

Biostratigraphy and palaeoenvironments of the Eocene deep-water deposits of the Tarcău Nappe (Eastern Carpathians, Romania) based on agglutinated foraminifera and calcareous nannofossil assemblages

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Abstract

The micropalaeontological and sedimentological study of two representative sections from the Tarcău Nappe (Brusturosu stream, External Flysch of the Eastern Carpathians, Romania) provides new biostratigraphical and palaeoenvironmental data on the Eocene deposits. In both sections the foraminiferal assemblages are dominated by agglutinated taxa (*Bathysiphon* sp., *Nothia* spp., *Ammodiscus* spp., *Paratrochamminoides* spp., *Reophax* spp., *Reticulophragmium* spp. etc.); the calcareous benthic taxa are rare, represented by *Laevidentalina* and *Stilostomella*. Except for the M3b morphogroup (flattened irregular forms), all agglutinated foraminifera morphogroups were identified in the studied samples. The assemblages are composed of deep-water agglutinated foraminifera species which belong to the “Flysch-Type Biofacies” characteristic of a bathyal palaeoenvironment. Based on the presence of the calcareous nannofossils *Chiasmolithus grandis*, *Isthmolithus recurvus*, *Chiasmolithus oamaruensis* and *Reticulofenestra reticulata* as well as the foraminiferal species *Psammimopelta gradsteini*, *Reticulophragmium amplexans* and *Saccamminoides carpathicus*, the age of the deposits is assigned to the Bartonian (the BR-1 section) and the Priabonian (the BR-2 section).

INTRODUCTION

A detailed micropalaeontological study (foraminifera and calcareous nannofossil assemblages) was carried out on two representative sections located south of Gura Humorului (Fig. 1) along a tributary stream of the Voroneţ River. The turbidites occurring in the basin of the Voroneţ River are a part of the Tarcău Nappe (Săndulescu, 1984; Bădescu, 2005; Juravle, 2007) and were previously studied by Dicea (1974), Ionesi (1971), Ionesi & Mare (2013), Bojar & Bojar (2013), Mare (2014), and Bindiu & Filipescu (2015). The only existing studies in the vicinity of the studied site (Brusturosu stream) were published by Dicea (1974) and Ionesi (1971). Dicea (1974) described the petrography and the micropalaeontological content of the Paleocene deposits and mentioned the presence of the Eocene Doamna Limestone. More information on lithostratigraphy was given by Ionesi (1971) who mapped the Paleocene to Oligocene deposits on the Brusturosu stream. The current study is the

first attempt to provide palaeoecological, palaeoenvironmental and biostratigraphical data in the area. We focused on the morphogroup composition, diversity, and biostratigraphy of fossil foraminifera and calcareous nannofossils. The investigations are correlated with sedimentological observations in order to gain a clear image of the evolution of the palaeoenvironmental parameters under the influence of sedimentary and organic input.

Location and Geological Setting

The studied sections (Fig. 1) are located on the Brusturosu stream (BR-1: N 47° 29' 37.4", E 25° 52' 23.1"; BR-2: N 47° 29' 24.1", E 25° 52' 08.0") about 5 km south of the Voroneţ Monastery. The Tarcău Nappe exposes Lower Cretaceous to Lower Miocene deposits (Dumitrescu, 1952; Băncilă, 1958; Ionesi, 1971; Săndulescu, 1984; Ştefănescu

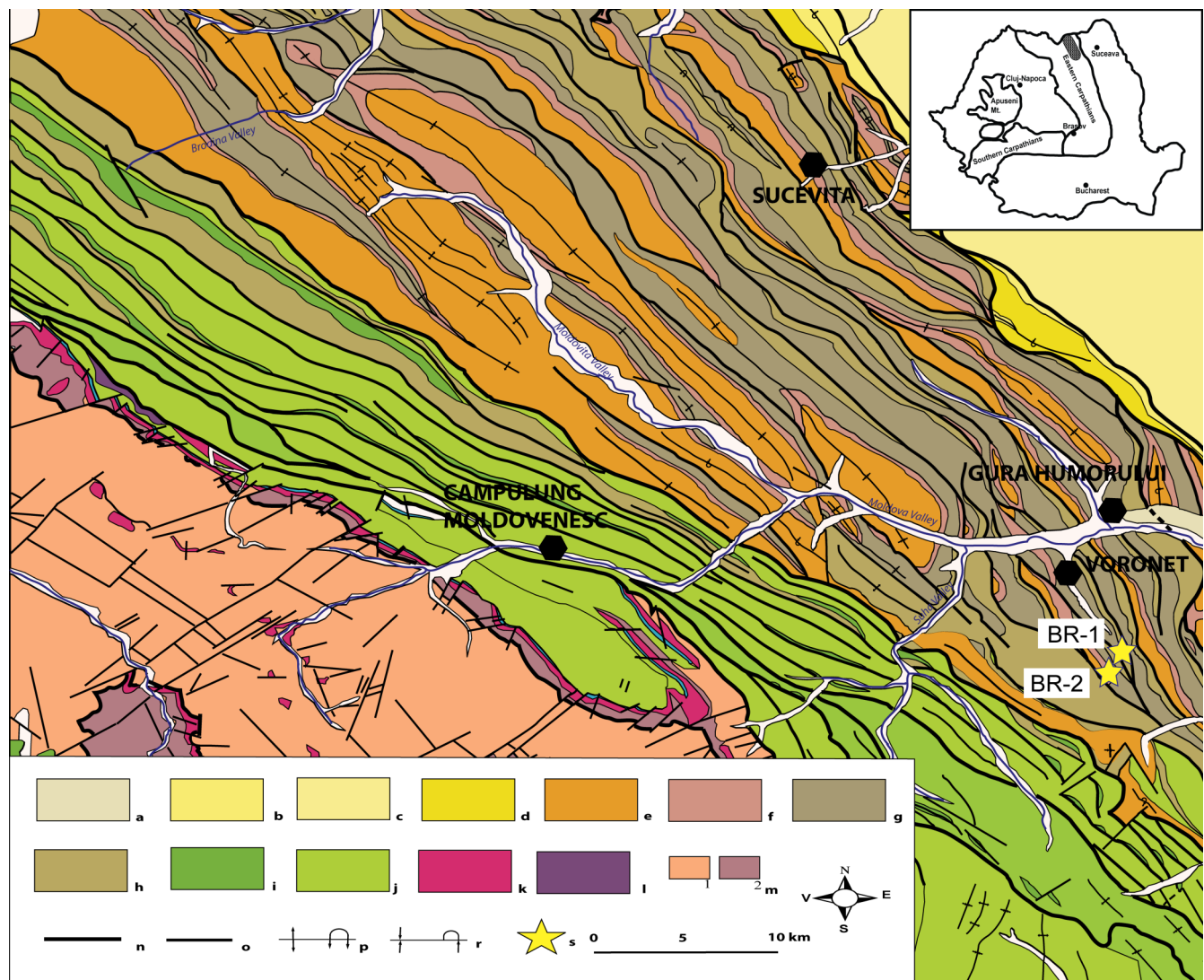


Figure 1. Location of the investigated sections. a: Quaternary, b: Langhian – Serravallian, c: Serravallian – Tortonian, d: Burdigalian, e: Oligocene, f: Upper Eocene, g: Paleocene – Eocene, h: Upper Cretaceous – Paleocene, i: Upper Cretaceous, j: Lower Cretaceous, k: Triassic, l: Mesozoic magmatites, m: Metamorphic rocks (1. phylites and sericite chloritous schists, 2. mica schists and paragneisses) n: faults, o: digitations, p: anticline (symmetrical, overturned), r: syncline (symmetrical, overturned), s: location of the investigated section (after the Geological Map of Romania, 1:200.000, Rădăuți sheet; Joja *et al.*, 1968).

et al., 2006) with vertical and lateral lithofacies variations (Guerrera *et al.*, 2012). According to Ionesi (1971) the deposits in the studied area belong to the Eocene Doamna lithofacies, characterised by fine to coarse turbidites of the Sucevița Formation, covered by the Doamna Limestone and the hemipelagites of the Bisericanî Formations (Athanasiei *et al.*, 1927; Joja *et al.*, 1963; Mutihac & Ionesi, 1974).

MATERIAL AND METHODS

The micropalaeontological content was examined in fifteen samples (seven samples from the BR-1 section and eight samples from the BR-2 section) collected from the fine-grained intercalations of the sections. The standard micropalaeontological methods (Armstrong & Brasier, 2005)

were used for foraminifera: samples were dried (at 93°C), weighed (250g of sediment), boiled in water with sodium carbonate and washed over a 63 µm sieve. All the foraminiferal individuals were picked from the prepared material under a stereomicroscope. The calcareous nannofossil content was studied only from a qualitative point of view using a light microscope (AxioLab A) at 1000x magnification and the photographs have been captured with an AxioCam ERc5s digital microscopy camera. Smear slides were prepared based on the gravity settling technique (Bown & Young, 1998). The biozonations of Martini (1971) and Varol (1998) were used for calcareous nannofossil biostratigraphy.

The palaeoecological interpretations are based on the distribution of agglutinated foraminifera morphogroups, diversity

Table 1. Agglutinated foraminiferal morphogroups (modified after Kaminski, Gradstein and collaborators, 2005; Cetean *et al.*, 2011; Setoyama *et al.*, 2011; 2013).

Morpho-group	Test Form	Environment	Main genera
M1	Tubular	Tranquil bathyal and abyssal with low organic flux	<i>Bathysiphon</i> <i>Kalamopsis</i> <i>Nothia</i> <i>Psammosiphonella</i> <i>Rhizammina</i> <i>Rhabdammina</i>
M2a	Globular	Bathyal and abyssal	<i>Hyperammina</i> <i>Psammosphaera</i> <i>Saccammina</i>
M2b	Rounded trochospiral and streptospiral	Shelf to deep marine	<i>Recurvoides</i>
	Planoconvex trochospiral		Not in this study
M2c	Elongate keeled	Shelf to marginal marine	<i>Spiroplectammina</i>
M3a	Flattened trochospiral	Lagoonal to abyssal	Not in this study
	Flattened planispiral and streptospiral		<i>Ammodiscus</i> <i>Glomospira</i>
M3b	Flattened irregular	Upper bathyal to abyssal	Not in this study
M3c	Flattened streptospiral	Upper bathyal to abyssal	<i>Ammosphaeroidina</i> <i>Paratrochamminoides</i> <i>Trochamminoides</i>
M4a	Rounded planispiral	Inner shelf to upper bathyal	<i>Haplophragmoides</i> <i>Reticulophragmium</i>
M4b	Elongate subcylindrical	Inner shelf to upper bathyal with increased organic matter flux	<i>Karrerulina</i>
	Elongate tapered		<i>Ammobaculites</i> <i>Reophax</i> <i>Subreophax</i>

indices, and sedimentological facies analysis. The morphogroups (Table 1) were separated based on the studies of Jones & Charnock (1985), Nagy *et al.* (1995), Van den Akker *et al.* (2000), Kaminski, Gradstein and collaborators (2005), Båk *et al.* (1997), Peryt *et al.* (2004), Cetean *et al.* (2011), Murray *et al.* (2011), Setoyama *et al.* (2011, 2013), Bindu *et al.* (2013, 2015). The diversity indices (Fisher α , Shannon, Simpson, and Equitability) were calculated by using the computer software PAST - Palaeontological Statistics (Hammer *et al.*, 2002), detailed by Murray (2006), and were drawn by using the Inkscape application (Hiitola, 2012). The abundance graphs of agglutinated foraminifera morphogroups were generated using the GpalWin computer software (Goeury, 1997).

