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The Badenian/Sarmatian (Middle Miocene) boundary in the Central Paratethys (Kreminna, western Ukraine): foraminiferal and palynological evidence

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The Badenian/Sarmatian boundary in the Paratethys basin, that marks the transition from normal marine to restricted semi-marine conditions due to isolation of the basin from the world ocean at the onset of Sarmatian time, is still far from being fully understood. The Kreminna section is located at the northeastern margin of the Carpathian Foreland Basin (Central Paratethys) in the Medobory Hills region. The Miocene deposits that overlie here the Upper Cretaceous substratum comprise the >1 m thick upper Badenian marls and clays passing upwards into ~4 m thick Sarmatian marly limestones with intercalations of marls, clays and limestones, and >2 m thick limestones in the uppermost part of the exposure. Fifty-three species of benthic foraminifera and four species of planktonic foraminifera have been recorded. Six benthic foraminiferal assemblages are composed almost exclusively of calcareous forms; agglutinated taxa are practically lacking. *Elphidium* spp., miliolids, *Lobatula lobatula* and *Ammonia* spp. are the most common calcareous benthic foraminifera in the material studied. Planktonic foraminifera are represented only by species of *Globigerina* and occur rarely in the lowermost part of the section. A characteristic feature of palynofacies is the very low proportion of land-derived elements – sporomorphs and cuticles, which suggests a sedimentary setting without terrestrial influx, and taxonomical impoverishment of dinoflagellate cyst assemblages, which are either monospecific or consist mainly of two to three species: in a majority of samples, assemblages with *Polysphaeridium zoharyi* and *P. subtile* occur. Most δ^{18}O values range from –1.5 to ~+0.5‰ VPDB and most δ^{13}C values are between 0 and +2‰ VPDB. In general, the δ^{13}C curve mirrors the δ^{18}O changes in the section. The Badenian/Sarmatian boundary is placed at the level where the *Cibicidoides ungerianus* Assemblage is replaced by the *Elphidium fichtelianum* Assemblage. At the boundary, planktonic foraminifers and most abundant stenohaline benthic foraminifera disappeared. Bottom waters were well-oxygenated both in the latest Badenian and earliest Sarmatian in the Kreminna location.

Key words: Middle Miocene, Carpathian Foredeep Basin, foraminifers, palynofacies, palaeoenvironments.

INTRODUCTION

Following the Badenian Salinity Crisis initiated at 13.81 ±0.08 (de Leeuw et al., 2010), when massive evaporite deposition occurred in parts of the Central Paratethys (Peryt, 2006), open marine conditions were re-established at ~13.36 Ma (Simon et al., 2019) owing to the reconnection of the Central Paratethys basin with the Mediterranean and Eastern Paratethys. Marine conditions persisted until ~12.65 Ma when a sudden change to brackish-marine conditions occurred (Palcu et al., 2015; Simon et al., 2019). This triggered the elimination of stenohaline organisms known as the Badenian/Sarmatian Extinction Event (BSEE; Harzhauser and Piller, 2004a; cf. Śliwiński et al., 2012 with references therein). Successions in marginal basins are reported to show erosional features and fauna reworking at the boundary level in the Carpathian Foredeep Basin (e.g., Grishkevich, 1970; Musiał, 1987; Andreyeva-Grigorovich et al., 1997; Studencka and Jasionowski, 2011; cf.

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Leszczyński and Nemec, 2015) and the Pannonian Basin System (e.g., Kojumdgieva, 1969; Kováč et al., 2007; Rögl et al., 2008; Cornée et al., 2009; Szuromi-Korecz et al., 2021). However, Palcu et al. (2015) indicated that there is no evidence for sea level change at or close to the BSEE in the Romanian part of the Carpathian Foredeep and suggested that sea level change is not a dominant factor at the BSEE. They concluded that the BSEE does correspond to a change in the configuration of the Central-Eastern Paratethys gateway and the resulting unification of the Paratethys at the beginning of the Sarmatian which caused, during less than 10 kyr, less saline conditions in the Central Paratethyan basins (Palcu et al., 2015). On the other hand, it seems that the BSEE timing is diachronous due to the complex tectonic evolution of the Carpathian-Pannonian region, reflecting the final isolation of the Central Paratethys (Kováč et al., 2018 with references therein).

As the Badenian-Sarmatian boundary – a key interval for understanding Central Paratethys evolution – is still far from being fully understood, analysis of every outcrop through this interval is essential (cf. Silye and Filipescu, 2016; Ruman et al., 2017). This paper deals with the Kreminna outcrop in Podolia, the Ukrainian Carpathian Foreland Basin (Fig. 1). The late Badenian and Sarmatian (Serravallian) evolution of depositional environments in this part of the Carpathian Foreland, east of the Medobory Reef Tract that was subject to many studies (Studencka and Jasionowski, 2011; Górka et al., 2012 with references therein), has never been fully explored. The aim of this paper is to clarify the palaeoenvironmental changes that took place in this area around the Badenian/Sarmatian boundary based on micropalaeontological analyses (foraminifers, dinoflagellate cysts, palynofacies) of the Kreminna section. This section is located ~500 km north of the Tisa Valley section studied by Palcu et al. (2015) and ~300 km ESE of the Babczyn 2 and Cieszanów 1 borehole sections recently examined by Peryt et al. (2021, 2024).

Foraminifers seem to be the most reliable group for the biostratigraphic dating of the Badenian/Sarmatian interval in the Carpathian Foredeep and its foreland basin because of direct and indirect age indications, good resolution, and the relatively easy identification of reworked specimens studied (Filipescu et al., 2020). They are also reliable indicators of environmental factors such as depth, salinity, and oxygen content of water using the data on environmental requirements of recent Mediterranean foraminifers (see review in Murray, 1991, 2006). In turn, changes of palynofacies composition correlated with taxonomical variations in dinoflagellate cyst assemblages may reflect some minor environmental fluctuations.

GEOLOGICAL SETTING

In the Carpathian Foredeep Basin and its foreland – the largest Central Paratethyan basin – the marine shelf-slope facies occurred during deposition of the Middle Miocene strata that are included into two regional stages: Badenian and Sarmatian (e.g., Oszczypko et al., 2006; Kováč et al., 2017 with references therein). Following the late Badenian transgression that resulted in the inundation of a much wider area in the northeastern part of the central Paratethys, sediments of the Machów Formation (in Poland) and Kosiv Formation (in Ukraine) were deposited. In the outer (Bilche-Volytsa) zone of the Ukrainian Carpathian Foredeep grey silty clays that alternate with interbeds of silts, sandstones, tuffs, and tuffites occur (Andreyeva-Grigorovich et al., 1997); they are 10–150 m thick (Kurovets et al., 2004). They are gradually passing, toward the basin margin, into scallop or

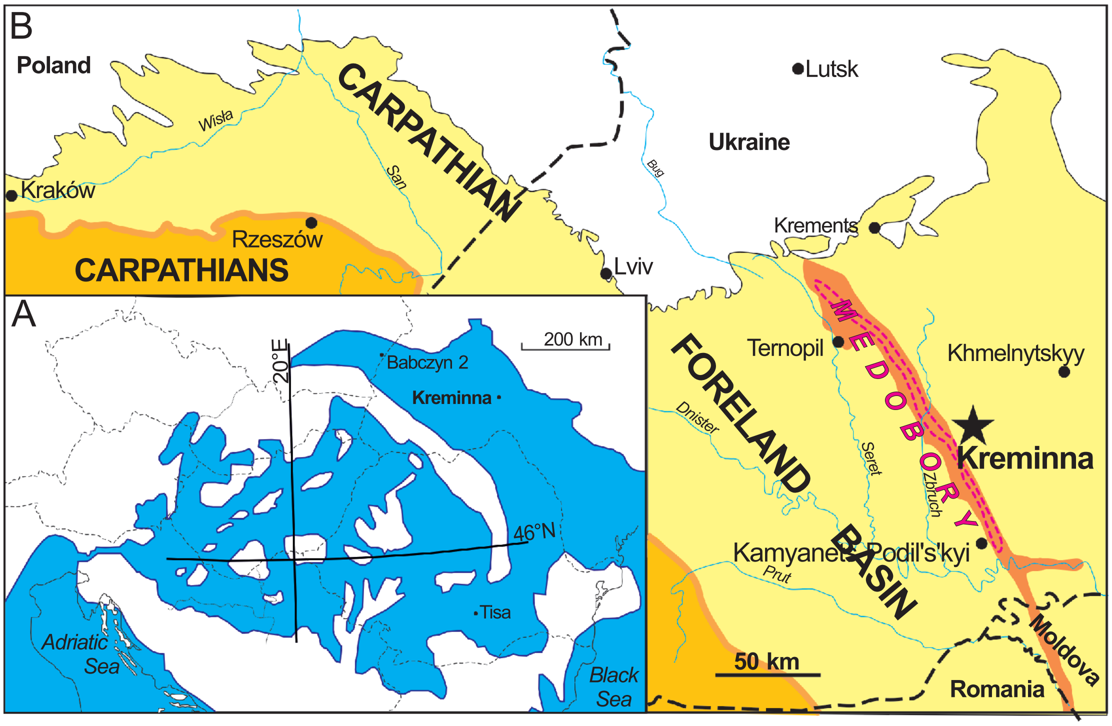

Fig. 1A – simplified palaeogeographic reconstruction of the Mediterranean-Paratethys region during the late Badenian (modified after Popov et al., 2006; Palcu et al., 2015), overlain on the present day map contours; B – distribution of Middle Miocene deposits in the northeastern part of the Carpathian Foredeep and the location of the Kreminna section

glauconitic marls, and then into calcareous marls and marly limestones with fine rhodoids. The thickness of this marginal facies of the Kosiv Formation is usually 4 to 15 m (Łomnicki, 1897; Teisseyre, 1900; Maslov and Utrobin, 1958; Studencka et al., 2012; Gedl et al., 2016). In the north-eastern part of the Ukrainian Carpathian foreland coralline algae-vermetid reefs in the Medobory Reef Tract and a variety of bioclastic facies occur (e.g., Korolyuk, 1952; Kudrin, 1966; Studencka and Jasionowski, 2011; Górka et al., 2012); these pass shoreward into siliciclastic deposits (Maslov and Utrobin, 1958).

In the Medobory Reef Tract, a geographically widespread unconformity occurs at the top of the Ternopil Beds. Field observations have shown the presence of breccias, vadose silt and vadose leaching in the uppermost coralline-algal boundstones, indicating considerable sea level fluctuations and a phase of emergence of the Medobory reefs in the latest Badenian (Jasionowski, 2006). The overlying Sarmatian deposits that partially overlay the Badenian reef deposits, are composed of a complex of carbonate, sandy and sandy-clay deposits collectively assigned to the Volhyn Beds (Andreyeva-Grigorovich et al., 1997). The thickness of the Volyn Beds reaches 35 m (Andreyeva-Grigorovich et al., 1997).

The Kreminna section (Khmeln'nyts'kyi province), one of classical middle Miocene localities in the Ukrainian Carpathian Foreland, for mentioned the first time in the geological literature by Du Bois de Montpereux (1831). It is located at the northeastern margin of the Carpathian Foreland Basin (Central Paratethys) in the Medobory Hills region, ~60 km north of the town of Kamyanets Podil's'kyi and 50 km north-east of the town of Khmeln'nyts'kyi. The Miocene deposits that overlie here the Upper Cretaceous substratum comprise the >1 m thick upper Badenian marls passing upwards into ~4 m thick lower Sarmatian marly limestones and marls with intercalations of limestone and clay followed by >2 m thick limestones (Fig. 2).

MATERIAL AND METHODS

The sampling of the section was done in 2010 (samples marked with numbers) and 2019 (samples marked with letters). At the base of the section, the light-grey and then olive-green marls with lithothamnia, bivalves (including pectens) and gastropods occur that are followed by light grey-green graded-bedded marls occur containing a 7 cm thick intercalation of clay near their top. Above these marls, a 20 cm thick limestone bed occurs (Fig. 2A); the limestone is bioclastic wackestone at the base (Fig. 2G) and bioclastic packstone at the top (Fig. 2F). Then, a thin bed of marl is followed by marly limestone (Fig. 2E) containing a clay intercalation near the top (Fig. 2A). The marly limestone bed above the clay is covered by the second limestone unit that in turn is overlain by marly limestone (Fig. 2C, D) with thin marl and thin limestone intercalations (Fig. 2A). The marly limestone unit is covered by a clay bed followed, one by one, by the third limestone bed characterized by varied thickness (4–20 cm), clay, marly limestone (Fig. 2B), and then the top limestone unit occurs (Fig. 2A).

