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The advancement of late Badenian (Middle Miocene) transgression in the Carpathian Foreland recorded by foraminiferal assemblages: Kudryntsi on Zbruch River (Ukraine)

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The upper Badenian section of the Kudryntsi quarry (Ukrainian Carpathian Foreland Basin) consists of the Ternopil and Prut members of the Kosiv Formation. Its lower part was previously described by Gedl and Peryt (2011), and here we report a 5.3 m thick newly-exposed upper part of the section. Fifty-five species of benthic foraminifera and five species of planktonic foraminifera occur there. Benthic foraminifera are represented by both calcareous and agglutinated forms. Planktonic foraminifera occur in the whole of the succession studied. Five benthic foraminiferal assemblages are recognized: Assemblage VIII (*Elphidium–Lobatula*), Assemblage IX (*Cibicidoides*), Assemblage X (*Uvigerina–Bulimina*), Assemblage XI (*Heterolepa*) and Assemblage XII (*Uvigerina–Bulimina*–agglutinated). The foraminiferal record indicates deposition in a shallow subtidal environment of normal marine salinity and temperate waters followed by gradual deepening of the basin to >50 m. Analysis of foraminiferal assemblages indicates that bottom waters were highly oxygenated during deposition of the lower and middle parts of the interval studied. During deposition of the upper part of the sequence, the oxygenation of bottom water decreased, as indicated by a large decrease in the proportion of oxic species and an increase in dysoxic taxa.

Key words: Paratethys, Carpathian Foredeep, Upper Badenian, foraminifers, palaeoenvironment.

INTRODUCTION

The advance of the late Badenian transgression that terminated the Badenian Salinity Crisis (BSC; Peryt, 2006 with references therein) in the Carpathian Foredeep Basin before 13.32 ±0.07 Ma and re-installed normal marine conditions, resulted from reconnection of the basin with the Mediterranean and Eastern Paratethys, primarily by tectonic modification of the interconnecting gateways (de Leeuw et al., 2018). The combined effect of a eustatic global base-level rise and the expansion of the foreland basin towards the passive margin due to progressive orogenic loading and lithospheric flexure (see de Leeuw et al., 2018) was already noticed during the deposition of the Badenian sulphate evaporites in the Ukrainian Carpathian Foredeep basin. The late Badenian transgression in the marginal part of the Ukrainian Carpathian Foredeep Basin resulted in flooding of the gypsum platform that developed during the BSC, and the sea-shore transgressed a few tens of kilometres landward when compared to the limit of the sedimentary basin in which evaporites were deposited.

In the Kudryntsi gypsum quarry which is one of the key sections of the Badenian in the Carpathian Foredeep Basin, the lower part (<3 m thick) of the strata occurring above the Ratyn Limestone was subject to studies aimed to record environmental changes related to the late Badenian transgression (Peryt and Peryt, 2009; Gedl and Peryt, 2011). In this paper we report the results of a study of the newly-exposed upper part (5.3 m thick) of the section located above its previously examined part that is exposed SE of the active part of the quarry (Fig. 1). The aim of this study is to reconstruct the palaeoenvironmental con-

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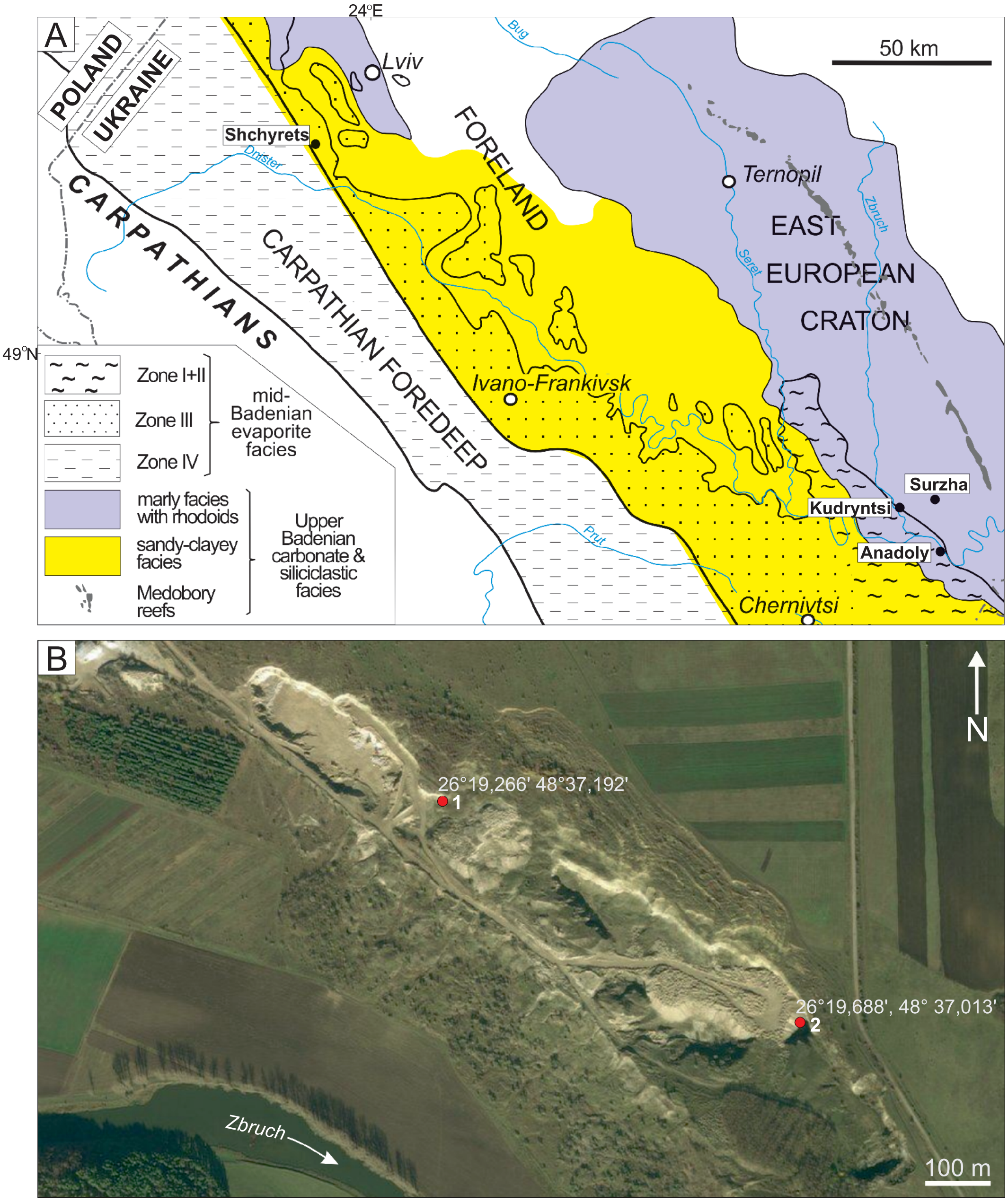

Fig. 1A – location map showing the mid-Badenian sulphate zones (after Peryt, 2006) and Upper Badenian facies in the Carpathian foreland (after Kudrin, 1966); B – Bing map showing the Kudryntsi quarry location (https://www.bing.com/maps?cc=pl&cp=48.618462%7E26.321812&lvl=15.9&style=h): point 1 – location of the section studied by Peryt and Peryt (2009: fig. 2) and Gedl and Peryt (2011: fig. 2); point 2 – SE end of the gypsum quarry; the section studied in this paper is located SSE of the point 2

ditions based on the study of foraminifera – a group that is commonly used in studies of the Miocene palaeoenvironment of the Central Paratethys Foredeep (e.g., Szczechura, 1982; Czepiec, 1996; Czepiec and Kotarba, 1998; Gonera, 2001; Báldi, 2006; Kováčová and Hudáčková, 2009; Kováčová et al., 2009; Garecka and Olszewska, 2011; Kováč et al., 2017; Scheiner et al., 2018, 2019; Pezelj and Drobnjak, 2019). Some of the Miocene foraminiferal species still live in modern seas and thus they are good bioindicators of marine environmental changes (Murray, 1991, 2006; Gull et al., 2025; Hayward et al., 2025).

