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Biostratigraphy and paleoenvironment of the Upper Cretaceous deposits in the northern Tarcău Nappe (Eastern Carpathians) based on foraminifera and calcareous nannoplankton

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Abstract: Late Cretaceous foraminiferal and calcareous nannoplankton assemblages from the northern part of the Tarcău Nappe, Hangu Formation in the northern Eastern Carpathians are documented in order to reconstruct paleoenvironmental settings and biostratigraphy. The foraminiferal assemblages are dominated by flysch-type agglutinated taxa suggesting bathyal environments, close to the calcite compensation depth (CCD), and mesotrophic to oligotrophic conditions. The morphogroup analyses display variations in tubular and infaunal morphotypes suggesting different levels of oxygenation and seafloor disturbance caused by currents. Reddish hemipelagites containing only agglutinated foraminifera (dominant infaunal forms) occurring in the middle part of the section suggest an increase of water depth and changes in redox conditions. Based on foraminifera, the deposits were assigned to planktonic *Globotruncana ventricosa* and agglutinated *Caudammina gigantea* Zones. The first occurrence of *Uniplanarius trifidus* and last occurrence of *Reinhardtites anthophorus* demonstrate the presence of Late Campanian $UC15_c^{TP}$–UC16/CC21–CC23 calcareous nannoplankton Zones. Foraminiferal and nannofossil assemblages in the red beds have a high potential for stratigraphic correlation on a regional scale.

Key words: Eastern Carpathians, paleoecology, biostratigraphy, morphogroup analysis, red beds, calcareous nannoplankton, agglutinated foraminifera.

Introduction

During the last decades, the Upper Cretaceous deposits of the Eastern Carpathian flysch in Romania were micropaleontologically studied by Neagu (1970, 1990), Neagu et al. (1992), Ion et al. (1995), Melinte & Bubík (2005), Melinte et al. (2007), Bojar et al. (2009), Bindiu & Filipescu (2011), and Cetean et al. (2011). The Late Santonian to Late Campanian interval was reported as a period of major sea-level fluctuations in the Tethyan area (Lüning et al. 1998; Li et al. 2000; Cetean et al. 2011) and therefore it offers a high potential for identification of stratigraphic events. This offered us a reason to look for new stratigraphic correlation criteria by examining the relationship between micropaleontological assemblages and paleoenvironments in the northern part of the Eastern Carpathians.

The Tarcău Nappe (Joja 1954) of the northern Moldavides (Săndulescu 1984) exposes Upper Cretaceous deposits throughout a relatively large area between the Suceava and Dâmboviţa Valleys (Mutihac & Ionesi 1974). This study focuses on a representative continuous section of Upper Cretaceous bathyal deposits cropping out along the Suceava Valley (N 47.87150°, E 25.39642° — Fig. 1) in order to establish the biostratigraphy and to reconstruct the paleoenvironmental settings based on foraminifera and calcareous nannoplankton assemblages.

Material and methods

The studied section is part of the Hangu Formation (Atanasiu 1939, 1943; Juravle 2007) and consists of medium-grained siliciclastic turbidites with $T_{b\text{-}c}$ (in the lower part of the section) and $T_{c\text{-}e}$ divisions of Bouma sequence (Bouma 1962); very fine-grained hemipelagites occur in the middle and upper part of the section. Twenty one samples for foraminifera and twenty three for calcareous nannofossils were collected from the fine-grained intercalations of the turbiditic sequence (Fig. 2). Sediment samples were processed by standard micropaleontological methods and more than 300 foraminifera were picked from the >63 μm fraction. Primary identification was done under the stereomicroscope, while several specimens were examined in detail with a scanning electron microscope. Paleoecological methods included the analysis of agglutinated foraminiferal morphogroups (Nagy et al. 1995; Van der Akker et al. 2000; Kaminski & Gradstein 2005; Cetean et al. 2011; Murray et al. 2011; Setoyama et al. 2011) and the diversity analysis (Fisher et al. 1943; Murray 2006). The lithological log was drawn using the StratDraw application (Hoelzel 2004), the abundance graphics with GpalWin (Goeury 1997) and the diversity was calculated using the PAST-Paleontological Statistics (Ryan et al. 1995). Tubular species were counted as one individual because fragmentation

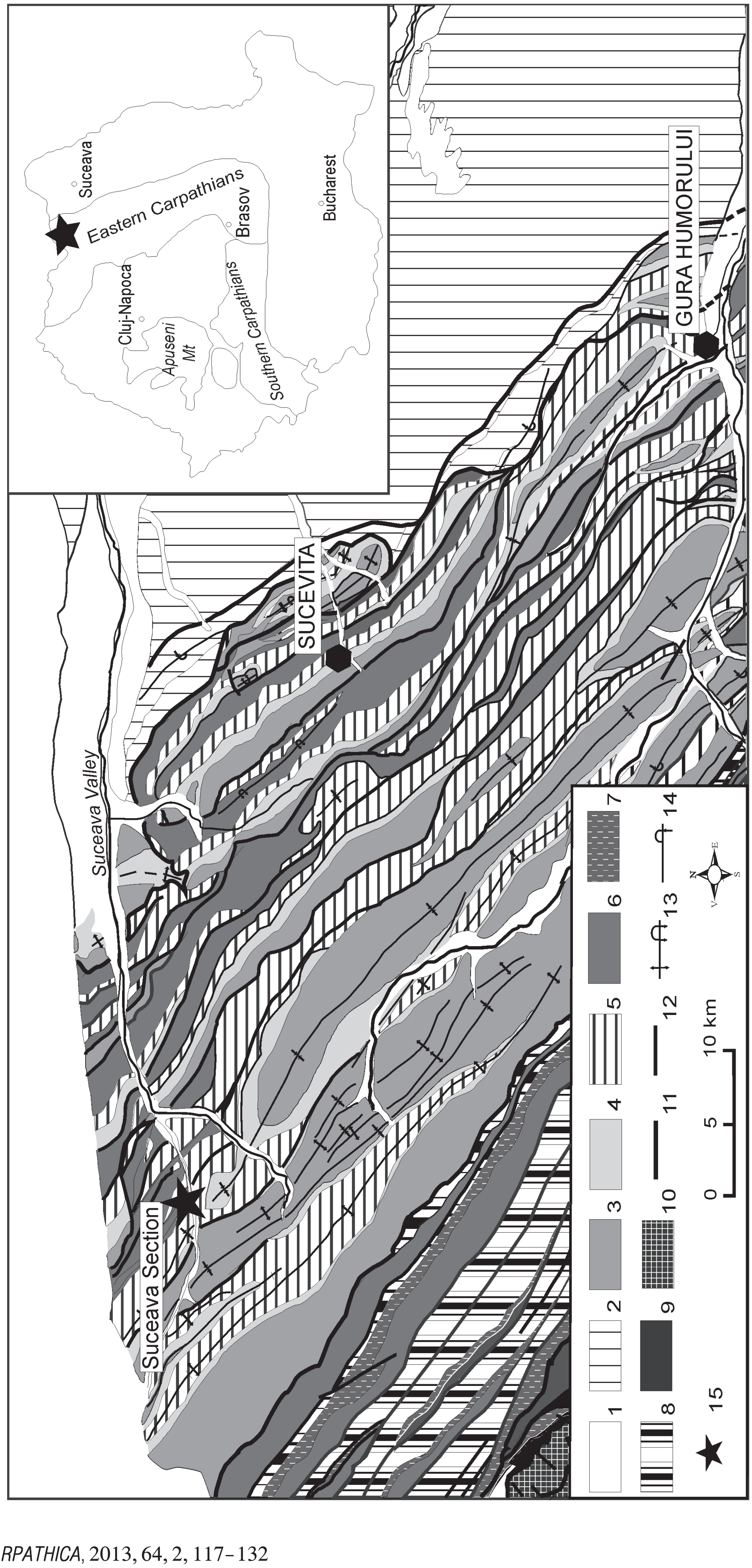

Fig. 1. Location of the investigated sections. **1** — Quaternary, **2** — Miocene, **3** — Oligocene, **4** — Eocene, **5** — Paleocene–Eocene, **6** — Upper Cretaceous–Paleocene, **7** — undivided Cretaceous, **8** — Lower Cretaceous, **9** — Triassic, **10** — Upper Proterozoic–Paleozoic, **11** — front of the nappes thrusting, **12** — faults, **13** — anticline (symmetrical, overturned), **14** — syncline (symmetrical, overturned), **15** — location of the investigated section (modified after the Geological Map of Romania, 1:200,000, Rădăuţi sheet; Joja et al. 1968).