Thirty-one samples from the Kreminna section were studied for foraminifera; sampling points in relation to the section are shown in Figure 3. Washed residues for foraminiferal study were obtained from the rocks by disaggregation using Na_2SO_4. An aliquot of ~200–300 specimens of foraminifers from the 63–700 µm size fraction was picked for the foraminiferal analyses.

Taxonomy of foraminifers follows Venglinskyi (1958, 1975), Łuczkowska (1972, 1974), Papp and Schmid (1985), and Cicha et al. (1998). The stratigraphically and palaeoenvironmentally important specimens were studied in detail and documented using a *Philips XL20 SEM* (Figs. 4–7). The figured specimens are deposited in the Institute of Paleobiology, Polish Academy of Sciences, Warsaw (ZPAL F. 77).

The relative abundance of infaunal and epifaunal forms within benthic foraminiferal assemblages, simple benthic diversity, the Shannon-Wiener diversity index H(S) were calculated (Fig. 8). The palaeoenvironmental interpretation based on foraminifera applies the requirements of present-day representatives of the recorded taxa (Jorissen et al., 2018; Dumitriu et al., 2020, with references therein; Consorti et al., 2021).

Taking into account the differentiated morphogroups and the inferred microhabitat depth of foraminifera the ecostratigraphic trends registered in foraminiferal assemblages were analysed. Foraminiferal assemblages are understood as groups of species whose composition and aspect is determined by the properties of the environment and by the relations to each other. They represent ecozones.

Changes in water salinity and other environmental parameters such as productivity, oxygen level in bottom waters, were interpreted using qualitative and quantitative analyses (Murray, 2006). To estimate the level of oxygenation of the sea floor the benthic foraminifera were grouped into oxic, suboxic and dysoxic indicators according to Thomas (1980), van der Zwaan (1982, 1983), Verhallen (1991), Jorissen et al. (1992), Kaiho (1994), Loubère (1996, 1997), Bernhard and Sen Gupta (1999), Kouwenhoven and van der Zwaan (2006), Holcová and Zágoršek (2008), and Kaminski (2012). The following taxa are included into the oxic group: *Cibicidoides* spp., *Heterolepa dutemplei*, *Lobatula lobatula*, *Anomalinoides badenensis, Hanzawaia boueana,* miliolids, keeled elphidiids. Oxic indices represent epifaunal species. Taxa tolerant of suboxic environments are: *Melonis pompilioides*, *Sphaeroidina bulloides*, *Porosononion, Astrononion perfossum, Reussella spinulosa, Dorothia* sp.*, Semivulvulina pectinata, Textularia laevigata* and taxa tolerant of dysoxic environments – *Bolivina* spp., *Bulimina* spp. and *Fursenkoina acuta.*

Foraminifera tolerant of suboxic environments represent mostly shallow infaunal species, while foraminifers tolerant of dysoxic environments represent mostly deep infauna and species with opportunistic behaviour.

Thirty five samples from the Kreminna section have been studied for palynology; sampling points in relation to the section are shown in Figure 9. The applied palynological procedure included 38% hydrochloric acid (HCl) treatment, 40% hydrofluoric acid (HF) treatment, heavy liquid ($ZnCl_2$ + HCl; density 2.0 g · cm^{-3}) separation, ultrasound for 10–15 s and sieving at 15 µm on a nylon mesh. No fuming nitric acid (HNO_3) treatment was applied. The quantity of rock processed depended on lithology: pale-coloured marls ~250 g, whereas clays up to 100 g. The rock samples, palynological residues and slides are stored in the collection of the Institute of Geological Sciences, Polish Academy of Sciences, Kraków.

Samples for isotopic analyses were carefully selected by picking foraminifer tests under binocular microscope. Analyses of carbon and oxygen stable isotope composition in the selected samples were performed using a *Thermo Scientific™ KIEL IV Carbonate Device* connected on-line to a *Finnigan Delta Plus* mass spectrometer in a *Dual Inlet* system in the Stable Isotope Laboratory (ISOLAB), Institute of Geological Sciences of the Polish Academy of Sciences, Research Centre in

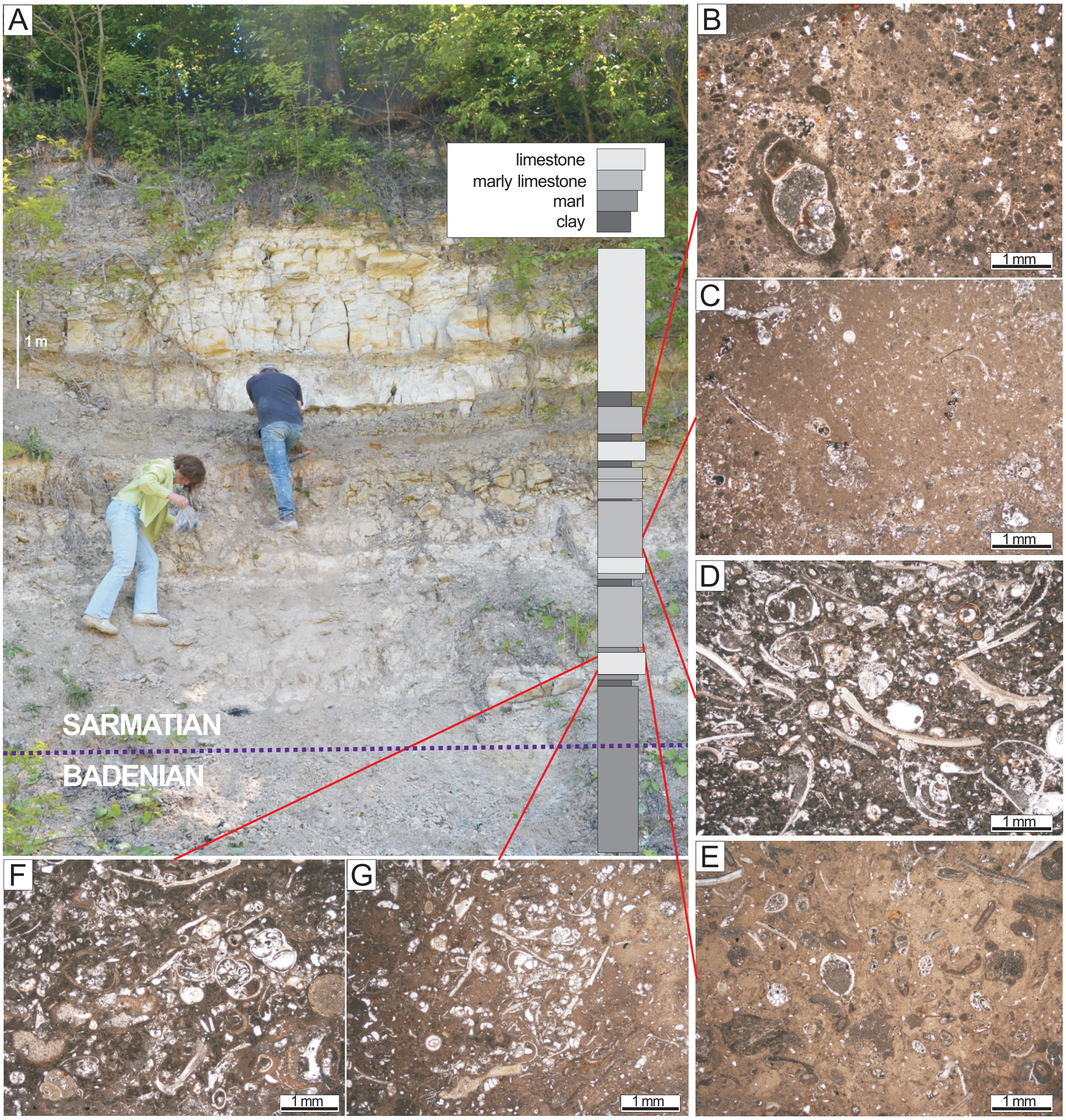

Fig. 2A – the sampled Kreminna section (photo 2019): outcrop and generalized lithology; B – lower part of the marly limestone unit below the top limestone unit (peloidal-lump packstone); C, D – lower part of the marly limestone unit above the second Sarmatian limestone bed (C is above D): C – peloidal-lump packstone, D – bioclastic packstone; E – lowermost part of the marly limestone above the first Sarmatian limestone bed (fossiliferous mudstone); F – upper part of the first Sarmatian limestone bed (bioclastic packestone); G – lower part of the first Sarmatian limestone bed (bioclastic wackestone)

Warsaw, Poland. Sample preparation was performed automatically according to the method described by McCrea (1950). Samples (min. 20 μg carbonate) were reacted with orthophosphoric acid (density 1.94 g/dm) at 70°C. One NBS 19 international standard was analyzed for every 10 samples. Results were given as d against the VPDB standard. The accuracy of measurements (standard deviation) is: (1δ) δ^{13}C ±0.03‰ and (1δ) δ^{18}O ±0.07‰.

RESULTS

FORAMINIFERA

Fifty seven species of foraminifera were identified in the Kreminna section (Fig. 3). Foraminiferal assemblages were composed mostly of calcareous benthic forms; agglutinated

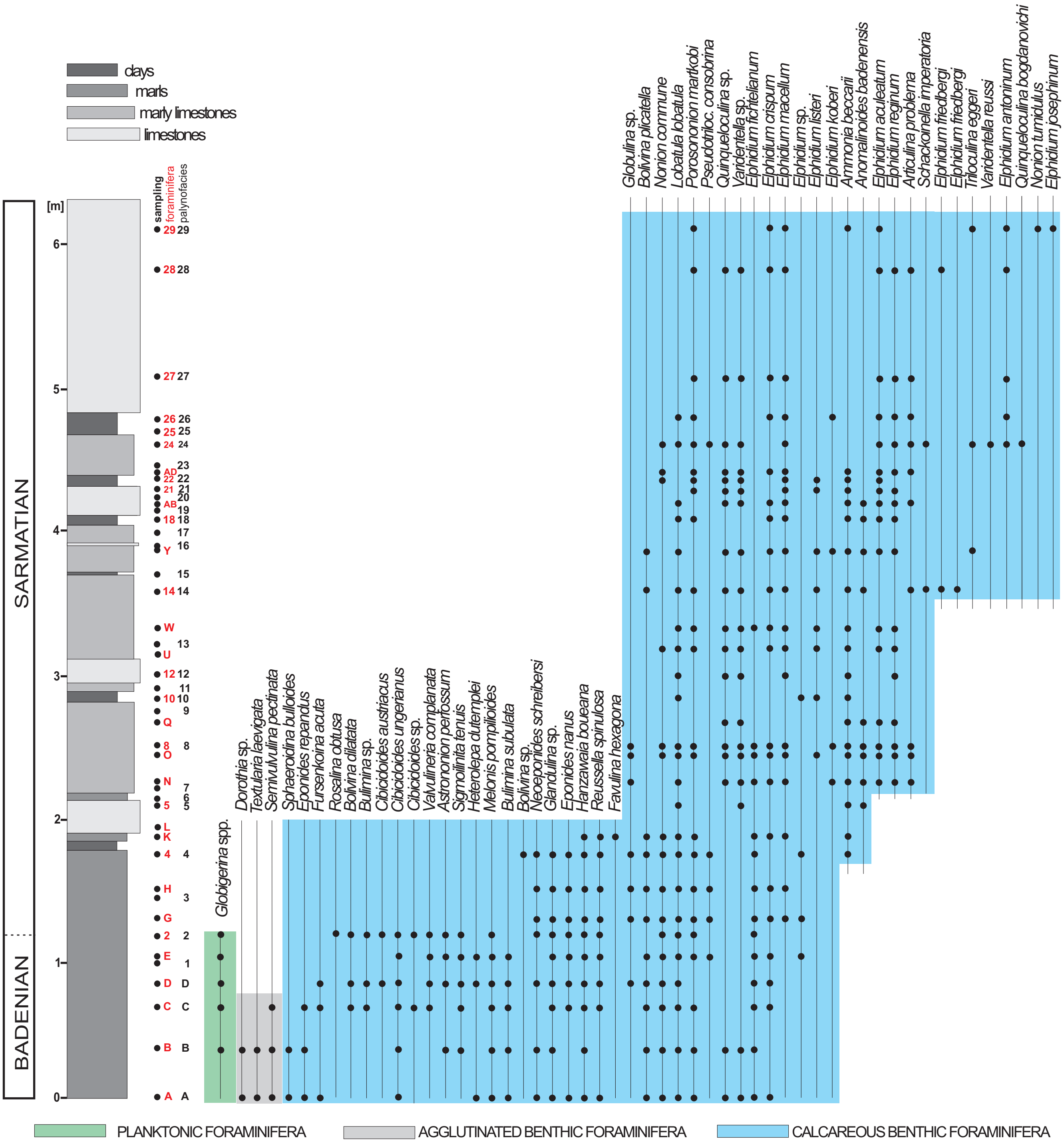

Fig. 3. Distribution of foraminifera in the uppermost Badenian and lowermost Sarmatian of the Kreminna section

ones occurred in the lowermost part of the succession. Recorded species are listed in Appendix 1. Figure 10 shows the relative percent abundances of common and dominant species, i.e. species that show abundance >5% in at least in one sample.

