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The Correlation between Fossil Foraminifera and the Depositional Environments in the Northern Part of the Tarcău Nappe (Eastern Carpathians, Romania)

Ph. D. Thesis - Summary

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THESIS CONTENTS

Keywords: foraminifera, Tarcău Nappe, Upper Cretaceous, Paleogene, biostratigraphy, paleoecology, Eastern Carpathians.

Introduction

The Carpathian chain represents, for almost two centuries, an interesting area for the study of the assemblages of foraminifera which, in most cases, were used to argue biostratigraphical and paleoecological issues.

The pioneer of applied biostratigraphy was Joseph Grzybowski who, in 1898, used for the first time the foraminifera for biostratigraphic correlation in the Potok Oil Field of Krosno, Poland. Afterwards, the foraminifera from deep water turbidites were studied throughout the Carpathians.

The motivation to study the assemblages of fossil foraminifera from the northern part of the Tarcău Nappe stems from the fact that their biostratigraphic and paleoenvironmental potential has not been sufficiently exploited; most previous studies were limited to a general description of the assemblages and taxonomical facts. Using statistical and micropaleontological methods, we tried to describe the assemblages and their relation to the depositional environment, to identify bioevents that can be stratigraphically correlated and to describe the evolution of the regional depositional basin. We focused on the northern part of the Tarcău Nappe (between Suceava Valley to the North and Moldovei Valley to the South) due to the micropaleontological potential of the paleogene turbiditic sequences. Most of the analyses attempt to create quantitative and qualitative description of the fossil foraminifera assemblages, morphology, taxonomy, biostratigraphy and paleoecology. Micropaleontological data were statistically analyzed and correlated with the sedimentological trend in turbiditic systems in order to obtain a clear picture of the spatial and temporal distribution and evolution of paleoenvironmental parameters under the influence of the sea level fluctuations and the terrigenous and nutritional flux.

Moreover, we tried to obtain regionally valid correlation criteria by using known bioevents from similar areas in order to support a better understanding of the evolution of the depositional basin.

Some of the results were published in the Studia UBB Geologia (Bindiu & Filipescu, 2011) and Geologica Carpathica (Bindiu et al., 2013) journals.

I’d like to thank Prof. Dr. Sorin Filipescu for advice in choosing the subject, scientific coordination, moral and logistical support throughout the research period and his help with structuring and reviewing the thesis content.

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Chapter I. Geology Of The Studied Area

The studied area lies between Suceava Valley to the North and Moldovei Valley to the South; it belongs to the northern units of the Upper Cretaceous - Paleogene flysch of the Eastern Carpathians.

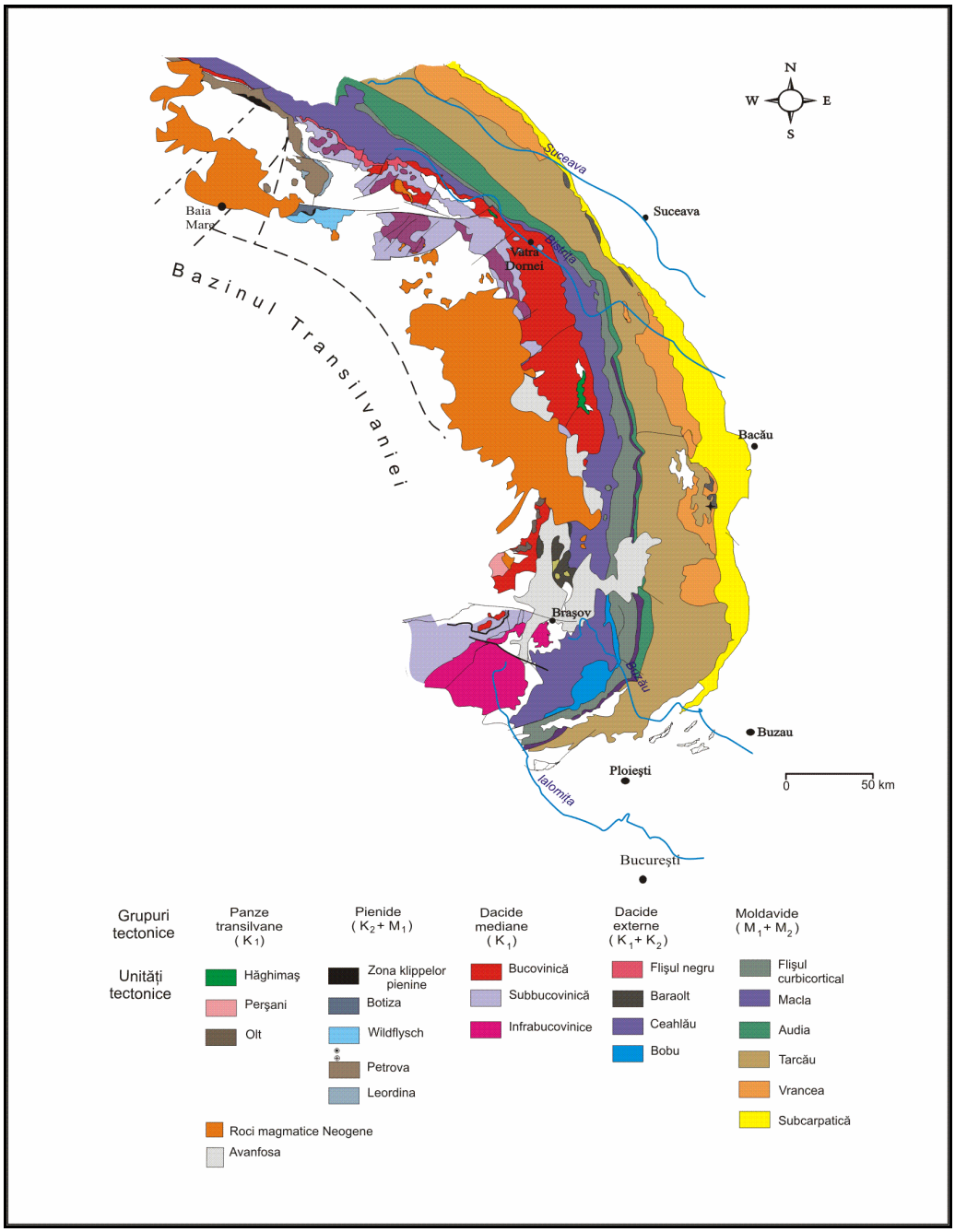

Figure 1. Map of structural units of the Eastern Carpathians (modified after Badescu, 2005)

Structurally, the area belongs to the Tarcău Nappe, respectively to the Extern Moldavides (sedimentary turbiditic formations that also contain hemipelagic sediments or bitumen rocks – Săndulescu, 1984). The Tarcău Nappe, together with the Vrancea and Subcarpathian nappes, are the most external Moldavids (fig. 1) layers that hold depositional layers from the Cretaceous-Cenozoic (Bădescu, 2005; Puglisi et al., 2006).

The Tarcău Nappe (Joja, 1954; Săndulescu, 1981, 1984), also known as the "Median-Exterior Unit" (Agheorghiresei et al., 1967) is a plurifacial unit (Dumitrescu 1948, 1952) whose extent, litographical composition and tectonical structure make it the most important unit of the External Flysch of the Eastern Carpathians.

From a litostratigraphy point of view, the Tarcău Nappe consists of formations belonging to the upper Cretaceous, Paleogene and Miocene (Săndulescu, 1984). The Paleogene age is marked by variable facies conditions along the depositional basin. Tectonic activity during the Eocene led to major differences between the depositional characteristics of the northern part (The Suceava – Putna area) and the southern part (Moldovei basin) respectively; the siliceous facie from Scorbura Sandstone (Joja, 1954) occur in the North and micaceous from the Tazlău and Sucevița Formation (Atanasiu, 1943; Agheorghiresei et al., 1967, Ionesi, 1971).

Chapter II. Previous Research in the Studied Area

Attempting to date and stratigraphically correlate the formations from the Tarcău Nappe, the micropaleontological studies were based on analyzing different groups of fossils (micro- and macro- foraminifera, calcareous nannofossils, mollusks. Most of the research studies based on the assemblages of foraminifera were focused on taxonomical observations, rarely on paleoenvironmental interpretations. One of the main research directions was to establish a biostratigraphical zonation for this area because the existence of tectonic complications sparked a lot of controversy in dating and correlation the formations. Studies based on assemblages of foraminifera from the Cretaceous deposits from the Tarcău Nappe were carried out by Tocorjescu (1954), Ion (1973, 1975 a,b), Neagu et al. (1992); the boundary between Cretaceous and Paleogene was studied by Costea & Balteș (1962), Joja et al. (1963), Ionesi & Tocorjescu (1968), Bratu & Alexandrescu (1970), Dicea (1974), Ionesi (1974), Bratu (1975) and the Paleogene by Ionesi (1957), Joja et al. (1963), Agheorghiresei et al. (1967), Dicea &

Dicea (1976, 1980), Ionesi (1987), Săndulescu et al. (1987), Săndulescu & Micu (1989), Juravle (2007) and Juravle et al. (2008).

Recent studies of the biostratigraphy and paleoecology of foraminifera from the Eastern Carpathians were carried out by Bubik (2006), Kaminski et al. (2007), Filipescu et al (2009), Cetean (2009), Cetean et al. (2008, 2011), Bindiu et al. (2010), Szabo et al. (2010), Szabo & Filipescu (2010), Bindiu & Filipescu (2011), Bindiu et al. (2011), Szabo et al. (2011), Szabo & Filipescu (2011), Bindiu et al. (2012), Bindiu et al. (2013).

Chapter III. Material and Methods

During the field trips performed in 2010 – 2012, 235 samples were collected. Since we wanted to cover a large area of the Tarcău Nappe and to obtain more micropaleontological information about the potential target sections, the initial area of study was located from Suceava Valley in the North to the Siriu Valley in the South. After the preparation of the first collected samples, the Siriu and nearby areas proved almost barren of foraminifera. Thus, the studied area was restricted to Suceava Valley (North) and Moldova Valley (South). This study pursued the following stages: sampling and preparation following the standard micropaleontological methods; qualitative and quantitative interpretations based on the foraminiferal assemblages (relative and absolute abundance, generic dominance), diversity indices (Fisher α, Hulbert, Shannon – Wiener, Equitability, Simpson), assemblages of agglutinated foraminifera, morphogroups of agglutinated foraminifera, P/B ratio and BFOI (in samples where calcareous benthic foraminifera were identified).

Chapter IV. Results and Discussions

The 27 studied sedimentary sequences from the northern part of the Tarcău Nappe can be observed in figure 2.

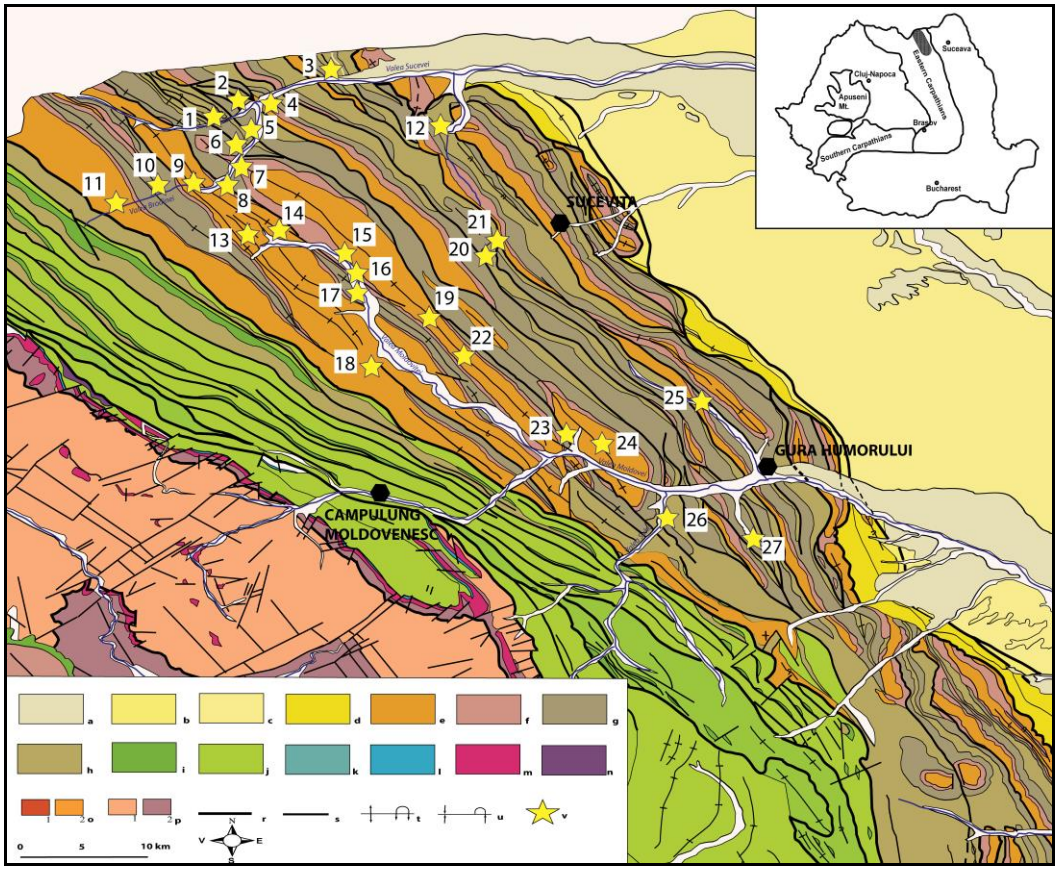

Figure 2. Location of the studied sections: a. Quaternary; b. Badenian; c. Sarmatian; d. Burdigalian; e. Oligocene; f. Eocene; g. Paleocene - Eocene; h. Upper Cretaceous – Paleocene; i. Upper Cretaceous; j. Lower Cretaceous; k. Upper Jurassic– Lower Cretaceous; l. Middle – Upper Jurassic; m. Triassic; n. Mesozoic magmatites; o. Neogene magmatites (1 – magmatic rocks,volcanogeno-sedimentary formation); p. Metamorphic rocks (1 - epimetamorphites, 2 - mezometamorphites); r. faults; s. digitations; t. anticline (symmetrical, overturned); u. Sincline (symmetrical, overturned); v. Location of the investigated sections: 1 – Suceava Valley 1; 2 – Suceava Valley 2; 3 - Straja Vest; 4 – Suceava Valley 3; 5 – Brodina Valley 1; 6 - Brodina Valley 2; 7 - Brodina Valley 3; 8 - Brodina Valley 4; 9 - Brodina Valley 5; 10 - Brodina Valley 6; 11 - Brodina Valley 7; 12 – Putna Valley; 13 - Argel 1; 14 - Argel 2; 15 - Argel 3; 16 – Raşca; 17 – Moldoviţa Valley; 18 – Boului Valley; 19 – Ciumârna; 20 – Palma; 21 – Rusca; 22 – Dragoşa; 23 – Dobra; 24 – Molidu; 25 – Humor Valley; 26 – Suha Valley; 27 - Voroneţ. (modified after The Geological Map of Romania, 1:200.000, Rădăuţi sheet).