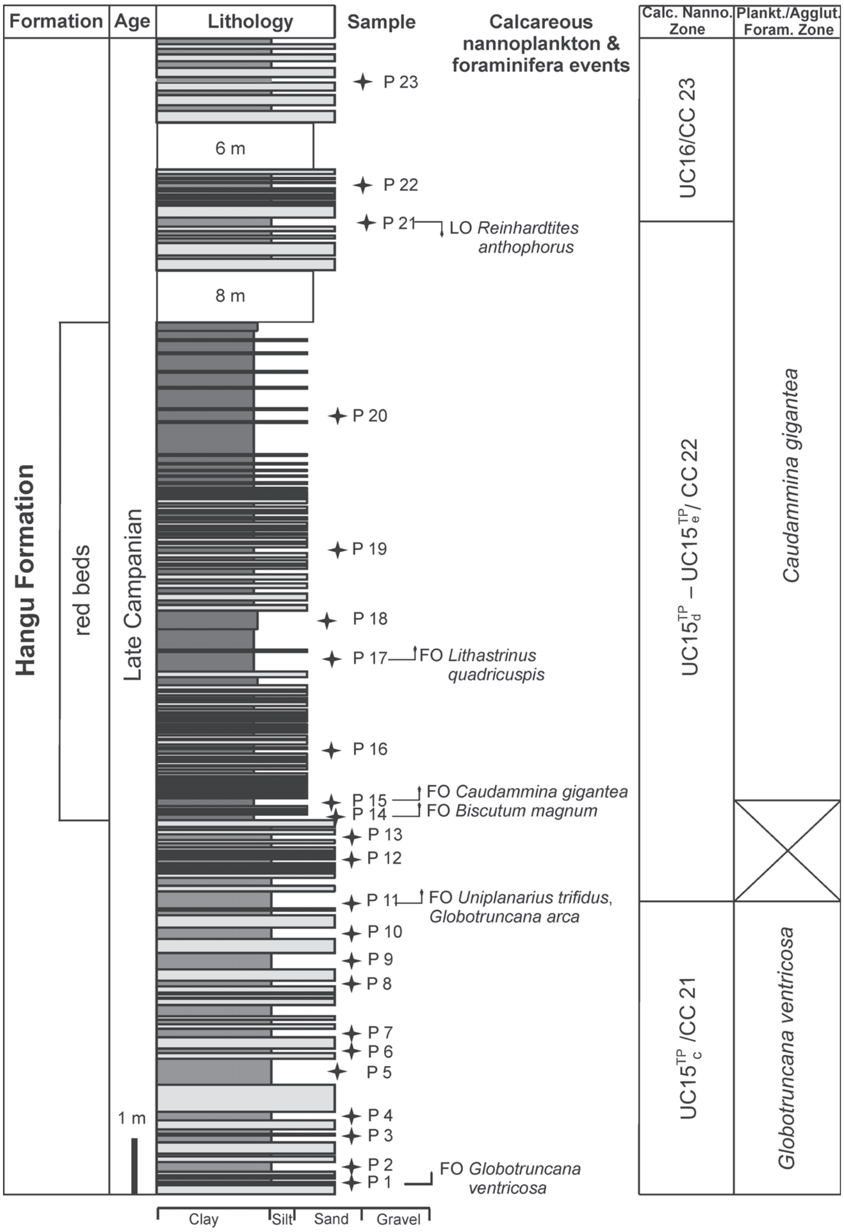

Fig. 2. Sedimentary log and biostratigraphy of the Suceava section.

(mostly observed on relatively rare *Rhizammina* individuals) was considered to have a low influence on the counting. Biostratigraphical interpretations are based on the agglutinated foraminiferal zonation of Cetean et al. (2011) for the Romanian Eastern Carpathians. Additional information was provided by the planktonic foraminifera and calcareous nannoplankton.

The samples studied for calcareous nannofossils were processed using the gravity settling technique (Bown & Young 1998). On every smear slide a minimum of 300 specimens were counted. 1000 fields of view (FOV) were examined from each sample in order to observe biostratigraphical index taxa and rare species. The individual abundance of the observed taxa was assessed as follows: R — rare: < 1 specimen per > 50 fields of view (FOV); F — few: 1 specimen per 2–50 FOV; C — common: 1 to 10 specimens per FOV; A — abundant: > 10 specimens per FOV. Preservation of nannofossils was put into the following categories: M — moderate (overgrowth and etching are present but the specimens are easily identifiable), P — poor (overgrowth and etching is intensive and making identification of some specimens difficult). Relative abundance of nannofossils in each sample: M — moderate (1–5 specimens per FOV), L — low (< 1 specimen per FOV). Zones defined by Burnett (1998) correlated with CC Zones (Sissingh 1977; Perch-Nielsen 1985) were used for biostratigraphic zonation. The taxa were studied at magnifications of ×1000, under a Zeiss Axiolab A light microscope and the photographs were captured with a digital microscopy camera AxioCam ERc5s. All the identified taxa are listed in the Appendices 1, 2.

Results

Types of foraminiferal assemblages

Most samples (except for samples 12 and 18) are rich in foraminifera (Table 1) and the preservation of the individuals varies from moderate to good.

Two different assemblages of foraminifera have been identified in the Suceava section:

- Assemblage A, consisting mostly of agglutinated taxa (60–90 % — *Nothia*, *Bathysiphon*, *Hyperammina*, *Psammosphaera*, *Ammodiscus* — Fig. 4) and subordinately calcareous benthics (1–5 % — *Eponides*, *Chrysalogonium*) and planktonics (*Globotruncana* — especially in samples nos. 4 and 11; Fig. 6) was identified in the basal part of the section (samples 1–14).
- Assemblage B, consisting mostly of agglutinated benthics and rare calcareous benthics; this is preserved in reddish claystones (red beds) located in the middle part of the section and greyish claystones in its upper part (samples 15–23). The following agglutinated genera are present: *Bathysiphon*, *Nothia*, *Rhabdammina*, *Glomospira*, *Paratrochamminoides*, *Recurvoides*, *Karrerullina*, *Caudammina* all having normal sizes (Fig. 5).

Foraminiferal morphogroups

M1 morphogroup (tubular forms represented mainly by specimens of *Nothia*, *Bathysiphon* and *Rhabdammina*) is present in all samples and represents more than 70 % of the assemblage in the basal and upper part of the section.

Table 1: Distribution of foraminifera in the examined samples. **R** — rare, 1–3 specimens; **F** — frequent, 4–9 specimens; **C** — common, 10–29 specimens; **A** — abundant, 30 or more specimens.

Lithostratigraphic unit	**Hangu Formation**																						
Stage	**Upper Campanian**																						
Planktonic foraminiferal Zone	***Globotruncana ventricosa***																						
Agglutinated foraminiferal Zone															***Caudammina gigantea***								
Sample	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Agglutinated foraminifera																							
Ammobaculites sp.																F			F				
Ammodiscus cretaceus	R		F	C	R	F	R	F					R	R		F	C		F	R	R	F	R
Ammodiscus glabratus				R	R	R	F	R			R		R	R		R	R					R	
Ammodiscus peruvianus	R	R	R	R	R	R	F	F	F	R	R		F	R	R	F	F		F	R		R	R
Ammodiscus tenuissimus			F	R				R		F	R		F	R	R	F	C		F		R		R
Ammosphaeroidina pseudopauciloculata		R	F	F	F	F	F	C	R		R		C	R		F	C		F	F	F	R	C
Arthrodendron grandis				R		R				R			R	F			R						
Bathysiphon sp.	C	A	A	C	C	A	A	A	C	C	C		A	C	A	C	A		C	C	C	A	A
Caudammina ovula		R	R	R	F	F	R	R		R	R		C	R	R	F	F		C	R		R	R
Caudammina ovuloides			R		R								R	R		R	F		R	R			
Caudammina gigantea															F	R	R				R		F
Conglophragmium irregularis				F									F	F		F	C		R	F	R	R	
Cribrostomoides subglobosus													R										
Cribrostomoides sp.													F										
Glomospira charoides								R	R					R			F						
Glomospira gordialis			R	R	F	R	R	F									F						
Glomospira irregularis								R															
Glomospira serpens						R		R															
Glomospira sp.							R						R	R	R	R	F		R	R	R		R
Haplophragmoides kirki	R							R															
Hormosina trinitatensis			R	F																			
Hormosina velascoensis		R				F	F	F		C	R		R	F		F	C		R	R			
Hormosinella distans								R		R	R		R	R		R	F		R	R	R		
Hyperammina dilatata																			R				
Hyperammina elongata	F		R	R	R	R	R	R	R				F		R	R	F		R	R	R		R
Hyperammina granulosa	F	R		R																			
Hyperammina rugosa	R				F	R	R	R		C	F		C	C	F	C	C		C	C	R	F	R
Hyperammina sp.		C						C	C														
Kalamopsis grzybowski								R		R				R			R		R		F	R	R
Karrerulina conversa													F				F						
Karrerulina horrida		R	C	F	C	R	C	C	F	C			A		R	A	A		A		C	R	R
Karrerulina sp.	R																						
Lituotuba lituiformis	R				R	R	R	R								R	R		R		R	R	
Nothia excelsa	A	A	A	A	A	A	A	A	A	A	A		A	A	A	A	A		A	A	A	A	A
Nothia latissima	C	C	C	R	R	R	C	C	C	R	R		R	R			R		R	R	R	R	
Nothia robusta		R		R		R											F				R	R	
Paratrochamminoides gorayskii				R													R						
Paratrochamminoides heteromorphus	A		R				R	R			R		F	C	R	F	F		F	F	R	R	R
Paratrochamminoides mitratus										R				R			F		R	R	R	R	
Paratrochamminoides olszewskii	R		R											R			R		F		R		
Psammosiphonella cilindrica			F	C	C	C	C	C	A	A	F		C	C	F	F	F		C	C	R	R	
Psammosiphonella discreta					R		R						R				R				R		R
Psammosphaera fusca	R								R														
Psammosphaera irregularis	C	C	F	F	C	C	F	C		C	F		F	F	F	F	C		F	F	C	R	R
Rectoprotomarssonella rugosa						R		R	R					R		F			F			R	R
Recurvoides anormis		F			C	R	C	C	R	C	C		A	C	F	A	A		A	C	R	F	R
Recurvoides sp.																						F	
Reophax duplex	R	R		R	R	R		F		R	R			R		F	F		R	R	R		
Reophax globosus	R	R		R	F					R	F		F	F	R	F	F		R	F	F		
Reophax pilulifer								R		R	R					R			R				
Reophax subfusiformis			F	R				R							R				R	R		R	
Reophax sp.																				R			
Rhabdammina linearis	F	R	R	F		R	R		R	R			F	R	R	F	R		R	R	R	R	R
Rhabdammina sp.	R	C	F								F			A					A	A	C	C	A
Rhizammina sp.	C	C	C	R			C	A			F			A	R	C	A		C	A	A	A	C
Rzehakina epigona				R					R												R		
Rzehakina lata		R																					
Saccammina grzybowski	R	F	F	R	R		R				R		R	F	R		F			R			R
Saccammina placenta		R	F	C	F	F	C	C	F	C	F		F	F	R	F	A		R	F	R	R	R
Spiroplectammina sp.														R									
Spiroplectinella dentata						R				R				R			F		R		F	R	R
Subreophax pseudoscalaris							R																
Subreophax scalaris			R		R	F	R	R		R	R		R	R			R		R	R			R
Trochamminoides dubius													R	R		R	C		R				R
Trochamminoides proteus				F													R						
Trochamminoides subcoronatus					R											R	F		R	F			R
Trochamminoides variolarius						F	F	A					F	F		C	C		F	C	F	R	F