GEOLOGICAL SETTING

The Kudryntsi section is located in the most peripheral part of the mid-Badenian evaporite basin in the Ukrainian Carpathian foreland basin (Fig. 1; Peryt, 2001; Bąbel, 2005). In the Ukraine, the Badenian sulphate evaporites and the overlying Ratyn Limestone are included in the Tyras Formation which is overlain by the deep-marine Kosiv Formation (Andreyeva-Grigorovich et al., 1997). The lower part of the Kosiv Formation consists of rhodoid limestones with intercalations of marls and claystones (Proniatyn facies of Teisseyre, 1900; *cf.* Siplivyy et al., 1974) and the upper part is clay-dominated, a typical Kosiv Formation. In the Surzha borehole located ~12 km NEE of Kudryntsi, the Kosiv Suite consists of two members: the Ternopil Mb. is 6 m thick succession of coralline-algal marly limestones with two thin fine-grained sandy-silty intercalations, and the overlying Prut Mb. (7 m thick) is predominantly laminated grey-green or grey-blue clayey silt with occasional sandy limestones (Studencka et al., 2012). In the Kudryntsi outcrop the boundary between the both members can be placed at the top of the bed that yielded sample no. 7 (Figs. 2 and 3).

Previous research (Gedl and Peryt, 2011) was concentrated on the lower part of the Ternopil Mb. in the Kudryntsi section that at the time was accessible to study. In the rhodoid complex (samples L to S) four foraminiferal assemblages have been identified: IV, V, VI and VII (Gedl and Peryt, 2011).

Their results indicated that the beginning of the deposition of the rhodoid complex was presumably still under slightly restricted conditions related to slightly increased water salinity, and the higher part of the rhodoid complex was deposited in marine, more off shore, but still rather near-shore environment. The monospecific assemblage V with *Lobatula lobatula* from the lower part of the rhodoid complex (sample N) indicates a shallow-marine environment with normal salinity, but characterized by very high-energy hydrodynamic conditions. The foraminiferal assemblages VI and VII characterize the highest taxonomical diversity; they include taxa living in shelf to bathyal marine environments, preferring temperate waters (warmer – VI, cooler – VII). This change may reflect a slight cooling during the late Badenian, but it may be also linked to deepening of the basin and appearance of colder bottom waters (Gedl and Peryt, 2011).

In this paper we focus on the newly accessible uppermost part of the succession comprising variously indurated limestones and marls in the lower part and mostly clay siltstones in the upper part. To tie the new section with the already published

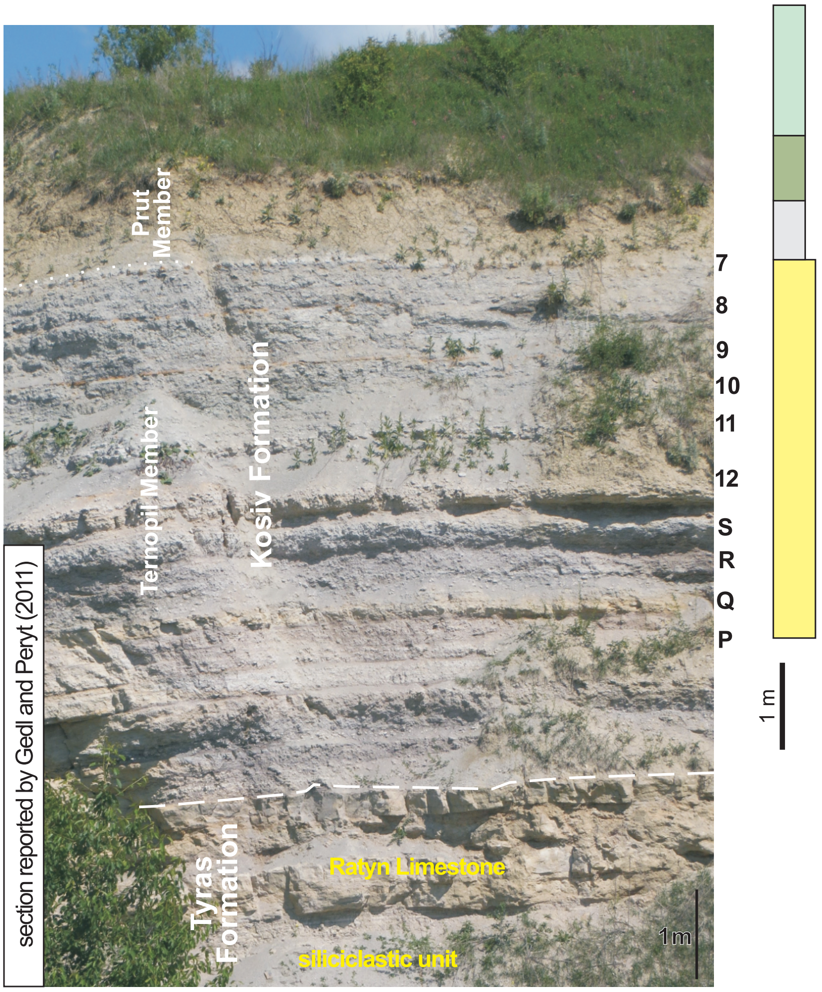

Fig. 2. Strata occurring above the Badenian gypsum in Kudryntsi quarry, showing the section studied previously and, right of the photo, the location, in the vertical section, of some samples examined by Gedl and Peryt (2011) and of samples 7–12 (this study)

Explanation of the colour bar right of the photo: yellow – variously cemented beige-grey coralline algal limestones with calcareous marly intercalations, light grey – beige-grey clay siltstones with coralline red algae, tarnished green – grey-green clay siltstones with coralline red algae, pale green – green clay siltstones

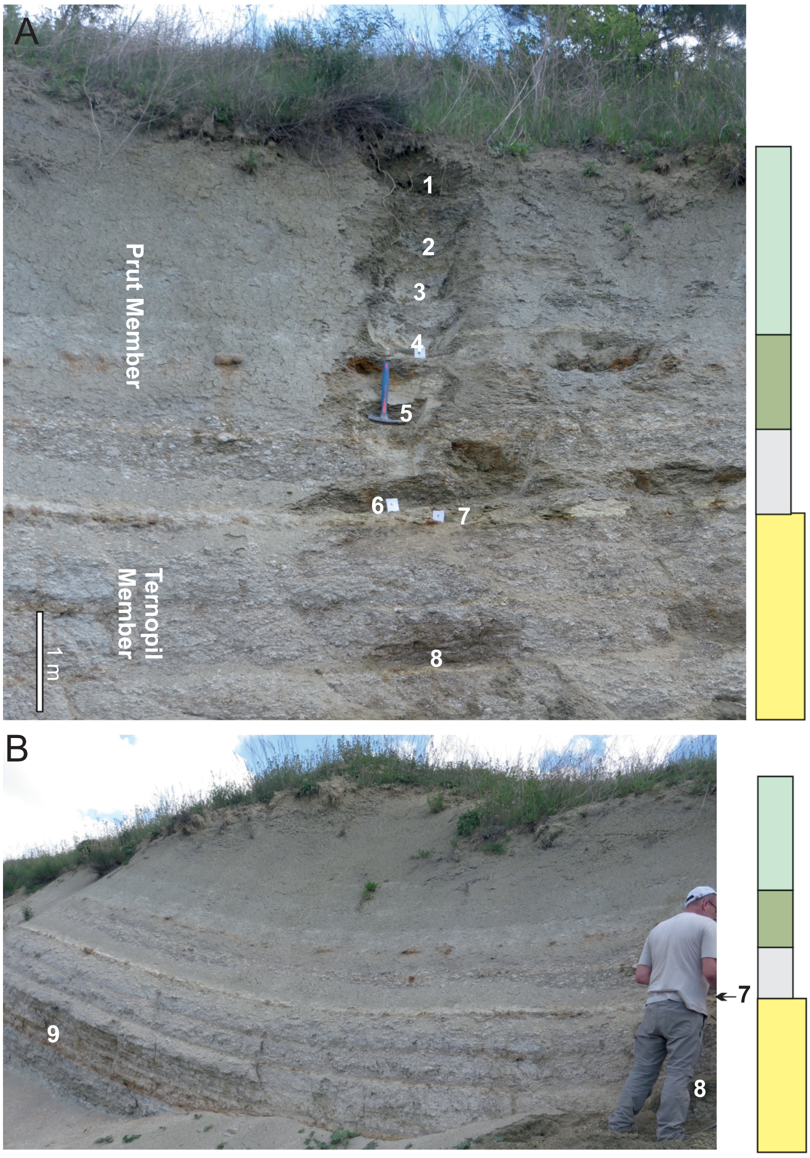

Fig. 3A – strata showing the location of samples 1–8; B – photo of sampled outcrop (photo shown in A is adjacent to this photo) and the location of samples 8, 9; arrow shows the bed that yielded sample 7

Explanation of the colour bar right of the photos in Figure 2

part of the Kudryntsi section (Gedl and Peryt, 2011) the uppermost part of that section (samples P-S) have been included in this paper.

