

Early middle Miocene paleoenvironmental evolution in southwest Transylvania (Romania): Interpretation based on foraminifera

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Abstract: The paleoenvironmental changes produced during the early middle Miocene have been restored based on foraminiferal assemblages collected from the Hațeg Basin in the southwestern part of Transylvania. The identified planktonics suggest a late early Badenian age (*Orbulina suturalis*: mid-late Langhian) and relatively warm water temperature (high percentages of *Trilobatus trilobus* together with *Trilobatus quadrilobatus*, *Globigerinella regularis*, and *Orbulina suturalis*). Composition, abundance, diversity, and distribution of the benthic assemblages indicate fluctuations in the paleoecological parameters and nutrient supply in shelf settings. Separating the assemblages based on the preferred life habitat and feeding strategies along with analysis of species distribution using univariate (Fisher Alpha, Shannon, Simpson, Pielou, Hurlbert) and multivariate statistical indices (Bray Curtis distance matrix) aided in interpreting the paleoenvironmental changes along the succession (food content, oxygenation, changes in the hydrodynamics). The results suggest a relatively shallow and well-oxygenated depositional environment with few intervals of increased nutrient supply and decreased oxygen content, warm surface waters as well as a deepening upward trend along the section.

Keywords: middle Miocene, foraminifera, statistics, paleoenvironment, biostratigraphy.

Introduction

The Transylvanian Basin, as one of the major basins of the Central Paratethys, evolved in several subsequent stages starting from the Oligocene and ending into the late Miocene (Krézsek & Bally 2006). Its stratigraphic record preserves more than 1500 m of normal marine, brackish, evaporitic, and volcano-sedimentary formations (Ciupagea et al. 1970; Krézsek & Filipescu 2005).

Diverse marine paleoenvironmental settings controlled the distribution of the marine assemblages during the early Badenian. Very sensitive to paleoenvironmental changes was the group of foraminifera (Popescu 1975; Filipescu 1996, 2001, 2004; Filipescu & Gîrbacea 1997; Filipescu & Silye 2008). For this reason, a detailed micropaleontological study on foraminifera was carried out on a representative section of upper lower Badenian (mid-upper Langhian) deposits from the southwestern part of Transylvania, south of Galați village (Fig. 1; 45.521434 N, 23.059556 E), in the transition area between the Transylvanian Basin and Pannonian Basin. Foraminifera assemblages from sites located not very far from the area, on the south-eastern border of the Pannonian Basin, were first studied in the mid-19th century by Neugeboren (1847, 1850, 1851, 1852, 1856) and Karrer (1868). Only one study focused on the smaller foraminifera from the “Globigerina marls” of

the lower Badenian in the area (Savu et al. 1968) with no reference to the paleoecology of the fossil assemblages.

Thus, the main aims of the present study were to reconstruct the basic paleoecological parameters (such as paleotemperature, paleobathymetry, amount of dissolved oxygen, nutrient supply, hydrodynamics, etc.). The novel univariate and multivariate statistical analysis allowed us to track how the assemblages had changed in response to the fluctuating paleoenvironmental conditions.

Material and methods

Sixty-one samples were collected from a section south of the Galați village, Hunedoara county (Fig. 1). The high-resolution sampling (Fig. 2) considered the lithology and basic sedimentological features (grain size and sedimentary structures).

Further preparation and processing of the samples were conducted following standard micropaleontological methods: drying, soaking in water, boiling, washing over a 63 μm brass mesh sieve, and drying (Armstrong & Brasier 2005). A minimum of 300 specimens was selected from each sample. The fossil foraminifera were identified at species-level (where the specimens had allowed this), sorted, and counted.

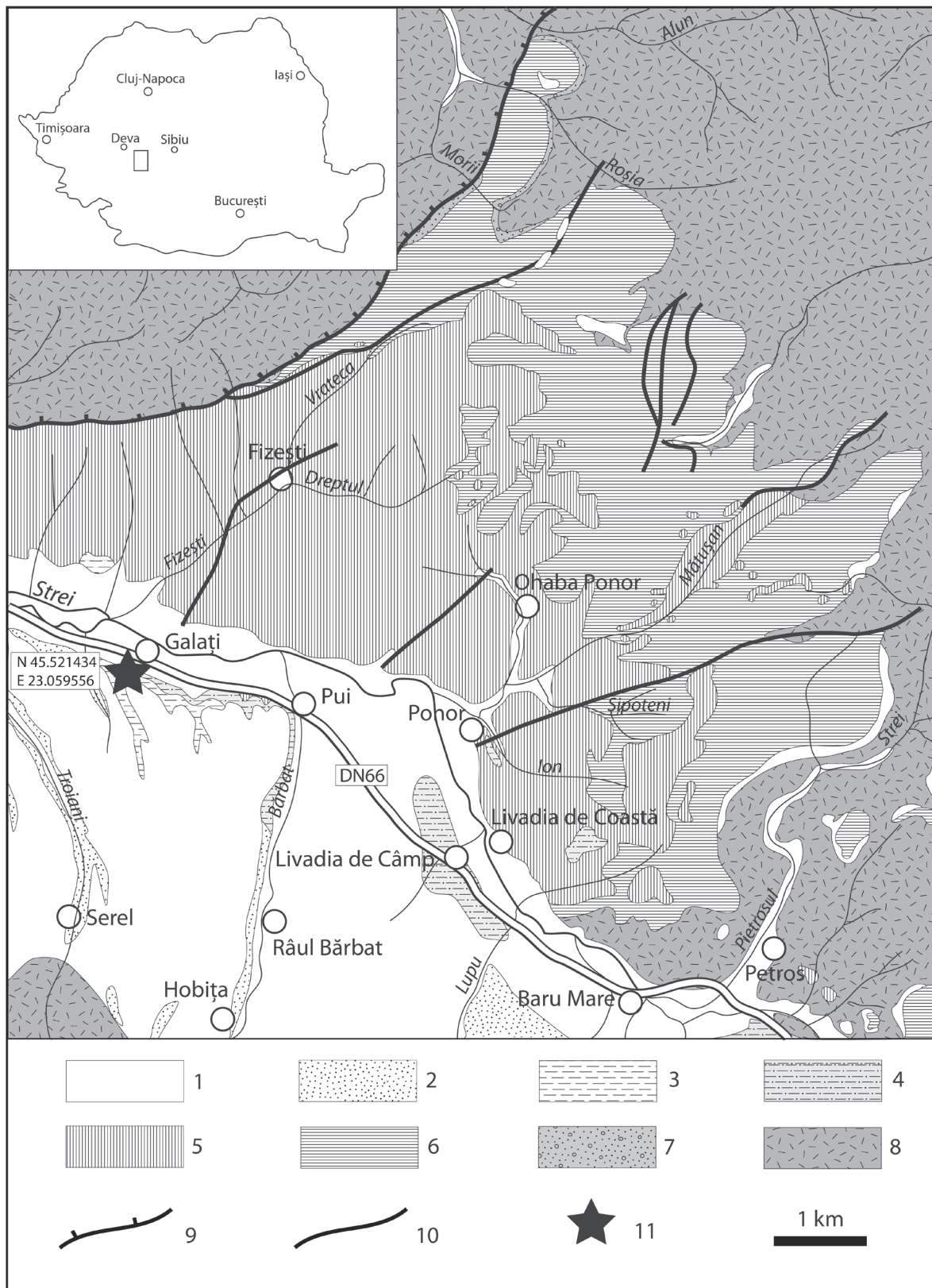


Fig. 1. Geological map of the studied section (based on Știllă 1985). 1 — Quaternary; 2 — Sarmatian; 3 — Badenian; 4 — Paleogene; 5 — Cretaceous; 6 — Jurassic; 7 — Permian; 8 — Paleozoic metamorphites; 9 — Thrust; 10 — Fault; 11 — Location of the studied section.

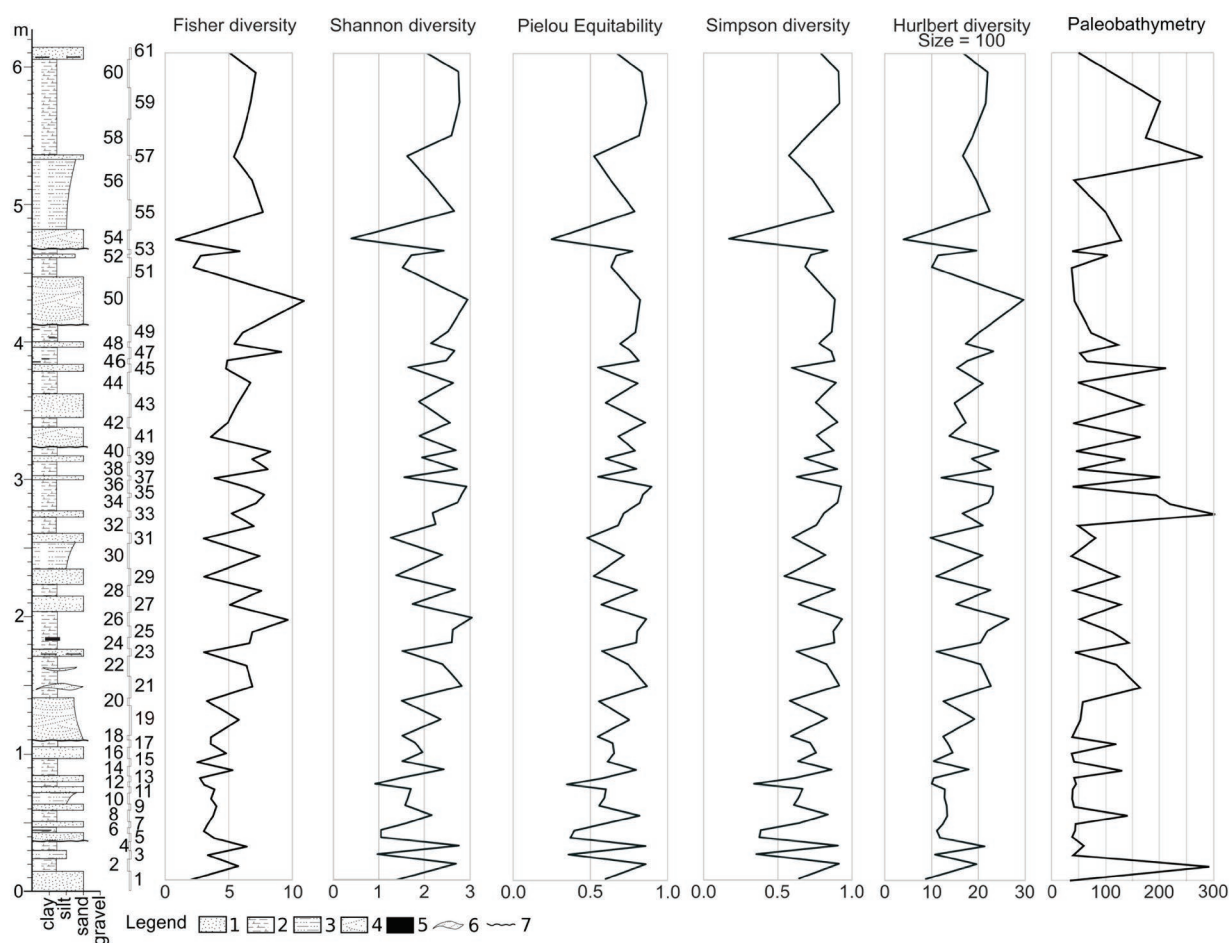


Fig. 2. Position of samples on lithological column, values of the diversity indices (Fisher, Shannon, Pielou Equitability, Hurlbert size 100) and paleobathymetry (in meters). 1 — Sand; 2 — Clay/Marls; 3 — Silt; 4 — Cross stratification structures; 5 — Coal; 6 — Sand lenses; 7 — Erosional surface.