Continued on the next page.

Table 1: *Continued.*

Lithostratigraphic unit	**Hangu Formation**																						
Stage	**Upper Campanian**																						
Planktonic foraminifera Zone	***Globotruncana ventricosa***																						
Agglutinated foraminifera Zone															***Caudammina gigantea***								
Sample	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Calcareous benthic foraminifera																							
Chrysalogonium elongatum							R			R	F				R								R
Cibicidoides velascoensis								R	R														
Eponides praemegastomus						F	F	R	F	R	F		F	F	R		F		R	R			
Stillostomella sp.													R										
Planktonic foraminifera																							
Contusotruncana fornicata				R																			
Globotruncana angulata				R																			
Globotruncana arca											C												
Globotruncana bulloides											C												
Globotrunana concavata				R																			
Globotruncana elevata	R																						
Globotruncana orientalis								R															
Globotruncana stuartiformis											F												
Globotruncana ventricosa	R		F	A	F			C	F		R												
Globotruncana sp.				C	C	R		F															

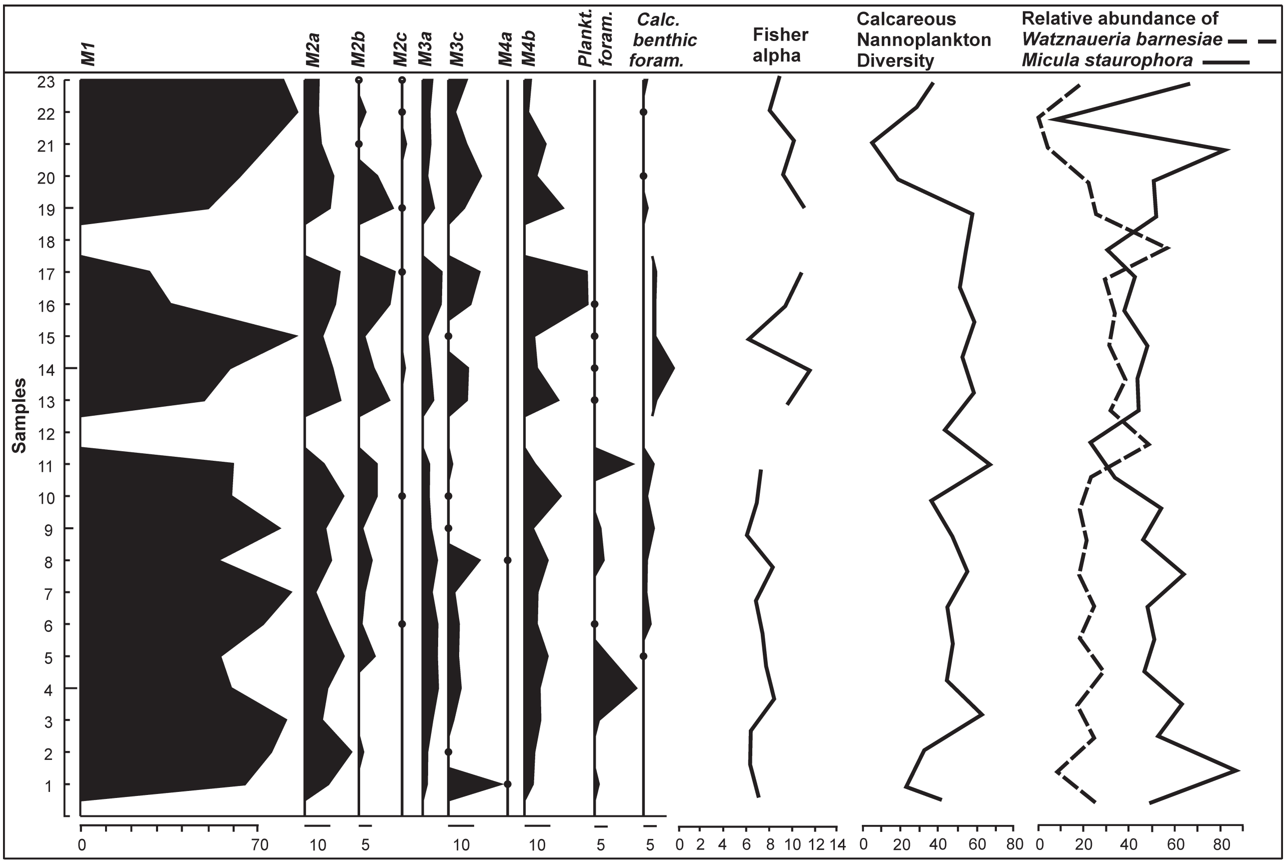

Fig. 3. Agglutinated foraminifera morphotypes (M1 — tubular; M2a — globular; M2b — rounded trochospiral and streptospiral/planconvex trochospiral; M2c — elongate keeled; M3a — flattened trochospiral/flattened planispiral and streptospiral; M3c — flattened streptospiral; M4a — rounded planispiral; M4b — elongate subcylindrical/elongate tapered), planktonic foraminifera, calcareous benthic foraminifera, diversity (Fisher alpha), and relative abundance (% of the assemblage) of two nannofosil taxa *Watznaueria barnesiae* and *Micula staurophora*.

A decrease in the relative abundance of M1 and an increase of M4b (infaunal forms of *Karrerulina*, *Reophax*, *Subreophax*) were observed in the red beds. The other morphogroups are present in relatively low proportions, never dominate the assemblages and are relatively uniformly distributed along the section (Fig. 3).

Diversity of foraminifera

The diversity of benthic foraminiferal species is highly variable along the studied section (Fig. 3). The high relative abundance of tubular forms can be correlated with low values of the alpha index. The diversity increases towards the