MATERIAL AND METHODS

Twelve samples were collected for foraminiferal study. Their location in the profile is shown in Figures 2 and 3. Washed residues were obtained by disaggregation of samples using Na_2SO_4. An aliquot of ~200–300 specimens from the >63 μm size fraction was used for qualitative and quantitative analyses. The specimens were studied and documented using a *Philips XL20 SEM*. Supraordinal classification follows Pawlowski et al. (2013). Species determination of foraminifera was based on Venglinskyi (1958, 1975), Papp and Schmid (1985), and Cicha et al. (1998). The figured specimens are deposited in the Institute of Paleobiology, Polish Academy of Sciences, Warszawa (ZPAL F. 70). The palaeoenvironmental interpretation based on foraminifers applies the requirements of present-day representatives of recorded taxa (see Hayward et al., 1997, 2025; Gedl et al., 2016; Jorissen et al., 2018; Rodrigues et al., 2018; Dumitriu et al., 2020 with references therein; Table 1).

The relative abundances of the most common benthic foraminiferal genera, the Shannon index (*H*) of diversity (Buzas and Gibson, 1969) calculated as:

$$H = -\sum_{i=1}^{S} p_i \ln p_i$$

where: p_i – proportion of individuals of species *ith* in the community; ln – natural logarithm; *S* – total number of species (richness).

Table 1

Environmental requirements of genera recorded at the Kudryntsi section

Genus	Modes of life	Substrate	T [C]	Salinity [%]	Depth/environment
Astrononion	epifaunal-infaunal, free or clinging		cold	marine	inner shelf-bathyal
Bulimina	infaunal	mud to fine sand	cold-temperate		inner shelf-bathyal
Cibicidoides	epifaunal	hard	cold	marine	shelf-bathyal
Elphidium (keeled)	epifaunal	sand	temperate-warm	salinity range 35–70‰	inner shelf, 0–50 m
Eponides	epifaunal, free or clinging	sediment or hard	cold to temperate	marine	shelf-abyssal
Hansenisca	epifaunal, free	mud	cold	marine	shelf-bathyal
Hanzawaia	epifaunal, free or clinging	hard	temperate-warm	marine	inner shelf
Heterolepa	epifaunal	hard	cold	marine	shelf-bathyal
Lobatula lobatula	epifaunal, clinging or attached	firm	temperate-warm	marine	lagoon and inner shelf, 0–50 m
Melonis	infaunal	mud and silt	<10°C	marine	shelf-bathyal
Neoconorbina	epifaunal, clinging or attached	firm	temperate	marine	inner shelf
Porosononion	infaunal	mud and sand		wide salinity range (0–70‰)	inner shelf
Pullenia	infaunal	mud	cold		middle shelf-bathyal
Reussella	infaunal	mud and sand	temperate-warm	marine	shelf-bathyal
Rosalina	epifaunal, clinging or attached	firm	temperate-warm	marine	lagoons and inner shelf, 0–100 m
Sphaeroidina	infaunal	mud	cold		middle shelf-bathyal
Uvigerina	mainly infaunal, some epifaunal, free	mud	cold	marine	shelf-bathyal, 100 to >4500 m

P/B ratio (percentage of planktonic foraminifera within the foraminiferal assemblages) (Murray, 1976; van Hinte, 1978) and the relative abundance of epifaunal, shallow infaunal and deep infaunal forms within benthic foraminiferal assemblages, were calculated (see Corliss and Chen, 1988; Murray, 1991, 2006; Reolid et al., 2008; Valchev and Stojanova, 2016; Kaminski et al., 2025). The ratio of the latter groups within benthic foraminiferal assemblages was used to estimate trophic conditions in surface waters and oxygen levels in bottom waters. Benthic and planktonic foraminifera characteristics were used to estimate palaeobathymetry (Murray, 1976, 1991, 2006; Hemleben et al., 1989; Van Hinsbergen et al., 2005; Kouwenhoven and van der Zwaan, 2006). H(S) values >2.1 indicate normal marine environments (Murray, 1991).

Taking into account the differentiated morphogroups and the inferred microhabitat depth of foraminifera, the ecostratigraphic trends registered in foraminiferal assemblages were analysed. Changes in water salinity and other environmental parameters such as productivity, oxygen level in bottom waters, were interpreted using qualitative and quantitative analyses. To estimate the level of oxygenation of the sea floor the benthic foraminifera were grouped into oxic, suboxic and dysoxic indicators according to van der Zwaan (1982, 1983), Verhallen (1991), Jorissen et al. (1992, 2007, 2018), Kaiho (1994), Loubere (1996, 1997), Bernhard and Sen Gupta (1999), Kouwenhoven and van der Zwaan (2006), Holcová and Zágoršek (2008), Kaminski (2012), Kranner et al. (2022), and Cristallo et al. (2024) (Table 1). The following taxa are included into the oxic group: *Cibicidoides, Eponides, Hansenisca, Heterolepa, Lobatula*, miliolids, keeled elphidiids. Taxa tolerant of suboxic environments are: *Hanzawaia, Melonis, Pullenia, Sphaeroidina, Nonion, Porosononion, Astrononion, Reussella, Uvigerina, Angulogerina, Glandulina, Globulina, Guttulina, Ammobaculites, Dorothia, Gaudryina, Semivulvulina, Spirorutilus, Textularia, Siphotextularia* and taxa tolerant of dysoxic environments – *Bolivina* and *Bulimina*. Oxic indices represent epifaunal species. 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.

RESULTS

Fifty-five species of benthic foraminifera and five planktonic species have been identified in the interval studied (samples 1–12; Appendix 1). The following genera have been recorded: *Ammobaculites, Angulogerina, Astrononion, Bolivina, Bulimina, Cibicidoides, Dorothia, Elphidium, Eponides, Gaudryina, Glandulina, Globigerina, Globulina, Guttulina, Hansenisca, Hanzawaia, Heterolepa, Lobatula, Melonis, Neoeponides, Nonion, Porosononion, Pullenia, Reussella, Rosalina, Quinqueloculina, Semivulvulina, Sigmoilinita, Siphotextularia, Sphaeroidina, Spirorutilus, Textularia, Trilobatus, Uvigerina* (Figs. 4–6; Appendix 1).

