



**Biostratigraphy and paleoenvironmental reconstruction
of the marine lower Miocene Chechiş Formation
in the Transylvanian Basin based on foraminiferal assemblages**

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Abstract: Planktonic and benthic foraminiferal assemblages were used for biostratigraphy and paleoenvironmental reconstruction of the marine lower Miocene Chechiş Formation from the Gălpâia section (Sălaj county, Romania) in the northwestern Transylvanian Basin. Planktonic foraminifera suggest an Eggenburgian (Burdigalian) age for the deposits studied and reveal episodes of high primary productivity and mostly cool surface waters. Benthic foraminiferal assemblages indicate paleoenvironmental deepening from outer shelf to upper bathyal settings. Deltaic influences may be observed at the base of the studied section in outer shelf (possibly upper bathyal) environments with oxygenated bottom water and episodic high primary productivity, as a consequence of nutrient input from the land. Changes in paleobathymetry resulted in reduction of primary productivity. The benthic assemblages from the uppermost part of the section are dominated by tubular agglutinated foraminifera and indicate an upper bathyal setting with low organic flux to the sea floor. The sediments of the studied section were deposited during the late stage of the first early Miocene relative sea-level rise in the Transylvanian Basin.

Key-words:

- Foraminifera;
- paleoecology;
- paleoenvironments;
- early Miocene;
- Transylvanian Basin;
- Central Paratethys

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Résumé : *Microbiostratigraphie (foraminifères) et reconstitution paléoenvironnementale de la Formation marine de Chechiş (Miocène inférieur) dans le Bassin Transylvanien.*- Les associations de foraminifères planctoniques et benthiques sont exploitées à des fins biostratigraphiques et de reconstitution des paléoenvironnements de la Formation Chechiş du Miocène inférieur marin dans la coupe de Gălpâia (district de Sălaj, Roumanie, NW du Bassin transylvanien). Les foraminifères planctoniques suggèrent un âge eggenburgien (Burdigalien) pour les dépôts objets de cette étude. Ils révèlent en outre l'existence d'épisodes de forte productivité primaire et la présence d'eaux de surface générale-

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ment froides. Les associations de foraminifères benthiques indiquent un approfondissement des paléo-environnements depuis le bord externe du plateau continental à la partie supérieure de l'étage bathyal. Des influences deltaïques peuvent être observées à la base de la coupe au sein des environnements du bord externe du plateau continental (peut-être même dans la partie supérieure de l'étage bathyal) avec des eaux de fond oxygénées et des épisodes de forte productivité primaire en raison d'apports de nutriments en provenance des terres émergées. Des variations paléobathymétriques ont entraîné une diminution de la productivité primaire. Les associations de formes benthiques de la partie sommitale de la coupe sont dominées par des foraminifères tubulaires à test agglutinant, marqueurs de la partie supérieure de l'étage bathyal, avec un faible flux de matière organique vers les fonds marins. Les sédiments de la coupe étudiée se sont déposés au cours du stade ultime de la première montée relative du niveau de la mer enregistrée au Miocène inférieur dans le Bassin transylvanien.

Mots-clefs :

- foraminifères ;
- paléoécologie ;
- paléoenvironnements ;
- Miocène inférieur ;
- Bassin Transylvanien ;
- Paratéthys centrale.

1. Introduction

As one of the major basins of the Central Paratethys (LASKAREV, 1924; BÁLDI, 1969; RÖGL, 1998), the Transylvanian Basin evolved as a sag basin during the Oligocene, while its Miocene sediments were deposited in a flexural basin (KRÉZSEK & BALLY, 2006). Initial marine flooding was followed by major shallowing during the early Miocene, as indicated by well data and regional interpretations (DICEA *et al.*, 1980; KRÉZSEK & BALLY, 2006; TISCHLER *et al.*, 2008). The marine lower Miocene is best developed in the northwestern part of the Transylvanian Basin, where various paleoenvironmental settings influenced the distribution of its fossil assemblages.

A detailed micropaleontological study was carried out on the lower Miocene deposits (Gălpâia section in the Chechiş Formation) in order to provide an accurate biostratigraphic framework and paleoenvironmental reconstructions.

2. Geological setting

The lithostratigraphy is based on the synthesis of S. FILIPESCU (2011). The Chechiş Formation (HOFMANN, 1879) overlies the nearshore Coruş or Buzaş formations and is represented by a 20 to 80 m thick offshore marine unit consisting of mudstones (POPESCU *et al.*, 1995). In some areas, a glauconitic layer is recorded at the base of the Chechiş Formation (ŞURARU, 1967, 1968; RUSU, 1969; POPESCU, 1970). The upper boundary is transitional to the Hida Formation or is an unconformity overlain by the middle Miocene Dej Tuff.

The fossil assemblages of the Chechiş Formation consist of abundant foraminifera (HOFMANN, 1879; POPESCU, 1975) and rare molluscs (RUSU, 1977). POPESCU (1970) assigned a Burdigalian age to the Chechiş Formation based on

planktonic foraminifera. Previous studies of foraminiferal assemblages focused primarily on taxonomy and biostratigraphy (ŞURARU, 1952; RUSU & POPESCU, 1965; POPESCU, 1971, 1975; POPESCU & IVA, 1971; NICORICI *et al.*, 1979), while paleoecological and paleogeographic considerations were addressed only recently (SZÉKELY *et al.*, 2016).

Continuous sedimentation in the Gălpâia section allows the description of the biostratigraphy of the marine early Miocene (Eggenburgian or Burdigalian) and of change in the assemblages of benthic and planktonic foraminifera as a result of environmental variation.

3. Material and methods

Fourteen micropaleontological samples were collected from the lower Miocene Chechiş Formation near Gălpâia village (47°8'15.30"N 23°14'13.11"E; Fig. 1), 50 km NNW of Cluj-Napoca. The sampled interval (7 m thick) consists of massive dark grayish mudstone with very rare laminar fine sandstone (Fig. 2). Clay nodules and coal have also been identified. Some levels are characterized by moderate bioturbation (vertical and horizontal burrows). Yellowish-red centimetric altered mudstone is locally present (Fig. 2).

Sediment samples were processed using standard micropaleontological methods. Approximately 300 foraminiferal tests were picked from the >63 µm fraction and identified under the stereomicroscope, while representative specimens were examined in detail using the scanning electron microscope.

Paleoecological proxies are inferred from univariate statistics (such as relative abundance, percentage of microhabitats, diversity indices), multivariate statistics (hierarchical clustering, SIMPER analysis) and agglutinated foraminiferal morphogroups.

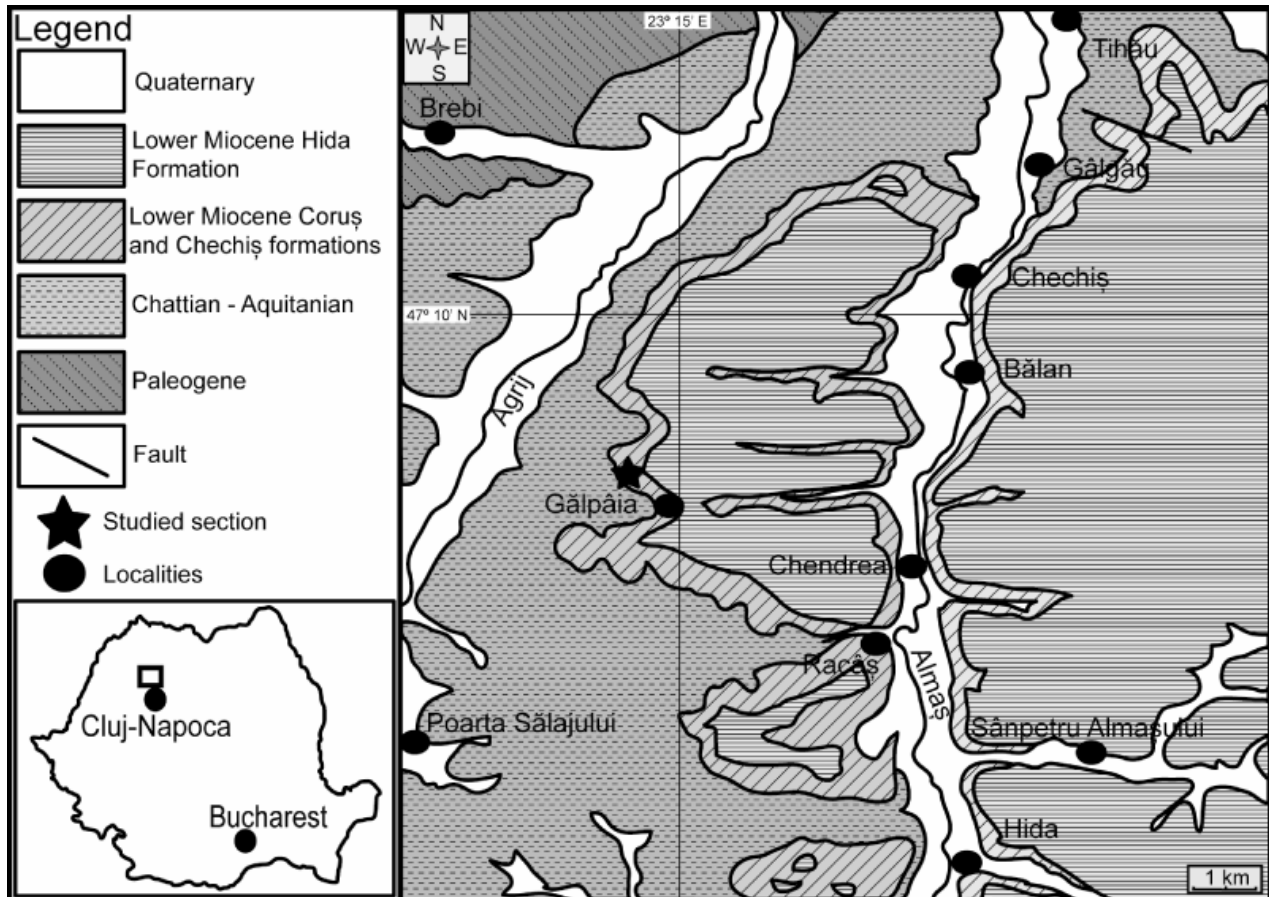


Figure 1: Geological map and location of the Gălpâia section (modified after the Geological Map of Romania, 1:200000, Sheet Cluj; PETRESCU & DRĂGHICI, 1964; BELDEAN & S. FILIPESCU, 2011).

The relative abundance of a certain benthic foraminiferal species or groups with similar paleoecological affinities is represented by the ratio between the number of specimens of the selected species (or group) and the total number of benthic specimens per sample.

The diversity indices (FISHER's Alpha and SHANNON-WIENER; HAMMER & HARPER, 2006) were calculated for the benthic assemblages using the software PAST of HAMMER *et al.* (2001).

Identification of the microhabitats of calcareous benthic foraminifera as epifaunal, shallow-infaunal and infaunal was inferred from the morphotypes proposed by CORLISS (1985, 1991) and CORLISS & CHEN (1988) or taken from the literature (*e.g.*, RÖGL & SPEZZAFERRI, 2003; MURRAY, 2006). The abundance of different microhabitats can be used to indicate organic carbon flux to the sea floor and bottom-water oxygenation (CORLISS & CHEN, 1988; JORISSEN *et al.*, 1995; JORISSEN, 2002). Agglutinated foraminifer morphogroup analysis is based on the concept that foraminiferal individuals with different test shapes occupy different habitats and have different feeding strategies, so that changes in the relative abundance of morphogroups in fossil assemblages reflect environmental changes (CORLISS, 1985; JONES & CHARNOCK, 1985; MURRAY *et*

al., 2011). Agglutinated foraminifer morphogroup analysis was performed according to the scheme developed by KAMINSKI *et al.* (2005).

Multivariate statistics were applied separately to the quantitative data of the benthic and planktonic assemblages using Primer 6 software (CLARKE & WARWICK, 2001), the analysis including hierarchical clustering. Raw data were double square root-transformed prior to the generation of a resemblance matrix based on the Similarity (CLIFFORD & STEPHENSON, 1975). With this process, the contribution of most abundant species was limited (FIELD *et al.*, 1982). Group Average Linking was used for hierarchical agglomerative clustering. Based on the same similarity matrix a SIMPER analysis was included to confirm taxa defining the clusters (CLARKE, 1993).

A summary of the paleoecological preferences of the most representative benthic foraminifera (species or groups with similar paleoecological affinities) was compiled for the section studied. The information gathered includes, where available: paleobathymetry, microhabitat, oxygen preferences, temperature, and additional ecological data (Table 1). The paleoecological preferences of planktonic foraminifera with respect to surface water temperature and productivity were also summarized (Table 2).



Table 1. Paleocological preferences of most common species/genera or groups with similar paleocological affinities compiled for the Gălpâia section. References: (a). CORLISS & CHEN (1988); (b). SPEZZAFERRI & ĆORIĆ (2001); (c). MOR-KHOVEN *et al.* (1986); (d). MURRAY (2006); (e). DE MAN (2006); (f). RÖGL & SPEZZAFERRI (2003); (g). SPEZZAFERRI *et al.* (2002); (h). SPEZZAFERRI *et al.* (2004); (i). KAMINSKI *et al.* (2005); (j). REOLID & NAGY (2008); (k). ZĂGORSEK *et al.* (2007); (l). GRUNERT *et al.* (2012); (m). KAIHO (1994); (n). BÁLDI (2006); (o). ALMOGI-LABIN *et al.* (2000); (p). MIAO & THUNELL (1993); (q). SCHMIEDL *et al.* (2000); (r). MULLINS *et al.* (1985).