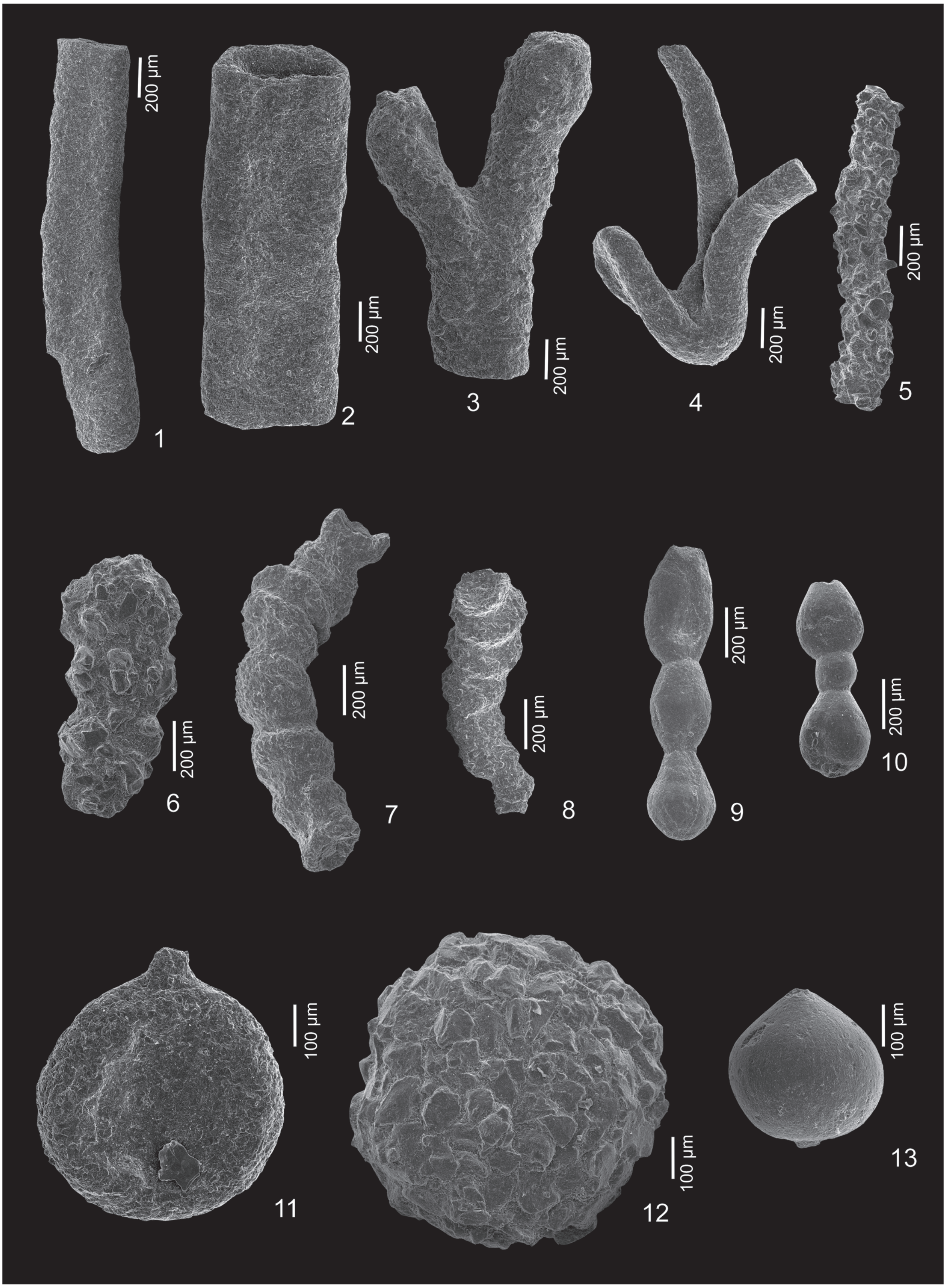

Fig. 4. Agglutinated foraminifera from the Suceava Valley section. **1** — *Nothia excelsa* (Grzybowski, 1898) emend. Geroch & Kaminski, 1992; Sample 2. **2** — *Nothia excelsa* (Grzybowski, 1898) emend. Geroch & Kaminski, 1992; Sample 6. **3** — *Nothia excelsa* (Grzybowski, 1898) emend. Geroch & Kaminski, 1992; Sample 13. **4** — *Rhizammina indivisa* Brady, 1884; Sample 5. **5** — *Rhizammina* sp.; Sample 11. **6** — *Reophax globosus* Sliter, 1968; Sample 13. **7, 8** — *Subreophax scalaris* (Grzybowski, 1896); Sample 6. **9, 10** — *Hormosina velascoensis* (Cushman, 1926); Sample 4. **11** — *Saccammina placenta* (Grzybowski, 1898) emend. Geroch, 1960; Sample 11. **12** — *Psammosphaera irregularis* (Grzybowski, 1896) emend. Liszka & Liszkowa, 1981; Sample 4. **13** — *Caudammina ovula* (Grzybowski, 1896); Sample 2.

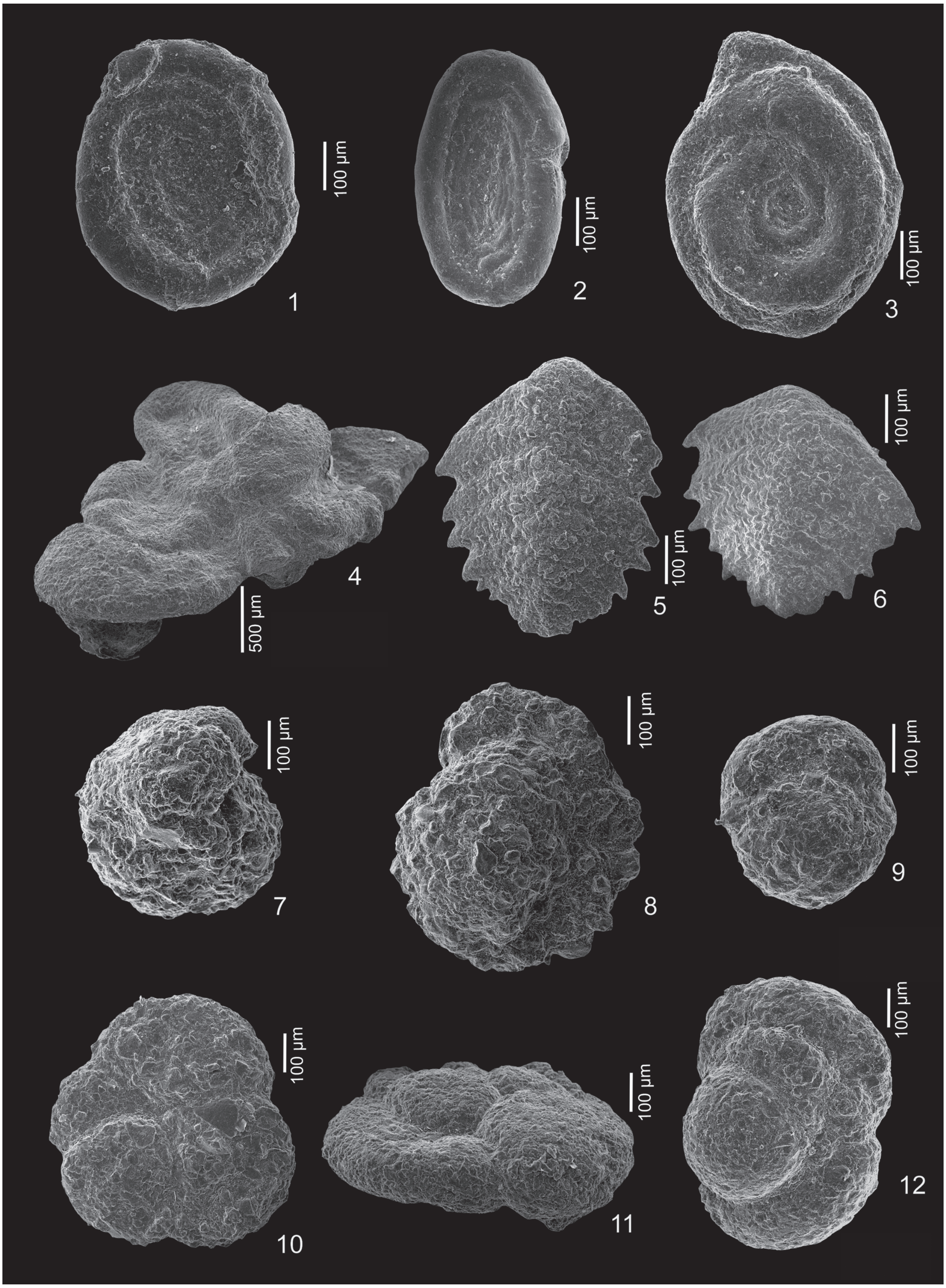

Fig. 5. Agglutinated foraminifera from the Suceava Valley section. **1** — *Ammodiscus cretaceus* (Reuss, 1845); Sample 2. **2** — *Ammodiscus peruvianus* Berry, 1928; Sample 13. **3** — *Glomospira gordialis* (Jones & Parker, 1860); Sample 22. **4** — *Glomospira irregularis* (Grzybowski, 1898); Sample 22. **5, 6** — *Spiroplectinella dentata* (Alth, 1850); Sample 4. **7** — *Recurvoides* sp.; Sample 3. **8, 9** — *Recurvoides anormis* Mjatliuk, 1970; Sample 16. **10** — *Portatrochammina profunda* Kender, Kaminski & Jones, 2007; Sample 22. **11** — *Haplophragmoides* sp. 1.; Sample 22. **12** — *Haplophragmoides* sp. 2.; Sample 23.