RESULTS

The preservation of foraminiferal individuals varies from moderate to good. A total of 42 species and 17 genera in the BR-1 section and respectively 53 species and 20 genera in the BR-2 section were identified (Appendix 1, Tables 2, 3). The foraminiferal assemblages are dominated by agglutinated forms (*Nothia* spp., *Bathysiphon* spp., *Kalamopsis grzybowski*, *Glomospira* spp., *Paratrochamminoides* spp., *Recurvoides* spp., *Karrerulina* spp., *Reticulophragmium* spp.);

the calcareous benthics are represented by specimens of *Laevidentalina* and *Stilostomella*. The benthic assemblages are more diverse in the hemipelagites of the BR-2 section and less abundant and diverse in the turbidites of the BR-1 section.

Except for the flattened irregular M3b morphogroup (*Ammolagena clavata*) all the agglutinated foraminifera morphogroups defined by Kaminski, Gradstein & collaborators (2005) are present in both sections. The M1 morphogroup is present in high percentages in all samples of the BR-1 section (Fig. 4) and is represented by thick and robust specimens of *Bathysiphon*, *Nothia*, *Psammosiphonella*, *Rhizammina* and *Rhabdammina* (Plate 1). The other morphogroups are less well represented, with a maximum of 13% of the M4a morphogroup (rounded planispiral individuals of *Haplophragmoides* and *Reticulophragmium* – Plates 2, 3) in sample 6. The distribution of agglutinated foraminifera morphogroups varies throughout the BR-2 section (Fig. 5): the values for the M1 morphogroup (*Kalamopsis grzybowski*, *Nothia*, *Bathysiphon*, *Rhizammina*, *Rhabdammina*) are lower compared to the first section being offset by the M2a (globular forms of *Saccammina*, *Psammosphaera* and *Caudammina*), M3a (flattened planispiral and streptospiral *Ammodiscus* and *Glomospira*), M3c (flattened streptospiral

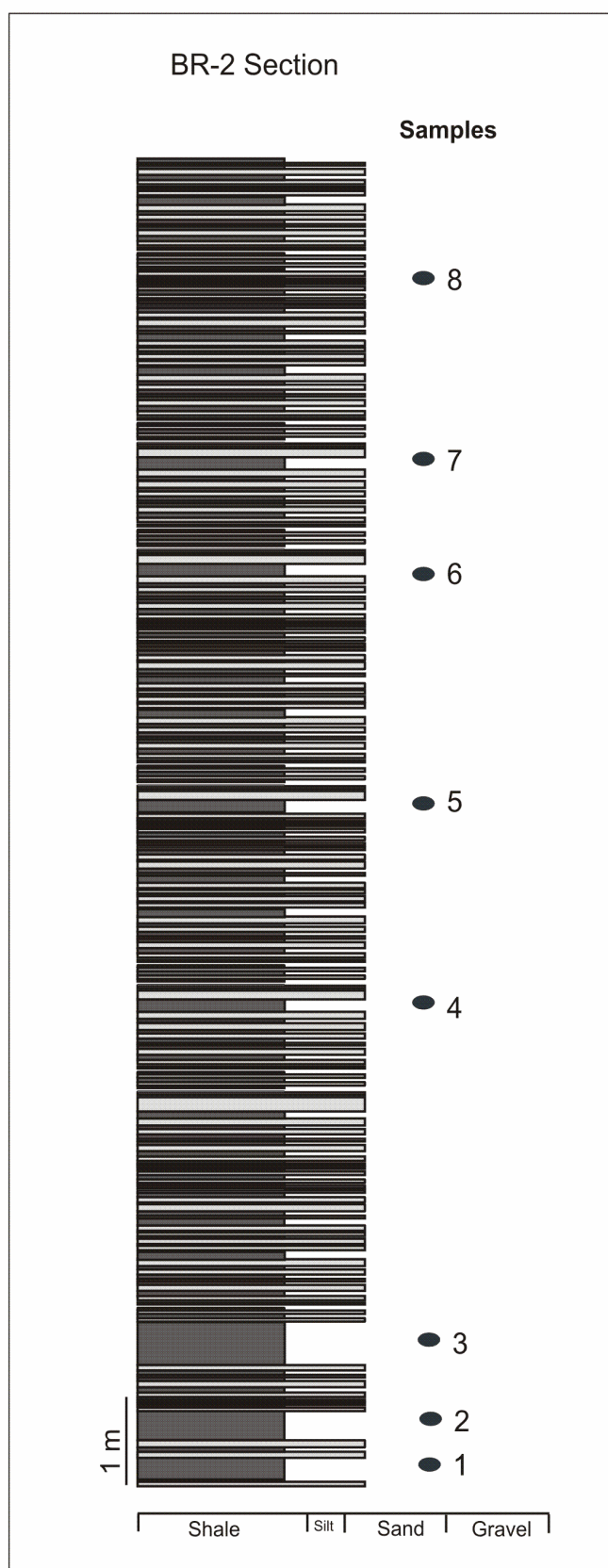
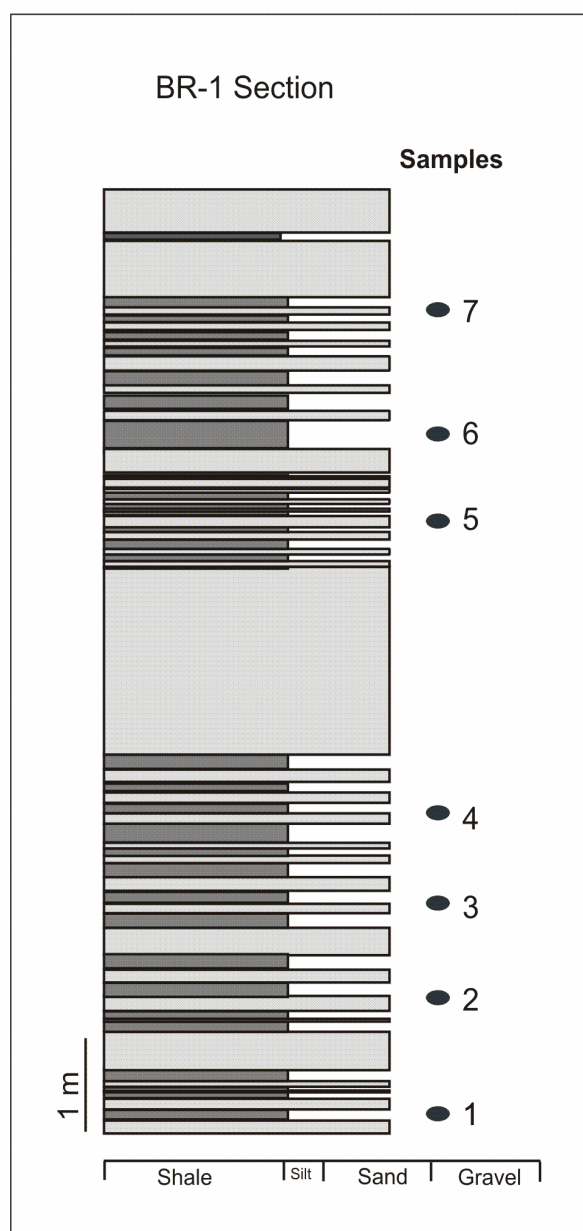


Figure 2. Lithological logs of the studied sections.