Species \ Genera \ Group	Paleobathymetry	Microhabitat	Oxygen	Temperature / Comments
<i>Alabamina</i> spp.		Epifaunal (e)	Suboxic (e), (m)	
<i>Ammodiscus</i> spp.	High-energy lagoons and estuary (i)	Surficial epifaunal (i)		Active and passive deposit feeding (i)
<i>Amphicoryna</i> spp.	Inner shelf-bathyal (f), 13-3000 m (f)		Low-oxygen (f)	Mud, glacial water (f)
<i>Bathysiphon taurinensis</i>	Bathyal and abyssal (i)	Erect epifaunal (i)		Tranquil environment and low organic matter flux (i)
<i>Bolivina</i> spp.	Inner shelf-bathyal (d)	Infaunal (a), epifaunal-infaunal (d), deep-infaunal (l)	Low-oxygen (g), some species tolerate dysoxia (d), dysoxic (m)	Cold-warm, free, muddy sediment, detritivore? (d)
<i>Budashevaella</i> spp.	Shelf to deep marine (i)	Surficial epifaunal (i)		Active deposit feeding (i)
<i>Bulimina elongata</i>	Upper neritic (c), 50-2500 m, abundant down to 80-100 m (h)		Low-oxygen (h)	Mud and muddy sand, river mouths, high organic matter (h), organic carbon preferring (g)
<i>Bulimina</i> spp.	Inner shelf-bathyal (d)	Infaunal (d)	Some species tolerate dysoxia (d)	Cold-temperate, free, mud-fine sand, detritivore? (d), organic carbon preferring (g)
<i>Chilostomella oolina</i>	Outer shelf-bathyal (d)	Deep infaunal (d)	Tolerates dysoxia (d), low-oxygen (g)	Free, mud, detritivore (d)
<i>Cibicidoides pachyderma</i>	30-3500 m (h)	Epifaunal, shallow-infaunal (d),(o),(p),(q)	Oxic (h),(q)	Passive suspension feeder, high energy (d), oligotrophic environment, stable physico-chemical conditions (o),(p),(q)
<i>Cibicidoides</i> \ <i>Heterolepa</i> spp.	Shelf-bathyal (d), 30-3500 m (h)	Epifaunal (d)	Oxic (f),(m)	Cold, clinging (d), hard substrates (d),(f), passive suspension feeder? (d)
<i>Glomospira</i> spp.	High-energy lagoons and estuary (i)	Surficial epifaunal (i)		Active and passive deposit feeding (i)
<i>Hansenisca soldanii</i>		Epifaunal (d)	Suboxic, dysoxic (d),(r)	Mud (d)
<i>Haplophragmoides</i> spp.	Marshes-bathyal (d), inner shelf and upper bathyal (i)	Infaunal to surficial (b), epifaunal-shallow infaunal (d),(i)		Cold-temperate, free, mud-sand, detritivore? (d), active deposit feeding (i)
<i>Heterolepa dutemplei</i>	Outer neritic-upper bathyal (c), 50-3000 m (h)	Epifaunal (d)	Oxic (d)	Cold-temperate, clinging?, hard substrates, passive suspension feeder? (d)
<i>Hyperammina</i> \ <i>Nothia</i> \ <i>Rhabdammina</i> \ <i>Rhizammina</i> \ <i>Psamosiphonella</i> \ <i>Nothia</i> spp.	Bathyal and abyssal (i)	Erect epifaunal (i)		Tranquil environment and low organic matter flux (i)
<i>Karrerella</i> \ <i>Karrerulina</i> spp.	Inner shelf - upper bathyal (i)	Deep infaunal (i)		Active deposit feeding and increased organic matter flux (i)
<i>Laevidentalina</i> spp.	Circalittoral-bathyal, 100-4000 m (f)		Suboxic, dysoxic (f)	Mud (f)
<i>Lenticulina</i> spp.	Outer shelf-bathyal (d), from 20 m down (f)	Epifaunal (a),(d),(e),(l)	Suboxic (e),(f),(l),(m), oxic (n)	Cold (d), free, mud, detritivore? (d),(e)
<i>Melonis pompilioides</i>	Circalittoral-bathyal, 50-4000 m (f)	Infaunal (d)	Suboxic (f)	Mud, high organic matter (f), high primary productivity (g)
<i>Praeglobbulimina pupoides</i>	30-4000 m (h)		Low-oxygen (g), dysoxic (k)	Stress marker (k)
<i>Praeglobbulimina</i> spp.	Circalittoral to bathyal, preferred depth 80-800 m (b)		Dysoxic (b)	High primary productivity (g)
<i>Recurvoides</i> spp.	Shelf to deep marine (i)	Surficial epifaunal (i), epifaunal to shallow infaunal (j)		Active deposit feeding (i)
<i>Reophax</i> spp.	Inner shelf-upper bathyal (i)	Deep infaunal (i)		Active deposit feeding and increased organic matter flux (i)
<i>Reticulophragmium</i> spp.	Inner shelf-upper bathyal (i)	Surficial epifaunal-shallow infaunal (i)		Active deposit feeding (i)
<i>Saccamina</i> spp.	Bathyal and abyssal (i)	Shallow infaunal (i)		Suspension feeding, passive deposit feeding (i)
<i>Stilostomella</i> \ <i>Mylostomella</i> \ <i>Neugeborina</i> spp.	230-2500 m (f)		Suboxic (f)	Mud (f)
<i>Trochammina</i> spp.	Shelf to deep marine (i)	Surficial epifaunal (i)		Active deposit feeding (i)
<i>Uvigerina</i> spp.	100 to >4500 m, rarely shallower than 100 m (f), shelf-abyssal (d)	Epifaunal-infaunal (d), infaunal (a)	Suboxic (f), (m), low-oxygen (g)	Cold, free, muddy sediments, detritivore? (d), high organic matter (f), high primary productivity (g)
<i>Valvulineria</i> spp.	Circalittoral to epibathyal, more abundant between 40-100 m (f)		Suboxic (f), dysoxic (b)	Mud, coastal terrigenous mud, high organic matter (f)



4. Results

4.1. Foraminiferal assemblages

Foraminiferal assemblages are abundant throughout the studied section and the preservation of specimens varies from moderate to good. A total of 139 benthic and 36 planktonic foraminiferal species were identified (Appendix).

The species diversity values, expressed by the FISHER's alpha diversity index, vary along the section and range from 13.8 to 37.9, while the SHANNON-WIENER diversity index displays values between 2.6 and 3.6. Both indices are marked by a decrease in the upper part of the outcrop (Fig. 2).

Except for the flattened irregular *Ammolagena* specimens (M3b morphogroup) all agglutinated foraminiferal morphogroups defined by KAMINSKI *et al.* (2005) are present. The graphic distribution of the morphogroups reveals several distinct features within the section: a constant distribution of all the morphogroups from sample G1 to G3, a sharp increase of morphogroup M1 and constant values for the rest of the morphogroups for samples G3-G13 and high abundances of morphogroup M1 (79.83%) and lower values for the rest of the morphogroups in the uppermost part of the section (samples G13-G14).

Table 2. Division of planktonic foraminifera based on water temperature preference (modified after SZÉKELY & S. FILIPESCU, 2016). References: (1). SPEZZAFERRI (1994); (2). SPEZZAFERRI (1995); (3). SPEZZAFERRI & ČORIĆ (2001); (4). RÖGL & SPEZZAFERRI (2003); (5). BICCHI *et al.* (2003); (6). BICCHI *et al.* (2006); (7). PEARSON *et al.* (2006); (8). LI *et al.* (1992); (9). SPEZZAFERRI *et al.* (2002); (10). KROON (1988); (11). ROETZEL *et al.* (2006); (12). AMORE *et al.* (2004).

Latitude \ Temperature indicator		High \ Cool	High-middle \ Cool-temperate	Middle \ Cosmopolitan \ No diagnostic	Middle-low \ Temperate-warm	Low \ Warm	Productivity	
Species \ Genera	Cool-temperate	<i>Globigerina anguliofficialis</i> (2)(4)(5)(6)			<i>Globigerina anguliofficialis</i> (7)			
		<i>Globigerina gnaucki</i> (2)(10)						
		<i>Globigerina lentiana</i> (2)(3)(4)(5)(6)(9)						
		<i>Globigerina officialis</i> (1)(2)(4)(5)(6)				<i>Globigerina officialis</i> (7)		
		<i>Globigerina ouachitensis</i> (1)(2)(4)(5)(6)				<i>Globigerina ouachitensis</i> (7)		
		<i>Globigerina ottnangiensis</i> (3)(4)(9)				<i>Globigerina ottnangiensis</i> (2)		High productivity (4)
		<i>Globigerina praebulloides</i> (1)(2)(3)(4)(5)(6)(9)						
		<i>Globigerina</i> spp. (2)(4)(5)(6)						Upwelling areas (10)
		<i>Globigerina tarchanensis</i> (4)						High productivity (4)
			<i>Globoturborotalita connecta</i> (2)(6)					
		<i>Globoturborotalita woodi</i> (1)(4)	<i>Globoturborotalita woodi</i> (1)(2)(5)(6)	<i>Globoturborotalita woodi</i> (3)		<i>Globoturborotalita woodi</i> (9)		
		<i>Tenuitella clemenciae</i> (1)(4)(8)						
		<i>Tenuitella gemma</i> (1)(4)(8)		<i>Tenuitella gemma</i> (7)				
		<i>Tenuitellinata juvenilis</i> (1)(3)(4)(8)(9)(11)		<i>Tenuitellinata juvenilis</i> (1)(2)				Upwelling conditions (11)
		<i>Tenuitella</i> spp. (1)(2)(4)(8)						
	<i>Turborotalita quinqueloba</i> (3)(4)(9)(11)						Upwelling conditions (11)	
						<i>Globigerinoides trilobus</i> (2)(3)(5)(6)(9)(12)		
	Warm-temperate	<i>Tenuitellinata angustiumbilicata</i> (3)(9)(11)			<i>Tenuitellinata angustiumbilicata</i> (1)(2)(5)(6)(7)		Upwelling conditions (11)	
No diagnostic			<i>Globigerinella obesa</i> (2)(3)	<i>Globigerinella obesa</i> (5)	<i>Globigerinella obesa</i> (9)			
		<i>Paragloborotalia nana</i> (1)(2)	<i>Paragloborotalia nana</i> (1)	<i>Paragloborotalia nana</i> (7)	<i>Paragloborotalia nana</i> (4)(7)			

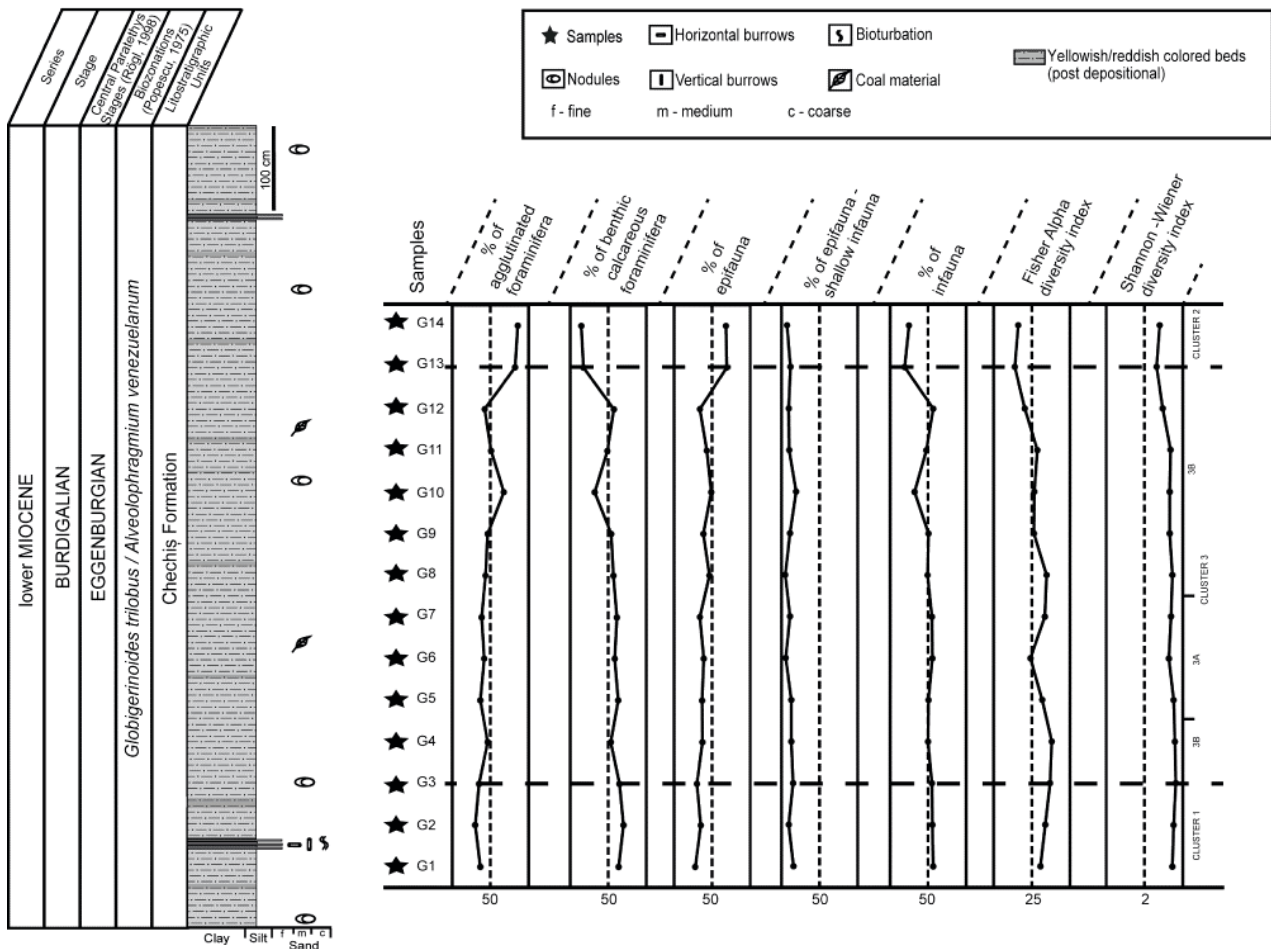


Figure 2: Graph representing identified biozones, sedimentary log of outcrop studied and positions of samples, and univariate statistics (P/B ratio, percent of agglutinated foraminifera, percent of calcareous benthic foraminifera, microhabitat of benthic foraminifera: percent epifauna, epifauna - shallow infauna and infauna, FISHER's alpha and SHANNON-WIENER diversity indices) for Gălpâia section.

4.1.1. Statistical data on planktonic foraminiferal assemblages

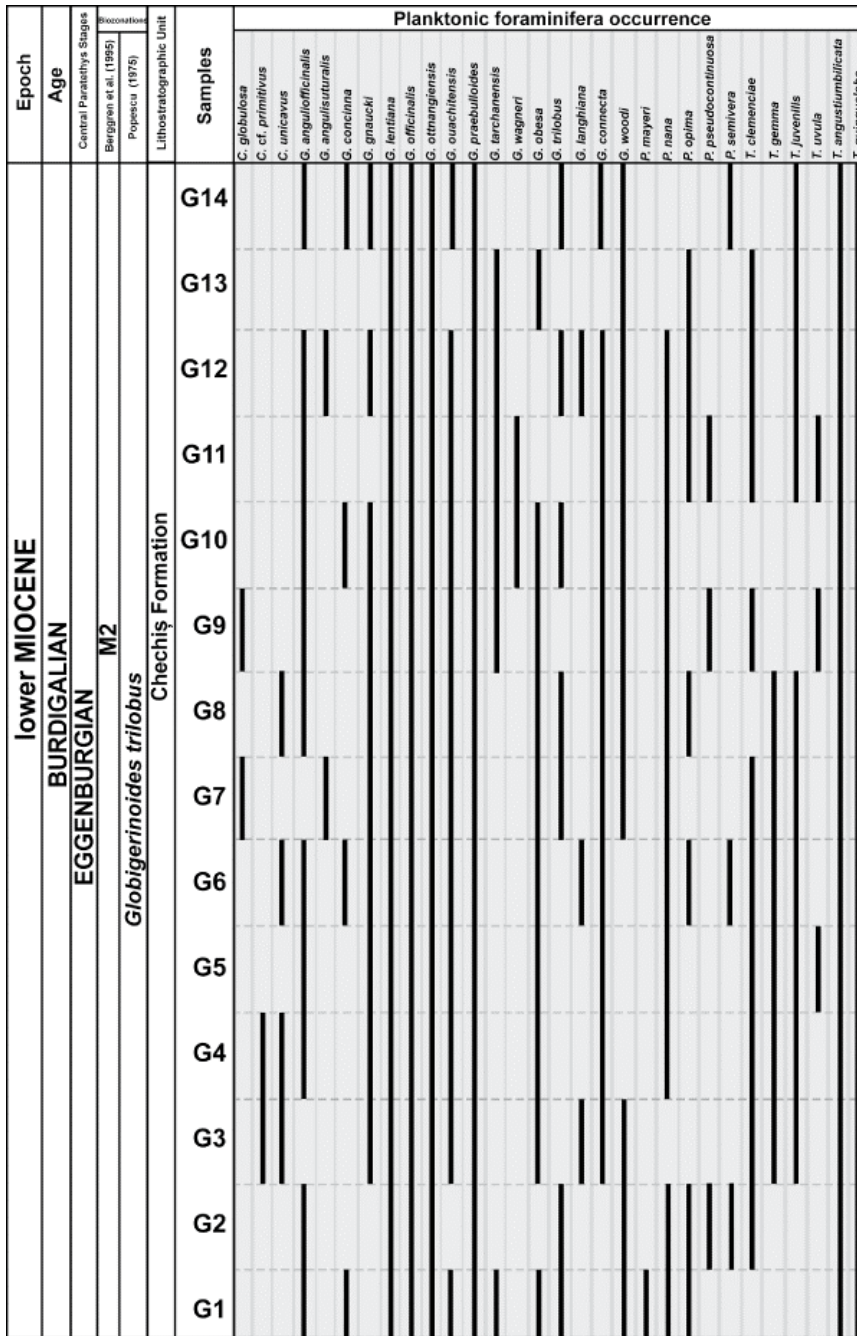
A quantitative examination of planktonic foraminifera was performed on the samples. Three cluster groups (Cluster 1, Cluster 2, and Cluster 3) were delimited in the planktonic assemblages at the 68% similarity level (Fig. 4) based on SIMPER analysis (Table 3) and visual investigation of species composition.