Relative abundances of genera which exceed 5% at least in one sample are shown on Figure 7. Among the benthic foraminifera, the calcareous forms dominate; agglutinated taxa are constantly present in small numbers, except in samples 10 and 3 where they exceed 10 and 20%, respectively (Fig. 7). The H(S) values in the significant part of the section vary between 1.7 and 2.2 (samples 12 to 6); in the uppermost part of the studied interval the H(S) values alternate between 2.0 in samples 4 nad 2 and 2.5 – in samples 5, 3 and 1 (Fig. 8). Planktonic foraminifera represented by *Globigerina* and *Trilobatus* occur in all samples in the studied interval. Their contribution to fora-

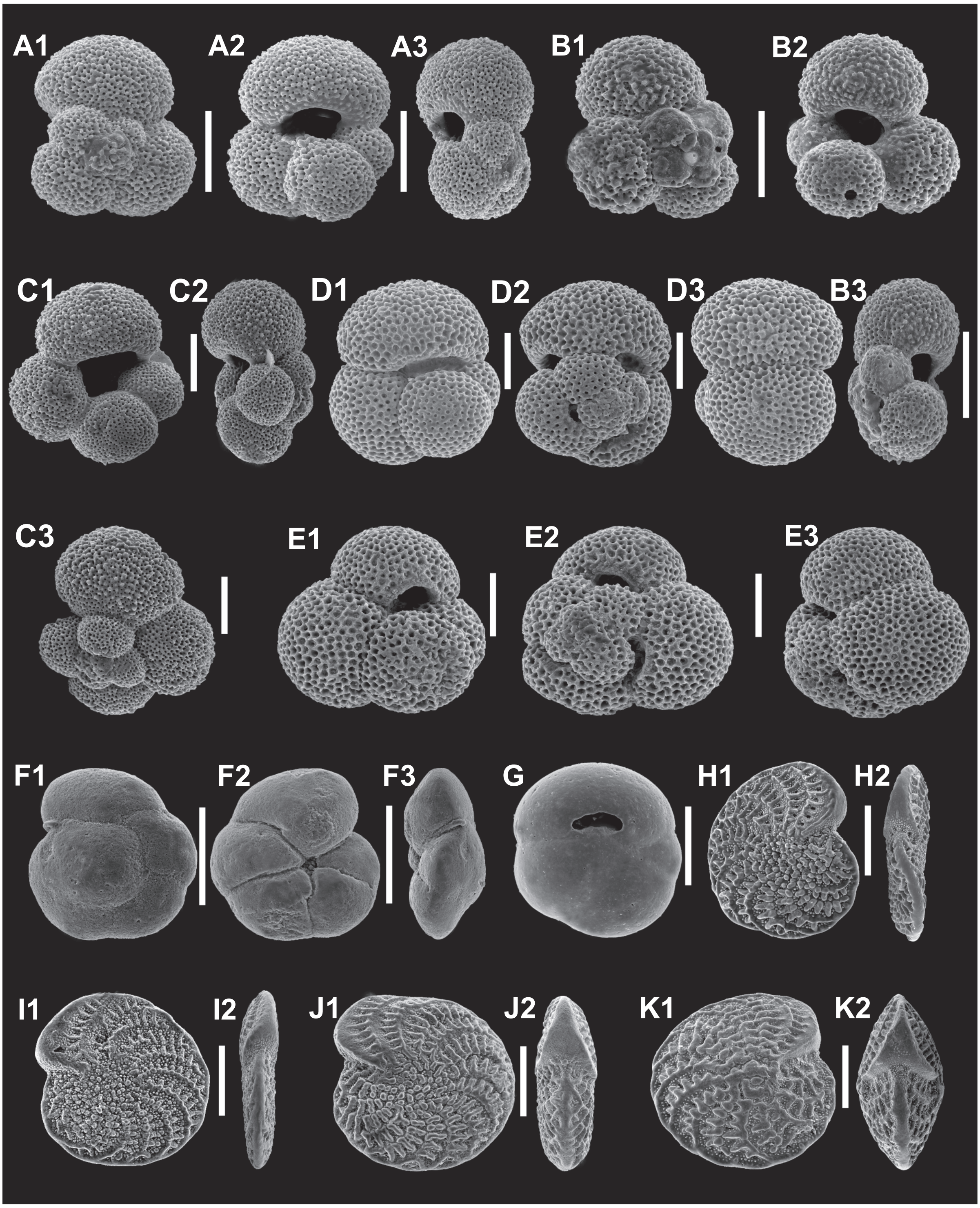

Fig. 4. Foraminifera from the upper Badenian sequence at Kudryntsi (scale bars A–E = 100 µm; F–K = 200 µm): A1–A3, B1–B3 – *Globigerina praebulloides*; C1–C3 – *Globigerina bulloides*; D1–D3 – *Trilobatus trilobus*; E1–E3 – *Trilobatus quadrilobatus*; F1–F3 – *Neoeponides* sp.; G – *Sphaeroidina bulloides*; H1, H2, I1, I2 – *Elphidium fichtelianum*; J1, J2 – *Elphidium joukovi*; K1, K2 – *Elphidium crispum*

A, C – sample 1; B, D, E, H, K – sample 11; F, I – sample 10; G – sample 2; J – sample 8

miniferal assemblages is generally low (1 to 15%), except in samples 7 and 11 where they form 29 and 40%, respectively. Neither benthic agglutinated foraminifera nor planktonic forms have been recorded from the underlying rhodoid complex (Gedl and Peryt, 2011). Additionally, in the lower part of the studied section (samples 12 to 6) *Uvigerina, Melonis, Reussella* and *Eponides* appeared, while *Neoconorbina, Rosalina* and *Baggina*, common in the rhodoid complex, were not recorded in this interval (Fig. 7). The most abundant genus is *Cibicidoides* reaching up to 70%, while *Elphidium* and *Lobatula* exceeded 40

