OLIGOCENE – LOWER MIOCENE BIOSTRATIGRAPHY AND SEDIMENTOLOGY OF THE BORŞA FORMATION (N ROMANIA, MARAMUREŞ REGION)

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Abstract Three sections, Moisei, Crasna Vişeului and Repedea, displaying Oligocene-Lower Miocene sediments of the Borşa Formation, have been investigated for the identification of the Oligocene-Miocene boundary. The investigated sediments are turbidites with alternations of sandstones and mudstones characterizing the outer to inner fan depositional paleoenvironment and showing an overall progradational pattern and a west to east paleocurrent transport direction.

The Moisei section covers the Early Oligocene interval (NP21, NP23 calcareous nannofossil zones), while at Repedea, the calcareous nannofossil assemblages are indicative for the Paleogene in general. At Crasna Vişeului, on Frumuşeaua Valley, the Upper Oligocene interval (NP24 and NP25 calcareous nannofossil biozones) as well as the Lower Miocene one (NN2, respectively NN2a subzone) have been pointed out.

Keywords: N Romania, Chattian-Aquitanian interval, calcareous nannofossils, sedimentology, turbidites

INTRODUCTION

Three sections belonging to the Borşa Formation have been investigated, in order to identify the Paleogene/Neogene Boundary in the Maramureş region (N Romania). These sections are exposed at Moisei and Crasna Vişeului localities (Frumuşeaua Valley) and at Repedea locality (Fig. 1). The Borşa Formation (firstly described as "The Borşa Sandstone" auct.) is 1,000-1,500 m thick and it is composed of massive micaceous sandstones with subordinate mudstone intercalations, emplaced by high-density depositional mass-flow mechanisms. The upper part of this unit exposed in the Maramureş region is a molasse, showing poor sorted microconglomerates in the basal part of each sedimentary cycle.

The Late Oligocene to Early Miocene interval, have generally been viewed as times of moderate global warmth and ice free conditions (Zachos et al., 1997; 2001).

The GSSP for base of the Miocene (=base of the Aquitanian stage) was established at 23.03 Ma, being located in Italy, Alessandria Province, Lemme-Carrosio section (Steininger et al., 1997). The primary markers are (Steininger et al., 1997): Magnetic -- base of Chron C6Cn.2n and the planktonic foraminifer FAD (=first appearance datum) of *Paragloborotalia kugleri*. In terms of calcareous nannofossil, the Oligocene-Miocene boundary is located near LAD (last appearance datum) of *Reticulofenestra bisecta* (base Zone NN1).

In that framework, a set of biostratigraphic events in planktonic microfossil groups was taken in consideration. In the case of calcareous nannofossils, reworking prevents use of LAD that elsewere have proven to be useful, such as the LO of *Zygrablithus bijugatus* and *Reticulofenestra bisecta*. As concerning the marine biostratigraphic correlation for calcareous nannofossils, the boundary correlates approximately to the base of NN1 Zone (*Triquetrorhabdulus carinatus* Zone of Martini, 1971), being marked by the FO (first occurrence) of the nannofossil *Sphenolithus capricornutus* (Steininger et al., 1997).

Still, the Oligocene-Miocene boundary is debated in the scientific community, due to the selection of the Upper Oligocene (Chattian stage) and lowermost Miocene (Aquitanian stage) stratotypes (Fornaciari & Rio, 1996). The Oligocene-Miocene boundary was recognized at the top of Zone NP25 (marked by the LOs of *Helicosphaera recta*, *Sphenolithus ciperoensis*, *Reticulofenestra* (=*Dictyococccites*) *bisectus*, *Zygrablithus bijugatus* and *Clausicoccus fenestratus*), which have different geochronologic meanings in different areas (Fornaciari & Rio, 1996). It was considered that the last occurrence of *Sphenolithus delphix* and *S. ciperoensis* offers the best potential of global correlation for defining the Oligocene-Miocene boundary. Hence, *S. ciperoensis* yielded its LO slightly below the top of the Oligocene, followed by the FO (first occurrence) of *Sphenolithus delphix*. At the stratotype, the first meter above the Oligocene-Miocene boundary contains the total range of *Sphenolithus capricornutus*, being folowed by the LO of *S. delphix* (Steininger et al., 1997).