Cluster 1 contains samples G3 - G8 (Figs. 2 and 4). The most representative species or groups are *Globigerina officinalis*, *G. spp.*, *G. praebulloides*, *G. lentiana*, *Tenuitellinata angustiumbilicata*, *Turborotalita quinqueloba*, *Globigerina ottnangiensis*, *Globoturborotalita connecta*, *Globigerina ouachitensis*, *G. gnaucki*, *Tenuitellinata juvenilis*, and *Globigerinella obesa* (Appendix and Fig. 3). Twelve species/groups account

for 81% of the average similarity within this cluster (Table 3).

Cluster 2 contains only sample G14 (Figs. 2 and 4). The most abundant species or groups within this cluster are: *Globigerina praebulloides*, *G. spp.*, *G. lentiana*, *G. ottnangiensis*, *Globoturborotalita connecta* and *Globigerina officinalis* (Appendix and Fig. 3).

Cluster 3 contains samples G1 - G2 and G9 - G13 (Figs. 2 and 4). The dominant species or groups within this cluster are: *Globigerina praebulloides*, *G. ottnangiensis*, *G. lentiana*, *G. spp.*, *G. officinalis*, *Tenuitellinata angustiumbilicata*, *Turborotalita quinqueloba*, *Globoturborotalita woodi*, *Globigerina anguliofficialis*, and *Paraglobotrotalia nana* (Appendix and Fig. 3). Ten species/groups account for 80% of the average similarity within this group (Table 3).



◀ **Figure 3:** Graph representing occurrences of most important planktonic foraminiferal species of Gălpâia section. Black lines indicate presence of species in respective sample.

4.1.2. Statistical data on benthic foraminiferal assemblages

A quantitative investigation of benthic foraminifera was performed on the samples. Three cluster groups were separated (Cluster 1, Cluster 2 and Cluster 3) at the similarity level of 45% (Fig. 5) based on SIMPER analysis (Table 4) and visual inspection of species composition in benthic assemblages.

Cluster 1 contains samples G1 to G3 from the base of the outcrop (Figs. 2 and 5). The benthic foraminiferal assemblages are composed of calcareous (dominant) and agglutinated forms (Fig. 2). The diversity indices display high values, with the FISHER's alpha index ranging from 30.6 to 36.8 and the SHANNON-WIENER index from 3.4 to

3.6 (Fig. 2). Benthic infaunal and epifaunal microhabitats are relatively well represented, and the epifaunal-shallow infaunal microhabitat less so (Fig. 2).

The most representative benthic calcareous species are *Cibicidoides pachyderma*, *Lenticulina inornata*, *Marginulina hirsuta*, *Praeglobobulimina pupoides*, and *Uvigerina popescui*, while the agglutinated foraminiferal assemblages are dominated by *Reticulophragmium* (Fig. 6) species. Lower amounts of calcareous benthic forms (*Hansenisca soldanii*, *Laevidentalina* spp., *Lenticulina arcuatostrata*, *Melonis pompilioides*, *Neugeborina boueana*, *Stilostomella adolphina*, *Uvigerina acuminata*, *Uvigerina farinosa*, and *Uvigerina mantaensis*) and agglutinated species (*Ammodiscus*

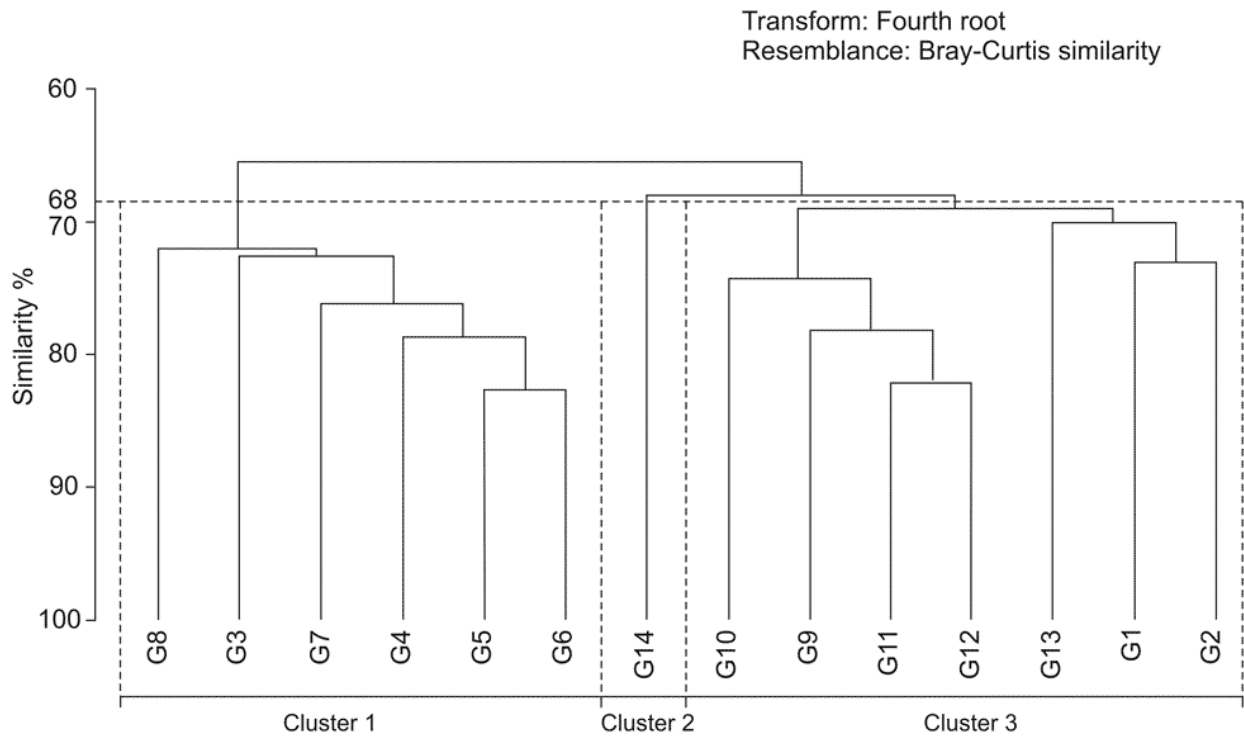


Figure 4: Dendrogram showing the hierarchical agglomerative clustering based on the similarity matrix of planktonic foraminifera. Horizontal dashed line represents the similarity cut and vertical dashed lines represent delimitations of resulting clusters.

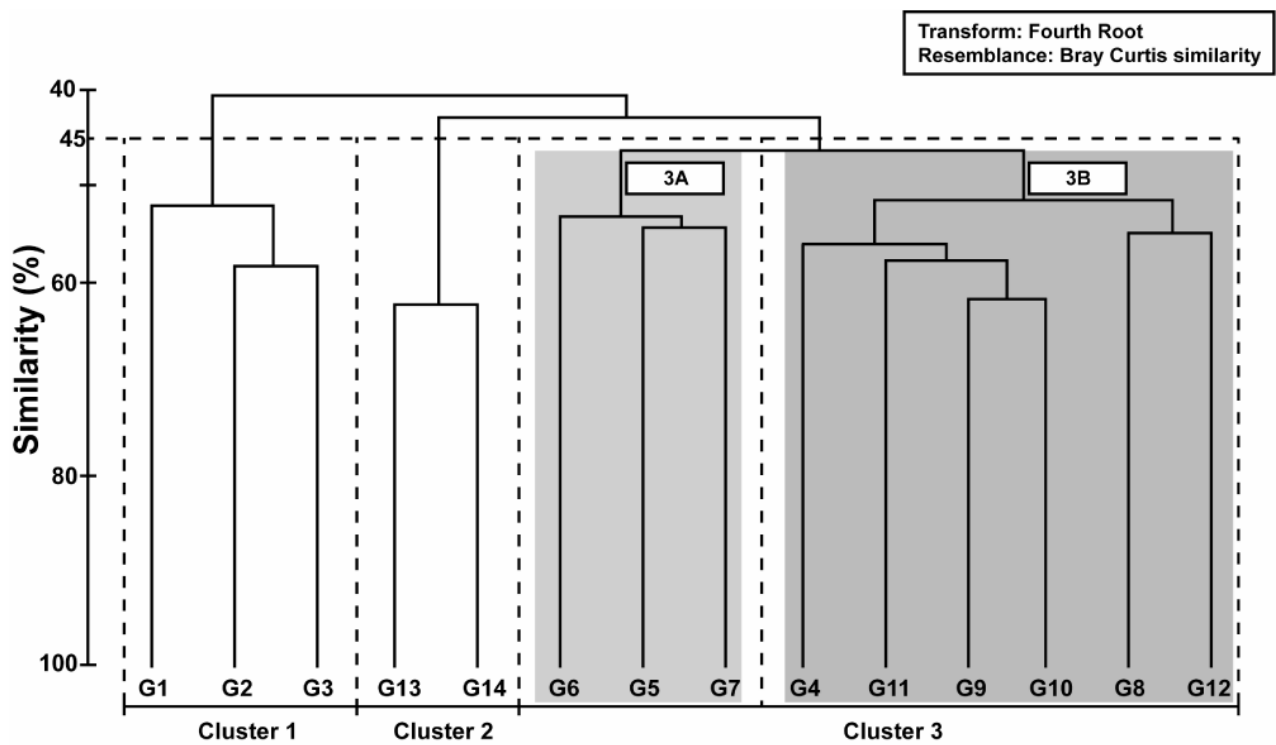


Figure 5: Dendrogram showing hierarchical agglomerative clustering based on the similarity matrix of the benthic foraminifera. Horizontal dashed line represents similarity cut and vertical dashed lines represent boundaries of resulting clusters.



cretaceus, *Bathysiphon taurinensis*, *Glomospira charoides*, *Haplophragmoides* spp., *Karrerulina* spp., *Nothia* spp., *Reophax* spp., *Rhabdammina* spp., and *Saccamina grzybowski*) are present in this cluster. Thirty-one species/groups account for 83% of the average similarity within this group (Table 4).

All agglutinated foraminiferal morphogroups (except M3b) are present in this cluster. The tubular agglutinated morphogroup M1 displays an increasing trend (Figs. 6 and 7). Morphogroup M2a also increases towards the top of the cluster (Fig. 7). Agglutinated foraminifera typical of the shelf (M2c morphogroup) decrease in abundance towards the top of Cluster 1.

Cluster 2 contains samples from the uppermost part of the outcrop (samples G13 and G14; Figs. 2 and 5). Benthic agglutinated forms clearly dominate these assemblages. The lowest values of the FISHER's alpha diversity index are found within this cluster (13.8 and 16.1), while the values of the SHANNON-WIENER diversity index are 2.6 and 2.8 (Fig. 2). Epifaunal forms are relatively well represented and dominate the benthic assemblages, while the infaunal and

epifaunal-shallow infaunal microhabitats are characterized by low abundance throughout this cluster (Fig. 2).

The dominant calcareous form is *Praeglobobulimina pupoides*, while among agglutinated foraminifera the following are common: *Bathysiphon taurinensis*, *Hyperammina* / *Rhabdammina* spp., *Nothia* spp., and *Saccamina grzybowski*. Less abundant benthic foraminifera from this cluster are *Bolivina beyrichi carinata*, *Hansenisca soldanii*, *Reophax* spp., and *Reticulophragmium acutidorsatum* (Fig. 8). Twenty-one species/ groups account for 100% of the average similarity within this group (Table 4).

Cluster 3 was further divided into two sub-clusters: **3A** and **3B** (Fig. 5) based on the species composition of the benthic assemblages. Samples of **subcluster 3A** (G5-G7) are well represented by both calcareous and agglutinated taxa (Fig. 2). The FISHER's alpha diversity indices range between 24.1 and 33.5, and the SHANNON-WIENER diversity indices between 3.2 and 3.5 (Fig. 2). Although the epifaunal microhabitat is well represented, infaunal forms dominate these assemblages (Fig. 2).

Table 3. Similarity-based SIMPER analysis of the resultant clusters derived from planktonic foraminiferal assemblages.

Group Cluster 1	Av.Abund	Av.Sim	Contrib%	Cum.%	Group Cluster 3	Av.Abund	Av.Sim	Contrib%	Cum.%
Average similarity: 74.68					Average similarity: 71.56				
<i>Globigerina officinalis</i>	2.33	7.39	9.9	9.9	<i>Globigerina praebulloides</i>	2.44	8.43	11.8	11.8
<i>Globigerina</i> sp.	2.21	6.97	9.33	19.2	<i>Globigerina ottangiensis</i>	2.4	7.9	11	22.8
<i>Globigerina praebulloides</i>	2.09	6.66	8.92	28.2	<i>Globigerina lentiana</i>	1.98	6.86	9.58	32.4
<i>Globigerina lentiana</i>	2.05	6.36	8.52	36.7	<i>Globigerina</i> sp.	1.93	6.75	9.43	41.8
<i>Tenuitellinata angustumbilicata</i>	1.9	5.19	6.95	43.6	<i>Globigerina officinalis</i>	1.97	6.66	9.31	51.1
<i>Turborotalita quinqueloba</i>	1.7	4.56	6.11	49.7	<i>Tenuitellinata angustumbilicata</i>	1.6	5.37	7.5	58.6
<i>Globigerina ottangiensis</i>	1.55	4.31	5.77	55.5	<i>Turborotalita quinqueloba</i>	1.57	4.99	6.98	65.6
<i>Globoturborotalita connecta</i>	1.48	4.05	5.42	60.9	<i>Globoturborotalita woodi</i>	1.46	4.4	6.15	71.8
<i>Globigerina ouachitensis</i>	1.36	3.92	5.24	66.2	<i>Globigerina anguliofficialis</i>	1.19	3.21	4.48	76.3
<i>Globigerina gnaucki</i>	1.32	3.84	5.14	71.3	<i>Paragloborotalia nana</i>	1.07	2.9	4.05	80.3
<i>Tenuitellinata juvenilis</i>	1.22	3.63	4.86	76.2	<i>Globigerina tarchanensis</i>	0.98	2.58	3.6	83.9
<i>Globigerinella obesa</i>	1.23	3.6	4.82	81	<i>Tenuitella clemenciae</i>	0.86	1.96	2.74	86.6
<i>Tenuitella gemma</i>	1.18	3.58	4.79	85.8	<i>Paragloborotalia opima</i>	0.77	1.88	2.63	89.3
<i>Tenuitella clemenciae</i>	1.33	3.13	4.19	90	<i>Globigerina ouachitensis</i>	0.85	1.67	2.33	91.6
<i>Paragloborotalia nana</i>	0.94	2.21	2.96	92.9	<i>Globoturborotalita connecta</i>	0.95	1.53	2.13	93.7
<i>Globigerina anguliofficialis</i>	0.79	1.38	1.84	94.8	<i>Globigerinoides trilobus</i>	0.64	1.09	1.53	95.3
<i>Catapsydrax unicavus</i>	0.75	1.37	1.84	96.6	<i>Globigerinella obesa</i>	0.72	1.08	1.51	96.8
<i>Tenuitella</i> sp.	0.67	0.83	1.11	97.7	<i>Tenuitellinata juvenilis</i>	0.55	0.65	0.9	97.7
<i>Globoturborotalita woodi</i>	0.63	0.78	1.04	98.7	<i>Globigerina gnaucki</i>	0.56	0.52	0.73	98.4
<i>Globigerinoides trilobus</i>	0.63	0.27	0.36	99.1	<i>Paragloborotalia pseudocontinuos</i>	0.43	0.51	0.72	99.1
<i>Catapsydrax cf. primitivus</i>	0.4	0.24	0.32	99.4	<i>Globigerina concinna</i>	0.29	0.17	0.24	99.4
<i>Globoquadrina langhiana</i>	0.33	0.22	0.3	99.7	<i>Globigerina wagneri</i>	0.29	0.16	0.22	99.6
<i>Paragloborotalia opima</i>	0.33	0.2	0.27	100	<i>Tenuitella uvula</i>	0.31	0.16	0.22	99.8



Table 4. Similarity-based SIMPER analysis of the resultant clusters derived from benthic foraminiferal assemblages.

