UNIVERSITATEA "BABEȘ-BOLYAI" CLUJ-NAPOCA
FACULTATEA DE BIOLOGIE ȘI GEOLOGIE
DEPARTAMENTUL DE GEOLOGIE

STUDY OF THE MARINE OFFSHORE OLIGOCENE AND EARLY MIOCENE FORAMINIFERA ASSEMBLAGES FROM THE NORTHWESTERN TRANSYLVANIAN BASIN.

PHD THESIS SUMMARY

Doctorand
Szabolcs-Flavius Székely

Coordonator științific
Prof. Dr. Sorin Filipescu

Cluj-Napoca
2015

Content

Keywords: foraminifera, Oligocene, Miocene, Transylvanian Basin.

Introduction

The present work deals mainly with the foraminifera assemblages of the Oligocene and Lower Miocene deposits from the north-western border of the Transylvanian Basin. The aim of this approach was to bring additional contributions to the knowledge of foraminifera assemblages and to reconstruct the evolution of the paleoenvironments based on quantitative analysis of foraminifera assemblages, sedimentology and geochemistry.

The objectives of the present study were:

- To document the foraminifera assemblages recovered from the Oligocene Vima Formation and Lower Miocene Chechiș and Hida formations, including their taxonomic overview.
- To identify planktonic foraminifera representative for regional (e.g. Popescu, 1975; Popescu & Brotea, 1989) and global biostratigraphic zonations (e.g. Berggren et al., 1995; Wade et al., 2011) in order to calibrate the identified assemblages to the stratigraphic framework.
- To identify paleoclimatic events based on planktonic foraminifera assemblages and to check their potential for correlation with local or global events.
- To quantitatively and qualitatively analyze the benthic foraminiferal communities in order to restore the history and evolution of the investigated paleoenvironments.
- To identify changes in species composition of foraminifera assemblages as a response to local paleoecological factors such as primary productivity, organic matter flux to the sea floor, bottom water oxygenation and bottom water temperatures.
- To conduct additional geochemical analyses on sediments recovered from the Vima Formation for a better paleoenvironmental reconstruction.

Chapter I.

Geology of the studied area

The Transylvanian Basin became a sedimentation area during the Late Cretaceous (at the end of the Alpine tectonics). The post-tectogenetic cover of the Late Cretaceous to Early Oligocene interval comprises normal and brackish marine and continental deposits characterized by alternating marine and continental settings. The sedimentary fill accumulated during the Late Oligocene to Early Miocene interval is dominated by marine and continental-lacustrine terrigenous deposits (Rusu et al., 1996).

Chapter II.

Previous micropaleontological studies in the north-western Transylvanian Basin

Paleontological studies of the Oligocene and lower Miocene formations from the Transylvanian Basin focused on different groups of fossils (such as molluscs, ostracodes and foraminifera). Most researches on foraminifera are mainly focused on taxonomy and biostratigraphy (e.g. Popescu, 1971; Popescu & Iva, 1971; Popescu, 1975) of benthic and planktonic foraminifera, while recent papers include paleoecological and paleogeographic interpretations (e.g. Filipescu & Beldean, 2008; Beldean et al., 2010; Beldean & Filipescu, 2011; Beldean et al., 2011; Beldean et al., 2012).

Chapter III.

Material and methods

A series of micropaleontological and geochemical analyses were conducted on samples collected from Oligocene and Lower Miocene outcrops from the north-western Transylvanian Basin, for a proper paleoambiental and biostratigraphic characterization. Following collection and standard micropaleontological preparation of samples, foraminifera assemblages were identified and data interpreted. Additionally, geochemical analyses were carried out on selected samples in order to gain more information on certain paleoecological factors.

Chapter IV.

Results and discussions

4.1. Fântânele section

Three outcrops of the Vima Formation (N47,41477 E23,82699; N47,41356 E 23,82637 and N47,41195 E 23,82692 - Fig. 4) located at Fântânele (Maramureș county) were sampled in mudstones and sandstones (Fig 5).

4.1.1. Biostratigraphy

The identified planktonic foraminifera have long stratigraphic ranges (Fig. 6). However, the presence of *Chiloguembelina cubensis* together with *Paragloborotalia opima* allows the placement of samples FA1 to FA11 in the Oligocene Zone O4 (*G. angulisuturalis / C. cubensis* Concurrent-range Zone) of Wade et al. (2011). The co-occurence of *Paragloborotalia opima* and *Globigerina ciperoensis* (Fig. 6) in samples from the FB section suggest the deposition of these sediments during the Late Oligocene (Zone O5 - *P. opima* Highest-occurrence Zone of Wade et al., 2011).

We consider planktonic foraminifera to be indicative of the age of the deposits (O4-O5 zones of Wade et al., 2011). The assessment of the Rupelian-Chattian boundary (placed in NP 24) is difficult because of the lack of index species; its position could be roughly estimated based both on planktonic foraminifera and calcareous nannofossil biozones between the first and the second outcrop.

4.1.2. Paleoclimate and paleoecology of planktonic foraminifera

The purpose of reconstructing the paleoclimatic curve based on planktonic foraminifera is to identify tendencies of temperature changes in the surface waters related to the climate.

Based on the visual analysis of the climatic curve (Fig. 7) and the abundance of various temperature indicators, we presumed that the surface water temperatures in the Fântânele section ranged between cool and temperate values. The number and intensity of the oscillations towards temperate waters increase in the third outcrop, indicating a possible warming in the Chattian. Our climatic curves from the Fântânele section reflect similar environmental conditions with the studies from the Paratethys: cool-temperate surface waters with possible influences from the North Sea Basin during the Rupelian slightly shifted to warmer temperatures in the

Chattian. It is possible that planktonic foraminifera from the Fântânele section reflect stronger influences from the north during the Rupelian, while the warmer surface waters from the Chattian were potentially related to the new paleogeographic configuration of the Paratethys (increased influence from the Mediterranean Sea and Indian Ocean due to the progressive closing of the Upper Rhine Graben in the late Oligocene - Martini, 1990; Gebhardt, 2003) and the beginning of the Late Oligocene Warming Event (Zachos et al., 2001).

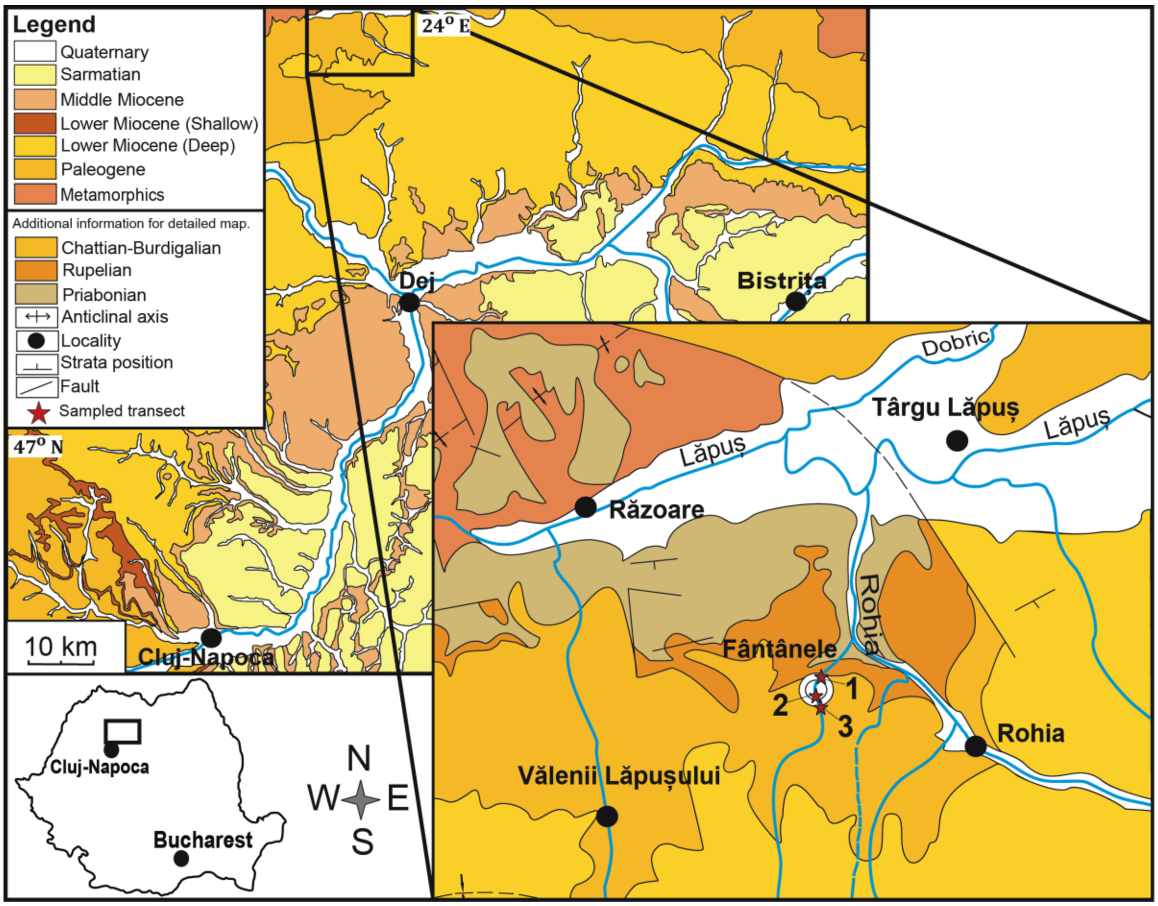

Fig. 4. *Geological map and location of the outcrops in the investigated area (modified after Beldean & Filipescu, 2011; detailed map redrawn after Giușcă & Rădulescu, 1967).*

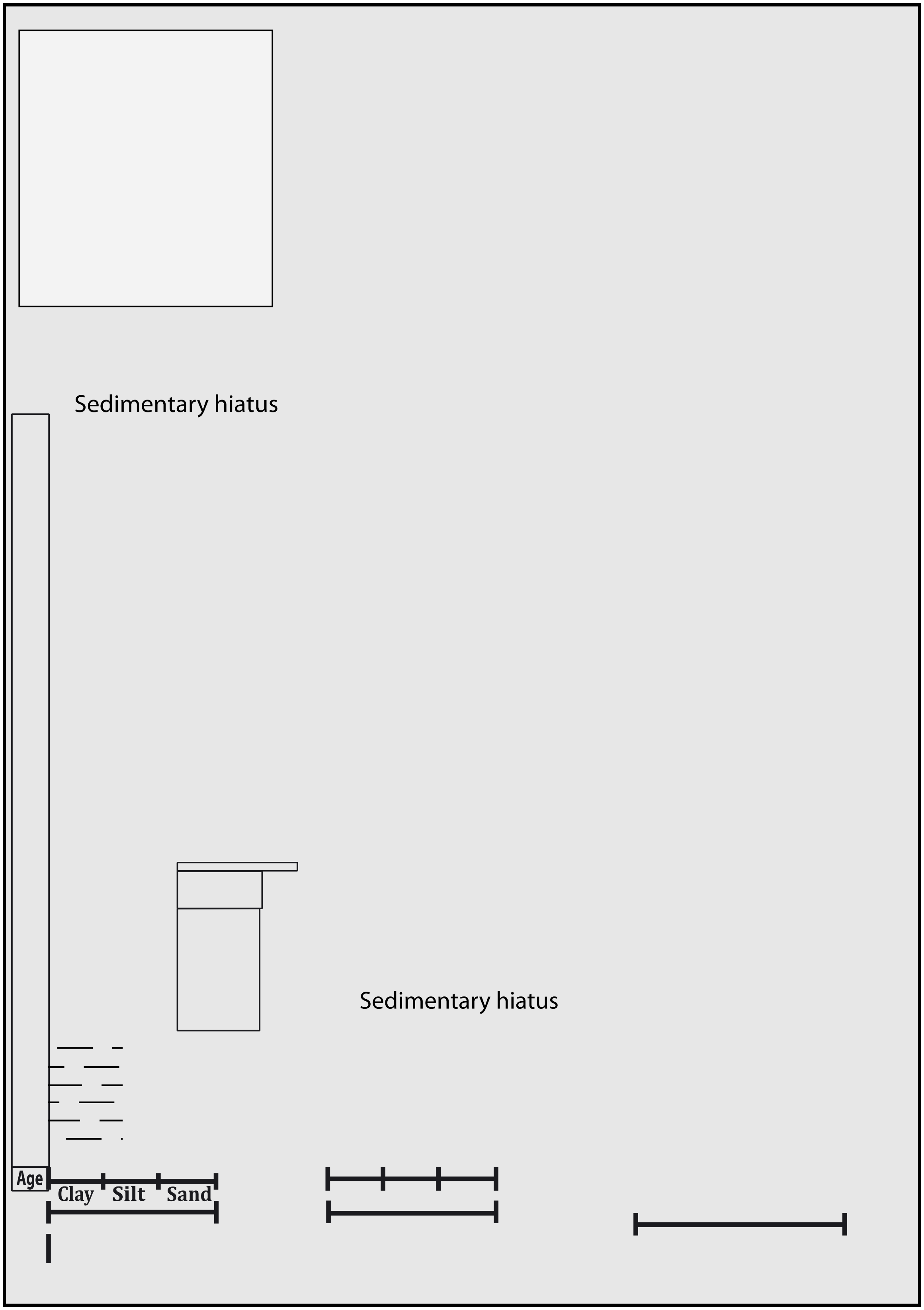

Fig. 5. *Simplified lithology and position of the samples in the outcrops from the Fântânele section.*

4.1.3. Paleoecology of benthic foraminifera

The species composition of the benthic foraminiferal assemblages from the Fântânele section reflects many environmental changes that occured during the Oligocene of the north-western Transylvanian Basin. The difference in distribution and diversity of benthic foraminiferal communities has the potential to point out changes such as water depth, salinity, bottom-water oxygenation or organic carbon flux to the sea floor (Murray, 1991; Murray, 2006). Paleoecology interpretations and the statistical treatment of the samples from the Fântânele section were combined in the following section.

4.1.3.1. Cluster FA-I (*Haplophragmoides carinatus assemblages* - Fig. 8)

The cluster contains two samples (FA2 and FA29, Fig. 8) entirely dominated by agglutinated foraminifera (Fig. 10). There are several potential hypotheses to explain the presence of exclusively agglutinated foraminiferal assemblages: the presence of cool, aggressive, undersaturated in calcium carbonate waters as suggested by Spezzaferri et al. (2002); the oxidation of rapidly deposited organic matter in early diagenesis, which releases carbonate-dissolving acids in deep-sea turbiditic environments (Jones, 1999); or high sedimentation rates and low oxygen conditions as suggested by Kender et al. (2008).

Certain assemblages from the Fântânele section are entirely composed of agglutinated forms. The species composition of such assemblages cannot be explained with a depositional setting below the CCD level, because paleobathymetrical estimates point to a potential upper bathyal (slope) setting.

There are many environmental factors that could have influenced the species composition of the agglutinated foraminifera assemblages from the Fântânele section. We suggest that low-oxygen conditions, basin stratification, water masses undersaturated in calcium carbonate, and possibly periodical higher sedimentation rate due to turbidity currents occurred in an upper bathyal-setting.