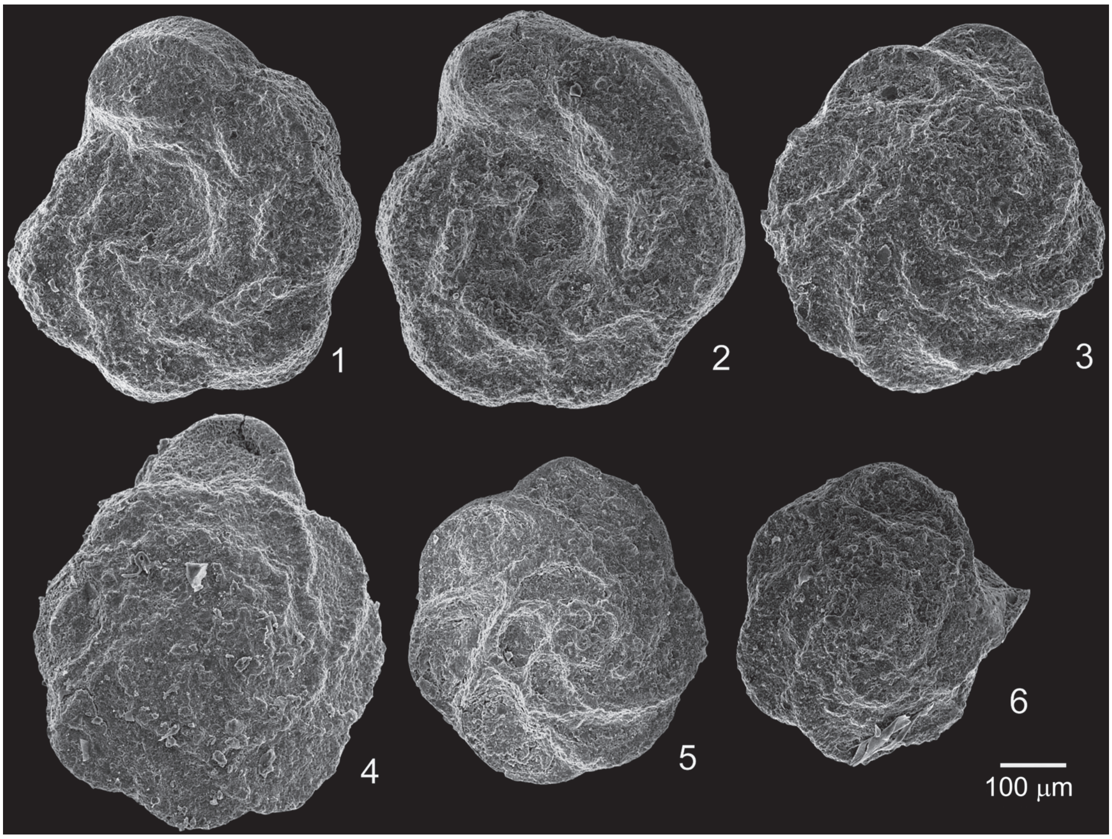

Fig. 6. Planktonic foraminifera from the Suceava Valley section. **1–4** — *Globotruncana ventricosa* White, 1928; Sample 4 (1, 2 — umbilical view; 3, 4; spiral view); **5, 6** — *Globotruncanita elevata* (Brotzen, 1934), spiral view; Sample 11.

middle and upper part of the section and reaches a maximum in the red shales containing only deep-water agglutinated foraminifera.

In the Upper Campanian red beds (middle part of the section — Fig. 2) the only observed micropaleontological assemblage consists of agglutinated foraminifera. Their diversity is moderate, but higher than throughout the rest of the section; the epibenthic and inbenthic morphotypes are abundant and trace fossils are present.

Calcareous nannofossils

The preservation of the nannofossils is moderate to poor in most analysed samples. It is very poor only in the upper part of the section. The assemblage is characterized by a moderate to low abundance (Table 2). The calcareous nannofossil assemblages contain both low-latitude and high-latitude species. Cold water taxa occur in moderate proportions in most of the analysed samples: *Ahmuellerella octoradiata*, *Gartnerago segmentatum*, *Kamptnerius magnificus*, *Biscutum constans*, *Biscutum magnum*, *Prediscosphaera stoveri*, *Monomarginatus quaternarius*. In contrast, the Tethyan taxa (*Uniplanarius sissinghii, Uniplanarius trifidus*, *Uniplanarius gothicus*, *Ceratolithoides aculeus*) are present in low proportions.

The calcareous nannofossil diversity curve displays a peak just below the red beds where the planktonic foraminifera are present in high numbers (sample 11). At the base of the red beds the calcareous nannofossil assemblage is dominated by cosmopolitan species. A drop in diversity and abundance has been observed in the upper part of the section, around the Campanian-Maastrichtian boundary (Fig. 3). The most abundant species is *Micula staurophora*, which locally can reach up to 87 %. It is followed by *Watznaueria barnesiae* (up to 49 %), *Prediscosphaera cretacea* and *Reinhardtites anthophorus*.

The ratio between *Micula* and *Watznaueria* has been calculated as follows: 3 : 1 in $UC15_c^{TP}$Zone, 1 : 1 in $UC15_d^{TP}$–$UC15_e^{TP}$ Zones (except for two samples where the ratio is 1 : 2), and 6 : 1 in UC16 Zone.

Biostratigraphy

According to the agglutinated foraminifera, the deposits from the Suceava section can be assigned to the *Caudammina gigantea* Zone (Fig. 2) of the Early Campanian to Maastrichtian (Olszewska 1981; Neagu et al. 1992; Olszewska 1997; Morgiel & Bąk 2004; Cetean et al. 2011). The first occurrence (FO) of *Caudammina gigantea* was observed in sample 15 (lower part of the CC22 Zone of calcareous nannoplankton). *Caudammina gigantea* was considered by Kuhnt et al. (1998), Bąk (2000), and Cetean et al. (2011), as not living above the middle bathyal zone and it seems that its first occurrence is diachronous along the Carpathians. In the Polish Outer Carpathians, Olszewska (1997) described an acme zone with *Caudammina gigantea* in the Late Santonian to Early Campa-

Table 2: Calcareous nannofossil stratigraphical distribution on Suceava section.

Age	**Late Campanian**																						
Nannofossil zones (Sissingh, 1977; Perch-Nielsen, 1985; Burnett, 1998)	**UC15$_c^{TP}$ / CC21**											**UC15$_d^{TP}$–UC15$_e^{TP}$ / CC22**										**UC16/ CC23**	
Sample	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
Preservation	**M**	**P**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**P**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**M**	**VP**	**VP**	**P**
Abundance	**L**	**L**	**M**	**L**	**L**	**L**	**M**	**M**	**L**	**L**	**M**	**M**	**L**	**L**	**L**	**M**	**M**	**L**	**M**	**L**	**L**	**L**	**M**
Ahmuellerella octoradiata			F		R	R		R			F		R	R	R	F	R	R		R			R
Ahmuellerella regularis											R		R			R							
Amphizigus brooksii											R		R				R			R			
Arkhangelskiella cymbiformis	R	R	F	R	R	R	F	F	R	R	F	F	R	R	R	R	F	R	R	R		R	R
Biscutum constans	R		F	R			F			R	R	F	R	R	R	R	F	R		R			R
Biscutum ellipticum	R		R	R	R	F	F	F	F	F	F	F	R	R	R	F	R	R	F	R	R		R
Biscutum magnum														R	R	R		R	R				
Braarudosphaera bigelowii		R	R	R			R	R	R			R				R							
Broinsonia enormis										R	R												
Broinsonia parca constricta	R	R	R	R	R	R	F	R	R	R	F	R	R	R	R	R	F	R	F	R	R		R
Broinsonia parca expansa			R					R			R			R									
Broinsonia parca parca	R	R	R	R	R	R	R	R	R	R	F	R	R	R	R	R	F	R	F	R	R		F
Broinsonia signata											R					R			R	R			
Calculites obscurus	R	R	R	R	R	R					R	R	R	R			R	R	R	R	R		R
Calculites ovalis		R	R	R	R	R	R	R			R	R					R						
Ceratolithoides aculeus	R		R			R			R		R	R	R	R	R	R			R	R			
Ceratolithoides prominens																				R			
Ceratolithoides sesquipedalis						R			R		R												
Chiastozygus amphipons										R	R						R						
Chiastozygus bifarius	R				R	R	R	R	R		F	R	R		R	R	F	R	F	R			
Chiastozygus litterarius							R	R			R				R								
Cretarhabdus striatus						R											R	R	R				
Cribrosphaerella ehrenbergii	R		R	R		R	R	R	R	R	R	R	R	F	R	R	R	R	R	R			R
Cribrocorona gallica											R		R	R	R			R	R	R	R		
Cylindralithus nieliae	R			R	R	R	R	R	R	R	R	R	R	R	R	R	F	R	R	R	R		R
Discorhabdus ignotus	R			R	R				R		R		R	R		R	R	R	R		R		
Eiffelithus eximius	R		R	R	R	R	R	R	R	R	R	F	R	R	R	F	F	R	F	R		R	
Eiffelithus gorkae				R					R	R	F	R				R							
Eiffelithus turriseiffelii				R	R	R	R	R		R	R		R		R		R	R	R				R
Gartnerago segmentatum	R		F	F	R		R	R	R		F	R	R	R	F	F			R	R			
Helicolithus anceps		R					F		R	R	R	F								R			
Helicolithus trabeculatus		R							R		R		R	R				R	R	R			
Kamptnerius magnificus	F		R	R	R	R	R	F		R	R		F	F	R	R	R	R		R			R
Lithastrinus quadricuspis																	R	R	R	R	R		R
Loxolithus armilla	R				R	R	R	R			R	R	R	R	R	R		R	R	R			
Lucianorhabdus maleformis	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	F	R	R	R	R		R
Manivitella pemmatoidea				R		R					R	R	R	R	R		R		R	R			
Markalius inversus	R			R	R	R	R				R		R						R				
Microrhabdulus decoratus	R				R		R			R	F		R	R	R	R	R	R	F				
Micula concava				R	R	R	R	R	R		R		R	R	R	R	R	R	R				
Micula cubiformis	R			R							R		R			R							
Micula staurophora	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	A	C	C	R	C
Micula swastica				R														R	R	R			
Monomarginatus quaternarius	R		R	R	R	R		R	R		R	R	R	R	R		R	R	R				
Octolithus multiplus				R					R	R	R		R	R		R	R	R					
Orastrum campanensis	R		R	R		R			R		R	R		R	R	R			R	R			
Placozygus fibuliformis	R										R		R	R			R	R		R			
Prediscosphaera arkhangelskyi	R		R	R	R	R	R	R	R	R	R	R	R		R	R	R		R	R			
Prediscosphaera cretacea	F	R	F	R	F	F	F	F	F	R	F	F	F	F	F	F	F	R	F	F	R	R	R
Prediscosphaera grandis	R	R	R	R	R	R	R	R	R		R	R	R	R	R	R		R	R	R			R
Prediscosphaera ponticula	R		R	R			R	R		R	R	R		R		R	R						
Prediscosphaera spinosa											R					R	R						R
Prediscosphaera stoveri	R		R	R		F					F	R				R				R			
Reinhardtites anthophorus	F	R	F	F	R	R	F	F	F	R	F	R	R	F	R	F	F	R	R	R			
Reinhardtites levis								R	R		F				R	R							R
Retecapsa angustiforata	R		R	R	R						R						R			R			
Retecapsa crenulata	R	R	R	R	R	F	R	F	F	R	F	F	F	R	R	F	F	F	F	F	R		F
Retecapsa ficula	R	R																					
Retecapsa schizobrachiata						R					R												
Seribiscutum gaultensis	R			R			R	R	R		F		R	R			R	R	F				
Staurolithites imbricatus											R					R		R		R			
Staurolithites laffittei	R		R	R	R			R	R	R	F			R	R	R		R					
Tranolithus minimus						R					R		R				R						
Tranolithus orionatus			R	R	R				R	R	F	R		R	R		R	R	R	R			
Uniplanarius gothicus													R										
Uniplanarius sissinghii	R			R							R				R					R	R		R
Uniplanarius trifidus											R	R		R	R		R	R					R
Watznaueria barnesiae	C	F	F	F	C	F	C	C	F	F	C	C	F	F	F	C	A	C	C	F	F	R	F
Watznaueria britannica											R				R								
Watznaueria ovata	R			R		R		R	R		R								R	R			
Zeugrhabdotus bicrescenticus	R				R	R	R	R	R		R	R	R	R	R	R	F	R	R		R		
Zeugrhabdotus diplogrammus			R	R	R				R		R						F	R					
Zeugrhabdotus embergeri	R		R	R	R			R	R		R	R	R		R		R	R	R	R			
Zeugrhabdotus praesigmoides	R			R							R		R		R		R		R	R			

