian. The gastropod fauna from Slovenia (Mikuž, 2009) shows large similarities with faunas of different areas of the Central Paratethys, but also with the fauna from the Mediterranean and Atlantic region, as well as the echinoid fauna from the same area of the Central Paratethys (Ali and Maczyszynski, 1986; Mikuž and Horvat, 2003). The connection seems to have been more active in the southern part of the Central Paratethys, while the northern part is considered to have been more restrictive to open-marine exchange (Kovácová et al., 2009). Based on a study of molluscs, salinity conditions and marine circulation in the Pannonian Basin, Kókay (1985: fig. 8, p. 46) considered that during some periods of the Late Bade- nian, the Central Paratethys communicated directly with the Mediterranean Sea, through its western part, across the area of today’s Slovenia towards northern Italy. Moreover, Kókay (1985) excluded the possibility of communication through the Eastern Paratethys. The existence of the Slovenian Corridor (Trans-Tethyan Trench Corridor) has also been postulated by the nannofossil and gastropod studies of Bartol et al. (2012, 2014), who stated that the Central Paratethys and Mediterrane- an Sea were connected from the Late Badenian (Early Serravallian) until the Early Sarmatian. By contrast, Studenczka et al. (1998), based upon bivalve studies, inferred that the Trans-Tethyan Trench Corridor was probably closed during the Late Badenian–Early Sarmatian and that the Central Paratethys directly communicated with the East Mediterranean Sea through the Axios-Vardar Trench. These authors further suggested that the Eastern Paratethys could also have communicated with the Mediterranean Sea through the re-opened Arks straits. Rögl (1998, 1999) interpreted the presence of Indo-Pacific microfossil associations in the Central Paratethys as a result of a re-opening of seaways along the Pontides to Eastern Anatolia. Palaeogeographic connections to the Indo-Pacific area have also been indicated by Popescu (1975), Filipescu and Silice (2008), and Silice (2015).

The foraminiferal assemblages identified by us, together with published data, allow us to compare the Late Badenian foraminiferal assemblages across different basins of the Central Paratethys (Carpathian Foredeep, Vienna and Pannonian basins) as well as the foraminiferal assemblages of the Central Paratethys with that of the Mediterranean realm (equivalent to the Early Serravallian). In total, 52 (~26%) of 198 species are in common between the Central Paratethys and the Mediterr-
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The existence of some species of foraminifera in common between the Central Paratethys and the Mediterranean realm (for details and references see Appendix 12). Among these, 21 out of 45 planktonic species and 31 out of 153 benthic ones are in common (for details see Appendix 12). Likewise, we identify ostracod taxa (*Cnestocythere lamellicosta*, *Cn. truncata*, *Cytheridea acuminata*, *Loxoconcha minima*) in common between the Central Paratethys and the Mediterranean realm (see also Aiello and Szczezuch, 2000).

CONCLUSIONS

Integrated foraminiferal, ostracod and calcareous nannofossil studies were carried out on seven Middle Miocene sections in Poland, Romania, and the Republic of Moldova. Based upon micropaleoontological data, we have interpreted variable palaeoenvironmental conditions in the Carpathian Foredeep Basin during the latest Badenian and Early Sarmatian. Quantitative and qualitative changes in both foraminiferal (planktonic and benthic) and ostracod assemblages strongly support a significant sea level fall across the Badenian-Sarmatian boundary in both basins studied, causing a transformation from fully marine settings to marginal marine environments. During the Early Sarmatian, the salinity of the Carpathian Foredeep Basin was very variable, likely oscillating from brackish to fully marine, with episodes of hypersaline conditions. This inference is supported by the presence of fully marine calcareous nannofossil species in several Early Sarmatian intervals in the ECFB. The salinity variability within the basin, during the Early Sarmatian, was probably related to some minor sea level fluctuations, when short-lived near-fully marine conditions were re-established.

During the Early Sarmatian, the environment in the ECFB was mostly shallow in the backbulge area and slightly deeper in the foredeep part of the basin, where in some intervals the palaeodepth was probably around a few tens of metres, <100 m in the foredeep depozone studied, and probably much less than 50 m in the backbulge depozone. Moreover, the foredeep depozone of the ECFB seems to have been deeper than that of the PCFB. The sea floor of the ECFB was characterized by generally oligotrophic conditions.

The Early–Late Sarmatian transition is interpreted as a period, at times, of low oxygen and deeper conditions in the Carpathian Foredeep Basin. The salinity of the Carpathian Foredeep Basin during the Early Sarmatian (Assemblages II, IV, V) was possibly close to normal marine.

Our studies indicate palaeoenvironmental similarity between different basins of the Central Paratethys but also support the earlier hypothesis of possible connections during the latest Badenian between different areas of the Central Paratethys as well as the existence of a gateway between the Central Paratethys and the Mediterranean realm.

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