Group Cluster 1					Group Cluster 3B				
Average similarity: 54.31	Av.Abund	Av.Sim	Contrib%	Cum.-%	Average similarity: 54.68	Av.Abund	Av.Sim	Contrib%	Cum.-%
<i>Globigerina officinalis</i>	2.33	7.39	9.9	9.9	<i>Globigerina praebulloides</i>	2.44	8.43	11.8	11.8
<i>Uvigerina popescui</i>	2.36	3.18	5.86	5.86	<i>Hyperammina / Rhabdammina sp.</i>	2.21	3.71	6.79	6.79
<i>Praeglobobulimina pupoides / affinis</i>	1.79	2.5	4.61	10.47	<i>Uvigerina popescui</i>	1.96	3.02	5.53	12.32
<i>Cibicoides pachyderma</i>	1.58	2.05	3.77	14.24	<i>Praeglobobulimina pupoides / affinis</i>	1.75	2.91	5.32	17.64
<i>Reticulophragmium rotundidorsatum</i>	1.46	1.95	3.6	17.84	<i>Reophax sp.</i>	1.46	2.46	4.5	22.14
<i>Marginulina hirsuta</i>	1.41	1.92	3.53	21.37	<i>Cibicoides pachyderma</i>	1.45	2.38	4.36	26.5
<i>Lenticulina inornata</i>	1.52	1.9	3.5	24.87	<i>Lenticulina arcuatostrata</i>	1.3	2.05	3.75	30.25
<i>Reticulophragmium venezuelanum</i>	1.47	1.87	3.44	28.31	<i>Haplophragmoides sp.</i>	1.28	2.04	3.74	33.99
<i>Uvigerina farinosa</i>	1.42	1.83	3.37	31.69	<i>Hansenisca soldanii</i>	1.22	1.99	3.63	37.62
<i>Reticulophragmium acutidorsatum</i>	1.31	1.75	3.22	34.91	<i>Bathysiphon taurinensis</i>	1.16	1.88	3.43	41.05
<i>Hansenisca soldanii</i>	1.29	1.69	3.11	38.02	<i>Valvulineria palmarealensis</i>	1.14	1.86	3.4	44.45
<i>Melonis pompilioides</i>	1.29	1.57	2.9	40.92	<i>Recurvoides sp.</i>	1.08	1.79	3.28	47.73
<i>Haplophragmoides sp.</i>	1.29	1.57	2.89	43.81	<i>Melonis pompilioides</i>	1.03	1.29	2.36	50.09
<i>Glomospira charoides</i>	1.13	1.51	2.79	46.59	<i>Karriella chilostoma</i>	1.04	1.27	2.33	52.42
<i>Nothia sp.</i>	1.25	1.51	2.79	49.38	<i>Saccamina grzybowski</i>	1.06	1.24	2.27	54.69
<i>Bathysiphon taurinensis</i>	1.17	1.51	2.78	52.16	<i>Nothia sp.</i>	0.98	1.23	2.25	56.93
<i>Lenticulina arcuatostrata</i>	1.23	1.51	2.78	54.94	<i>Hyperammina rugosa</i>	0.98	1.16	2.12	59.06
<i>Haplophragmoides vasiceki vasiceki</i>	1.2	1.51	2.78	57.72	<i>Bulimina elongata</i>	0.88	1.1	2.02	61.08
<i>Laevidentalina inornata</i>	1.17	1.51	2.78	60.5	<i>Reticulophragmium rotundidorsatum</i>	0.99	1.1	2.02	63.09
<i>Laevidentalina elegans</i>	1.06	1.42	2.62	63.11	<i>Reticulophragmium venezuelanum</i>	0.96	1.08	1.98	65.08
<i>Karrerulina apicularis</i>	1.19	1.42	2.62	65.73	<i>Amphicoryna armata</i>	0.8	1.08	1.98	67.06
<i>Karrerulina conversa</i>	1.06	1.42	2.62	68.35	<i>Hyperammina elongata</i>	0.8	1.07	1.96	69.01
<i>Reophax sp.</i>	1.14	1.42	2.62	70.96	<i>Trochammina sp.</i>	0.84	1.05	1.92	70.93
<i>Saccamina grzybowski</i>	1.11	1.42	2.62	73.58	<i>Ammobaculites agglutinans</i>	0.8	1.04	1.91	72.84
<i>Stilostomella adolphina</i>	1.06	1.42	2.62	76.2	<i>Martinottiella communis</i>	0.84	1.04	1.91	74.75
<i>Lenticulina sp.</i>	0.91	0.64	1.18	77.37	<i>Cibicoides pygmeus</i>	0.86	1.03	1.89	76.64
<i>Uvigerina acuminata</i>	0.91	0.64	1.18	78.55	<i>Laevidentalina elegans</i>	0.84	1.03	1.89	78.53
<i>Neugeborina boueana</i>	0.89	0.58	1.06	79.61	<i>Lenticulina sp.</i>	0.78	0.65	1.19	79.72
<i>Uvigerina mantaensis</i>	0.79	0.58	1.06	80.67	<i>Praeglobobulimina ovata</i>	0.79	0.61	1.12	80.84
<i>Rhabdammina sp.</i>	0.84	0.56	1.04	81.71	<i>Subreophax sp.</i>	0.73	0.6	1.1	81.94
<i>Ammodiscus cretaceus</i>	0.73	0.49	0.89	82.6	<i>Reticulophragmium acutidorsatum</i>	0.72	0.57	1.05	82.99
<i>Haplophragmoides horridus</i>	0.67	0.49	0.89	83.49	<i>Uvigerina farinosa</i>	0.7	0.56	1.03	84.02

Group Cluster 2					Group Cluster 3A				
Average similarity: 62.57	Av.Abund	Av.Sim	Contrib%	Cum.-%	Average similarity: 53.84	Av.Abund	Av.Sim	Contrib%	Cum.-%
<i>Hyperammina / Rhabdammina sp.</i>	2.54	5.71	9.12	9.12	<i>Hyperammina / Rhabdammina sp.</i>	1.93	3.79	7.04	7.04
<i>Hyperammina rugosa</i>	2.03	4.65	7.43	16.55	<i>Praeglobobulimina pupoides / affinis</i>	1.59	2.76	5.12	12.17
<i>Bathysiphon taurinensis</i>	1.65	3.7	5.91	22.47	<i>Uvigerina popescui</i>	1.45	2.71	5.04	17.2
<i>Nothia sp.</i>	1.65	3.7	5.91	28.38	<i>Reophax sp.</i>	1.41	2.71	5.04	22.24
<i>Praeglobobulimina pupoides / affinis</i>	1.62	3.7	5.91	34.29	<i>Melonis pompilioides</i>	1.35	2.65	4.91	27.15
<i>Rhabdammina sp.</i>	1.49	3.34	5.34	39.63	<i>Alabamina polita</i>	1.31	2.39	4.44	31.59
<i>Saccamina grzybowski</i>	1.55	3.34	5.34	44.97	<i>Hansenisca soldanii</i>	1.29	2.39	4.44	36.03
<i>Nothia excelsa</i>	1.3	2.81	4.49	49.47	<i>Valvulineria palmarealensis</i>	1.28	2.29	4.26	40.29
<i>Reophax sp.</i>	1.3	2.81	4.49	53.96	<i>Hyperammina rugosa</i>	1.27	2.22	4.13	44.41
<i>Reticulophragmium acutidorsatum</i>	1.25	2.81	4.49	58.45	<i>Saccamina grzybowski</i>	1.17	2.14	3.97	48.38
<i>Bolivina beyrichi carinata</i>	1	2.36	3.78	62.23	<i>Stilostomella adolphina</i>	1.13	2.14	3.97	52.35
<i>Hansenisca soldanii</i>	1	2.36	3.78	66	<i>Bolivina beyrichi carinata</i>	1.14	2.01	3.73	56.08
<i>Hyperammina elongata</i>	1.16	2.36	3.78	69.78	<i>Bulimina alsatica</i>	1.11	2.01	3.73	59.82
<i>Lenticulina calcar</i>	1.09	2.36	3.78	73.56	<i>Cibicoides pygmeus</i>	1.11	2.01	3.73	63.55
<i>Melonis pompilioides</i>	1.09	2.36	3.78	77.34	<i>Fursenkoina sp.</i>	1.06	2.01	3.73	67.28
<i>Praeglobobulimina ovata</i>	1	2.36	3.78	81.11	<i>Lenticulina inornata</i>	1.06	2.01	3.73	71.02
<i>Psamosphaera fusca</i>	1.09	2.36	3.78	84.89	<i>Nothia sp.</i>	1.06	2.01	3.73	74.75
<i>Reticulophragmium rotundidorsatum</i>	1.09	2.36	3.78	88.67	<i>Uvigerina mantaensis</i>	1.06	2.01	3.73	78.48
<i>Rhizzamina algaeformis</i>	1	2.36	3.78	92.45	<i>Bulimina elongata</i>	1	0.88	1.64	80.12
<i>Subreophax sp.</i>	1.25	2.36	3.78	96.22	<i>Ammosphaeroidina pseudopauiculolata</i>	0.73	0.68	1.26	81.38
<i>Trochammina sp.</i>	1	2.36	3.78	100	<i>Bulimina arndti</i>	0.73	0.68	1.26	82.64
					<i>Cibicoides pachyderma</i>	0.77	0.68	1.26	83.91

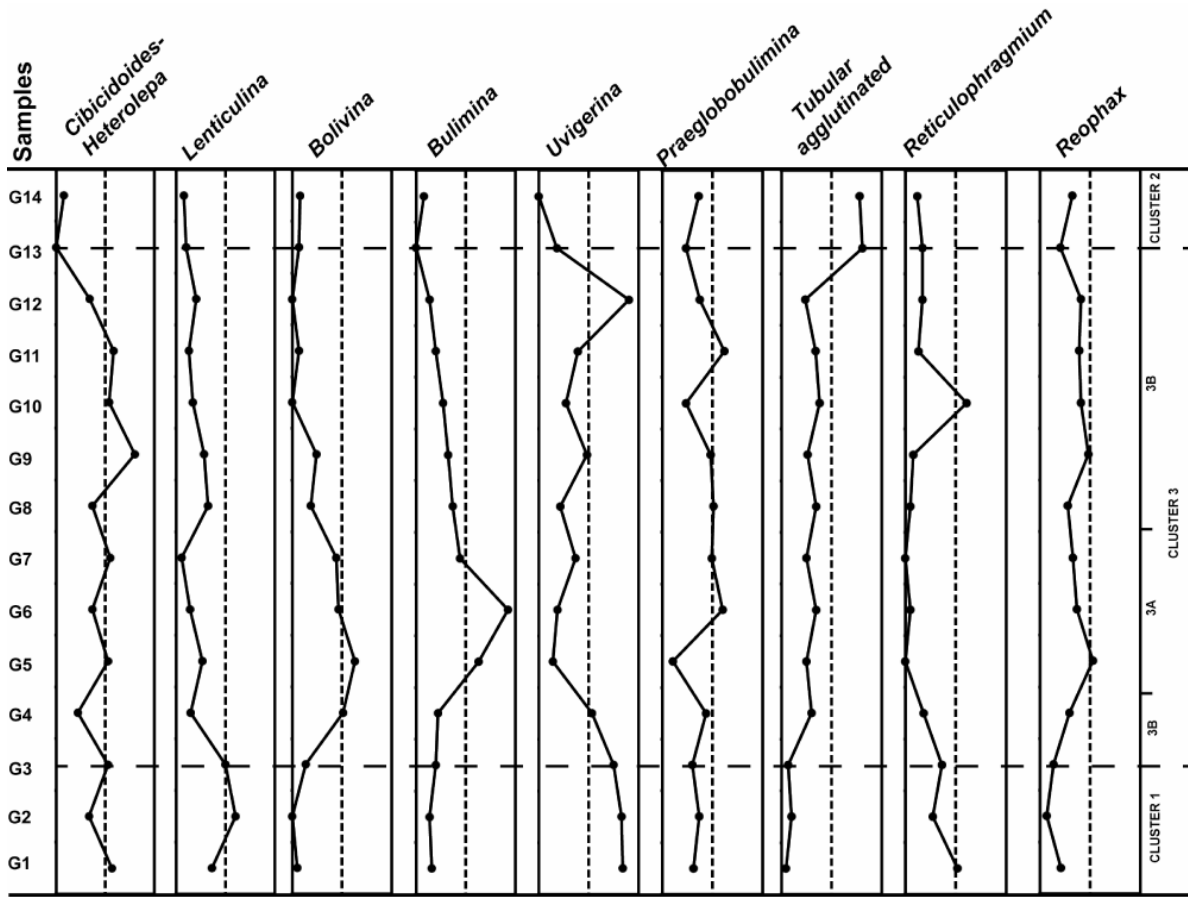


Figure 6: Graph showing relative abundances of most important genera or groups with similar paleoecological affinities for Gălpăia section.