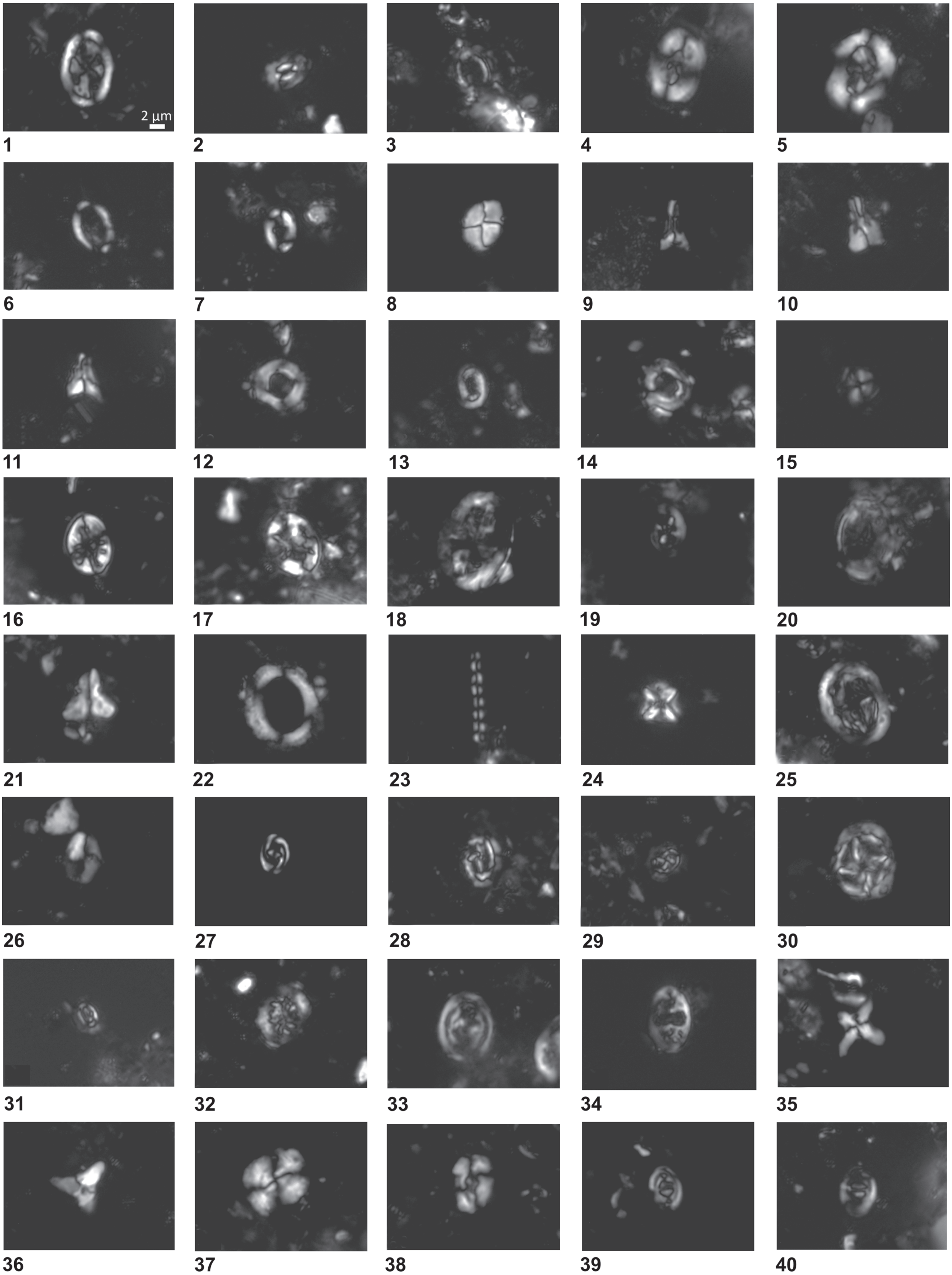
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Fig. 7.

nian, while in the Romanian Eastern Carpathians, Neagu et al. (1992) reported it from the Early Campanian & Cetean et al. (2011) identified it in the Late Campanian.

Planktonic foraminifera occur only in the basal part of the section (grey marlstones) with high proportions in samples 4 and 11 (Fig. 2), where *Globotruncana arca*, *G. elevata*, *G. angulata*, *G. orientalis* are characteristic. Additionally, the presence of *Globotruncana ventricosa* (FO in sample 1 and a maximum in sample 4) allows the correlation with the *Globotruncana ventricosa* Zone (e.g. Postuma 1971; Caron 1985) of the Late Campanian. The high proportion of *Globotruncana arca* in sample 11 correlates with the base of the Late Campanian and CC22 Biozone (defined between the first occurrence of *Uniplanarius trifidus* and the last occurrence (LO) of *Reinhardtites anthophorus*) of calcareous nannoplankton (Fig. 2). The interval between samples 11 to 15 contains foraminifera with long stratigraphic range and therefore can hardly be assigned to a certain planktonic foraminiferal zone; useful information is given by calcareous nannofossils instead.

According to UC Zones introduced by Burnett (1998), correlated with the Tethyan biozonation schemes of Sissingh (1977) and Perch-Nielsen (1985), the calcareous nannofossils are characteristic for the Late Cretaceous (UC15c^{TP}–UC16; CC21–CC23) — Fig. 2. The absence of *Uniplanarius trifidus* in the basal part of the section argues for the presence of UC15$_c^{TP}$ Subzone (early Late Campanian). The FO of *Uniplanarius trifidus* (base of UC15$_d^{TP}$ Subzone — approximately early Late Campanian or base of Late Campanian CC22 Zone in the Tethyan Realm) was recorded at sample 11, while the LO of *Reinhardtites anthophorus* (base of Late Campanian CC23 Zone or UC16 Zone) was observed in sample 21. The boundary between UC15$_d^{TP}$–UC15$_e^{TP}$ Subzones cannot be drawn due to the absence of the marker species (*Eiffelithus parallelus*). These two subzones can be approximately correlated with CC22 Biozones of Sissingh (1977) and Perch-Nielsen (1985). Thus, the studied interval can be considered as Late Campanian in age. Two additional bioevents have been recorded in the UC15$_d^{TP}$–UC15$_e^{TP}$/CC22 Biozone: FO of *Biscutum magnum* in sample 14 followed by FO of *Lithastrinus quadricuspis* at sample 17 (Late Campanian CC22 Zone — Le Callonec et al. 1997). Other Late Campanian species constantly occurring, but in low proportions in the Hangu Formation are *Ceratolithoides aculeus*, *Uniplanarius sissinghii*, *Reinhardtites levis*, *Orastrum campanensis*, *Monomarginatus quaternarius*, *Octolithus multiplus*.