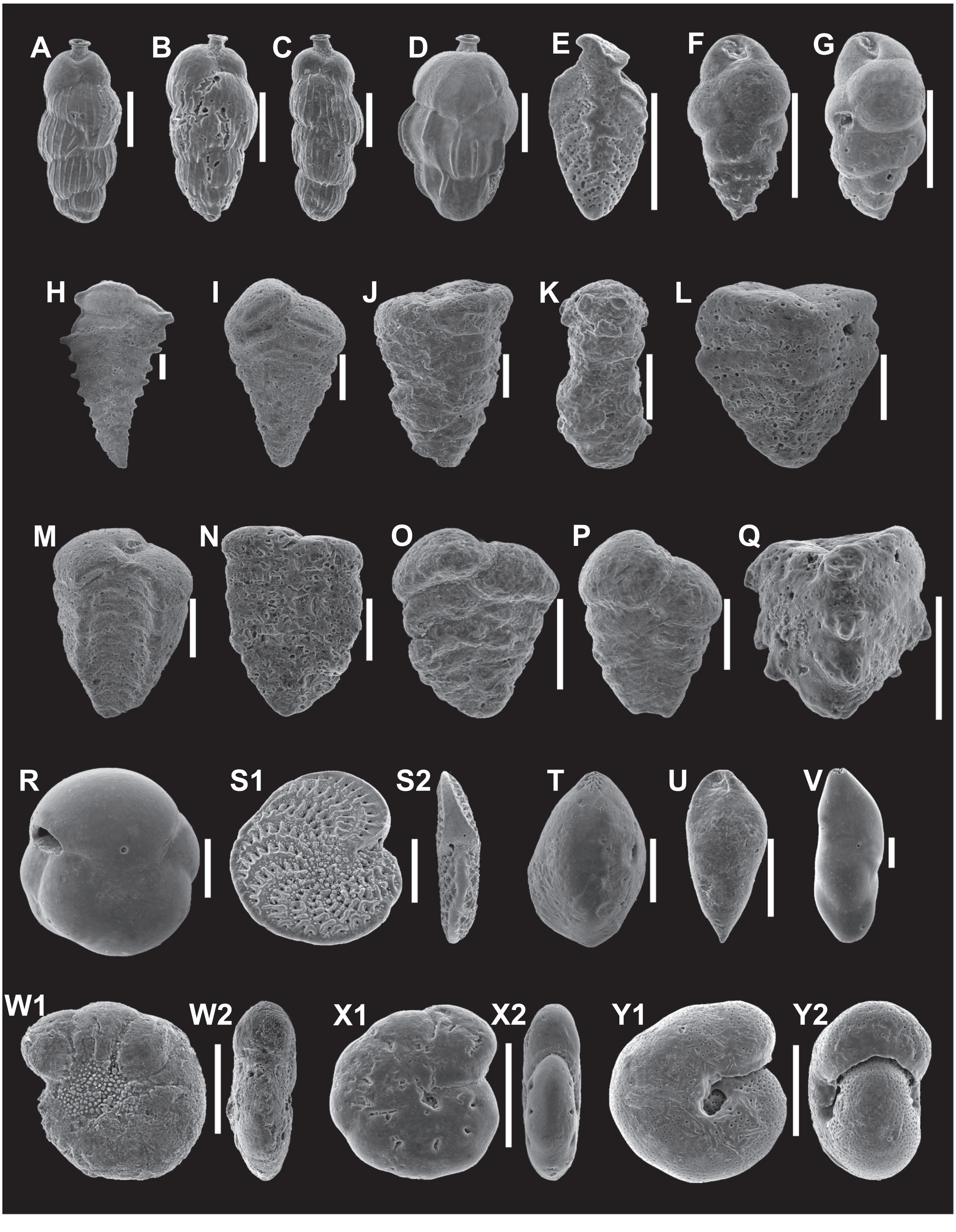

Fig. 5. Foraminifera from the upper Badenian sequence at Kudryntsi (scale bars = 200 µm): A, C – *Uvigerina semiornata*; B – *Uvigerina* sp.; D – *Uvigerina bellicostata*; E – *Bolivina* sp.; F – *Bulimina aculeata*; G – *Bulimina schischkinskayae*; H – *Spirorutilus carinatus*; I – *Siphotextularia* sp., K – *Ammobaculites agglutinans*; L – *Textularia pala*; M – *Siphotextularia concava*; N – *Textularia* sp., O, P – *Textularia gramen*; Q – ?*Gaudryina* sp., R – *Sphaeroidina bulloides*; S1, S2 – *Elphidium fichtelianum*; T – *Guttulina communis*; U – *?Bulimina* sp.; V – *Glandulina* sp., W1, W2 – *Porosononion martkobi*; X1, X2 – *Astrononion perfossum*; Y1, Y2 – *Melonis pompilioides*

A–C, S, Y – sample 11; D, H, I, M – sample 3; E–G, U – sample 5; J, K, O, P, X – sample 9; L, N, Q, T – sample 10; R, V – sample 1; S, Y – sample 11; T – sample 10; V – sample 1; W – sample 6

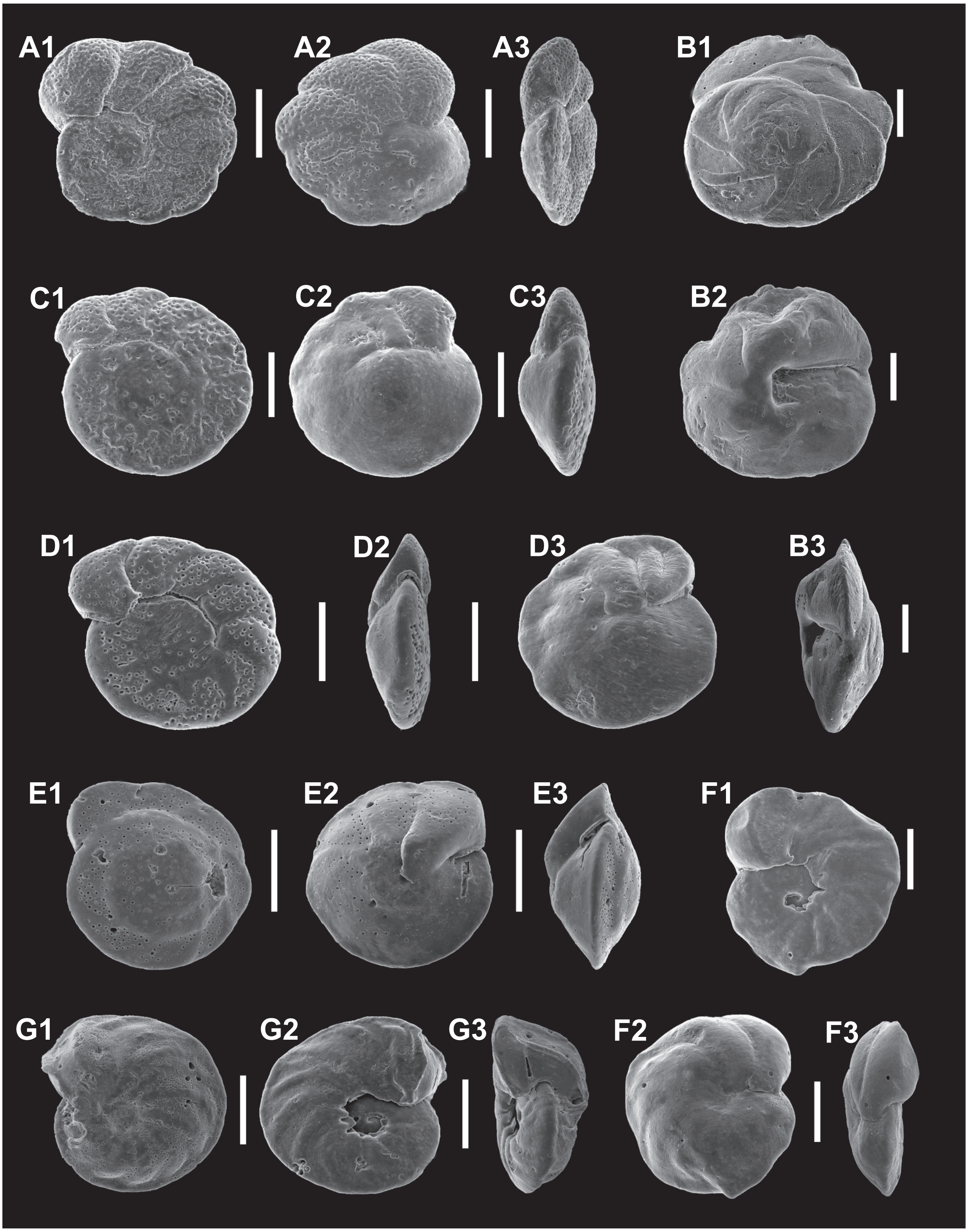

Fig. 6. Foraminifera from the upper Badenian sequence at Kudryntsi (scale bars = 200 µm): A1–A3 – *Cibicidoides austriacus*; B1–B3 – *Eponides repandus*; C1–C3 – *Cibicidoides pseudoungerianus*; D1–D3 – *Cibicidoides ungerianus*; E1–E3 – *Heterolepa dutemplei*; F1–F3 – *Hanzawaia* sp., G1–G3 – *Hanzawaia crassiseptata*