4.1.3.2. Cluster FA-II (Transitional assemblages - Fig. 8)

This represents mixed benthic assemblages, where the agglutinated foraminifera are dominant. Tubular agglutinated forms are abundant in the majority

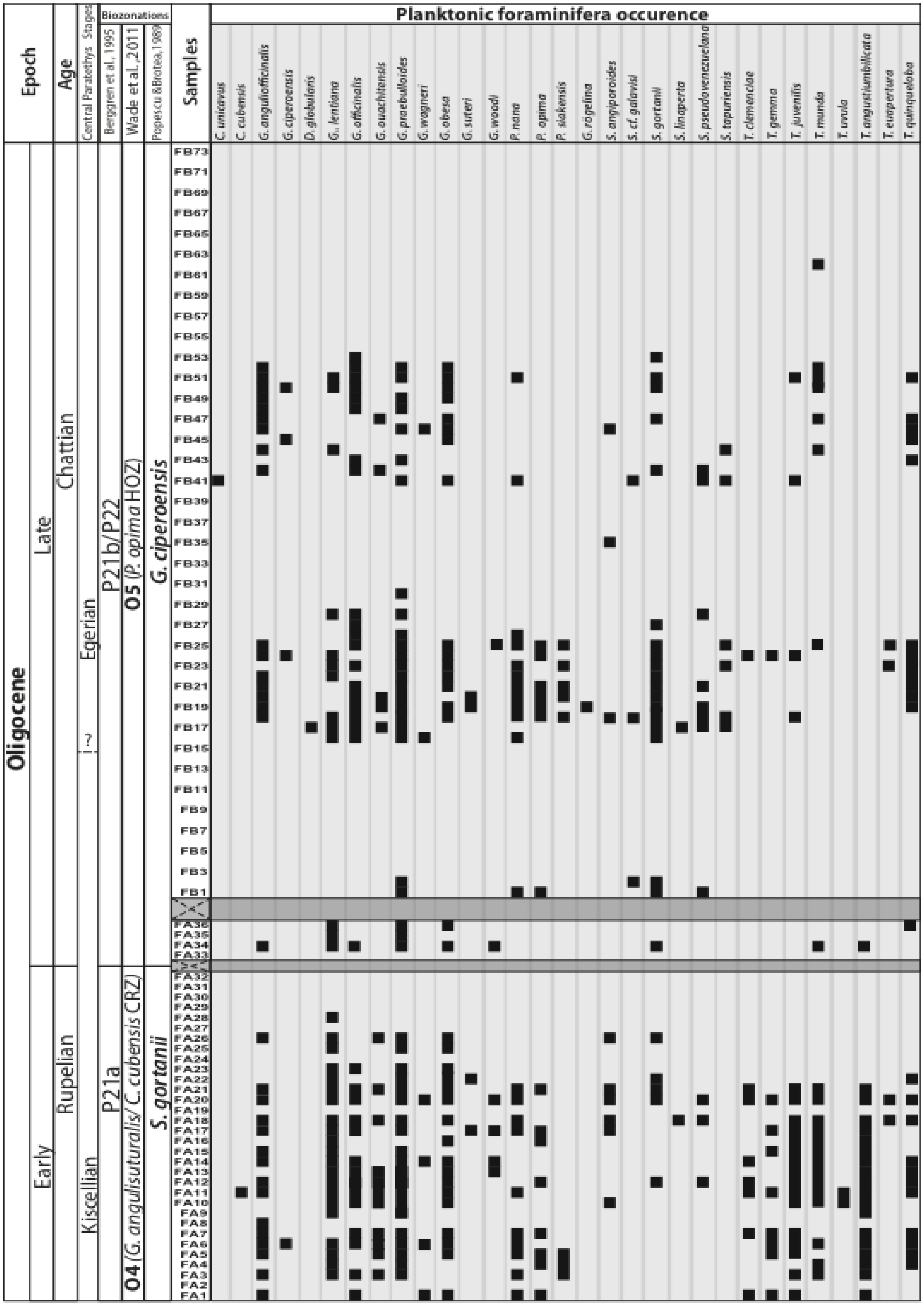

Fig. 6. *Occurrence of planktonic foraminifera throughout the Fântânele section. Central Paratethys stages taken from Rögl (1998), biozonations from Popescu & Brotea (1989), Berggren et al. (1995), Wade et al. (2011). Dark grey horizontal stripes represent sedimentary hiatus between the outcrops. Black filled rectangles represent the presence of species in samples. CRZ-Concurrent-range Zone, HOZ- Highest-occurence Zone.*

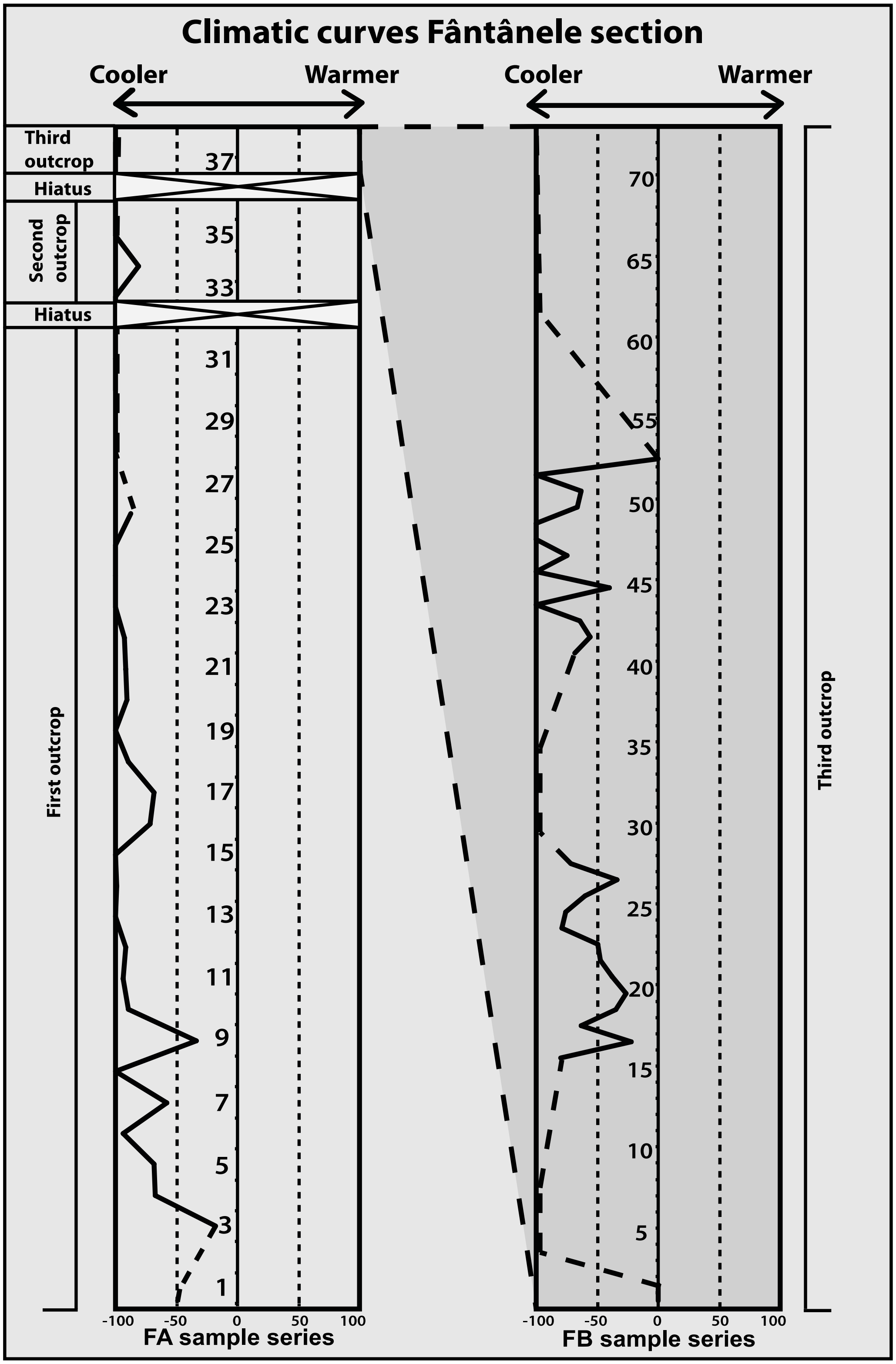

Fig. 7. *Climatic curves for the Fântânele section. The curves represent the algebraic sum of abundance (%) of warm-water indicators (positive values) and abundance (%) of cool-water indicators (negative values) following Spezzaferri (1995).*

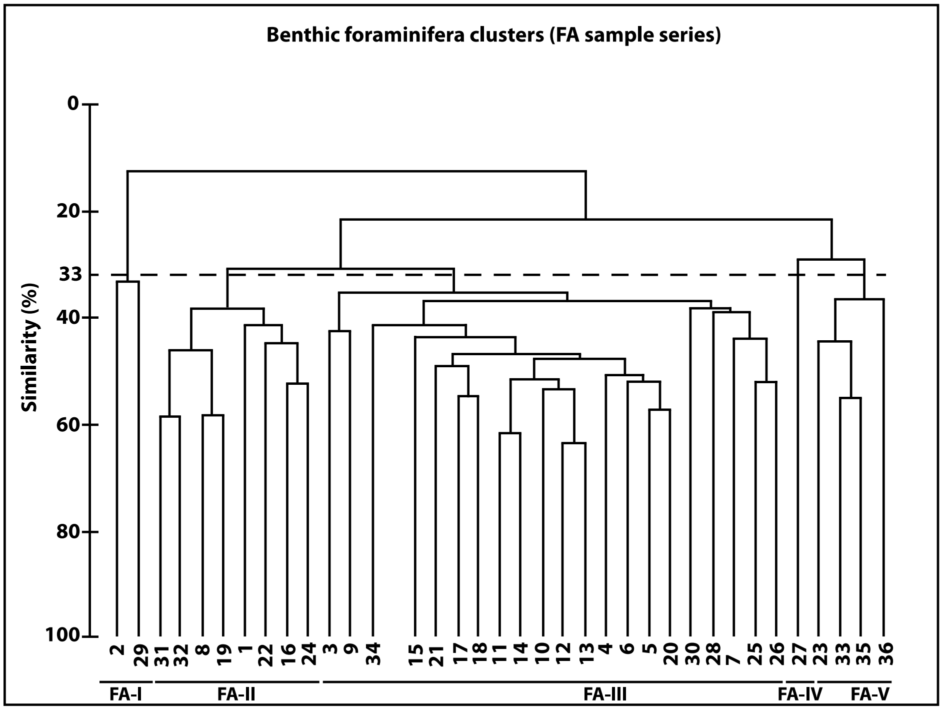

Fig. 8. *Dendrogram representing the hierarchical agglomerative clustering based on the Bray-Curtis Similarity matrix of the benthic foraminifera, FA sample series, first and second outcrops, Fântânele section. Dashed line represents the similarity cut-level.*

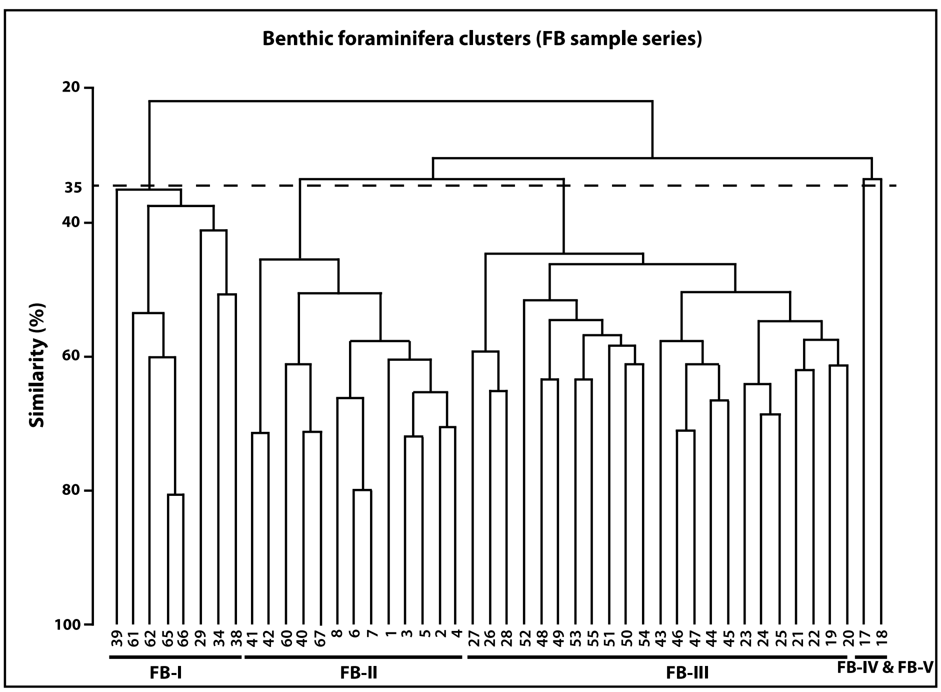

Fig. 9. *Dendrogram representing the hierarchical agglomerative clustering based on the Bray-Curtis Similarity matrix of the benthic foraminifera, FB sample series, third outcrop, Fântânele section. Dashed line represents the similarity cut-level.*

of the samples (Fig. 13) and are specific to tranquil bathyal and abyssal environments.

The mixed assemblages included in the FA-II cluster resemble the "flysch-type" assemblages described by Gradstein & Berggren (1981). Samples included in this cluster are scattered throughout the section and represent the transitional assemblages between the outer shelf-upper slope environment and the benthic communities found in upper-middle bathyal settings associated with turbidity currents.

The clusters FA-I and FA-II represent probably the deepest depositional settings of this section where cold deep waters might have hampered the development of calcareous taxa. The increased abundance of tubular agglutinated foraminifera in cluster FA-II suggests slope settings, with episodes of higher and lower flux of organic matter, relatively well oxygenated bottom waters and different current regimes (possibly associated with turbidites).

4.1.3.3. Cluster FA-III (Mixed assemblages - Fig. 8)

It contains most of the FA samples. The assemblages are of mixed nature and composed of benthic calcareous and agglutinated foraminifera. The highest values of the P/B ratio (up to 60%) are always associated with samples included in this cluster (Fig. 10). The depth range of the species in these assemblages indicate a shallower (outer shelf) depositional setting compared to the deeper benthic assemblages from previous clusters (Clusters FA-I and FA-II). This hypothesis is also enforced by the presence of species that are abundant on the outer shelf such as *Bulimina schischkinskayae.* The good representation of all three microhabitats (Fig. 10) suggests good oxygenation of the bottom waters with possible intervals of high primary productivity and pulselike flux of organic carbon to the seafloor and this might have resulted in the development of the infaunal forms associated with high primary productivity and consequent short episodes of low-oxygen availability on the sea-floor (the periodic high abundance of low oxygen tolerant taxa - Fig. 13). In contrast with the low-diversity communities described in previous clusters, these show a more stable environment with high species diversity (Fig. 10).

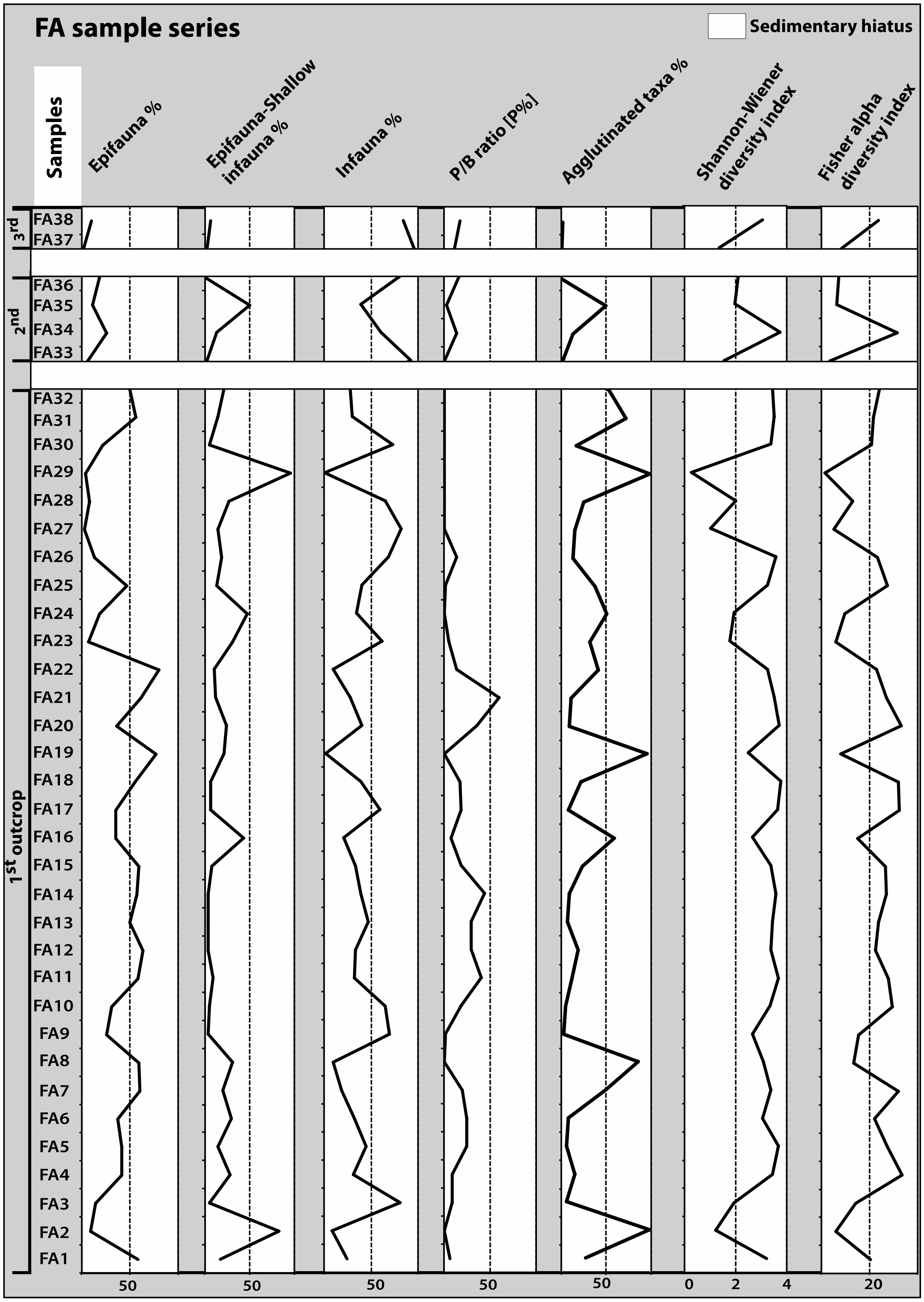

Fig. 10. *Graph representing the microhabitat of benthic foraminifera (percent of epifauna, epifauna-shallow infauna and infauna), percent of planktonic foraminifera, percent of agglutinated foraminifera, the Shannon-Wiener diversity index and the Fisher alpha diversity index from each FA sample, all three outcrops, Fântânele section.*

4.1.3.4. Cluster FA-IV (*Bulimina schischkinskayae* assemblage - Fig. 8) and FA-V (*Bolivina – Bulimina - Fursenkoina* assemblages - Fig. 8)

Clusters FA-IV and FA-V (Fig. 8) contain high proportions of infaunal low-oxygen tolerant taxa (Fig. 13); based on the depth range of the constituent species, these suggest an outer shelf setting.

With the exception of sample FA36, where the presence of epifaunal forms (Fig. 10) could be an indicator of episodes with well oxygenated bottom waters, the species composition of the benthic assemblages suggest low dissolved oxygen content at the water-sediment interface.