4.1. Characterization of the Micropaleontological Assemblages

After performing the micropaleontological analyses the following general observations were made: the foraminifera assemblages show high variety and abundance (more than 230 taxa, the agglutinated foraminifera dominate); the assemblages fit the "flysch–type" category of agglutinated foraminifera assemblages; all the morphogroups of agglutinated foraminifera were identified.

4.1.1. Suceava Valley 1

The sedimentary sequence consists of medium-grained and fine-grained siliciclastic turbidites, with Tb-c and Tc-e Bouma sequences in the basal and upper part of the section; the median part consists of very fine-grained red hemipelagites, which can be assigned to "red beds" units.

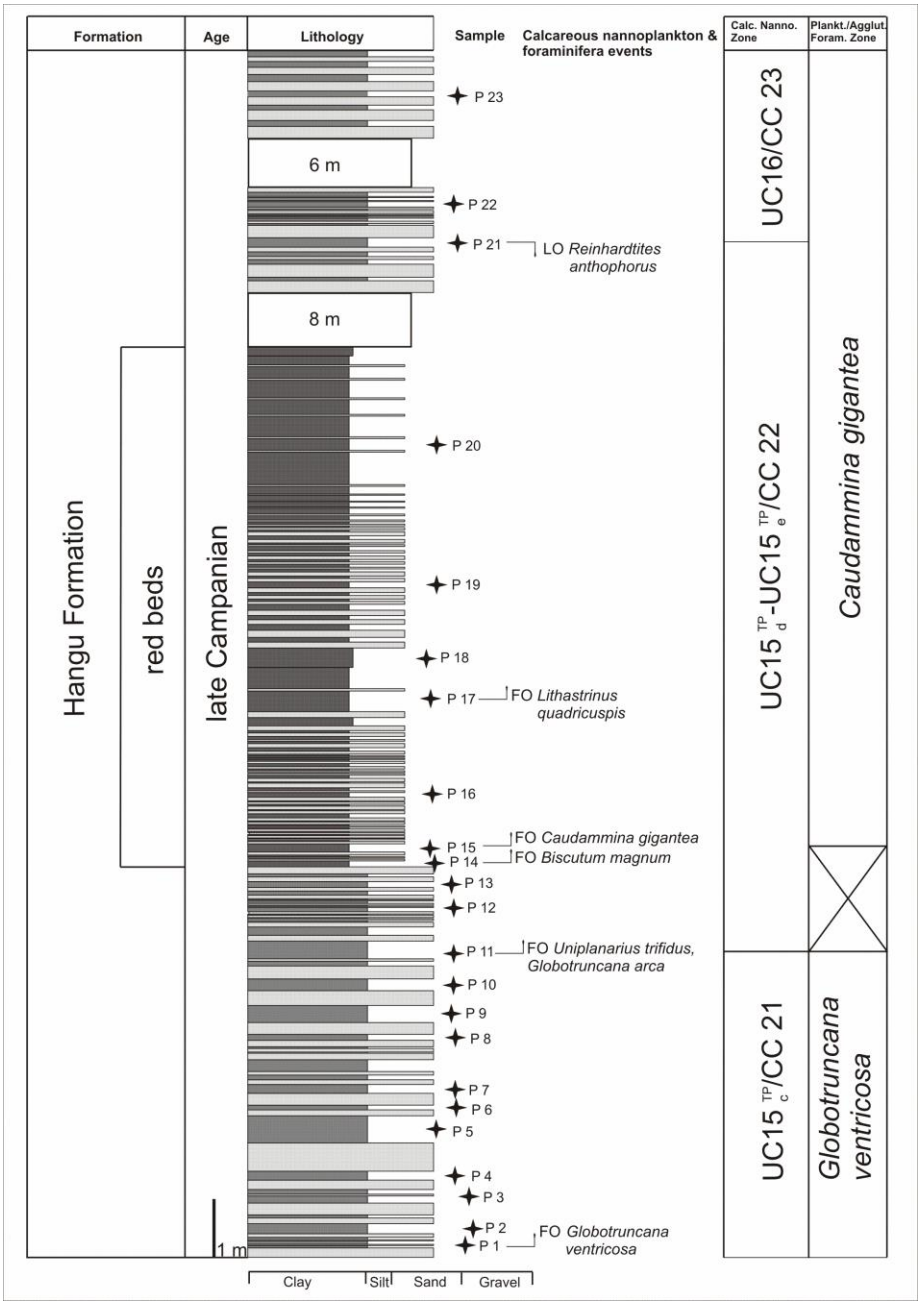

Figure 3. Lithological log and biostratigraphy of the Suceava Valley 1 section.

The investigated deposits are Late Campanian in age and belong to the Hangu Formation (fig. 3); the assignment of this age was based on the presence of

Globortruncana ventricosa (basal part) and *Caudammina ovulum gigantea* (median and upper part) taxa. Useful biostratigraphic information was provided by calcareous nannofossils which confirmed the Late Campanian age. The diversity and agglutinated morphogroups analyses suggest median-lower bathyal environments; M1 morphogroup (tubular forms) represents more than 70% of the assemblage in the basal and upper part suggesting environments with very low content of organic matter; in the median part the content of organic matter is high (shown by high percentages of infaunal foraminiferal species).

4.1.2. Brodinei Valley 2

The investigated section is located in the Brodina de Jos village, near the Brodina Valley and consists of strong tectonized siliciclastic turbidites; these belong to the upper part of the Hangu Formation of the Tarcău Nappe. The foraminifera assemblages are characteristic to deep water paleoenvironments, supported also by the sporadic occurrence of some radiolaria species. The only biostratigraphic marker found in the assemblages is *Caudammina ovulum gigantea*; based on it, the deposits can be assigned to the *Caudammina ovulum giganeea* Zone specific to the Middle Campanian – Maastrichtian interval. The presence of *Remesella varians*, *Rzehakina inclusa* şi *Rzehakina minima* suggest a possibility of restricting the age to the Late Maastrichtian, very close with the boundary with the Paleogene. The assemblages of foraminifera are dominated by tubular taxa (M1 morphogroup – fig. 4) suggesting bathyal paleoenvironments with low organic matter flux and moderate oxygenation.

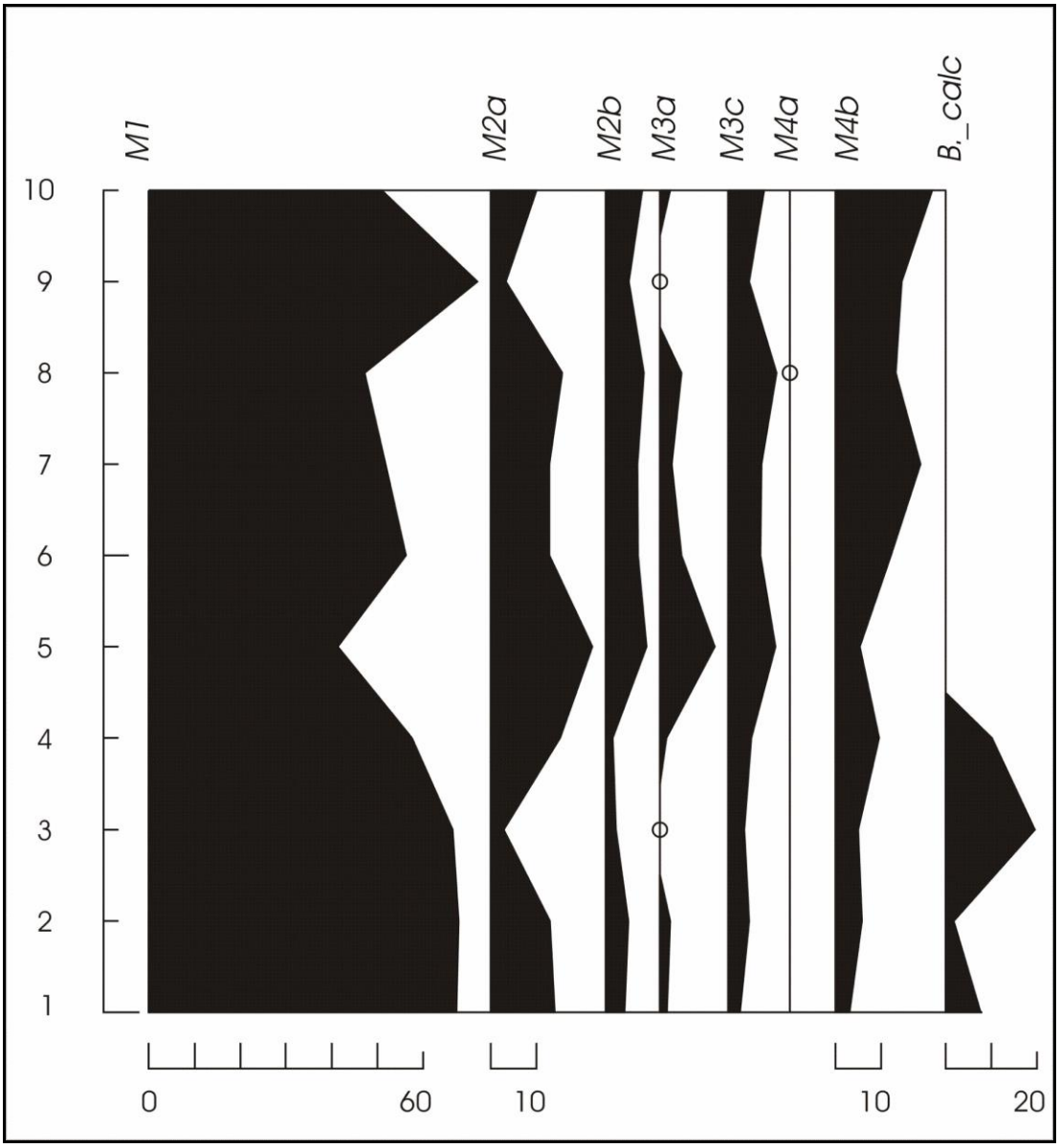

Figure 4. Distribution of agglutinated foraminifera morphogroups (M1 - tubular; M2a - globular; M2b – rounded trochospiral and streptospiral/planconvex trochospiral; M3a - flattened trochospiral/ flattened planispiral and streptospiral; M3c – flattened streptospiral; M4a –rounded planispiral; M4b – elongate subcylindrical/elongate tapered) and of calcareous benthic foraminifera at Brodinei Valley 2.

4.1.3. Putna Valley

The depositional sequence of the Putnei Valley presents ample development, with continuous sections; it consists of upper cretaceous, paleocene and eocene deposits belonging to the Hangu, Putna (Izvor), Straja and Scorbura formations.

Based on the first and last occurrence and specific abundance (fig. 5)of certain agglutinated taxons, we have identified 4 zones in the Putnei Valley deposits.

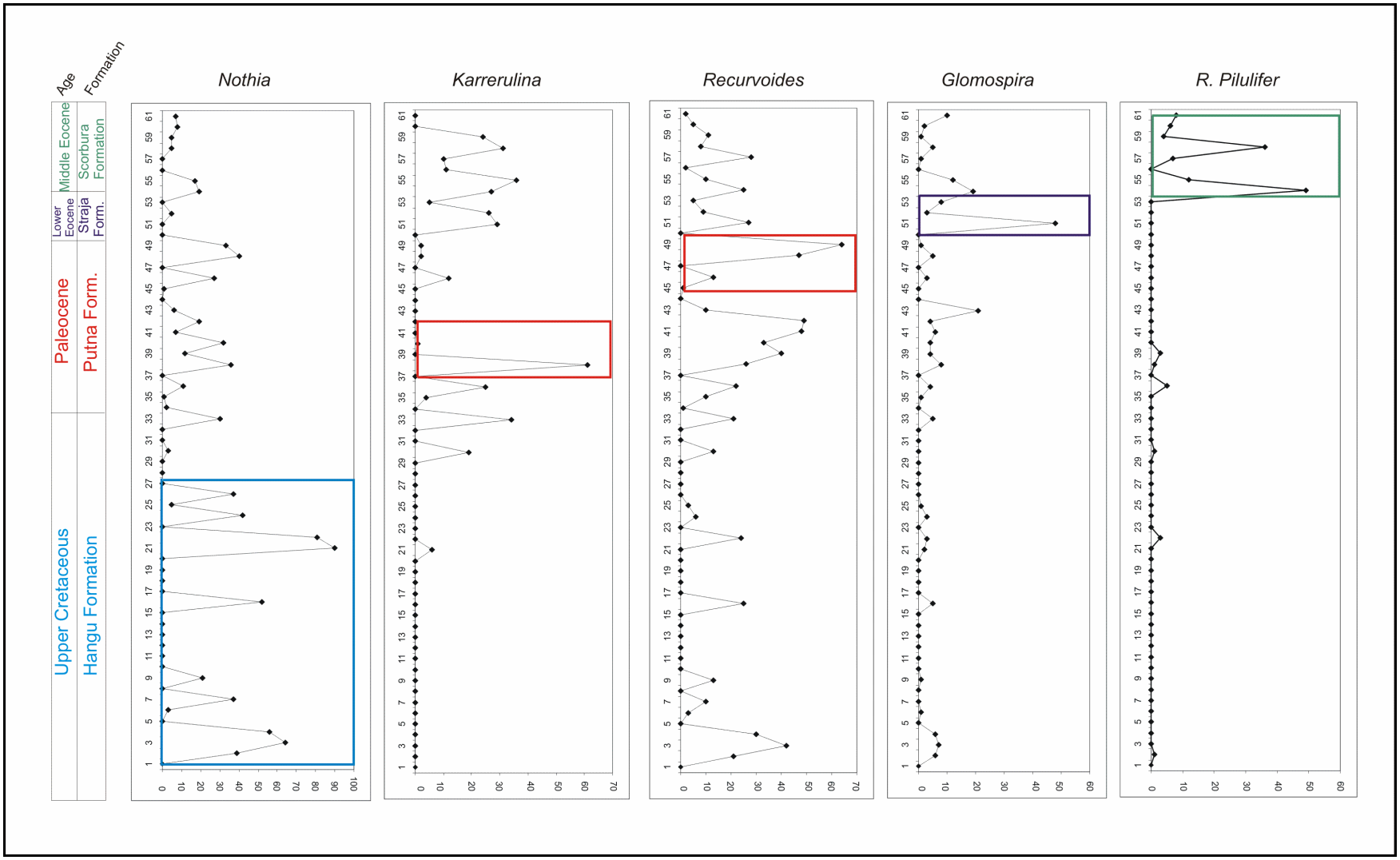

Figure 5. The abundance of the main foraminiferal taxa from Putna Valley.

1. The *Caudammina ovulum gigantea* zone, defined by the first and last occurrence of the taxon. In the Putnei Valley, the first occurrence of the taxon has been found in sample no. 2 and the last occurrence in sample 33.
2. The *Rzehakina fissistomata* zone, defined by the first and last occurrence of this taxon; it is characteristic to the Paleocene (Morgiel & Olszewska, 1981; Geroch & Nowak, 1984; Neagu et *al.*, 1992). In the Putnei Valley Section, the first occurrence has been identified in sample 38 and the last one in sample 48.
3. The *Glomospira* div. Zone: sample 51 (Straja Fromation – Lower Eocene) shows very high abundance of the *Glomospira charoides* and *Glomospira gordialis* species. This bioevent is characteristic to the Lower Eocene from many regions associated to the Tethys (Morgiel & Olszewska, 1981; Ortiz, 1995; Olszewska, 1997; Bak, 2004; Allegret et al., 2005, 2009, 2010; Giusberti et al., 2009; Bindiu & Filipescu, 2011).
4. The *Reophax pilulifer* zone, defined by the high abundance of the species in the interval from sample 54 to sample 57. This zone is characteristic for the upper part of the Middle Eocene in the Polish Carpathians (Morgiel & Olszewska, 1981).