A, C – sample 8; B, D – sample 10; E – sample 2; F, G – sample 1

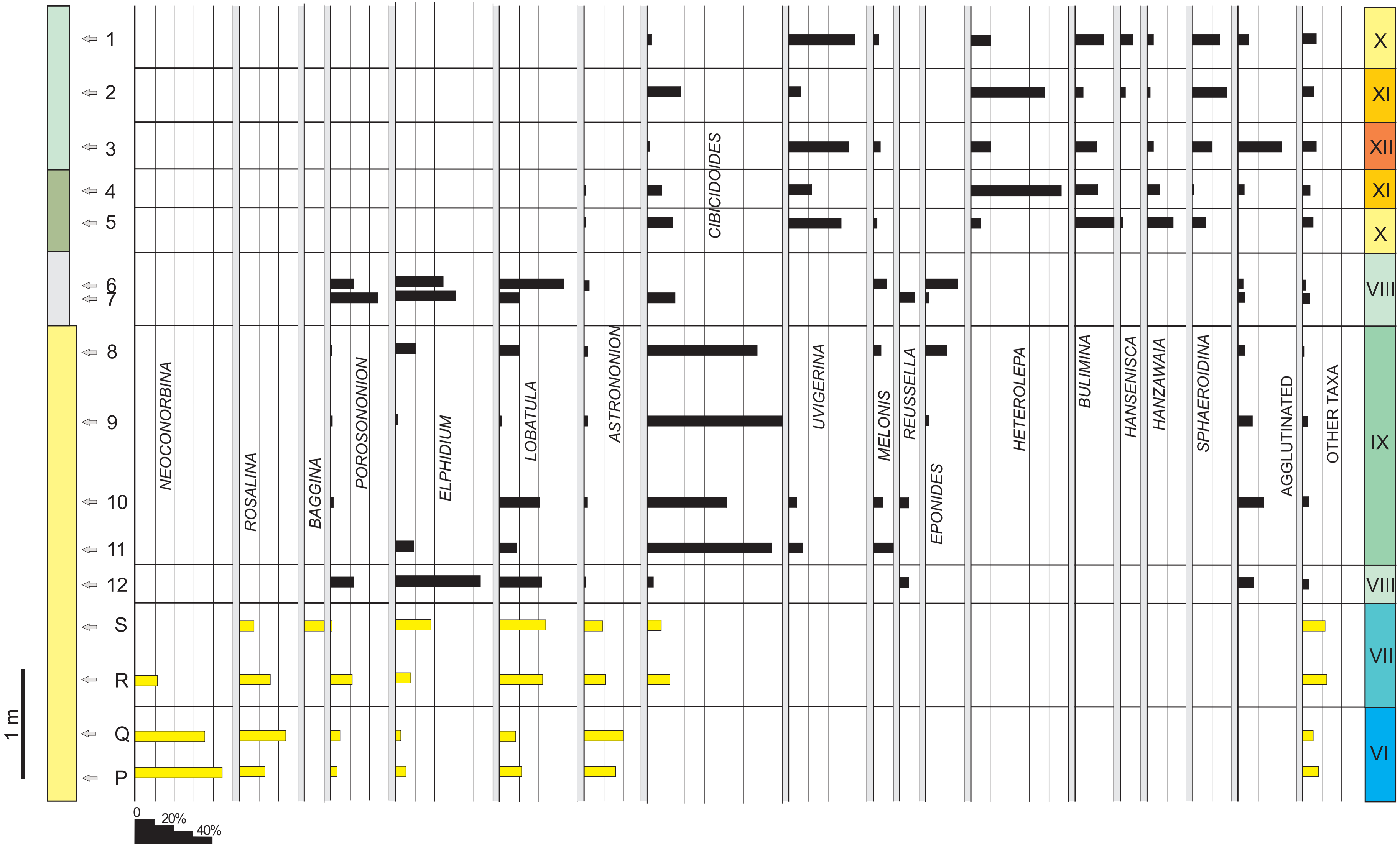

Fig. 7. The relative abundances of the most common benthic foraminiferal genera (in percentages) within the uppermost part of the rhodoid complex and overlying succession (data for samples P-S after Gedl and Peryt, 2011)

Explanation of the colour bar (left side) in Figure 2 and 30%, respectively. Foraminiferal assemblages from the upper part of the studied succession (samples 5 to 1) underwent an important successional reorganization. Species of *Porosononion, Elphidium, Lobatula, Reussella* and *Eponides* dominant or common in the lower part of the studied interval completely disappeared at the level of sample 6. They were replaced by *Heterolepa, Uvigerina, Bulimina, Hansenisca, Hanzawaia* and *Sphaeroidina* which are common in the upper part of the studied section. Benthic foraminifera that occurred in almost the entire studied succession were *Cibicidoides*, *Melonis,* and agglutinated forms (Fig. 7).

INTERPRETATION

Five benthic foraminiferal assemblages have been recorded in this part of the succession: VIII to XII (Fig. 7). Numbering of assemblages is a continuation of the previously published research on the older part of the profile (Gedl and Peryt, 2011). Foraminiferal assemblages are understood as groups of species with a clear dominance of one or a few characteristic taxa and whose composition is determined by the properties of the environment and by their mutual relations.

Assemblage VIII is recorded in samples 6, 7 and 12 (Fig. 7). This assemblage is characterized by the dominance of keeled *Elphidium* and *Lobatula lobatula*. *Elphidium* forms from 24 to 53% of the assemblage while *Lobatula lobatula* from 22 to 32%; common is also *Porosononion martkobi* (11 to 26%). Additionally, *Eponides* and *Cibicidoides* exceed 10% in this assemblage. *Astrononion perfossum, Reussella spinulosa* and agglutinated forms are minor components; they not exceed 10%. The H(S) diversity index is 1.9 to 2.0. Epifaunal taxa form 57 to 80% of the assemblage (Fig. 8).

Assemblage IX occurs in samples 8–11 (Fig. 7). It is dominated by *Cibicidoides* which form from 40 to 70% of the assemblage. *Lobatula lobatula* is less common than in assemblage VIII. Its contribution drops to 9 to 20%. *Elphidium, Melonis* and *Eponides* form up to 10%. Agglutinated taxa are also stable components of this assemblage (3 to 14%). *Porosononion* and *Astrononion* occur in small numbers. The H(S) diversity index is 1.9 to 2.2. Epifaunal taxa comprise 62 to 89% of the assemblage (Fig. 8).

Assemblage X has been found in samples 1 and 5 (Fig. 7). Dominant taxa in this assemblage are: *Uvigerina* (27 to 33%) and *Bulimina* (15 to 26%); common are *Sphaeroidina* (6 to 17%) and *Hanzawia* (3 to 14%). *Cibicidoides, Melonis, Hansenisca, Heterolepa* and agglutinated forms are minor components; they do not reach 10% of the assemblage. The H(S) diversity index is 2.5. Epifaunal taxa form 13 to 15% of the assemblage (Fig. 8).

Assemblage XI occurs in samples 2 and 4 (Fig. 7). This assemblage is dominated by *Heterolepa dutemplei* which forms 38 to 47% of the assemblage. *Uvigerina* and *Bulimina* decreased and in this assemblage they form from 4 to 11% while *Sphaeroidina* occasionally reaches up to 18%. The H(S) diversity index is 1.9 to 2.0. Epifaunal taxa comprise 56 to 59% of the assemblage; deep infaunal species form 9 to 13% of the assemblage (Fig. 8).

Assemblage XII is recorded in sample 3 (Fig. 7). In this assemblage *Uvigerina* and agglutinated taxa are dominant. They form 30 to 23%, respectively, of the assemblage. *Heterolepa, Bulimina* and *Sphaeroidina* form ~10% each. *Melonis* and *Hanzawaia* are minor components. The H(S) diversity index is 2.5. Epifaunal taxa form 12% of the assemblage, while deep infauna – 13%; shallow infaunal taxa dominate and comprise 75% of the assemblage (Fig. 8).

DISCUSSION

Foraminifera are one of the best tools for palaeoenvironmental interpretations. Planktonic foraminifera, because of their depth stratification, may be good indicators of ancient sea-level changes, of proximity of marginal seas to an ocean, as well as water mass temperatures (Schiebel and Hemleben, 2017); benthic foraminifera are valuable proxies because of the correlation between their test shapes and palaeoenvironmental requirements (e.g., Jorissen et al., 1995, 2018 with references therein). Planktonic *Globigerina* and *Trilobatus* (formerly assigned to *Globigerinoides)* are recorded in the studied succession. The two taxa inhabit shallow marine environments. *Globigerina bulloides*, the most common planktonic species in the material studied, exhibits a maximum abundance within the upper 60 m of the water column and is also considered to be an indicator of cooler waters while *Trilobatus* characterizes temperate to warmer waters (Schiebel and Hemleben, 2017). Generally, the percentage of planktonic foraminifera within assemblages increases with increasing distance from the shore (Murray, 1976; van Hinte, 1978).

The benthic foraminifera distribution is a function of the interplay between the food availability and oxygen concentrations at the sea floor (phytodetritus input *versus* bacterial activity, respectively) (Jorissen et al., 1995, 2007, 2018; Rodrigues et al., 2018). In oligotrophic and well-oxygenated environments benthic foraminiferal assemblages are dominated by epifaunal species; in eutrophic and dysoxic environments deep infauna dominate assemblages.

The qualitative and quantitative analyses of the foraminifera showed that the studied succession accumulated under variable sedimentary conditions (Fig. 9). The foraminiferal assemblages VI and VII described by Gedl and Peryt (2011) from the upper part of the rhodoid complex are characterized by moderate diversity and taxa preferring temperate-warm to cold shelf to bathyal marine environments. The assemblage VI consists of taxa preferring temperate-warm shallow marine environments, whereas the assemblage VII suggests temperate to cold marine inner shelf environment.

In the entire clayey-marly succession overlying rhodoid complex only a few species of shallow water planktonic foraminifera *Globigerina* and *Trilobatus* occur in low numbers. Their presence confirms a normal marine inner shelf environment as well the H(S) values in most cases >2 (Figs. 8 and 9).