Sea-level changes and tectonic activity (Tischler et al., 2008) during the late Rupelian - early Chattian from the north-western Transylvanian Basin probably influenced the water depth and, consequently, the development of benthic communities in outer shelf to upper bathyal settings. Main environmental factors that shaped the species distribution and diversity of the assemblages are bottom water oxygenation, primary productivity, organic carbon flux to the sea-floor and sediment input. The complex interaction of these factors and related depth changes resulted in well oxygenated environments with episodes of high primary productivity and, consequently, low oxygen content on the outer shelf and the unstable conditions associated to turbidity currents in a calcium-carbonate undersaturated upper slope setting.

4.1.3.5. Cluster FB-I (Transitional and mixed assemblages - Fig. 9)

The cluster represents the transition to intervals with infrequent foraminifera (Fig. 15, light grey stripes). The mixed assemblages within cluster FB-I (Fig. 9) are mostly dominated by agglutinated foraminifera (Figs. 14 and 15). The presence of abundant coarse-grained agglutinated foraminiferal tests in these samples may suggest episodes with higher current regime. The benthic assemblages (Fig. 9) could suggest a transitional setting to shallower depths (increased microfossil dilution in the following sediments indicate high sediment supply) and episodes of oligotrophic and tranquil environment (suggested by tubular agglutinated foraminifera) with low organic flux (Kaminski & Gradstein, 2005), disturbed by a higher current

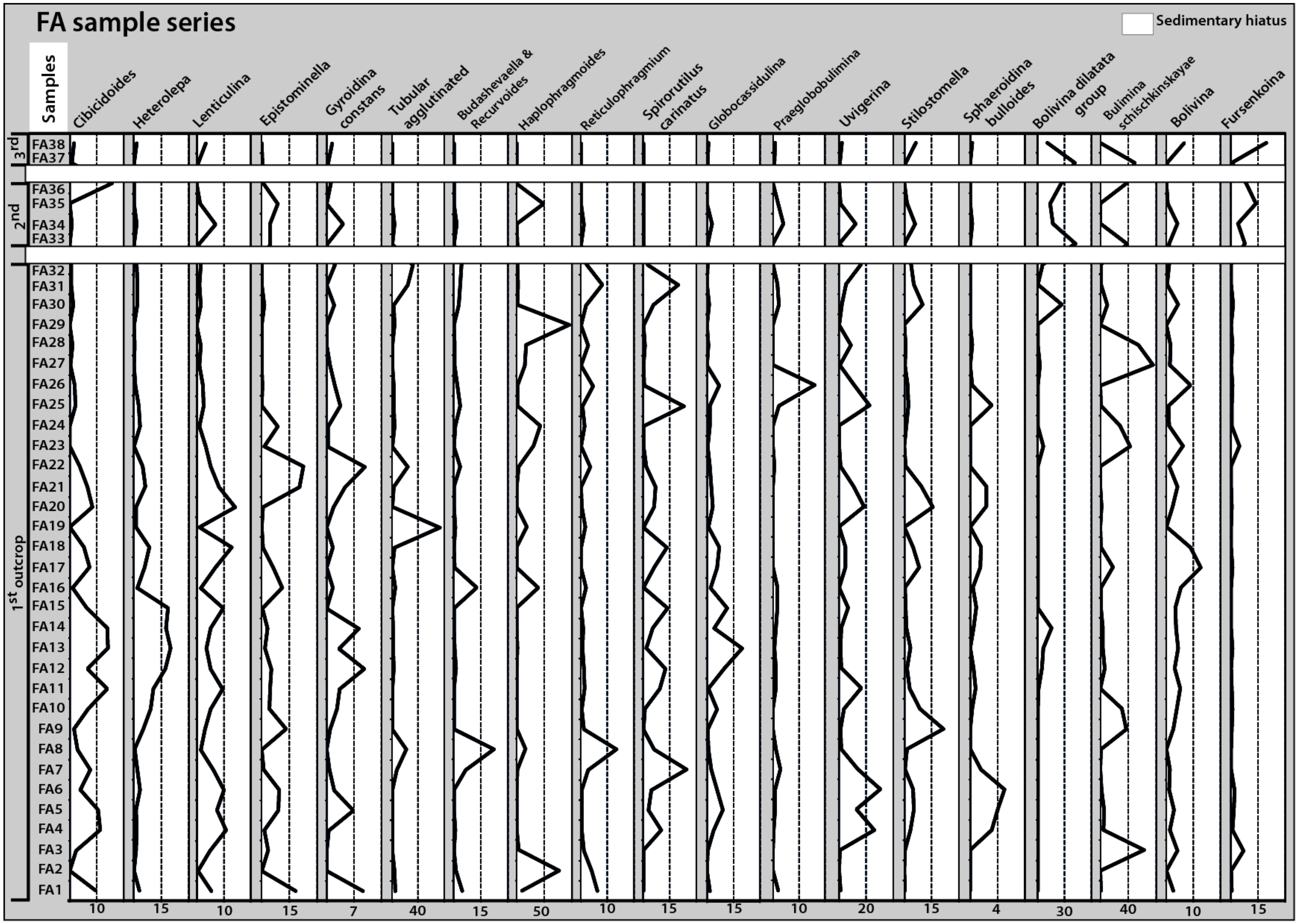

Fig. 13. *Graph representing percent abundance of the most important species, genera or groups with similar paleoecological affinities from each FA sample, all three outcrops, Fântânele section. White filled horizontal rectangles represent sedimentary hiatus between the outcrops.*

regime, followed by re-colonization of the sediment and consumption of the newly transported organic matter by the *Reophax* species.

Alternatively, the tubular agglutinated foraminifera and *Reophax* species coexisted in an environment with low organic matter flux, where the increasingly refractory organic matter deeper in the sediment was the food source for the infaunal benthic forms (Jorissen et al., 1995).

4.1.3.6. Cluster FB-II (The *Bolivina-Fursenkoina* assemblages - Fig. 9)

Samples have low diversity indices (Shannon-Wiener between 1 and 2, and Fisher alpha between 1.5 to 4.7, Fig. 14) and are characteristic for the base, middle, and top parts of the outcrop. Well represented bolivinids (Fig. 15) are indicators of high organic carbon flux to the sea floor (e.g. Thomas et al., 2000; Grunert et al., 2010; Hess & Jorissen, 2009; Fenero et al. 2012) and suggest low oxygen conditions (e.g., Murray, 1991, Bernhard & Sen Gupta, 1999). In the case of Fântânele section, we suggest that the absence of low-oxygen intolerant taxa (such as *Cibicidoides* or *Heterolepa*) and the high abundance of low-oxygen tolerant taxa such as *Bolivina dilatata dilatata, Bolivina dilatata hyalina, Bulimina schischkinskayae* indicate predominantly low bottom water oxygenation (Rögl & Spezzaferri, 2003; Murray, 2006). Periodic high primary productivity at the water surface may have triggered the delivery of phytodetritus to the sea-floor and the consequent spreading of *Alabamina*, *Epistominella* species and of the opportunistic species such as *Fursenkoina mustoni, Fursenkoina halkyardi* and *Fursenkoina schreibersiana* (De Man, 2006).

4.1.3.7. Cluster FB-III (High diversity mixed assemblages - Fig. 9)

This cluster displays the highest Fisher alpha (6.8-17.7) and Shannon-Wiener (1.6-3) diversity indices in FB. The high abundance of low-oxygen tolerant taxa such as the *Bolivina dilatata* group, species of *Fursenkoina, Uvigerina, Praeglobobulimina,* and *Chilostomella* indicate low bottom water oxygenation (Spezzaferri et al., 2002); periodically, low dissolved oxygen occurring in eutrophic conditions could have been the controlling factor in the species distribution of the assemblages. The high flux of organic matter to the sea-floor was inferred based on the presence of *Uvigerina* (Rögl & Spezzaferri, 2003).

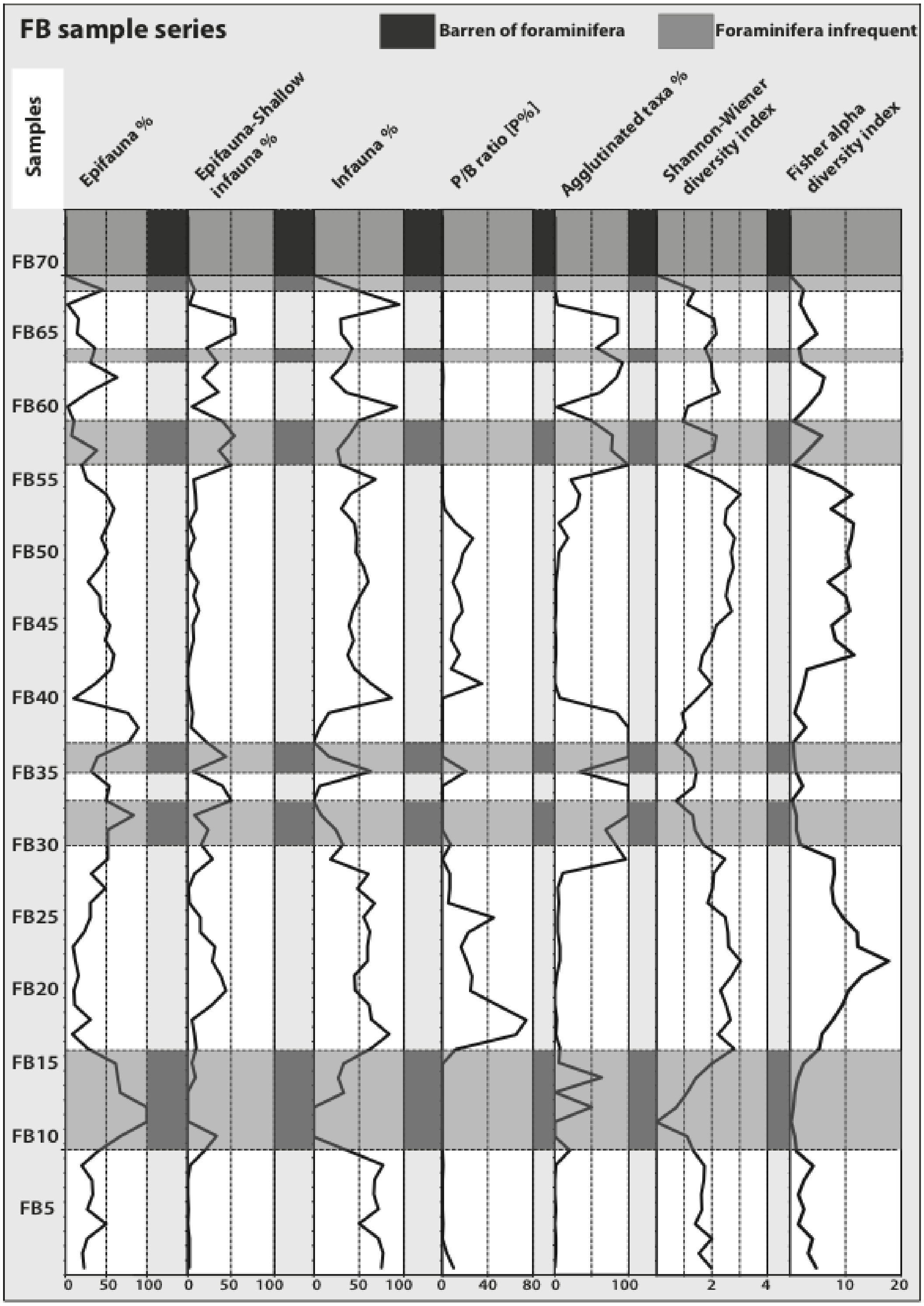

Fig. 14. *Graph representing the microhabitat of benthic foraminifera (percent of epifauna, epifauna-shallow infauna and infauna), percent of planktonic foraminifera, percent of agglutinated foraminifera, the Shannon-Wiener diversity index and the Fisher alpha diversity index from each FB sample, third outcrop, Fântânele section. Dark grey rectangle represents barren samples while light grey rectangles represent samples with infrequent foraminifera.*

4.1.3.8. Clusters FB-IV and FB-V

These clusters contain the highest P/B ratio in this outcrop (Fig. 14). The microhabitat preferences of benthic foraminifera (Fig. 15) suggest a mesotrophic environment (Jorissen et al., 1995).

The following depositional environments were differentiated in the third outcrop: (1). The deepest environments on the shelf (Clusters FB-IV and FB-V) characterized by increased abundance of planktonic foraminifera. (2) The outer shelf (Clusters FB-II and FB-III) is characterized by seasonal high primary productivity and the alternation of higher (Cluster FB-III) and lower (Cluster FB-II) dissolved oxygen content in the cold bottom waters (Fig. 12); (3). The transitional environment to shallower water depths (Cluster FB-I, Fig. 12) is characterized by oligotrophic conditions occasionally disturbed by higher current regime. (4). Shallower environments (samples FB9-FB15) characterized by coarse-grained sediments and high sediment input, where foraminifera assemblages with low abundance and diversity indicate well-oxygenated bottom waters and current activity.

4.1.4. Foraminifera assemblages and potential applications to sequence stratigraphy for the Fântânele section

Three high-frequency sequences (HFS1-HFS3) have been separated in the first outcrop and another three in the third outcrop (HFS4-HFS6) based on lithological observations on the outcrop and fossil content (Figs. 5 and 13). The succession of high frequency sequences from the FA outcrop indicates progressive shallowing.

Although stratigraphic sequence surfaces necessary to identify systems tract boundaries (Cătuneanu, 2002; Zecchin & Cătuneanu, 2013) are absent, the progradational stratal stacking pattern of the identified high-resolution sequences may suggest the affiliation of these deposits to a late highstand systems tract.

The eustatic sea-level curve of Haq et al. (1987) displays at the Rupelian-Chattian boundary (TA4.5 – TB1.1 cycles) a major sea-level drop. The highstand systems tract suggested by the HFSs at Fântânele, which was biostratigraphically demonstrated as part of the early Chattian, highlights the possible influence of the tectonic control in the area. Tischler et al., (2008) also pointed out that the

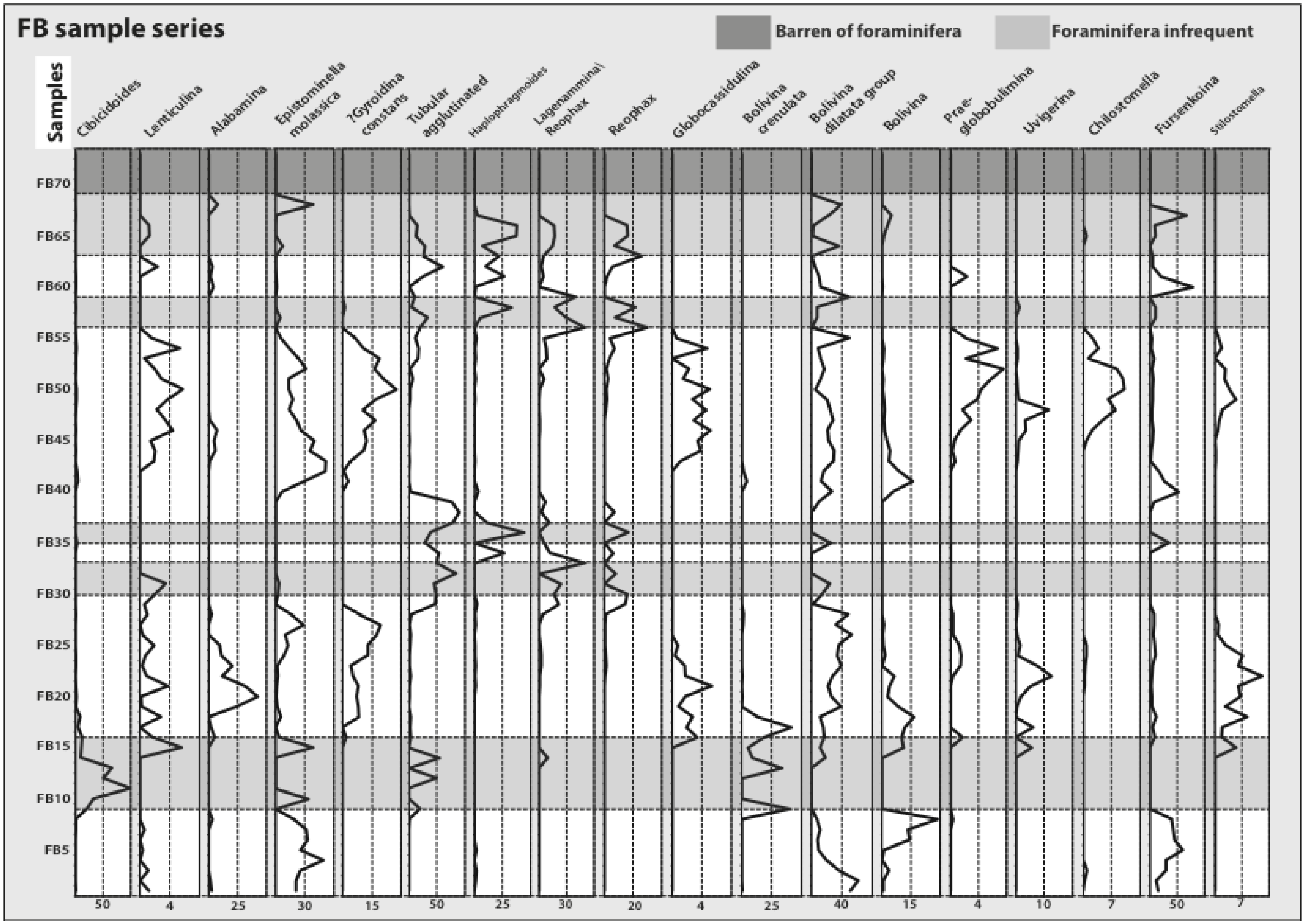

Fig. 15. *Graph representing percent abundance of the most important species, genera or groups with similar paleoecological affinities from each FB sample, third outcrop, Fântânele section.*

progradation phases of sand-dominated siliciclastics do not match the eustatic sea-level curve of Haq et al. (1987) and that the convergence of ALCAPA and Tisza-Dacia plates resulted in a late Rupelian to Burdigalian flexural foredeep development.