The paleoecological reconstruction based on micropaleontological assemblages has been done by assigning species to agglutinated foraminifera morphogroups. The distribution of foraminifera morphogroups, the high relative and general abundance of certain species or genera and the values of the diversity suggest middle-bathyal deep-water environments with low organic matter flux in the basal part of the section (Upper Cretaceous), increased depth during the Paleocene (samples 35-49) with lower-bathyal to abyssal environments and good living conditions; these good conditions are preserved for the Lower and Middle Eocene interval.

4. 1. 4. Suha Valley and Suceava Valley 2

These two depositional sequences show similar lithologic character consisting of centimetrical/decimetrical layers of sandstones, clays and marls which belongs to the Putna (Izvor) Formation from the Tarcău Nappe (Săndulescu & Dimitrescu, 2004).

The Paleocene age is demonstrated by the presence of the *Rzehakina fissistomata* marker. The section from Suha Valley is characterized by frequent paleoenvironmental instability with variations in the content of organic matter and

oxygenation; at Suceava Valley 2 the foraminifera assemblages are dominated by tubular forms.

4. 1. 5. Palma

The deposits from Palma belong to the Putna (Izvor) Formation and consist of medium grained, very tectonized turbidites. The Paleocene age is given by the presence of *Rzehakina fissistomata*. The paleoecological interpretations are similar to those from Suceava Valley 2

4. 1. 6. Straja Vest and Brodina Valley 1

The sedimentary sequences consist of variegate clays (red and green) with layers of glauconitic sandstones; the upper parts of the sections consist of massive sandstones.

In both of the sections the diversity of foraminifera shows low values, the assemblages being composed of high percentages of *Glomospira charoides*, *G. gordialis*, *G. diffundens*. Thus, for both sections, we identified the "assemblage with *Glomospira*" typical for the Lower Eocene from the Tethys and North Atlantic. This bioevent suggests an increase of organic matter flux (Morgiel and Olszewska, 1981; Bak, 2004), an enrichment of productivity and oxygen deficit in surface waters (Arreguin-Rodriguez et al., 2013).

4. 1. 7. Dobra, Rusca and Grozăveşti

In these 3 locations we have noticed that the *Karrerulina conversa*, *Karrerulina horida and Karrerulina coniformis* species are present in very high ratios (41% of the whole count at Rusca). The abundance of these species supports the definition of the "*Karrerulina* assemblage". Similar assemblages have been identified in the Lower Eocene interval and above the *Glomospira* zone assemblages found in the Polish Carpathians (Bąk, 2004). This type of assemblage suggests deep water environments with high organic matter flux and relatively high Oxygen levels in the substrate.

4. 1. 8. Brodina Valley 3, Brodina Valley 6 and Voroneţ

At Brodina Valley 3, Brodina Valley 6 and Voroneţ we observed the first occurrence of some new taxa characteristic for Middle Eocene: *Reticulophragmium*

amplectens, *Ammodiscus latus*, *Reophanus berggreni*, *Eratidus gerochii*, *Haplophragmoides parvulus, Spirosigmoilinela compressa* şi *Psamminopelta gradseini.* Also, we noticed a relatively high abundance of *Reophax pilulifer* – a characteristic trait of the Middle Eocene age (Morgiel & Olszewska, 1981). At Brodina Valley 3, sample 8, the distribution of the morphogroups records a major change with high percentages of M1 (fig. 6) suggesting a transition from good to "stressed" life conditions.

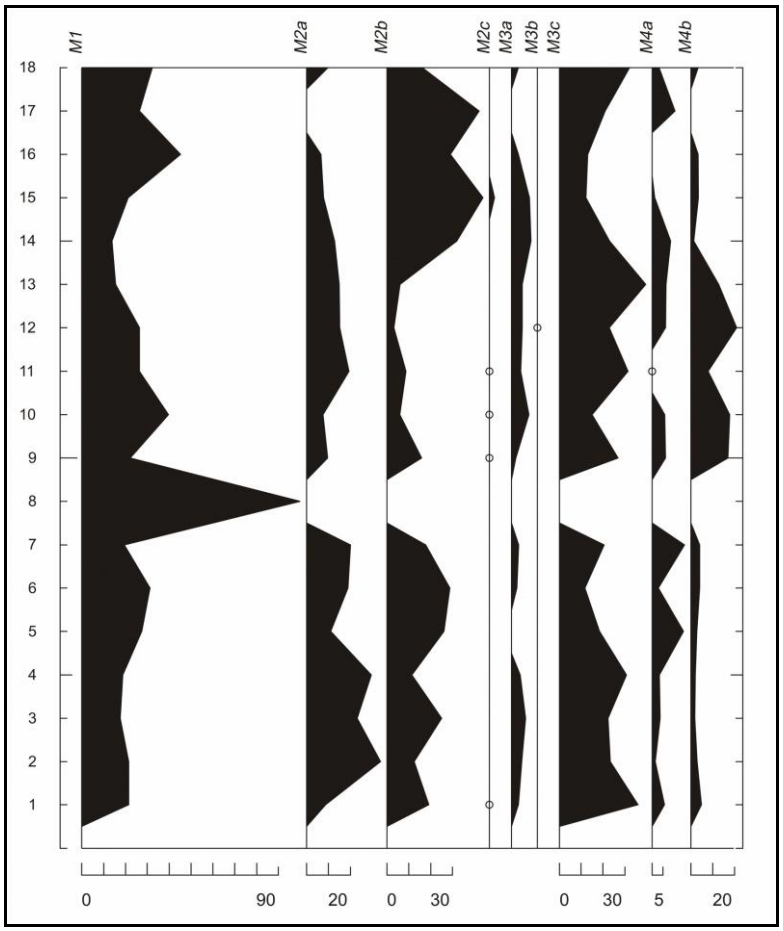

Figure 6. Distribution of agglutinated morphogroups at Valea Brodinei 3.

At Brodina Valley 6 and Voroneţ the diversity values are moderate and suggest stable paleoenvironmental conditions.

4. 1. 9. Suceava Valley 3

The sedimentary succession is represented by a rhythmical alternation of green and grey calcareous clays with thin sandstones, three red clays intervals being separated on the basal part of the section.

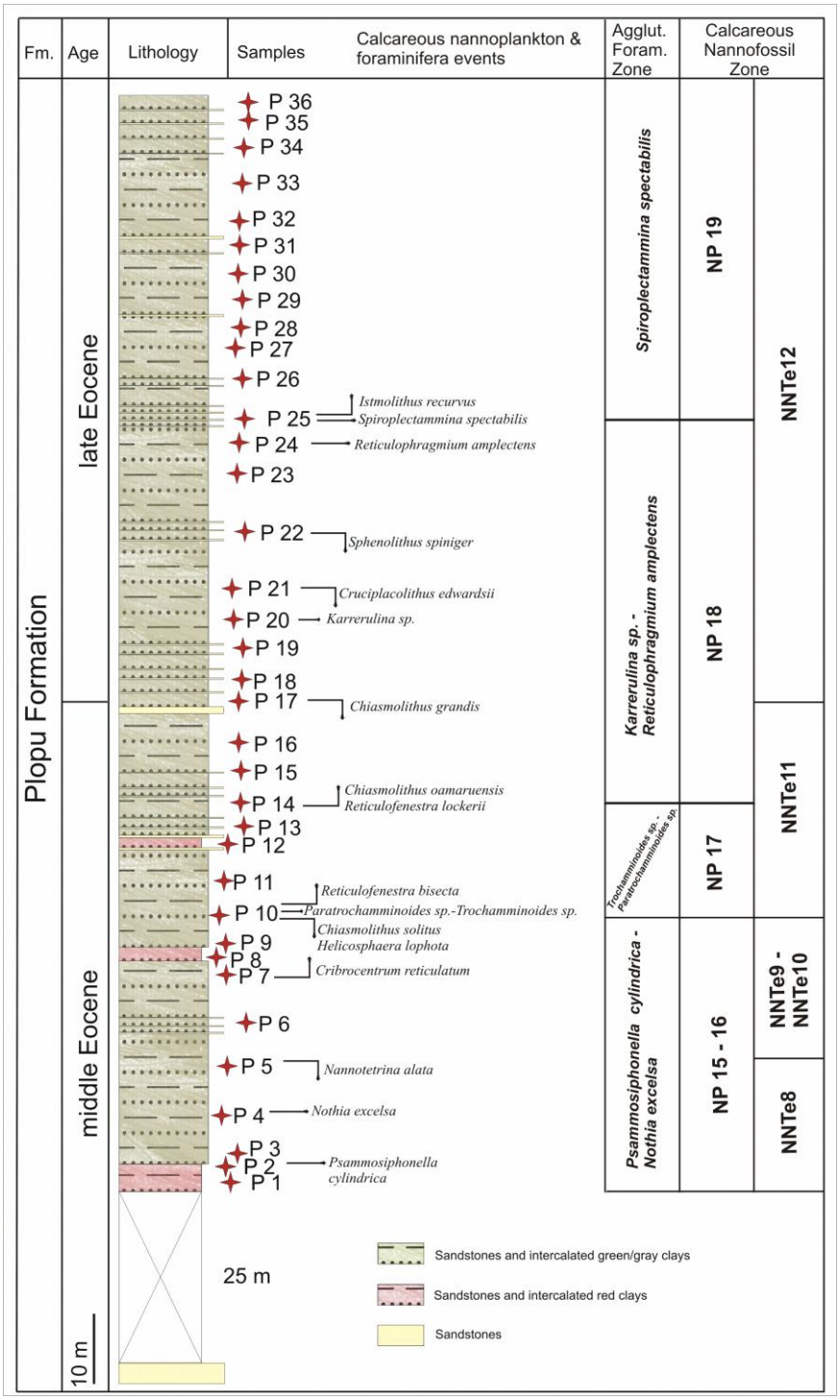

Figure 7. Sedimentary log and biostratigraphy of the Suceava Valley 3 section.

The biostratigraphical data (fig. 7) given by foraminifera (*Reticulophragmium amplectens*, *Spiroplectammina spectabilis*) and calcareous nannofossils (LO of *Chiasmolithus grandis* in sample 17; LO of *Cruciplacolithus edwardsii* –sample 21; LO of *Sphenolithus spiniger* – sample 22 and FO of *Istmolithus recurvus* – sample 25) prove that the boundary between middle and late Eocene is located within the Plopu

Formation, as some authors stated in the past (Joja et al. 1963, Agheorghiresei et al. 1967, Săndulescu et al. 1987, Bădescu, 2005). The foraminiferal and calcareous nannoplankton assemblages indicate a warm period with low organic matter flux and moderate oxygenation during the middle Eocene, followed by a cooling episode accompanied by an increase of organic matter and siliciclastic flux during the Late Eocene

4. 1. 10. Moldoviţei Valley

The deposits from Moldoviţei Valley are lithologically and micropaleontologically similar to those from the upper part of the Suceava Valley 3 section. We noticed the high abundance of *Spiroplectammina spectabilis* (morphogroup M2c), characteristic for the Late Eocene. The paleoecological interpretations are similar to those already established for the late Eocene in the Suceava Valley 3 succesion.

4. 1. 11. Humorului Valley

At Humorului Valley the outcrops are limited and consist of fine to medium grained turbidites. Most of the samples were almost barren micropaleontologically. However, we noticed the presence of *Reticulophragmium amplectens* and *Reophanus berggreni* which allow us to assign the middle – late Eocene age for these deposits (Kaminski & Gradstein, 2005).

4. 1. 12. Valea Boului

The section from Boului Valley consists of strongly tectonized turbidites made of alternations of centimetrical to decimentrical gray clays and sandstones. Based on calcareous nannofossils (*Triquetrorhabdulus carinatus, Helicosphaera ampliaperta*, *H. recta* etc. - NN1 – NN4 nannozones), Chira et al. (2011) considered that the age of these deposits is Lower Miocene. The only significant paleoecological information is based on the P/B ratio. The presence of the planktonic species suggests a decrease in the deposition depth and marine environments placed above the CCD.

4. 1. 13. Sections barren of foraminifera.

Unfortunately, a few sections were barren of foraminifera. These are: Ciumârna (5 samples), Dragoşa (5 samples), Molidu (2 samples), Argel (3 samples), Raşca (1 sample), Brodina Valley 4 (4 samples), Brodina Valley 5 (1 sample), Brodina Valley 7 (2 samples).

4.2. Correlation of the investigated sections

The analysis of foraminifera assemblages from the northern part of the Tarcău Nappe allows us to distinguish a few bioevents characteristic for the Upper Cretaceous – Late Eocene interval. Fig. 8 shows the stratigraphic distribution and the high abundances of the main foraminifera taxa with biostratigraphic significance. All these supported correlations between the investigated sections (fig. 9).