Planktonic foraminifera are represented primarily by *Globigerina bulloides*, *G. praebulloides*, *Globigerina tarchanensis* and *Globigerina* sp. They occurred in the lowermost part of section where they formed 5 to 20% of the assemblages. The last occurrence of this group was coeval with the disappearance of most Badenian stenohaline foraminifera (sample 2). Agglutinated foraminifera (*Dorothia* sp., *Textularia laevigata* and *Semivulvulina pectinata*) occurred in the basal part of the section (samples A, B). They formed up to 10% of foraminiferal assemblages (Fig. 10). Among the calcareous benthic foraminifera in the lower part of the section (samples A to 2), *Cibicidoides* dominated assemblages (25 to 45%). *Heterolepa dutemplei*, *Astrononion perfossum* and *Melonis pompilioides* also significantly contributed to the assemblages; they formed 15 to 20% of the assemblages. Keeled *Elphidium*, primarily *E. fichtelianum* and

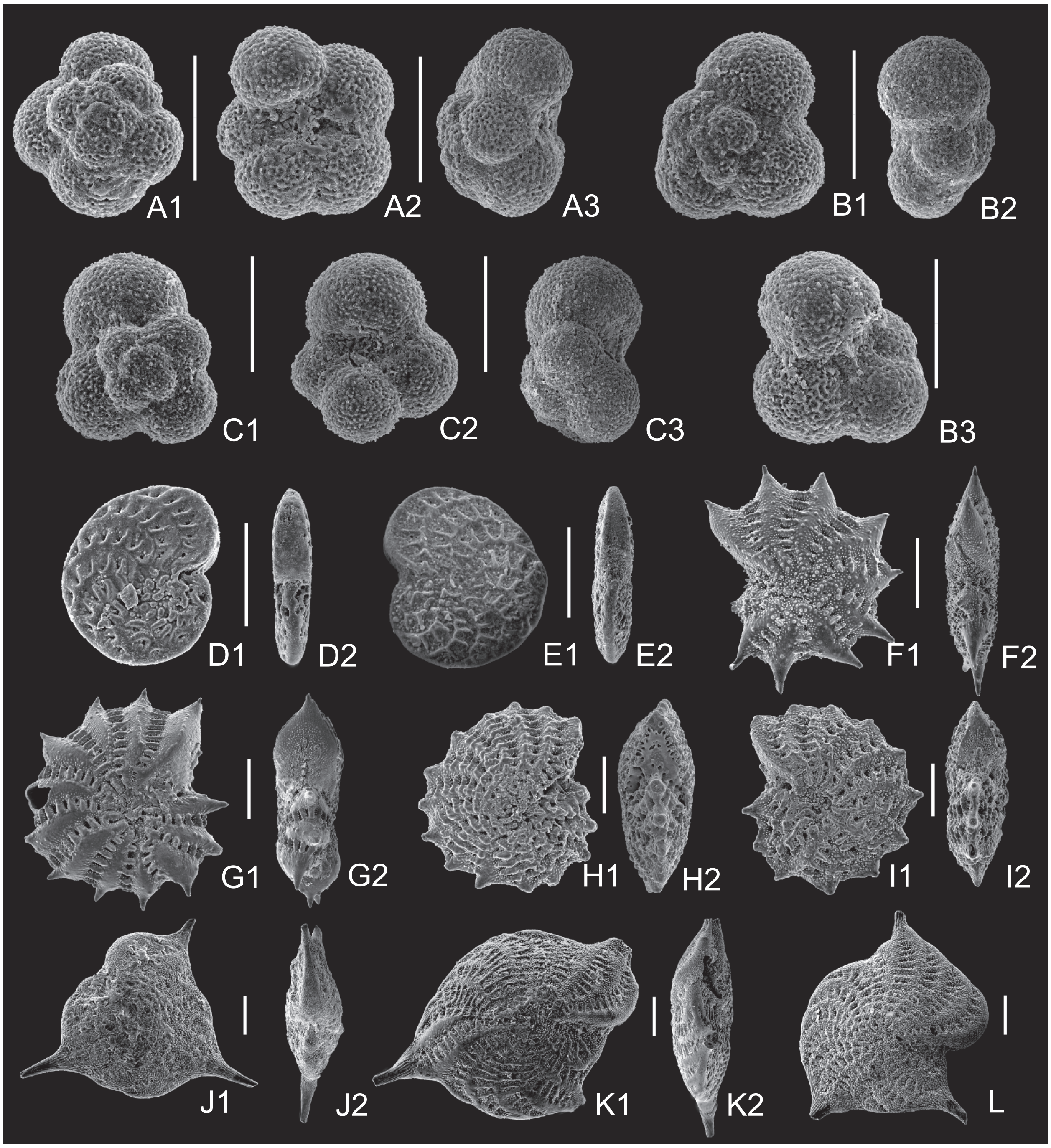

Fig. 4A – *Globigerina tarchanensis* Subbotina and Chutzieva; B – *Globigerina* sp.; C – *Globigerina bulloides* d'Orbigny; D, E – *Elphidium fichtelianum* (d'Orbigny); F, G – *Elphidium josephinum* (d'Orbigny); H, I – *Elphidium aculeatum* (d'Orbigny); J–L – *Elphidium reginum* (d'Orbigny)

A–E – sample 2; F–G – sample 29; H–I – sample 21; J–L – sample 28; scale bar = 200 μm

E. crispum, also were important components of the assemblages and formed 5 to 15% of them. *Hanzawaia boueana*, *Neoeponides schreibersi* and *Lobatula lobatula* temporarily exceeded 5%; other species, e.g., *Bolivina* spp., *Bulimina* sp, *Glandulina* sp., *Sigmoilinita tenuis* were minor components of assemblages. In the sample 2 stenohaline *Cibicidoides ungerianus*, *Melonis pompilioides*, *Astrononion perfossum*, *Heterolepa dutemplei* occurred for the last time in the section (Fig. 10).

In the overlying rock interval (samples G–K) *Elphidium* flourished and formed 40 to 80% of the assemblages. Miliolids appeared in the lower part of this interval (sample G) reaching 10% in samples H and 4, and at the top of this interval (sample 4) *Ammonia beccarii* appeared (Fig. 10).

The rock interval represented by samples L to Q was dominated by *Lobatula lobatula* (40 to 93%); miliolids exceeded 10%; *Elphidium* formed ~10% except in sample O where it reached 30%. In this sample also the last appearance of *E. fichtelianum*

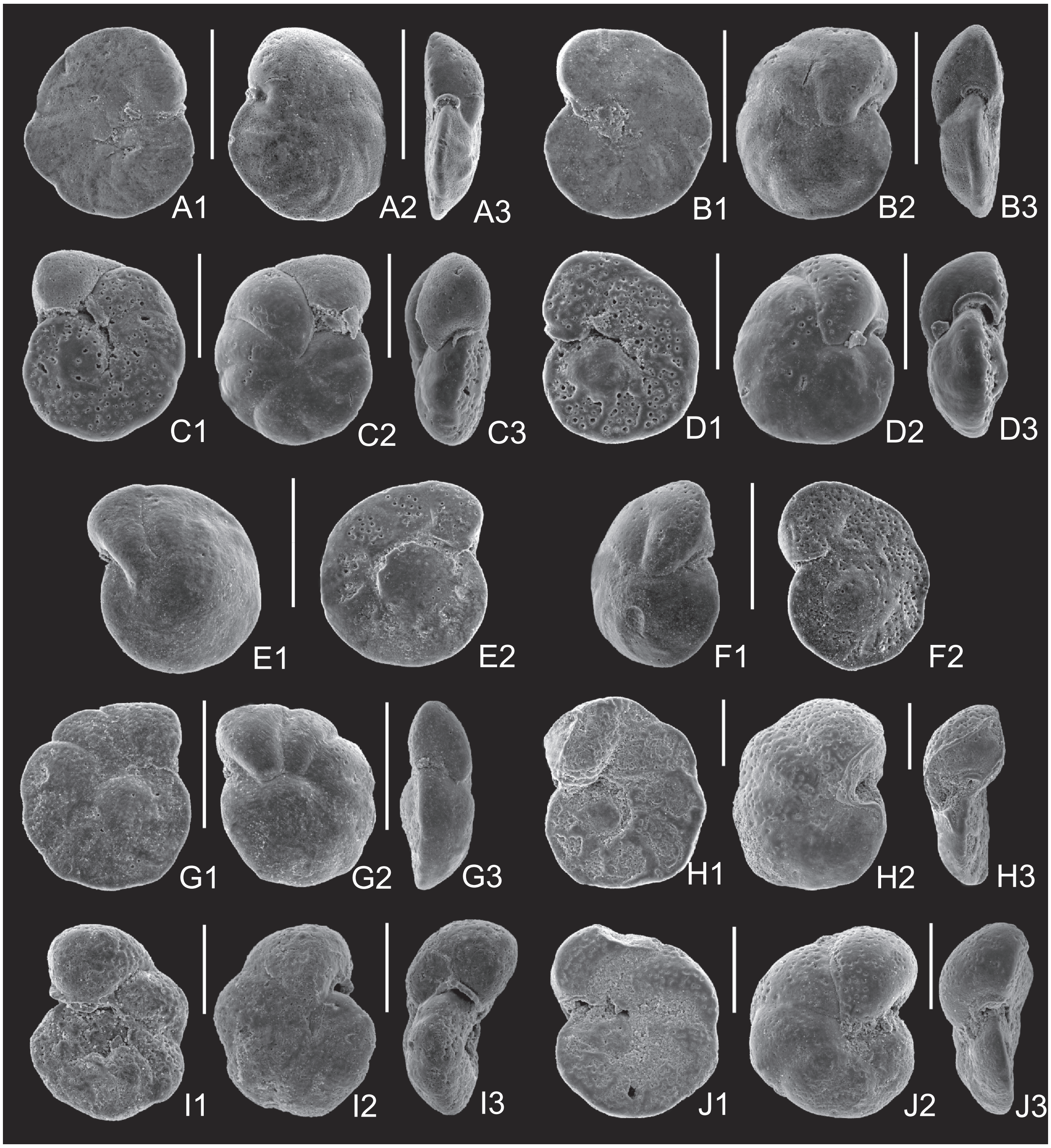

Fig. 5A, B – *Hanzawaia boueana* (d'Orbigny); C, D – *Cibicidoides austriacus* (d'Orbigny); E, F – *Cibicidoides* sp.; G – *Cibicidoides ungerianus* (d'Orbigny); H, J – *Lobatula lobatula* (Walker and Jacob); I – *Anomalinoides badenensis* (d'Orbigny);

A–H, J – sample 2, I – sample 8; scale bar = 200 μm

was observed. At the same level the lowest occurrence of *E. listeri* was recorded. In this interval also *Anomalinoides badenensis* occurred as a minor component of the assemblages.

The rock interval comprising samples 10 to 26 was dominated by elphidiids, *Lobatula lobatula*, miliolids and *Ammonia beccarii*. *Elphidium reginum*, which appeared in sample N of the underlying interval, was a minor component. Abundances of miliolids and *Ammonia beccarii* are negatively correlated. Increasing abundance of miliolids was accompanied by decreasing trends of *Ammonia beccarii*. *Lobatula lobatula* did not occur in the rock interval represented by samples 27–29; the interval was dominated by elphidiids (*Elphidium crispum, E. macellum, E. listeri, E. aculeatum, E. reginum*) forming 75 to 85% of the assemblages. *Elphidium reginum* together with *E. listeri* were dominant species in these assemblages, and their contribution ranged between 25 and 35%. In the interval miliolids formed 15%, and *Ammonia* occurred rarely (Fig. 10).