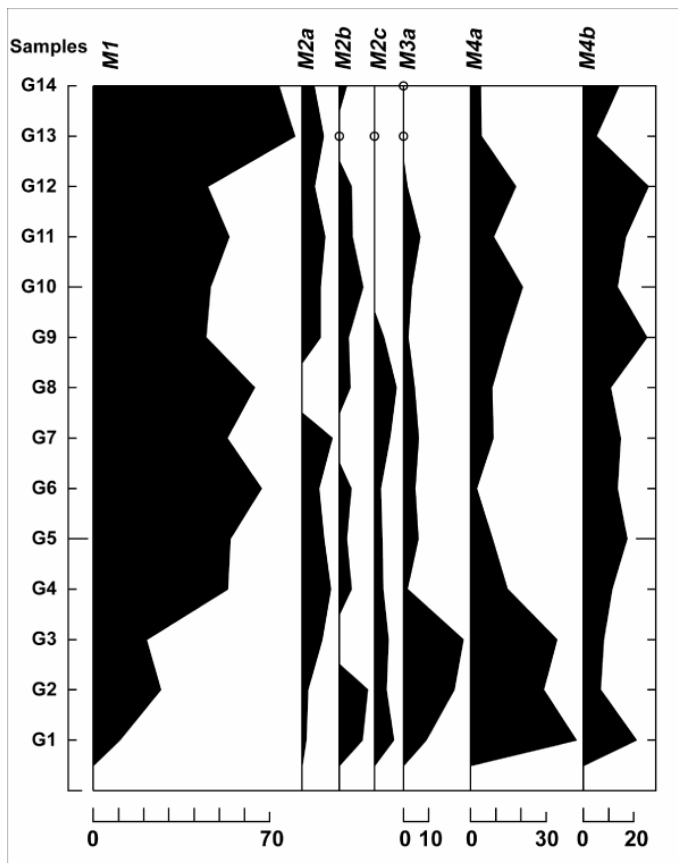
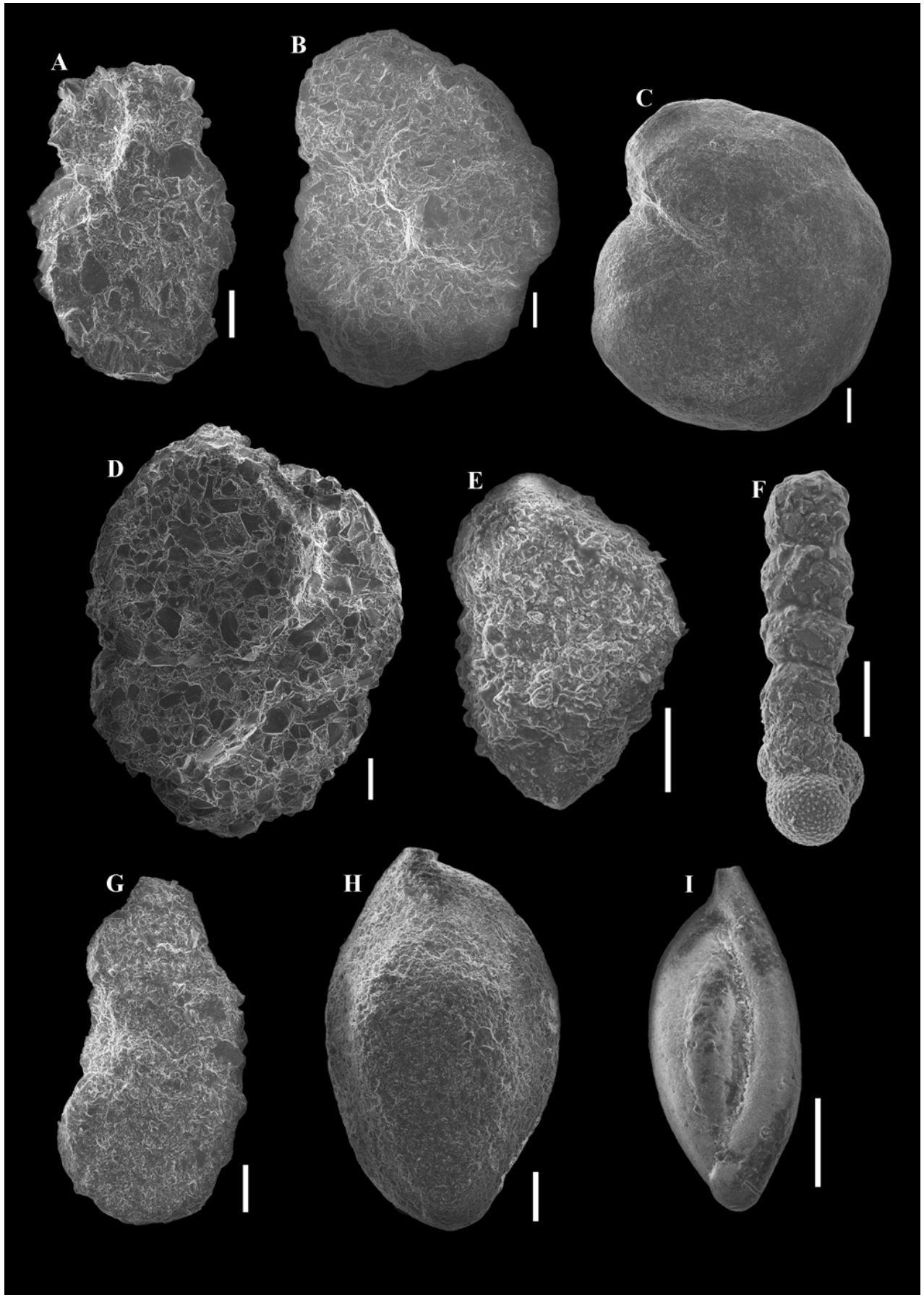


Figure 7: Graph showing abundance (percent) of agglutinated foraminiferal morphogroups defined by KAMINSKI *et al.* (2005). Abundance of each morphogroup is calculated relative to the total abundance of agglutinated foraminifera.





The dominant benthic calcareous species are *Alabamina polita*, *Melonis pompilioides*, *Praeglobobulimina pupoides* and *Uvigerina popescui* (Fig. 9), while the agglutinated forms are well represented by species of *Hyperammina* / *Rhabdammina* and *Reophax*. Less abundant benthic foraminifera include *Ammosphaeroidina pseudopauciloculata*, *Bolivina beyrichi carinata*, *Bulimina alsatica*, *B. arndti*, *B. elongata*, *Cibicoides pachyderma*, *C. pygmeus*, *Fursenkoina* spp., *Hansenisca soldanii*, *Lenticulina* spp., *Nothia* spp., *Saccamina grzybowski*, *Stilostomella adolphina*, *Uvigerina mantaensis*, and *Valvulineria palmarealensis*. Twenty-two species/groups account for 83% of the average similarity within this group (Table 4).

Subcluster 3B includes samples G4 and G8 - G12 (Figs. 2 and 5). As with subcluster 3A, benthic foraminiferal assemblages are characterized by both calcareous and agglutinated taxa (Fig. 2). The FISHER's alpha diversity indices range between 20.3 and 38, and the SHANNON-WIENER diversity indices between 2.9 and 3.6 (Fig. 2). Epifaunal and infaunal forms are well represented, while the epifaunal-shallow infaunal microhabitat is uncommon (Fig. 2).

The dominant benthic calcareous species are *Praeglobobulimina pupoides* and *Uvigerina popescui*, while the agglutinated forms are well represented by species of *Hyperammina* / *Rhabdammina*. Less common are *Ammobaculites agglutinans*, *Amphicoryna armata*, *Bathysiphon taurinensis*, *Bulimina elongata*, *Cibicoides pachyderma*, *C. pygmeus*, *Hansenisca soldanii*, *Haplophragmoides* spp., *Laevidentalina elegans*, *Lenticulina* spp., *Martinottiella communis*, *Melonis pompilioides*, *Karrerella chilostoma*, *Nothia* spp., *Praeglobobulimina ovata*, *Recurvoides* spp., *Reophax* spp., *Reticulophragmium* spp., *Saccamina grzybowski*, *Subreophax* spp., *Trochammina* spp., *Uvigerina farinosa*, and *Valvulineria palmarealensis*. Thirty-one species/groups account for 84% of the average similarity within this group (Table 4).

In **Cluster 3**, the tubular agglutinated morphogroup is better represented than Cluster 1 (Figs. 6 and 7). Furthermore, the bathyal- and abyssal-type agglutinated foraminifera (morphogroup M2a) are more abundant in Cluster 3 than in other clusters (except sample G8 - Fig. 7). The shallow-water agglutinated forms (such as *Spirorutilus carinatus*, *Spiroplectammina pectinata*, and *Vulvulina haeringensis*) and morphogroup

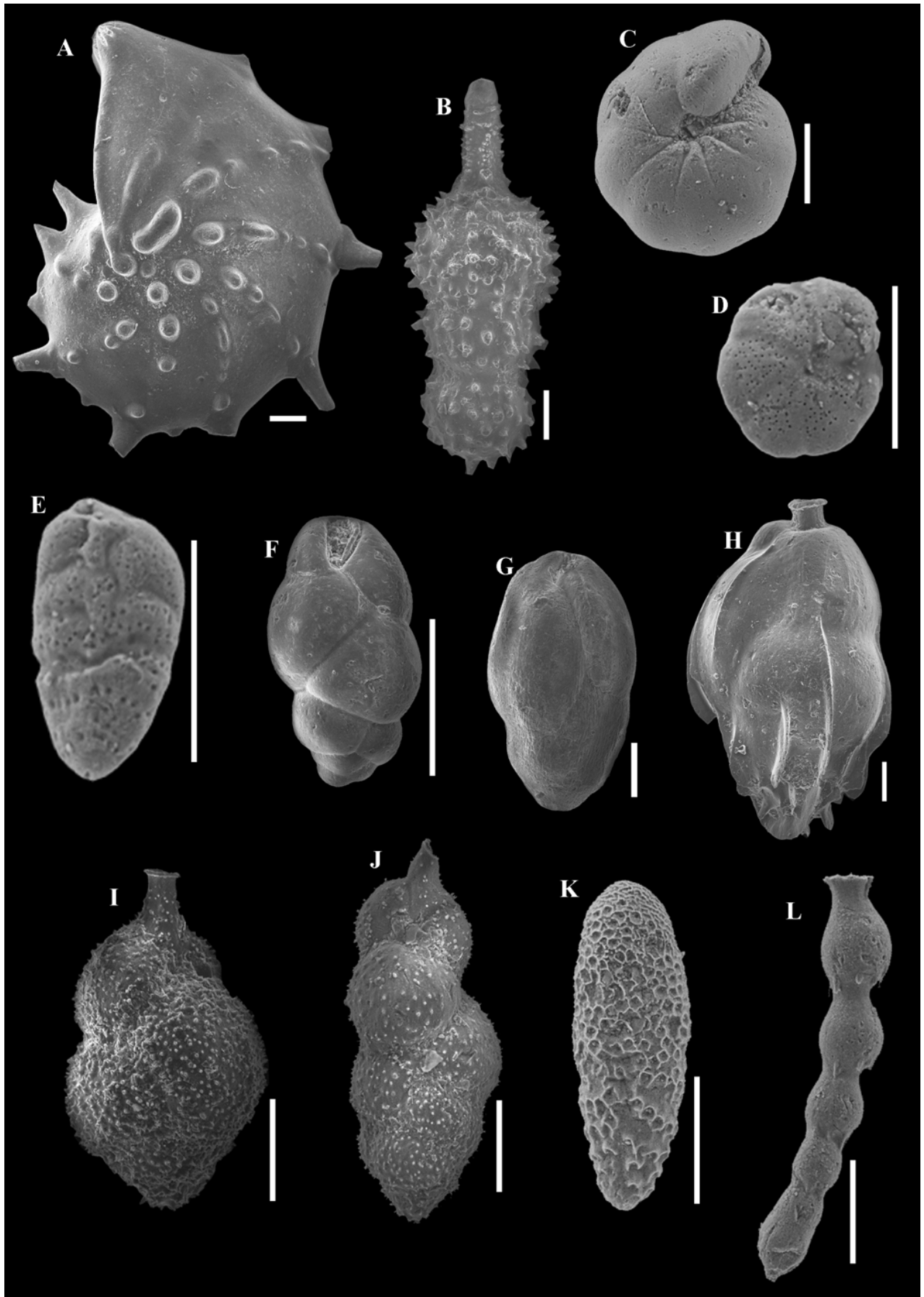
M4a are less abundant than in Cluster 1 (Fig. 7). Morphogroups M3a and M2b are also less commonly represented.

5. Discussions and interpretation

5.1. Biostratigraphy

Most of the identified planktonic species from the Gălpâia section have long stratigraphic ranges. Possibly reworked individuals of *Paragloborotalia opima* were also observed (samples G1 - G2, G6, G8, G11 - G12, and G13). Nevertheless, the presence of the planktonic *Globigerinoides trilobus* (in samples G1, G2, G7, G8, G10, G12, and G14 - Figs. 3 and 10) suggests equivalence with the early Miocene (Aquitanian-Burdigalian) *Globigerinoides trilobus* Biozone of POPESCU (1975) represented by the stratigraphic interval from the first appearance of the nominate taxon to the first occurrence of *Praeorbulina glomerosa* (BLOW, 1956) or the mass occurrence of *Globoquadrina dehiscens* (CHAPMAN *et al.*, 1934). The latter two species of planktonic foraminifera were not identified in the samples from the Gălpâia section. More recent papers (*e.g.*, WADE *et al.*, 2011) place the *Globigerinoides trilobus* Zone (more precisely the *Globigerinoides trilobus* Partial-range Zone) in Zone M12 (partial M13a zone of BERGGREN *et al.*, 1995). According to CICHA *et al.* (1998), the stratigraphic range of the species *Cassigerinella globulosa* (EGGER, 1857) and *Globigerina ottnangiensis* RÖGL, 1969, is Eggenburgian to Karpatian, while *Paragloborotalia semivera* (HORNIBROOK, 1961) is of Egerian to Eggenburgian age. Based on the identified planktonic foraminiferal species and their distribution, the age of the deposits from the Gălpâia section is probably Eggenburgian (Burdigalian)(RÖGL, 1998). The well-represented agglutinated *Reticulophragmium venezuelanum* (MAYNC, 1952) permits correlation with the *Alveolophragmium venezuelanum* Zone of POPESCU (1975). Another of POPESCU's (1975) benthic foraminiferal zones is the *Uvigerina beccarii* / *Uvigerina galloway* Zone, defined by the occurrence of the two nominate taxa. The species *Uvigerina beccarii* FORNASINI, 1898, recorded by POPESCU (1975) from the Chechiş Clays, was later described as *Uvigerina popescui* RÖGL (1998). This calcareous benthic species, initially considered of Eggenburgian age, is also present in the Oligocene of the Vima Formation from the Transylvanian Basin (SZÉKELY & S. FILIPESCU, 2015, 2016).

- ◀ **Figure 8:** **a.** *Hyperammina elongata* BRADY, 1878. Side view, sample G1.
b. *Reticulophragmium venezuelanum* (MAYNC, 1952). Side view, sample G10.
c. *Reticulophragmium acutidorsatum* (HANTKEN, 1868). Side view, sample G1.
d. *Gaudryinopsis megagranosus* (VENGLINSKYI, 1953). Side view, sample G14.
e. *Textularia* sp. Side view, sample G4.
f. *Subreophax* sp. Side view, sample G8.
g. *Sabellivoluta humboldti* (REUSS, 1851). Side view, sample G1.
h. *Sigmoilopsis schlumbergeri* (SILVESTRI, 1904). Side view, sample G12.
i. *Sigmoilinita tenuis* (CZJZEK, 1848). Side view, sample G1.
All scales represent 100 µm.