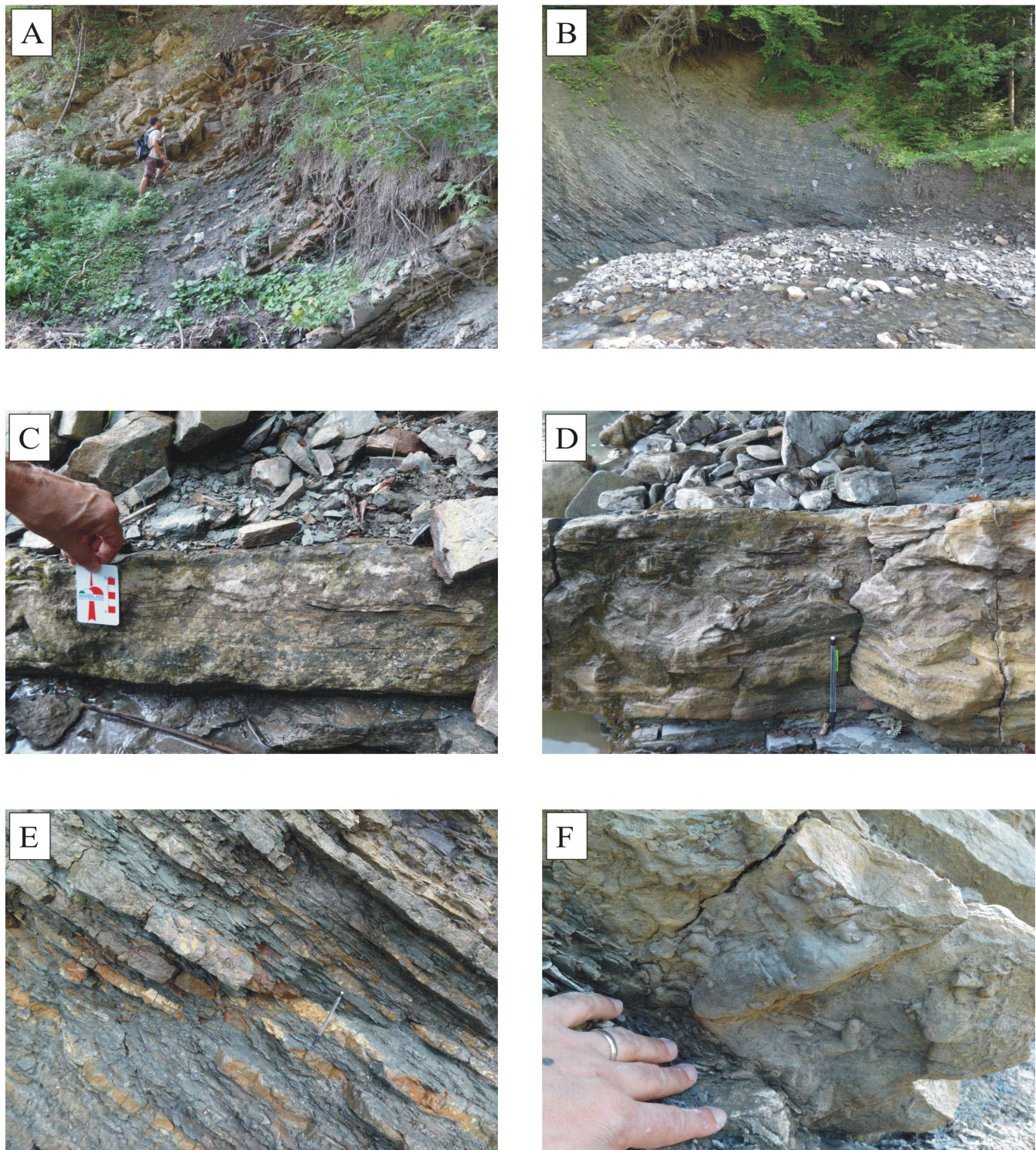


Figure 3. Sedimentological features of the studied sections. A) Overview image of the BR-1 section. B) Overview image of the BR-2 section. C) Climbing ripples in Tc Bouma divisions (BR-1). D) Tb-d Bouma sequence (BR-1). E) Alternating sandstones and shales (BR-2). F) Ichnofossils (BR-2).

Ammosphaeroidina and *Paratrochamminoides*) and M4b (elongate subcylindrical and tapered *Karrerulina* and *Reophax*) morphogroups.

A similar trend can be observed in the diversity indices (Figs. 6, 7), with lower values in the BR-1 section (Fisher α :

4.96-10.24; Shannon: 2.30-2.96; Equitability: 0.79-0.84; Simpson: 0.86-0.92) compared to the values from the BR-2 (Fisher α : 4.36-16.05; Shannon: 2.04-3.54; Equitability: 0.81-0.92; Simpson: 0.80-0.96).

Different calcareous nannofossil assemblages were identi-

Table 2. Distribution of foraminifera in the BR-1 section. R (rare): 1-3 specimens, F (frequent): 4-9 specimens, C (common): 10-29 specimens, A (abundant): 30 or more specimens.

Samples (BR-1 section)	1	2	3	4	5	6	7
Foraminifera							
<i>Ammodiscus cretaceus</i>	0	0	0	F	0	0	0
<i>Ammodiscus glabratus</i>	R	R	F	0	0	0	0
<i>Ammodiscus pennyi</i>	R	0	0	0	R	0	0
<i>Ammodiscus peruvianus</i>	0	R	R	0	0	R	R
<i>Ammodiscus</i> sp.	0	0	R	0	0	R	R
<i>Ammosphaeroidina pseudopauciloculata</i>	R	0	0	0	0	0	0
<i>Bathysiphon microrhaphidus</i>	R	0	F	0	0	0	0
<i>Bathysiphon</i> sp.	C	C	A	C	C	C	A
<i>Glomospira charoides</i>	F	F	F	R	0	R	F
<i>Glomospira diffundens</i>	R	0	0	0	R	0	R
<i>Glomospira glomerata</i>	0	0	R	0	R	0	0
<i>Glomospira irregularis</i>	C	0	R	R	0	0	0
<i>Glomospira serpens</i>	0	0	R	R	R	0	R
<i>Glomospira</i> sp.	0	0	R	0	0	R	F
<i>Haplophragmoides horridus</i>	F	R	0	0	0	0	0
<i>Haplophragmoides</i> sp.	R	0	0	0	R	F	0
<i>Haplophragmoides walteri</i>	0	0	R	0	0	0	0
<i>Hyperammina rugosa</i>	0	0	0	R	0	0	0
<i>Karrerulina coniformis</i>	F	R	R	R	0	R	0
<i>Karrerulina horrida</i>	0	F	0	F	0	R	0
<i>Karrerulina</i> sp.	0	0	0	0	R	R	0
<i>Karrerella</i> sp.	0	0	R	0	0	0	0
<i>Karrerulina conversa</i>	0	0	F	0	0	0	F
<i>Laevidentalina inornata</i>	0	0	0	0	0	F	0
<i>Laevidentalina</i> sp.	0	0	0	0	0	F	0
<i>Lituotuba lituiformis</i>	R	0	0	0	0	0	0
<i>Nothia excelsa</i>	C	A	A	F	A	A	C
<i>Nothia latissima</i>	0	F	R	0	0	0	0
<i>Nothia robusta</i>	0	0	R	0	0	R	0
<i>Nothia</i> sp.	0	0	F	0	0	R	R
<i>Paratrochamminoides acervulatus</i>	0	0	F	0	0	0	0
<i>Paratrochamminoides deflexiformis</i>	0	0	F	0	0	0	0
<i>Paratrochamminoides gorayskii</i>	R	0	0	0	0	0	0
<i>Paratrochamminoides heteromorphus</i>	0	F	0	0	0	0	0
<i>Paratrochamminoides</i> sp.	0	0	F	0	F	R	0
<i>Psammosphaera irregularis</i>	0	0	F	0	0	0	R
<i>Psammosphaera</i> sp.	R	0	0	R	0	0	0
<i>Psammosiphonella cylindrica</i>	F	A	C	C	C	0	C
<i>Psammosiphonella discreta</i>	C	F	C	F	C	0	F
<i>Psammosiphonella</i> sp.	0	0	R	0	0	0	R
<i>Pseudonodosinella elongata</i>	0	0	R	0	0	R	0
<i>Recurvoides anormis</i>	0	0	0	F	0	0	0
<i>Recurvoides</i> sp.	0	F	R	0	R	0	0
<i>Recurvoides walteri</i>	R	R	F	0	F	0	0
<i>Reticulophragmium amplexans</i>	0	0	0	0	0	R	R
<i>Reticulophragmium intermedium</i>	0	0	F	R	0	R	0
<i>Reticulophragmium</i> sp.	R	R	0	0	0	F	0
<i>Rhabdammina linearis</i>	F	F	C	0	C	0	F
<i>Rhabdammina</i> sp.	F	0	F	R	R	0	0
<i>Rhizammina</i> sp.	C	A	C	F	A	0	A

Samples (BR-1 section)	1	2	3	4	5	6	7
Foraminifera							
<i>Saccamina grybowskii</i>	F	F	0	R	F	0	F
<i>Saccamina placenta</i>	0	0	0	0	0	0	C
<i>Saccamina sphaerica</i>	0	0	R	0	0	0	0
<i>Saccaminoides carpathicus</i>	0	0	R	0	0	0	0
<i>Spiroplectamina spectabilis</i>	0	R	0	0	0	0	0
<i>Stilostomella</i> sp.	0	0	F	0	F	0	R
<i>Subreophax scalaris</i>	0	0	0	0	0	R	0
<i>Trochamminoides</i> sp.	0	0	0	0	0	F	0
<i>Trochamminoides subcoronatus</i>	R	0	R	R	0	R	R
<i>Trochamminopsis</i> sp.	0	0	0	R	0	0	0

Table 3. Distribution of foraminifera in the BR-2 section. R (rare): 1-3 specimens, F (frequent): 4-9 specimens, C (common): 10-29 specimens, A (abundant): 30 or more specimens.

Samples (BR-2 section)	1	2	3	4	5	6	7	8
Foraminifera								
<i>Ammobaculites agglutinans</i>	0	0	0	0	0	0	0	R
<i>Ammodiscus pennyi</i>	0	0	0	0	R	0	0	0
<i>Ammodiscus peruvianus</i>	0	0	R	0	0	0	0	0
<i>Ammodiscus</i> sp.	0	0	0	0	0	R	R	0
<i>Ammospaheroidina pseudopauciloculata</i>	0	0	0	F	F	0	0	0
<i>Arthrodendron carpatica</i>	0	0	0	0	F	0	0	F
<i>Arthrodendron grandis</i>	0	R	F	F	R	0	0	0
<i>Arthrodendron</i> sp.	0	R	F	0	R	0	0	R
<i>Bathysiphon</i> sp.	0	0	F	0	F	0	0	C
<i>Bathysiphon microrhaphidus</i>	0	0	0	0	0	0	0	R
<i>Caudamina excelsa</i>	0	R	R	R	0	0	0	0
<i>Caudamina ovuloides</i>	0	0	0	0	0	0	0	F
<i>Caudamina</i> sp.	0	0	0	0	0	0	0	R
<i>Eratidus gerochi</i>	0	0	0	0	0	R	0	R
<i>Glomospira charoides</i>	0	0	0	F	F	0	0	0
<i>Glomospira diffundens</i>	R	0	0	R	R	0	0	F
<i>Glomospira glomerata</i>	R	R	0	F	R	0	R	R
<i>Glomospira irregularis</i>	0	0	0	0	F	0	R	0
<i>Glomospira serpens</i>	0	0	0	0	0	0	R	0
<i>Glomospira</i> sp.	R	F	R	R	C	0	0	F
<i>Haplophragmoides horridus</i>	0	0	0	F	0	0	0	F
<i>Haplophragmoides</i> sp.	0	F	0	F	F	F	R	F
<i>Haplophragmoides walteri</i>	0	0	R	0	F	0	0	0
<i>Hormosina trinidadensis</i>	0	0	0	R	F	0	0	R
<i>Hyperammina rugosa</i>	0	0	F	0	0	0	0	0
<i>Hyperammina dilatata</i>	0	0	0	F	0	0	0	R
<i>Hyperammina</i> sp.	0	0	0	R	0	0	0	R
<i>Kalamopsis grybowskii</i>	0	A	A	C	A	0	A	F
<i>Karrerulina conversa</i>	0	R	0	0	0	R	0	R
<i>Karrerulina horrida</i>	0	C	C	C	F	0	F	C
<i>Karrerulina</i> sp.	0	0	F	0	0	R	R	F
<i>Lituotuba lituiformis</i>	0	0	0	R	R	R	R	R
<i>Laevidentalina inornata</i>	0	0	0	0	0	0	0	0