For a correct interpretation, the analyzes were done separately on benthic and planktonic species (Fig. 3). A biozonation scheme was made for the studied area with the position of the studied section (Fig. 4).

Planktonic foraminifera were used to estimate the paleobathymetry (Fig. 2) by planktonic/benthic (P/B) ratios (Murray 1991). Additional data were gathered by using the van der Zwaan et al. (1990) transfer function: $D = 2.71828^{[3.58718 + (0.03534 * \%P)]}$, where “D” is the estimated water depth and “%P” is the percentage of planktonic foraminifera. Important information on paleoecology was provided by smaller benthic foraminifera by analyzing the preferred feeding strategies (suspensivore, detritivore, and herbivore feeders – Fig. 3 right column) and on their preferred living habitat (epifaunal, infaunal – Fig. 3 middle column). The separation into groups was done based on Murray’s papers (1991, 2006).

Benthic foraminifera were used to estimate the level of dissolved oxygen in the water (BFOI – Benthic Foraminifera Oxygenation Index; Kaiho 1991, 1994; Kaiho & Hasegawa 1994). Oxidic (O), dysoxic (D), and intermediate species (I)

were separated and the calculated BFOI values were converted into analog oxygen values (Table 1). The BFOI respects the following equation: $BFOI = 100(O/O+D)$. When $O=0$ and $D+I>0$ the equation becomes $BFOI = 50[I/(I+D)-1]$ where I represents the number of intermediate indices. Due to the high number of *Asterigerinata planorbis* individuals and in order to correlate the distribution of the species with the oxygenation, a graph of the percentage distribution was computed (Fig. 5). Relative paleotemperature was estimated by correlating the planktonic foraminifera species with their respective preferred environment or climate (Bicchi et al. 2006; Hohenegger et al. 2008; Szekely et al. 2017 – Table 2).

Following counting of the fossil foraminifera specimens, statistical methods (including both univariate and multivariate indices) were applied to obtain paleoecological proxy records (Fig. 2), using a statistical program (microStatistics) having the same functions as PAST version 0.96 (Hammer et al. 2001). The following diversity indices were used: Fisher Alpha Diversity Index (Fisher et al. 1943), which takes into account the species abundance and the number of individuals. High values of this index indicate high diversities of the assemblages

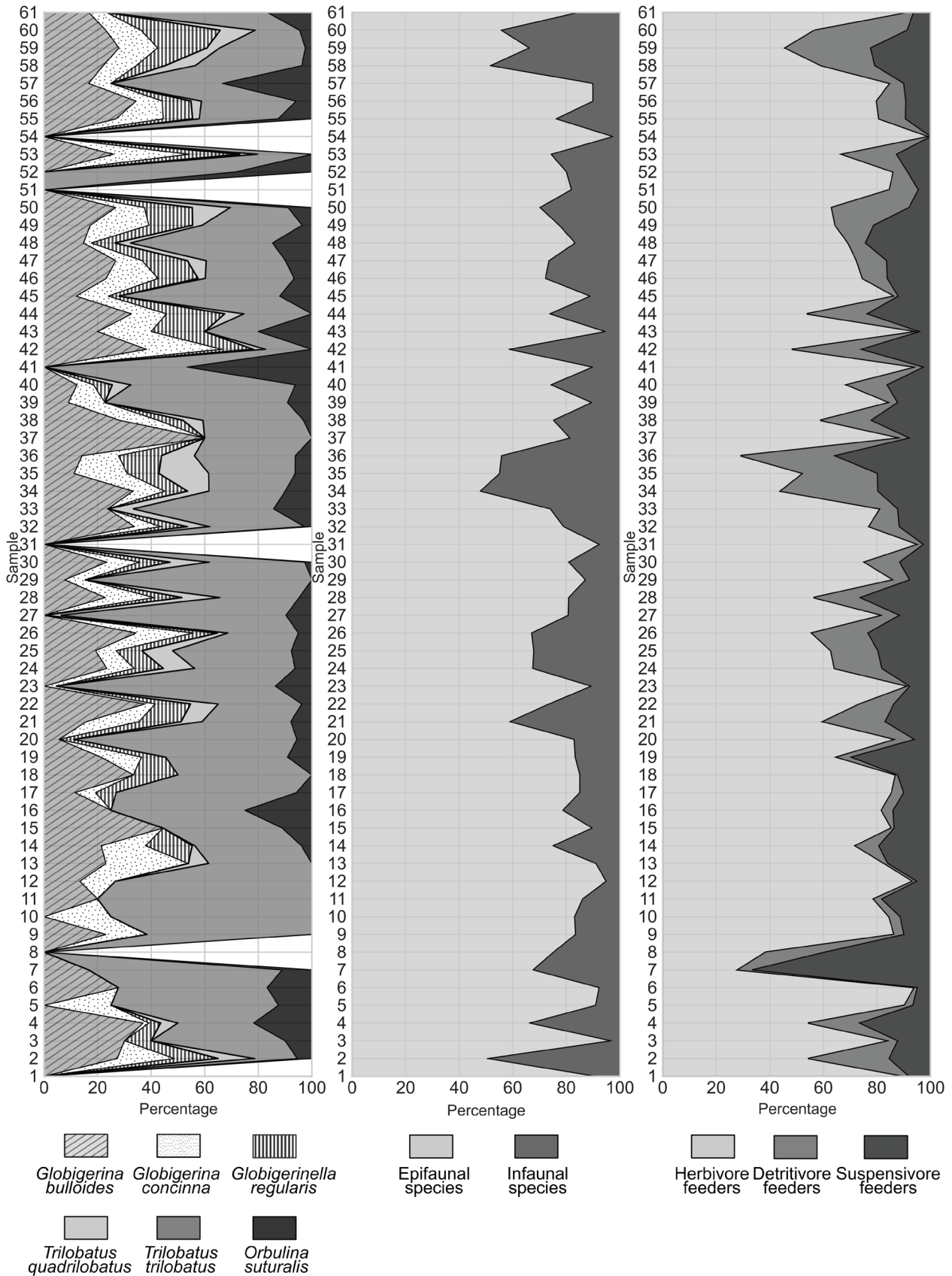


Fig. 3. Distribution of planktonic species, the distribution of species based on the preferred living habitat (infaunal, epifaunal), and feeding strategies (herbivore, detritivore, suspensivore).

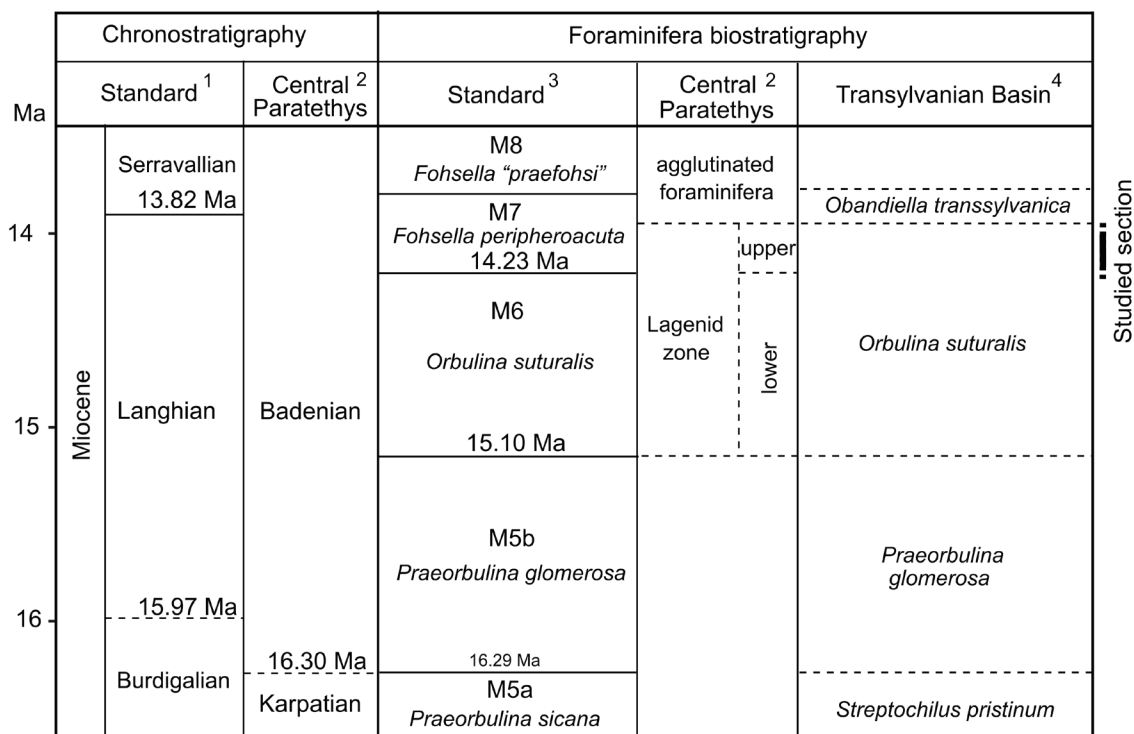


Fig. 4. Lower to middle Miocene chronostratigraphy and foraminifera biostratigraphy including the position of the studied section (based on Popescu 1975; Beldean et al. 2010; Wade et al. 2011; Gradstein et al. 2012; de Leeuw et al. 2013; Filipescu & Filipescu 2014; Hohenegger et al. 2014). 1 — Based on Gradstein et al. (2012); 2 — Based on Hohenegger et al. (2014); 3 — Based on Wade et al. (2011); 4 — Based on Popescu (1975), Beldean et al. (2010), de Leeuw et al. (2013), and Filipescu & Filipescu (2014); Horizontal line — formal boundary; Dashed line — informal boundary.