4.1.5. Total Organic Carbon (TOC) and benthic foraminifera assemblages

The parameters determined by the Rock-Eval 6 equipment for the FA1-FA38 samples are presented in Table 4. Values of TOC*1* content range between 0.38 -1.34 wt % with an average of 0.76 wt %, while the S2*2* parameter ranges between 0.4 – 2.67 mg HC*3*/g sample indicating variable source rock potential. HI*4* values are from 57 to 231 mg HC/TOC and an average around 135 mg HC/g TOC, while OI*5* values range between 33-99 with an average around 53. The TOC values of the investigated samples from the Fântânele section suggest poor to good petroleum potential (ranging between 0 – 2 wt %), the S1*6* values fall in the poor petroleum potential category, while the S2 values (ranging between 0 – 5 mg HC/g rock) indicate poor to fair petroleum potential (Peters & Cassa, 1994). All of the *Tmax*7 values are below 435˚ C suggesting immature stage of thermal maturity for oil (Peters & Cassa, 1994).

The S2 vs. TOC diagram (Pyrolizable Hydrocarbons versus Total Organic Carbon)

The organic matter of sedimentary deposits may have two sources: continental and marine (Nuńez-Betelu & Baceta, 1994). The corrected regression line (Fig. 16) suggests that samples from the Fântânele section fall in the marine and terrestrial organic matter type fields (Type II and Type III kerogen fields).

The Hydrogen Index versus the Oxygen Index (Fig. 16)

Most of the investigated samples from the Fântânele section fall in the type II organic matter that is oil and gas prone, while a number of samples fall close to the type II - type III boundary curve (type III kerogen is gas prone).

---

1 TOC - Total Organic Carbon (weight %).

2 S2 - Hydrocarbons with potential of release after maturation (mg hydrocarbons / g rock).

3 HC - Hydrocarbons.

4 HI - Hydrogen Index (mg HC/g TOC).

5 OI - Oxygen Index (mg CO_2/g TOC).

6 S1 - Quantity of free hydrocarbons (mg hydrocarbons / g rock).

7 Tmax - Maturity parameter.

Benthic foraminifera and organic matter

The distribution of benthic foraminifera assemblages is strongly related to organic carbon flux to the sea floor and oxygenation of bottom waters. The purpose of the tentative correlation of benthic foraminifera assemblages and organic matter content is to determine additional information regarding the controlling paleoecological factors (e.g. influx of organic matter to the sea floor related to the variability of primary productivity, bottom water oxygenation, current activity).

At the Fântânele section, the organic matter of terrestrial origin represents an important constituent in many samples, therefore the total amount of TOC is partially related to sediment supply from the continent. The sediment supply also increases nutrient input at the surface waters enhancing primary productivity and the availability of organic matter of marine origin. It is not excluded that the organic matter of terrestrial origin is an important component in samples with kerogen type II (marine origin). The higher TOC values from the Fântânele section are probably the result of combined factors: the availability of organic matter and special environments (low bottom water oxygenation) that favored the preservation of organic matter. There is evidence of high primary productivity also in samples with lower TOC values. In this case, the organic matter probably has been deposited during or followed by episodes with well-oxygenated bottom waters. The low TOC values of coarse-grained samples containing dominating agglutinated foraminifera could be the result of low flux of organic matter or higher sediment supply in relation to the deposition of organic matter. The type of organic matter is considered responsible for the composition of the benthic foraminifera assemblages. For example, several authors (e.g. Koho, 2008; Phipps, 2012) suggested that calcareous taxa are strongly favoured by abundant supply of fresh phytodetritus, while agglutinated forms are less dependent on fresh food input. These assumptions were confirmed by Jannink et al., (1998) and Schumacher et al., (2007), who observed a clear increase in the proportion of agglutinated taxa from 200 to 1000 m depths. At Fântânele, probably the species composition of benthic foraminifera assemblages, dominated by agglutinated forms, may also be related to decreased labile organic matter arriving at the seafloor at greater depths.

Sample	PC [%]	RC [%]	TOC [%]	MINC [%]	HI [mg HC/g TOC]	OI [mg CO2/g TOC]	Tmax [°C]	S1 [mg HC/g]	S2 [mg HC/g]	S3
FA38	0.07	0.64	0.71	1.45	102	43	426	0.03	0.73	0.30
FA37	0.24	1.10	1.34	0.63	200	33	426	0.05	2.67	0.44
FA36	0.15	0.96	1.12	0.48	151	35	425	0.04	1.69	0.39
FA35	0.12	0.77	0.89	2.07	146	43	428	0.04	1.30	0.38
FA34	0.11	0.70	0.81	1.42	140	48	428	0.03	1.14	0.39
FA33	0.13	0.90	1.03	0.77	135	36	426	0.04	1.39	0.37
FA32	0.06	0.45	0.51	1.16	113	55	424	0.03	0.57	0.28
FA31	0.05	0.44	0.49	1.03	104	61	426	0.02	0.51	0.30
FA30	0.12	0.59	0.71	0.84	188	53	430	0.03	1.34	0.38
FA29	0.05	0.73	0.78	0.07	57	63	419	0.01	0.44	0.49
FA28	0.19	0.87	1.06	0.68	189	58	426	0.08	2.01	0.61
FA27	0.10	0.71	0.81	0.67	133	52	427	0.04	1.07	0.42
FA26	0.10	0.58	0.68	1.01	152	52	426	0.03	1.03	0.35
FA25	0.09	0.58	0.67	1.58	144	57	428	0.02	0.96	0.38
FA24	0.17	0.92	1.09	0.64	173	36	428	0.02	1.88	0.39
FA23	0.14	0.92	1.06	1.05	141	38	427	0.02	1.48	0.40
FA22	0.07	0.57	0.64	0.32	109	39	427	0.03	0.70	0.25
FA21	0.04	0.34	0.38	1.79	104	63	426	0.02	0.40	0.24
FA20	0.11	0.38	0.49	2.93	231	79	431	0.09	1.14	0.39
FA19	0.08	0.61	0.69	1.04	121	56	426	0.02	0.84	0.39
FA18	0.07	0.45	0.52	2.24	129	67	426	0.09	0.67	0.35
FA17	0.05	0.36	0.41	3.05	117	99	426	0.03	0.48	0.41
FA16	0.08	0.68	0.76	0.82	114	46	429	0.02	0.86	0.35
FA15	0.05	0.45	0.50	2.38	95	79	427	0.01	0.47	0.39
FA14	0.08	0.57	0.65	2.08	118	74	427	0.02	0.76	0.48
FA13	0.08	0.60	0.68	1.45	118	58	428	0.02	0.81	0.39
FA12	0.12	0.70	0.83	2.16	158	57	430	0.04	1.31	0.47
FA11	0.08	0.55	0.63	2.82	130	57	430	0.02	0.82	0.36
FA10	0.19	0.92	1.10	1.20	188	39	431	0.03	2.08	0.43
FA9	0.13	0.80	0.93	0.21	155	33	430	0.03	1.43	0.30
FA8	0.05	0.51	0.56	0.75	92	54	429	0.01	0.52	0.30
FA7	0.08	0.50	0.58	1.01	125	59	427	0.08	0.73	0.34
FA6	0.09	0.59	0.67	2.82	133	52	428	0.02	0.89	0.35
FA5	0.10	0.70	0.80	2.41	137	49	428	0.03	1.09	0.39
FA4	0.09	0.56	0.65	3.12	127	80	427	0.04	0.82	0.52
FA3	0.14	0.82	0.96	0.40	167	33	427	0.02	1.60	0.32
FA2	0.08	0.69	0.78	0.22	111	47	426	0.03	0.86	0.36
FA1	0.08	0.67	0.75	0.31	116	35	427	0.01	0.87	0.26

Table 4. *Rock-Eval 6 pyrolysis data of samples FA1-FA38 from the Fântânele section.*

4.1.6. Phosphorus (P) content of the Fântânele section

The aim of the phosphorus content analysis is to obtain additional information on paleoecological factors such as primary productivity (organic bound P), sediment input (detrital P), and bottom water oxygenation (authigenic P, iron bound P, organic bound P).

Samples taken from Fântânele (FA1-FA38 and FB1-FB70) were analyzed for their phosphorus (P) content using the five-step sequential extraction method (SEDEX method - Ruttenberg, 1992; Ruttenberg et al., 2009). The development of such sophisticated sequential extraction method allows differentiation between different buried phosphate phases, which are preserved in sediments (Ruttenberg, 1992; 1993). This method separates solid phosphate phases such as loosely sorbed P, iron-bound P (iron and manganese oxyhydroxides), authigenic P (carbonate fluorapatite – CFA, and phosphorus associated to fish debris, to calcium carbonate, and smectite), detrital P (associated to igneous, metamorphic and sedimentary apatites) and organic P can be distinguished (e.g. Ruttenberg, 1992).

The variations in the concentrations of various phosphorus phases among the three studied outcrops (samples FA1-FA38 and FB1-FB70) are displayed in figures 18 and 19 together with TOC concentrations (only for FA samples).

In the FA sample series, iron-bound phosphorus represents the most abundant form (on average 40% of total phosphorus) followed by authigenic phosphorus (32% on average). Detrital and organic-bound P represent 16% and 10% out of total phosphorus, respectively (Table 6). In the FB sample series, iron-bound phosphorus represents the most abundant form (on average 50% of total phosphorus), while authigenic, detrital and organic phosphorus represent 26%, 16% and 6.8%, respectively (Table 6).

Samples		Loosely-bound P (µmoles P/g)	Iron-bound P (µmoles P/g)	Authigenic P (µmoles P/g)	Detrital P (µmoles P/g)	Organic P (µmoles P/g)
FA samples	Minimum value	0.0194	5.1333	1.2225	1.4482	1.1957
	Average	0.0484	6.6892	6.5837	2.9307	1.8768
	Maximum Value	0.1162	9.8793	35.2341	6.6846	10.4412
	Average %	0.2689	40.0801	32.5959	16.1741	10.8809
FB samples	Minimum value	0.0003	8.8964	0.5160	1.4883	1.0565
	Average	0.0634	12.8086	7.2926	4.6768	1.7189
	Maximum Value	0.6585	33.7057	20.6177	22.2960	2.7682
	Average %	0.22	49.99	26.13	16.86	6.80

Table 6. *Concentrations and percentages of phosphorus phases from Fântânele section.*

4.1.7. Geochemical data (total organic carbon and phosphorus phases) and benthic foraminifera assemblages

The analysis of phosphorus phases and total organic carbon content contributed to the understanding of the main local paleoecological factors controlling the species composition of benthic foraminifera assemblages.

Higher sediment supply from the continent, as suggested by detrital P, oxygenated the environments and enabled the development of diverse benthic foraminifera assemblages in the shallower environments on the shelf. There is evidence for high primary productivity; nevertheless the oxygenated bottom waters inhibited the preservation of organic matter (low TOC and low organic bound P) increasing the potential amount of dissolved P for authigenic P formation.

On the outer shelf, the relatively high organic matter concentration related to high primary productivity (also suggested by organic bound P) represents the controlling factor

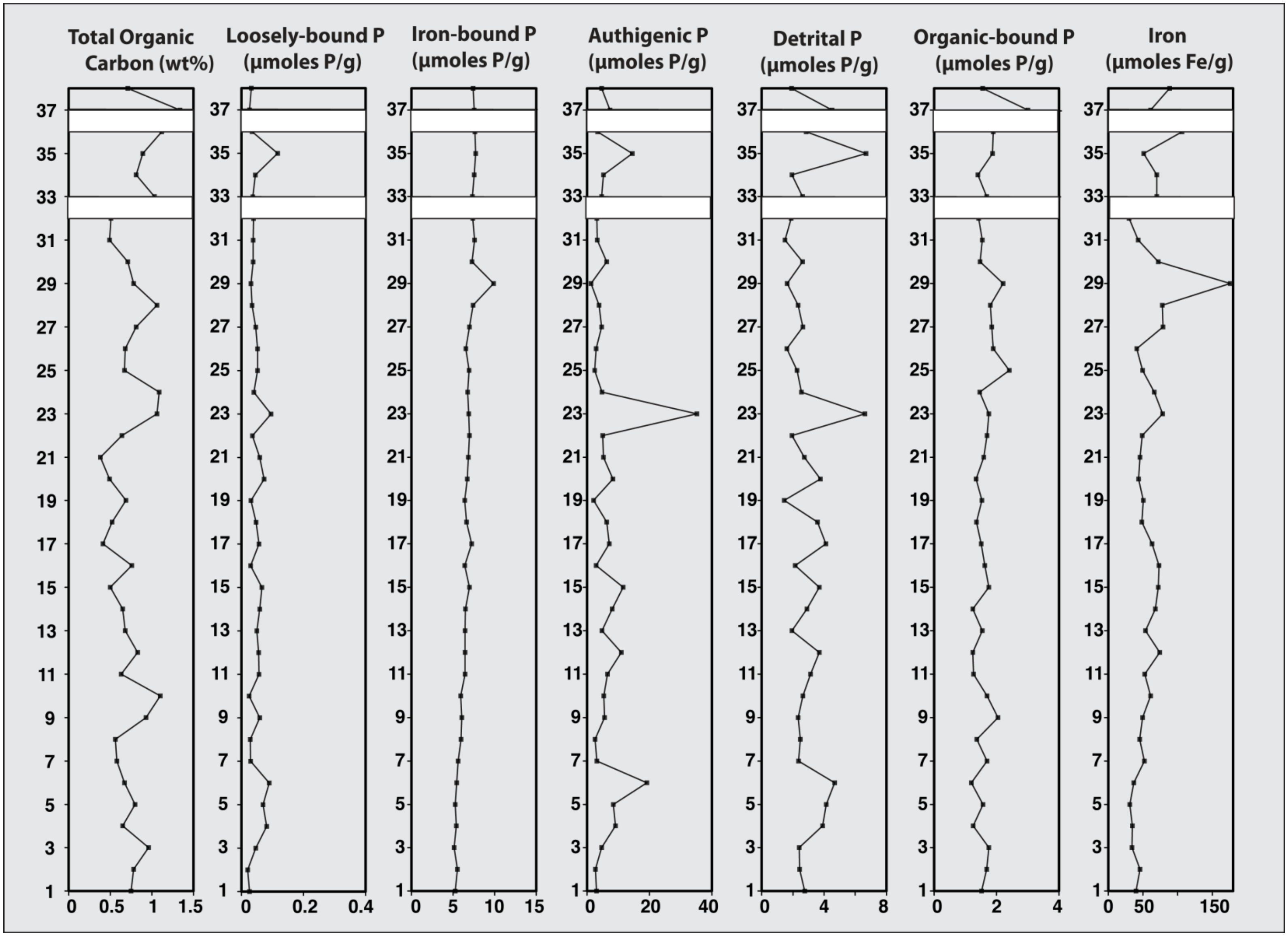

Fig. 18. *Graph showing content of Total Organic Carbon (wt %), Iron (in µmoles Fe/g) and sedimentary phosphorus phases (Loosely-bound P, Iron-bound P, Authigenic P, Detrital P and Organic-bound P expressed in µmoles P/g) for the FA sample series from the Fântânele section. White bands represent outcrop delimitations.*

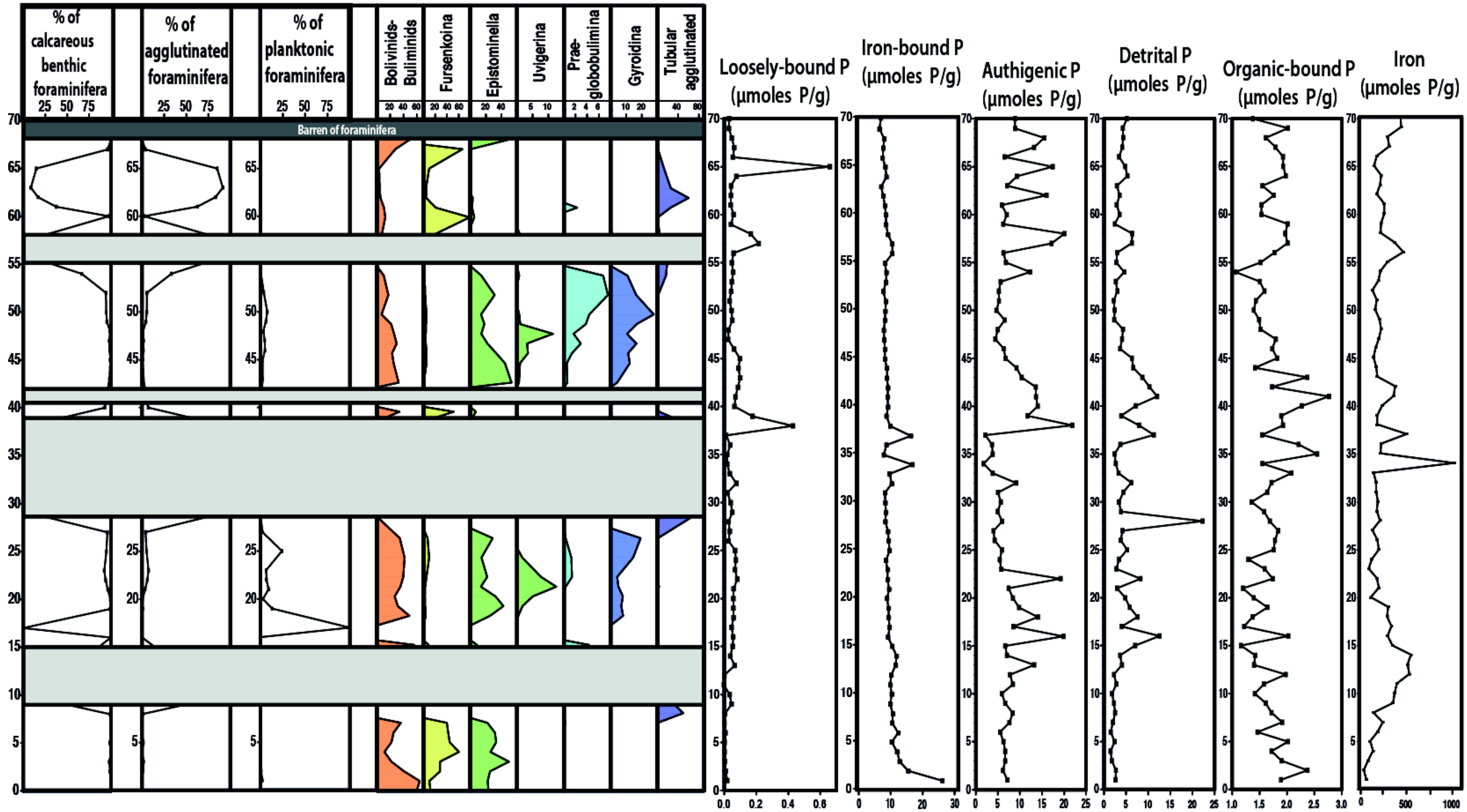

Fig. 19. *Graphic representation of important foraminifera groups or genera and of phosphorus phases of the FB1-FB70 samples from the Fântânele section. Horizontal grey rectangles represent intervals with infrequent foraminifera.*

of benthic assemblages developed in oxygen-depleted environments that lack currents that oxygenate the bottom waters.