Samples (BR-2 section)	1	2	3	4	5	6	7	8
Foraminifera								
<i>Laevidentalina</i> sp.	0	R	F	F	0	0	F	0
<i>Nothia excelsa</i>	F	C	C	A	C	C	F	C
<i>Nothia robusta</i>	0	0	0	F	0	F	0	R
<i>Nothia</i> sp.	F	R	0	0	F	F	0	F
<i>Paratrochamminoides acervulatus</i>	0	0	R	R	0	R	0	0
<i>Paratrochamminoides deflexiformis</i>	F	0	R	R	0	C	0	0
<i>Paratrochamminoides gorayskii</i>	0	0	F	0	R	0	0	R
<i>Paratrochamminoides heteromorphus</i>	0	0	R	R	R	R	0	0
<i>Paratrochamminoides olszewskii</i>	0	R	R	0	0	0	0	0
<i>Parathrochamminoides</i> sp.	0	F	R	F	0	F	F	0
<i>Psamminopelta gradsteini</i>	0	0	R	0	0	0	0	R
<i>Psammosiphonella cylindrica</i>	0	0	0	F	0	F	0	0
<i>Psammosiphonella</i> sp.	0	0	0	0	0	R	0	0
<i>Psammosphaera irregularis</i>	0	0	0	0	F	0	0	R
<i>Psammosphaera</i> sp.	0	0	0	0	0	0	0	R
<i>Pseudonodosinella elongata</i>	0	0	0	F	R	R	0	0
<i>Recurvoides anormis</i>	0	0	0	R	0	0	0	0
<i>Recurvoides contortus</i>	R	0	0	0	0	0	0	0
<i>Recurvoides walteri</i>	F	0	F	C	R	0	0	F
<i>Recurvoides</i> sp.	R	F	0	F	R	0	R	F
<i>Reophax duplex</i>	0	0	C	F	C	F	R	C
<i>Reophax globus</i>	0	R	C	F	C	F	0	F
<i>Reophax pilulifer</i>	0	0	0	0	0	A	0	0
<i>Reophax</i> sp.	0	0	0	0	F	0	0	C
<i>Reticulophragmium amplexans</i>	0	0	R	0	0	R	0	0
<i>Reticulophragmium intermedium</i>	0	0	0	0	0	R	0	0
<i>Reticulophragmium</i> sp.	0	R	0	0	0	R	0	R
<i>Rhizammina</i> sp.	F	F	F	C	C	0	F	C
<i>Rhabdammina linearis</i>	0	0	0	C	0	0	0	0
<i>Rhabdammina</i> sp.	0	0	0	0	C	0	0	0
<i>Saccammina grzybowski</i>	C	R	C	F	C	F	F	F
<i>Saccammina placenta</i>	0	C	F	F	C	C	F	C
<i>Saccammina sphaerica</i>	0	0	0	0	R	0	0	0
<i>Sacammmina</i> sp.	0	R	R	0	F	F	0	F
<i>Spiroplectammina spectabilis</i>	0	0	0	R	0	0	0	F
<i>Stilostomella</i> sp.	0	F	F	C	0	0	F	F
<i>Subreophax scalaris</i>	R	0	0	R	0	0	0	R
<i>Trochamminoides grzybowski</i>	0	0	0	0	0	0	0	R
<i>Trochamminoides subcoronatus</i>	0	R	0	F	C	0	F	F
<i>Trochamminoides</i> sp.	0	0	0	F	F	0	R	F
<i>Trochamminoides variolarius</i>	0	R	0	0	0	0	0	0

fied in the two studied sections (cf. Plate 4). The first assemblage (BR-1 section) comprises 32 species with a moderate to poor preservation. An important component of the association is the genus *Discoaster*, but the identification, at the species level, was difficult due to the poor preservation of the diagnostic features. Still, nine *Discoaster*

species, autochthonous and reworked from the Lower Paleogene, have been identified (Appendix 2). Other important groups are represented by the *Reticulofenestra*, *Coccolithus* and *Sphenolithus* species. Rare and continuous occurrences have been observed for *Chiasmolithus* spp., rare and discontinuous occurrences for *Helicosphaera* spp., and very rare

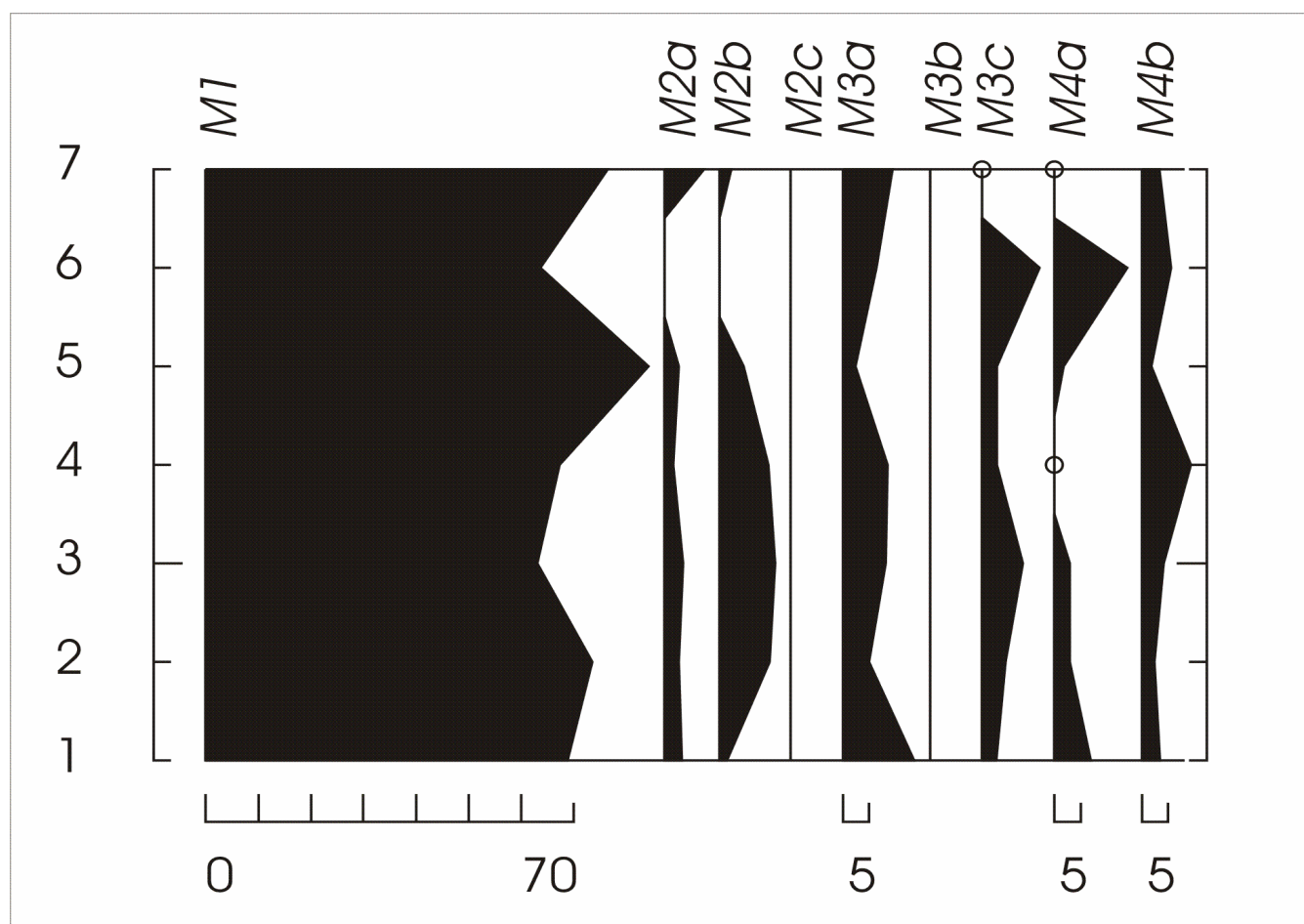


Figure 4. Distribution (in percentages) of agglutinated foraminiferal morphogroups in the BR-1 section (circles represent percentages < 1%).

and discontinuous for *Calcidiscus* spp. and *Pontosphaera* spp.

The calcareous nannofossil assemblage from the BR-2 section contains 23 species, clearly dominated by *Reticulofenestra* spp. (mostly by *R. bisecta*, and *R. umbilicus*). *Coccolithus* spp. is next in terms of abundance and some other species (*Isthmolithus recurvus*, *Pontosphaera* spp., *Sphenolithus* spp.) are present along the entire section but in low percentage. One of the main characteristics of this assemblage is the very rare presence of *Discoaster* spp. (only two small fragments being observed). Reworked specimens (Cretaceous or Lower Paleogene) are present in both studied sections.

Sedimentologically, Ta-e divisions of the Bouma sequence with climbing ripples and sand:shale > 1 were observed on the coarse grained intercalations (sandstones) from the BR-1 section (Fig. 3), which suggests a high sedimentation rate and high energy hydrodynamics. The BR-2 section is characterised by a thickening upward trend, with 1:1 sand/shale ratio, frequent bathyal ichnofossils. The turbiditic sedimen-

tary structures are the lamination of the Td Bouma interval associated with hemipelagic deposits suggesting low energy hydrodynamics (Fig. 3).