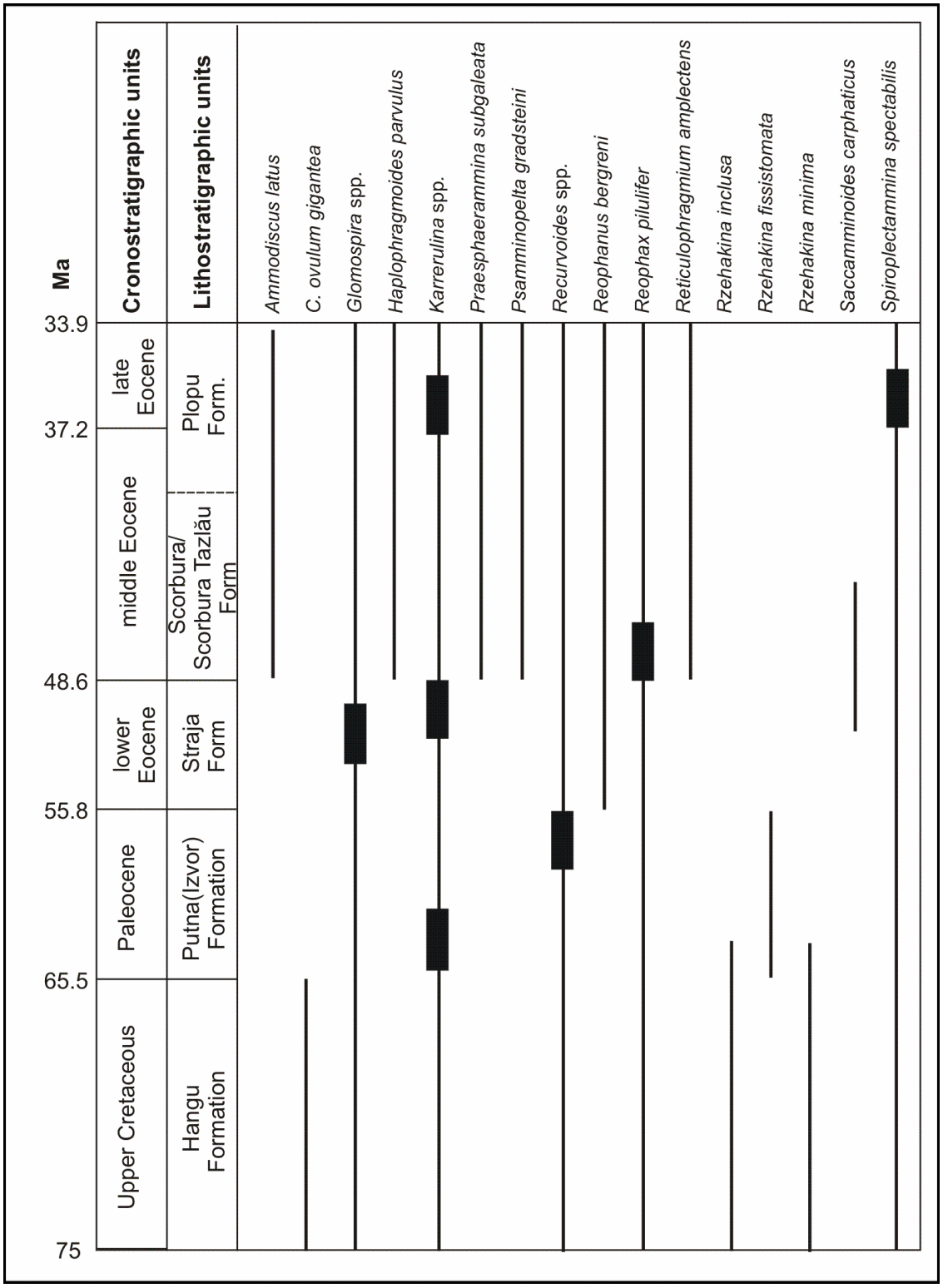

Figure 8. Stratigraphic distribution and high relative abundances of the main species of foraminifera with biostratigraphic significance in the northern part of the Tarcău Nappe.

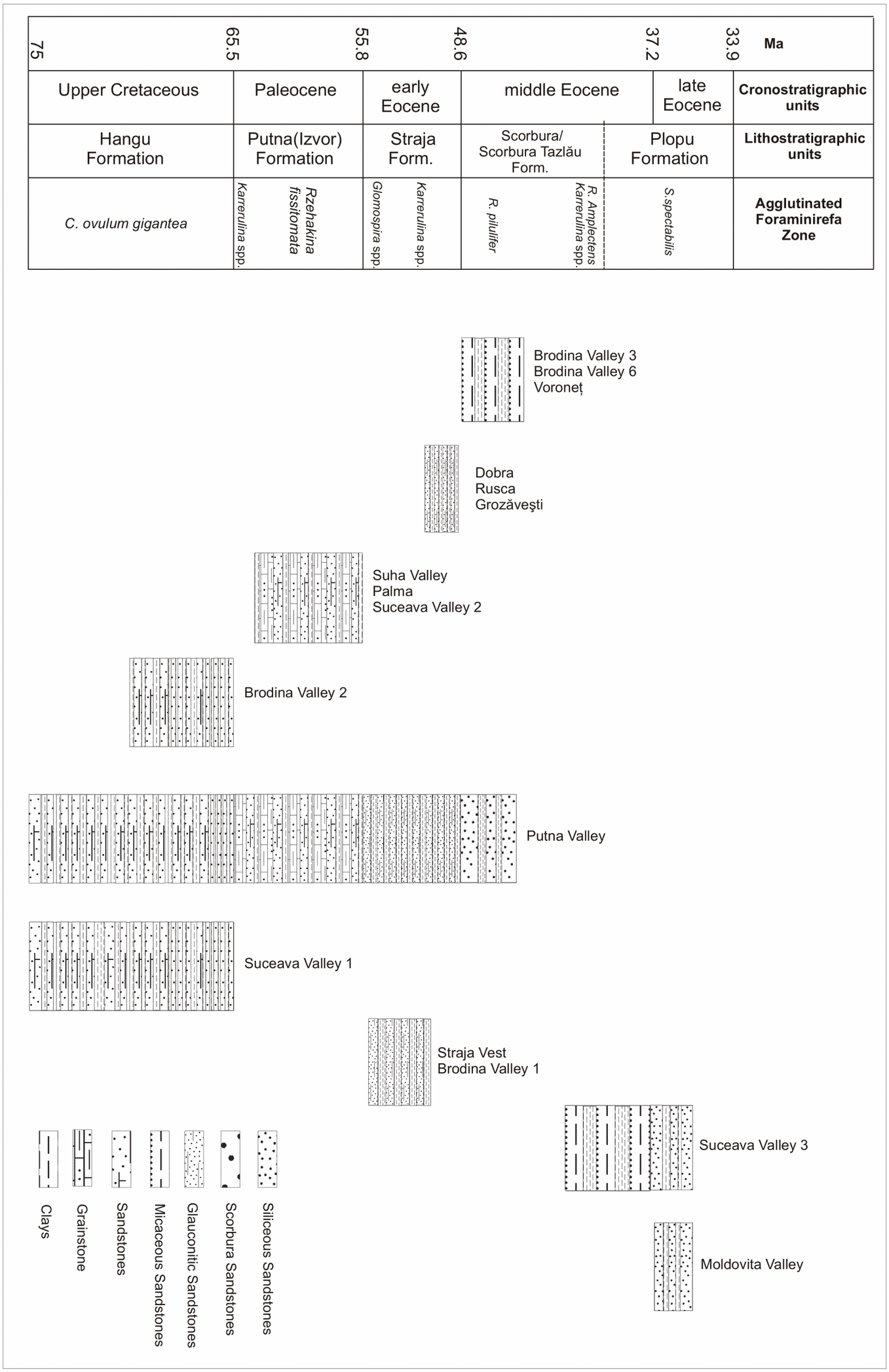

Figure 9. Correlation of the investigated sections in the northern part of the Tarcău Nappe.

Chapter V. Systematic Description of the Foraminifera from the Northern Part of the Tarcău Nappe

More than 230 species of foraminifera have been identified in the northern part of the Tarcău Nappe.

The identified agglutinated foraminifera have been arranged in taxonomic order by following the suprageneric classification of Kaminski (2004). Benthic foraminifera are arranged following the suprageneric classification of Loeblich & Tappan (1987). Planktonic foraminifera follow the classification of Kennett and Srinivasan (1983).
Species identification is based mainly on the works of Morkhoven et al. (1986), Kennett & Srinivasan (1983), Morkhoven et al. (1986), Kaminski & Geroch (1993), Bolli et al. (1994), Cicha et al. (1998), Premoli-Silva & Sliter (2002), Premoli-Silva et al. (2003), Premoli-Silva & Verga (2004), Kaminski & Gradstein (2005), Pearson et al. (2006).

Chapter VI. Conclusions

The analysis of fossil foraminiferal assemblages from the northern part of the Tarcău Nappe (Eastern Carpathians) was the main objective of this study; it aimed to establish biostratigraphical marks and to reconstruct the paleoenvironmental parameters that controlled the foraminiferal populations in the context of the evolution of the depositional basins throughout the Upper Cretaceous to Oligocene and Miocene interval.

Overall, the foraminiferal assemblages are dominated by agglutinated foraminifera, characteristic to deep water environments (from upper-bathyal to abyssal) that host the representative formations of the northern area of the Tarcău Nappe.

The composition of the agglutinated foraminifera morphogroups and the statistic diversity analyses show that all the populations belong to the „flysch type" foraminifera biofacies, consisting of coarsely agglutinated individuals typical for deep-water environments.

Based on the first and last occurrence of some species having regional biostratigraphical value and some bioevents that generate peculiar abundances, seven

„zones" of agglutinated foraminifera have been identified covering the Upper Cretaceous – Upper Eocene interval:

- The "*Caudammina ovulum giganteea*" Zone, defined by the first and last occurrence of the taxon, has been identified in the Sucevei Valley 1, Brodinei Valley 2 and Putnei Valley sections. It is characteristic to the Hangu Formation and, from a biostratigraphic point of view, defines the Campanian – Upper Maastrichtian interval.
- The "*Rzehakina fissistomata*" Zone is characteristic to the Paleocene; it has been defined by the first and last occurrence of the index species. It is typical for the Putna (Izvor) Formation and has been idenfied in the Suha Valley, Palma, Sucevei Valley 2 and Putna Valley sections.
- The "*Glomospira*" Zone is specific to the Straja Formation and has been identified în the Straja Vest, Brodinei Valley 1 and Putnei Valley sections. It is defined by the high abundance of the *Glomospira charoides*, *G. gordialis*, *G. serpens* species and it is particular to the lower part of the Eocene.
- The "*Reophax pilulifer*" Zone defines the lower part of the Middle Eocene in the Scorbura Formation that we encountered at Putnei Valley, Brodinei Valley 3, Brodinei Valley 6 and Voroneț. It has been defined based on the high abundance of the species.
- The "*Reticulophragmium amplectens* şi *Karrrerulina*" Zone has been identified in the Sucevei Valley 3 section. It is characteristic to the Middle to Upper Eocene in the Plopu Formation.
- The "*Spiroplectammina spectabilis*" Zone is defined by the high abundance of the index species; it is specific to the Upper Eocene în the Plopu Formation, encountered at Suceava Valley 3 and Moldoviței Valley.

A peculiar situation is observed with respect to the "*Karrerulina*" Zone, characterized by high abundances of *Karrerulina conversa* and *K. horrida* and suggesting eutrophic paleoenvironments. Although this zone was described as being specific to the Lower Eocene, in the present study it has been identified in the paleocene depositional sequences from Putnei Valley, the lower eocene sequences from the Dobra Valley, Rusca, Grozăvești and the middle eocene sequences from

Sucevei Valley 3. The presence of this zone in different stratigraphical levels suggests that its importance is more paleoecological than biostratigraphical.

These seven ecozones with agglutinated foraminifera allow temporal and spatial correlation of the individual facies.

The composition of the studied assemblages of foraminifera solves the controversy regarding the age of the Plopu Formation. In the Suceava Valley 3 section, the identified foraminifera and calcareous nannofossils are characteristic to the Middle Eocene – Late Eocene interval; the middle/late Eocene boundary is placed within the Plopu Formation.

The identified assemblages of foraminifera allowed delineating of the evolution of the sedimentary basin during the Upper Cretaceous – Oligocene and Miocene interval:

- During the Upper Cretaceous the settings were upper/middle bathyal with low content of organic matter flux;
- The Paleocene was defined by a deepening of the deposition to middle/lower bathyal to abyssal settings;
- The beginning of the Eocene was characterized by unstable middle bathyal settings with low sedimentary rate;
- In the middle and upper Eocene the settings were upper bathyal;
- The planktonic foraminifera from the Oligocene and Miocene suggest a new episode of marine flooding.

The sequence of the identified paleoenvironments allows a reconstruction of the sea level trends even if in turbiditic environments such an interpretation is typically difficult. Thus, we can identify transgressive intervals during the Paleocene and Oligocene and Miocene, enclosing a regressive interval during the Middle Eocene.

The present study provides an overview of the temporal and spatial distribution of the foraminifera assemblages and of the evolution of the sedimentary basin in the northern part of the Tarcău Nappe; it provides criteria for local and regional facies correlation and allows the reconstruction of a part of the sedimentary basin history controlled by the dynamics of the Carpathians.

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Selected Plates

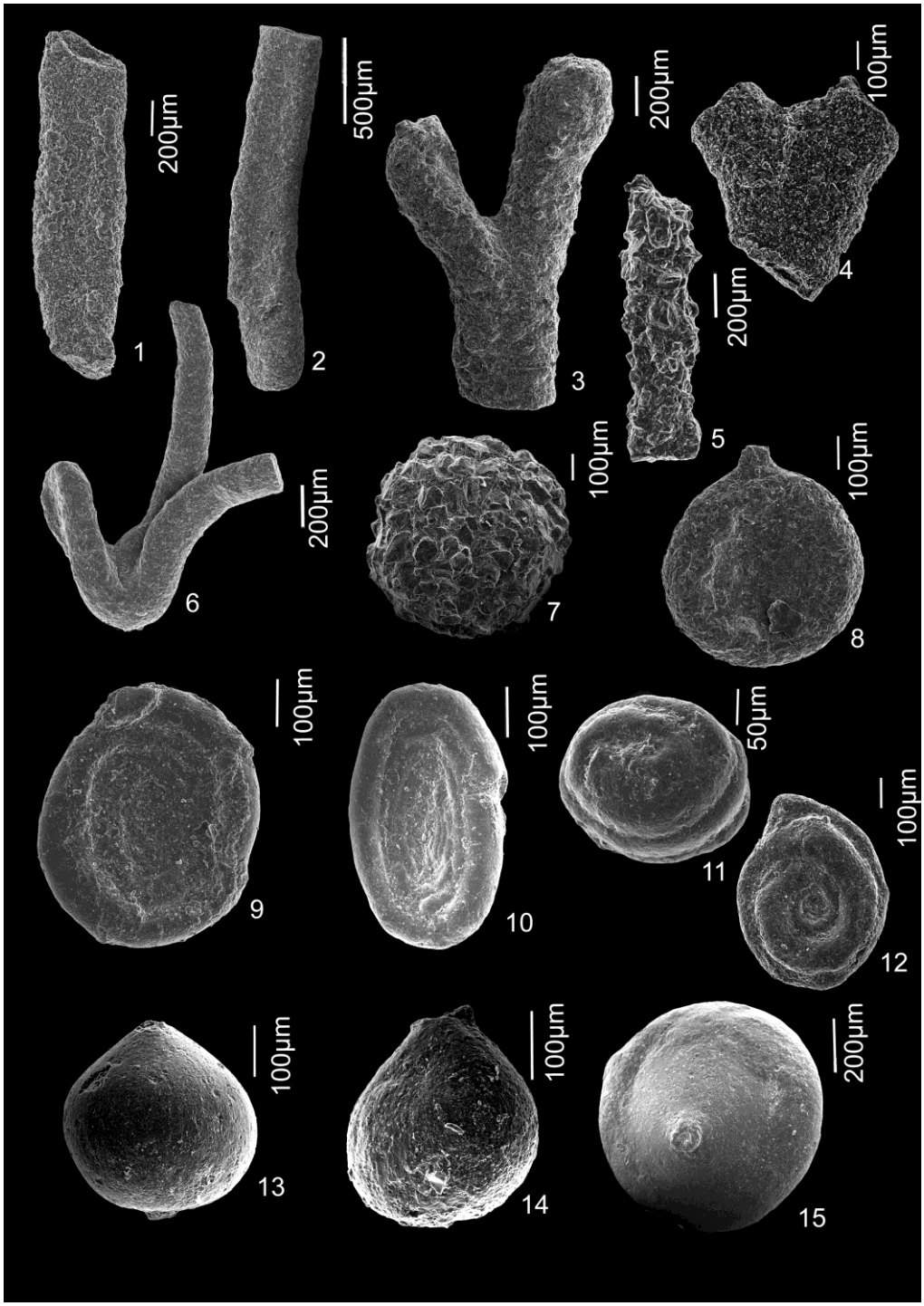


Plate 1. Agglutinated Foraminifera from Suceava Valley 1:1 – *Bathysiphon* sp. – sample 2; 2 – *Nothia excelsa* (Grzybowski) – sample 2; 3 – *Nothia excelsa* (Grzybowski) – sample 5; 4 – *Nothia excelsa* (Grzybowski) – sample 7; 5 – *Rhabdammina* sp. – sample 14;6 – *Rhizammina* sp. – sample 23; 7 – *Psammosphaera irregularis* (Grzybowski) – sample 6; 8 – *Placentammina placenta* (Grzybowski) – sample 10; 9 – *Ammodiscus cretaceus* (Reuss) – sample 4; 10 – *Ammodiscus peruvianus* Berry – sample 7; 11 – *Glomospira gordialis* (Jones & Parker) – sample 17; 12 – *Glomospira* sp. – sample 14; 13 – *Caudammina ovula* (Grzybowski) – sample 13; 14 - *Caudammina ovula* (Grzybowski) – sample 19; 15 – *Caudammina ovulum gigantea* (Geroch) – sample 15.