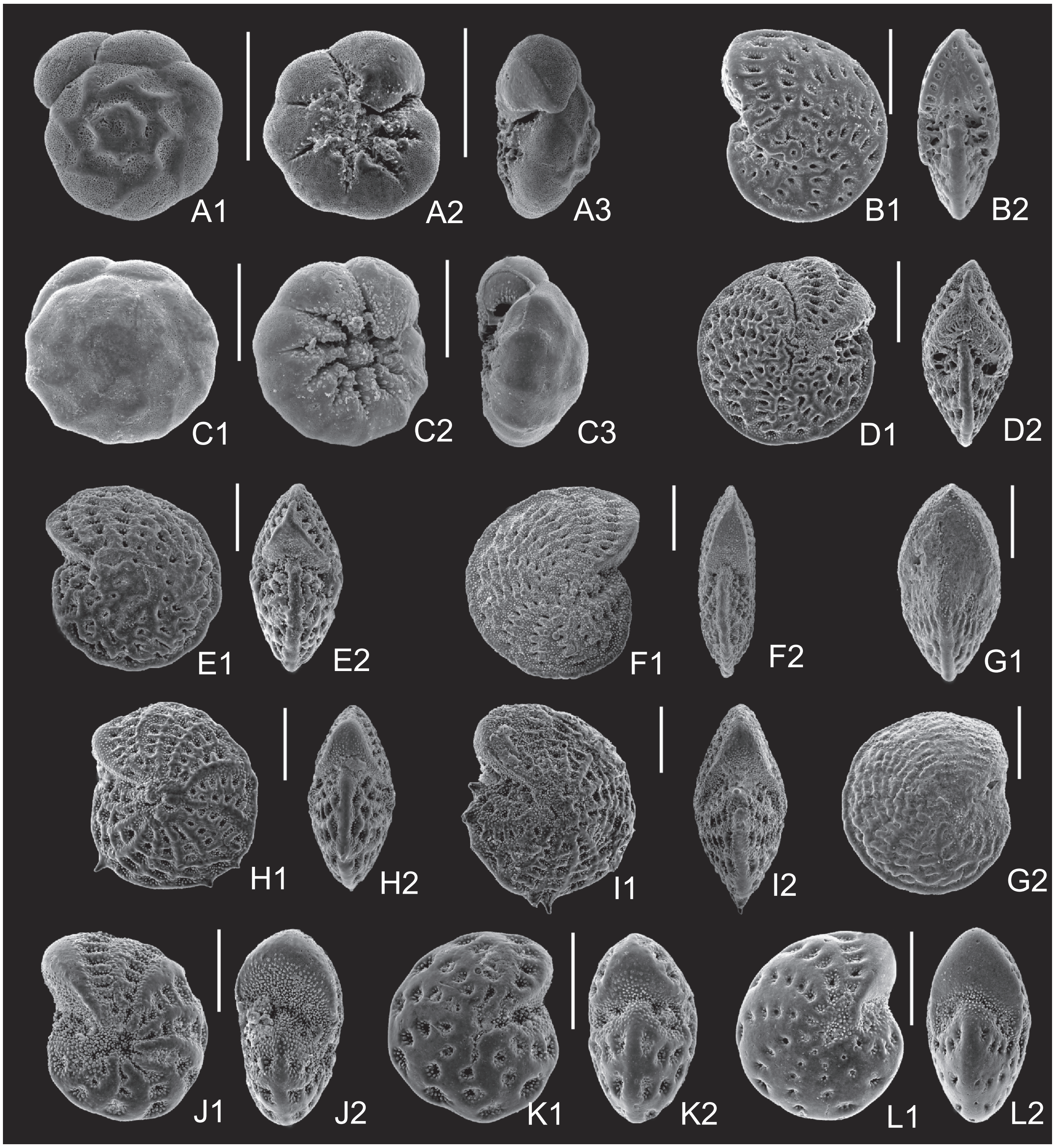

Fig. 6A, C – *Ammonia beccarii* (Linné); B, E – *Elphidium macellum* (Fichtel and Moll); D, H, I – *Elphidium crispum* (Linné); F – *Elphidium joukovi* Serova; G – *Elphidium friedbergi* Serova; J – *Elphidium antoninum* (d'Orbigny); K, L – *Elphidium listeri* (d'Orbigny)

A, C, D, H, I, K, L – sample 29; B, E – sample 21; F, G, J – sample 14; scale bar = 200 µm

In the topmost part of the section (sample 29) within the *Elphidium* association, *E. reginum* was replaced by *E. josephinum*, and miliolids disappeared from the foraminiferal assemblage.

The Badenian/Sarmatian boundary is placed at the level where the most abundant stenohaline benthic foraminifera disappeared (sample 2) (Fig. 10).

PALYNOFACIES

The following groups of phytoclasts and palynomorphs have been distinguished in the material studied:

- black opaque phytoclasts;
- dark brown translucent, commonly highly disintegrated particles, in some cases larger, with preserved cuticular structure;

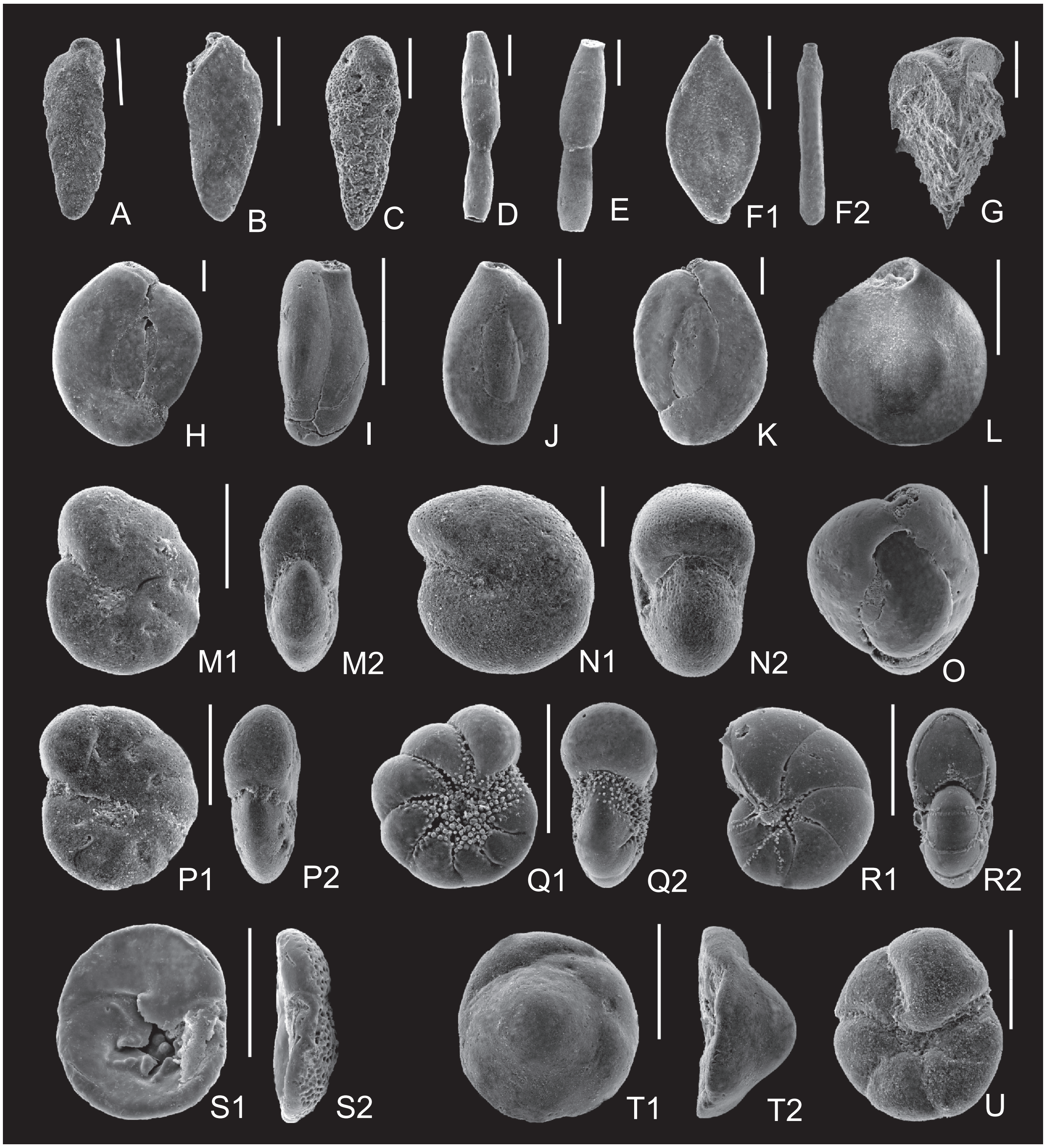

Fig. 7A – ***Bolivina*** **sp.; B –** ***Bolivina dilatata*** **Reuss; C –** ***Bolivina plicatella*** **Cushman; D, E –** ***Articulina problema*** **Bogdanowicz; F –** ***Sigmoilinita tenuis*** **(Czjzek); G –** ***Reussella spinulosa*** **(Reuss); H –** ***Triloculina eggeri*** **(Bogdanowicz); I, J –** ***Pseudotriloculina consobrina*** **(d'Orbigny); K –** ***Quinqueloculina bogdanovichi*** **(Serova); L –** ***Varidentella reussi*** **(Bogdanowicz); M, P –** ***Astrononion perfossum*** **(Clodius); N –** ***Melonis pompilioides*** **(Fichtel and Moll); O –** ***Varidentella*** **sp.; Q –** ***Porosononion martkobi*** **(Bogdanowicz); R –** ***Nonion tumidulus*** **Pishvanova; S –** ***Rosalina obtusa*** **d'Orbigny; T, U –** ***Neoeponides schreibersi*** **(d'Orbigny)**

A–F – sample 4; G – sample K; H–L, O – sample 24; M, N, P, S–U – sample 2; Q, R – sample 29; scale bar = 200 μm

– pollen grains;
– dinoflagellate cysts (Fig. 11).

Their distribution is shown in Figure 9. It should be noted that the presented ratios of particular palynofacies elements, especially those representing palynodebris, might be imprecise. This is due to the low frequency of counted particles (commonly <300, especially in lower part of the section), and due to their tendency to disintegrate.

Majority of studied samples yielded low to even trace amounts of palynological organic matter, despite that quantity of processed rock was exceeding standard amounts. Their palynofacies consists of black opaque phytoclasts, in some

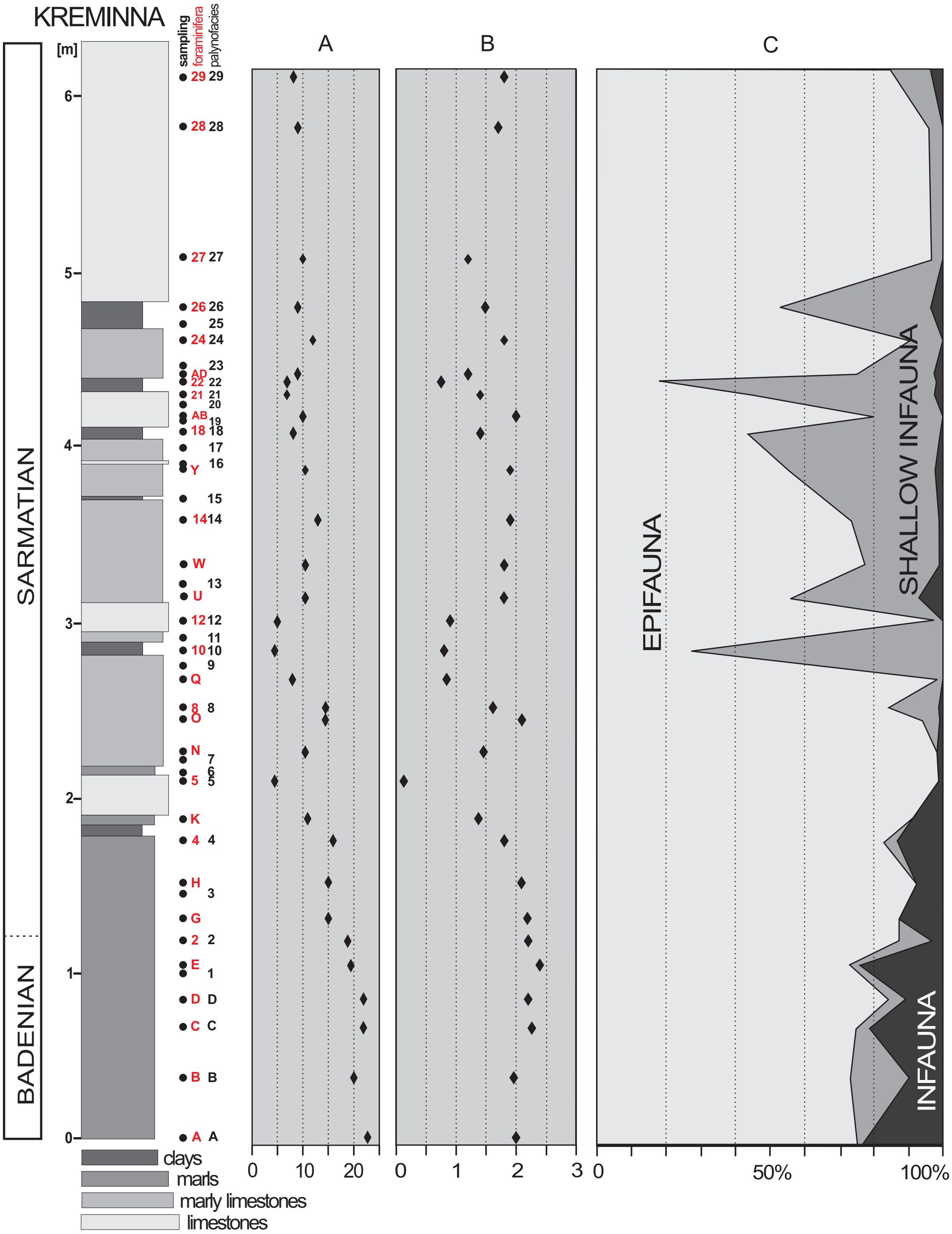

Fig. 8. Benthic foraminiferal assemblages in the uppermost Badenian and lowermost Sarmatian in the Kreminna section

A – simple benthic foraminiferal diversity (number of species), **B** – H(S) – Shannon-Wiener diversity index, **C** – relative abundance of epifaunal, shallow infaunal and infaunal morphogroupes of benthic foraminifera

samples associated by rare dinoflagellate cysts. Some samples contain dark brown translucent particles, which tend to disintegrate (14–16, 25–28). A few samples only, mainly from upper part of the studied section, contain a slightly higher amount of palynological organic matter (13, 19A, 22–24, 28, 29). The latter consists chiefly of dinoflagellate cysts, and subordinate black phytoclasts. Some samples contain a high ratio of land plant tissues (12, 26, 28), which, are rather a recent contamination.