DISCUSSION AND INTERPRETATION

By analysing the distribution of agglutinated foraminifera morphogroups a clear dominance of the tubular forms (M1) can be observed in the BR-1 section. The presence of high percentages of this morphogroup (with thick and robust specimens) and the low values of diversity indices suggest a mesotrophic turbiditic bathyal deposition (Kaminski & Kuhnt, 1995) with low organic matter flux (Kaminski, Gradstein and collaborators, 2005; Cetean *et al.*, 2011). Sharp decreases in the abundance of the M1 morphogroup and an increase of the rest of the morphogroups can be observed in samples 3 and 6, probably caused by fluctuations in palaeoenvironmental conditions. This can be also observed in the diversity indices (Fisher α and Shannon), which record at these intervals the highest values in the entire section. The “stressed” environmental conditions, where the only foraminifera able to survive were the tubular ones,

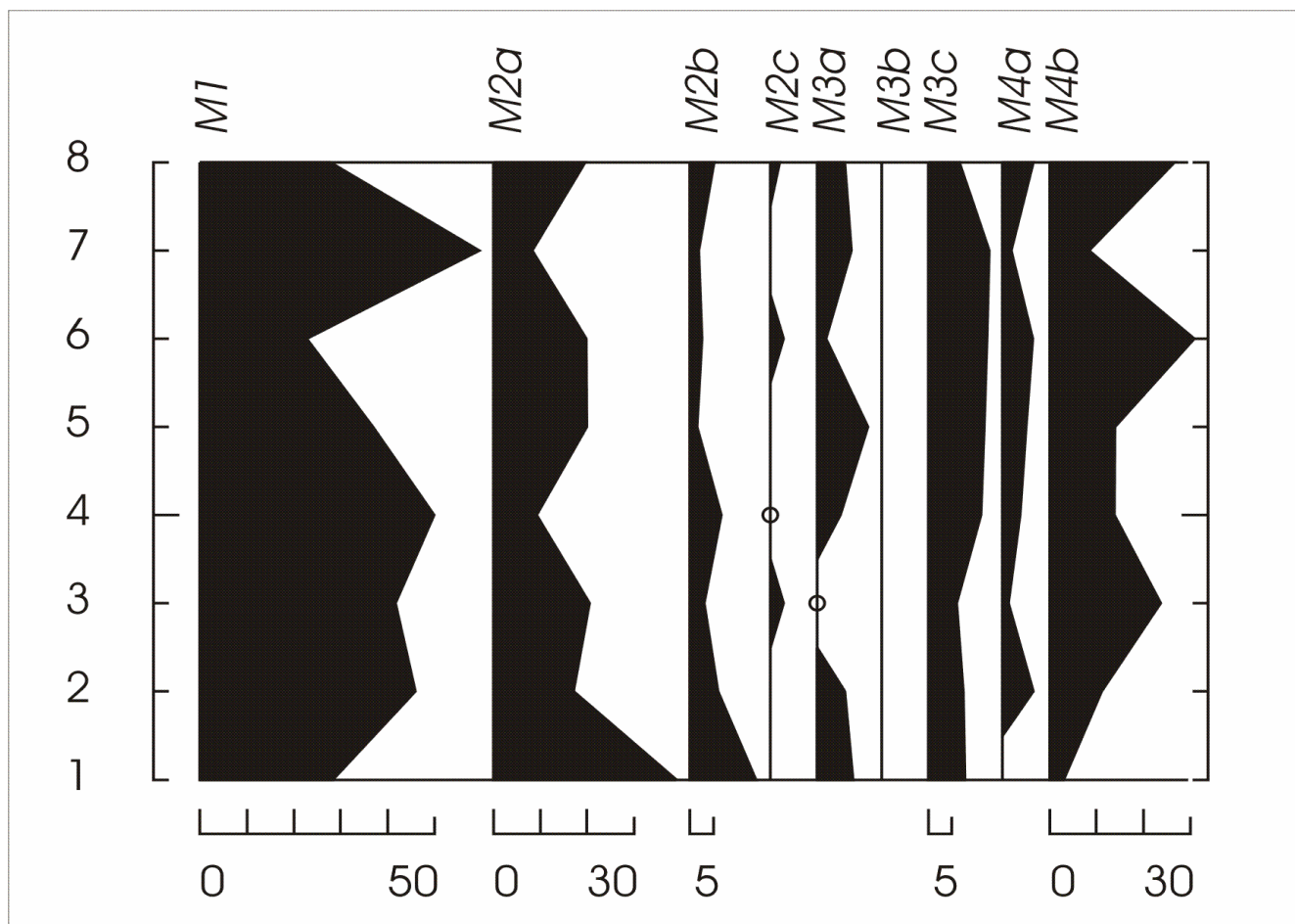


Figure 5. Distribution (in percentages) of agglutinated foraminiferal morphogroups in the BR-2 section (circles represent percentages < 1%).

are also indicated by the sedimentary structures characteristic for the turbiditic deposition with high hydrodynamics. The presence of climbing ripples suggests a high sedimentation rate within the basin.

The presence and/or abundance of some calcareous nanofossil species was also directly controlled by the environmental parameters. Thus, the abundance of *Discoaster* spp. in section BR-1 may be related to warm-waters and oligotrophic conditions (Bukry, 1973; Wei & Wise, 1990; Aubry, 1998; Bralower, 2002; Kahn & Aubry, 2004; Tremolada & Bralower, 2004), deep dwelling environments (Aubry, 1998; Jiang & Wise, 2006), and mid latitudes (Mutterlose *et al.*, 2007).

The foraminiferal assemblages from the BR-2 section are characterised by a higher diversity; the morphogroups have a variable distribution compared to BR-1. It may be noticed that the M1 morphogroup is still well represented; the other morphogroups, especially M2a, M3c and M4b, have a higher presence compared to BR-1 (Fig. 5). A few palaeoecological events are indicated by changes in the proportions of the

M1 and M4b morphogroups. A drop in the relative abundance of M1 and an increase of M4b can be observed in samples 3, 6 and 8 (Fig. 5). As we have already mentioned, the dominance of tubular forms suggests a mesotrophic palaeoenvironment. On the other hand, the M4b morphogroup (deep infaunal taxa) is characteristic in areas with eutrophic conditions (Kaminski, Gradstein and collaborators, 2005). According to Tyszkla *et al.* (2010), the M4a and M2b morphogroups (*Haplophragmoides* and *Recurvoides*) are also known to be adapted to areas with high organic matter flux. By analysing the morphogroup distribution in BR-2 section (Fig. 5) it can be noticed that high abundances of M4b morphogroup are correlating with high abundances of M2a morphogroup (*Saccammina* spp, *Psammospaera* spp.). The predominant individuals of M2a morphogroup (*Saccammina* spp.) was reported to be adapted to low carbonate availability with high capability for dispersal and colonization of abiotic substrates being common on modern productive continental margins (Gooday *et al.*, 2008; Kuhnt & Kaminski, 1993; Giusberti *et al.*, 2016). The frequent oscillations in the distribution of the morphogroups suggest changes in the circulation of bottom waters and the amount

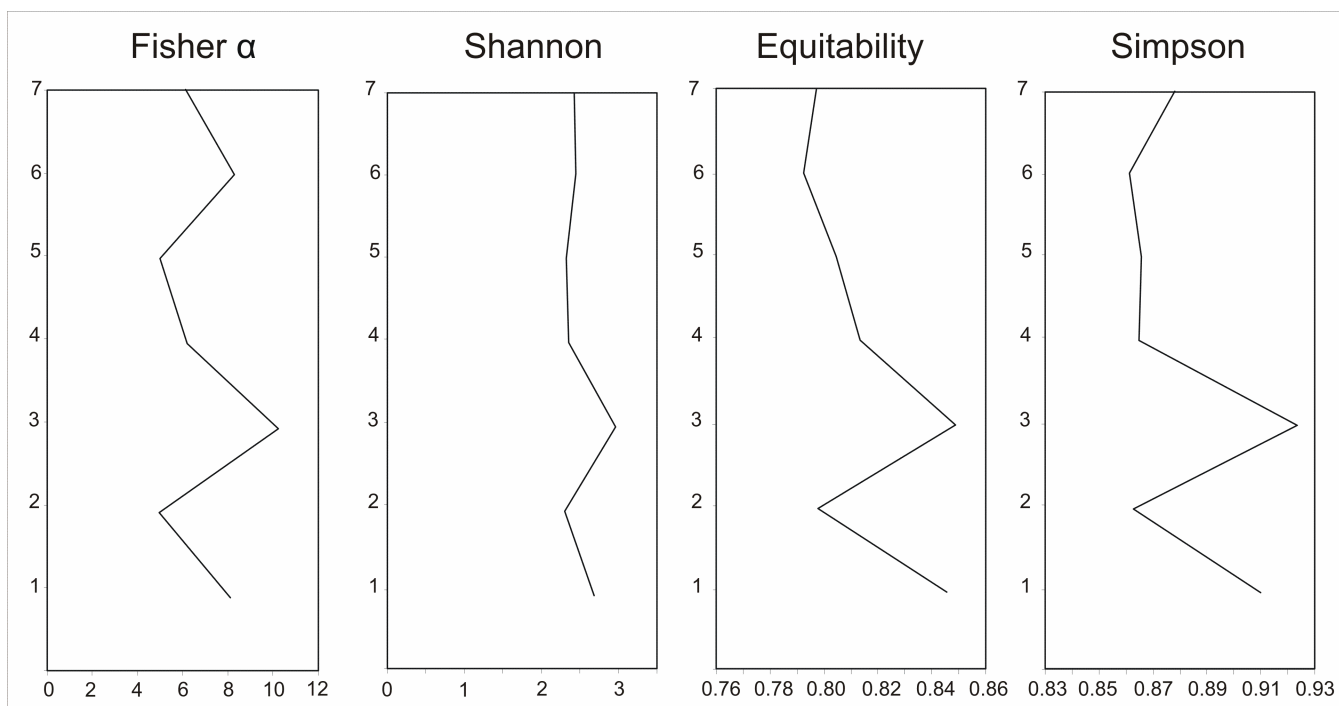


Figure 6. Diversity indices for the BR-1 section.