(Murray 1991); Shannon Diversity Index (Shannon 1948) depends both on the relative abundance of a species as well as the richness of the sample (Murray 1991); Simpson Diversity Index (Simpson 1949) is an index that measures the likelihood that two individuals randomly chosen belong to the same species; it considers the evenness of the sample as well as its richness; Hurlbert's Index (Hurlbert 1971) assumes that the richness of a species usually increases with a greater number of individuals that belong to that species. To compare two different samples in which the total number of individuals differ, the index proposes that the samples should be reduced to a common size, noted with *n*.; Pielou's equitability (Pielou 1975) measures how even an analyzed sample is in regard to the individuals belonging to each species.

Multivariate indices (described by Hammer & Harper 2006) were applied to the benthic taxa. Hierarchical clustering (dendrograms – Fig. 6) was performed using the Paired group algorithm (distance), the Bray-Curtis similarity index (Clifford & Stephenson 1975), and a 0.83 correlation coefficient.

The resulting dendrogram grouped certain samples into clusters based on the level of similarity between the benthic foraminiferal assemblages. The clusters were compared with the raw data (present in Appendix) which contains the absolute number of individuals of each benthic species in each analyzed sample to better understand the way certain samples were grouped by the program.

Table 1: Oxygen values in the environment and the corresponding BFOI values (after Kaiho 1991, 1994; Kaiho & Hasegawa 1994).

Oxygenation values in the environment	BFOI
Very oxygenated 3.0–6.0 ml/l	50 to 100
Oxic 1.5–3.0 ml/l	0 to 50
Suboxic 0.3–1.5 ml/l	–40 to 0
Disoxic 0.1–0.3 ml/l	–50 to –40
Anoxic 0.0–0.1 ml/l	–55

Results

Sedimentation

The studied section consists of thin alternating beds and laminae of sand, silt, and clay, showing a fining upward trend (Fig. 2). The first meters of the succession are characterized by relatively thick sand intervals when compared to the silt and clay intervals. Towards the top of the succession, the thick beds of sand are replaced by increasingly thicker beds of silt and especially clay, suggesting a deepening trend. Coal thin intercalations (samples 6, 23, 24, 46 and 61), cross-stratification intervals (samples 18–20, 41, 50 and 54), erosional surfaces (samples 4–5, 17–18, 40–41, 49–50 and 53–54), and

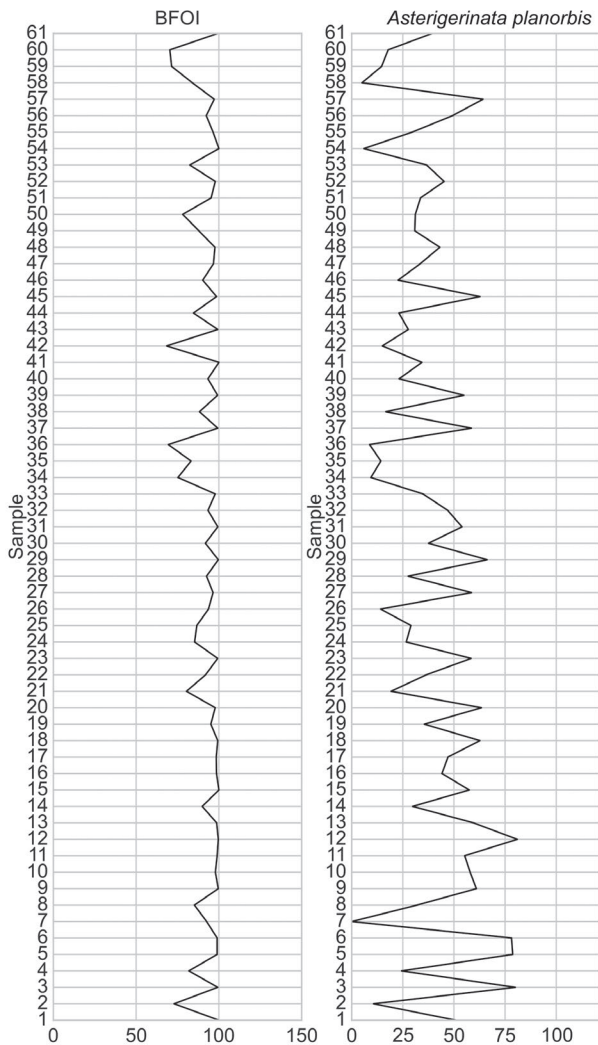


Fig. 5. BFOI values corresponding to each sample and the distribution of the epifaunal species *Asterigerinata planorbis*.

strata discontinuities were observed throughout the sedimentary succession; all these observations were illustrated in the lithological log in Figure 2.

Biostratigraphy

The first occurrence *Orbulina suturalis* in the Transylvanian Basin corresponds to the C5ADn Chron, more precise to the upper part of the early Badenian (de Leeuw et al. 2013). This is consistent with the major biozonations from the central Paratethys (Cicha et al. 1998; Hohenegger et al. 2014; Kováč et al. 2018). Even if we could not identify the first stratigraphic occurrence of *Orbulina suturalis* Brönnimann, its constant presence along the studied section suggests a late early Badenian (mid-late Langhian) age for the sampled interval (Fig. 4) (Hohenegger et al. 2014).

Additionally, *Uvigerina grilli* is also very common (Appendix) and it seems to be restricted to the mid Badenian “upper Lagenid zone” (Papp et al. 1978; Cicha et al. 1998).

Table 2: Planktonic foraminifera and their water temperature preference (Spezzaferri 1992; Bicchi et al. 2006; Hohenegger et al. 2008; Rupp & Hohenegger 2008 and Szekely et al. 2017).

Species	Climate/Temperature
<i>Globigerina bulloides</i>	Temperate (10–20 °C)
<i>Globigerina concinna</i>	Temperate (10–20 °C)
<i>Globigerinella regularis</i>	Warm (20–25 °C)
<i>Orbulina suturalis</i>	Warm (20–25 °C)
<i>Trilobatus quadrilobatus</i>	Warm (20–25 °C)
<i>Trilobatus trilobus</i>	Warm (20–25 °C)

As Hohenegger et al. (2014) exclude the overlap of the *Orbulina suturalis* and “upper Lagenid” biozones, we consider that either the biostratigraphic value of *Uvigerina grilli* should be reconsidered or the correlation between the “Lagenid zones” and the planktonic biozones should be revised.

Based on the facts mentioned above, we consider that the age of the investigated section should be late early Badenian (Fig. 4).

Foraminifera paleoecology

The foraminifera assemblages are diverse and abundant in the analyzed section, while the preservation of individuals is variable but usually moderate to good (Figs. 7 and 8). The identified taxa (46 species and 8 genera) and their distribution and abundance are presented in Appendix. Among the benthic foraminifera assemblages, the calcareous benthics are by far the most well-represented group in all the samples (out of the total species they are distributed in 42); the agglutinated group is represented only by: *Martinotiella karreri*, *Spirorutilus carinatus*, and *Textularia* sp. The planktonics are represented by: *Globigerina concinna*, *G. bulloides*, *Trilobatus quadrilobatus*, *T. trilobus*, *Globigerinella regularis*, *Orbulina suturalis*.

All the identified foraminifera species were separated based on their preferred habitat (benthic infaunal, epifaunal, and planktonic – Fig. 3 – middle and left column) and their feeding strategies (suspensivore, detritivore, and herbivore – Fig. 3 – right column) (Murray 1991, 2006).

The infaunal and epifaunal species distribution graph shows that the most abundant are the epifaunal rotaliids (*Amphistegina mamilla*, *Asterigerinata planorbis*, *Cibicidoides ungerianus*, *Hanzawaia boueana*, *Heterolepa dutemplei*). Their abundance varies throughout the section, with a minimum of 50.46 % in sample 2 and a maximum of 97.33 % in sample 54. The graph also shows a clear negative correlation between the abundance of epifaunal and planktonic species. The most common infaunal species and genera are *Ammonia vienensis*, *Bolivina* sp., *Elphidium fichtelianum*, *Hoeglundina elegans*, *Lagena striata*, *Melonis pompilioides*, *Nonion commune*, and *Uvigerina grilli*. Their percentual distribution ranges from a minimum of 2.66 % in sample 54 to a maximum of 52.13 % in sample 34.

The suspension feeders (*Anomalinoidea badenensis*, *Cibicidoides ungerianus*, *Hanzawaia boueana*, *Heterolepa*

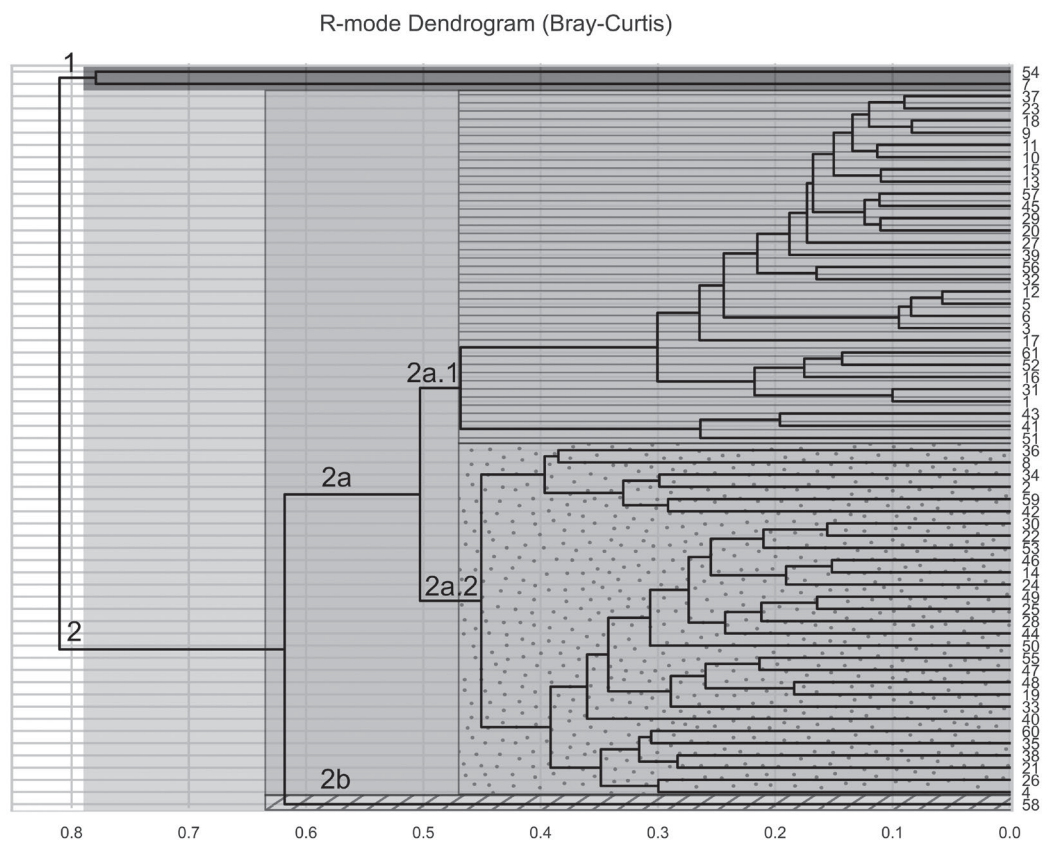


Fig. 6. R-mode Dendrogram using the Bray-Curtis distance matrix.

dutemplei, *Lobatula lobatula*) (Murray 1991, 2006) and detritus feeders (*Bolivina* sp., *Bulimina striata*, *Hoeglundina elegans*, *Laevidentalina* sp., *Lagena striata*, *Lenticulina inornata*, *Melonis pompilioides*, *Pullenia bulloides*, *Uvigerina* sp.) (Murray 1991, 2006) are the least predominant in all the samples. The percentual distribution of the suspension feeders ranges from 0 % in sample 54 to 66.66 % in sample 7. The percentual distribution of the detritus feeders varies from a minimum of 0.66 % in sample 54 to a maximum of 34.36 % in sample 34. The herbivores (*Ammonia vienensis*, *Amphistegina mamilla*, *Asterigerinata planorbis*, *Elphidium* sp., *Nonion commune*, *Pararotalia aculeata*, *Quinqueloculina hauerina*, *Spiroloculina canaliculata*) (Murray 1991, 2006) represent by far the most abundant group, the percentages ranging from 27.95 % in sample 7 to 99.33 % in sample 54.