In deeper environments (upper bathyal) the development of benthic foraminifera assemblages was mainly influenced by organic carbon flux to the sea floor and the physico-chemical properties of the water masses. Here, the dominance of agglutinated foraminifera assemblages is possibly related low organic carbon flux (low TOC content), mixed quality of organic matter (terrestrial or degraded and marine) and calcium carbonate subsaturation (low mineral carbon and authigenic P content).

The variability of local paleoecological parameters is probably in strong connection with the complex interaction of eustatic sea-level fluctuations, regional tectonics, climatic events and the paleogeographic configuration of the Transylvanian Basin in the context of the Paratethys. These influenced water depth, sediment supply and consequent primary productivity and bottom water oxygenation.

4.2. Gălpâia section

Twenty-seven samples were picked from the Lower Miocene Chechiș Formation near the Gălpâia village (N 47,08154 E 23,1413; Fig. 21) for foraminiferal analysis and paleoenvironmental reconstruction.

The studied outcrop interval consists of massive dark grayish mudstones with very rare intercalations of fine sandstones lamina (Fig. 22). Nodules and carbonaceous material have also been identified. Some levels are characterized by moderate bioturbation (vertical/horizontal burrows). Regular, yellowish/reddish cm thick altered mudstones develop along the studied outcrop (Fig. 22).

4.2.1. Biostratigraphy

Planktonic foraminifera assemblages are well represented throughout the Gălpâia section. The presence of the planktonic species *Globigerinoides trilobus* (in samples G1-G4, G12-G15, G19, G23, and G26-G27) enable the correlation with the Early Miocene (Aquitanian-Burdigalian) *Globigerinoides trilobus* Biozone of Popescu (1975). According to Cicha et al., (1998), the stratigraphic range of the species *Cassigerinella globulosa* (Egger) and *Globigerina ottnangiensis* Rögl is Eggenburgian-Karpatian, while *Paragloborotalia semivera* (Hornibrook) is of Egerian-Eggenburgian

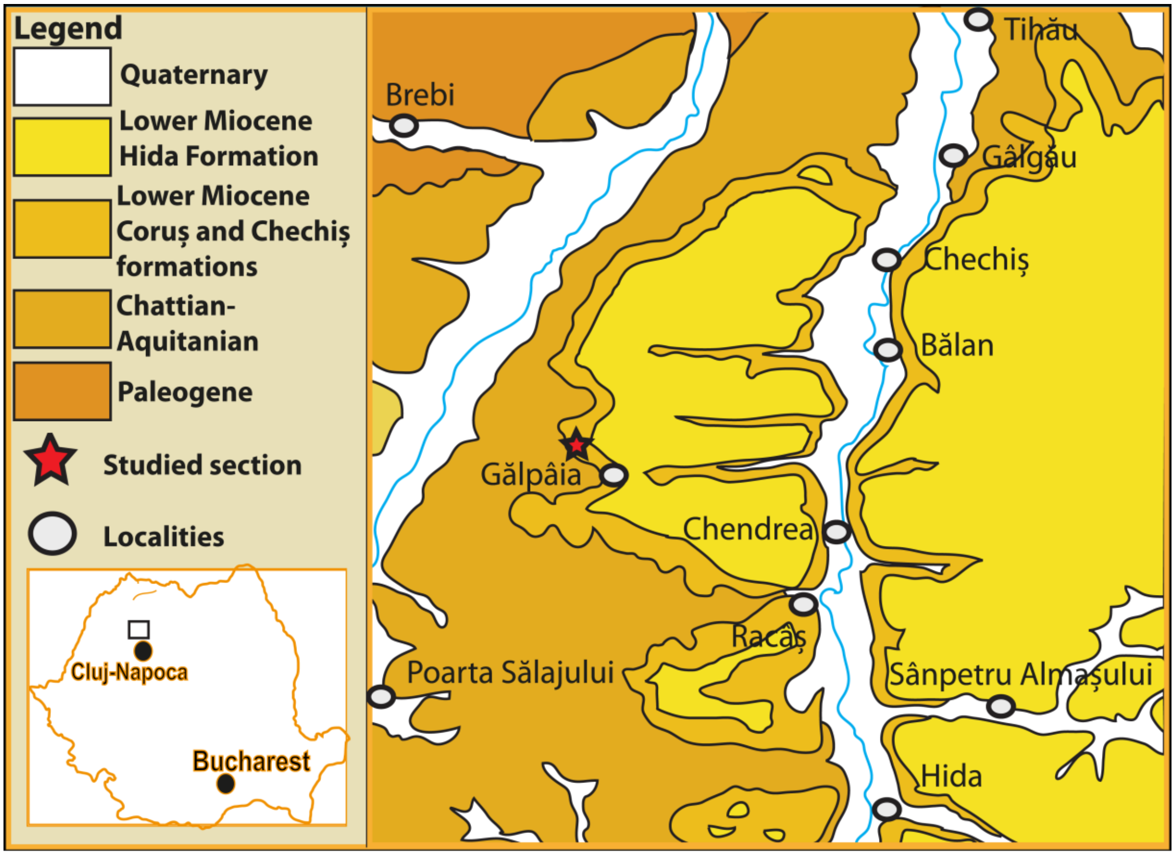

Fig. 21. *Geological map and location of the Gălpâia section and the studied outcrop (modified after the Geological Map of Romania, 1:200000, Sheet Cluj; Petrescu & Drăghici, 1964; Beldean & Filipescu, 2011).*

age. Based on the identified planktonic foraminifera species and their distribution, the age of the deposits form the Gălpâia section is probably Eggenburgian.

4.2.2. Planktonic/Benthic ratio and paleoecology of planktonic foraminifera

The increasing trend of the P/B ratio (34-66%) from the base of the outcrop (samples G1-G9) could indicate gradual deepening of the environment from a possible middle neritic (50-100 m) to outer neritic (100-200 m) or upper bathyal setting (>200m). Following this interval, the curve representing the percentage of planktonic forms of the subsequent samples (G10-G25) displays relatively constant values with a slight decrease towards the top of the outcrop (64-54%). In the youngest sediments (samples G25-G27) the P/B ratio (53-59%) slightly increases. The abundance of planktonic foraminifera from the second part of the outcrop suggests slight oscillations of the water depth.

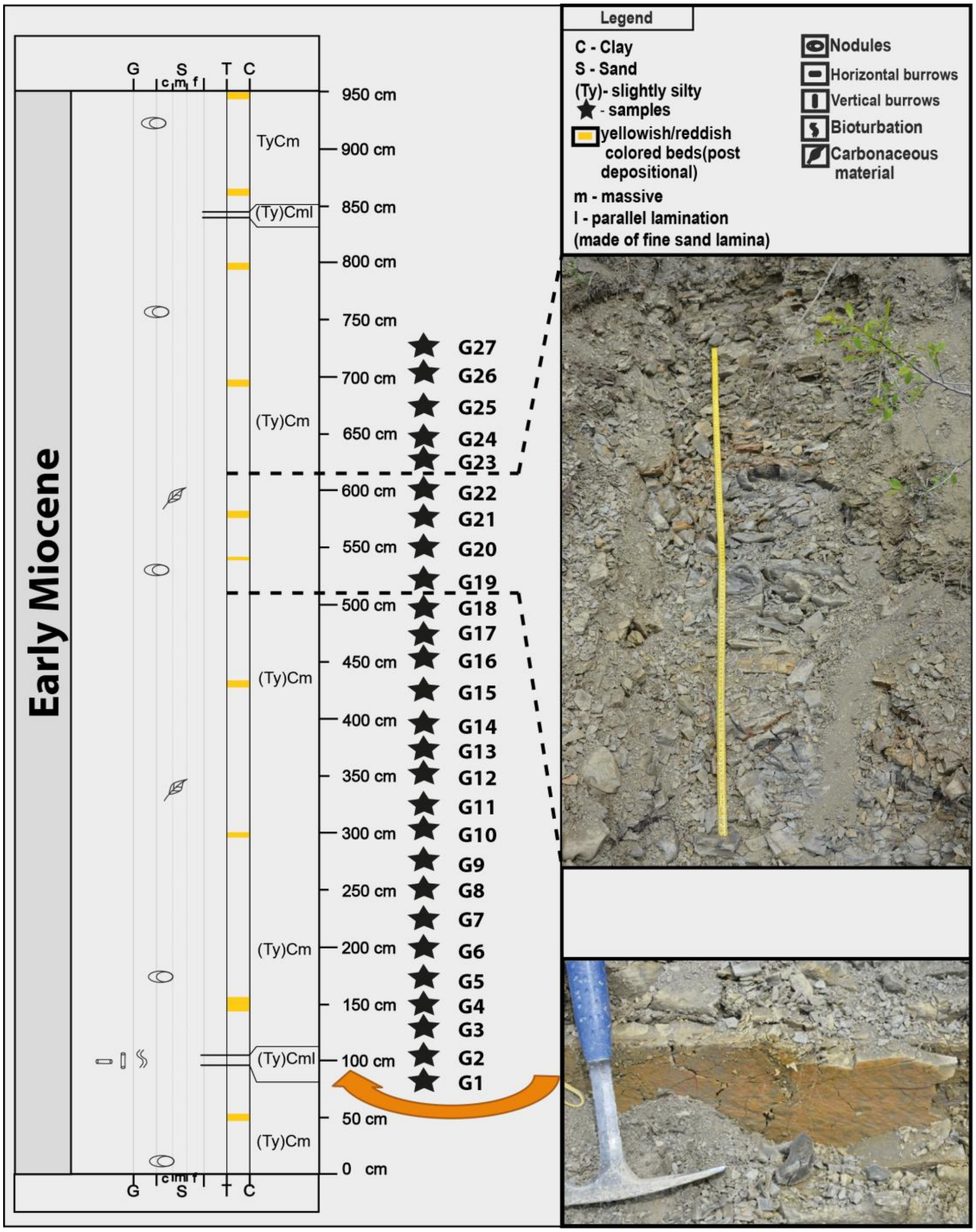

Fig. 22. *Sedimentary log of the studied outcrop from the Gălpâia section and position of samples.*

The planktonic foraminifera from Gălpâia are dominated throughout the section by cool-temperate water indicators. Episodes of warming tendency at the surface waters are indicated by the increase in abundance of *Globigerinoides trilobus* (samples G12-G15). Furthermore, episodes of high primary productivity are indicated by the small-sized microperforate forms (e.g. *Tenuitella*), small five-chambered globigerinids (e.g. *Globigerina ottnangiensis, G. tarchanensis*) and the *Globigerina* group.

4.2.3. Statistical treatment and paleoenvironments of benthic foraminifera assemblages

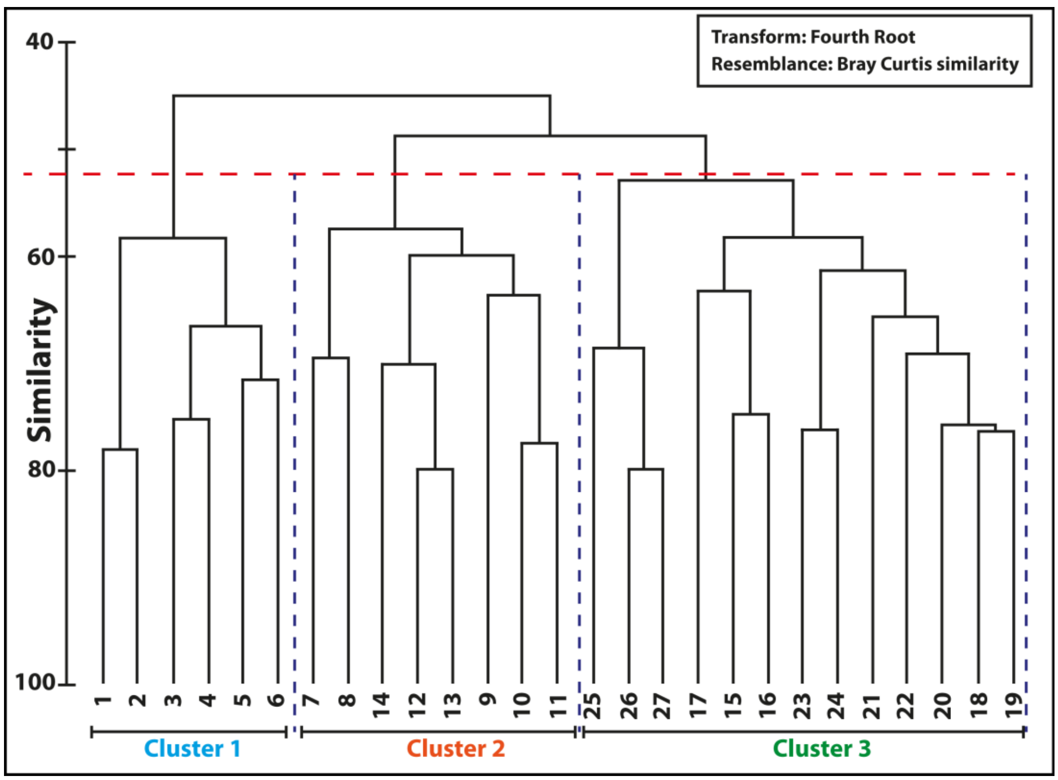

Fig. 23. *Dendrogram representing the hierarchical agglomerative clustering based on the Bray-Curtis similarity matrix of the benthic foraminifera. Horizontal dashed line represents the similarity cut and vertical dashed lines represent delimitations of the resulted clusters.*

Cluster 1

Benthic foraminifera assemblages from Cluster 1 suggest episodes of higher energy currents, well-oxygenated environments and intervals of high primary productivity. The oxygenated, stable environment and flux of organic matter to the sea floor enabled the development of well-diversified benthic assemblages on an outer shelf setting. Increase in P/B ratio, tubular agglutinated forms, the bathyal-abyssal M2a morphogroup and the decrease of shelf-type agglutinated foraminifera indicate a gradual increase in water depth for Cluster 1.

Cluster 2

It is possible that the paleoenvironments inferred within Cluster 2 are characterized by longer episodes of oxygenated bottom waters with lower energy of currents in which epifaunal oxic taxa and tubular agglutinated forms developed. Primary productivity indicators are less abundant and might suggest shorter episodes of high primary productivity. The small increase of deep infaunal forms (*Bolivina* and *Bulimina* species) could be related to changes in water depth or the consumption of refractory organic matter during the more oxygenated intervals. Increased water depth is also supported by the agglutinated foraminifera morphogroups.

Cluster 3

This whole interval (G15-G23) is characterized by oscillations of episodes with higher current energy, high primary productivity and tranquil episodes with lower organic input. Following this interval, the agglutinated foraminifera dominate the assemblages with greatest abundance represented by the tubular agglutinated forms. This might be related to deepening of the environment, where the development of calcareous taxa is inhibited. Such changes in paleobathymetry could also be suggested by the complete disappearance of the shallow water agglutinated foraminifera (morphogroup M2c represented by *Vulvulina haeringensis, Spiroplectammina carinata* and *Spirorutilus carinatus*) in sample G18, and the general increase of the

bathyal-abyssal M2a morphogroup starting with sample G15.