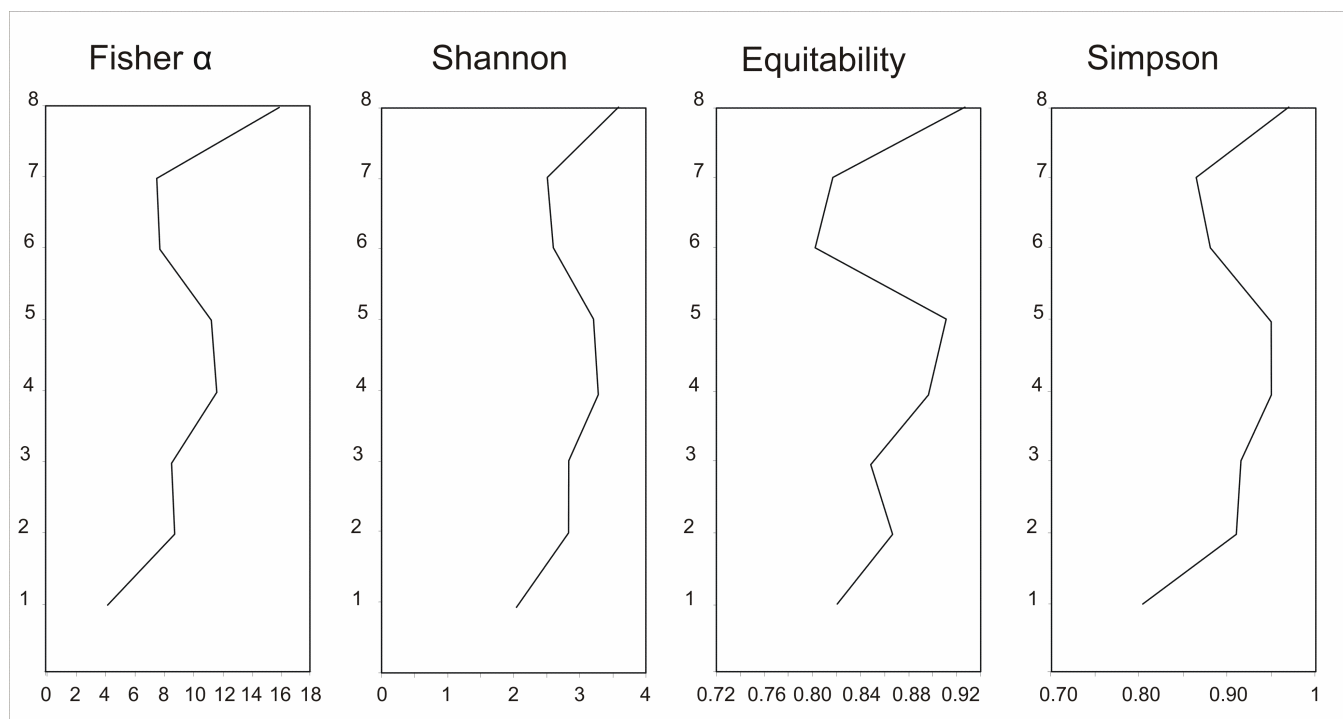


Figure 7. Diversity indices for the BR-2 section.

of organic matter flux. This is supported by the fluctuation of the diversity indices, with high values where the M2a, M4b and M4a morphogroups record high percentages and low values in the rest of the intervals. Overall, the morphogroup analysis and the diversity of foraminiferal assemblages from this section suggest that the bottom water envi-

ronments were mostly eutrophic with a relatively high organic matter flux. The lithology (alternating layers of sandstones and shales with similar thickness), the lack of the complete classic turbidity sedimentary structures, the presence of bathyal ichnofossils and the diverse foraminiferal assemblages suggest a deep water environment that is shal-

lower than in the BR-1 section. The fine intervals are clearly shaley, this suggests slow depositional rates. All these observations point to a eutrophic inter-fan environment in which the turbidity currents were of low-energy, allowing balanced deposition of sands and shales and creating favorable environmental conditions for the foraminiferal assemblages.

The calcareous nannofossil assemblage is in accordance with the foraminifera- and sedimentological facies analysis: the dominance of the *Reticulofenestra* group, suggests an environment with colder and more eutrophic waters (Aubry, 1992), with a higher nutrient supply (Agnini *et al.*, 2006) than in the BR-1 section.

The presence of the tubular robust agglutinated forms (*Bathysiphon*, *Nothia*, *Rhabdammina*, *Psammosiphonella*) together with the coarse grained ones (*Saccamina*, *Psammosphaera*) stands for the “flysch-type” agglutinated foraminiferal biofacies (Kuhnt & Kaminski, 1989, Kuhnt & Kaminski, 1990, Kaminski *et al.*, 1999, Kuhnt, 1990, Kaminski, Gradstein and collaborators, 2005) for both sections, which is characteristic of the Carpathian basins for the Cretaceous to Oligocene interval.

Even if the foraminifera assemblages are dominated by the agglutinated forms typical for the “flysch-type” biofacies, the presence of calcareous nannofossils and low proportions of calcareous benthic foraminifera suggest a bathyal environment close to the Calcite Compensation Depth. Miller *et al.* (1982) analysed similar flysch-type agglutinated assemblages and they argued that this type of assemblages is not restricted only to environments placed below CCD.

Biostratigraphy

The identified agglutinated foraminifera are well represented in both sections but unfortunately most of them have a long stratigraphic range. Still, the presence of the *Psamminopelta gradsteini*, *Reticulophragmium amplexens* and *Saccaminoides carpathicus* taxa in the assemblages allows us to assume that the deposits are not older than Eocene.

Psamminopelta gradsteini is known to be a cosmopolitan deep-water agglutinated species and it was first described with this new name by Kaminski & Geroch (1997). According to Kaminski, Gradstein and collaborators (2005) its stratigraphic range is late middle Eocene to ?Early Miocene. It was found in the upper middle Eocene – lower Oligocene deposits in the southern Labrador Sea (Miller *et al.*, 1982; Kaminski *et al.*, 1989) and in the upper Eocene to Oligocene deposits from the Norwegian-Greenland Sea (Kaminski *et al.*, 1990).

Reticulophragmium amplexens is one of the markers of the Eocene, ranging in the Atlantic and Tethys from the late early Eocene to latest Eocene/earliest Oligocene (Kaminski, Gradstein and collaborators, 2005). This species reaches high abundances in the middle Eocene deposits from the Romanian and Polish Carpathians (Joja *et al.*, 1963; Agheorghiesei *et al.*, 1967; Bratu, 1975; Săndulescu *et al.*, 1987; Geroch & Nowak, 1984). According to Waśkowska (2011) *Saccaminoides carpathicus* first appeared in the early Eocene and persisted until the middle Eocene. This species was reported from the Romanian and Ukrainian Carpathians (Geroch, 1955, Mjatluk, 1970; Olaszewska *et al.*, 1996) and is considered to be endemic for the Carpathian basins.

More precise ages are given by the calcareous nannofossil assemblages. Even though stratigraphically important species are missing in the BR-1 section, the presence of some taxa (e.g., *Chiasmolithus grandis*) and the absence of others (e.g., *Chiasmolithus oamaruensis*, *Helicosphaera bramlettei*) offer the possibility to assign these deposits to the Bartonian (*Discoaster saipanensis* Zone): NNTe11A SZ (Varol, 1998) respectively the base of the NP17 Zone (Martini, 1971).

The age of the deposits from BR-2 is established based on the continuous presence of *Isthmolithus recurvus* together with *Chiasmolithus oamaruensis* and *Reticulofenestra reticulata* and can be outlined as Priabonian. Attribution to a certain biozone is difficult due to the scarce data. Based on the Martini (1971) biozonation scheme the calcareous nannofossils assemblages can be included into the NP19–NP21 Zones. According to Varol (1998) these biozones correspond to the NNTe12–NNTe13 Zones.

CONCLUSIONS

Based on the agglutinated foraminifera, calcareous nannofossils and sedimentological features from the Brusturosu sections, an integrated biostratigraphy and paleoecology was established for the Eocene of the northern Tarcau Nappe (Eastern Carpathians, Romania).

The micropalaeontological assemblages, together with the sedimentological observations, suggest deep-water environments for the studied deposits.

The composition of the foraminiferal assemblages fits the “flysch-type” biofacies characteristic for bathyal palaeoenvironments, probably close to the Calcite Compensation Depth.

The foraminifera and calcareous nannofossils analyses suggest mesotrophic to oligotrophic environments with warm-waters and low organic matter flux for the BR-1 section,

and colder eutrophic environments for the BR-2 section.

Sedimentological and micropalaeontological interpretations indicate that the BR-2 section (Priabonian) represent a shallower environment than BR-1 section (Bartonian).

The foraminifera and calcareous nannofossil assemblages indicate a Bartonian age for the BR-1 section and Priabonian for the BR-2 section. In consequence, the deposits from the BR-1 section belong to the Sucevița Formation, while the BR-2 deposits are assigned to the Bisericanii Formation.

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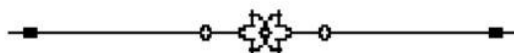
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Appendix 1. List of identified foraminifera taxa

Brusturosu 1 (BR-1)

Ammodiscus cretaceus (Reuss, 1845)
Ammodiscus glabratus Cushman & Jarvis, 1928
Ammodiscus pennyi Cushman & Jarvis, 1928
Ammodiscus peruvianus Berry, 1928
Ammodiscus sp.
Ammospaeroidina pseudopauciloculata (Mjatluk, 1966)
Bathysiphon microrhaphidus Samuel, 1977
Bathysiphon sp.
Glomospira charoides (Jones & Parker, 1860)
Glomospira diffundens Cushman & Renz, 1946
Glomospira glomerata (Grzybowski, 1898)
Glomospira irregularis (Grzybowski, 1898)
Glomospira serpens (Grzybowski, 1898)
Glomospira sp.
Haplophragmoides horridus (Grzybowski, 1901)
Haplophragmoides sp.
Haplophragmoides walteri (Grzybowski, 1898)
Hyperammina rugosa Verdenius & van Hinte, 1983
Karrerella sp.
Karerrulina coniformis (Grzybowski, 1898)
Karerrulina conversa (Grzybowski, 1901)
Karerrulina horrida (Mjatluk, 1970)
Karerrulina sp.
Laevidentalina inornata (d'Orbigny, 1846)
Laevidentalina sp.
Lituotuba lituiformis (Brady, 1879)
Nothia excelsa (Grzybowski, 1898) emend. Geroch & Kaminski, 1992
Nothia latissima (Grzybowski, 1898)
Nothia robusta (Grzybowski, 1898)
Nothia sp.
Paratrochamminoides acervulatus (Grzybowski, 1896)
Paratrochamminoides deflexiformis (Noth, 1912)
Paratrochamminoides gorayskii (Grzybowski, 1898) emend. Kaminski & Geroch, 1993
Paratrochamminoides heteromorphus (Grzybowski, 1898)
Paratrochamminoides sp.
Psammosphaera irregularis (Grzybowski, 1896)
Psammosphaera sp.
Psammosiphonella cylindrica (Glaessner, 1937)
Psammosiphonella discreta (Brady, 1881)
Psammosiphonella sp.
Pseudonodosinella elongata (Grzybowski, 1898)
Recurvoides anormis Mjatluk, 1970
Recurvoides sp.
Reticulophragmium amplexens (Grzybowski, 1898)
Recurvoides walteri (Grzybowski, 1898) emend. Mjatluk, 1970
Reticulophragmium intermedium (Mjatluk, 1970)
Reticulophragmium sp.
Rhabdammina linearis Brady, 1879
Rhabdammina sp.
Rhizammina sp.
Saccammina grzybowskii (Schubert, 1902)
Saccammina placenta (Grzybowski, 1898)
Saccammina sphaerica Brady, 1871
Saccamminoides carpathicus Geroch, 1955
Spiroplectammina spectabilis (Grzybowski, 1898)
Stilostomella sp.
Subreophax scalaris (Grzybowski, 1896)
Trochamminoides sp.
Trochamminoides subcoronatus (Grzybowski, 1896)
Trochamminopsis sp.