The BFOI (Benthic Foraminifera Oxygenation Index, Kaiho 1994) method was used to estimate the amount of dissolved oxygen in the water. After separating the groups into oxic (*Ammonia vienensis*, *Amphistegina mamilla*, *Asterigerinata planorbis*, *Cibicidoides ungerianus*, *Elphidium* sp., *Hanzawaia boueana*, *Heterolepa dutemplei*, *Lobatula lobatula*, *Planostegina* sp., *Planularia venezuelana*), dysoxic (*Amphicoryna badenensis*, *Bolivina antiqua*, *B. dilatata*, *Bulimina striata*, *Laevidentalina* sp.), and suboxic (*Lenticulina inornata*, *Melonis pompilioides*, *Uvigerina grilli*) taxa (Kaiho 1994) the resulting graph shows the oxygen levels present in

the environment and the corresponding BFOI value (Fig. 5), with the minimum value of 70 in samples 36 and 42 and the maximum of 100 in 16 samples throughout the studied section. It is observed that these values are correlated with the percentage values of the species *Asterigerinata planorbis* which has a percentual distribution of 8.77 % in sample 36, 15 % in sample 42 and ranges from 27.67 % to 80.94 % in the samples with the highest BFOI values. The presence of *Asterigerinata planorbis* in sample 54 is only 5.96 % and therefore the reason for the high BFOI value is attributed to the large percentage of the oxic species *Amphistegina mamilla*.

The percentual distribution of the planktonic species (Fig. 3 – left column) shows that the distribution of *Globigerina bulloides* ranges from 0 % in some samples to 60 % in sample 37, while *Globigerina concinna* ranges from 0 % to 30.76 % in sample 13. *Trilobatus quadrilobatus* has a maximum distribution of 18.63 % in sample 35, *Globigerinella regularis* reaches its maximum distribution in sample 60 (29.60 %), and the marker species *Orbulina suturalis*, present in almost all the samples, is the most frequent in sample 52 (28.57 %). The most abundant planktonic species is *Trilobatus trilobus*, often dominating the assemblages, with its maximum distribution (84.61 %) in sample 29.

The values of the calculated diversity indices range widely: Fisher Alpha from 0.85 to 10.89, Simpson from 0.17 to 0.93, Shannon from 0.40 to 3.03, Hurlbert from 4.01 to

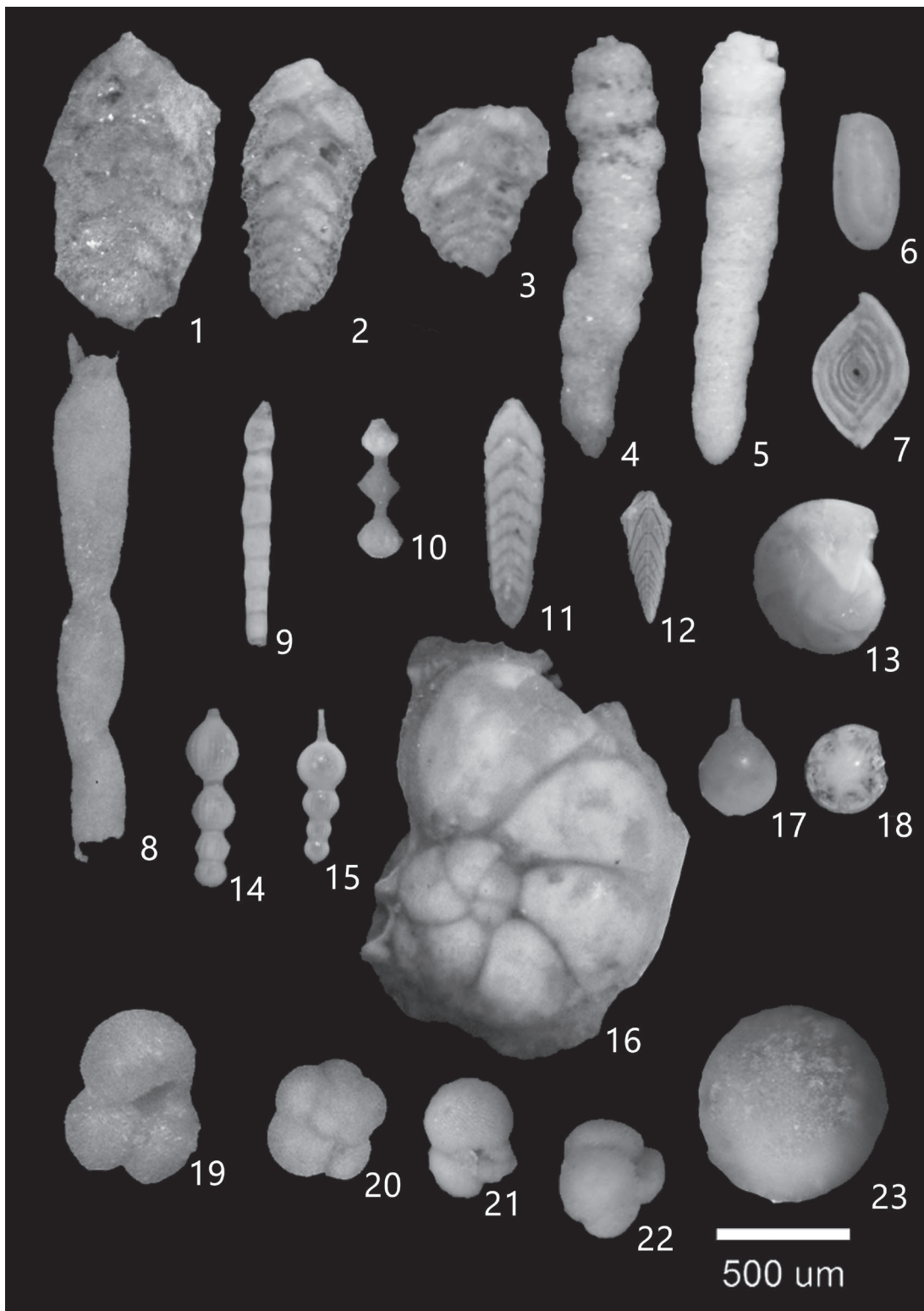


Fig. 7. 1–3 — *Spirorutilus carinatus* (d'Orbigny, 1846) samples 28, 36, 40; 4–5 — *Martinottiella karreri* Cushman, 1933 samples 12 and 30; 6 — *Quinqueloculina hauerina* d'Orbigny, 1846 sample 4; 7 — *Spiroloculina canaliculata* d'Orbigny, 1846 sample 36; 8 — *Dentalina* sp. sample 4; 9 — *Laevidentalina communis* (d'Orbigny, 1826) sample 4; 10 — *Nodosaria hipsida* d'Orbigny, 1846 sample 13; 11 — *Plectofrondicularia digitalis* Neugeboren 1850 sample 22; 12 — *Frondicularia* sp. sample 22; 13 — *Lenticulina inornata* (d'Orbigny, 1846) sample 11; 14–15 — *Amphicoryna badenensis* (d'Orbigny, 1846) sample 4; 16 — *Planularia venezuelana* Hedberg, 1937 sample 7; 17 — *Lagena striata* (d'Orbigny, 1839) sample 9; 18 — *Hoeglundina elegans* (d'Orbigny, 1826) sample 21; 19 — *Globigerina bulloides* d'Orbigny, 1826 sample 2; 20 — *Globigerina concinna* Reuss 1850 sample 2; 21 — *Trilobatus trilobus* (Reuss, 1850) sample 14; 22 — *Trilobatus quadrilobatus* (d'Orbigny, 1846) sample 24; 23 — *Orbulina suturalis* Brönnimann, 1951 sample 4.