It was proposed (Fornaciari and Rio, 1996) to point out a transition interval of the Oligocene-Miocene boundary for the Mediterranean region and to correlate it with the global zonation scheme of calcareous nannofossils. Therefore, the nannofossil subzone MNP25a encompasses the Upper Chattian, and the subzones MNP25b, MNN1a, MNN1b covers the Oligocene-Miocene

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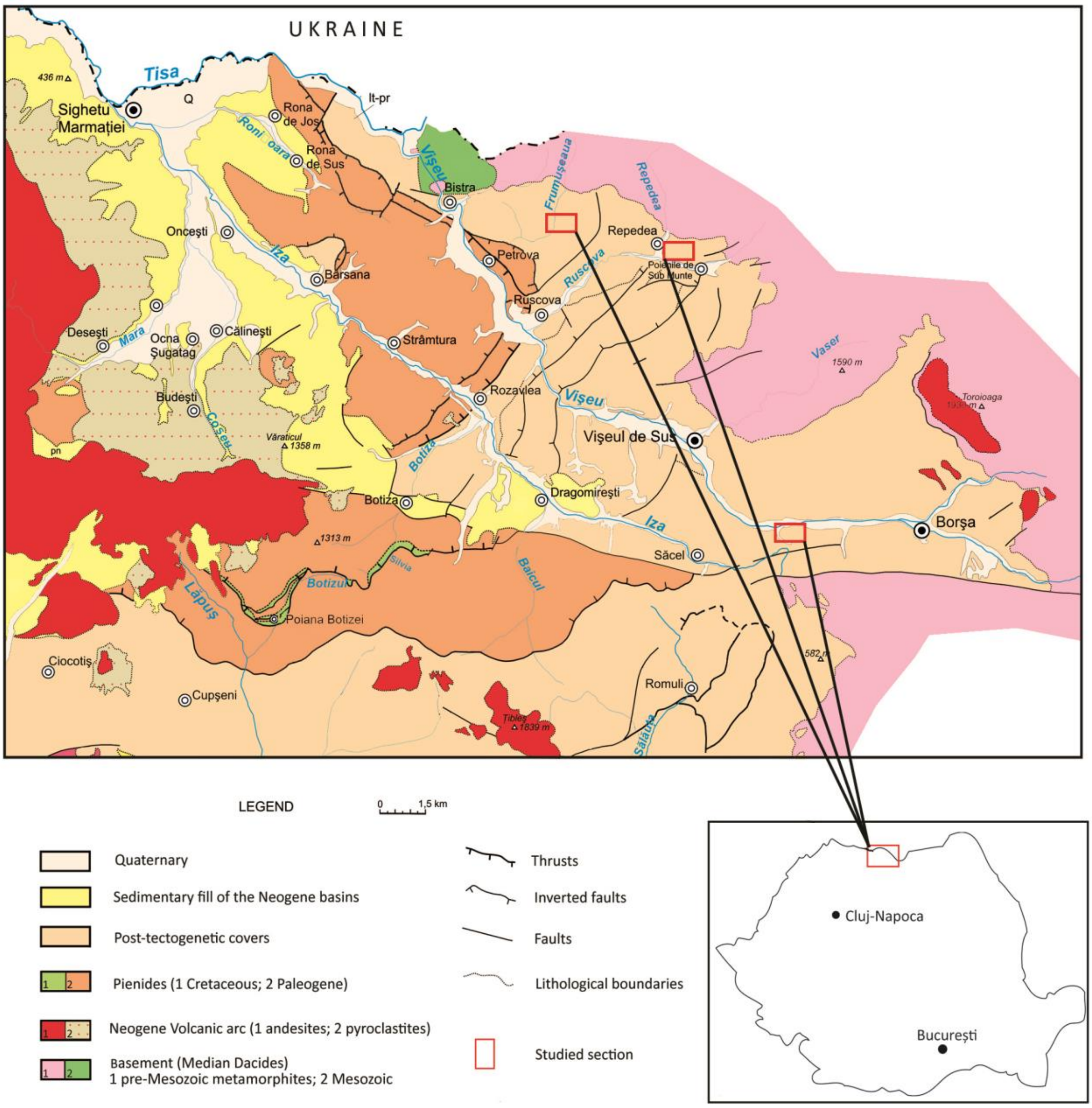

Fig. 1 Simplified geological map 1:200.000 after Gherasi et al., 1967 and Patrulius et al., 1968.

boundary. The subzone MNN1c was referred to the Aquitanian (lowermost Miocene).

The Oligocene-Miocene boundary in the Central and Eastern Paratethys is characterized by fully marine conditions that allow the calcareous nannoplankton to florish and led the disappearance of cavate cysts (Andreyeva-Grigorovich & Gruzman, 1994). These authors indicate that, in the studied sections, the Oligocene-Miocene boundary coincides with the top of Lower Krosno and Middle Menilite “subformations” (members) of the Ukrainian Carpathians, Chernobayev Formation of the Northern Black Sea area and the Caucasian regional stage of the Northern Caucasus.

Detailed studies concerning the Oligocene-Miocene boundary in Romania were realized in different regions, i.e., the Carpathians and Transylvanian Basin (Mărunţeanu, 1992; Mészáros, 1992; Melinte, 2005 and Melinte-Dobrinescu & Brustur, 2008).