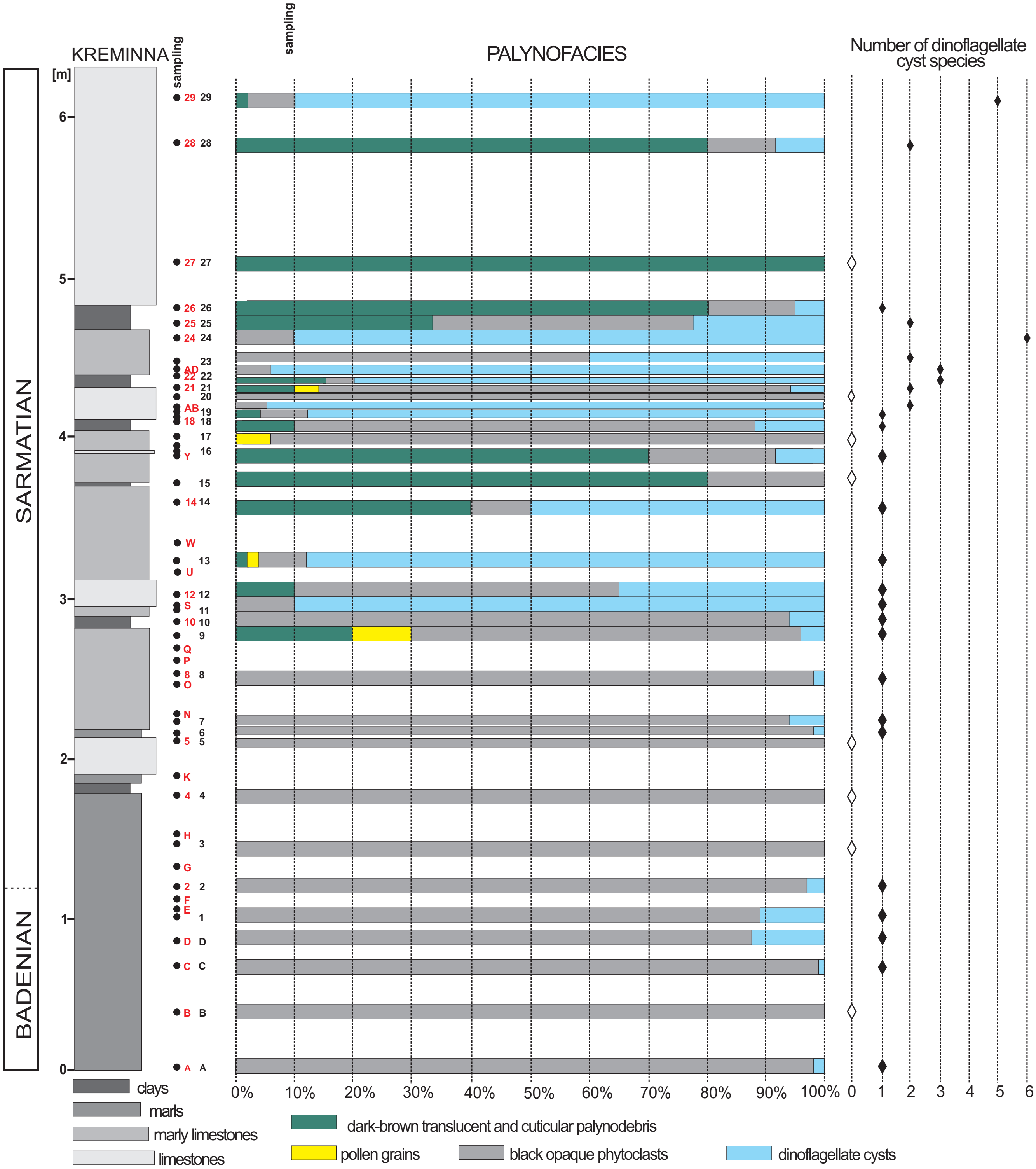

Fig. 9. Palynofacies and diversity of dinoflagellate cysts from the Kreminna section

Sporomorphs are rare; they are represented in the material studied by infrequent bisaccate pollen grains, which occur in samples 9, 13, 17, 21A (Fig. 9).

Dinoflagellate cysts occur in majority of the samples studied (Fig. 9). They are absent in samples B, 3–5, 15, 17, 20, 27, i.e., samples, which contain a very low amount of palynological organic matter. The distribution of dinoflagellate cysts in the remaining samples shows a quantitative and qualitative diversification. The basal part of the section (samples A-10), which generally yielded a very small amount of palynological organic matter, contain very rare dinoflagellate cysts. Higher samples 11–14 contain frequent dinoflagellate cysts, but samples 15–18 that follow are barren or they yielded very rare, single specimens only. In this interval, frequent dark brown translucent par-

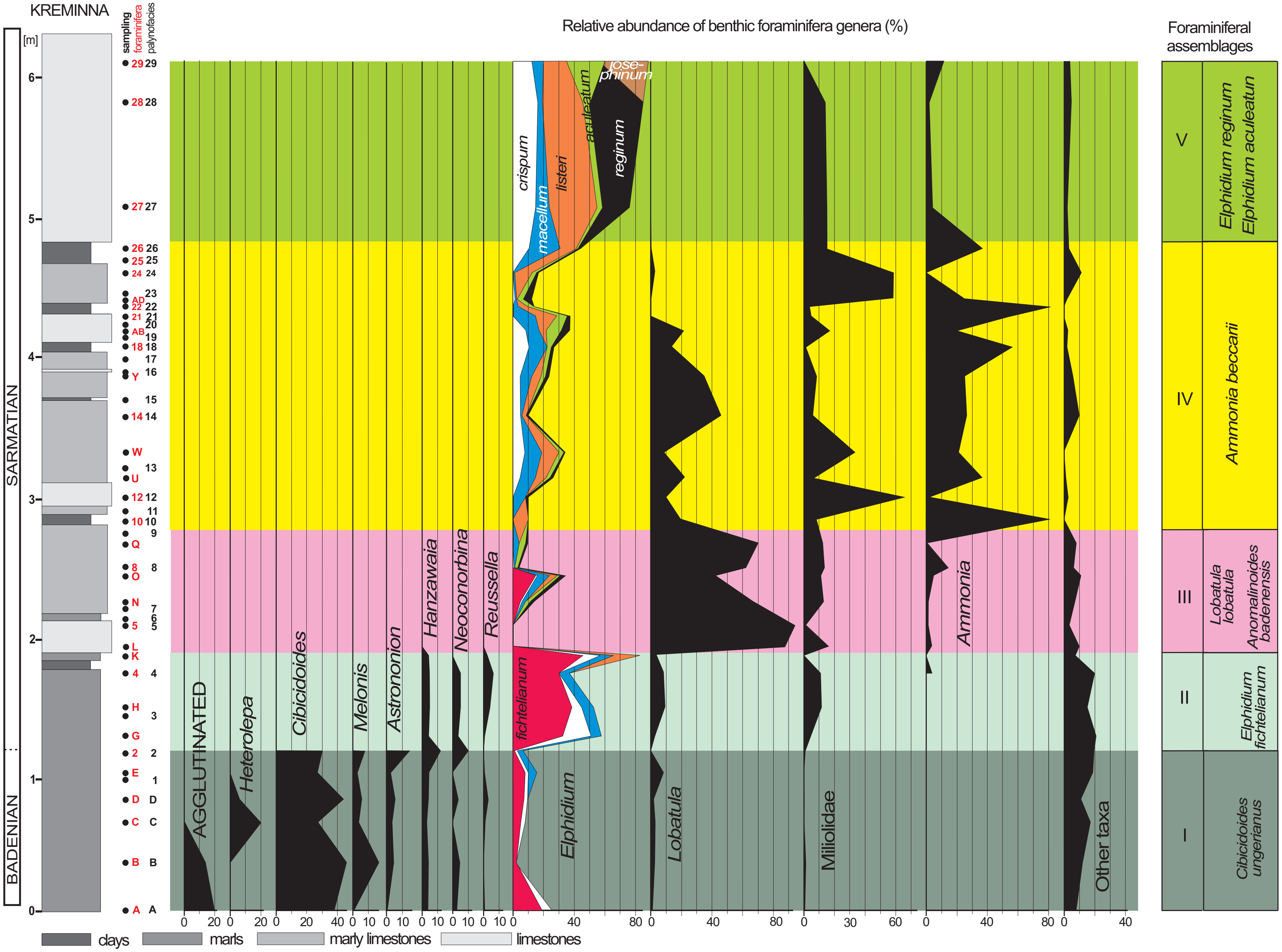

Fig. 10. The relative abundance of the most common genera or groups of species and foraminiferal assemblages in the Kreminna section

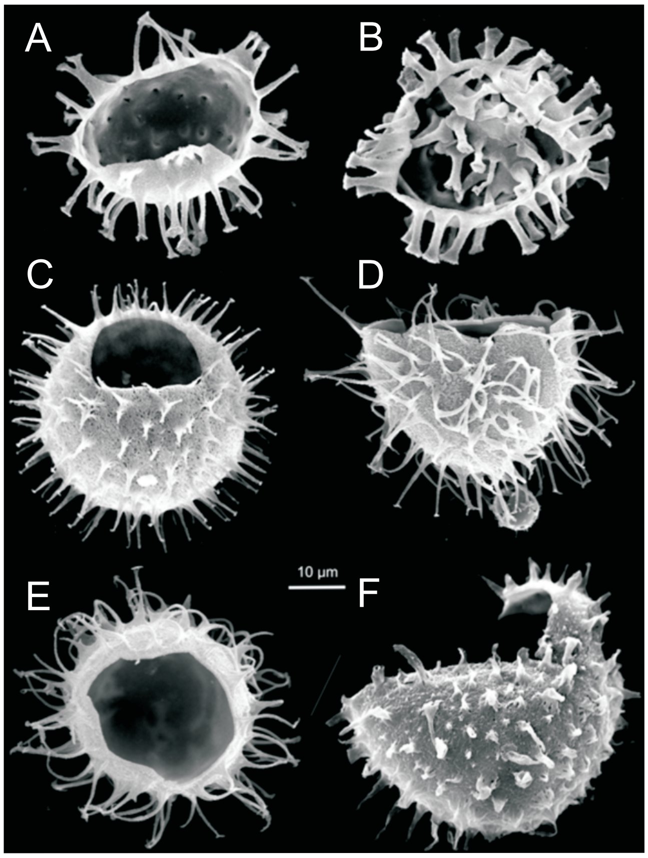

Fig. 11. Dinoflagellate cysts from the Kreminna section

A, B – *Polysphaeridium zoharyi*(Deflandre et Cookson, 1955) Wall, 1967; **C** – *Operculodinium centrocarpum* (Rossignol, 1962) Bujak et al. (1980); **D, E** – *Cleistosphaeridium placacanthum* (Deflandre et Cookson, 1955) Eaton et al. (2001); **F** – *Lingulodinium machaerophorum* (Deflandre et Cookson, 1955) Wall (1967)

ticles occur. Frequent dinoflagellate cysts occur in samples 19A and 19B, whereas samples 20 and 21A are almost barren. The highest part of the section, except samples 26 and 27, contains frequent dinoflagellate cysts, which in some samples occur in mass amount (22, 24, 29). Dark brown translucent particles dominate in samples 25–28, which coincide, similarly as in case of samples 15–18, with a decline of dinoflagellate cyst assemblages. Aquatic palynomorphs are also represented by infrequent Leiosphaeridia (sample 26).