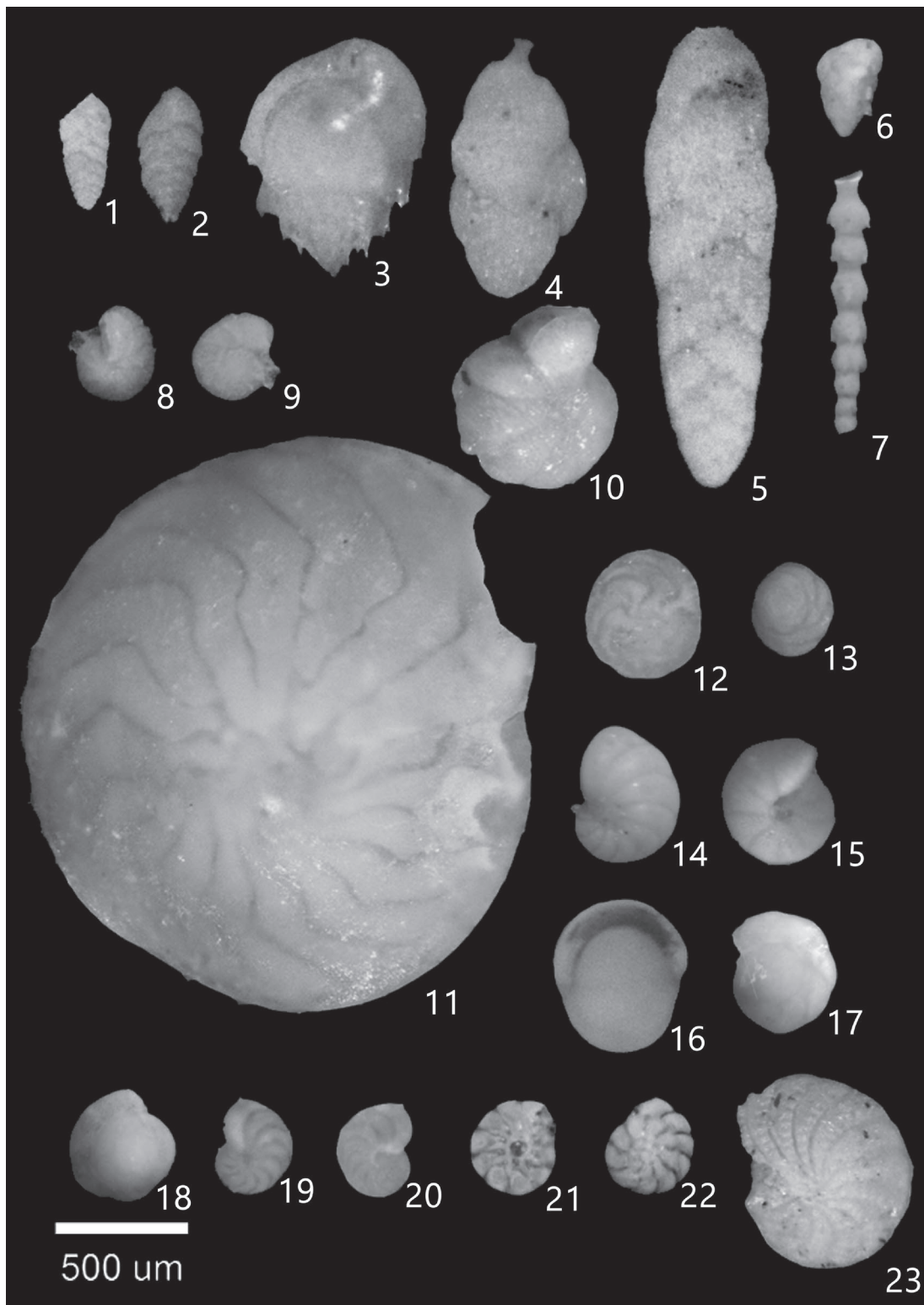


Fig. 8. 1 — *Bolivina antiqua* (d'Orbigny, 1846) sample 4; 2 — *Bolivina dilatata* Reuss, 1850 sample 19; 3 — *Bulimina striata* d'Orbigny, 1832 sample 8; 4 — *Uvigerina grilli* Schmid, 1971 sample 8; 5 — *Loxostomum digitalis* (d'Orbigny 1846) sample 35; 6 — *Reusella spinulosa* (Reuss, 1850) sample 12; 7 — *Stillostomella adolphina* (d'Orbigny, 1846) sample 2; 8–9 — *Cibicidoides ungerianus* (d'Orbigny, 1846) sample 11; 10 — *Lobatula lobatula* (Walker & Jacob, 1798) sample 21; 11 — *Amphistegina mamilla* (Fichtel & Moll, 1798) sample 41; 12–13 — *Asterigerinata planorbis* (d'Orbigny, 1846) sample 3; 14 — *Nonion commune* (d'Orbigny, 1846) sample 16; 15 — *Melonis pompilioides* (Fichtel & Moll, 1798) sample 21; 16 — *Pullenia bulloides* (d'Orbigny, 1846) sample 4; 17–18 — *Heterolepa dutemplei* (d'Orbigny, 1846) sample 10; 19–20 — *Hanzawaia boueana* (d'Orbigny, 1846) sample 8; 21–22 — *Ammonia vienensis* (d'Orbigny, 1846) sample 9; 23 — *Elphidium fichtelianum* (d'Orbigny, 1846) sample 15.

29.63, and Pielou's equitability from 0.24 to 0.89, as shown in Fig. 2.

Two main clusters, informally named 1 (dark grey) and 2 (light grey) have been separated for benthic foraminifera assemblages (Fig. 6). Samples 7 and 54 are combined in cluster 1 and are both characterized by low percentages of *Asterigerinata planorbis* and low diversities (Fig. 2). Sample 7 shows the highest number of *Anomalinoidea badenensis* (55.8 %) when compared to other samples while sample 54 is dominated by very high numbers of *Amphistegina mamilla* (90.7 %).

Sub-cluster 2a was separated into sub-clusters 2a.1 (horizontal lines) and 2a.2 (dots). In general, the samples contained in sub-cluster 2a.1 are characterized by the lowest diversities (e.g., the average of Fisher alpha index: 3.98) in all the assemblages (Fig. 2) and relatively high BFOI values (Fig. 5). In general, samples contained in sub-cluster 2a.2 (dots) are characterized by the highest diversities throughout the section (e.g., the average of Fisher alpha index: 6.78) (Fig. 2). This is largely due to an increase in the number of infaunal species and individuals (e.g. *Bolivina* sp., *Bulimina* sp., *Uvigerina* sp.). A moderate increase in the number of *Uvigerina* sp. (ranging from 2.14 % in sample 42 to 7.69 % in sample 8) and a high increase in the number of *Bolivina* sp. (5.49 % in sample 59 and 8.92 % in sample 42) was observed in samples 2, 8, 34, 36 and especially 42 and 59. Inside cluster 2a.1, samples 41 and 43 were grouped due to a sudden increase in *Quinqueloculina hauerina* (5.94 % in sample 41 and 13.20 % in sample 43).

Sample 58 (slant lines) is considered an outlier sample, separated based on the highest proportion (24.24 %) of *Nonion commune* out of the benthic species.

Discussions

Paleotemperature

Planktonic foraminifera are known to be good indicators of climate change throughout the earth's history (Bemis et al. 1998; Kucera et al. 2005; Kucera 2007). Even if the number of species is not high (all planktonic individuals belong to: *Globigerina concinna*, *G. bulloides*, *Trilobatus quadrilobatus*, *T. trilobus*, *Globigerinella regularis*, *Orbulina suturalis* taxa), their presence in the assemblages can be a good indicator for the paleotemperature of the surface water. The preferred paleoclimatic characteristics of the aforementioned species were correlated with the references from literature (Spezzaferri 1992; Bicchi et al. 2006; Hohenegger et al. 2008; Rupp & Hohenegger 2008; Szekely et al. 2017) and synthesized in Table 2. Although almost all samples contain planktonic foraminifera with variable percentual distributions, the most frequent species is *Trilobatus trilobus* (with a maximum of 84.61 % in sample 29 out of all the planktonic species identified in that particular sample). This species was reported from warm surface waters with salinity fluctuations (Bé 1977;

Reynolds & Thunell 1985; Hemleben et al. 1989; Schiebel & Hemleben 2005; Schmuker 2000; Holcová et al. 2019). Like *T. trilobus* the *Trilobatus quadrilobatus*, *Globigerinella regularis* and *Orbulina suturalis* taxa were reported as characteristic of warm waters conditions (Spezzaferri & Premoli Silva 1991; Spezzaferri 1995, 1996; Bicchi et al. 2003).

At few intervals (for example samples 42 and 53) the proportion of temperate taxa (*Globigerina bulloides* and *Globigerina concinna*) exceeds the warm taxa. *Globigerina bulloides* was reported to thrive in cold to temperate waters with oscillations in temperature and salinity (Rupp & Hohenegger 2008; Kretschmer et al. 2018). The species is characteristic for sub-surface waters with high productivity during the spring (Holcová et al. 2019) and is associated with open-ocean and/or coastal upwelling (Naidu & Malmgren 1996; Kincaid et al. 2000; Mohiuddin et al. 2005; Storz et al. 2009). Both *G. bulloides* and *G. concinna* belong to the "Four-chambered globigerinids" group which is characteristic for cold waters (Spezzaferri 1992; Bicchi et al. 2003; Rupp & Hohenegger 2008).

The paleotemperature and climate can only be estimated, but when compared with published data (Spezzaferri 1992; Bicchi et al. 2003, 2006; Hohenegger et al. 2008; Rupp & Hohenegger 2008; Szekely et al. 2017) it can be presumed that the net abundance of *T. trilobus* occurring together with warm water indicators *T. quadrilobatus*, *Globigerinella regularis*, and *Orbulina suturalis* characterize warm waters for most of the succession (Table 2). The local abundance of temperate indicators may be attributed to cold currents or seasonal influences.

Paleobathymetry and paleoecology

Paleobathymetry was calculated by using the relative abundance of planktonic foraminifera (van der Zwaan et al. 1990; Murray 1991; Spezzaferri et al. 2002; Szekely et al. 2017). Even if salinity, productivity, oxygenation, and connections to the world oceans (Ulleberg 1974; Naidu & Malmgren 1996; Hohenegger 2005; van Hinsbergen et al. 2005) have their influence, we consider the planktonic/benthic (P/B) ratio as a reliable indicator of changes in paleobathymetry. Taking into account the composition of the foraminifera assemblages and the P/B ratio, it can be assumed that the sediments were deposited in shallow marine settings with a minimum depth in samples 1, 31, and 54 and a maximum depth in sample 34 (Fig. 2). Intervals with cross-stratification, erosional surfaces, and strata discontinuities suggest episodes of instability in the environment, mainly due to increased hydrodynamic energy. In general, sandy intervals are characterized by the low diversity of the assemblages. A good example is sample 54, which is almost entirely dominated by one species – *Amphistegina mamilla* – with particularly large, thick, and robust tests, suggesting the developed adaptability to agitated waters and a rough substrate. The thin intercalations of coal can probably be related to regressive episodes.

The benthic (infaunal and epifaunal) and planktonic distribution graphs reveal that the epifaunal rotaliids (*Amphistegina mamilla*, *Asterigerinata planorbis*, *Cibicidoides ungerianus*, *Elphidium fichtelianum*, *Hanzawaia boueana*, *Heterolepa dutemplei*) negatively correlate with the planktonic forms, under the influence of paleodepth and hydrodynamic energy. Generally, increased numbers of epifaunal species indicate shallow, high energy, sandy depositional environment, while an increased number of planktonic foraminifera suggests deeper water, muddy sediment, and low current velocities (Murray 1991, 2006). In our case, the highest values of the P/B ratio correspond to the clay intervals in which the epifaunal forms occur in lower proportions (Figs. 2 and 3 – samples 2, 34, and 56).

The relative depth of the water can be correlated with the overall size and thickness of the *Amphistegina mamilla* tests, which tend to reduce with depth (Hallock & Hansen 1979). Most of the collected tests are large, thick, and robust, thus suggesting shallow waters. The sand intervals with cross-stratification sedimentary structures (Fig. 2) also suggest shallow, agitated waters, while the high BFOI values (Fig. 5) and low diversity suggest an oligotrophic environment.

Shallower conditions correspond to samples 7 and 54 from Cluster 1 (a low proportion of *Asterigerinata planorbis* and a high proportion of symbiont bearing *Amphistegina mamilla*). Furthermore, the paleobathymetry graph (Fig. 2) and the absence of planktonic species support this interpretation.