In Romania, the Oligocene-Miocene boundary corresponds to the boundary between the NP25 and NN1 calcareous nannofossil zones (Mărunţeanu, 1992). The calcareous nannofossils of *Triquetrorhabdulus carinatus* - NN1 Zone of Martini (1971) were described from the nappes of the Eastern Carpathians, i.e. the Outer Moldavides (Mărunţeanu, 1999). The assemblages mainly consist of: *Coccolithus pelagicus*, *C. eopelagicus*, *Cyclicargolithus abisectus*, *C. floridanus*, *Discoaster adamanteus*, *D. deflandrei*, *Helicosphaera euphratis*, *H. intermedia*, *H. paleocarteri*, *Sphenolithus conicus*, *Reticulofenestra minuta*, *R. minutula* and *Triquetrorhabdulus carinatus*. Additionally, the FO of *Helicosphaera mediterranea* was observed, bioevent which is considered to mark the boundary between the NP25-NN1 zones, respectively between Oligocene and Miocene. Mărunţeanu (1999) observed that the LOs of *Helicosphaera recta*, *Sphenolithus ciperoensis* and *Zygrablithus bijugatus* are successive events, taking place within the Oligocene-Miocene boundary interval. The Lower Miocene NN2 Zone = *Discoaster druggii* zone of Martini (1971) that characterizes the upper Aquitanian-lower Burdigalian interval was

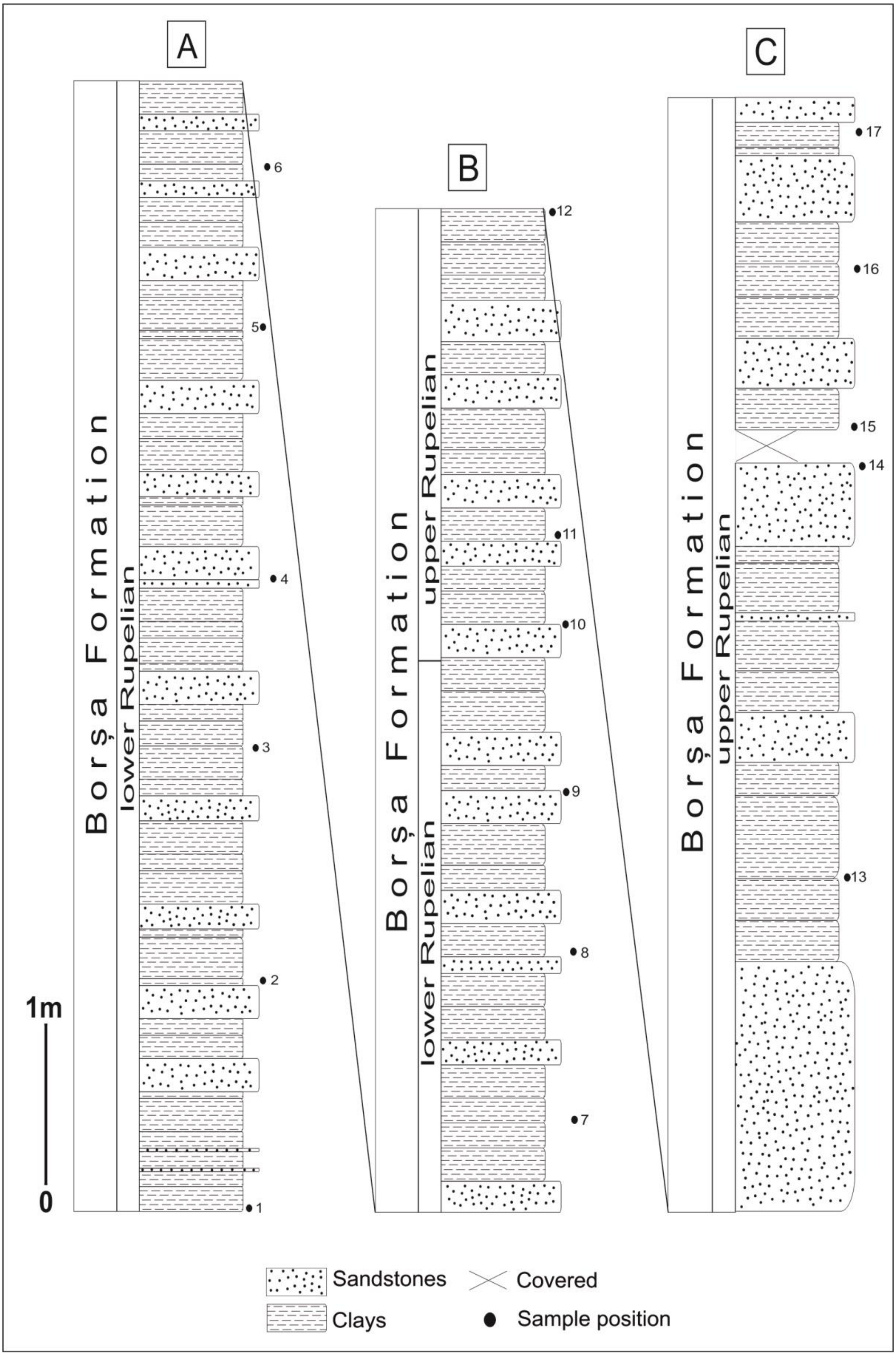

Fig. 2 Moisei section from Moisei (column B is the continuation of A and C is the continuation of B).