Brusturosu 2 (BR-2)

Ammobaculites agglutinans (d'Orbigny, 1846) emend. Bartenstein, 1952
Ammodiscus pennyi Cushman & Jarvis, 1928
Ammodiscus peruvianus Berry, 1928
Ammodiscus sp.

Ammospaeroidina pseudopauciloculata (Mjatluk, 1966)
Arthrodendron carpathica (Neagu, 1964)
Arthrodendron grandis (Grzybowski, 1898)
Arthrodendron sp.
Bathysiphon sp.
Bathysiphon microrhaphidus Samuel, 1977
Caudammina excelsa (Dyląganka, 1923)
Caudammina ovuloides (Grzybowski, 1901)
Caudammina sp.
Glomospira charoides (Jones & Parker, 1860)
Glomospira diffundens Cushman & Renz, 1946
Glomospira glomerata (Grzybowski, 1898)
Glomospira irregularis (Grzybowski, 1898)
Glomospira serpens (Grzybowski, 1898)
Glomospira sp.
Haplophragmoides horridus (Grzybowski, 1901)
Haplophragmoides sp.
Haplophragmoides walteri (Grzybowski, 1898)
Hormosina trinitatis Cushman & Renz, 1946
Hyperammina rugosa Verdenius & van Hinte, 1983
Hyperammina dilatata Grzybowski, 1896
Hyperammina sp.
Kalamopsis grzybowskii (Dyląganka, 1923)
Karerrulina conversa (Grzybowski, 1901)
Karerrulina horrida (Mjatluk, 1970)
Karerrulina sp.
Lituotuba lituiformis (Brady, 1879)
Laevidentalina inornata (d'Orbigny, 1846)
Laevidentalina sp.
Nothia excelsa (Grzybowski, 1898) emend. Geroch & Kaminski, 1992
Nothia robusta (Grzybowski, 1898)
Nothia sp.
Paratrochamminoides acervulatus (Grzybowski, 1896)
Paratrochamminoides deflexiformis (Noth, 1912)
Paratrochamminoides gorayskii (Grzybowski, 1898) emend. Kaminski & Geroch, 1993
Paratrochamminoides heteromorphus (Grzybowski, 1898)
Paratrochamminoides olszewskii (Grzybowski, 1898)
Paratrochamminoides sp.
Psamminopelta gradsteini Kaminski & Gradstein, 1997
Psammosiphonella cylindrica (Glaessner, 1937)
Psammosiphonella sp.
Psammosphaera irregularis (Grzybowski, 1896)
Psammosphaera sp.
Pseudonodosinella elongata (Grzybowski, 1898)
Recurvoides anormis Mjatluk, 1970
Recurvoides contortus Earland, 1933
Recurvoides walteri (Grzybowski, 1898) emend. Mjatluk, 1970
Recurvoides sp.
Reophax duplex Grzybowski, 1896
Reophax globosus Sliter, 1968
Reophax pilulifer Brady, 1884
Reophax sp.
Reticulophragmium amplexens (Grzybowski, 1898)
Reticulophragmium intermedium (Mjatluk, 1970)
Reticulophragmium sp.
Rhizammina sp.
Rhabdammina linearis Brady, 1879
Rhabdammina sp.
Saccammina grzybowskii (Schubert, 1902)
Saccammina placenta (Grzybowski, 1898)
Saccammina sphaerica Brady, 1871
Saccammina sp.
Spiroplectammina spectabilis (Grzybowski, 1898) emend. Kaminski, 1984
Stilostomella sp.
Subreophax scalaris (Grzybowski, 1896)
Trochamminoides grzybowskii Kaminski & Geroch, 1992
Trochamminoides subcoronatus (Grzybowski, 1896)
Trochamminoides sp.
Trochamminoides variolarius (Grzybowski, 1898)

Appendix 2. List of identified calcareous nannofossil taxa

Brusturosu 1 (BR-1)

Calcidiscus sp. Kamptner, 1950

Campilosphaera dela (Bramlette & Sullivan, 1961) Hay & Mohler, 1967

Chiasmolithus sp. Hay *et al.*, 1966

Chiasmolithus grandis (Bramlette & Riedel, 1954) Radomski, 1968

Chiasmolithus nitidus Perch-Nielsen, 1971

Coccolithus eopelagicus (Bramlette & Riedel, 1954) Bramlette & Sullivan, 1961

Coccolithus foraminis Bown, 2005

Coccolithus formosus (Kamptner, 1963) Wise, 1973

Coccolithus pelagicus (Wallich 1877) Schiller, 1930

Cruciplacolithus primus Perch-Nielsen, 1977

Cyclicargolithus floridanus (Roth & Hay, in Hay *et al.*, 1967) Bukry, 1971

Discoaster barbadiensis Tan, 1927

Discoaster binodosus Martini, 1958

Discoaster deflandrei Bramlette & Riedel, 1954

Discoaster distinctus Martini, 1958

Discoaster lodoensis Bramlette & Riedel, 1954

Discoaster saipanensis Bramlette & Riedel, 1954

Discoaster septemradiatus (Klupp 1953) Martini 1958

Discoaster spinescens Bown & Dunkley Jones, 2006

Helicosphaera bramlettei (Müller, 1970) Jafar & Martini, 1975

Helicosphaera lophota (Bramlette & Sullivan, 1961) Locker, 1973

Helicosphaera truempyi Biolzi & Perch-Nielsen, 1982

Neococcolithus minutus (Perch-Nielsen, 1967) Perch-Nielsen, 1971

Pontosphaera plana (Bramlette & Sullivan, 1961) Haq, 1971

Reticulofenestra bisecta (Hay, Mohler & Wade, 1966) Roth, 1970

Reticulofenestra dictyoda (Deflandre in Deflandre & Fert, 1954) Stradner in Stradner & Edwards, 1968

Reticulofenestra scissura Hay, Mohler & Wade (1966)

Sphenolithus sp. Deflandre in Grassé, 1952

Sphenolithus arthurii Bown, 2005

Sphenolithus moriformis (Bronnimann & Stradner, 1960) Bramlette & Wilcoxon, 1967

Sphenolithus orphanknollensis Perch-Nielsen, 1971

Sphenolithus radians Deflandre in Grassé, 1952

Umbilicosphaera bramlettei (Hay & Towe, 1962) Bown *et al.*, 2007

Zigrablithus bijugatus (Deflandre in Deflandre & Fert, 1954) Deflandre, 1959

Brusturosu 2 (BR-2)

Chiasmolithus sp. Hay *et al.*, 1966

Chiasmolithus cf. *oamaruensis* (Deflandre, 1954) Hay *et al.*, 1966

Coccolithus pelagicus (Wallich, 1877) Schiller, 1930

Coccolithus eopelagicus (Bramlette & Riedel, 1954) Bramlette & Sullivan, 1961

Coccolithus foraminis Bown, 2005

Coccolithus formosus (Kamptner, 1963) Wise, 1973

Cyclicargolithus floridanus (Roth & Hay, in Hay *et al.*, 1967) Bukry, 1971

Discoaster sp. Tan, 1927

Discoaster cf. *nodifer* (Bramlette & Riedel, 1954) Bukry, 1973

Helicosphaera sp. Kamptner, 1954

Helicosphaera bramlettei (Müller, 1970) Jafar & Martini, 1975

Isthmolithus recurvus Deflandre in Deflandre & Fert, 1954

Nannotetrina alata (Martini, 1960) Haq & Lohmann, 1976

Pontosphaera exilis (Bramlette & Sullivan, 1961) Romein, 1979

Pontosphaera multipora Kamptner, 1948 ex Deflandre in Deflandre & Fert, 1954) Roth, 1970

Pontosphaera obliquipons (Deflandre in Deflandre & Fert, 1954) Romein, 1979

Reticulofenestra bisecta (Hay, Mohler & Wade, 1966) Roth, 1970

Reticulofenestra callida (Perch-Nielsen, 1971) Bybell, 1975

Reticulofenestra daviesii (Haq, 1968) Haq, 1971

Reticulofenestra dictyoda (Deflandre in Deflandre & Fert, 1954) Stradner in Stradner & Edwards, 1968

Reticulofenestra lockeri Müller, 1970

Reticulofenestra minuta Roth, 1970

Reticulofenestra reticulate (Gartner & Smith, 1967) Roth & Thierstein, 1972

Reticulofenestra umbilicus (Levin, 1965) Martini & Ritzkowski, 1968

Sphenolithus moriformis (Bronnimann & Stradner, 1960)

Bramlette & Wilcoxon, 1967

Sphenolithus radians Deflandre in Grassé, 1952

Cretaceous – reworked species

Arkhangelskiella cymbiformis Vekshina, 1959

Chiastozygus amphipons (Bramlette & Martini, 1964) Gartner, 1968

Chiastozygus bifarius Bukry, 1969

Eiffellithus turreseiffelii (Deflandre in Deflandre & Fert, 1954) Reinhardt, 1965

Macula staurophora (Gardet, 1955) Stradner, 1963

Prediscosphaera cretacea (Arkhangelsky, 1912) Gartner, 1968

Reinhardtites anthophorus (Deflandre, 1959) Perch-Nielsen, 1968

Reinhardtites levis Prins & Sissingh in Sissingh, 1977

Retecapsa crenulata (Bramlette & Martini, 1964) Grün in Grün & Allemann, 1975

Watznaueria barnesia (Black in Black & Barnes, 1959) Perch-Nielsen, 1968

Zeugrhabdotus diplogrammus (Deflandre in Deflandre & Fert, 1954) Burnett in Gale *et al.*, 1996



Plate 1. Agglutinated foraminifera from the studied sections. 1. *Rhabdammina* sp. (BR-1, sample 2); 2. *Bathysiphon* sp. (BR-2, sample 3); 3. *Kalamopsis grzybowskii* (BR-2, sample 5); 4. *Psammosiphonella discreta* (BR-1, sample 2); 5. *Psammosiphonella* sp. (BR-1, sample 2); 6. *Pseudonodosinella elongata* (BR-2, sample 5); 7-9. *Saccamina grzybowskii* (BR-2, sample 2); 10. *Psammosphaera irregularis* (BR-2, sample 2); 11. *Ammodiscus cretaceus* (BR-1, sample 3); 12-13. *Ammodiscus peruvianus* (BR-1, sample 3); 14. *Glomospira* sp. (BR-2, sample 2); 15. *Kalamopsis grzybowskii* (BR-2, sample 2); 16. *Reophax duplex* (BR-2, sample 4)



Plate 2. Agglutinated foraminifera from the studied sections. 1-3. *Reophax pilulifer* (BR-2, samples 3-4); 4. *Hormosina trinitatensis* (BR-2, sample 3); 5. *Saccamminoides carpathicus* (BR-1, sample 3); 6. *Paratrochamminoides deflexiformis* (BR-2, sample 2); 7. *Trochamminoides subcoronatus* (BR-1, sample 5); 8. *Paratrochamminoides* sp. (BR-1, sample 3); 9. *Haplophragmoides walteri* (BR-2, sample 4); 10. *Recurvoides anormis* (BR-2, sample 4); 11. *Recurvoides* sp. (BR-1, sample 2); 12-14. *Spiroplectammina spectabilis* (BR-2, sample 4).