In the lower part of the studied section two foraminiferal assemblages occur: Assemblage VIII and Assemblage IX. Assemblage VIII is dominated by keeled *Elphidium* and *Lobatula*. Three *Elphidium* species: *E. crispum*, *E. macellum* and *E. fichtelianum* of the Assemblage VIII live in modern seas (Hayward et al., 1997, 2025). They prefer temperate, normal salinity, sandy, shallow subtidal (0–20 m) environments. *Lobatula lobatula* lives on hard substrates, in high energy, oligotrophic environments; tolerant for depths: from 0 to 2000 m and temperatures: from warm to cold. Jorissen et al. (2018) included *Cibicides lobatulus* (=*Lobatula lobatula*) to Group I containing „sensitive species", i.e. taxa which are very sensitive to organic enrichment. The ecological requirements of dominant taxa of this assemblage suggest temperate, normal salinity, sandy, shallow

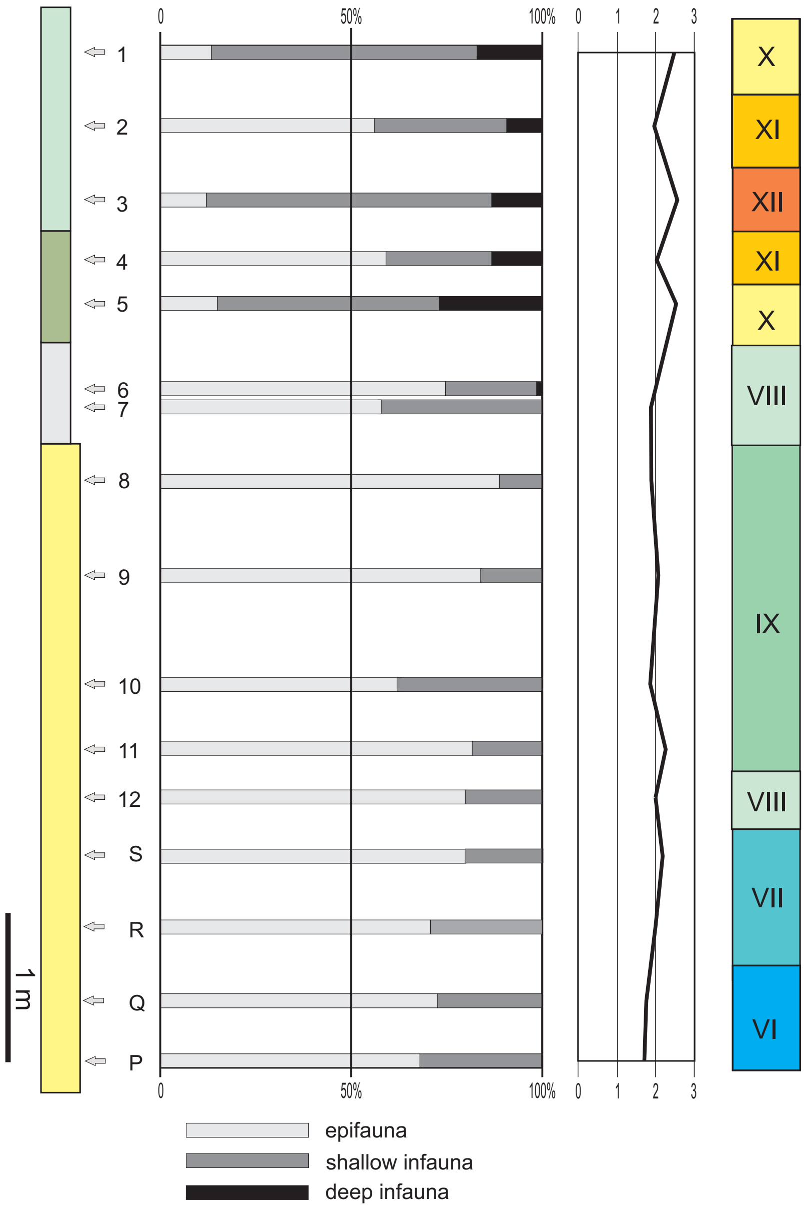

Fig. 8. The relative abundances (in percentages) of epifaunal, shallow infaunal and infaunal taxa, the Shannon-Wiener indices H(S) and foraminiferal assemblages (data for samples P-S after Gedl and Peryt, 2011)

Explanation of the colour bar (left side) in Figure 2

subtidal, of 20 m depth, mesotrophic, close to oligotrophic environment at the site. Assemblage IX dominated by *Cibicidoides* alternates with Assemblage VIII. *Cibicidoides* prefers cold, shelf to bathyal marine environments. *Lobatula lobatula,* second in abundance next to *Cibicidoides*, is a common taxon in Assemblage IX and has similar ecological requirements.

Elphidium is absent or rare in this interval. It dominates in cold and deep water suggesting cooling and deepening of the sea down to ~50 m. Both assemblages are dominated by epifaunal taxa: keeled *Elphidium*, *Lobatula* and *Cibicidoides*. They form 57 to almost 90% of these assemblages; shallow infauna represents 10 to 43%; deep infaunal taxa are not present. High dominance of epifaunal foraminifera in this interval indicates mesotrophic, close to oligotrophic surface waters and well-oxygenated bottom waters. A significant reorganisation of the taxonomic composition of foraminiferal assemblages in the upper part of the studied succession reflects also a greater environmental change. Shallow, temperate-warm water *Elphidium*, *Lobatula* and *Porosononion* disappeared. In this interval three alternating assemblages occur: X – dominated by *Uvigerina* and *Bulimina*, XI – dominated by *Heterolepa* and XII – dominated by *Uvigerina* and agglutinated taxa. These genera live in cold, shelf-bathyal environments (Table 1). The highest H(S) values up to 2.5–2.6 are calculated in assemblages X and XII where infaunal species (shallow and deep) exceed 85%; epifaunal forms comprise 12 to 15%. In Assemblage XI the H(S) value drops to 2.0 and relative abundance of epifaunal taxa increases up to 60%. Taxonomic composition of the assemblages in this part of the section indicates colder and deeper marine environment during sedimentation than in un-