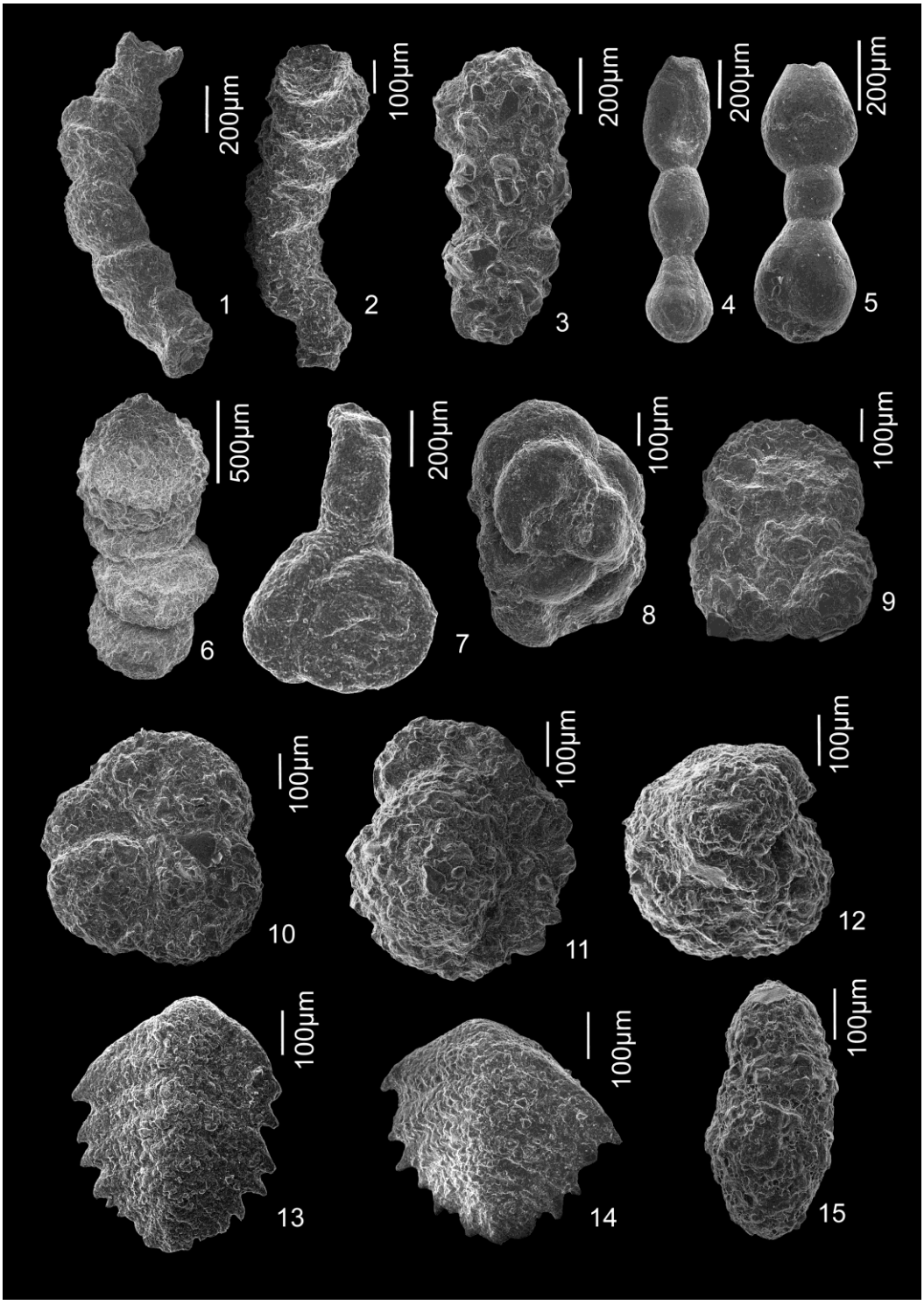


Plate II. Agglutinated Foraminifera from Suceava Valley 1: 1 – *Subreophax scalaris* (Grzybowski) – sample 3; 2 – *Subreophax scalaris* (Grzybowski) – sample 23; 3 – *Reophax globosus* Sliter – sample 1; 4 – *Hormosina velascoensis* (Cushman) – sample 2; 5 – *Hormosina velascoensis* (Cushman) - sample 17; 6 – *Hormosina trinitatensis* Cushman & Renz – sample 4; 7 – *Lituotuba lituiformis* (Brady) – sample 21; 8 – *Paratrochamminoides acervulatus* (Grzybowski) – sample 13; 9 – *Trochamminoides variolarius* (Grzybowski) – sample 8; 10 – *Haplophragmoides kirki* Wickenden – sample 1; 11 – *Recurvoides anormis* Mjatliuk – sample 5; 12 – *Recurvoides anormis* Mjatliuk – sample 8; 13 – *Spiroplectinella dentata* (Alth) – sample 6; 14 - *Spiroplectinella dentata* (Alth) - sample 21; 15 – *Karrerulina* sp. – sample 17.

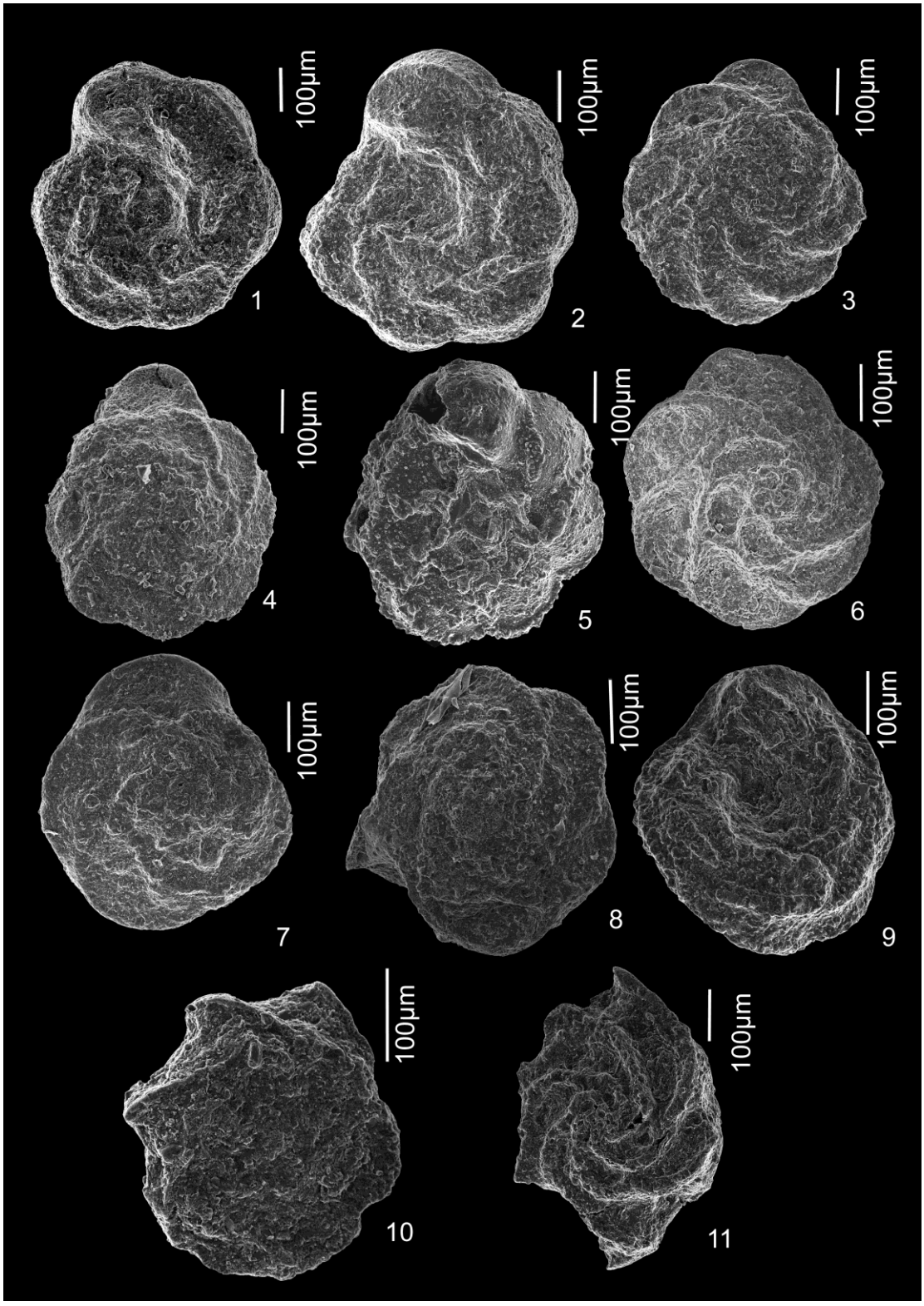


Plate 3. Planktonic foraminifera from Suceava Valley 1: 1 – *Globotruncana ventricosa* White – sample 1; 2 – *Globotruncana ventricosa* White – sample 3; 3 – *Globotruncana ventricosa* White – sample 4; 4 – *Globotruncana ventricosa* White – sample 8; 5 – *Globotruncana arca* (Cushman) – sample 11; 6 – *Globotruncanita elevata* (Brotzen) – sample 1; 7 – *Globotruncanita elevata* (Brotzen) – sample 1; 8 – *Globotruncanita elevata* (Brotzen) – sample 4; 9 – *Globotruncana* sp. – sample 4**;** 10 – *Globotruncana* sp. – sample 5; 11 – *Radotruncana calcarata* (Cushman) – sample 4.

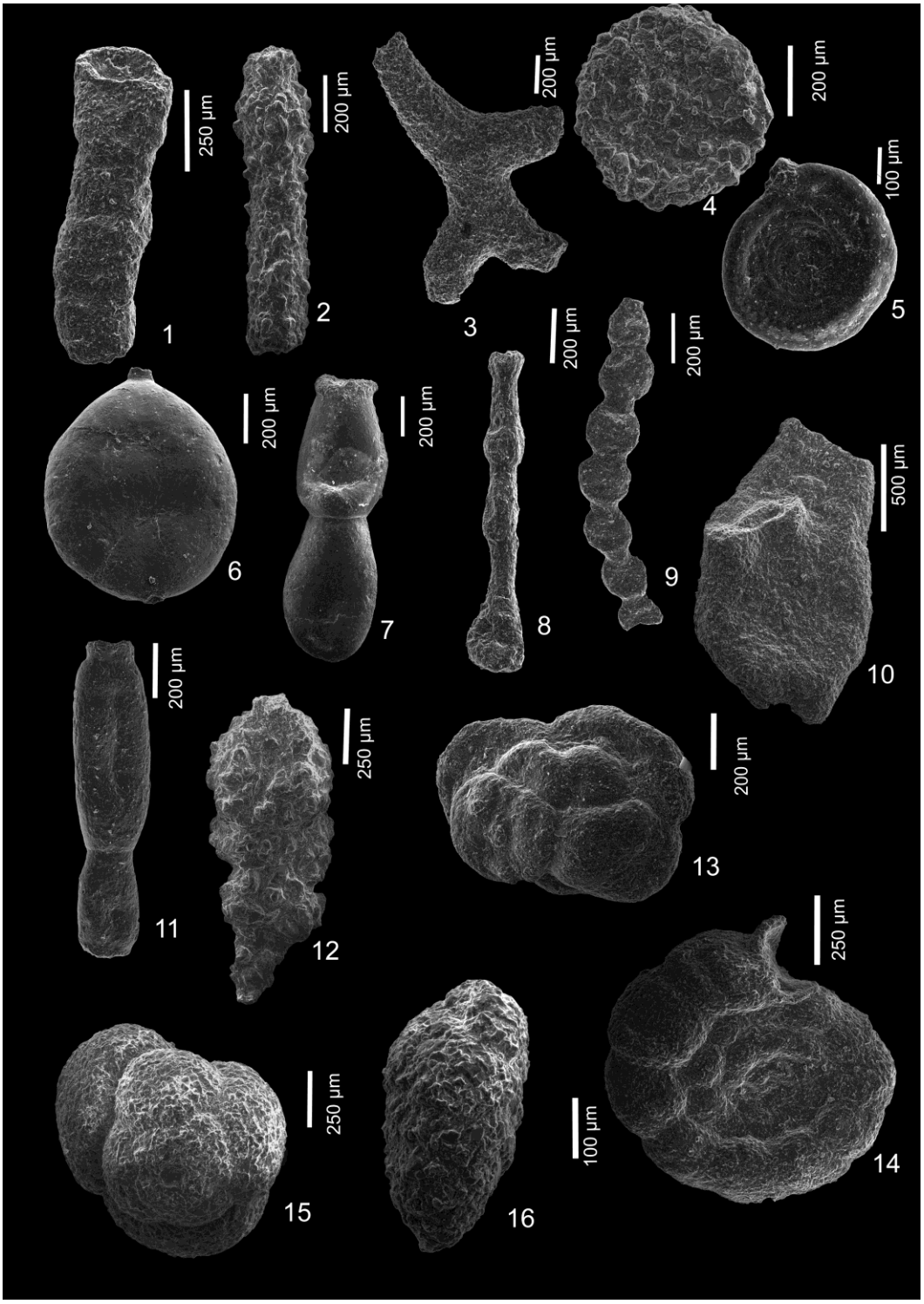


Plate 4. Agglutinated foraminifera from Brodina Valley 2: 1 – *Bathysiphon* sp. – sample 9; 2 – *Psammosiphonella discreta* (Brady) – sample 10; 3 – *Rhabdammina abyssorum* Sars – sample 6; 4 – *Psammosphaera irregularis* (Grzybowski) – sample 5; 5 – *Ammodiscus* sp. – sample 1; 6 – *Caudammina ovulum gigantea* (Geroch) – sample 6; 7 – *Caudammina ovuloides* (Grzybowski) – sample 8; 8 – *Caudammina excelsa* (Dylążanka) – sample 4; 9 – *Hormosinelloides gutifer* (Brady) – sample 7; 10 – *Aschemocella carphatica* (Neagu) – sample 6; 11 – *Kalamopsis grzybowski (*Dylążanka) – sample 4; 12 – *Reophax globosus* Sliter – sample 2; 13 – *Trochamminoides subcoronatus* (Grzybowski) – sample 10; 14 – *Trochamminoides proteus* (Karrer) – sample 7; 15 – *Conotrochammina voerigensis* Gradstein & Kaminski – sample 9; 16 – *Karrerulina* sp. – sample 10.