Qualitatively, dinoflagellate cysts show a low diversification (Fig. 9). *Polysphaeridium* is the only genus that occurs in lower part of the section (samples A-19A). *Cleistosphaeridium placacanthum* has its lowest occurrence in sample 19B. Higher samples (20–28) that yielded dinoflagellate cysts contain assemblages composed of *Polysphaeridium zoharyi*, or dominated by this species and with subordinate *Cleistosphaeridium placacanthum* and *Batiacasphaera*. An exception is the assemblage from sample 24, which consists of dominant *Cleistosphaeridium placacanthum*, and subordinate *Polysphaeridium zoharyi* (rare specimens of *Lingulodinium machaerophorum*, *Operculodinium centrocarpum*, *Batiacasphaera* sp., *Spiniferites* sp. also occur). The highest sample 29 yielded a similarly diversified assemblage: it consists of dominant *Polysphaeridium zoharyi*, and subordinate *Cleistosphaeridium placacanthum*, *Pentadinium laticinctum*, *Spiniferites pseudofurcatus* and *Operculodinium*? sp.

Table 1

$\delta^{13}C$ and $\delta^{18}O$ values of Middle Miocene foraminifera of the Kreminna section

Sample	Taxon measured	$\delta^{18}O$ [‰]	$\delta^{13}C$ [‰]
2	*Cibicidoides*	0.273	1.715
4	*Elphidium fichtelianum*	0.483	0.283
5	*Lobatula lobatula*	–3.659	0.723
8	*Lobatula lobatula*	0.741	2.377
10	*Ammonia beccarii*	–3.477	–4.412
14	*Elphidium* spp.	–0.171	1.215
18	*Elphidium* spp.	–0.057	0.311
21b	*Elphidium crispum* + *Elphidium reginum*	–0.555	0.77
22	*Ammonia beccarii*	–1.426	0.198
24	*Lobatula lobatula* + *Elphidium crispum*	0.29	0.385
25	*Ammonia beccarii*	–1.43	–0.952
	Elphidium crispum	–0.253	0.119
28	*Elphidium reginum*	0.364	1.281
29	*Elphidium aculeatum*	–0.957	0.408

ISOTOPES

The $\delta^{13}C$ and $\delta^{18}O$ values of studied foraminifer taxa are shown in Table 1. Most $\delta^{18}O$ values range from –1.5 to ~+0.5‰ VPDB (Fig. 12). The exceptions are two samples from the lower part of the section where $\delta^{18}O$ values are as low as ~–3.5‰. Generally very slight gradual decrease of $\delta^{18}O$ values (i.e. depletion in heavy oxygen isotope) upward the section can be observed (Fig. 12). Excluding one sample with a very low $\delta^{13}C$ value (just below –4‰ VPDB), all other measurements range from –1 to >+2.5‰ VPDB, and most are between 0 and +2‰ VPDB. In general, the $\delta^{13}C$ curve mirrors the $\delta^{18}O$ changes in the section.

The sample(s) from the bottommost part of the section being undoubtedly of Badenian age, do not differ isotopically from the Sarmatian samples from the rest of the section. In fact, the isotopically heaviest sample is of Sarmatian age (sample no. 8).

The carbon isotopic signatures of the Kreminna foraminifers are identical, as e.g. those from the roughly coeval Sarmatian sections of the Zsámbék Basin in Hungary (the central part of the Pannonian Basin near Budapest). The $\delta^{18}O$ values in Kreminna are quite high when compared to other Sarmatian locations – in the Zsámbék Basin $\delta^{18}O$ in foraminifers ranges from –3.5 to ~–0.5 (Tóth et al., 2010). Comparison of the Kreminna isotopic data with those measured in benthic foraminifers coming from other upper Badenian sections in the Paratethys shows that the Kreminna data are usually isotopically slightly lighter in the case of oxygen and significantly heavier for carbon (cf. Peryt et al., 2014). In the Shchyrets section in Ukraine the $\delta^{18}O$ values are usually close to +2‰ VPDB and $\delta^{13}C$ values are in the range between -3 and 0‰ VPDB (Peryt et al., 2014).

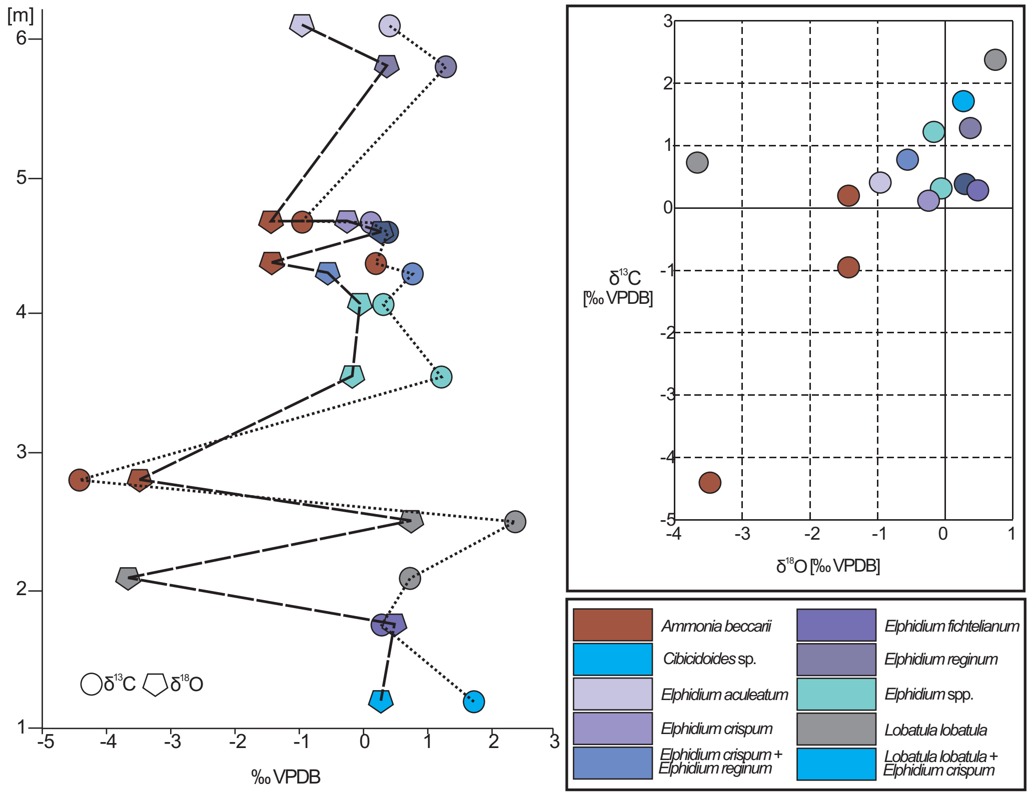

Fig. 12. Left side – Isotope profile of the Kreminna section (X-axis shows the sampled section as shown in Fig. 3); right side – the plot of δ^{18}O *versus* δ^{13}C values for the Kreminna section

INTERPRETATION

FORAMINIFERA

Five foraminiferal assemblages were recognized in the Kreminna section (Fig. 12) which suggests changes in the palaeoenvironment. There is a direct relationship between the abundance of species within community and its environment. Abundance fluctuations of benthic foraminifera are sensitive palaeoceanographic indicators responding to changing palaeotemperature, salinity, nutrient supply and oxygen conditions.

The extinction of several rare species would have a minor impact on the total population as their combined species abundances are not likely to exceed 2–10%. Extinction of one or more of the dominant species, however, would have a major impact as they may comprise 50% or more of the total population and reflect significant environmental change.

The *Cibicidoides ungerianus* Assemblage (Assemblage I) occurs in marls with common biodetritus of lithothamnia, bivalves and gastropods at the base of the studied section (samples A–F, 2; Fig. 10). This assemblage is characterized by the dominance (30 to almost 50%) of *Cibicidoides* represented mainly by *Cibicidoides ungerianus* and *C. austriacus*. Other important components are the elphidiids, which exceed 20%. Rare specimens of *Lobatula lobatula* and *Quinqueloculina* sp. also occur. In the lowermost part agglutinated forms and *Heterolepa dutemplei* in the middle form up to 20% of the assemblage. The presence in this assemblage of planktonic foraminifera, mainly *Globigerina bulloides* indicates a normal salinity marine environment, and approximately 50 to 70 m water depth (Hemleben et al., 1989; Schiebel et al., 1997). Moderate benthic foraminiferal diversity indicated by 19 to 24 species, H(S) diversity index from 1.9 to 2.4 and the predominance of stenohaline species over euryhaline ones confirm such a suggestion. Bottom waters were well-oxygenated; epifaunally living foraminifera form >70% of the assemblage (Fig. 10).

The *Elphidium fichtelianum* Assemblage (Assemblage II) is recorded in light grey-green marls underlying a limestone complex (samples G, H, 4, K; Fig. 10). This assemblage is dominated by elphidiids; they contributing 40–80% to the assemblage (Fig. 10). Minor components in this assemblage are miliolids and *Lobatula lobatula*. Recent keeled elphidiids occur in shallow marine environments (inner shelf) with warm to temperate and normal to hypersaline (35–70‰) waters (Murray, 1991, 2006). Miliolids which exceed 10% in the assemblage also tolerate a wide range of salinity limits (32–65‰) (Murray, 1991, 2006).

This assemblage reflects a significant palaeoenvironmental change. The disappearance of abundant groups of stenohaline Badenian foraminifera, such as *Cibicidoides, Melonis, Heterolepa, Astrononion,* and their replacement, in Assemblage II, by keeled forms of *Elphidium* and the absence of planktonic foraminifera (in contrast to Assemblage I) can be interpreted as due to a shallowing of the sea to a depth <50 m and a salinity increase. Oxygenation of bottom waters was similar to that in Assemblage I.

The *Lobatula lobatula-Anomalinoides badenensis* Assemblage (Assemblage III) occurs in organodetrital limestone and dark brown marls with numerous gastropods (samples L, 5, N, O, 8, Q; Fig. 10). It is dominated by *Lobatula lobatula* which form 40 to 90% of the assemblage. *Lobatula lobatula* is accompanied by *Anomalinoides badenensis*. Miliolids, elphidiids and *Ammonia beccarii* are minor components and in most samples they slightly exceed 10%; only in sample O elphidiids reached 30%. This assemblage indicates a shallow high energy shelf environment and is characterized by the dominance of epifaunal morphotypes and almost the complete absence of infaunal ones (Fig. 8). According to the TROX model proposed by Jorissen et al. (1995), this is the response of benthic microfauna either to oligotrophic or to fully eutrophic environments. In such environments, the degradation of organic matter within the sediment where infaunal foraminifera thrive consumes more oxygen than that provided by bioturbation and diffusion. This results in excess of food in the sediment. A further increase in the organic flux results in an increased consumption of oxygen in the benthic environment and shallowing of the oxygenated sediment layer. In extreme situations, all oxygen is consumed at the sediment surface and deeper sediment layers are anoxic, as under extremely oligotrophic conditions, all benthic foraminifera are observed exclusively at the sediment-water interface (Jorissen et al., 1995).

The *Ammonia beccarii* Assemblage (Assemblage IV) occurs in ~2 m thick rock interval (from sample 10 to 26) composed by clays, marls and two thin limestone beds (Fig. 10). In this part of the succession *Ammonia beccarii* is a dominant species reaching from 30 to 80%; miliolids form ~15%, except of two short intervals in the lower and upper part where they dominate and form almost 60% of the assemblage. *Lobatula lobatula* in the lower and middle part of this interval forms from 10 up to 30% of the assemblage in sample W. It disappears in the upper part. Elphidiids occur constantly throughout the interval and are minor contributors (10–15%). (Fig. 10). *Ammonia* is a foraminifer characteristic of littoral and neritic environments. This genus usually thrives in estuarine, brackish and saltmarsh environments (Jorissen, 1988; Murray, 2006) or under the influence of fluctuating water salinity, temperature and nutrient input (Debenay et al., 1998). Adult *A. beccarii* mostly prefers an epiphytic suspension-feeder life style, both on seagrass leaves or on calcareous algae (Debenay et al., 1998). *Ammonia beccarii* is also abundant under more open marine conditions or estuaries with fluctuating water salinity. Hayward et al. (2021) placed *A. beccarii* in their "subtidal inner shelf group" of *Ammonia* species characterizing 0–50 m water depth.