5.2. Paleocology of planktonic foraminifera

The planktonic foraminifera from Gălpâia are dominated throughout the section by cool-water and high-productivity indicators (Clusters 2 and 3, Tables 2 and 3). Nevertheless, **Cluster 1** contains a higher abundance of the species *Globobulimina connecta*, which indicates cool-temperate surface waters. At the same stratigraphic levels, the small five-chambered species *Globigerina ottangiensis* shows a reduced distribution compared to **Clusters 2** and **3**. Furthermore, episodes of warmer surface waters and changes in primary productivity could be indicated by the significant increase in abundance of *Globigerinoides trilobus* in samples G7-G8. This trend possibly corresponds with the warming event documented from the Chechiş Formation (Eggenburgian) by SZÉKELY *et al.* (2016). Changes in primary productivity are also reflected by the significant decrease in abundance of the benthic genus *Uvigerina* (Cluster 3A) and a drop in species diversity of the benthic assemblages (Figs. 2 and 6).

Episodes of high primary productivity are indicated in **Clusters 2** and **3** by the small micro-perforate forms (e.g., *Tenuitella*), small five-chambered globigerinids (e.g., *Globigerina ottangiensis*, *G. tarchanensis*) and the *Globigerina* group (see Table 2).

Similar planktonic assemblages with small globigerinids (including *Globigerina* spp., *Tenuitella* spp., and *Tenuitellinata* spp.) and low abundance of *Globigerinoides* have been reported from the early Miocene (BELDEAN *et al.*, 2012) and the middle Miocene (S. FILIPESCU, 2001; S. FILIPESCU & SILYE, 2008; R. & S. FILIPESCU, 2015) of the Transylvanian Basin. LI & MCGOWRAN (1998) and AL-SABOUNI *et al.* (2007) associated these kinds of assemblages with mixing of warm and cold waters and upwelling, respectively.

5.3. Paleocology of benthic foraminifera

The presence of the epifaunal genus *Cibicides* in **Cluster 1** (Fig. 6) suggests episodes of high-energy well-oxygenated bottom waters (see Table 1). Recent *Cibicides pachyderma* is characteristic in oligotrophic environments (see Table 1) and was reported primarily as an upper bathyal species but is also present in shelf assemblages (BERGGREN & HAQ, 1976).

Indicators of high primary productivity are most abundant in this cluster. The genus *Uvigerina* prefers muddy sediments and suggests high organic-matter flux to the sea floor and paleodepths greater than 100 m (see Table 1). Similarly, the genus *Praeglobobulimina* indicates high primary productivity and poor oxygenation, and it has a preferred depth range of 80 to 800 m (SPEZZAFERRI & ĆORIĆ, 2001; SPEZZAFERRI *et al.*, 2002). Both genera are relatively well represented in **Cluster 1** (Fig. 6). The less abundant infaunal species *Melonis pompilioides* also supports the interpretation of episodic high primary productivity (see Table 1). Some authors (e.g., CORLISS & CHEN, 1988; GUPTA & THOMAS, 1999; LOUBERE, 1998; MURRAY, 2006) associated the genus *Pullenia* with high carbon flux rates, variable food flux and low-oxygen environments. According to RÖGL & SPEZZAFERRI (2003), this genus is a suboxic indicator present in circum-littoral to bathyal environments. In particular, the species *Pullenia bulloides* has a 200 to 500 m depth range (SPEZZAFERRI *et al.*, 2004). Episodic decreased bottom-water oxygenation is also suggested by the presence of suboxic-dysoxic *Lenticulina*, the suboxic-dysoxic *Laevidentalina* and the mud-preferring epifaunal *Hansenisca soldanii* together with low-oxygen-tolerant taxa such as species of *Bolivina* and *Bulimina* (see Table 1, Fig. 6). The genus *Lenticulina* is a shallower-water taxon (see Table 1), which has been reported as a significant component of assemblages from Eggenburgian-Ottangian outer-neritic deposits of the Alpine Foreland Basin (GRUNERT *et al.*, 2012).

Agglutinated foraminiferal morphogroup M1 is characteristic in bathyal and abyssal environments with low-organic matter flux. *Saccamina grzybowski* (important component of morphogroup M2a in this study) is known as an outer neritic to abyssal agglutinated form (KAMINSKI *et al.*, 2005). The relatively good representation of morphogroup M4b in this cluster supports the interpretation of episodically increased organic-matter flux to the sea floor. The deep-water forms of morphogroup M3 (M3a, Fig. 7) are here represented by flattened surficial epifaunal species of *Glomospira*. *Glomospira charoides*, reported from the early Eocene North Atlantic, Mediterranean and Alpine-Carpathian Flysch (BINDIU & S. FILIPESCU, 2011), is considered to respond positively to high organic-matter flux (KAMINSKI *et*

◀ **Figure 9:** a. *Lenticulina subpapillosa* (NUTTALL, 1932). Side view, sample G2.

b. *Amphicoryna hirsuta* (ORBIGNY, 1826). Side view, sample G2.

c. *Hansenisca soldanii* (ORBIGNY, 1826). Umbilical view, sample G1.

d. *Cibicides pygmaeus* (HANTKEN, 1875). Umbilical view, sample G8.

e. *Bolivina dilatata dilatata* REUSS, 1850. Side view, sample G6.

f. *Bulimina elongata* ORBIGNY, 1846. Side view, sample G1.

g. *Praeglobobulimina pupoides* (ORBIGNY, 1846). Side view, sample G6.

h. *Uvigerina popescui* RÖGL, 1998. Side view, sample G1.

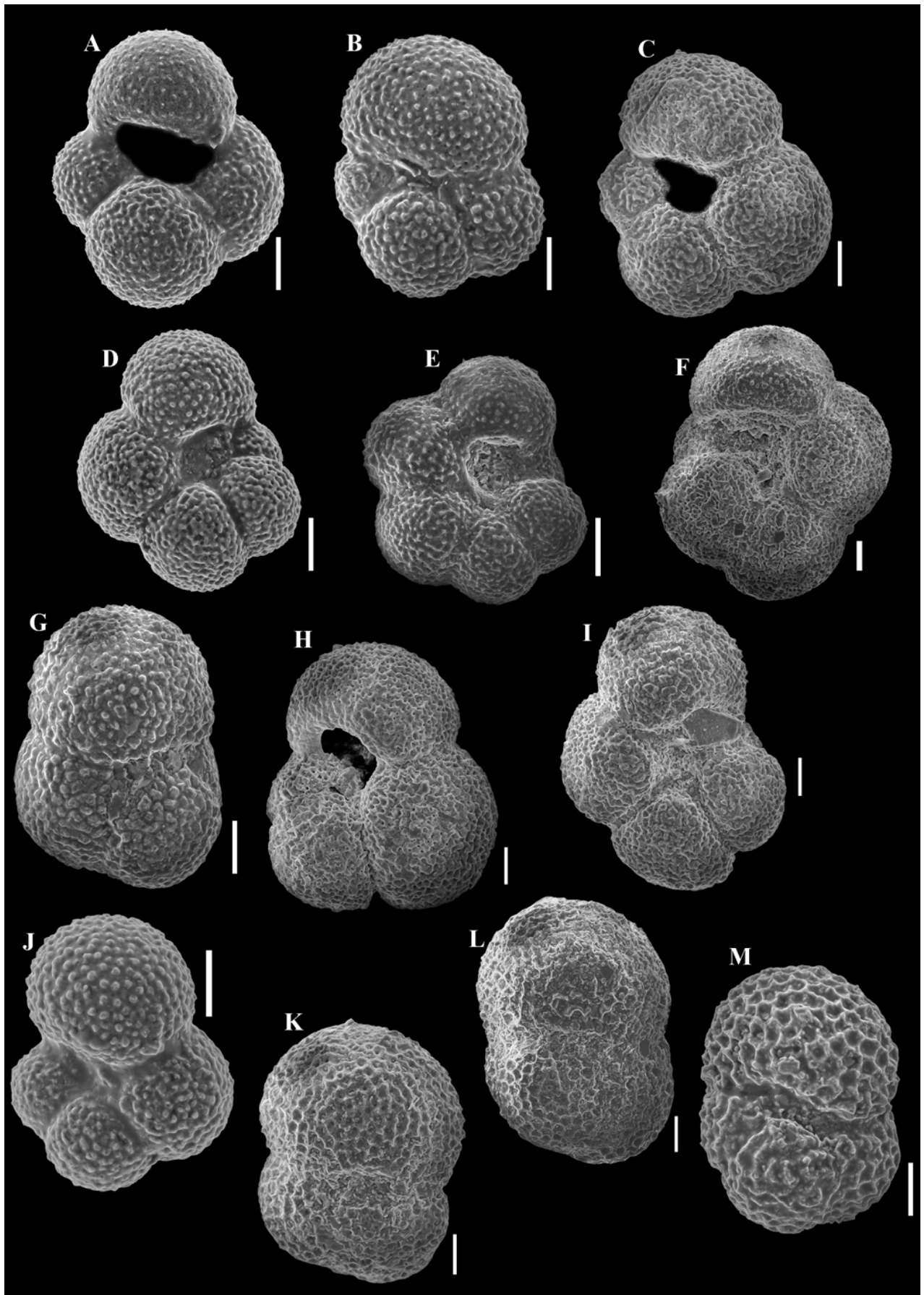
i. *Uvigerina mantaensis* CUSHMAN & EDWARDS, 1938. Side view, sample G1.

j. *Uvigerina farinosa* HANTKEN, 1875. Side view, sample G3.

k. *Lapugyina schmidi* POPESCU, 1998. Side view, sample G8.

l. *Stilostomella adolphina* (ORBIGNY, 1946). Side view, sample G6.

All scales represent 100 µm.





al., 2005). Nevertheless, this species was reported also from oligotrophic intervals in the Mediterranean (DE RIJK *et al.*, 2000). The occurrence of *G. charoides* in Cluster 1 may be related to high primary productivity and the consequent organic-matter flux to the sea floor.

Benthic foraminiferal assemblages of **Cluster 1** suggest episodic high-energy currents, intervals with well-oxygenated environments (also supported by the presence of vertical and horizontal burrows - Fig. 2), and episodes of high primary productivity with possible reduced oxygen levels as indicated by the frequent occurrence of *Praeglobobulimina* species. These interpretations are supported by the diversity indices, which show high values (Fig. 2). The occasionally oxygenated, stable environments and organic-matter flux to the sea floor enabled the diversification of benthic assemblages in an outer shelf (possibly upper bathyal) setting. Tubular agglutinated forms, the bathyal-abyssal morphogroup M2a, and the decrease of shelf-type agglutinated foraminifera (Fig. 7) indicate a gradual increase in water depth for **Cluster 1**.

Benthic foraminiferal assemblages in **Cluster 2** are clearly dominated by agglutinated forms (with the tubular morphogroup M1 most abundant: Figs. 2, 6 and 7). Of benthic calcareous foraminifera, *Cibicidoides* and *Heterolepa* are almost completely absent, while primary productivity indicators (*Uvigerina*) decrease in abundance in parallel with the increase of the agglutinated tubular morphogroup, suggesting low organic flux to the sea floor. This may be related to the deepening of the environment to an upper bathyal setting, where the development of calcareous taxa was inhibited. The above-mentioned paleoecological factors are also reflected by the low species diversity indices (Fig. 2). Some benthic species have probably been the subject of reworking from shallower environments, *e.g.*, *Hanzawaia boueana* usually found on the inner shelf (preferred depth range of 0 - 50 m - SPEZZAFERRI & ĆORIĆ, 2001) and shelf-type agglutinated foraminifera such as *Spiroplectamina* and *Vulvulina*.

Similar to Cluster 1, **subcluster 3A** contains *Cibicidoides* species (*e.g.*, *Cibicidoides pachyderma*, *C. pseudoungerianus* and the diminutive *C. pygmeus*) (Fig. 6) suggesting intervals with

high-energy well-oxygenated bottom waters. The presence of *Uvigerina* and *Praeglobobulimina* together with *Melonis pompilioides* and *Valvulineria palmarealensis* are evidence for intervals with high primary productivity and organic carbon flux to the sea floor and probably lowered oxygenation (see Table 1), although the significant decrease of *Uvigerina* species (Fig. 6) and the increase of the tubular agglutinated morphogroup may suggest shorter episodes. The lower species diversity values (compared to subcluster 3B) could be the result of the aforementioned conditions. Furthermore, the presence of the infaunal species *Globocassidulina subglobosa* suggests a flux of phytodetritus to the sea floor (CORLISS & CHEN, 1988; GOODAY, 1994). The highest abundance in the Gălpâia section of the low-oxygen taxa (*Bolivina*, *Bulimina* and *Praeglobobulimina*) and the sole appearance of the opportunist genus *Fursenkoina* could be related to abrupt changes in water depth, decreased bottom water oxygenation as a consequence of high primary productivity, and a lack of currents to oxygenate the bottom waters. Alternatively, the above-mentioned genera appeared during more oxygenated intervals in an environment where the food source was represented by refractory organic matter. An increase in water depth is also supported by the significant increase of the tubular agglutinated morphogroup. The species composition of benthic foraminiferal assemblages from samples included in **subcluster 3B** is similar to those of subcluster 3A. Nevertheless, the abundances of low-oxygen taxa (representatives of *Bolivina* and *Bulimina*) strongly decreases towards the top of **subcluster 3B**. Samples G9 and G12 are characterized by the high abundance of the oxic (such as *Cibicidoides*) and primary productivity (*Uvigerina* and *Praeglobobulimina*) indicators (Fig. 6). High-energy currents and episodes of high primary productivity might have characterized this interval. Simultaneously, agglutinated infaunal morphogroup M4b is very abundant in samples G9 and G12, supporting high primary productivity for these levels (Fig. 7). The existence of such an environment may also be reflected in the decrease of tubular agglutinated morphogroup M1 (Fig. 7), which suggests low organic-matter flux to the sea floor (KAMINSKI *et al.*, 2005). These intervals may indicate water-depth change (shallowing).

◀ **Figure 10:** a. *Globigerina ouachitensis* HOWE & WALLACE, 1932. Apertural view, sample G7.

b. *Globigerina officinalis* SUBBOTINA, 1953. Apertural view, sample G7.

c. *Globigerina lentiana* RÖGL, 1969. Apertural view, sample G7.

d. *Globigerina otthangiensis* RÖGL, 1969. Apertural view, sample G8.

e. *Globigerina tarchanensis* SUBBOTINA & CHUTZIEVA, 1950. Apertural view, sample G2.

f. *Globigerina concinna* REUSS, 1850. Apertural view, sample G10.

g. *Globoturborotalita connecta* (JENKINS, 1964). Apertural view, sample G1.

h. *Globoturborotalita woodi* JENKINS, 1960. Apertural view, sample G2.

i. *Globigerina gnaucki* BLOW & BANNER, 1962. Apertural view, sample G7.

j. *Globigerinella obesa* (BOLLI, 1957). Apertural view, sample G7.

k. *Globigerinoides trilobus* (REUSS, 1850). Spiral view, sample G8.

l. *Globigerinoides trilobus* (REUSS, 1850). Apertural view, sample G8.

m. *Globigerinoides* sp. Apertural view, sample G8.

All scales represent 100 µm.



The epifaunal to shallow infaunal (MURRAY, 2006) *Cribrostomoides subglobosus* from the middle and upper part of the outcrop is included in morphogroup M2b (KAMINSKI *et al.*, 2005). Its depth range is considered to be from 400 to 5700 m (SPEZZAFERRI *et al.*, 2004). Another species present in the second part of the outcrop is the outer neritic - abyssal *Psammosphaera fusca* (KAMINSKI *et al.*, 2005). The highest abundance of the agglutinated species *Karrieriella chilostoma* (morphogroup M4a) appears in this cluster. According to VAN SIMAEYS *et al.* (2004), this species is an outer shelf to bathyal indicator.