4.2.4. Succession of paleoenvironments of the Gălpâia section

Based on the processed data, the sediments from the base of the outcrop were probably deposited in a middle?-outer neritic paleoenvironment characterized by episodes of higher energy (poor representation of tubular agglutinated foraminifera and the presence of the genus *Cibicidoides*), well-oxygenated bottom

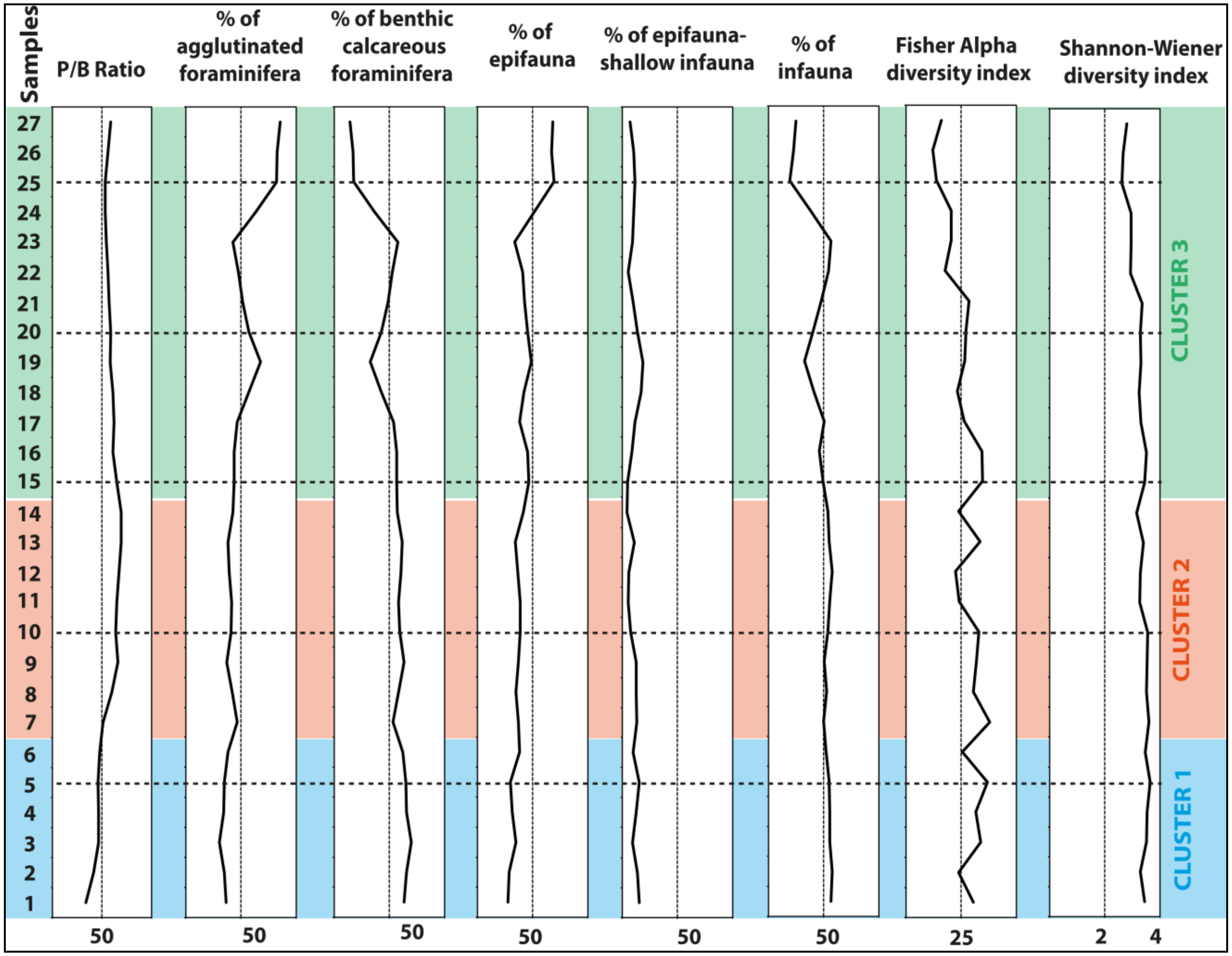

Fig. 24. *Graph representing the P/B ratio, percent of agglutinated foraminifera, percent of calcareous benthic foraminifera, the microhabitat of benthic foraminifera (percent of epifauna, epifauna-shallow infauna and infauna), the Fisher alpha diversity index, and the Shannon-Wiener diversity index for the Gălpâia section.*

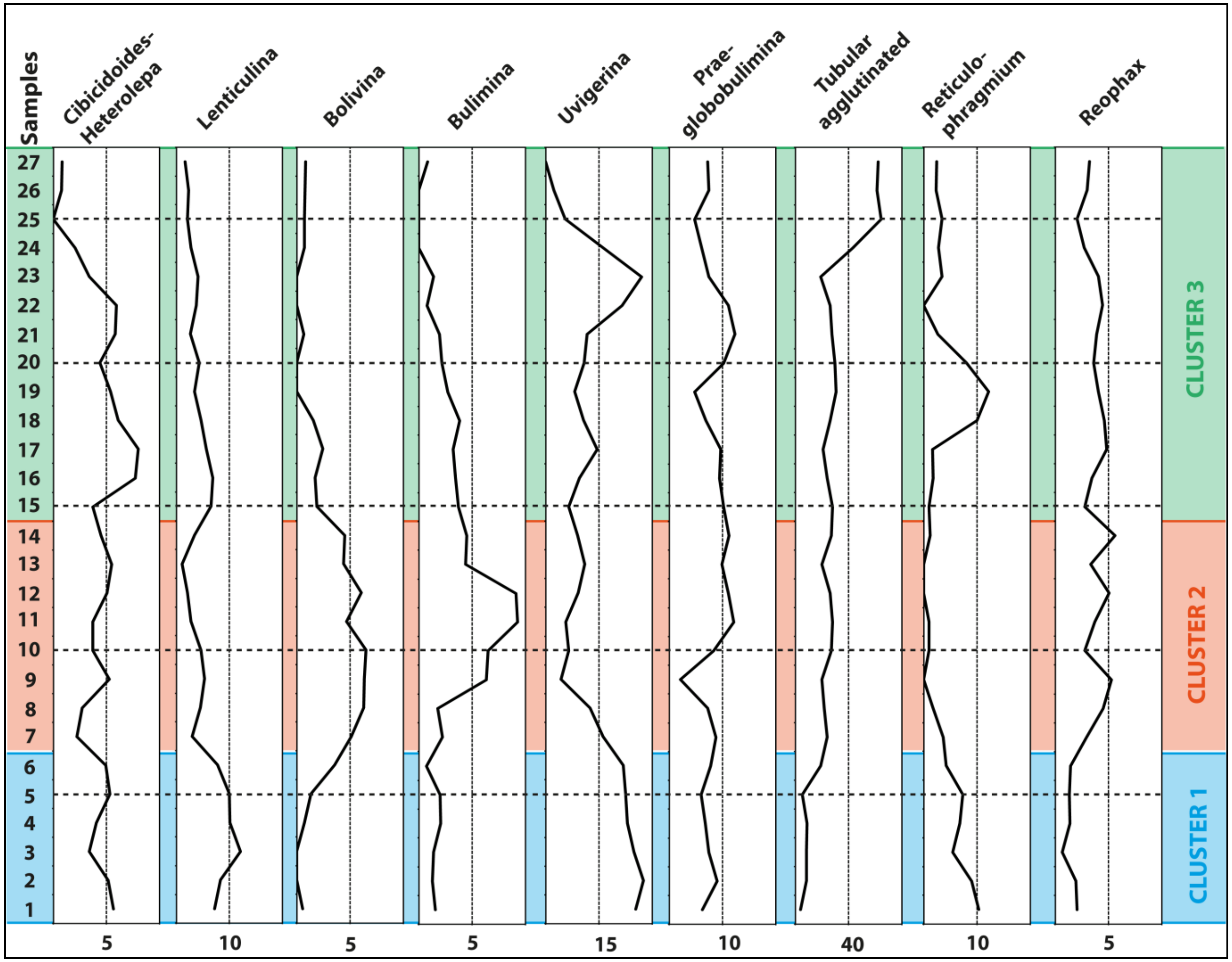

Fig. 25. *Graph representing percent of abundance of the most important genera or groups with similar paleoecological affinities for the Gălpâia section.*

waters (suggested by *Cibicidoides*) and intervals with enhanced primary productivity (the good representation of *Uvigerina* and *Praeglobobulimina* species).

Planktonic/benthic ratio suggests gradual increase in water depth, while planktonic foraminifera species support the existence of episodes of high primary productivity probably as a consequence of high nutrient flux from the land. Increase in water depth (outer neritic setting) in the middle part of the outcrop probably resulted in changes in bottom water current energy (increased abundance of tubular agglutinated foraminifera).

At the sea floor, changes in primary productivity are indicated by the decreasing *Uvigerina* specimens and increased tubular agglutinated foraminifera, typical for environments with low organic carbon flux. As a consequence, because of the shorter intervals of primary productivity, the episodes of oxygenated bottom waters became longer. In these environments, the epifaunal benthic forms probably consumed the labile organic matter, while the deep infaunal foraminifera fed on refractory organic matter (more *Bolivina* and *Reophax* species).

The upper part of the outcrop is characterized by oscillations in paleoecological factors such as the intensity of bottom water currents and primary productivity. The increase in the lowermost samples of this part of shallow water agglutinated foraminifera might indicate oscillation in water depth (slight shallowing). Following this interval, the complete disappearance of typical shallow water agglutinated foraminifera (species of *Spirorutilus, Vulvulina* and *Spiroplectammina*), the increase of bathyal-abyssal indicating agglutinated forms and the decrease in abundance of calcareous benthic forms might suggest the transition to an upper slope environment in the uppermost part of the outcrop. Transport of some foraminifera species from shallower environments could also be noticed.

The origin of the fine sand laminas might be related to storm activity, alongshore drifts or delta influences (the presence of coal material). The delta influence could support the nutrient flux to the marine environment (and

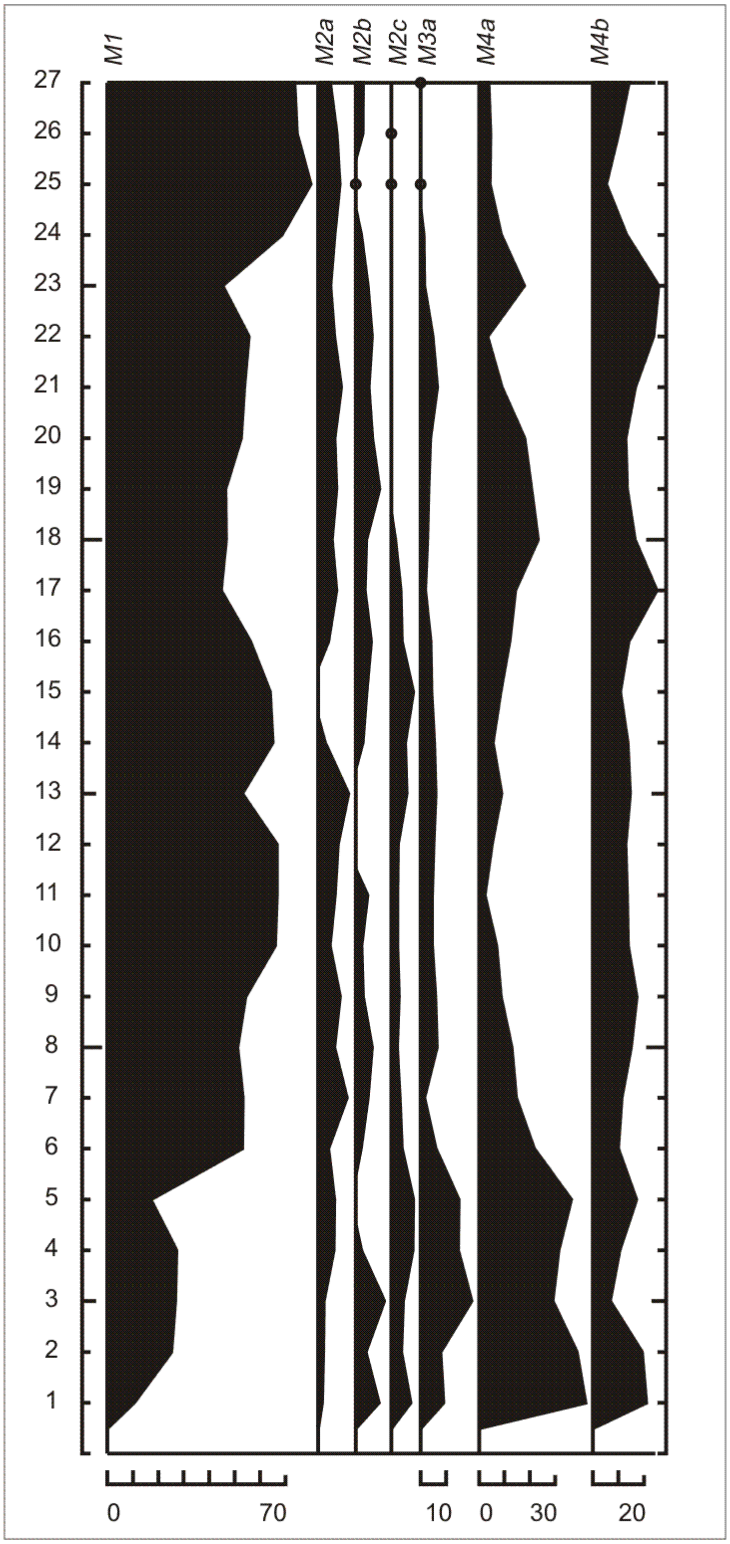

Fig. 26. *Graph representing the percent of agglutinated foraminifera morphogroups defined by Kaminski, Gradstein & collaborators (2005). Percent of each morphogroup is calculated relative to the total abundance of agglutinated foraminifera.*

seasonal high primary productivity) and periodic higher current energy and consequent oxygenation of the bottom water. This influence might have diminished during deposition of the sediments from the middle of the outcrop concomitant with the increase in surface water temperatures. According to Krézsek & Bally (2006), in the studied area (central parts of the Transylvanian Basin) a shelf/delta environment existed during the Early Miocene. The basin was characterized by wedge-like deposits that thickened towards the Pienides and thinned towards the forebulge area.

4.3. Tihău section

The studied section from Tihău displays parts of the Coruș, Chechiș and Hida formations. Nineteen samples were collected from fine siliciclastic sediments from the Chechiș and Hida formations near the Tihău locality (Lânii Valley, Sălaj County - 47°12'20.96"N, 23°20'34.32"E, fig. 28). Seventeen samples were recovered from a continuous succession (samples T1-T17, fig. 30), while two of them were collected from a different outcrop below these (samples TH1 and TH2, fig. 29).

4.3.1. Sedimentology

The transgressive deposits belonging to the Coruș Formation are represented by well-sorted thick packages of sandstones alternating with centimetric / decimetric conglomerates containing large molluscs (especially pectinidae) typical for the littoral areas (Moisescu & Popescu, 1980). The sandstones are characterized by cross- and parallel bedding (subaqueous dunes). The transition from the sandstones belonging to the Coruș Formation to the bioclastic silty-sandy clays with glauconite (approximately 2.5 m thick) of the Chechiș Formation is gradational or net (Fig. 29). Above the deposits with glauconite, the sediments are characterized by gray clays (samples TH1 and TH2).

Decimetric intercalations of orto- and paraconglomerates were observed in the mudstones of the Chechiș Formation (Fig. 30). The base of the coarse grained deposits is weakly erosional while the top becomes gradational. The extraformational clasts have rounded to sub-rounded forms suggesting feeding of the fan deltas with fluvial sediments.