Miliolids *(Cycloforina, Varidentella, Quinqueloculina, Triloculina)* are epiphytes, however, their distribution is not related to a specific type of phytal substrate (Langer, 1993). They prefer shallow marine environments (0–50 m water depth) of normal salinity to hypersaline (32–65‰), characteristic of lagoons (Murray, 1991, 2006). Because *Ammonia beccarii* and miliolids are epiphytes it seems that changes in temporal availability of phytal substrates are primarily responsible for their abundance fluctuation. Their co-occurrence with stenohaline forms indicates normal salinity marine environments. A very high share of shallow infauna indicates depletion of oxygen within the sediment (Fig. 10).

The *Elphidium reginum-Elphidium aculeatum* Assemblage (Assemblage V) occurs in the uppermost limestone bed (samples 27–29). *Elphidium* forms 75 to 85% of the assemblage while *Elphidium* with spines (*E. reginum*, *E. aculeatum*, *E. josephinum*) are very abundant and reach 35 to 50% of the assemblage. Miliolids and *Ammonia beccarii* are minor components of the assemblage. Stenohaline species are practically absent. *Elphidium aculetaum* lives recently on arborescent algae and is an epiphytic, suspension feeding form. *Elphidium macellum* presumably also had the same smaller algae microhabitat (Langer, 1993). Recently it is a common member of low tidal and shallow subtidal (0–20 m depth) foraminiferal associations (Hayward et al., 1997). The predominance of keeled elphidiids suggests dense arborescent algal substrate. However, *E. reginum* possesses a few long spines on the periphery, and the reason of morphological adaptation can be explained with the transition of the algal into seagrass vegetation (cf. Tóth et al., 2010). This assemblage reflects an increased salinity environment, with a sediment layer very impoverished in oxygen.

PALYNOFACIES

A characteristic feature of palynofacies from the studied section is the very low proportion of land-derived elements – sporomorphs and cuticles (Fig. 9), suggesting a sedimentary setting without terrestrial influx. Another characteristic feature is the taxonomical impoverishment of dinoflagellate cyst assemblages, which are either monospecific or consist mainly of two to three species (Fig. 9).

Assemblages with *Polysphaeridium zoharyi* and *P. subtile*, which occur in a majority of samples, suggest stressed conditions, most likely related to increased salinity. *Pyrodinium bahamense*, the recent motile stage of *P. zoharyi*, forms monospecific blooms in hypersaline waters; fossil *P. zoharyi* is commonly found in rocks deposited during increased salinity conditions (e.g., Wall and Dale, 1969; Dale, 1976; Wall et al., 1977; Morzadec-Kerfourn, 1979, 1983; Bradford and Wall, 1984; Edwards and Andrle, 1992). The occurrence of these species, together with a limited terrestrial influx may suggest a restricted, hypersaline lagoonal environment.

A basal part of the section studied, characterized by very low amounts of palynological organic matter, consists of interlayering intervals of strata that yielded *Polysphaeridium* only with dinoflagellate cyst barren intervals. Strata with *Polysphaeridium* (samples A, C, D, 1, 2, 6–13) were deposited in conditions favourable for this genus only and hostile for other species. The lack of dinoflagellate cysts in samples B and 3–5 is presumably related to the increased factors responsible for stress conditions hostile for all dinoflagellates. Higher up in the section, an interval with *P. zoharyi* (samples 6–13), which presumably reflects similar environmental conditions as the basal one (samples A, C, D, 1 and 2), passes into an interval with an increased content of dark brown translucent particles and a decline in dinoflagellate cysts (samples 14–16). The latter interval was presumably deposited in a similar setting as the topmost one (samples 25–28) characterized by a high ratio of dark brown translucent particles and lack of dinoflagellate cysts. These two intervals are separated by an interval, which yielded dinoflagellate cysts, in some samples appearing in mass amounts.

The occurrence of *Cleistosphaeridium placacanthum* at some levels suggests slightly different, but presumably still increased-salinity conditions compared to the levels with monospecific *P. zoharyi* assemblages. *C. placacanthum* is a cosmopolitan species known from marine palaeoenvironments. It was reported from fully marine Middle Miocene strata of Carpathian Foredeep where it is associated with diversified assemblages (e.g., Gedl, 1996; Peryt and Gedl, 2010; Peryt et al., 2014). But it also occurs, commonly as frequent to dominating species, in numerous settings of proximal Badenian of the Carpathian Foredeep where it is associated with taxonomically impoverished assemblages with *Polysphaeridium zoharyi* and *Lingulodinium machaerophorum* (Gedl and Peryt, 2011; Gedl, 2016;

Gedl et al., 2016). This distribution pattern of *C. placacanthum* suggests that this species occurs in a wide spectrum of palaeoenvironments, being also tolerant for proximal settings with a presumably increased salinity.

The diversity increase noted in the upper part of the studied section (above sample 19B; Fig. 9) suggests a slight improvement in environmental conditions. Most diversified assemblages from samples 24 and 29 presumably reflect fairly marine conditions, although salinity remained still above normal levels as suggested by the common occurrence (sample 24) and dominance (sample 29) of *Polysphaeridium zoharyi*. Another indication of stress conditions related to increased salinity might be the presence of *Leiosphaeridia* in sample 26. This apparently prasinophycean alga (see Guy-Ohlson, 1996) is known to have appeared in various environments, commonly related to increased salinity (e.g., Brugman et al., 1994). *Leiosphaeridia* commonly occurs in the Badenian evaporite deposits of Carpathian Foredeep (Gedl, 1997, 2004; Gedl in Peryt et al., 1997) or in strata directly overlying them (Gedl, 1999).

ISOTOPES

Isotopic studies of calcareous skeletons cannot escape the question of a possible diagenetic alteration that may potentially modify their pristine composition; another constrain in the case studied is the reliability of the small data set for any palaeoenvironmental considerations (Fourel et al., 2015). The isotopic data from Kreminna are likely obscured to some degree by diagenesis, which makes the possibility of their use in the palaeoenvironmental interpretation difficult. However, most of the δ^{18}O and δ^{13}C isotopic signatures measured in the Kreminna section may be considered more or less primary as they do not deviate from values reasonably expected for pristine biogenic carbonate both in the case of oxygen as well as carbon signatures (Fig. 12). Only two samples with the lowest δ^{18}O values are influenced undoubtedly by meteoric diagenesis (i.e. contamination of foraminifer tests with meteoric cement and/or recrystallization of the tests itself) and should be excluded in further considerations.

The measured δ^{18}O and δ^{13}C signatures are within the range typical of the Sarmatian of the Carpathian Foredeep in Poland and Ukraine (see Jasionowski, 2006). Their highest values, however, are significantly lower (by ~2‰ in the case of δ^{18}O and by over 1‰ for δ^{13}C) than the isotopically heaviest samples of roughly coeval precipitates (cements and microbial sediments) building the nearby serpulid-microbialite reefs of the Medobory region (see Jasionowski, 2006). The reefs are interpreted to originate in semi-marine waters that were enriched in the heavy oxygen isotope due to intense evaporation (Jasionowski, 2006; Studencka and Jasionowski, 2011). The Kreminna site was situated closer to the shore of the basin, actually in the lagoon at the back of the reefs, and was probably more exposed to inputs of meteoric water, which was also enriched in isotopically lighter biogenic carbon.

Because salinity of the Paratethys basin cannot be precisely determined it is difficult to interpret the oxygen signatures of the Kreminna section in terms of temperature. As already mentioned above, it is generally believed that the Sarmatian Paratethys as a whole was a semi-marine basin with reduced salinity due to isolation from the world ocean and an excess of meteoric water entering the basin over evaporation (e.g., Rögl, 1998; Studencka and Jasionowski, 2011). Although, there have also been views of normal marine or even locally hypersaline conditions in the Paratethys (see e.g., Piller and Harzhauser, 2005). Anyway, locally the Sarmatian water could be strongly enriched in the heavier oxygen isotope, as presumably happened during the formation of Sarmatian serpulid-micriobialite reefs (Jasionowski, 2006; Studencka and Jasionowski, 2011). Thus, local conditions may have played a key role in the formation of the oxygen isotopic composition of water at specific locations in the Sarmatian basin, which consequently makes virtually impossible to make unambiguous estimations of palaeotemperature.

With the above in mind if one assumes the present-day isotopic composition of seawater (i.e. δ^{18}O 0‰ VSMOW), the precipitation temperatures of the foraminifer tests from Kreminna fall within the wide range from ~12 to ~22°C (calculated using equations given e.g., by Epstein at al., 1953 or Kim and O'Neil, 1997). Lowering the δ^{18}O of water by 1‰ gives temperatures in the range of 8–17°C, and by 2‰ as low as 5–13°C. So it is clear that the depletion of water in the heavy oxygen isotope cannot be very strong, otherwise calculated temperatures would be unrealistic.

The barely visible decreasing trend in δ^{18}O (i.e. depletion in heavy oxygen isotope) upward the section (Fig. 12) may reflect a gradual decrease in salinity with time, after the transition from normal marine conditions in the latest late Badenian (the very bottom of the section studied) to semi-marine ones with reduced salinity in the earliest Sarmatian (the rest of the section). The same explanation can be applied to the similar decrease in δ^{13}C upward the section, reflecting a slightly increasing contribution of biogenic TOC in Sarmatian waters coupled with larger input of meteoric water. Fluctuations of carbon isotope signatures may reflect the variable contribution of biogenic carbonate ions in water possibly correlated with the meteoric water inflows to the marginal parts of the basin and its mixing with the basin water reservoir. The apparent linear correlation between δ^{18}O and δ^{13}C supports this hypothesis (unless it is diagenetic).

DISCUSSION

At the Badenian/Sarmatian boundary a major change in the benthic and planktonic foraminiferal assemblages occurred, and stenohaline foraminifers were replaced by euryhaline ones. Łuczkowska (1964, 1985) concluded that above the level of extinction of foraminifers from the upper Badenian *Hanzawaia crassiseptata* Zone, the assemblage with *Anomalinoides dividens* and some other Sarmatian species appeared abruptly as a reflection of shallowing and a decrease in salinity. She introduced the *Anomalinoides dividens* Zone considered an assemblage zone with a mass occurrence of *A. dividens* along with elphidiids and miliolids in its upper part (Łuczkowska, 1964) that is widely applied in the regional biostratigraphy of the Central Paratethys (e.g., Łuczkowska, 1967; Czepiec, 1996; Filipescu, 2004; Harzhauser and Piller, 2004b; Dumitriu et al., 2017; Fig. 13). However, Peryt et al. (2021) documented, in two borehole sections from the Carpathian Foredeep of SE Poland (Babczyn 2 and Cieszanów 1), *Anomalinoides dividens* appeared some time after the extinction of Badenian foraminifers because it was separated by an interval with depauparate assemblages composed of a few species of elphidiids and miliolids of the *Elphidium angulatum* Partial Range Zone. Consequently, the base of *Anomalinoides dividens* Zone, considered as an indicator of the Badenian/Sarmatian boundary, is not coeval with the upper boundary of the *Hanzawaia crassiseptata* zone (Fig. 13). They discussed two options to assign the Badenian/Sarmatian boundary based on the foraminiferal assemblages: one on the