Discussion and interpretation

The foraminiferal assemblage A is very similar to assemblages described from the Subsilesian Unit of the Polish Carpathians (Waśkowska-Oliwa 2005); this correlation suggests that the interval between samples 1 to 14 corresponds to an environment placed just above calcite compensation depth (CCD). This is consistent with the calcareous nannofossil diversity curve which displays a peak just below the red beds where the planktonic foraminifera are present in a high proportion (sample 11).

On the basis of the identified species, the foraminiferal assemblage B fits very well into the "flysch-type" agglutinated foraminiferal biofacies, characteristic of the middle to lower bathyal settings (Kaminski & Gradstein 2005). The lack of planktonic foraminifera and the very rare calcareous benthics point to a lower bathyal settings, probably above but close to the CCD.

Dominance of the tubular forms (M1 morphorgoup) in the basal and upper part of the section suggests low energy, middle to lower bathyal environments with moderate to low levels of organic flux to the sea bottom; this is confirmed by the low values of the alpha index (Fig. 3).

The decrease in the relative abundance of M1 and increase of M4b, noticed in the red beds, suggest seafloor disturbance, changes in the circulation of the bottom waters and well-oxygenated oligotrophic conditions on the seafloor (Hu et al. 2005). This is supported by the relatively higher diversity, the abundance of epifaunal and infaunal morphotypes and the presence of trace fossils (Bąk 2000 and Hu et al. 2005). These red shales, containing only deep-water foraminifera and showing an increase of the species diversity, also support the hypothesis of Setoyama et al. (2011) that the diversity of benthic foraminiferal assemblages usually increases with greater water depth.

Hu et al. (2005) stated that similar Upper Cretaceous deposits formed in relation to a major change in the oceanic sedimentation starting with mid-Cretaceous. Same kind of deposits was reported in the Romanian Eastern Carpathians by Melinte (2002) and Melinte & Jipa (2005) and was assigned to

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Fig. 7. Calcareous nannofossils from the Suceava Valley section. The photographs were taken under cross-polarized light. **1** — *Arkhangelskiella cymbiformis*; Sample 11. **2** — *Biscutum constans*; Sample 11. **3** — *Biscutum magnum*; Sample 14. **4** — *Broinsonia parca constricta*; Sample 4. **5** — *Broinsonia parca parca*; Sample 11. **6** — *Broinsonia parca expansa*; Sample 8. **7** — *Broinsonia signata*; Sample 16. **8** — *Calculites obscurus*; Sample 12. **9** — *Ceratolithoides aculeus*; Sample 6. **10** — *Ceratolithoides prominens*; Sample 9. **11** — *Ceratolithoides sesquipedalis*; Sample 6. **12** — *Cribrocorona gallica*; Sample 14. **13** — *Cribrosphaerella ehrenbergii*; Sample 7. **14** — *Cylindralithus* sp.; Sample 13. **15** — *Discorhabdus ignotus*; Sample 13. **16** — *Eiffelithus eximius*; Sample 16. **17** — *Eiffelithus turriseiffelii*; Sample 8. **18** — *Gartnerago segmentatum*; Sample 3. **19** — *Helicolithus anceps*; Sample 2. **20** — *Kamptnerius magnificus*; Sample 5. **21** — *Lucianorhabdus maleformis*; Sample 13. **22** — *Manivitella pemmatoidea*; Sample 11. **23** — *Microrhabdulus decoratus*; Sample 7. **24** — *Micula staurophora*; Sample 20. **25** — *Monomarginatus quaternarius*; Sample 15. **26** — *Orastrum campanensis*; Sample 6. **27** — *Placozygus fibuliformis*; Sample 13. **28** — *Prediscosphaera arkhangelskyi*; Sample 16. **29** — *Prediscosphaera cretacea*; Sample 18. **30** — *Prediscosphaera grandis*; Sample 15. **31** — *Prediscosphaera stoveri*; Sample 6. **32** — *Retecapsa crenulata*; Sample 11. **33** — *Reinhardtites anthophorus*; Sample 11. **34** — *Tranolithus orionatus*; Sample 11. **35** — *Uniplanarius sissinghii*; Sample 4. **36** — *Uniplanarius trifidus*; Sample 23. **37** — *Watznaueria barnesiae*; Sample 11. **38** — *Watznaueria britannica*; Sample 11. **39** — *Zeugrhabdotus bicrescenticus*; Sample 11. **40** — *Zeugrhabdotus diplogrammus*; Sample 11.

the Late Campanian-Maastrichtian CC21–CC26 Nannozones. A possible explanation of the red colour is a change in redox conditions on the ocean floor (Hu et al. 2005), low sedimentary rate and oligotrophy. This is supported by the relatively high proportion of inbenthic forms.

The differences in the number of cold water vs. Tethyan calcareous nannoplankton taxa suggest a possible migration of the high-latitude boreal nannoplankton into the Tethyan Realm. This could be related to the existence of a corridor between the Tethyan basins and North European basins during the Campanian–Maastrichtian, as suggested by Malata & Poprawa (1997). The influence from the Boreal Realm has been demonstrated by Švábenická (2001) based on studying calcareous nannofossils in Upper Campanian deposits from the Outer Western Carpathians.

Micula staurophora (recognized as an abundant species in poorly-preserved samples and reaching the lowest abundance in well-preserved ones — Eshet & Almogi-Labin 1996) is the most abundant species throughout the section. It is followed by *Watznaueria barnesiae*, *Prediscosphaera cretacea* and *Reinhardtites anthophorus*. Their high proportions may be related to a better resistance to dissolution compared to other taxa. *Micula* overcoming *Watznaueria* in most of the samples can also be interpreted as a cooling episode since *Watznaueria barnesiae* was defined as a warm water taxon (Bukry 1973; Thierstein 1981; Huber & Watkins 1992; Lees 2002 o.a.).

The dominance of the cosmopolitan calcareous nannofossil species at the base of red beds was also noted by Melinte & Jipa (2005) in relation to a high sea level. The relative abundance of *Watznaueria barnesiae* in the studied red beds overcomes *Micula staurophora* in two samples (samples 12 and 18 in Fig. 3) suggesting increase in paleoproductivity (the distribution of *Watznaueria barnesiae* usually shows a positive correlation with the productivity curves — Eshet & Almogi-Labin 1996).

The drop of calcareous nannoplankton diversity and abundance in the upper part of the section (Fig. 3) suggests changes in the environmental conditions (a regressive episode and/or high productivity interval).

Distinct distribution of micro- and nannofossil assemblages correlates with the sedimentological data. The transgressive interval can be documented by fining upwards turbidites (T_{b-c} followed by T_{c-e}) containing mainly agglutinated foraminifera and afterwards large amounts of planktonics. The hemipelagic red beds must have been deposited in even deeper settings (containing agglutinated foraminifera that lived below the CCD). The reactivation of turbiditic sedimentation after the deposition of red beds demonstrates the beginning of the regressive trend. By marking a sea-level maximum, the red beds and associated agglutinated foraminiferal assemblage have a high correlation potential for the Late Campanian.

Conclusions

The Suceava section (northern Tarcău Nappe of the Eastern Carpathians) provided rich foraminiferal and calcareous nannoplankton assemblages, suitable for biostratigraphic and paleoenvironmental analyses. The data allow biostratigraphic correlation support for the Hangu Formation, by assigning the deposits to the Late Campanian *Caudammina gigantea* Zone, *Globotruncana ventricosa* (foraminifera) and $UC15_c^{TP}$–UC16 (calcareous nannoplankton) Biozones.

The foraminiferal assemblages are dominated by agglutinated taxa. Low proportions of planktonic and calcareous benthic forms in the lower part of the section suggest environments placed above the CCD. On the other hand, the dominance of agglutinated foraminifera and the presence of calcareous nannofossils and sporadic forms of calcareous benthic foraminifera in the median and upper parts suggest deposition above the CCD but close to it.

The character of the foraminiferal assemblages is typical of "flysch type" biofacies from middle to lower bathyal settings. The morphogroup analysis suggests that for the lowermost deposits the bottom water environments were mesotrophic and relatively well oxygenated. The red beds display higher diversities and high proportions of infaunal forms suggesting an increased oxygenation, higher water depth, low sedimentation rate and oligotrophic conditions.

Sedimentological and micropaleontological data suggest a deepening trend up to the level of the red beds, followed by a regressive trend. The red beds and associated micropaleontological assemblage have a high potential for stratigraphic correlation at regional scale.