A large number of herbivore species (*Ammonia vienensis*, *Amphistegina mamilla*, *Asterigerinata planorbis*, *Elphidium* sp., *Nonion commune*, *Pararotalia aculeata*), sometimes reaching more than 90 % (samples 1, 5, 6, 12, 23, 31, 41, 43, 54 and 61) and low to moderate percentages of suspension feeders (*Anomalinoidea badenensis*, *Cibicidoides ungerianus*, *Hanzawaia boueana*, *Heterolepa dutemplei*, and *Lobatula lobatula*) and detritus feeders (*Bolivina* sp., *Bulimina striata*, *Hoeglundina elegans*, *Laevidentalina* sp., *Lagena striata*, *Lenticulina inornata*, *Melonis pompilioides*, *Pullenia bulloides*, and *Uvigerina grilli*) can be correlated with the relatively shallow water depth (mean calculated values around 80 m). Additionally, the presence of herbivore species suggests that the paleoenvironment was restricted to the photic zone. Due to the increased percentages of the herbivore *Asterigerinata planorbis*, it can be deduced that the substrate was vegetated, based on the preference of this species for seagrass meadows.

The amount of the oxygen dissolved in the water expressed by BFOI values was estimated using the oxic (*Ammonia vienensis*, *Amphistegina mamilla*, *Asterigerinata planorbis*, *Cibicidoides ungerianus*, *Elphidium* sp., *Hanzawaia boueana*, *Heterolepa dutemplei*, *Lobatula lobatula*, *Planostegina* sp., *Planularia venezuelana*), dysoxic (*Amphicoryna badenensis*, *Bolivina antiqua*, *B. dilatata*, *Bulimina striata*, *Laevidentalina* sp.), and suboxic (*Lenticulina inornata*, *Melonis pompilioides*, *Uvigerina grilli*) species (Fig. 5). Although there are some variations in the oxygen levels, the BFOI never dropped below 50, which suggests very well-oxygenated waters and substrate surfaces. The BFOI levels are correlated with the granulation

of the sediment, meaning that the infaunal species increase in clay or silt intervals, while the BFOI values slightly decrease. The reduced amount of dissolved oxygen was deduced from the increase in infaunal species tolerant to more dysoxic and suboxic conditions. The relative abundance of the most dominant *Asterigerinata planorbis* (Fig. 5) indicates very well-oxygenated waters (Murray 1991; Rögl & Spezzaferri 2002; Di Bella 2010; Pezelj et al. 2016) and an environment with algal or seagrass meadows (Pezelj et al. 2016; Pivko et al. 2017). Although not entirely parallel, the two graphs have the same trend and fluctuate in similar ways, suggesting that the oxygen levels directly correlate with the number of *Asterigerinata planorbis* specimens. This epiphytic species is most abundant in the sands on the shelf (Drinia et al. 2007), predominantly thriving at depths between 0–100 m (Pipperr & Reichenbacher 2009). Its abundance correlates with high BFOI values, as it prefers well-oxygenated environments; its frequency decreases significantly in muddy intervals together with the BFOI values, while suboxic and dysoxic infaunal taxa dominate.

The lower proportion of infaunal species and very low diversity in samples 3, 5, 6, 12, and 54, suggest mesotrophic to oligotrophic conditions. The abundant *Asterigerinata planorbis* (samples 3, 5, 6, 12) and *Amphistegina mamilla* (sample 54) indicate higher levels of dissolved oxygen, as supported by the BFOI values.

The diversity graphs (Fig. 2) also show intervals with particularly high diversities (samples 21, 26, 34, 36, and 50), with increased proportions of infaunal species (*Bolivina dilatata*, *Bulimina striata*, *Nonion commune*, *Uvigerina grilli*) and planktonics (*Globigerina* and *Trilobatus*). The BFOI values are slightly lower compared to the previous interval, due to the higher proportion of suboxic and dysoxic species. The estimated water depth graph (Fig. 2) shows an increase for the upper part of the section, as also suggested by the higher proportion of planktonics and the muddy substrate. The high diversity and low BFOI values suggest mesotrophic conditions. The influence of the substrate on diversity and abundance can be observed in the interval between samples 37 to 47 (Fig. 2), where the diversity changes with the grain size of the sediment (lower diversity in sands and higher diversity in clays).

Samples represented in sub-cluster 2a.1 (lowest diversities and high BFOI values – Figs. 2 and 5) are specific for intervals with decreased organic matter availability, well-oxygenated environments, and oligotrophic conditions. The sudden increase of *Quinqueloculina hauerina* in samples 41 (5.94 %) and 43 (13.20 %) (Sub-cluster 2a.1) suggest low oxygen conditions (Eichler et al. 2003); this is supported by the high BFOI values (Fig. 5). The genus *Quinqueloculina* sp. seems to tolerate salinity and temperature fluctuations (Murray 2006, Gómez-León et al. 2018), as probably was the case of the mentioned samples, which follow an erosional surface (Fig. 2), where the paleoecological parameters changed.

Favorable paleoecological conditions can be attributed to the intervals from sub-cluster 2a.2, which record the highest

diversities throughout the section (Fig. 2) and a high number of infaunal specimens (*Bolivina* sp., *Bulimina* sp., *Uvigerina* sp.). Increased percentages of *Bolivina* were reported from the Miocene deposits (Thomas 1986; Sen Gupta & Machian-Castilio 1993; Sen Gupta 2002; Beldean et al. 2010), while bolivinids are considered to be indicators of high productivity (Smart et al. 2007). The high diversities point out high organic matter flux and poorly oxygenated subsurface. The abundant infaunal dysoxic and suboxic species correlate with lower levels of oxygen (Fig. 5) compared to the rest of the succession. These suggest eutrophic conditions for the mentioned intervals.

The sub-cluster 2b (sample 58) characterizes an interval with particular eutrophic conditions indicated by the highest percentages of *Nonion commune* (24.24 % out of the benthic species), high percentages of the infaunal group (Fig. 3) and relatively high diversity values (Fig. 2). Similar abundances of *Nonion commune* were reported by Holcová (2017) and are associated with a high supply of organic material to the seafloor provided by riverine input.

Conclusions

The analyses and interpretations showed that the foraminifera assemblages are well preserved, diverse and abundant and therefore the studied section can be used for biostratigraphic correlation and paleoenvironmental reconstructions at a basin and regional scale.

Biostratigraphically, the planktonic *Orbulina suturalis*, and the benthic *Uvigerina grilli* support a late early Badenian age.

Although the paleoenvironments frequently fluctuate from the inner to the outer shelf, the main depositional environment can be restricted to the continental shelf. The lithology and composition of foraminifera assemblages demonstrate facies shifts and a deepening upward trend along the section.

Paleotemperatures suggested by planktonic foraminifera indicate relative warm waters with local influences of cold currents or seasonal influences.

The dominant epifaunal rotaliid species can be correlated with high BFOI values, suggesting very well-oxygenated waters and substrate, with rare episodes of decreased oxygen content.

The diversity changes throughout the section, pointing towards variations in the nutrient supply, temperature, salinity, and hydrodynamic conditions.

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Appendix

Distribution of foraminifera in the studied samples.

Species/Samples	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
<i>Ammonia vienensis</i> (d'Orbigny, 1846)	15	5	0	0	3	7	13	0	28	18	18	2	0	0	7	21
<i>Amphistegina mamilla</i> (Fichtel & Moll, 1798)	91	0	5	20	5	8	57	0	21	33	27	3	39	6	42	54
<i>Amphicoryna badenensis</i> (d'Orbigny, 1846)	0	9	0	9	0	0	0	0	0	0	0	0	0	9	0	0
<i>Anomalinoidea</i> sp.	0	1	2	14	0	0	168	7	0	0	0	0	0	0	0	0
<i>Asterigerinata planorbis</i> (d'Orbigny, 1846)	154	33	236	76	237	236	0	54	178	172	168	238	187	81	166	136
<i>Bolivina antiqua</i> (d'Orbigny, 1846)	0	0	2	11	2	3	3	0	0	3	1	1	1	2	0	2
<i>Bolivina dilatata</i> Reuss, 1850	0	6	0	7	1	0	5	11	1	0	0	0	3	3	0	0
<i>Bulimina striata</i> d'Orbigny in Guerin-Meneville, 1832	0	5	0	8	0	0	0	9	0	3	2	0	0	0	0	2
<i>Cibicidoides ungerianus</i> (d'Orbigny, 1846)	11	8	13	23	6	10	3	23	13	17	24	0	26	11	21	23
<i>Dimorphina akneriana</i> (d'Orbigny, 1826)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Elphidium fichtelianum</i> (d'Orbigny, 1846)	7	3	0	7	13	7	8	4	8	12	7	11	10	3	14	9
<i>Elphidium flexuosum</i> (d'Orbigny, 1846)	0	0	0	10	1	5	0	0	0	8	8	0	8	4	5	10
<i>Favulina hexagona</i> (Williamson, 1848)	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Fursenkoina acuta</i> (d'Orbigny, 1846)	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Glandulina ovula</i> d'Orbigny, 1846	6	0	0	0	3	0	0	0	5	3	4	0	0	0	0	3
<i>Globigerina bulloides</i> d'Orbigny, 1826	0	50	3	17	0	5	3	0	3	0	1	2	3	22	4	1
<i>Globigerina concinna</i> Reuss, 1850	0	39	0	1	2	0	0	0	2	1	0	2	4	17	0	0
<i>Globigerinella regularis</i> (d'Orbigny, 1826)	0	30	1	2	0	0	0	0	0	0	0	0	0	18	0	0
<i>Trilobatus quadrilobatus</i> (d'Orbigny, 1846)	0	25	0	3	0	0	0	0	0	0	0	0	1	1	0	0
<i>Trilobatus trilobus</i> (Reuss, 1850)	0	29	5	13	5	10	13	0	8	3	4	11	5	41	4	2
<i>Gutulina comunis</i> (d'Orbigny, 1826)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
<i>Hanzawaia boueana</i> (d'Orbigny, 1846)	10	7	11	25	7	2	8	25	9	5	25	9	22	11	17	6
<i>Heoglundina elegans</i> (d'Orbigny, 1826)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Heterolepa dutemplei</i> (d'Orbigny, 1846)	3	2	6	6	6	2	7	3	5	11	4	5	0	3	0	13
<i>Karrerella chilostoma</i> (Reuss, 1852)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Laevidentalina comunis</i> (d'Orbigny, 1826)	0	0	0	2	0	0	0	1	0	0	0	0	0	0	0	0
<i>Laevidentalina elegans</i> (d'Orbigny, 1846)	0	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0
<i>Lagena striata</i> (d'Orbigny, 1839)	0	0	2	0	0	0	1	0	3	0	0	0	0	0	0	0
<i>Lenticulina inornata</i> (d'Orbigny, 1846)	0	0	0	0	0	0	0	0	1	1	5	2	0	0	0	2
<i>Lobatula lobatula</i> (Walker & Jacob, 1798)	0	0	3	0	0	0	0	9	0	0	1	0	0	6	0	0
<i>Loxostomum digitalis</i> (d'Orbigny 1846)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Martinotiella karreri</i> Cushman, 1933	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
<i>Melonis pompilioides</i> (Fichtel & Moll, 1798)	3	9	3	0	0	0	6	0	2	0	0	0	0	0	0	0
<i>Nodobacularella</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Nonion commune</i> (d'Orbigny, 1846)	0	18	0	21	0	0	0	0	0	0	4	0	5	19	0	13
<i>Orbulina suturalis</i> (Brönnimann, 1951)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Pappina parkeri</i> (Karrer, 1877)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Pararotalia aculeata</i> (d'Orbigny, 1846)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
<i>Planostegina</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Planularia venezuelana</i> Hedberg, 1937	0	0	0	0	1	0	4	0	0	0	0	4	0	0	0	0
<i>Plectofrondicularia digitalis</i> (Neugeboren, 1850)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Pseudotriloculina consobrina</i> (d'Orbigny, 1846)	0	0	0	0	0	0	0	4	0	0	0	0	0	2	0	0
<i>Pullenia bulloides</i> (d'Orbigny, 1846)	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	1
<i>Pyrgo</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Quinqueloculina hauerina</i> d'Orbigny, 1846	0	4	0	5	0	2	0	3	0	2	0	0	0	0	0	2
<i>Reusella spinosa</i> (Reuss, 1850)	0	0	0	0	2	2	0	0	2	0	0	3	0	0	0	0
<i>Spiroloculina canaliculata</i> d'Orbigny, 1846	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Spirorutilus carinatus</i> (d'Orbigny, 1846)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Stilostomella adolphina</i> (d'Orbigny, 1846)	0	5	0	5	0	0	0	3	0	0	0	0	0	2	0	0
<i>Textularia</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Uvigerina grilli</i> Schmid, 1971	2	7	0	13	6	0	0	13	3	5	1	0	0	7	3	6