Subcluster 3B probably represents the transition from outer shelf to upper bathyal settings. Several episodes with high-energy well-oxygenated bottom waters and high primary productivity may mark shallowing events alternating with lower organic flux to the sea floor in deeper settings. The environmental transition is also suggested by the complete absence of the shallow-water agglutinated foraminifera (morphogroup M2c represented by *Vulvulina haeringensis*, *Spiroplectammina carinata* and *Spirorutilus carinatus*) from sample G10 and the general increase of the bathyal - abyssal morphogroup M2a starting with sample G8.

5.4. Succession of paleoenvironments of the Gălpâia section and the evolution of the northwestern Transylvanian Basin

Based on the data presented above, the rocks at the base of the sequence were probably deposited in an outer shelf (possibly upper bathyal) setting characterized by episodes of higher energy (indicated by the presence of the genus *Cibicidoides*), well-oxygenated bottom waters (suggested by *Cibicidoides*) and intervals with enhanced primary productivity (the strong representation of *Uvigerina* and *Praeglobobulimina* species). Planktonic foraminiferal species support the existence of episodes of high primary productivity probably as a consequence of high nutrient flux from the land.

In the middle of the section, the decreasing abundance of *Uvigerina* and increased tubular agglutinated foraminifera, typical for environments with low organic carbon flux, indicate oscillations in primary productivity. 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) (JORISSEN *et al.*, 1995).

The upper part of the sequence is characterized by oscillations in paleoecological factors (such as primary productivity). Towards the top of the outcrop the increase of agglutinated forms indicating bathyal-abyssal environments and the decrease in abundance of calcareous benthic forms suggest the transition to an upper bathyal environment. Besides a low organic-matter flux to the sea floor, transport of some

foraminiferal species from shallower environments characterizes the upper bathyal environments of the uppermost part of the section.

The origin of the fine sand laminae may be related to storm activity, longshore drifts or deltaic influences (supported by the presence of coally material). A deltaic influence would support a high nutrient flux to the marine environment (and seasonal high primary productivity), periodic higher current energy and consequent oxygenation of the bottom water. This influence might have diminished during deposition of the sediments in the middle of the sequence. According to KRÉZSEK & BALLY (2006), the study area (central part of the Transylvanian Basin) occupied a shelf/delta environment during the early Miocene.

In the Transylvanian Basin, the underlying Coruș Formation is considered to be the first unit deposited during the early Miocene marine transgression (POPESCU *et al.*, 1995). A glauconite facies at the base of the Chechiș Formation was described by ȘURARU (1967) and associated in the neighbouring area (Tihău section) with the maximum flooding surface of the first early Miocene transgression (SZÉKELY *et al.*, 2016). The deposits above this glauconite level are considered to have formed during the highstand. The succession studied in the Gălpâia section probably represents the middle and upper parts of the Chechiș Formation and based on the inferred paleoenvironmental evolution also represents a highstand systems tract. The sediments belonging to the Chechiș Formation near the Tihău locality (Fig. 1) were deposited on a narrow shelf with deltaic influences (SZÉKELY *et al.*, 2016) while, at Gălpâia, the shelf was probably characterized by a different morphology and decreased deltaic influence.

6. Conclusions

(1) Planktonic and benthic foraminiferal assemblages were analyzed from outcrops of the lower Miocene Chechiș Formation in the Gălpâia section. Biostratigraphic study of the planktonic assemblages allowed the determination of an Eggenburgian/Burdigalian age (*Globigerinoides trilobus* Biozone of POPESCU, 1975) for these deposits.

(2) Planktonic foraminiferal assemblages are mainly dominated by globigerinids and tenuitellids indicating cool surface waters and enhanced primary productivity, while warm-water indicators are rather scarce. Increase in abundance of the species *Globigerinoides trilobus* in the middle part of the outcrop may suggest a warmer/transgressive interval or changes in primary productivity.

(3) Paleoenvironmental reconstruction based on planktonic and benthic foraminiferal assemblages indicates a general deepening of the environment from outer shelf to upper bathyal. Deltaic influences are 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 the retrogradation of the environments, with consequences for primary productivity and a decrease of organic-matter flux to the sea floor. In the second part of the section, a transition was observed from outer shelf to upper bathyal. A mainly low organic flux to the sea floor characterized the upper bathyal setting.

(4) The sedimentary succession studied was probably deposited during the late stage of the relative sea-level rise (highstand systems tract) following the initial early Miocene transgression in the Transylvanian Basin. The species composition and distribution of the foraminiferal assemblages reflect changing paleoecological factors as a consequence of the above-mentioned aspects.

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Appendix

Foraminiferal counts from the Gălpâia section, Romania	Samples													
	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	G13	G14
Gălpâia species list														
Benthic foraminifera														
<i>Alabamina polita</i> BECKER & DUSENBURY	0	0	0	1	6	2	2	1	0	0	0	0	0	0
<i>Ammobaculites agglutinans</i> (ORBIGNY)	2	0	1	1	1	0	0	1	0	1	1	1	0	1
<i>Ammodiscus cretaceus</i> (REUSS)	0	1	2	0	0	0	0	0	0	0	0	0	0	0
<i>Ammodiscus miocenicus</i> KARRER	3	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Ammodiscus peruvianus</i> BERRY	0	4	0	0	0	0	0	0	0	0	0	0	0	0
<i>Ammodiscus</i> sp.	0	0	0	0	2	1	0	2	1	0	2	0	0	1
<i>Ammosphaeroidina pseudopauciloculata</i> (MJATLIUK)	0	0	2	1	0	1	2	0	0	1	2	1	0	0
<i>Amphicoryna armata</i> (NEUGEBOREN)	0	3	0	2	0	0	0	1	1	1	0	1	0	0
<i>Amphicoryna hirsuta</i> (ORBIGNY)	4	1	0	0	0	0	1	0	0	1	0	0	0	0
<i>Amphicoryna</i> sp.	1	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Astacolus</i> sp.	1	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Asterigerinoides guerichi</i> (FRANKE)	0	0	0	0	0	0	1	0	0	0	0	0	0	0
<i>Bathysiphon taurinensis</i> SACCO	2	3	1	3	1	0	0	1	3	2	3	1	6	9
<i>Bigenerina agglutinans</i> ORBIGNY	0	0	0	1	0	0	0	0	1	0	1	0	0	0
<i>Bolivina antiqua</i> ORBIGNY	0	0	0	2	2	0	0	0	0	0	0	0	0	0
<i>Bolivina beyrichi carinata</i> HANTKEN	0	0	0	1	1	4	1	2	2	0	0	0	1	1
<i>Bolivina crenulata</i> CUSHMAN	0	0	1	3	0	0	2	0	1	0	0	0	0	0
<i>Bolivina dilatata dilatata</i> REUSS	0	0	0	0	1	1	0	0	0	0	0	0	0	0
<i>Bolivina fastigia</i> CUSHMAN	1	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Bolivina molassica</i> HOFMANN	0	0	0	0	1	0	0	0	0	0	0	0	0	0
<i>Bolivina</i> sp.	0	0	1	1	1	0	1	0	0	0	1	0	0	0
<i>Budashevaella laevigata</i> (VOLOSHINOVA)	3	1	0	0	0	0	0	1	0	0	1	0	0	0
<i>Budashevaella multicamerata</i> (VOLOSHINOVA)	0	0	0	0	1	1	0	0	0	0	0	0	0	0
<i>Bulimina alsatica</i> CUSHMAN & PARKER	0	0	0	0	3	1	1	1	0	0	0	0	0	1
<i>Bulimina arndti</i> HAGN	0	2	0	0	0	1	2	0	2	4	1	0	0	0
<i>Bulimina elongata</i> ORBIGNY	2	0	1	2	3	8	0	2	1	0	1	2	0	0
<i>Bulimina schischkinskayae</i> SAMOYLOVA	0	0	2	0	0	0	0	0	0	0	0	0	0	0
<i>Bulimina</i> sp.	0	0	0	0	0	0	1	1	0	0	1	0	0	0
<i>Bulimina striata striata</i> ORBIGNY	1	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Bulimina subulata</i> CUSHMAN & PARKER	0	0	0	1	0	0	0	0	0	0	0	0	0	0
<i>Bulimina tenera</i> REUSS	0	0	0	0	0	0	0	0	1	0	0	0	0	0
<i>Ceratobulimina contraria</i> (REUSS)	0	0	0	0	2	0	0	0	0	0	1	0	0	0
<i>Chilostomella oolina</i> SCHWAGER	0	0	0	0	0	0	1	1	0	0	0	0	0	0
<i>Cibicides amphysiliensis</i> (ANDREAEE)	0	0	0	0	1	0	0	0	0	0	0	0	0	0
<i>Cibicoides lopjanicus</i> (MJATLIUK)	0	0	2	0	0	0	0	0	0	0	0	0	0	0
<i>Cibicoides pachyderma</i> (RZEHAK)	11	4	5	2	0	3	1	2	6	5	6	4	0	0
<i>Cibicoides pseudoungerianus</i> (CUSHMAN)	0	0	1	0	1	0	1	1	0	0	0	1	0	0
<i>Cibicoides pygmeus</i> (HANTKEN)	0	0	0	1	1	1	3	1	3	1	1	0	0	0
<i>Cibicoides</i> sp.	0	0	0	0	2	0	0	0	0	0	0	0	0	0
<i>Cibicoides ungerianus ungerianus</i> ORBIGNY	0	1	0	0	0	0	0	0	0	0	0	0	0	0
<i>Cribrostomoides subglobosus</i> (CUSHMAN)	0	0	0	1	0	0	0	0	0	6	0	0	0	1
<i>Cylindroclavulina rudis</i> (COSTA)	0	0	1	0	0	0	0	0	0	0	0	0	0	4
<i>Dentalina leguminiformis</i> (BATSCH)	0	0	0	1	0	0	0	0	0	0	0	0	0	0
<i>Elphidiella</i> sp.	0	0	0	0	0	0	0	0	0	0	1	0	0	0
<i>Epistominella exigua</i> (BRADY)	0	0	0	0	0	0	0	0	1	0	0	0	0	0
<i>Fronovaginulina tenuissima</i> (HANTKEN)	1	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Fursenkoina</i> sp.	0	0	0	0	2	1	1	0	0	0	0	0	0	0
<i>Gaudryinopsis megagranosus</i> (VENGLINSKY1)	0	0	0	0	0	0	0	0	0	0	0	0	0	1
<i>Globocassidulina oblonga</i> (REUSS)	1	1	0	0	0	0	0	0	0	0	0	0	0	0
<i>Globocassidulina subglobosa</i> (BRADY)	0	0	0	0	2	0	1	1	0	0	0	0	0	0
<i>Globulina gibba</i> ORBIGNY	1	0	0	0	0	0	1	0	0	0	1	0	0	0
<i>Glomospira charoides</i> (JONES & PARKER)	1	2	2	0	0	0	0	0	0	1	0	0	0	0
<i>Glomospira gordialis</i> (JONES & PARKER)	1	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Guttulina communis</i> (ORBIGNY)	0	0	1	0	0	0	0	0	0	0	0	0	0	0
<i>Gyroidinaconstans</i> (REISER)	0	0	0	2	0	0	0	0	0	0	0	1	0	0
<i>Gyroidinoides umbonatus</i> (SILVESTRI)	1	0	0	1	0	0	0	0	0	0	0	0	0	0
<i>Hansenisca soldanii</i> (ORBIGNY)	5	2	2	0	2	5	2	2	3	1	2	4	1	1
<i>Hanzawaia boueana</i> (ORBIGNY)	0	0	0	0	0	0	1	1	0	0	1	0	1	0
<i>Haplophragmoides carinatus</i> CUSHMAN & RENZ	0	0	0	1	0	0	0	0	0	0	0	0	0	0
<i>Haplophragmoides horridus</i> (GRZYBOWSKI)	0	1	1	0	0	0	2	1	1	0	0	0	0	0
<i>Haplophragmoides</i> sp.	6	3	1	3	3	0	1	1	4	2	3	5	0	1
<i>Haplophragmoides suborbicularis</i> (GRZYBOWSKI)	0	0	0	0	0	0	0	0	1	0	0	0	0	0