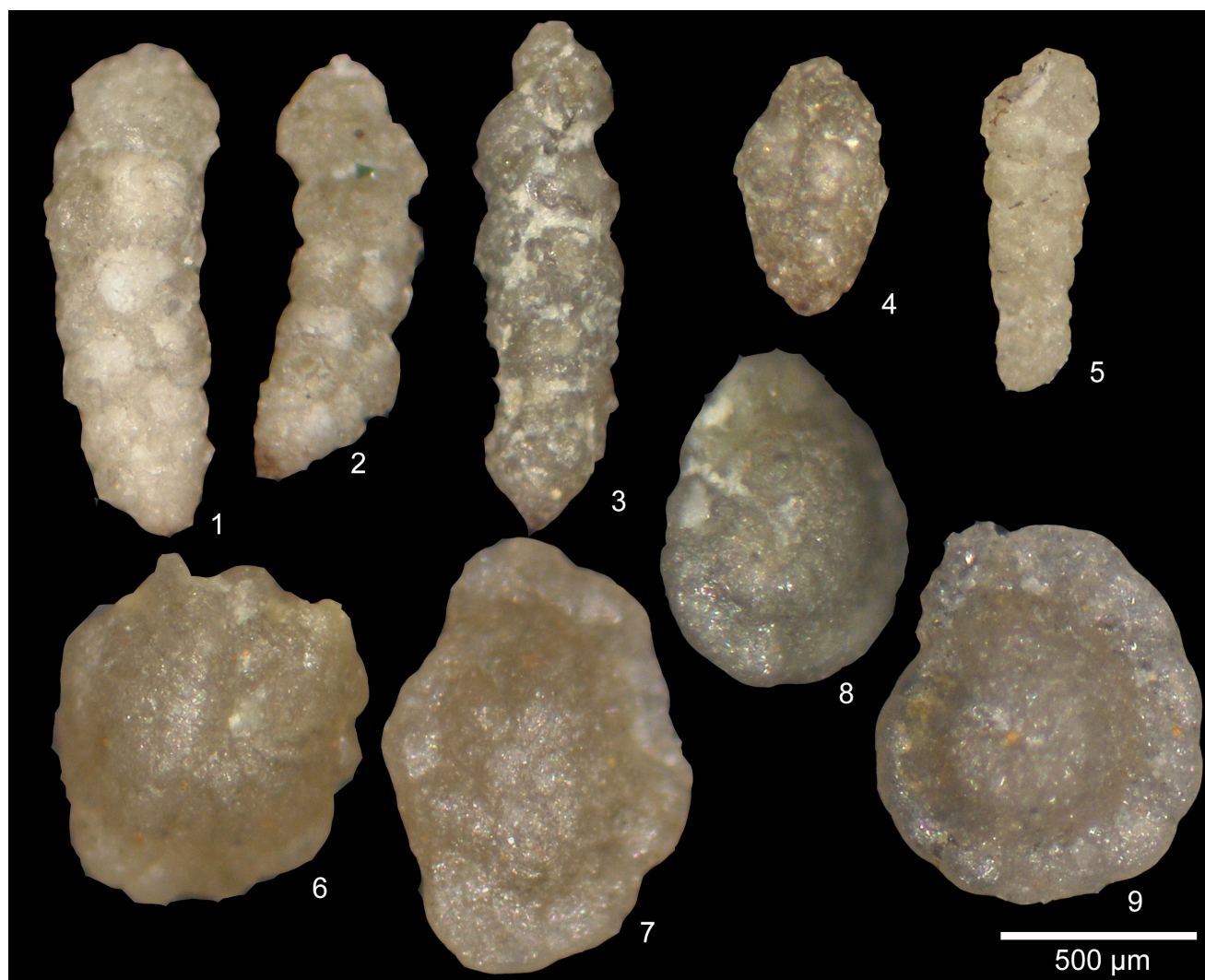


Plate 3. Agglutinated foraminifera from the studied sections. **1.** *Karrerulina conversa* (BR-2, sample 4); **2-3.** *Karrerulina horrida* (BR-2, samples 3-4); **4.** *Karrerulina coniformis* (BR-2, sample 2); **5.** *Karrieriella* sp. (BR-1, sample 3); **6-7.** *Reticulophragmium amplexans* (BR-2, samples 1,2); **8-9.** *Reticulophragmium intermedium* (BR-2, samples 2,3).

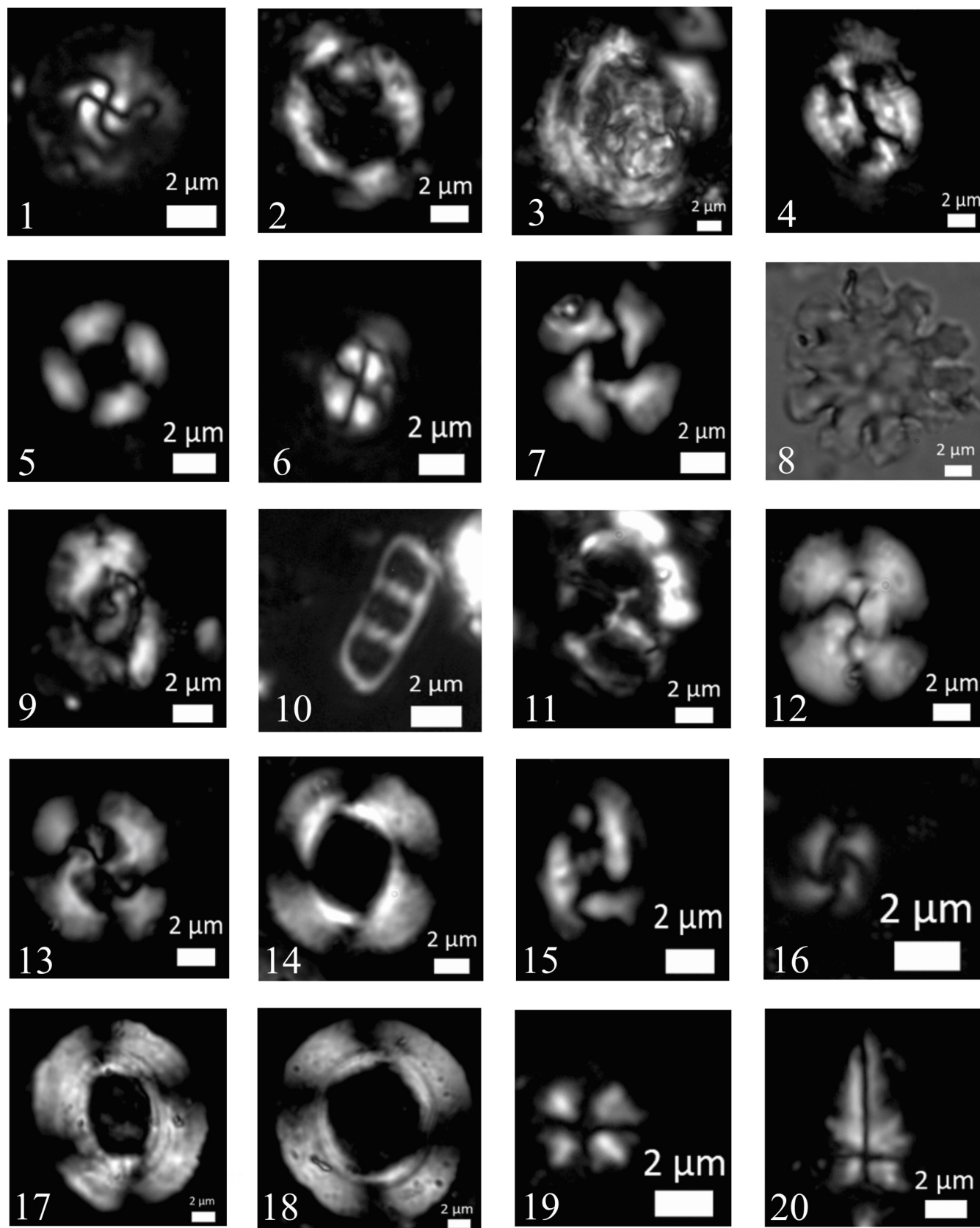


Plate 4. Calcareous nannofossils from the studied sections. **1.** *Calcidiscus* sp. (BR-1, sample 5); **2.** *Chiasmolithus* cf. *oamaruensis* (BR-2, sample 8); **3.** *Chiasmolithus grandis* (BR-1, sample 3); **4.** *Coccolithus eopelagicus* (BR-2, sample 7); **5.** *Coccolithus formosus* (BR-2, sample 1); **6.** *Coccolithus pelagicus* (BR-2, sample 4); **7.** *Cyclicargolithus floridanus* (BR-1, sample 5); **8.** *Discoaster septemradiatus* (BR-1, sample 3); **9.** *Helicosphaera lophota* (BR-1, sample 3); **10.** *Isthmolithus recurvus* (BR-2, sample 2); **11.** *Neococcolithes minimus* (BR-1, sample 3); **12.** *Reticulofenestra bisecta* (BR-2, sample 2); **13.** *Reticulofenestra callida* (BR-2, sample 1); **14.** *Reticulofenestra dictyoda* (BR-2, sample 7); **15.** *Reticulofenestra lockeri* (BR-2, sample 8); **16.** *Reticulofenestra minuta* (BR-2, sample 8); **17-18.** *Reticulofenestra umbilicus* (BR-2, sample 1 and 2); **19.** *Sphenolithus moriformis* (BR-2, sample 1); **20.** *Sphenolithus radians* (BR-2, sample 2).