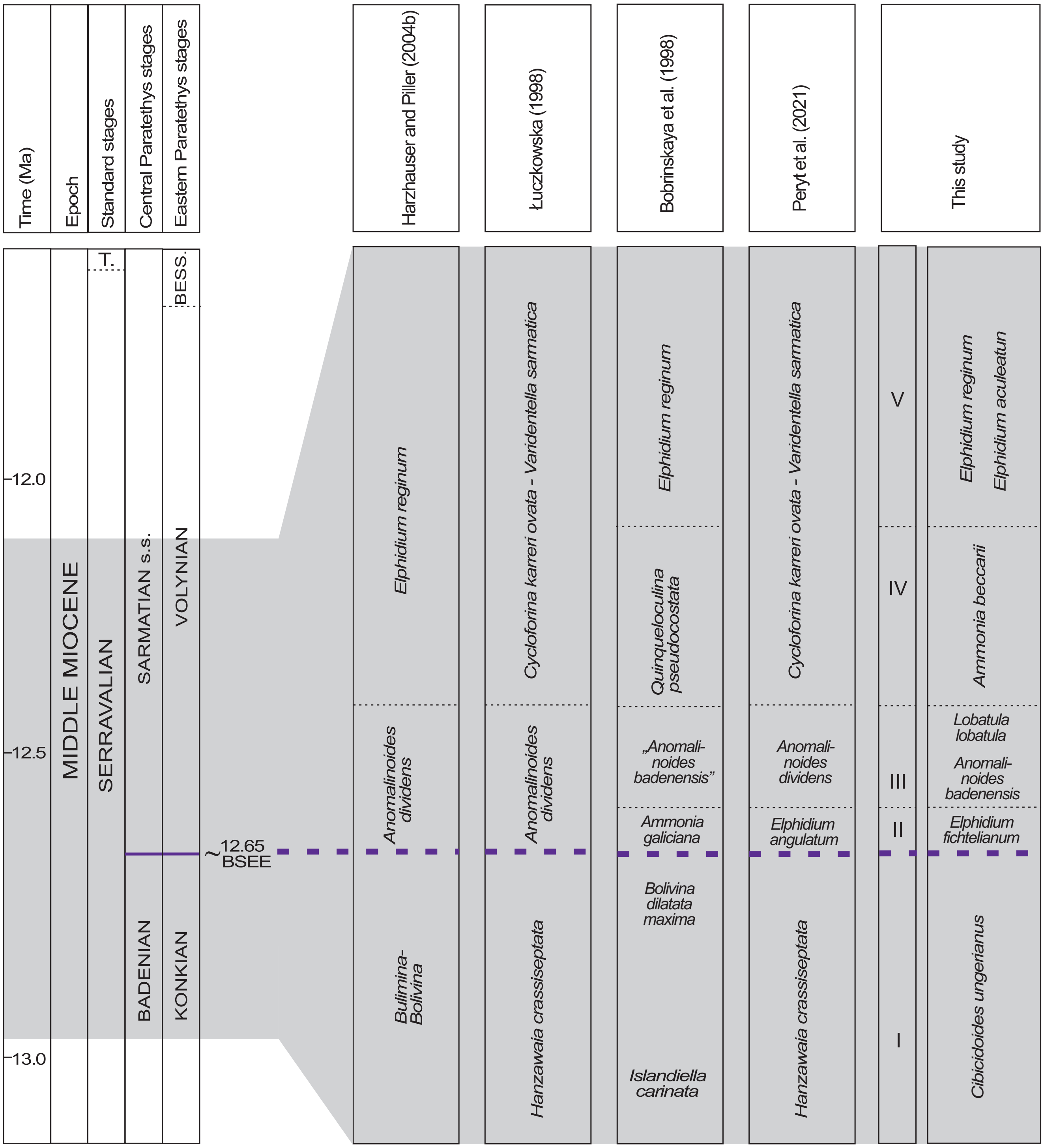

Fig. 13. Comparison of benthic foraminiferal assemblages in the Central Paratethys

major change of foraminiferal assemblages, induced by a change in the configuration of the Central–Eastern Paratethys gateway (cf. Palcu et al., 2015), and the second at the base of *Anomalinoides dividens* Zone, being in favour of the first one.

In the Kreminna section a distinctive change in the composition of foraminiferal assemblages, from those dominated by stenohaline species to those dominated by euryhaline species is observed within marls occurring in the lower part of the section (Figs. 2A, 3, 8 and 10). The place of this change was located between samples 2 and G, and above it the planktonic species disappeared, which otherwise was characteristic for the BSEE (Harzhauser and Piller, 2007). Therefore, this change is regarded as an indication of the Badenian/Sarmatian boundary.

Some Badenian stenohaline species, minor contributors to the foraminiferal assemblages (such as *Hanzawaia boueana, Neoconorbina schreibersi, Eponides nanus, Reussella spinulosa*) crossed the boundary but disappeared soon after, and some species continued till the top of the section although they became rarer upwards. On the other hand, new, previously not-occurring, species appeared: first *Ammonia beccarii* (in the top part of the interval with foraminifers disappearing soon after the Badenian/Sarmatian boundary), then *Anomalinoides badenensis* (starting from the first limestone bed) and next *Elphidium aculeatum*, *E. reginum* and *Articulina problema* (Fig. 3). As noticed by Harzhauser and Piller (2007), the foraminiferal fauna of the onset of the Sarmatian was characterized by large elphidiids, *Anomalinoides* species, and very characteristic *Schackoinella imperatoria* (d'Orbigny) which, however, in the Kreminna section was noted higher in the section (Fig. 3). At the same time, this is the most diversified assemblage, possibly related to the Sarmatian transgression that was recorded in many basins of the Central Paratethys (Nováková et al., 2020 with references therein) and that effected that the early (but not the earliest, as indicated by Peryt et al., 2021) Sarmatian deposition covered a larger surface than the latest Badenian one. This transgression was triggered by the tectonic reorganization in the region combined with a global sea level rise (see Palcu et al., 2015). The first relative sea level fall in Central Paratethys occurred within the Early Sarmatian *Mohrensternia* Zone and divides the *Anomalinoides dividens* Zone from the *Elphidium reginum* Zone (Harzhauser and Piller, 2004b).

The boundary between the upper Badenian and Sarmatian sediments in the Kreminna section is characterized by its conformity like the coeval boundary at the Donje Orešje locality (Croatia) described by Vrsaljko et al. (2006). In the Croatian case, a gradual change of palaeoecological characteristics they observed from a normal marine to reduced salinity fauna has been interpreted as due to sedimentation in the deeper part of the basin (Vrsaljko et al., 2006). In the Kreminna section, the foraminiferal turnover was gradual. Assemblage I records the changes. First the agglutinated forms went extinct, followed soon by *Heterolepa dutemplei*. The third step was the disappearance of planktonic *Globigerina* spp and *Cibicidoides* and *Melonis pompilioides* which were dominant benthic forms. This level, i.e. the extinction of the abundant group of stenohaline Badenian foraminifera, marks the Badenian/Sarmatian boundary. The *Cibicidoides* Assemblage corresponds to the *Hanzawaia crassiseptata* Zone distinguished in the Babczyn 2 borehole (Peryt et al., 2021). The *Elphidium fichtelianum* Assemblage corresponds to the *Elphidium angulatum* Zone from SE Poland (Fig. 13). *Anomalinoides dividens* was not recorded in the Kreminna section. A possible explanation may be that, as concluded by Czepiec (1997), the species had a mass occurrence in the clayey-marly facies, but in the detrital facies it was very rare. This, however, raises the question if such facies control does not contradict a possibly planktonic or pseudo-planktonic mode of life of *Anomalinoides dividens* as was assumed by Filipescu (2004). In turn, in the detrital facies, Elphidiidae prevailed over Miliolacea that are dominant in the clayey-marly facies.

However, *Anomalinoides badenensis* appeared in the first limestone bed as minor contributor in the Assemblage III with *Lobatula lobatula*. This Assemblage is regarded as coeval with the *Anomalinoides dividens* Zone from the Babczyn 2 borehole. Bobrinskaya et al. (1998) distinguished it as "*Cibicides badenensis*". The following assemblage (*Ammonia beccarii* assemblage) can be correlated with the *Quinqueloculina crassiseptata* assemblage of Bobrinskaya et al. (1998). The youngest assemblage, the *Elphidium reginum–E. angulatum* Zone, corresponds to the *Elphidium reginum* assemblage of Bobrinskaya et al. (1998) (Fig. 13). Garecka and Olszewska (2011) included the lower part of the Dashava Formation from the NE Ukrainian Carpathian Foredeep into two foraminiferal Zones of Łuczkowska (1964): *Anomalinoides dividens* and *Cycloforina karreri ovata.*

Palcu et al. (2015) assumed that the BSEE does correspond to a change in the configuration of the Central–Eastern Paratethys gateway but Silye and Filipescu (2016) suggested that the end Badenian closure of the Paratethyan basins was most probably diachronous due to their complex tectonic evolution. Both the Babczyn 2 section and Kreminna section that show a similar pattern of changes of foraminiferal assemblages that are possibly isochronous considering that the both localities are located within the East European Platform.

CONCLUSIONS

1. The Miocene deposits comprising the >1 m thick upper Badenian marls clays passing upwards into ~4 m thick Sarmatian marly limestones with intercalations of marls, clays and limestones that are overlain by >2 m thick limestones in the Kreminna section, contain 53 species of benthic foraminifera and four species of planktonic foraminifera.

2. Five benthic foraminiferal assemblages that are distinguished in the Kreminna section, are composed almost exclusively of calcareous forms; agglutinated taxa are recorded only in the lowermost part of the *Cibicidoides ungerianus* Assemblage. *Elphidium* spp., miliolids, *Lobatula lobatula* and *Ammonia* spp. are the most common calcareous benthic foraminifera; planktonic foraminifera are represented only by *Globigerina* species and occur rarely in the lowermost part of the section.

3. Palynofacies are characterized by a very low proportion of land-derived elements – sporomorphs and cuticles, implying a sedimentary setting without terrestrial influx, and taxonomical impoverishment of dinoflagellate cyst assemblages.

4. Dinoflagellate cyst assemblages are either monospecific or consist mainly of two to three species: in a majority of samples, assemblages with *Polysphaeridium zoharyi* and *P. subtile* occur.

5. Most δ^{18}O values range from –1.5 to ~+0.5‰ VPDB and most δ^{13}C values are between 0 and +2‰ VPDB. In general, the δ^{13}C curve mirrors the δ^{18}O changes in the section.

6. The Badenian/Sarmatian boundary is placed at the level where planktonic foraminifers and most abundant stenohaline benthic foraminifera disappeared, i.e. at the boundary between the *Cibicidoides ungerianus* Assemblage and the *Elphidium fichtelianum* Assemblage.

7. Bottom waters were well oxygenated both in the latest Badenian and earliest Sarmatian in the Kreminna location.

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Appendix 1
List of the identified foraminifera

Benthic foraminifera	
Ammonia beccarii (Linné, 1758)	Fig. 6A, C
Anomalinoides badenensis (d'Orbigny, 1846)	Fig. 5I
Articulina problema Bogdanowicz, 1952	Fig. 7D, E
Astrononion perfossum (Clodius, 1922)	Fig. 7M, P
Bolivina dilatata Reuss, 1850	Fig. 7B
Bolivina plicatella Cushman, 1930	Fig. 7C
Bolivina sp.	Fig. 7A
Bulimina subulata Cushman and Parker, 1937	
Bulimina sp.	
Cibicidoides austriacus (d'Orbigny, 1846)	Fig. 5C, D
Cibicidoides ungerianus (d'Orbigny, 1846)	Fig. 5G
Cibicidoides sp.	Fig. 5E, F
Dorothia sp.	
Elphidium aculeatum (d'Orbigny, 1846)	Fig. 4H, I
Elphidium antoninum (d'Orbigny, 1846)	Fig. 6J
Elphidium crispum (Linné, 1758)	Fig. 6D, H, I
Elphidium fichtelianum (d'Orbigny, 1846)	Fig. 4D, E
Elphidium friedbergi Serova, 1955	Fig. 6G
Elphidium josephinum (d'Orbigny, 1846)	Fig. 4F, G
Elphidium joukovi Serova, 1955	Fig. 6F
Elphidium koberi Tollmann, 1955	
Elphidium listeri (d'Orbigny, 1846)	Fig. 6K, L
Elphidium macellum (Fichtel and Moll, 1798)	Fig. 6B, E
Elphidium reginum (d'Orbigny, 1846)	Fig. 4J–L
Elphidium sp.	
Eponides nanus (Reuss, 1850)	
Eponides repandus (Fichtel and Moll, 1798)	
Favulina hexagona (Williamson, 1848)	
Fursenkoina acuta (d'Orbigny, 1846)	
Glandulina sp.	
Globulina sp.	
Hanzawaia boueana (d'Orbigny, 1846)	Fig. 5A, B
Heterolepa dutemplei (d'Orbigny, 1846)	
Lobatula lobatula (Walker and Jacob, 1798)	Fig. 5H, J
Melonis pompilioides (Fichtel and Moll, 1798)	Fig. 7N
Neoeponides schreibersi (d'Orbigny, 1846)	Fig. 7T, U
Nonion commune (d'Orbigny, 1846)	
Nonion tumidulus Pishvanova, 1960	Fig. 7R
Porosononion martkobi (Bogdanowicz, 1947)	Fig. 7Q
Pseudotriloculina consobrina (d'Orbigny, 1846)	Fig. 7I, J
Reussella spinulosa (Reuss, 1850)	Fig. 7G
Rosalina obtusa d'Orbigny 1846	Fig. 7S
Quinqueloculina bogdanovichi (Serova, 1955)	Fig. 7K
Quinqueloculina sp.	
Schackoinella imperatoria (d'Orbigny, 1846)	
Semivulvulina pectinata (Reuss, 1850)	
Sigmoilinita tenuis (Czjzek, 1848)	Fig. 7F
*Sphaeroidina bulloide*s d'Orbigny, 1826	
Textularia laevigata d'Orbigny, 1826	
Triloculina eggeri (Bogdanowicz, 1952)	Fig. 7H
Valvulineria complanata (d'Orbigny, 1846)	
Varidentella reussi (Bogdanowicz, 1947)	Fig. 7L
Varidentella sp.	Fig. 7O

Planktonic foraminifera	
Globigerina bulloides d'Orbigny, 1826	Fig. 4C
Globigerina praebulloides Blow, 1959	
Globigerina tarchanensis Subbotina and Chutzieva 1950	Fig. 4A
Globigerina sp.	Fig. 4B