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Appendix 1

List of identified foraminiferal taxa

Agglutinated foraminifera

Ammobaculites sp.
Ammodiscus cretaceus (Reuss, 1845)
Ammodiscus glabratus Cushman & Jarvis, 1928
Ammodiscus peruvianus Berry, 1928
Ammodiscus tenuissimus Grzybowski, 1898
Ammosphaeroidina pseudopauciloculata (Mjatliuk, 1966)
Arthrodendron grandis (Grzybowski, 1898)
Bathysiphon sp.
Caudammina ovula (Grzybowski, 1896)
Caudammina ovuloides (Grzybowski, 1901)
Caudammina gigantea (Geroch, 1960)
Conglophragmium irregularis (White, 1928)
Cribrostomoides subglobosus (Cushman, 1910)
Cribrostomoides sp.
Glomospira charoides (Jones & Parker, 1860)
Glomospira gordialis (Jones & Parker, 1860)
Glomospira irregularis (Grzybowski, 1898)
Glomospira serpens (Grzybowski, 1898)
Glomospira sp.
Haplophragmoides kirki Wickenden, 1932
Hormosina trinitatensis Cushman & Renz, 1946
Hormosina velascoensis (Cushman, 1926)
Hormosinella distans (Brady, 1881)
Hyperammina dilatata Grzybowski, 1896
Hyperammina elongata Brady, 1878
Hyperammina granulosa (Brady, 1879)
Hyperammina rugosa Verdenius & van Hinte, 1983
Hyperammina sp.
Kalamopsis grzybowski (Dylążanka, 1923)
Karrerulina conversa (Grzybowski, 1901)
Karrerulina horrida (Mjatliuk, 1970)
Karrerulina sp.
Lituotuba lituiformis (Brady, 1879)
Nothia excelsa (Grzybowski, 1898) emend. Geroch & Kaminski, 1992
Nothia latissima (Grzybowski, 1898)
Nothia robusta (Grzybowski, 1898)
Paratrochamminoides gorayskii (Grzybowski, 1898) emend. Kaminski & Geroch, 1993
Paratrochamminoides heteromorphus (Grzybowski, 1898)
Paratrochamminoides mitratus (Grzybowski, 1901)
Paratrochamminoides olszewskii (Grzybowski, 1898)
Psammosiphonella cylindrica (Glaessner, 1937)
Psammosiphonella discreta (Brady, 1881)
Psammosphaera fusca Schultze, 1875 emend. Heron–Allen & Earland, 1913
Psammosphaera irregularis (Grzybowski, 1896)
Rectoprotomarssonella rugosa (Hanzlíková, 1955)
Recurvoides anormis Mjatliuk, 1970
Recurvoides sp.
Reophax duplex Grzybowski, 1896
Reophax globosus Sliter, 1968
Reophax pilulifer Brady, 1884
Reophax subfusiformis Earland, 1933 emend. Höglund, 1947
Reophax sp.
Rhabdammina linearis Brady, 1879
Rhabdammina sp.
Rhizammina sp.
Rzehakina epigona (Rzehak, 1895)
Rzehakina lata Cushman & Jarvis, 1928

Saccammina grzybowski (Schubert, 1902)
Saccammina placenta (Grzybowski, 1898)
Spiroplectammina sp.
Spiroplectinella dentata (Alth, 1850)
Subreophax pseudoscalaris (Samuel, 1977)
Subreophax scalaris (Grzybowski, 1896)
Trochamminoides dubius (Grzybowski, 1901)
Trochamminoides proteus (Karrer, 1866) emend. Rögl, 1995
Trochamminoides subcoronatus (Grzybowski, 1896)
Trochamminoides variolarius (Grzybowski, 1898)

Calcareous benthic foraminifera

Chrysalogonium elongatum Cushman & Jarvis, 1934
Cibicidoides velascoensis (Cushman, 1925)
Eponides praemegastomus (Mjatliuk, 1953)
Stillostomella sp.

Planktonic foraminifera

Contusotruncana fornicata (Plummer, 1931)
Globotruncana angulata Tilev, 1951
Globotruncana arca (Cushman, 1926)
Globotruncana bulloides Vogler, 1941
Globotrunana concavata (Brotzen, 1934)
Globotruncana elevata (Brotzen, 1934)
Globotruncana orientalis El Naggar, 1966
Globotruncana stuartiformis Dalbiez, 1955
Globotruncana ventricosa White, 1928
Globotruncana sp.

Appendix 2

List of identified calcareous nannoplankton taxa

Ahmuellerella octoradiata (Górka, 1957) Reinhardt, 1966
Ahmuellerella regularis (Górka, 1957) Reinhardt & Górka, 1967
Amphizigus brooksii Bukry, 1969
Arkhangelskiella cymbiformis Vekshina, 1959
Biscutum constans (Górka, 1957) Black, 1959 in Black & Barnes, 1959
Biscutum ellipticum (Górka, 1957) Grün in Grün & Allemann, 1975
Biscutum magnum Wind & Wise in Wise & Wind, 1977
Braarudosphaera bigelowii (Gran & Braarud, 1935) Deflandre, 1947
Broinsonia enormis (Shumenko, 1968) Manivit, 1971
Broinsonia parca (Stradner, 1963) Bukry, 1969, ssp. *constricta* Hattner et al., 1980
Broinsonia parca (Stradner, 1963) Bukry, 1969, ssp. *expansa* Wise & Watkins in Wise, 1983
Broinsonia parca (Stradner, 1963) Bukry, 1969, ssp. *parca*
Broinsonia signata (Noël, 1969) Noël, 1970
Calculites ovalis (Stradner, 1963) Prins & Sissingh in Sissingh, 1977
Calculites obscurus (Deflandre, 1959) Prins & Sissingh in Sissingh, 1977
Ceratolithoides aculeus (Stradner, 1961) Prins & Sissingh in Sissingh 1977
Ceratolithoides prominens Burnett, 1997
Ceratolithoides sesquipedalis Burnett, 1998
Chiastozygus amphipons (Bramlette & Martini, 1964) Gartner, 1968
Chiastozygus bifarius Bukry, 1969
Chiastozygus litterarius (Górka, 1957) Manivit, 1971
Cretarhabdus striatus (Stradner, 1963) Black, 1973
Cribrocorona gallica (Stradner, 1963) Perch-Nielsen, 1973
Cribrosphaerella ehrenbergii (Arkhangelsky, 1912) Deflandre in Pivetteau, 1952
Cylindralithus nieliae Burnett, 1998
Discorhabdus ignotus (Górka, 1957) Perch-Nielsen, 1968
Eiffelithus eximius (Stover, 1966) Perch-Nielsen, 1968
Eiffelithus gorkae Reinhardt, 1965
Eiffelithus turriseiffelii (Deflandre in Deflandre & Fert, 1954) Reinhardt, 1965
Gartnerago segmentatum (Stover, 1966) Thierstein, 1974
Helicolithus anceps (Górka, 1957) Noël, 1970
Helicolithus trabeculatus (Górka, 1957) Verbeek, 1977
Kamptnerius magnificus Deflandre, 1959
Lithastrinus quadricuspis Farhan, 1987
Loxolithus armilla (Black in Black & Barnes, 1959) Noël, 1965
Lucianorhabdus maleformis Reinhardt, 1966
Manivitella pemmatoidea (Deflandre in Manivit, 1965) Thierstein, 1971
Markalius inversus (Deflandre in Deflandre & Fert, 1954) Bramlette & Martini, 1964
Microrhabdulus decoratus Deflandre, 1959
Micula concava (Stradner in Martini & Stradner, 1960) Verbeek, 1976
Micula cubiformis Forchheimer, 1972
Micula staurophora (Gardet, 1955) Stradner, 1963
Micula swastica Stradner & Steinmetz, 1984
Monomarginatus quaternarius Wind & Wise in Wise & Wind, 1977
Octolithus multiplus (Perch-Nielsen, 1973) Romein, 1979
Orastrum campanensis (Cepek, 1970) Wind & Wise in Wise & Wind, 1977
Placozygus fibuliformis (Reinhardt, 1964) Hoffmann, 1970

Prediscosphaera arkhangelskyi (Reinhardt, 1965) Perch-Nielsen, 1984
Prediscosphaera cretacea (Arkhangelsky, 1912) Gartner, 1968
Prediscosphaera grandis Perch-Nielsen, 1979
Prediscosphaera ponticula (Bukry, 1969) Perch-Nielsen, 1984
Prediscosphaera spinosa (Bramlette & Martini, 1964) Gartner, 1968
Prediscosphaera stoveri (Perch-Nielsen, 1968) Shafik & Stradner, 1971
Reinhardtites anthophorus (Deflandre, 1959) Perch-Nielsen, 1968
Reinhardtites levis Prins & Sissingh in Sissingh, 1977
Retecapsa angustiforata Black, 1971
Retecapsa crenulata (Bramlette & Martini, 1964) Grün in Grün & Allemann, 1975
Retecapsa ficula (Stover, 1966) Burnett, 1998
Retecapsa schizobrachiata (Gartner 1968) Grün in Grün & Allemann 1975
Seribiscutum gaultensis Mutterlose, 1992
Staurolithites imbricatus (Gartner, 1968) Burnett, 1998
Staurolithites laffittei Caratini, 1963
Tranolithus minimus (Bukry, 1969) Perch-Nielsen, 1984
Tranolithus orionatus (Reinhardt, 1966a) Reinhardt, 1966
Uniplanarius gothicus (Deflandre, 1959) Hattner & Wise, 1980
Uniplanarius sissinghii Perch-Nielsen, 1986
Uniplanarius trifidus (Stradner in Stradner & Papp, 1961) Hattner & Wise, 1980
Watznaueria barnesiae (Black, 1959) Perch-Nielsen, 1968
Watznaueria britannica (Stradner, 1963) Reinhardt, 1964
Watznaueria ovata Bukry, 1969
Zeugrhabdotus bicrescenticus (Stover, 1966) Burnett in Gale et al., 1996
Zeugrhabdotus diplogrammus (Deflandre in Deflandre & Fert, 1954) Burnett in Gale et al., 1996
Zeugrhabdotus embergeri (Noël, 1958) Perch-Nielsen, 1984
Zeugrhabdotus praesigmoides Burnett, 1998