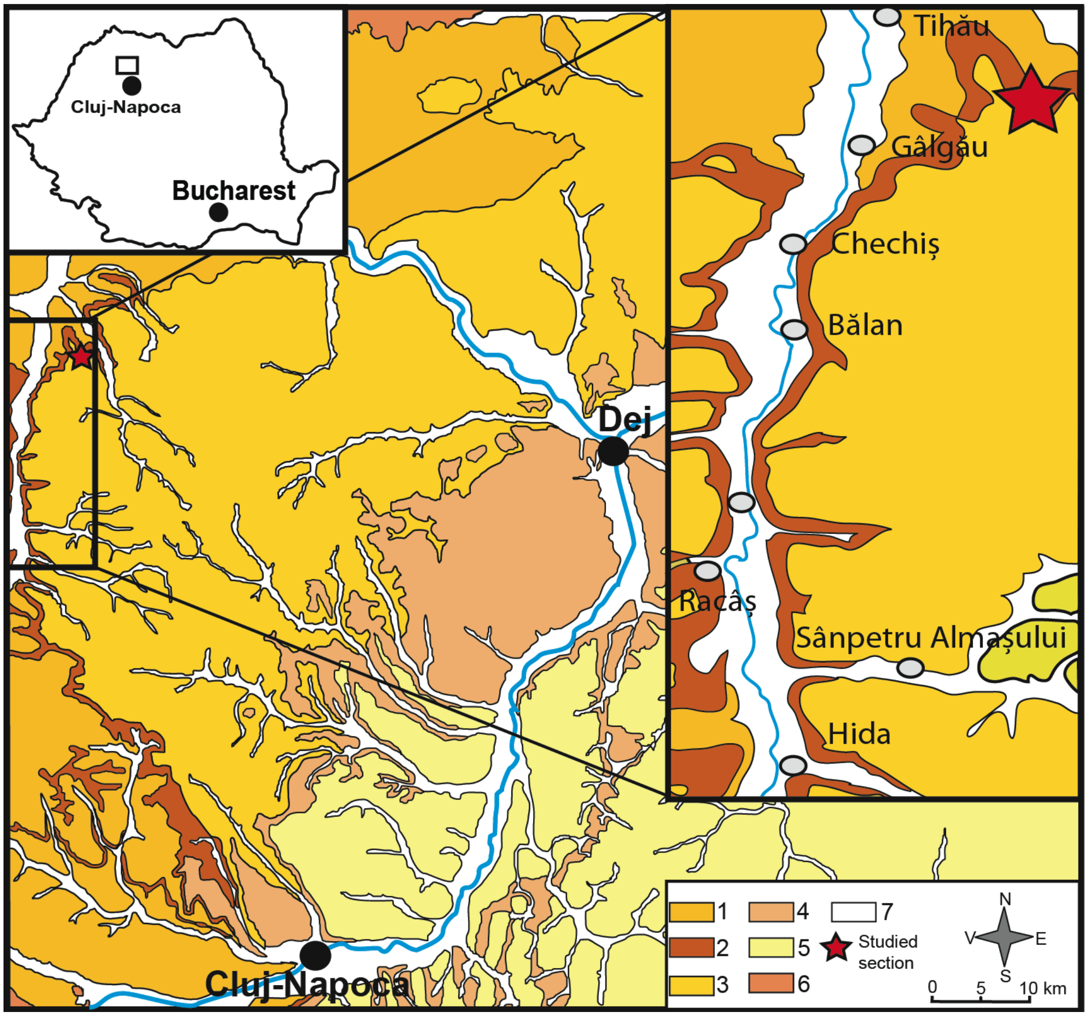

Fig. 28. Geological map and location of the studied outcrop (modified after Beldean & Filipescu, 2011). ***1*** *- Paleogene,* ***2*** *- Shallow marine Lower Miocene (Coruș and Chechiș formations),* ***3*** *– Deep marine Lower Miocene (Hida Formation),* ***4*** *– Badenian (Middle Miocene),* ***5*** *- Sarmatian (Middle Miocene),* ***6*** *– Metamorphics,* ***7*** *- Quaternary.*

Turbiditic sedimentation, specific for the Hida Formation, was observed in the middle and upper part of the studied section (Fig. 30). These sediments are characterized by intervals with sands/fine gravel or sandstones with carbonate cement alternating with marly-clays. Complete and incomplete Bouma sequences, erosional and deformational structures were recognized suggesting the deposition of turbidites in mid-fan settings.

4.3.1. Biostratigraphy and paleoecology of planktonic foraminifera

Planktonic foraminifera assemblages are relatively well represented in the sedimentary succession corresponding to samples T1-T17, while the first outcrop contains low abundance of planktonic forms (samples TH1 and TH2). The presence of *Globigerinoides trilobus* (in samples T1-T12 and T14-T15) enables the correlation with the *Globigerinoides trilobus* Biozone (Aquitanian-Burdigalian) of Popescu (1975). According to Cicha et al. (1998) the stratigraphic range of the species *Globigerina ottnangiensis* and *Globigerina dubia* in the Central Paratethys is Eggenburgian-Karpatian. Based on the identified planktonic foraminifera species, the sediments of the studied outcrops were probably deposited during the Burdigalian.

Similarly with the Gălpâia section, the planktonic assemblages from Tihău are mostly dominated by cold-temperate water and high primary productivity indicating species or groups (such as small-sized five-chambered globigerinids; *Globoturborotalita woodi; Tenuitellinata, Tenuitella,* and *Catapsydrax* - Li et al., 1992; Spezzaferri, 1994; Spezzaferri, 1995; Spezzaferri & Ćorić, 2001; Spezzaferri et al., 2002; Rögl & Spezzaferri, 2003; Bicchi et al., 2003; Roetzel et al., 2006; Bicchi et al., 2006).

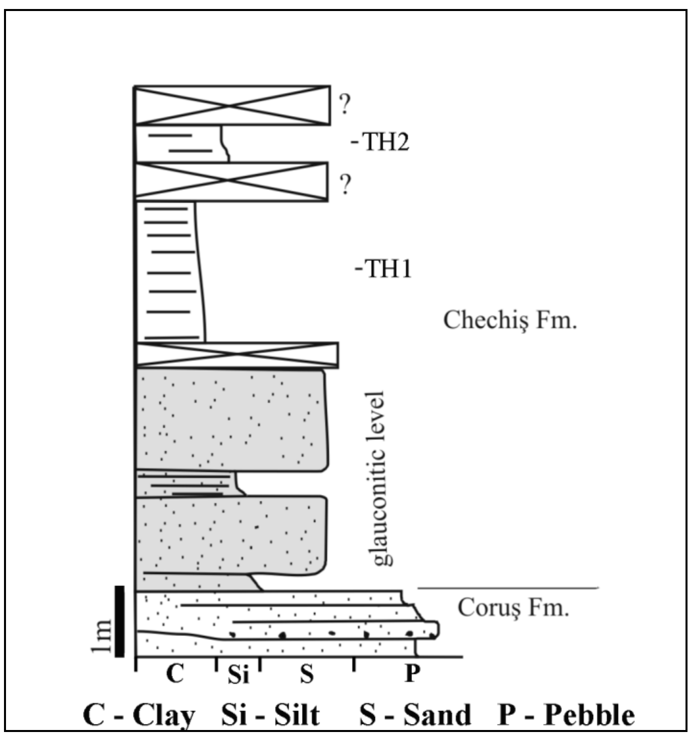

Fig. 29. *Lithology of the Coruș and of the base of the Chechiș formation and position of the samples collected.*

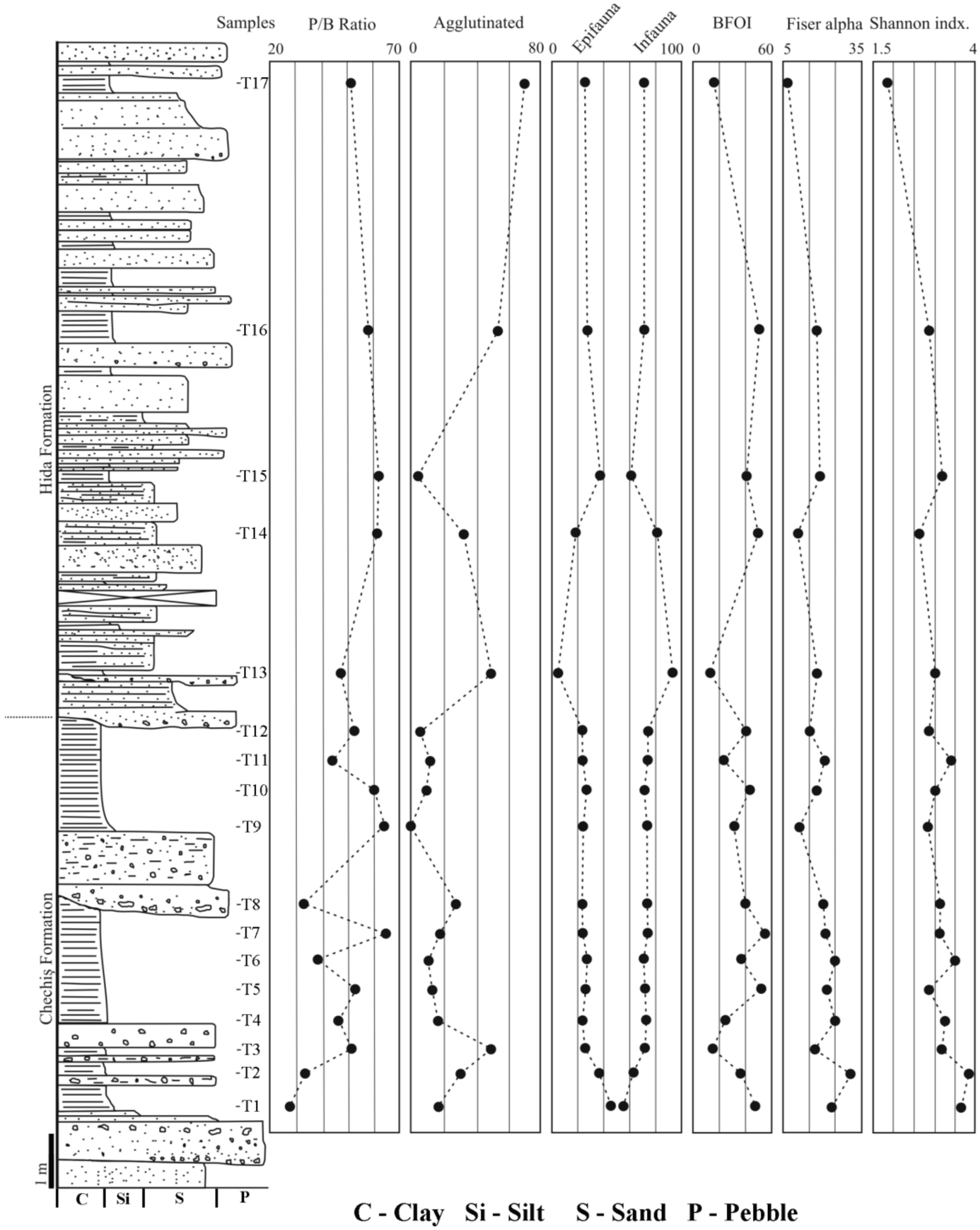

Fig. 30. *Graph showing the lithology of the second outcrop (Chechiș and Hida formations), position of samples and univariate statistics such as the P/B ratio, percent of agglutinated foraminifera, percent of epifauna and infauna microhabitats, the BFOI index, and diversity indices (Fisher alpha and Shannon-Wiener indices).*

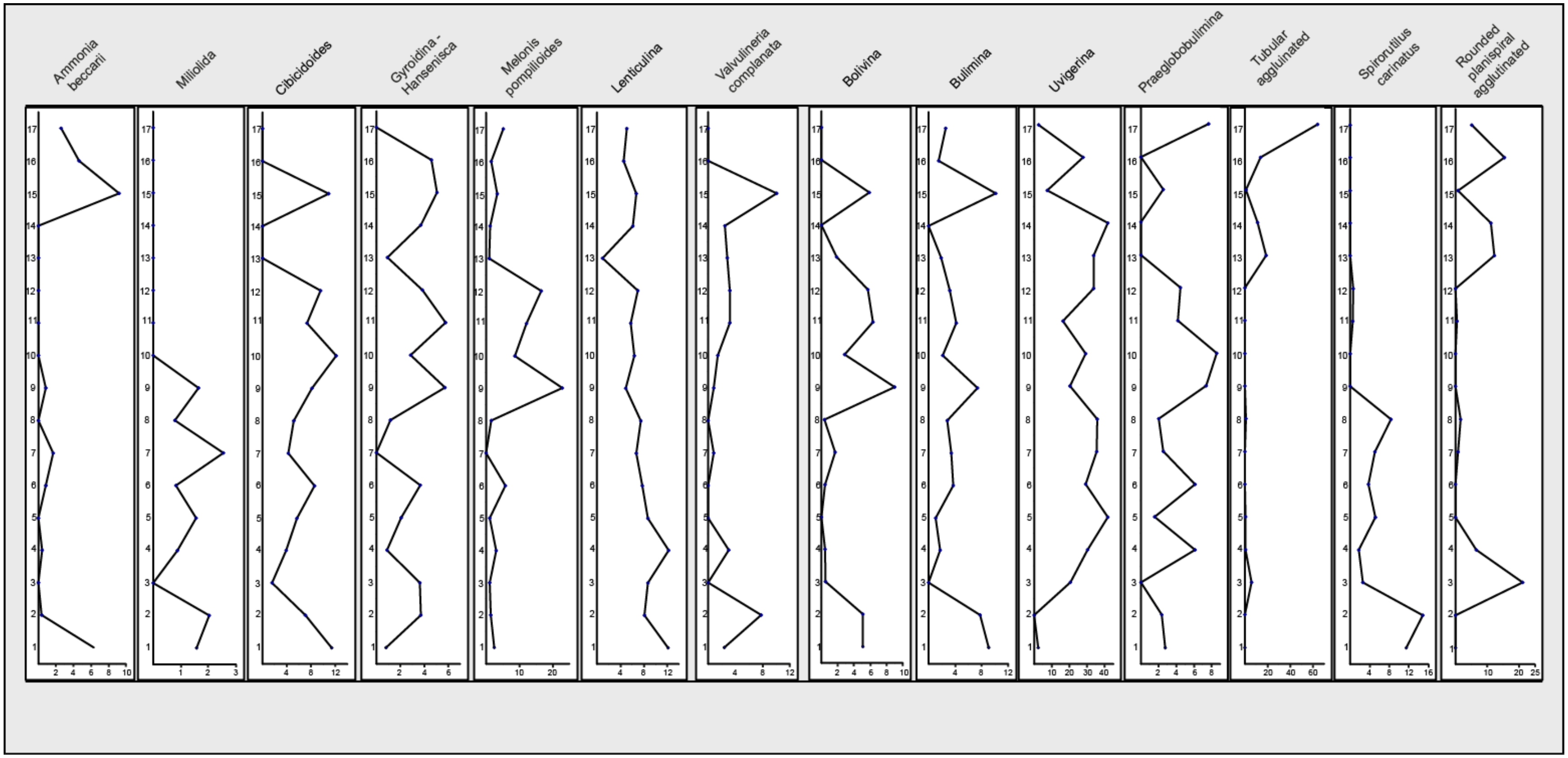

Fig. 31. *Graph showing the percent (relative to total benthic abundance) of most important benthic foraminifera species, genera or groups with similar paleoecological affinities for samples T1-T17 from the Tihău section.*

Warm-temperate surface waters are suggested by *Globigerinoides* (e.g. *Globigerinoides trilobus, G. primordius, G. quadrilobatus*) and *Paragloborotalia* (e.g. *Paragloborotalia continuosa* and *P. semivera*) groups, and the species *Globigerina ciperoensis* (Spezzaferri, 1994; Rögl & Spezzaferri, 2003; Bicchi et al., 2003; Amore et al., 2004). Intervals with surface water warming tendency were identified in samples T2-T7 (Chechiș Formation), where the species *Globigerinoides trilobus* is better represented compared with the rest of the samples.

A more detailed paleoclimatic study based on palynological data from the Miocene (Țabără & Chirilă, 2012) revealed an increase followed by a drop in the mean annual temperatures in the middle part of the Eggenburgian. Probably the warming tendency identified in the Gălpâia and Tihău sections can be correlated with the event mentioned by Țabără & Chirilă (2012).

4.3.3. Succession of paleoenvironments from the Tihău section

The lowermost benthic foraminifera assemblage from the Chechiș Formation (sample TH1, fig. 29) indicates an outer-neritic to upper bathyal paleoenvironment (characterized by high primary productivity) for the sedimentary succession above the level with glauconite, considered here as the maximum flooding surface. The sediments were probably deposited during the subsequent Highstand Systems Tract characterized by the late stage of the relative sea-level rise. A shallowing of the depositional setting starting with sample TH2 (outer neritic) has been interpreted. This trend continues until sample T2, where the paleoenvironment was probably characterized by a 50 - 100 m paleodepth. Shallowing of the environment was followed by good oxygenation of the bottom waters and low primary productivity. The upper part of the Chechiș Formation (samples T3-T12) is characterized by minor paleodepth oscillations occurring in an outer neritic environment, and episodes of high primary productivity. Bottom waters were relatively well oxygenated and probably alternated with episodes of oxygen depletion. In the uppermost part of the Chechiș Formation, benthic foraminifera assemblages suggest intense high primary productivity and enhanced oxygen depletion in the bottom waters. The frequent environmental shifts in the Chechiș Formation were probably the result of changing rates between relative sea level and sedimentary input from the land (sedimentation associated with fan deltas on a narrow shelf).

The studied part of Hida Formation was deposited in an upper bathyal setting suggested by deep-water agglutinated foraminifera assemblages. A shallowing interval in the middle part of the formation might be inferred by the presence of calcareous benthic forms. The transported calcareous benthic foraminifera from shallower environments in the upper part of the formation may suggest a stronger progradational trend of the sediments.

During the Early Miocene, the northern part of the Transylvanian Basin developed as a flexural basin due to the thrust of the Pienides (Krézsek & Bally, 2006). The prograding turbiditic sediments of the Hida Formation, developed under regional tectonic control, contain deep-water agglutinated assemblages, similar to those described by Filipescu & Beldean (2008), Beldean & Filipescu (2011), and Beldean et al., (2011).

Chapter 5.

Systematic taxonomy

Identification of foraminifera was mainly based on the works of Bhatia (1955), Batjes (1958), Larsen & Dinesen (1959), Kümmerle (1963), Grossheide & Trunkó (1965), Popescu & Iva (1971), Popescu (1975), Sztrákos (1979), Reiser (1987), Spezzaferri (1994), Cicha et al. (1998), Horváth (2003), and Kaminski, Gradstein & collaborators (2005). Classification of calcareous foraminifera is based on the suprageneric classification of Loeblich & Tappan (1988), while the classification of Kaminski (2004) was used for the agglutinated forms.

Chapter VI.

Conclusions

The main objective of the present study was to follow the environmental changes in the marine environments along the Upper Oligocene to Lower Miocene in the Transylvanian Basin, based on the analysis of fossil foraminifera assemblages.

The study focused on the Oligocene Vima Formation and Lower Miocene Chechiș and Hida Formations in order to reconstruct some of the local paleoenvironmental parameters that were controlled by the evolution of the Transylvanian Basin.