Foraminiferal counts from the Gălpâia section, Romania	Samples													
	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	G13	G14
Gălpâia species list														
Benthic foraminifera														
<i>Haplophragmoides vasiceki vasiceki</i> CICHA & ZAPLETALOVA	2	1	4	0	0	0	0	1	0	0	0	1	0	0
<i>Hemirobulina eximia</i> (NEUGEBOREN)	1	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Hemirobulina hantkeni</i> (BANDY)	0	0	1	0	0	0	0	0	0	0	0	0	0	0
<i>Heterolepa dutemplei</i> (ORBIGNY)	0	0	0	0	0	0	0	0	1	2	2	0	0	1
<i>Hormosinelloides</i> sp.	0	0	0	0	0	0	0	0	1	0	0	0	0	0
<i>Hyperammina / Rhabdammina</i> sp.	0	0	0	18	12	16	14	19	17	33	28	24	51	34
<i>Hyperammina elongata</i> BRADY	0	1	1	1	2	0	1	1	1	0	1	1	3	1
<i>Hyperammina rugosa</i> VERDENIUS & VAN HINTE	0	1	0	6	3	5	1	3	0	4	2	1	19	15
<i>Hyperammina</i> sp.	2	0	0	0	0	1	0	2	0	0	0	1	0	1
<i>Karrerella bradyi</i> (CUSHMAN)	0	0	0	0	0	0	1	0	0	0	0	0	0	0
<i>Karrerella chilostoma</i> (REUSS)	0	0	0	0	0	0	0	0	2	2	3	5	1	0
<i>Karrerella victoriensis</i> (CUSHMAN)	0	0	0	0	0	0	0	0	0	1	0	0	0	0
<i>Karrerulina apicularis</i> (CUSHMAN)	6	1	1	0	0	0	0	0	1	0	0	0	0	0
<i>Karrerulina conversa</i> (GRZYBOWSKI)	1	1	2	1	0	1	1	0	0	1	0	0	0	0
<i>Laevidentalina boueana</i> (ORBIGNY)	0	2	5	1	1	0	1	0	0	0	1	0	0	0
<i>Laevidentalina elegans</i> (ORBIGNY)	2	1	1	2	2	0	0	1	1	1	2	0	0	0
<i>Laevidentalina inornata</i> (ORBIGNY)	2	1	3	0	0	0	1	1	0	0	1	0	0	0
<i>Lagena</i> sp.	2	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Lagenammina</i> sp.	0	0	0	2	0	0	3	0	0	0	1	0	0	0
<i>Lapugyina schmidi</i> POPESCU	0	0	0	0	1	1	0	2	0	0	0	1	0	0
<i>Lenticulina arcuatostrata</i> (HANTKEN)	5	2	1	1	0	0	0	3	6	4	1	2	0	0
<i>Lenticulina calcar</i> (ORBIGNY)	0	0	0	0	0	0	0	0	0	0	0	2	2	1
<i>Lenticulina cf. crassa</i> (ORBIGNY)	0	0	1	0	0	0	0	0	0	0	0	0	0	0
<i>Lenticulina depauperata</i> (REUSS)	1	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Lenticulina gibba</i> (ORBIGNY)	4	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Lenticulina inornata</i> (ORBIGNY)	2	7	9	3	2	1	1	0	1	1	0	0	0	0
<i>Lenticulina limbosa</i> (REUSS)	1	3	0	0	0	0	0	0	0	0	0	0	1	0
<i>Lenticulina melvilli</i> (CUSHMAN & RENZ)	0	0	1	0	0	0	0	0	0	0	0	0	0	0
<i>Lenticulina olianensis</i> (RUIZ DE GAONA & COLOM)	0	0	0	0	0	2	0	0	0	0	0	0	0	0
<i>Lenticulina</i> sp.	0	4	3	0	3	0	0	4	0	0	3	2	0	1
<i>Lenticulina subpappilosa</i> (NUTTALL)	1	1	0	0	0	0	0	0	0	0	0	0	0	0
<i>Marginulina behmi</i> (REUSS)	0	0	0	0	0	1	0	0	0	0	0	0	0	0
<i>Marginulina hirsuta</i> ORBIGNY	3	4	5	1	0	0	0	0	0	0	0	2	0	0
<i>Martinottiella communis</i> (ORBIGNY)	0	0	0	0	0	1	0	1	0	1	2	1	1	0
<i>Melonis pompilioides</i> (FICHTEL & MOLL)	1	6	3	2	4	3	3	6	2	2	0	2	2	1
<i>Milammina</i> sp.	0	0	1	0	0	0	0	0	0	0	1	0	0	1
<i>Mylostomella advena</i> (CUSHMAN & LAIMING)	0	2	0	0	1	0	0	0	0	0	0	0	0	0
<i>Mylostomella recta</i> (PALMER & BERMUDEZ)	1	0	0	1	0	1	1	0	0	1	1	0	0	0
<i>Neolenticulina peregrina</i> (SCHWAGER)	0	1	0	0	0	0	0	0	0	0	0	0	0	0
<i>Neugeborina longiscata</i> (ORBIGNY)	0	0	1	0	3	0	0	1	1	0	0	1	0	0
<i>Nodosaria rudis</i> ORBIGNY	0	0	0	0	0	0	0	1	0	0	0	0	0	0
<i>Nothia excelsa</i> (GRZYBOWSKI)	0	0	0	0	0	0	0	2	0	0	4	0	4	2
<i>Nothia</i> sp.	1	2	6	3	1	1	2	2	3	2	2	0	6	9
<i>Oridorsalis umbonatus</i> (REUSS)	1	1	0	1	1	0	1	0	1	0	1	5	0	0
<i>Pararotalia</i> sp.	0	0	0	1	0	0	0	0	0	0	0	0	0	0
<i>Percultazonaria fragaria</i> (GÜMBEL)	0	0	0	0	0	0	0	2	0	0	0	0	0	0
<i>Placentamina placenta</i> (GRZYBOWSKI)	1	0	2	1	0	0	0	0	2	1	0	0	2	0
<i>Planularia kubinyi</i> (HANTKEN)	0	0	1	0	0	0	0	0	0	0	0	0	0	0
<i>Popovia johnrolandi</i> (PREECE et al.)	0	1	1	0	0	0	0	0	0	0	0	0	0	0
<i>Popovia</i> sp.	1	1	0	0	0	0	0	0	0	1	1	0	1	0
<i>Praeglobobulimina ovata</i> (ORBIGNY)	0	0	0	0	0	0	0	0	0	2	6	2	1	1
<i>Praeglobobulimina pupoides</i> (ORBIGNY)	11	11	9	12	2	12	9	11	12	5	13	8	6	8
<i>Praeglobobulimina pyrula</i> (ORBIGNY)	1	0	0	0	0	1	0	0	0	0	0	1	0	0
<i>Protobellina vermiculata</i> LUCZKOWSKA	0	2	0	2	0	1	0	0	1	2	1	0	0	0
<i>Psamosiphonella cylindrica</i> (GLAESSNER)	0	0	0	0	0	0	0	0	0	0	0	0	1	0
<i>Psamosphaera fusca</i> SCHULTZE	0	0	0	0	0	0	0	0	1	1	0	2	2	1
<i>Pseudonodosaria inflata</i> (BORNEMANN)	0	0	0	0	0	0	0	0	0	0	1	0	0	0
<i>Pullenia bulloides</i> (ORBIGNY)	2	1	0	0	0	0	0	1	0	0	0	0	0	0
<i>Pullenia salysburii</i> (STEWART & STEWART)	0	2	0	1	0	0	0	0	0	0	0	0	0	0
<i>Pyramidulina catesbyi</i> (ORBIGNY)	0	0	0	0	0	0	0	0	0	0	0	0	1	0
<i>Pyramidulina latejugata</i> (GÜMBEL)	0	1	0	0	0	0	0	0	0	0	3	1	0	0
<i>Recurvoides renzi</i> (ASANO)	0	3	0	0	0	0	0	0	0	0	0	0	0	0
<i>Recurvoides</i> sp.	0	0	0	1	0	1	0	1	1	1	2	2	0	0
<i>Reophax excentricus</i> CUSHMAN	0	0	0	1	0	0	0	0	0	0	0	0	0	0
<i>Reophax pilulifer</i> BRADY	0	0	1	0	0	0	0	0	1	1	0	0	0	0
<i>Reophax scorpiurus</i> MONTFORT	0	0	0	0	0	0	0	0	0	0	0	2	0	0



Foraminiferal counts from the Gălpâia section, Romania	Samples													
	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	G13	G14
Gălpâia species list														
Benthic foraminifera														
<i>Reophax</i> sp.	4	1	1	3	5	4	3	3	5	5	6	4	2	4
<i>Reophax subfusiformis</i> EARLAND	0	0	0	0	0	0	0	0	0	0	0	0	1	0
<i>Reticulophragmium acutidorsatum</i> (HANTKEN)	4	2	3	1	0	1	0	1	0	4	0	2	3	2
<i>Reticulophragmium rotundidorsatum</i> (HANTKEN)	6	3	5	2	0	0	0	0	1	7	3	1	2	1
<i>Reticulophragmium venezuelanum</i> (MAYNC)	10	3	3	2	0	0	0	0	1	7	1	2	0	0
<i>Rhabdammina</i> sp.	2	3	0	0	0	1	0	0	0	1	1	0	4	6
<i>Rhizzamina algaeformis</i> BRADY	0	0	0	0	0	5	0	0	0	1	0	0	1	1
<i>Sabellovoluta humboldti</i> (REUSS)	1	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Saccamina grzybowski</i> (SCHUBERT)	1	1	3	3	3	2	1	0	3	5	5	1	8	4
<i>Saccamina sphaerica</i> BRADY	0	0	0	2	0	1	0	0	0	1	1	0	0	0
<i>Saracenaria</i> sp.	0	1	0	0	1	0	0	0	0	1	0	0	1	0
<i>Scallopstoma ovicula</i> (ORBIGNY)	0	0	0	1	0	0	0	0	0	0	0	0	0	0
<i>Semivulvulina pectinata</i> (REUSS)	0	1	1	1	0	0	2	1	0	0	0	0	0	0
<i>Sigmoilinita tenuis</i> (CZIZEK)	1	0	0	0	1	0	0	0	0	0	0	0	0	0
<i>Sigmoilopsis schlumbergeri</i> (SILVESTRI)	3	0	1	0	0	0	1	0	0	2	0	1	0	0
<i>Sigmoilopsis</i> sp.	0	0	1	1	0	0	0	0	0	0	0	0	0	0
<i>Sigmoilopsis triangularis</i> (POPESCU)	0	0	1	0	0	0	0	0	0	0	0	0	0	0
<i>Siphogenerinoides vasarhelyi</i> (HANTKEN)	0	0	0	0	0	0	0	2	0	0	0	0	0	0
<i>Siphonina reticulata</i> (CZIZEK)	0	0	1	0	0	0	0	1	0	1	0	1	0	0
<i>Siphonodosaria consobrina</i> (ORBIGNY)	1	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Spirorutilus carinatus</i> (ORBIGNY)	2	0	0	0	0	1	0	0	0	0	0	0	0	0
<i>Stilostomella adolphina</i> (ORBIGNY)	1	1	2	1	2	2	1	0	0	0	1	0	1	0
<i>Stilostomella</i> sp.	0	0	0	0	0	0	0	0	0	0	2	0	0	0
<i>Subreophax</i> sp.	1	0	1	0	0	0	0	0	3	1	0	3	1	5
<i>Textularia gramen</i> ORBIGNY	1	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Textularia nussdorfensis</i> ORBIGNY	1	0	1	1	0	0	2	1	0	0	0	0	1	0
<i>Textularia pala</i> CZIZEK	0	0	0	0	1	0	0	0	0	0	0	0	0	0
<i>Textularia</i> sp.	1	0	1	0	0	0	0	0	0	0	0	0	0	0
<i>Trochammina globigeriniformis</i> (PARKER & JONES)	0	0	0	0	0	0	0	0	0	0	0	0	0	1
<i>Trochammina kibleri</i> VENGLINSKYI	3	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Trochammina</i> sp.	0	1	0	1	0	0	0	0	1	2	1	1	1	1
<i>Uvigerina acuminata</i> HOSTIUS	0	3	4	0	0	0	0	0	0	0	0	0	0	0
<i>Uvigerina farinosa</i> HANTKEN	6	2	5	3	0	0	2	3	2	1	0	0	0	0
<i>Uvigerina mantaensis</i> CUSHMAN & EDWARDS	0	2	2	5	1	2	1	0	0	0	0	0	0	0
<i>Uvigerina popescui</i> RÖGL	43	30	23	14	3	4	7	4	16	11	18	40	8	0
<i>Vaginulinopsis</i> sp.	0	0	0	0	0	0	0	0	0	2	0	0	0	0
<i>Valvulina flexilis</i> CUSHMAN & RENZ	0	0	0	0	0	0	0	0	0	0	0	0	0	1
<i>Valvulineria complanata</i> (ORBIGNY)	0	1	0	2	0	0	0	0	0	0	0	0	0	1
<i>Valvulineria palmarealensis</i> (NUTTALL)	0	0	1	1	1	4	4	1	3	1	2	2	0	1
<i>Virgulinitella pertusa</i> (REUSS)	0	0	0	0	0	2	0	0	0	0	0	0	0	0
<i>Vulvulina haeringensis</i> (GÜMBEL)	0	1	1	0	0	0	0	1	1	0	0	0	0	0



Foraminiferal counts from the Gălpâia section, Romania	Samples													
	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10	G11	G12	G13	G14
Gălpâia species list														
Planktonic foraminifera														
<i>Cassigerinella globulosa</i> (EGGER)	0	0	0	0	0	0	1	0	2	0	0	0	0	0
<i>Catapsydrax cf. primitivus</i> (BLOW & BANNER)	0	0	1	4	0	0	0	0	0	0	0	0	0	0
<i>Catapsydrax</i> sp.	0	0	4	0	0	0	0	0	0	0	0	0	0	1
<i>Catapsydrax unicavus</i> BOLLİ et al.	0	0	1	2	0	1	0	3	0	0	0	0	0	0
<i>Globigerina anguliofficialis</i> BLOW	2	3	0	1	4	3	0	1	4	2	7	6	0	1
<i>Globigerina angulisurealis</i> BOLLİ	0	0	0	0	0	0	1	0	0	0	0	3	0	0
<i>Globigerina bulloides</i> ORBIGNY	0	0	0	0	0	0	0	0	0	3	0	0	0	0
<i>Globigerina concinna</i> REUSS	1	0	0	0	0	2	0	0	0	1	0	0	0	2
<i>Globigerina diplostoma</i> REUSS	1	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Globigerina gnaucki</i> BLOW & BANNER	0	0	7	1	3	1	5	5	4	5	0	1	0	3
<i>Globigerina lentiana</i> RÖGL	17	23	20	23	25	8	25	12	9	9	16	14	24	29
<i>Globigerina officinalis</i> SUBBOTINA	8	9	26	31	28	40	19	37	38	15	13	19	15	8
<i>Globigerina ottangiensis</i> RÖGL	9	29	1	4	5	21	4	11	25	49	80	45	26	25
<i>Globigerina ouachitensis</i> HOWE & WALLACE	3	0	8	4	1	6	5	1	7	1	1	1	0	1
<i>Globigerina praebulloides</i> BLOW	19	29	20	15	16	24	26	16	33	61	35	30	56	47
<i>Globigerina</i> sp.	10	16	25	22	31	32	24	13	14	12	13	10	26	40
<i>Globigerina tarchanensis</i> SUBBOTINA & CHUTZIEVA	8	0	0	0	0	0	0	0	1	1	1	1	2	0
<i>Globigerina wagneri</i> RÖGL	0	0	0	0	0	0	0	0	0	1	1	0	0	0
<i>Globigerinella obesa</i> (BOLLİ)	1	0	2	4	1	1	6	2	11	2	0	0	1	0
<i>Globigerinoides altiapturus</i> BOLLİ	0	0	0	0	0	0	0	1	0	0	0	0	0	0
<i>Globigerinoides quadrilobatus</i> (ORBIGNY)	0	0	0	0	0	0	0	1	0	0	0	0	0	0
<i>Globigerinoides trilobus</i> (REUSS)	2	3	0	0	0	0	3	37	0	1	0	1	0	2
<i>Globoquadrina langhiana</i> CITA & GELATI	0	0	1	0	0	1	0	0	0	0	0	1	0	0
<i>Globorotaloides suteri</i> BOLLİ	0	0	0	1	0	0	0	0	0	0	0	0	0	0
<i>Globoturborotalita connecta</i> (JENKINS)	0	0	4	1	2	4	7	25	7	8	9	7	0	11
<i>Globoturborotalita woodi</i> (JENKINS)	1	1	2	0	0	0	2	4	7	21	3	9	4	1
<i>Paragloborotalia mayeri</i> (CUSHMAN & ELLISOR)	1	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Paragloborotalia nana</i> (BOLLİ)	5	2	0	3	1	3	1	1	2	1	4	2	0	0
<i>Paragloborotalia opima</i> (BOLLİ)	2	1	0	0	0	1	0	1	0	0	2	1	1	0
<i>Paragloborotalia pseudocontinosa</i> (JENKINS)	0	1	0	0	0	0	0	0	1	0	1	0	0	0
<i>Paragloborotalia semivera</i> (HORNIBROOK)	0	1	0	0	0	1	0	0	0	0	0	0	0	1
<i>Tenuitella clemenciae</i> (BERMUDEZ)	0	2	2	5	12	5	14	0	3	0	2	3	1	0
<i>Tenuitella gemma</i> (JENKINS)	0	0	1	2	2	1	4	3	0	0	0	0	0	0
<i>Tenuitella liverovskae</i> (BYKOVA)	0	0	0	1	0	0	0	0	0	0	0	0	1	0
<i>Tenuitella</i> sp.	0	0	0	0	4	3	3	0	1	0	0	1	0	0
<i>Tenuitellinata angustumbilicata</i> (BOLLİ)	2	6	1	14	29	15	40	8	12	5	9	11	6	1
<i>Tenuitellinata juvenilis</i> (BOLLİ)	0	0	1	2	3	5	3	1	0	0	3	2	3	3
<i>Tenuitellinata uvula</i> (EHRENBERG)	0	0	0	0	1	0	0	0	2	0	1	0	0	0
<i>Turborotalia euapertura</i> (JENKINS)	0	0	0	0	0	0	0	0	0	1	0	0	0	0
<i>Turborotalia</i> sp.	0	0	0	0	0	0	1	0	0	0	0	0	0	0
<i>Turborotalita quinqueloba</i> (NATLAND)	7	3	1	1	17	23	15	17	26	8	3	7	2	2