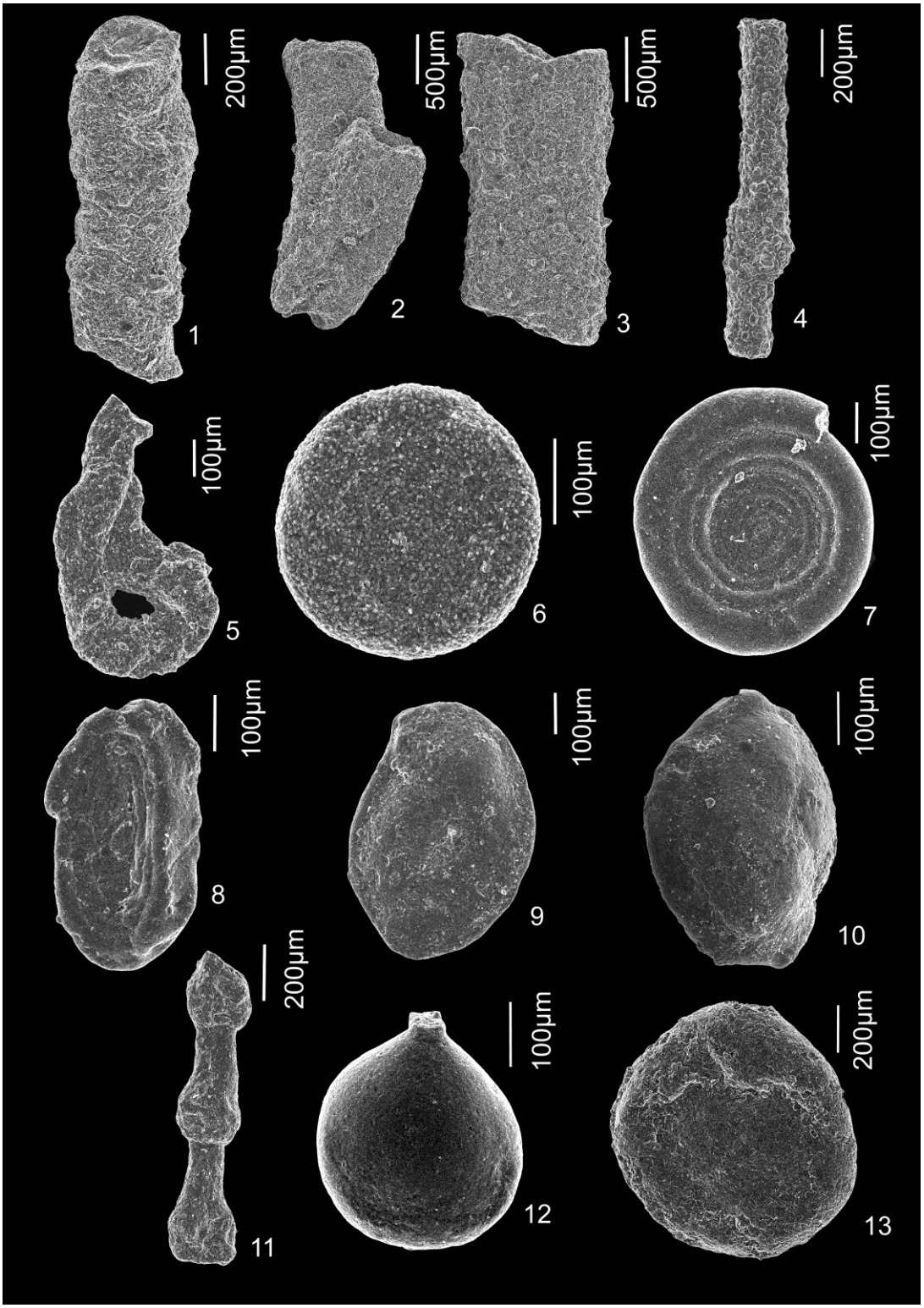


Plate 5. Agglutinated foraminifera from Putna Valley (Upper Cretaceous): 1 – *Bathysiphon* sp. – sample 6; 2 – *Nothia robusta* (Grzybowski) – sample 2; 3 – *Nothia latissima* (Grzybowski) – sample 3; 4 – *Rhabdammina linearis* Brady – sample 16; 5 – *Rhizammina* sp. – sample 6; 6 – *Placentammina placenta* (Grzybowski) – sample 9; 7 – *Ammodiscus cretaceus* (Reuss) – sample 33; 8 – *Ammodiscus peruvianus* Berry – sample 22; 9 – *Rzehakina inclusa* (Grzybowski) – sample 26; 10 – *Rzehakina inclusa* (Grzybowski) – sample 27; 11 – *Caudammina excelsa* (Dylążanka) – sample 30; 12 – *Caudammina ovula* (Grzybowski) – sample 24; 13 – *Caudammina ovulum gigantea* (Geroch) – sample 3.

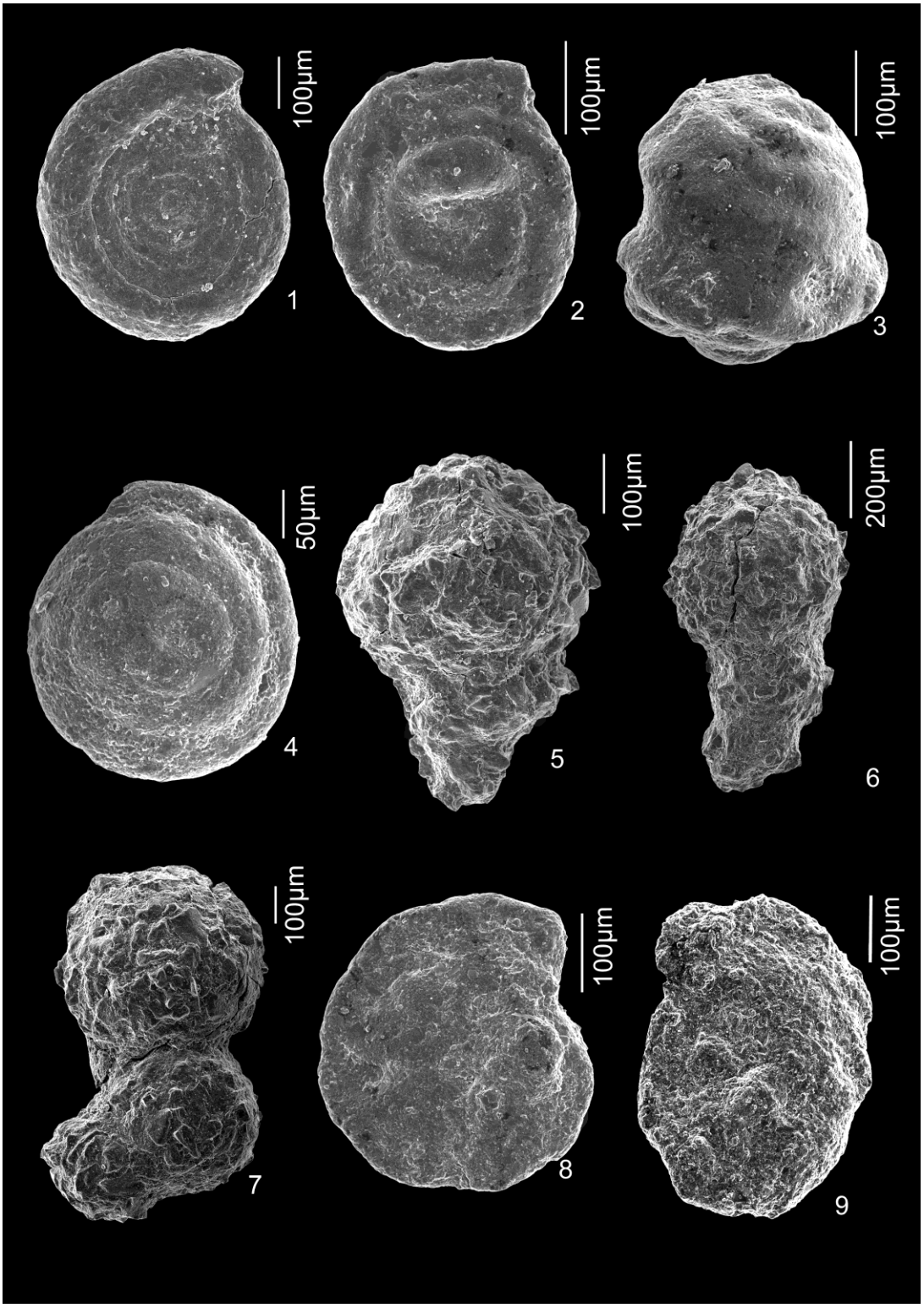


Plate 6. Agglutinated foraminifera from Putna Valley (Eocene): 1 – *Ammodiscus latus* Grzybowski – sample 61; 2 – *Ammodiscus penny* Cushman & Jarvis – sample 57; 3 – *Glomospira charoides* (Jones & Parker) – sample 51; 4 – *Glomospira charoides* (Jones & Parker) – sample 51; 5 – *Saccamminoides carpathicus* Geroch – sample 54; 6 – *Reophax pilulifer* Brady – sample 54; 7 – *Reophax pilulifer* Brady – sample 58; 8 – *Haplophragmoides excavatus* Cushman & Waters – sample 51; 9 – *Trochamminoides subcoronatus* (Grzybowski) – sample 52.

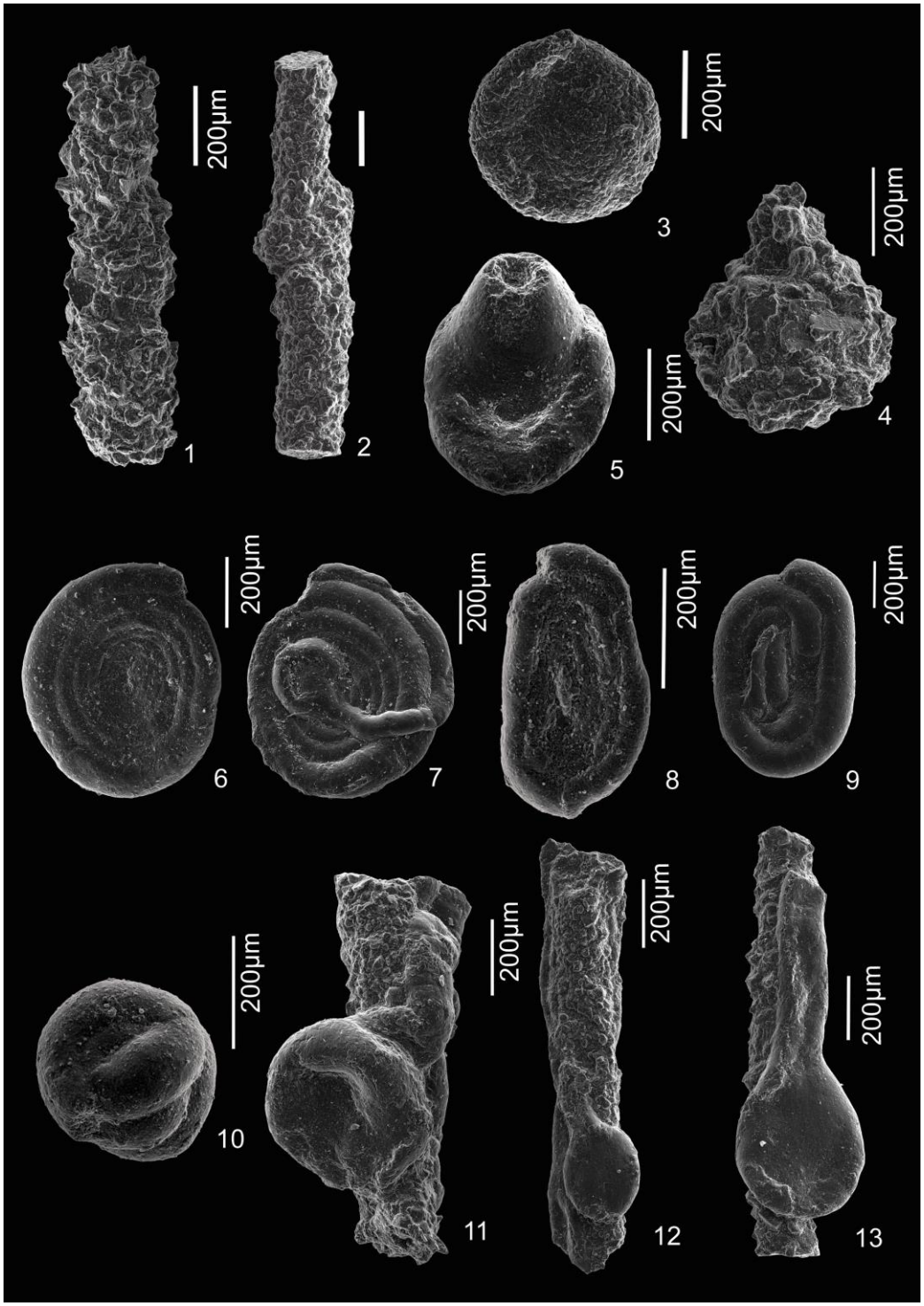


Plate 7. Agglutinated foraminifera from Suha Valley: 1 – *Rhabdammina* sp. – sample 4; 2 – *Rhabdammina linearis* Brady – sample 6; 3 – *Placentammina placenta* (Grzybowski) – sample 1; 4 – *Saccammina grzybowskii* (Schubert) – sample 11; 5 – *Hyperammina dilatata* Grzybowski – sample 2; 6 – *Ammodiscus cretaceus* (Reuss) – sample 10; 7 – *Ammolagena clavata* Jones & Parker fixată pe *Ammodiscus* sp. – sample 9; 8 – *Ammodiscus peruvianus* Berry – sample 5; 9 – *Annectina grzybowskii* (Jurkiewicz) – sample 7; 10 – *Glomospira* sp. – sample 6; 11 – *Ammolagena clavata* Jones & Parker fixată pe *Rhabdammina* sp. – sample 5; 12 – *Ammolagena clavata* Jones & Parker fixată pe *Psammosiphonella* sp. – sample 6; 13 – *Ammolagena clavata* Jones & Parker fixată pe *Psammosiphonella* sp. – sample 15.