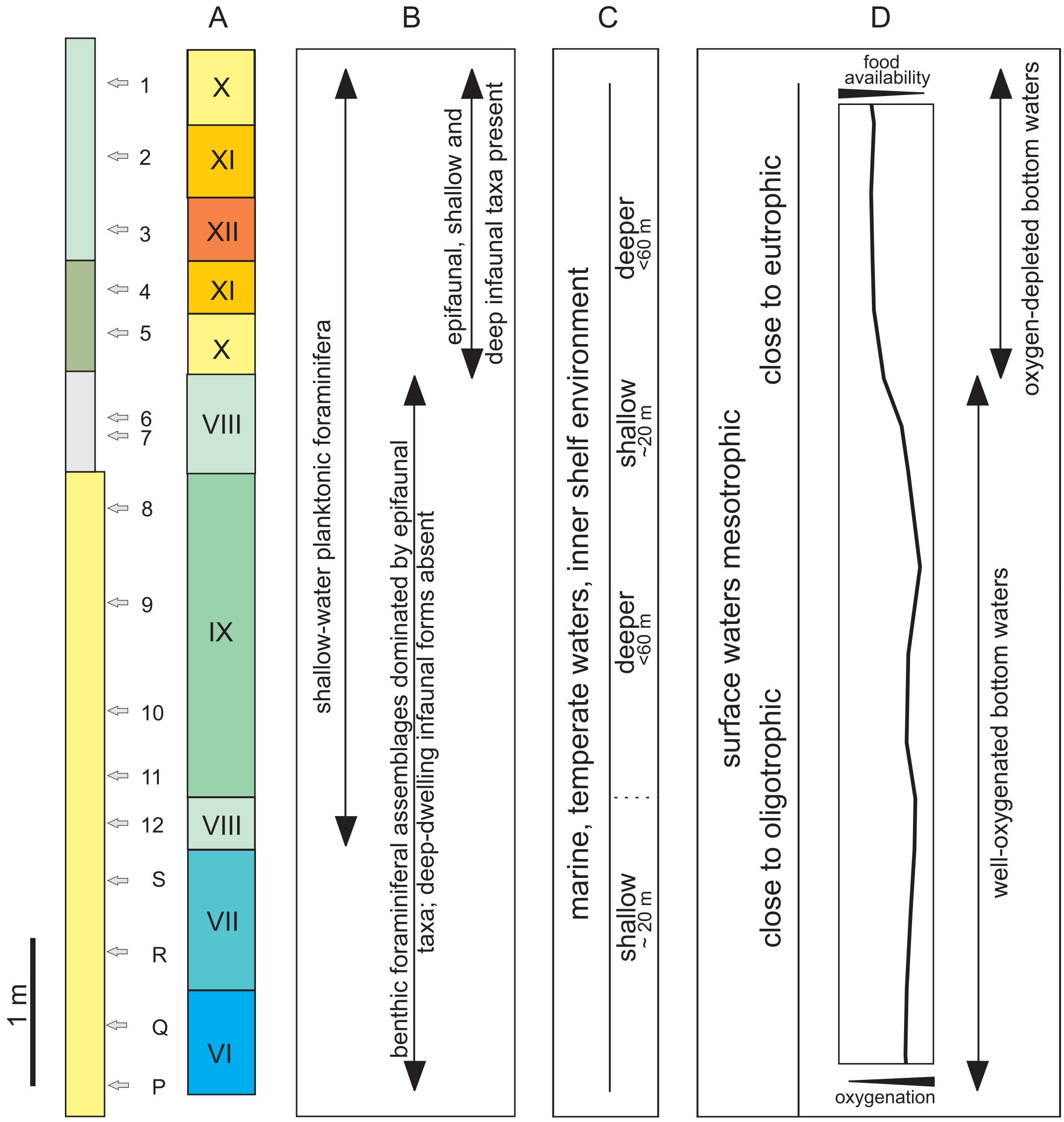

Fig. 9. Palaeoenvironmental changes in the upper Badenian based on foraminiferal data from the Kudryntsi profile (after Gedl and Peryt, 2011 and this work): A – foraminiferal assemblages; B – foraminiferal events; C, D – interpretation

Explanation of the colour bar (left side) in Figure 2

derlying strata comprising Assemblage VIII. The possible cause of this distribution pattern of benthic foraminifera in the study area might be short-lived sea-level fluctuations likely controlled mainly by the ongoing intensive tectonic evolution in the Central Paratethys (Kováč et al., 2017). The high dominance of infaunal taxa in assemblages X and XII indicates a large supply of organic matter to the sea floor, the dominance of eutrophic conditions in the surface waters, and the oxygen impoverishment of the bottom waters in this area. The relative increase of epifauna in Assemblage XI indicates a change from eutrophic to mesotrophic conditions, a decrease in the organic matter supply, and an amelioration in oxygen in bottom waters.

Summarizing, inferred from foraminiferal data, the studied succession of the Kudryntsi quarry located in Ukrainian Carpathian Foreland Basin, shows that environmental conditions were variable in this part of Central Paratethys during the late Badenian. Tectonic activity was most probably responsible for the depth changes within the basin. The changes in oxygenation of bottom waters reflected the variable flux of organic matter from the sea surface.

CONCLUSIONS

1. The newly exposed (5.3 m thick) and studied Upper Badenian Kudyntsi succession comprises variously indurated coralline algal limestones with calcareous marly intercalations in the lower part that are included, as the strata previously studied by Gedl and Peryt (2011) to the Ternopil Member of Kosiv

Formation, and clay siltstones, often with coralline red algae that represent the Prut Member of the Kosiv Formation.

2. Fifty-five species of benthic foraminifera and five planktonic species have been identified in the interval studied. They form five benthic foraminiferal assemblages VIII to XII (Fig. 7). Qualitative and quantitative analyses of the foraminifera show that the studied succession accumulated under variable sedimentary conditions.

3. Low-diversity, shallow-water planktonic foraminifera (*Globigerina* and *Trilobatus*) indicates normal marine, temperate, inner shelf environments.

4. Alternation of shallow-water benthic foraminiferal Assemblage VIII with deeper-water assemblages IX and X might reflect the short-lived sea-level fluctuations likely controlled mainly by the ongoing intensive tectonic evolution in the Central Paratethys.

5. High dominance of epifaunal benthic foraminifera and lack of deep infaunal species within assemblages indicates mesotrophic close to oligotrophic surface waters and well-oxygenated bottom waters at this site during sedimentation of the lower part of the studied succession.

6. Assemblages X, XI and XII from the upper part of the studied succession suggest fluctuations in organic matter flux to the sea floor. Assemblages X and XII highly dominated by infaunal species indicate dysoxic bottom waters and high input of organic matter from mesotrophic to eutrophic surface waters. Assemblage XI with an almost equal contribution of epifaunal and infaunal species reflects mesotrophic surface waters and oxygenated bottom waters.

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APPENDIX 1

List of the identified foraminifera

Benthic foraminifera

Ammobaculites agglutinans (d’Orbigny, 1846)	Fig. 5K
Angulogerina angulosa (Williamson, 1858)	
Astrononion perfossum (Clodius, 1922)	Fig. 5X
Bolivina dilatata Reuss, 1850	
Bolivina sp.	Fig. 5E
Bulimina aculeata d’Orbigny, 1826	Fig. 5F
Bulimina schischkinskayae Samoylova, 1947	Fig. 5G
Bulimina subulata Cushman and Parker, 1937	
Bulimina sp.	Fig. 5U
Cibicidoides austriacus (d’Orbigny, 1846)	Fig. 6A
Cibicidoides pseudoungerianus (Cushman, 1922)	Fig. 6C
Cibicidoides ungerianus (d’Orbigny, 1846)	Fig. 6D
Cibicidoides sp.	
Dorothia sp.	
Elphidium crispum (Linné, 1758)	Fig. 4K
Elphidium fichtelianum (d’Orbigny, 1846)	Fig. 4H, I and 5S
Elphidium joukovi Serova, 1955	Fig. 4J
Elphidium macellum (Fichtel and Moll, 1798)	
Elphidium sp.	
Eponides nanus (Reuss, 1850)	
Eponides repandus (Fichtel and Moll, 1798)	Fig. 6B
?*Gaudryina* sp.	Fig. 5Q
Glandulina sp.	Fig. 5V
Globulina sp.	
Guttulina communis (d’Orbigny, 1826)	Fig. 5T
Hansenisca soldanii (d’Orbigny, 1826)	
Hanzawaia boueana (d’Orbigny, 1846)	
Hanzawaia crassiseptata (Łuczkowska, 1955)	Fig. 6G
Hanzawaia sp.	Fig. 6F
Heterolepa dutemplei (d'Orbigny, 1846)	Fig. 6E
Lobatula lobatula (Walker and Jacob, 1798)	
Melonis pompilioides (Fichtel and Moll, 1798)	Fig. 5Y
Neoeponides schreibersi (d’Orbigny, 1846)	
Neoeponides sp.	Fig. 4F
Nonion tumidulus Pishvanova, 1960	
Porosononion martkobi (Bogdanowicz, 1947)	Fig. 5W
Pullenia bulloides (d’Orbigny, 1826)	
Reussella spinulosa (Reuss, 1850)	
Rosalina obtusa d’Orbigny, 1846	
Quinqueloculina sp.	
Semivulvulina pectinata (Reuss, 1850)	
Sigmoilinita tenuis (Czjzek, 1848)	
Siphotextularia inopinata Łuczkowska, 1955	
Siphotextularia concava (Karrer, 1868)	Fig. 5M
Siphotextularia sp.	Fig. 5I
Sphaeroidina bulloides d’Orbigny, 1826	Fig. 4G and 5R
Spirorutilus carinatus (d’Orbigny, 1846)	Fig. 5H
Textularia gramen d’Orbigny, 1846	Fig. 5O, P
Textularia laevigata d’Orbigny, 1826	
Textularia pala Czjzek, 1848	Fig. 5L
Textularia sp.	Fig. 5N
Uvigerina bellicostata Łuczkowska, 1955	Fig. 5D
Uvigerina brunnensis Karrer, 1877	
Uvigerina semiornata d’Orbigny, 1846	Fig. 5A, C
Uvigerina sp.	Fig. 5B

Planktonic foraminifera

Globigerina bulloides d'Orbigny, 1826	Fig. 4C
Globigerina praebulloides Blow, 1959	Fig. 4A, B
Trilobatus quadrilobatus (d'Orbigny, 1846)	Fig. 4E
Trilobatus trilobus (Reuss, 1850)	Fig. 4D
Trilobatus sp.	