Distribution of foraminifera in the studied samples.

Species/Samples	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
<i>Ammonia vienensis</i> (d'Orbigny, 1846)	10	25	10	13	0	0	13	2	11	0	12	5	12	3	7	12
<i>Amphistegina mamilla</i> (Fichtel & Moll, 1798)	0	21	30	15	12	6	46	2	0	24	2	5	28	7	101	13
<i>Amphicoryna badenensis</i> (d'Orbigny, 1846)	0	0	2	0	6	4	2	11	5	4	1	3	0	2	0	1
<i>Anomalinoidea</i> sp.	0	2	2	0	0	8	0	1	2	3	0	3	0	0	0	2
<i>Asterigerinata planorbis</i> (d'Orbigny, 1846)	144	188	107	201	57	114	174	87	86	45	181	83	194	118	165	154
<i>Bolivina antiqua</i> (d'Orbigny, 1846)	1	2	0	6	5	3	0	0	3	0	6	3	0	6	2	3
<i>Bolivina dilatata</i> Reuss, 1850	0	0	6	0	5	4	0	3	3	0	2	2	1	3	0	6
<i>Bulimina striata</i> d'Orbigny in Guerin-Meneville, 1832	2	0	4	0	8	2	0	8	9	0	0	4	0	3	0	5
<i>Cibicidoides ungerianus</i> (d'Orbigny, 1846)	5	13	38	3	6	10	12	13	11	15	16	16	6	12	2	13
<i>Dimorphina akneriana</i> (d'Orbigny, 1826)	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0
<i>Elphidium fichtelianum</i> (d'Orbigny, 1846)	8	11	7	10	9	7	7	5	11	10	15	6	7	4	5	3
<i>Elphidium flexuosum</i> (d'Orbigny, 1846)	2	5	6	5	6	2	7	0	0	7	5	0	0	2	5	3
<i>Favulina hexagona</i> (Williamson, 1848)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Fursenkoina acuta</i> (d'Orbigny, 1846)	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Glandulina ovula</i> d'Orbigny, 1846	0	3	4	0	2	0	3	0	0	3	7	0	0	0	6	0
<i>Globigerina bulloides</i> d'Orbigny, 1826	12	2	7	2	20	40	0	30	20	34	0	24	1	27	0	24
<i>Globigerina concinna</i> Reuss, 1850	8	0	5	0	25	4	1	13	8	21	0	19	1	14	0	7
<i>Globigerinella regularis</i> (d'Orbigny, 1826)	8	1	3	2	20	14	0	14	10	9	0	11	0	13	0	7
<i>Trilobatus quadrilobatus</i> (d'Orbigny, 1846)	0	0	0	0	10	11	0	15	12	4	2	15	0	17	0	6
<i>Trilobatus trilobus</i> (Reuss, 1850)	70	3	15	30	42	33	18	48	46	26	26	31	11	41	0	25
<i>Gutulina comunis</i> (d'Orbigny, 1826)	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0
<i>Hanzawaia boueana</i> (d'Orbigny, 1846)	15	11	26	11	6	6	9	14	13	22	12	25	8	10	5	7
<i>Heoglundina elegans</i> (d'Orbigny, 1826)	0	0	0	0	2	2	0	0	2	3	0	2	0	2	0	0
<i>Heterolepa dutemplei</i> (d'Orbigny, 1846)	0	8	6	3	5	3	0	2	6	6	1	4	8	0	1	6
<i>Karrerella chilostoma</i> (Reuss, 1852)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Laevidentalina comunis</i> (d'Orbigny, 1826)	0	0	0	0	1	0	0	0	2	2	0	0	0	0	0	0
<i>Laevidentalina elegans</i> (d'Orbigny, 1846)	0	0	0	0	2	0	0	0	0	3	0	0	0	0	0	0
<i>Lagena striata</i> (d'Orbigny, 1839)	0	0	0	7	0	0	0	3	0	2	1	2	10	0	1	2
<i>Lenticulina inornata</i> (d'Orbigny, 1846)	6	0	3	0	0	0	0	0	4	5	1	12	0	1	0	3
<i>Lobatula lobatula</i> (Walker & Jacob, 1798)	0	2	5	0	10	0	0	3	5	2	2	2	0	0	0	2
<i>Loxostomum digitalis</i> (d'Orbigny 1846)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Martinotiella karreri</i> Cushman, 1933	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
<i>Melonis pompilioides</i> (Fichtel & Moll, 1798)	0	0	0	0	8	3	0	6	2	11	0	3	5	3	0	3
<i>Nodobacularella</i> sp.	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
<i>Nonion commune</i> (d'Orbigny, 1846)	7	0	8	0	11	16	0	20	10	19	3	5	0	7	0	9
<i>Orbulina suturalis</i> (Brönnimann, 1951)	0	0	0	2	10	4	3	8	8	5	3	5	0	3	0	2
<i>Pappina parkeri</i> (Karrer, 1877)	0	0	0	0	2	0	0	1	0	1	0	2	0	3	1	0
<i>Pararotalia aculeata</i> (d'Orbigny, 1846)	0	3	0	0	0	0	0	0	0	6	0	0	0	0	2	3
<i>Planostegina</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Planularia venezuelana</i> Hedberg, 1937	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Plectofrondicularia digitalis</i> (Neugeboren, 1850)	0	0	0	0	0	3	0	0	0	0	0	0	0	2	0	0
<i>Pseudotriloculina consobrina</i> (d'Orbigny, 1846)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Pullenia bulloides</i> (d'Orbigny, 1846)	0	0	0	0	0	3	0	0	3	2	0	0	1	0	0	2
<i>Pyrgo</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Quinqueloculina hauerina</i> d'Orbigny, 1846	0	0	0	0	0	0	0	0	0	3	0	3	0	2	0	0
<i>Reusella spinosa</i> (Reuss, 1850)	0	0	3	0	0	3	1	0	0	3	4	0	0	2	0	0
<i>Spiroloculina canaliculata</i> d'Orbigny, 1846	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Spirorutilus carinatus</i> (d'Orbigny, 1846)	0	0	0	0	0	0	0	0	2	1	0	2	0	0	0	0
<i>Stillostomella adolphina</i> (d'Orbigny, 1846)	0	0	0	0	0	0	0	2	0	6	0	0	0	2	0	0
<i>Textularia</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Uvigerina grilli</i> Schmid, 1971	0	0	0	7	6	8	2	10	3	8	7	3	0	3	3	5

Distribution of foraminifera in the studied samples.