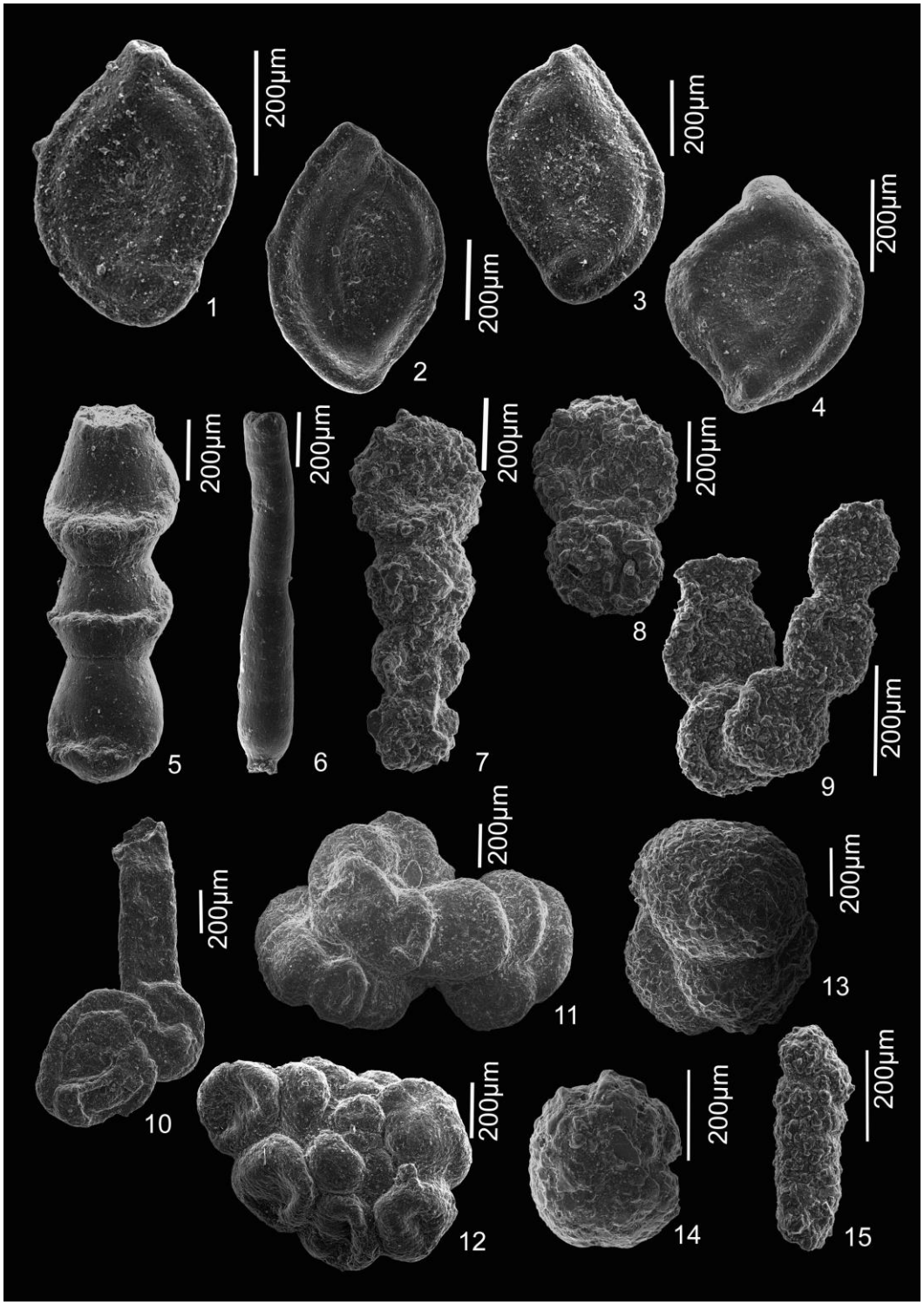


Plate 8. Agglutinated foraminifera from Suha Valley. 1 – *Rzehakina fissistomata* (Grzybowski) – sample 1; 2 – *Rzehakina fissistomata* (Grzybowski) – sample 2; 3 – *Rzehakina fissistomata* (Grzybowski) – sample 4; 4 – *Rzehakina fissistomata* (Grzybowski) – sample 9; 5 – *Hormosina velascoensis* (Cushman) – sample 10; 6 – *Kalamopsis grzybowski (*Dylążanka) – sample 17; 7 – *Reophax globosus* Sliter – sample 5; 8 – *Reophax duplex* Grzybowski – sample 15 ; 9 – *Subreophax scalaris* (Grzybowski) – sample 14; 10 – *Lituotuba lituiformis* (Brady) – sample 15; 11 – *Paratrochamminoides mitratus* (Grzybowski) – sample 7; 12 – *Paratrochamminoides deflexiformis* (Noth) – sample 2; 13 – *Trochamminoides variolarius* (Grzybowski) – sample 9; 14 – *Recurvoides* sp. – sample 7; 15 – *Karrerulina conversa* (Grzybowski) – sample 11

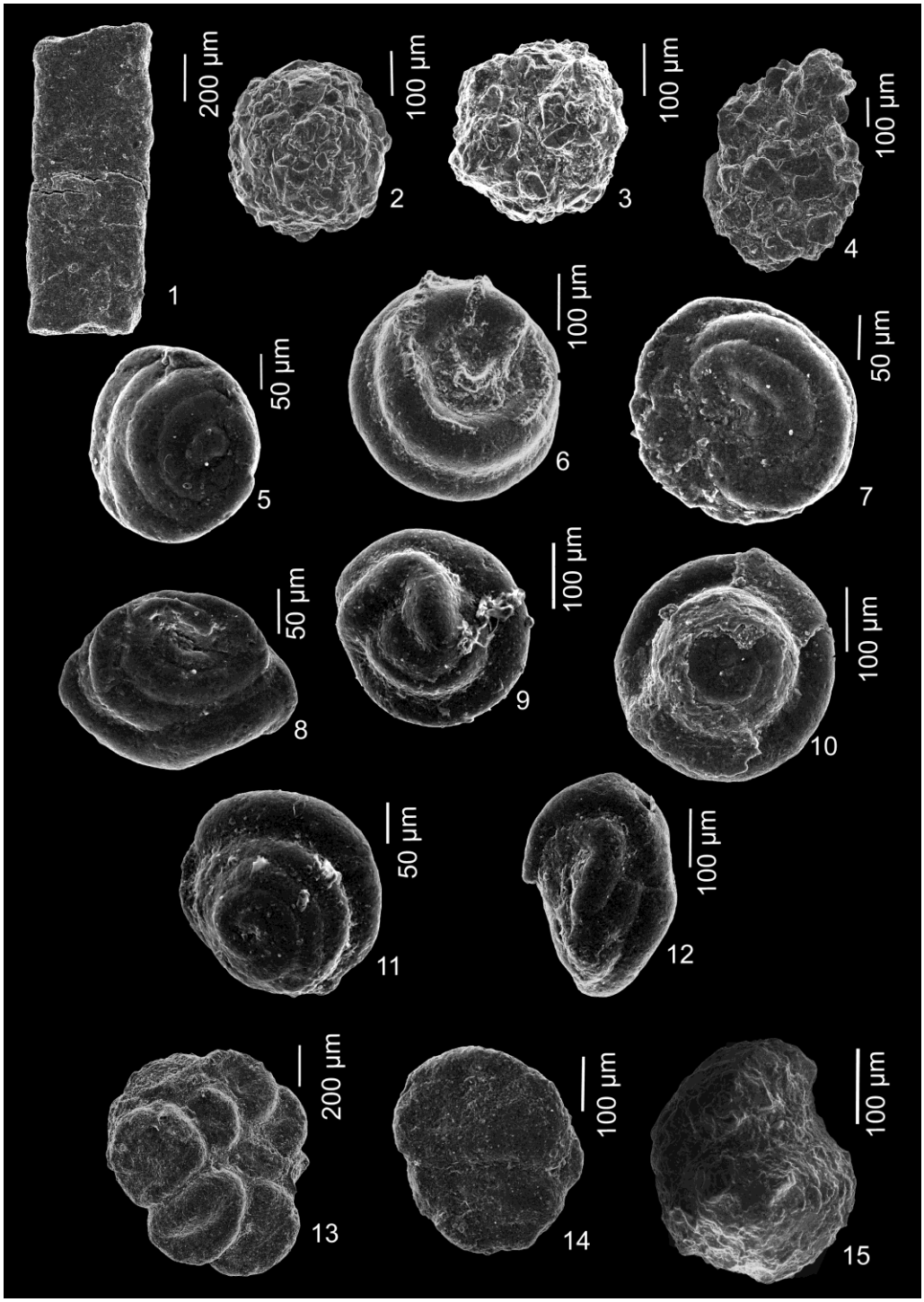


Plate 9. Agglutinated foraminifera from Straja Vest and Brodina Valley 1:
1 – *Nothia* sp. (Straja) – sample 1; 2 – *Psammosphaera irregularis* (Grzybowski) (Straja) – sample 1; 3 –. *Psammosphaera fusca* Schultze (Straja) – sample 1; 4 – *Saccammina grzybowskii* (Schubert) (Straja) – sample 1; 5 – *Glomospira diffundens* Cushman & Renz (Straja) – sample 1; 6 – *Glomospira gordialis* (Jones & Parker) (Straja) – sample 1; 7 – *Glomospira gordialis* (Jones & Parker) (Straja) – sample 1; 8 – *Glomospira gordialis* (Jones & Parker) (Straja) – sample 1; 9 – *Glomospira gordialis* (Jones & Parker) (Valea Brodinei 1) – sample 2; 10 – *Glomospira charoides* (Jones & Parker) (Straja) – sample 1; 11 – *Glomospira charoides* (Jones & Parker) (Valea Brodinei 1) – sample 3; 12 – *Glomospira serpens* (Grzybowski) (Straja) – sample 1; 13 – *Trochamminoides subcoronatus* (Grzybowski) (Straja) – sample 1; 14 – *Ammosphaeroidina pseudopauciloculata* (Mjatliuk) (Valea Brodinei 1) – sample 4;
15 – *Recurvoides* sp. (Valea Brodinei 1) – sample 5

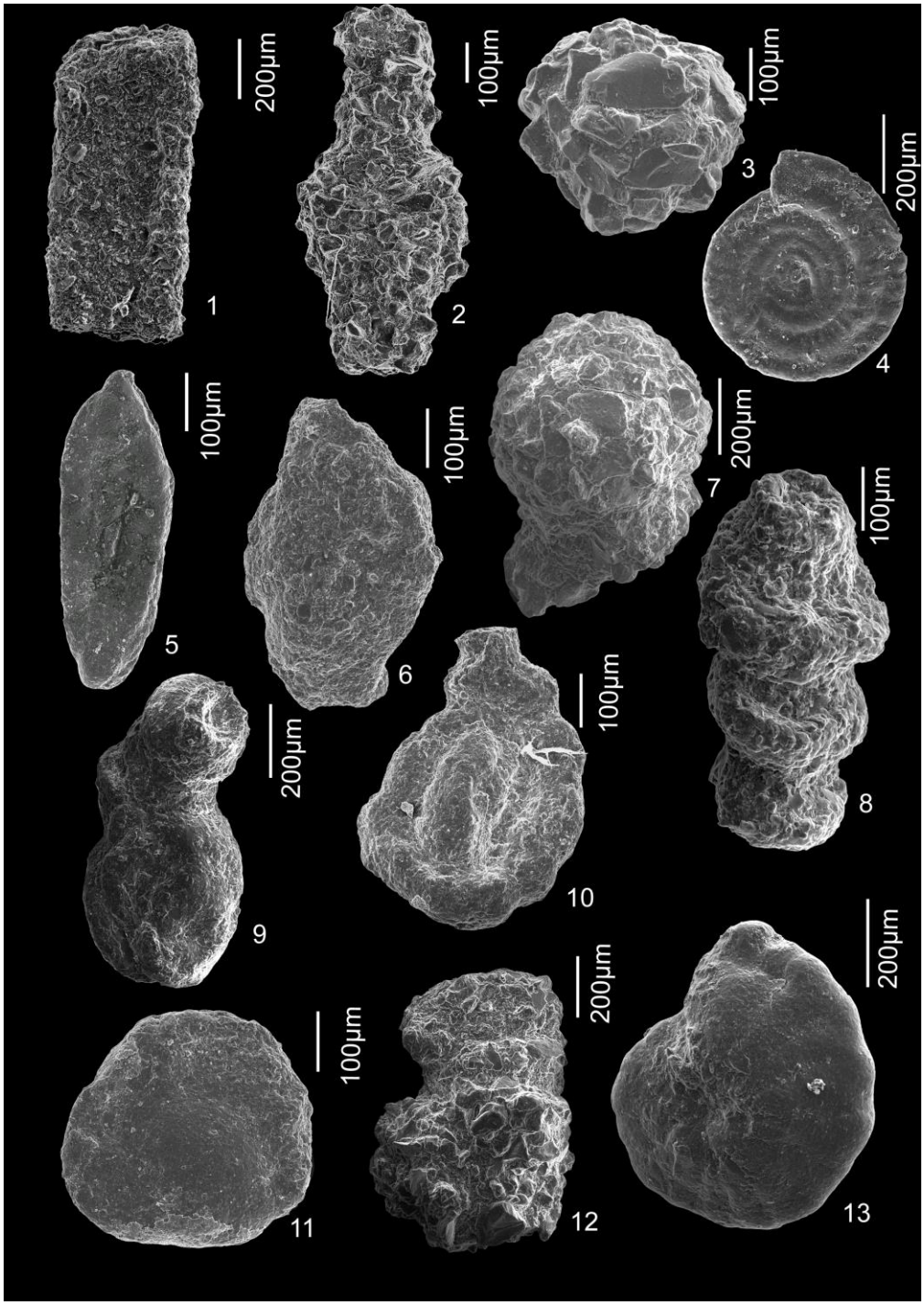


Plate 10. Agglutinated foraminifera from Brodina Valley 3, Brodina Valley 6 and Voroneţ: 1 – *Nothia excelsa* (Grzybowski) (Valea Brodinei 3) – sample 8; 2 – *Rhabdammina linearis* Brady (Valea Brodinei 3) – sample 12; 3 – *Psammosphaera fusca* Schultze (Valea Brodinei 6) – sample 1; 4 – *Ammodiscus tenuissimus* Grzybowski (Valea Brodinei 6) – sample 2; 5 – *Psamminopelta gradsteini* (Matsunaga) (Valea Brodinei 3) – sample 12; 6 – *Reophanus berggreni* Gradstein & Kaminski (Valea Brodinei 3) – sample 9; 7 – *Saccamminoides carpathicus* Geroch (Voroneţ) – sample 1; 8 – *Hormosina velascoensis* (Cushman) (Voroneţ) – sample 1; 9 – *Paratrochamminoides heteromorphus* (Grzybowski) (Valea Brodinei) – sample 13; 10 – *Trochamminoides grzybowskii* Kaminski & Geroch (Voroneţ) – sample 1; 11 – *Praesphaerammina subgaleata* (Vašiček) (Voroneţ) – sample 2; 12 – *Ammobaculites agglutinans* (d'Orbigny) (Valea Brodinei 3) – sample 7; 13 – *Reticulophragmium amplectens* (Grzybowski) - (Voroneţ) – sample 1.