Taxonomic investigation resulted in a detailed record of the foraminifera species, which were illustrated in the attached plates. Their signification for paleoenvironmental and paleoclimatic reconstructions was discussed based on modern and ancient analogs, with additional, very useful support of statistical and geochemical data.

Benthic and planktonic foraminifera were studied from three representative outcrops of the Vima Formation from **Fântânele section**. Based on the studied assemblages, we concluded that the investigated section was deposited during the late Rupelian to early Chattian, more precisely the O4 (*G. angulisuturalis*/ *C. cubensis*) and O5 (*P. opima*) planktonic foraminifera biozones of Wade et al., (2011).

Paleoclimatic data provided by planktonic foraminifera suggest cool to temperate surface waters for the late Rupelian, indicating a possible boreal influence from the North Sea, while a warming tendency towards temperate surface waters was observed for the Chattian. The observed climatic change might be coeval either with the beginning of the Late Oligocene Warming Event (Zachos et al., 2001) or the result of increased influence from the Mediterranean Sea.

Paleoambiental reconstructions based on the Oligocene benthic communities from the north-western Transylvanian Basin indicate repeatedly changing paleoecological parameters. Paleobathymetry estimates suggest oscillating water depths due to relative sea-level changes, from outer shelf to upper bathyal environments. The outer shelf was controlled by seasonal primary productivity, as suggested by temporarily developped eutrophic conditions and local abundances of digitate planktonic foraminifera *Globigerinella roegelina*, which produced variable oxygen content on substrate. The bathyal settings evolved mainly in oligotrophic conditions, with fluctuating sediment input due to turbidity currents, periodic low-oxygen content induced by water column stratification, and undersaturated waters in calcium carbonate. Benthic foraminiferal assemblages suggests cold bottom water temperatures for the whole Fântânele section.

The identified high-frequency sequences in the 1st and 3rd outcrop are related to short-term relative sea-level oscillations. The dynamic shifts of the foraminifera assemblages between environments correlate with water depth fluctuations and associated paleoecological factors. The aggradational to progradational stacking pattern of the high-frequency sequences makes possible the association of these deposits to a high stand systems tract.

Geochemical data suggest that the composition of benthic foraminifera assemblages was controlled by the interaction of paleoecological factors such as water depth, sediment supply, current activity, primary productivity and organic carbon flux to the sea floor, quality of organic matter, and the physico-chemical properties of water masses.

The paleoenvironmental reconstruction for the Fântânele section shows the particular development of the north-western Transylvanian Basin in the context of the Paratethyan evolution during the Oligocene. Inferred upper Rupelian and lower Chattian sea-level changes do not coincide with the eustatic sea-level changes at global level (Haq et al., 1987), thus highlighting the effects of the paleogeographic evolution of the Paratethys under the geotectonic influence. Possible episodic isolations of the basin and regional tectonic activity (emplacement of the Pienide Nappe) influenced the paleobathymetry and the interplay of local paleoecological factors such as sediment supply to the basin, primary productivity and oxygen content of bottom waters.

For the Chechiș Formation investigated at **Gălpâia**, the biostratigraphic study of planktonic foraminifera pointed out that the age is Eggenburgian. The paleoambiental reconstruction based on planktonic and benthic foraminifera assemblages indicates a general deepening of the environment from middle-outer shelf to possibly upper bathyal. Deltaic influences may be suggested by the occurrence of benthic foraminifera originating in shallower environments, with strong bottom currents, high oxygen levels and high primary productivity. Increase in water depth resulted in decrease of bottom water energy and a retrogradation of the environments, with consequences on primary productivity and consequent drop organic matter flux to the sea floor. The possibly upper bathyal environment was characterized by oscillating paleoecological factors such as bottom water energy and primary productivity.

A more complete image on the Lower Miocene could be restored from **Tihău** section. The biostratigraphic data enable the correlation of the deposits with the Burdigalian *Globigerinoides trilobus* Biozone of Popescu (1975).

Palaeoenvironments inferred based on foraminiferal assemblages suggests for the Chechiş Formation frequent shifts between lower shoreface to upper bathyal, while for the Hida Formation an upper bathyal depositional setting. The distribution of benthic foraminiferal assemblages throughout the section indicate fluctuations in primary productivity and bottom water oxygenation.

The correlation between the sedimentology and foraminifera assemblages allowed the delineating of the evolution of the sedimentary basin:

1. The coarse grained deposits of the Coruş Formation represent the first term of marine transgression in this area;

2. The glauconite facies from the base of the Chechiș Formation can be associated with the maximum flooding surface;

3. The sediments belonging to the middle and upper part of the Chechiş Formation deposited on a narrow shelf, probably related to the onset of deltas during the early highstand;

4. The turbiditic sedimentation specific for the Hida Formation continued under regional tectonic control (flexure and uplifting of the Pienides to the north), in deeper settings during the highstand and preogressively shallower settings during the subsequent falling of the sea-level.

Planktonic foraminifera assemblages within the Chechiș Formation from both sections (Gălpâia and Tihău) potentially indicate a warming tendency of surface waters, possibly related to a warming event that took place during the second part of the Eggenburgian (Țabără & Chirilă, 2012).

The succession of paleoenvironments enables the large-scale reconstruction of relative sea-level fluctuations for the studied sections. The global eustatic sea level (Haq et al., 1987; Hardenbol, 1998) coincides only partially with the reconstructed sea-level curve highlighting the importance of regional tectonics also responsible for the generation of high order cycles. Therefore, this study provides an overview of the temporal and spatial distribution of the foraminifera assemblages and of the evolution of the paleoenvironments in the Oligocene and Miocene of the northwestern part of the Transylvanian Basin. It also provides criteria for local and regional facies correlation and allows the reconstruction of parts of the basin's history under the control of the Pienides' dynamics.

Selected references

Arnott, R.W.C., 1995. The parasequence definition - are transgressive deposits inadequately addressed? Journal of Sedimentary Research, B65: 1–6.

Aroldi, C., 2001. The Pienides in the Maramureș. Sedimentation, Tectonics and Paleogeography. Cluj-University Press, Cluj-Napoca, 156 pp.

Behar, F., Beaumont, V. & Penteado, H.L. De B., 2001. Rock-Eval 6 Technology: Performances and Developments. Oil & Gas Science and Technology - Rev. IFP, 56(2): 111-134.

Beldean, C., 2010. Relația dintre asociațiile de foraminifere fosile și mediile depoziționale din Formațiunea de Hida (Nord-vestul Bazinului Transilvaniei). Unpublished PhD Thesis, "Babeș-Bolyai" University, Cluj-Napoca.

Beldean, C. & Filipescu, S., 2011. "Flysch-type" agglutinated foraminifera from the Lower Miocene of the Transylvanian Basin (Romania). In: Kaminski, M.A. & Filipescu, S., (Eds.). Proceedings of the Eighth International Workshop on Agglutinated Foraminifera. Grzybowski Foundation Special Publication, 16, pp. 1-18.

Beldean, C., Filipescu, S., Aroldi, C., Iordache, Gh. & Bindiu, R., 2011. Foraminiferal assemblages and Early Miocene paleoenvironments in the NW Transylvanian Basin. Acta Paleontologica Romaniae, 7: 9-16.

Beldean, C., Filipescu, S. & Bălc, R., 2012. Paleoenvironmental and biostratigraphic data for the Early Miocene of the north-western Transylvanian Basin based on planktonic foraminifera. Carpathian Journal of Earth and Environmental Sciences, 7(1): 171-184.

Berggren, W.A., Kent, D.V., Swisher III, C.C. & Aubry, M.P.A, 1995. Revised Cenozoic geochronology and chronostratigraphy. In: Berggren, W.A., Kent, D.V. & Hardenbol, J., (eds.). Geochronology, time scale and global stratigraphic correlations: a unified temporal framework for a historical geology. Society of Economic Paleontologists and Mineralogists, Special Publication, 54: 129-212.

Bindiu, R. & Filipescu, S., 2011. Agglutinated Foraminifera from the Northern Tarcău Nappe (Eastern Carpathians, Romania). Studia Universitatis Babes-Bolyai, Geologia, 56 (2): 31-41.

Blow, W.H., 1969. Late Middle Eocene to Recent planktonic foraminiferal biostratigraphy. In: Brönnimann, P. & Renz, H.H. (Eds.). Proceedings of the First International Conference on Planktonic Microfossils, Geneva, Leiden, 1: 199-421.

Cătuneanu, O., 2006. Principles of Sequence Stratigraphy. Elsevier, Amsterdam, 386 pp.

Cicha, I., Rögl, F., Rupp, Ch. & Ctyroka, J., 1998. Oligocene – Miocene Foraminifera of the Central Paratethys. Abhandlungen der Senckenbergischen Naturforschenden Gesellschaft, 549: 325 pp.

Delaney, M.L., 1998. Phosphorus accumulation in marine sediments and the oceanic phosphorus cycle. Global Biogeochemical Cycles, 12(4): 563– 572.

Espitalié, J., Deroo, G., Marquis, F., 1985. La pyrolyse Rock–Eval et ses applications (deuxiéme partie). Revue de I'Institut Francais du Petrole, 40: 755–784.

Filipescu, S., 2011. Cenozoic lithostratigraphic units in Transylvania. In Bucur, I.I. & Săsăran, E. (Eds.), Calcareous algae from Romanian Carpathians. Field Trip Guide Book, Tenth International Symposium on Fossil Algae, Cluj-Napoca, Romania, 12-18 September, Cluj University Press, pp. 37-48.

Filipescu, S. & Silye, L., 2008. New biozones of planktonic foraminifera in the Middle Miocene of the Transylvanian Basin as potential opportunities for the Paratethyan stratigraphy. Geologica Carpathica, 59(6): 537–544.

Föllmi, K.B., 1996. The phosphorus cycle, phosphogenesis and marine phosphate-rich deposits. Earth-Science Reviews, 40, pp. 55-124.

Harzhauser, M. & Piller, W.E., 2007. Benchmark data of a changing sea – Palaeogeography, Palaeobiogeography and events in the Central Paratethys during the Miocene. Palaeogeography, Palaeoclimatology, Palaeoecology, 253: 8–31.

Horváth, M., 2003. Data to revision and distribution of small Foraminifera species described by Hantken (1868, 1875). Part II. Nodosariidae and Vaginulinidae. Fragmenta Palaeontologica Hungarica, 21: 5-32.

Jones, R.W. & Charnock, M.A., 1985. "Morphogroups" of agglutinated foraminifera. Their life positions and feeding habits and potential applicability in (paleo)ecological studies. Revue de Palèobiologie, 4: 311–320.

Jorissen, F.J., 2002. Benthic Foraminiferal Microhabitats below the Sediment-Water Interface. In: Sen Gupta, B.K. (Ed.), Modern Foraminifera. Kluwer Academic Publishers, pp. 161-180.

Jorissen, F.J., Fontanier, C. & Thomas, E., 2007. Paleoceanographical proxies based on deep-sea benthic foraminiferal assemblage characteristics. In: Hillaire-Marcel, C. & de Vernal, A. (Eds.), Developments in Marine Geology, Volume 1. Proxies in Late Cenozoic Paleoceanography, Part 2 – Biological tracers and biomarkers, Elsevier, pp 263-325.

Kaminski, M.A., Gradstein, F.M. & collaborators, 2005. Atlas of Paleogene Cosmopolitan deep-water Agglutinated Foraminifera. Grzybowski Foundation Special Publication, 10, 546 + vii pp.

Kováč, M., Baráth, I., Harzhauser, M., Hlavatý, I. & Hudáčková, N., 2004. Miocene depositional systems and sequence stratigraphy of the Vienna Basin. Courier Forschungsinstitut Senckenberg, 246: 187-212.

Krézsek, Cs. & Bally, A.W., 2006. The Transylvanian Basin (Romania) and its relation to the Carpathian fold and thrust belt: Insights in gravitational salt tectonics. Marine and Petroleum Geology, 23: 405-442.

Leckie, R.M. & Olson, H.C., 2003. Foraminifera as proxies for sea-level change on siliciclastic margins. In: Olson, H.C. & Leckie, R.M. (Eds.), Micropaleontologic Proxies for Sea-Level Change and Stratigraphic Discontinuities. SEPM Society for Sedimentary Geology, SEPM Special Publication 75, pp. 5-19.

Murray, J.W., 2006. Ecology and Applications of Benthic Foraminifera. Cambridge University Press, Cambridge. 438 pp.

Nagymarosy, A., 1990. Paleogeographical and paleotectonical outlines of some Intracarpathian Paleogene basins. Geologicky Zbornik, Geologica Carpathica, 41(3): 259-274.

Popescu, G. & Brotea, D., 1994. Evolution of the Transylvanian foraminiferal assemblages during Late Oligocene and Middle Miocene. In: Nicorici, E., Bedelean, I., Mészáros, N. & Petrescu, I. (Eds.). The Miocene from the Transylvaniann Basin, Romania. Geological Formations of Transylvania, Romania 4, Cluj-Napoca, Romania, pp. 119–124.

Popov, S.V., Rögl, F., Rozanov, A.Y., Steininger, F.F., Shcherba, I.G. & Kováč, M., 2004. Lithological-Paleogeographic maps of Paratethys. Courier Forschungsinstitut Senckenberg, 250, 46 pp.

Rögl, F., 1994. *Globigerina ciperoensis* (Foraminiferida) in the Oligocene and Miocene of the Central Paratethys. Annalen des Naturhistorischen Museums in Wien, 96 A: 133-159.

Rögl, F., 1999. Mediterranean and Paratethys. Facts and hypothesis of an Oligocene to Miocene paleogeography (short overview). Geologica Carpathica, 50: 339–349.

Ruttenberg K.C., Ogawa N.O., Tamburini F., Briggs R.A., Colasacco N.D., & Joyce, E., 2009. Improved, high-throughput approach for phosphorus speciation in natural sediments via the SEDEX sequential extraction method Limnology and Oceanography, Methods (7): 319–333.

Spezzaferri, S., 1995. Planktonic foraminiferal paleoclimatic implications across the Oligocene-Miocene transition in the oceanic record (Atlantic, Indian and South Pacific). Paleogeography, Palaeoclimatology, Palaeoecology, 114: 43-74.

Spezzaferri, S., Rögl, F., Ćorić, S. & Hohenegger, J., 2004. Paleoenvironmental changes and agglutinated foraminifera across the Karpatian/Badenian (early/Middle Miocene) boundary in the Styrian Basin (Austria, Central Paratethys). In: Bubík, M. & Kaminski, M.A. (Eds.), Proceedings of the sixth International Workshop on Agglutinated Foraminifera. Grzybowski Foundation Special Publication, 8, pp. 423-459.

Şuraru, N., 1967. Beträge zur Kenntnis des Burdigals im nordwestlichen teil des Siebenbürger Beckens zwischen Cluj und Surduc (Rumänien). N. Jb. Geol. Paläont. Mh., 8: 489-497.

Ţabără, D. & Chirilă, G., 2012. Paleoclimatic estimation from Miocene of Romania, based on palynological data. Carpathian Journal of Earth and Environmental Sciences, 7(2): 195-208.

Van Der Zwaan, G.J., Jorissen, F.J. & De Stigter, H.J., 1990. The depth dependency of planktonic/benthic foraminiferal ratios: constraints and applications. Marine Geology, 95: 1–16.

Wade, B.S., Pearson, P., Berggren, W.A. & Pälike, H., 2011. Review and revision of Cenozoic tropical planktonic foraminiferal biostratigraphy and calibration to the geomagnetic polarity and astronomical time scale. Earth-Science Reviews, 104: 111–142.

Zachos, J., Pagani, M., Sloan, L., Thomas, E. & Billups, K., 2001. Trends, Rhythms, and Aberrations in Global Climate 65 Ma to Present. Science, 292: 686-693.

Acknowledgements

First of all, I wish to thank my supervisor, Prof. Dr. Sorin Filipescu, for proposing an interesting PhD topic, for his scientific guidance, moral and logistic support during these years and for structuring and revising this manuscript.

I express my gratitude to Dr. Silvia Spezzaferri (University of Fribourg, Switzerland) for all her help during my stay in Fribourg, for the interesting discussions and for giving me the opportunity to conduct additional geochemical analyses and to participate on the Eurofleets scientific cruise. Also, many thanks for

Christophe Neururer for technical help with the SEM work and for the colleagues from Fribourg for their friendship and for making my stay in Switzerland an unforgettable experience.

I would also like to thank the reviewers for their patience to read and evaluate this manuscript.

I would like to thank my colleagues at the Department of Geology, Babeș-Bolyai University, for their friendship during these years. Special thanks to Raluca Bindiu for company and scientific discussions, Claudia Beldean for the constructive discussions and help during the field campaigns.

I want to thank Răzvan Bercea for keeping me company on the field and for the interesting discussions on sedimentology. Mădălina Kallanxhi is acknowledged for providing correlative calcareous nannofossil data. The assistance of Dr. Lucian Barbu-Tudoran during SEM sessions is also acknowledged.

I would also like to thank my family for moral and material support during all these years and to my girlfriend Reli for her help and her patience.

The research was made possible by the financial support of the Sectoral Operational Programme for Human Resources Development 2007-2013, co-financed by the European Social Fund, under the project POSDRU/159/1.5/S/133391 - "Doctoral and postdoctoral excellence programs for training highly qualified human resources for research in the fields of Life Sciences, Environment and Earth". The Sciex 12.116 Grant, the Grzybowski Foundation, the Brian J. O'Neill Memorial Grant-in-Aid and the S.N.G.N. Romgaz (Contract 18/2011) are also warmly thanked for financial support.