Species/Samples	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
<i>Ammonia vienensis</i> (d'Orbigny, 1846)	10	4	2	0	26	3	5	12	5	0	10	0	11	4	16	7
<i>Amphistegina mamilla</i> (Fichtel & Moll, 1798)	62	2	0	0	41	7	26	10	100	4	122	6	15	9	21	21
<i>Amphicoryna badenensis</i> (d'Orbigny, 1846)	0	8	3	11	0	5	0	3	0	11	2	5	0	3	0	0
<i>Anomalinoidea</i> sp.	3	7	5	15	0	0	0	0	0	0	0	3	0	0	3	0
<i>Asterigerinata planorbis</i> (d'Orbigny, 1846)	99	33	45	30	179	54	164	70	104	42	88	73	195	81	111	131
<i>Bolivina antiqua</i> (d'Orbigny, 1846)	2	0	5	7	1	0	1	0	0	0	0	2	2	0	4	3
<i>Bolivina dilatata</i> Reuss, 1850	1	10	0	3	1	0	0	2	0	25	0	4	0	8	1	3
<i>Bulimina striata</i> d'Orbigny in Guerin-Meneville, 1832	0	4	7	6	0	6	1	5	0	4	0	10	2	0	0	0
<i>Cibicidoides ungerianus</i> (d'Orbigny, 1846)	0	10	5	21	12	3	5	17	5	14	5	20	11	13	17	41
<i>Dimorphina akneriana</i> (d'Orbigny, 1826)	0	0	0	7	0	0	0	2	0	0	0	0	0	0	0	0
<i>Elphidium fichtelianum</i> (d'Orbigny, 1846)	16	12	5	4	9	8	12	2	7	3	0	5	8	7	13	12
<i>Elphidium flexuosum</i> (d'Orbigny, 1846)	3	0	7	5	3	2	3	10	8	0	5	0	3	6	6	8
<i>Favulina hexagona</i> (Williamson, 1848)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Fursenkoina acuta</i> (d'Orbigny, 1846)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Glandulina ovula</i> d'Orbigny, 1846	0	0	0	0	0	1	5	2	8	0	4	0	3	0	2	0
<i>Globigerina bulloides</i> d'Orbigny, 1826	5	70	18	23	3	45	2	14	0	49	1	45	3	42	19	5
<i>Globigerina concinna</i> Reuss, 1850	0	25	32	22	0	23	3	7	0	36	1	18	3	35	7	1
<i>Globigerinella regularis</i> (d'Orbigny, 1826)	0	18	19	26	0	15	0	8	0	15	1	30	1	27	12	3
<i>Trilobatus quadrilobatus</i> (d'Orbigny, 1846)	2	17	30	20	0	12	0	8	0	6	0	10	0	5	5	2
<i>Trilobatus trilobus</i> (Reuss, 1850)	11	60	52	61	2	60	15	70	8	22	1	35	15	60	21	18
<i>Gutulina comunis</i> (d'Orbigny, 1826)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Hanzawaia boueana</i> (d'Orbigny, 1846)	18	4	10	14	10	23	12	7	2	12	2	5	17	13	16	18
<i>Heoglundina elegans</i> (d'Orbigny, 1826)	2	3	3	0	1	0	0	0	0	0	0	5	0	0	1	0
<i>Heterolepa dutemplei</i> (d'Orbigny, 1846)	6	2	7	0	2	6	10	0	0	4	3	13	3	2	2	5
<i>Karrerella chilostoma</i> (Reuss, 1852)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Laevidentalina comunis</i> (d'Orbigny, 1826)	0	0	0	2	0	2	0	0	0	0	0	1	0	2	1	0
<i>Laevidentalina elegans</i> (d'Orbigny, 1846)	2	1	2	7	0	2	0	0	0	0	0	1	0	2	1	0
<i>Lagena striata</i> (d'Orbigny, 1839)	0	2	6	0	0	0	1	0	6	0	1	3	0	0	0	0
<i>Lenticulina inornata</i> (d'Orbigny, 1846)	0	5	7	0	0	8	0	3	0	1	2	2	0	0	6	2
<i>Lobatula lobatula</i> (Walker & Jacob, 1798)	5	3	3	8	0	2	5	4	0	6	2	0	3	0	3	0
<i>Loxostomum digitalis</i> (d'Orbigny, 1846)	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0
<i>Martiniella karreri</i> Cushman, 1933	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
<i>Melonis pompilioides</i> (Fichtel & Moll, 1798)	9	3	1	12	5	3	2	7	0	0	0	3	0	0	9	0
<i>Nodobaculiella</i> sp.	0	0	0	0	0	0	2	2	2	0	8	0	0	0	2	0
<i>Nonion commune</i> (d'Orbigny, 1846)	21	7	18	6	8	11	0	0	0	17	0	4	5	18	13	2
<i>Orbulina suturalis</i> (Brönnimann, 1951)	3	21	10	10	0	5	2	7	7	0	1	0	3	12	7	5
<i>Pappina parkeri</i> (Karrer, 1877)	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
<i>Pararotalia aculeata</i> (d'Orbigny, 1846)	0	0	2	0	0	0	7	5	18	0	8	0	0	0	0	1
<i>Planostegina</i> sp.	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
<i>Planularia venezuelana</i> Hedberg, 1937	0	0	0	0	0	2	5	2	3	2	5	0	0	0	2	2
<i>Plectofrondicularia digitalis</i> (Neugeboren, 1850)	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0	0
<i>Pseudotriloculina consobrina</i> (d'Orbigny, 1846)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Pullenia bulloides</i> (d'Orbigny, 1846)	1	5	0	0	0	0	0	0	0	0	0	3	0	0	0	0
<i>Pyrgo</i> sp.	0	0	0	0	0	0	1	0	0	1	3	0	0	0	1	0
<i>Quinqueloculina hauerina</i> d'Orbigny, 1846	0	0	0	0	0	3	2	7	18	0	42	5	6	4	0	0
<i>Reusella spinosa</i> (Reuss, 1850)	3	0	0	0	1	0	5	5	0	0	0	0	2	0	4	5
<i>Spiroloculina canaliculata</i> d'Orbigny, 1846	0	0	0	2	0	2	0	2	0	0	0	0	0	0	0	0
<i>Spirorutilus carinatus</i> (d'Orbigny, 1846)	0	2	0	4	0	0	0	2	0	0	0	0	0	0	1	0
<i>Stilostomella adolphina</i> (d'Orbigny, 1846)	0	2	2	6	0	6	0	3	0	0	0	0	0	0	2	0
<i>Textularia</i> sp.	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
<i>Uvigerina grilli</i> Schmid, 1971	0	11	8	10	2	2	2	4	2	6	0	5	0	4	0	9

Distribution of foraminifera in the studied samples.

Species/Samples	49	50	51	52	53	54	55	56	57	58	59	60	61
<i>Ammonia vienensis</i> (d'Orbigny, 1846)	0	0	0	23	0	6	10	3	4	0	8	0	28
<i>Amphistegina mamilla</i> (Fichtel & Moll, 1798)	0	3	135	70	6	274	15	10	26	18	5	5	70
<i>Amphicoryna badenensis</i> (d'Orbigny, 1846)	8	10	0	0	7	0	2	6	2	3	10	0	0
<i>Anomalinoidea</i> sp.	3	0	8	0	0	0	0	3	0	0	0	3	0
<i>Asterigerinata planorbis</i> (d'Orbigny, 1846)	95	89	103	131	107	18	97	172	199	16	40	55	123
<i>Bolivina antiqua</i> (d'Orbigny, 1846)	3	0	2	6	0	0	0	4	3	0	5	5	2
<i>Bolivina dilatata</i> Reuss, 1850	2	6	7	0	12	0	0	2	3	1	10	7	0
<i>Bulimina striata</i> d'Orbigny in Guerin-Meneville, 1832	8	8	4	0	6	0	2	2	0	6	8	13	0
<i>Cibicoides ungerianus</i> (d'Orbigny, 1846)	18	5	0	12	6	0	7	8	13	16	17	5	12
<i>Dimorphina akneriana</i> (d'Orbigny, 1826)	0	0	0	0	0	0	0	0	0	2	0	0	0
<i>Elphidium fichtelianum</i> (d'Orbigny, 1846)	11	10	10	0	0	0	7	2	5	8	0	2	7
<i>Elphidium flexuosum</i> (d'Orbigny, 1846)	2	0	11	18	0	0	5	0	5	0	0	0	2
<i>Favulina hexagona</i> (Williamson, 1848)	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Fursenkoina acuta</i> (d'Orbigny, 1846)	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Glandulina ovula</i> d'Orbigny, 1846	0	1	0	2	0	0	7	0	3	0	0	5	4
<i>Globigerina bulloides</i> d'Orbigny, 1826	19	15	0	0	23	0	32	35	2	41	35	35	5
<i>Globigerina concinna</i> Reuss, 1850	24	6	0	0	25	0	21	10	1	23	18	20	2
<i>Globigerinella regularis</i> (d'Orbigny, 1826)	18	10	0	0	17	0	13	11	0	20	23	45	0
<i>Trilobatus quadrilobatus</i> (d'Orbigny, 1846)	4	8	0	0	6	0	3	4	0	21	6	20	0
<i>Trilobatus trilobus</i> (Reuss, 1850)	41	12	0	5	18	0	35	36	5	74	40	25	18
<i>Gutulina comunis</i> (d'Orbigny, 1826)	0	1	0	0	0	0	0	1	0	0	0	0	0
<i>Hanzawaia boueana</i> (d'Orbigny, 1846)	13	5	0	7	11	0	6	6	8	8	10	5	2
<i>Heoglundina elegans</i> (d'Orbigny, 1826)	0	4	0	0	3	0	0	1	0	0	0	2	0
<i>Heterolepa dutemplei</i> (d'Orbigny, 1846)	6	2	6	5	3	0	2	5	6	2	3	0	3
<i>Karrerella chilostoma</i> (Reuss, 1852)	0	2	0	0	0	0	0	0	0	0	0	0	0
<i>Laevidentalina comunis</i> (d'Orbigny, 1826)	0	3	0	0	1	0	1	0	0	3	0	4	0
<i>Laevidentalina elegans</i> (d'Orbigny, 1846)	0	9	0	0	4	0	1	3	0	0	3	3	0
<i>Lagena striata</i> (d'Orbigny, 1839)	0	0	14	3	1	2	0	0	2	1	2	2	0
<i>Lenticulina inornata</i> (d'Orbigny, 1846)	3	3	0	0	0	0	2	5	0	3	0	2	0
<i>Lobatula lobatula</i> (Walker & Jacob, 1798)	0	5	0	0	5	0	3	0	2	0	1	0	0
<i>Loxostomum digitalis</i> (d'Orbigny 1846)	0	3	0	0	0	0	0	0	0	0	0	0	0
<i>Martiniotiella karreri</i> Cushman, 1933	0	0	0	0	0	0	2	0	0	0	0	0	0
<i>Melonis pompilioides</i> (Fichtel & Moll, 1798)	4	6	0	0	4	0	7	2	4	7	0	0	0
<i>Nodobacularella</i> sp.	0	3	0	0	0	0	0	0	0	0	0	2	0
<i>Nonion commune</i> (d'Orbigny, 1846)	8	11	0	0	15	0	11	3	0	32	3	20	0
<i>Orbulina suturalis</i> (Brönnimann, 1951)	4	5	0	2	0	0	15	6	4	7	3	7	5
<i>Pappina parkeri</i> (Karrer, 1877)	0	0	0	0	0	0	0	0	0	1	0	0	0
<i>Pararotalia aculeata</i> (d'Orbigny, 1846)	0	0	0	0	0	0	0	0	0	0	0	0	5
<i>Planostegina</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	3
<i>Planularia venezuelana</i> Hedberg, 1937	2	0	0	0	0	0	3	0	0	0	0	2	5
<i>Plectofrondicularia digitalis</i> (Neugeboren, 1850)	0	2	0	0	0	0	0	2	0	0	0	0	0
<i>Pseudotriloculina consobrina</i> (d'Orbigny, 1846)	0	4	0	0	0	0	0	0	0	0	0	0	0
<i>Pullenia bulloides</i> (d'Orbigny, 1846)	3	5	0	0	0	0	0	0	0	4	0	0	0
<i>Pyrgo</i> sp.	0	0	0	0	0	0	0	0	0	0	1	0	0
<i>Quinqueloculina hauerina</i> d'Orbigny, 1846	5	10	0	0	3	0	10	0	7	0	6	2	10
<i>Reusella spinosa</i> (Reuss, 1850)	0	2	0	0	0	2	5	0	3	1	0	0	2
<i>Spiroloculina canaliculata</i> d'Orbigny, 1846	0	6	0	0	0	0	0	0	0	0	0	0	2
<i>Spirorutilus carinatus</i> (d'Orbigny, 1846)	0	5	0	0	0	0	2	0	0	0	3	0	0
<i>Stillostomella adolphina</i> (d'Orbigny, 1846)	4	2	0	0	3	0	0	3	0	0	7	5	0
<i>Textularia</i> sp.	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Uvigerina grilli</i> Schmid, 1971	0	5	6	6	6	0	2	4	3	0	6	8	3