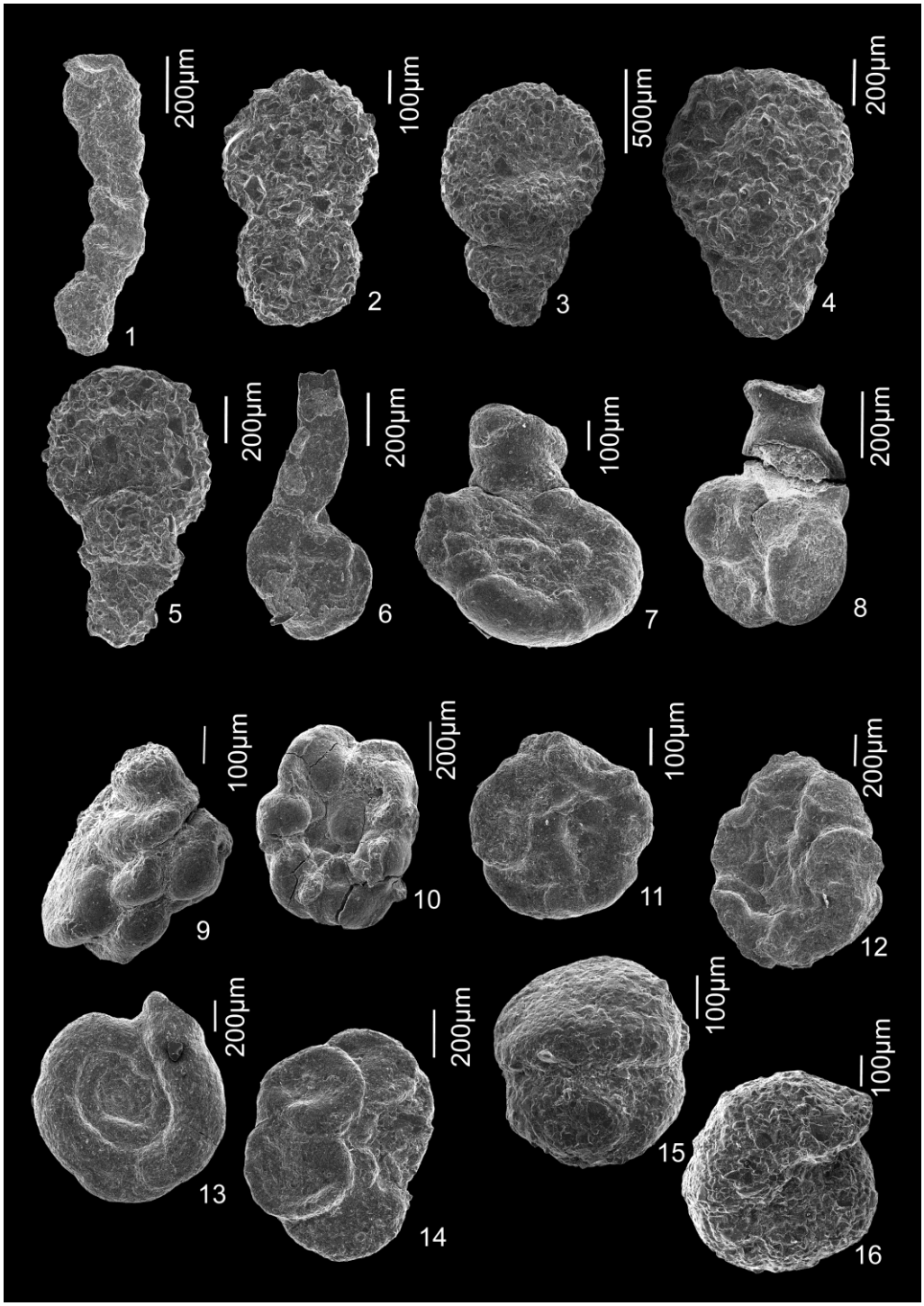


Plate 11. Agglutinated foraminifera from Suceava Valley 3: 1 – *Subreophax scalaris* (Grzybowski) – sample 31; 2 – *Reophax duplex* Grzybowski – sample 22; 3 – *Hormosina trinitatensis* Cushman & Renz – sample 25; 4 – *Hormosina trinitatensis* Cushman & Renz – sample 27; 5 – *Hormosina trinitatensis* Cushman & Renz – 29;6 – *Lituotuba lituiformis* (Brady) – sample 31; 7 – *Paratrochamminoides heteromorphus* (Grzybowski) – sample 10; 8 – *Paratrochamminoides heteromorphus* (Grzybowski) – sample 13; 9 – *Paratrochamminoides acervulatus* (Grzybowski) – sample 10; 10 – *Paratrochamminoides acervulatus* (Grzybowski) – sample 11; 11 – *Paratrochamminoides* sp. 1 – sample 2; 12 – *Paratrochamminoides* sp. 2 – sample 10; 13 – *Trochamminoides* sp. – sample 9; 14 - *Trochamminoides subcoronatus* (Grzybowski) – sample 10; 15 – *Praesphaerammina subgaleata* (Vašiček) – sample 6; 16 – *Recurvoides* sp. – sample 5.

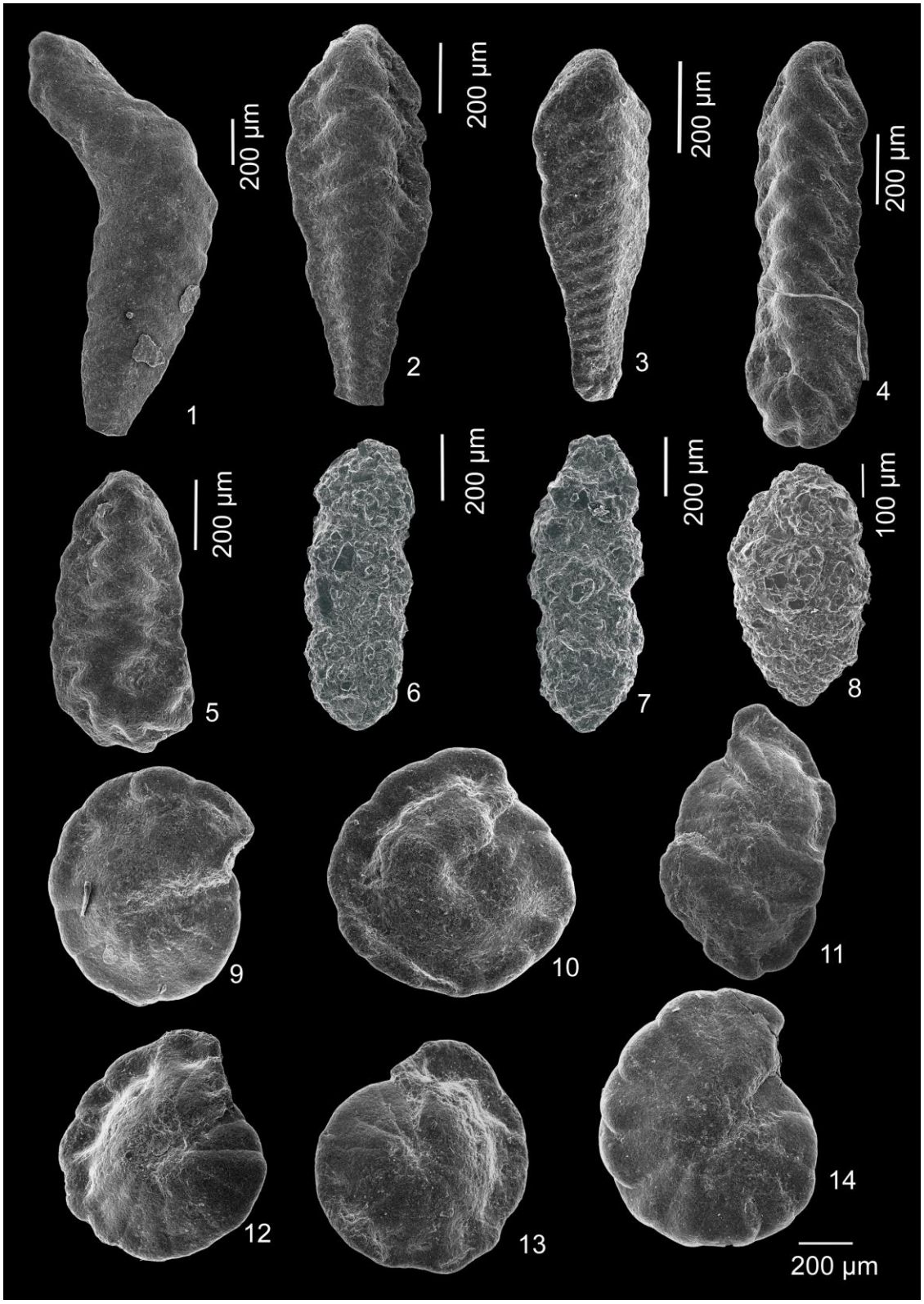


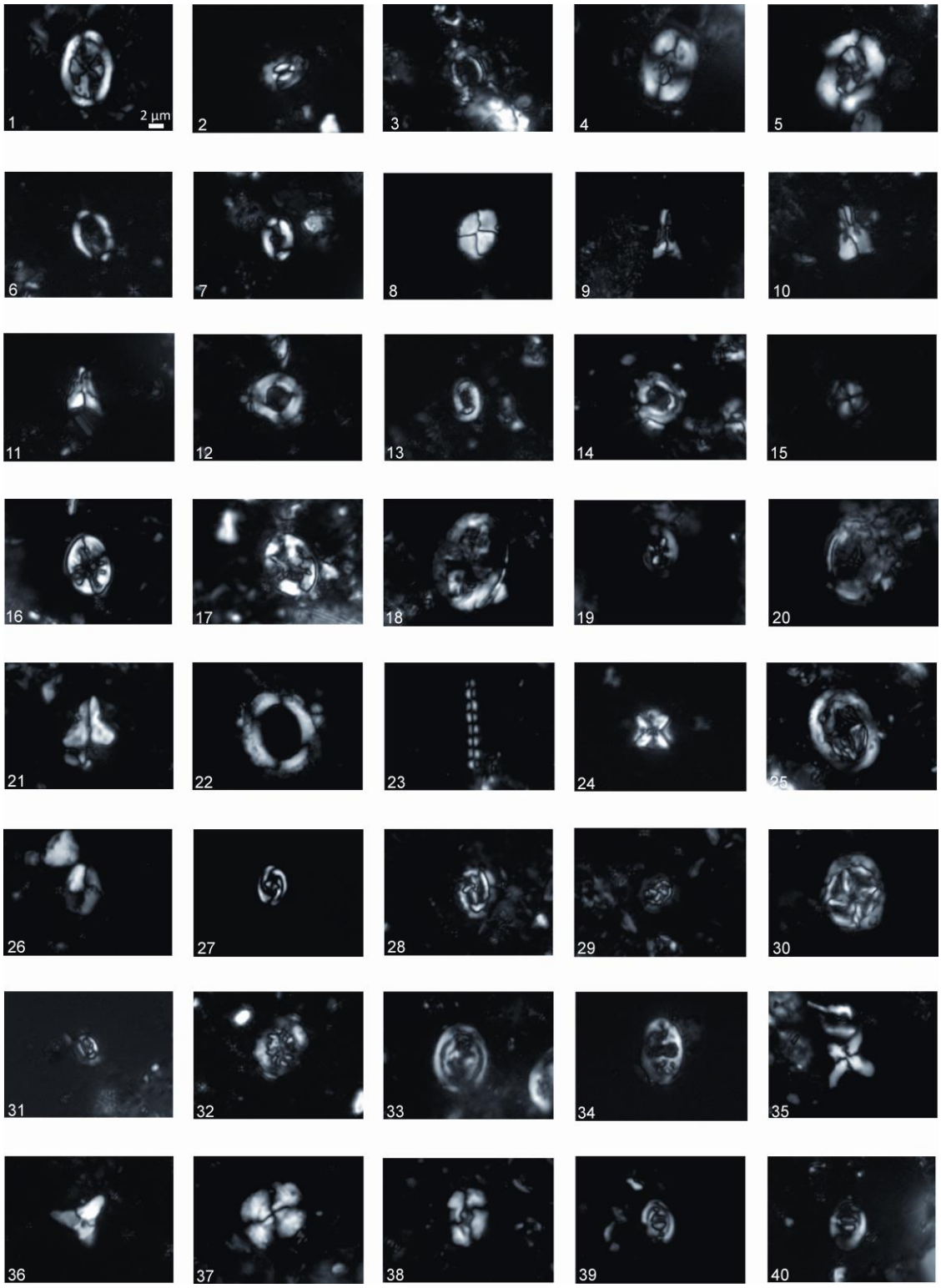
Plate 12. Agglutinated foraminifera from Suceava Valley 3: 1-5 – *Spiroplectammina spectabilis* (Grzybowski) – sample 25; 6 – *Karrerulina horrida* (Mjatliuk) –sample 20; 7 – *Karrerulina horrida* (Mjatliuk) – sample 29; 8 – *Karrerulina coniformis* (Grzybowki) – sample 35; 9 - 14 – *Reticulophragmium amplectens* (Grzybowski) – sample 24.

Plate 13

Calcareous nannofossils from Suceava Valley 1

(after Bindiu el al., 2013 – plate and explanations-Bălc Ramona)

1. *Arkhangelskiella cymbiformis* Vekshina
2. *Biscutum constans* (Górka)
3. *Biscutum magnum* Wind & Wise
4. *Broinsonia parca constricta* Hattner
5. *Broinsonia parca parca* (Stradner)
6. *Broinsonia parca expansa* Wise & Watkins
7. *Broinsonia signata* (Noël)
8. *Calculites obscurus* (Deflandre)
9. *Ceratolithoides aculeus* (Stradner)
10. *Ceratolithoides prominens* Burnett
11. *Ceratolithoides sesquipedalis* Burnett
12. *Cribrocorona gallica* (Stradner)
13. *Cribrosphaerella ehrenbergii* (Arkhangelsky)
14. *Cylindralithus* sp.
15. *Discorhabdus ignotus* (Górka)
16. *Eiffelithus eximius* (Stover)
17. *Eiffelithus turriseiffelii* (Deflandre)
18. *Gartnerago segmentatum* (Stover)
19. *Helicolithus anceps* (Górka)
20. *Kamptnerius magnificus* Deflandre
21. *Lucianorhabdus maleformis* Reinhardt
22. *Manivitella pemmatoidea* (Deflandre)
23. *Microrhabdulus* sp.
24. *Micula staurophora* (Gardet)
25. *Monomarginatus quaternarius* Wind &Wise
26. *Orastrum campanensis*(Cepek)
27. *Placozygus fibuliformis* (Reinhardt)
28. *Prediscosphaera arkhangelskyi* (Reinhardt)
29. *Prediscosphaera cretacea* (Arkhangelsky)
30. *Prediscosphaera grandis* Perch-Nielsen
31. *Prediscosphaera stoveru* (Perch-Nielsen)
32. *Retecapsa crenulata* (Bramlette & Martini)
33. *Reinhardtites anthophorus* (Deflandre)
34. *Tranolithus* sp.
35. *Uniplanarius sissinghii* Perch-Nielsen
36. *Uniplanarius trifidus* (Stradner)
37. *Watznaueria barnesiae* (Black)
38. *Watznaueria britannica* (Stradner)
39. *Zeugrhabdotus bicrescenticus* (Stover)
40. *Zeugrhabdotus diplogrammus* (Deflandre)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