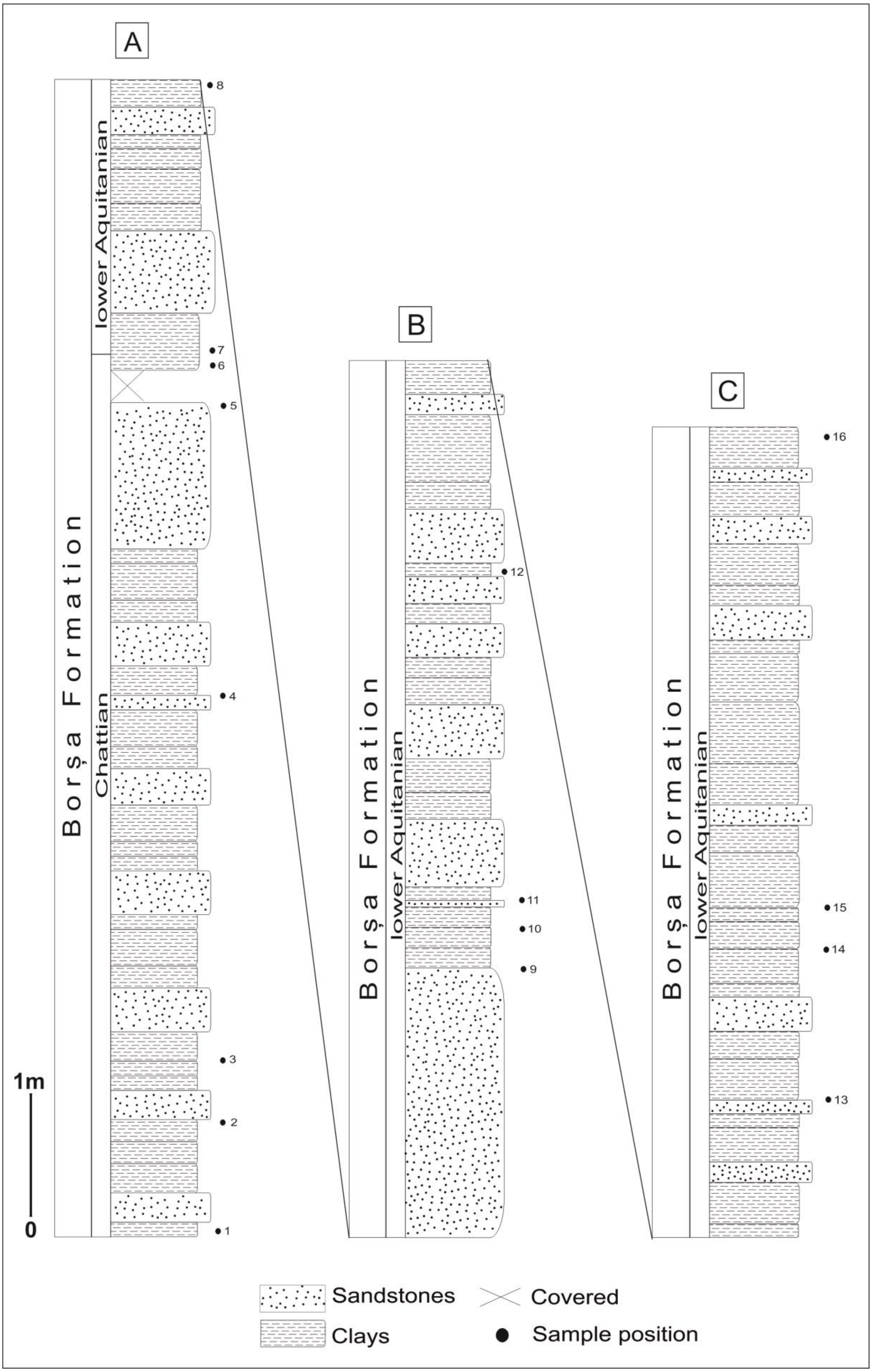

Fig. 3 Frumuşeaua Valley section at Crasna Vişeului (column B is the continuation of A and C is the continuation of B).

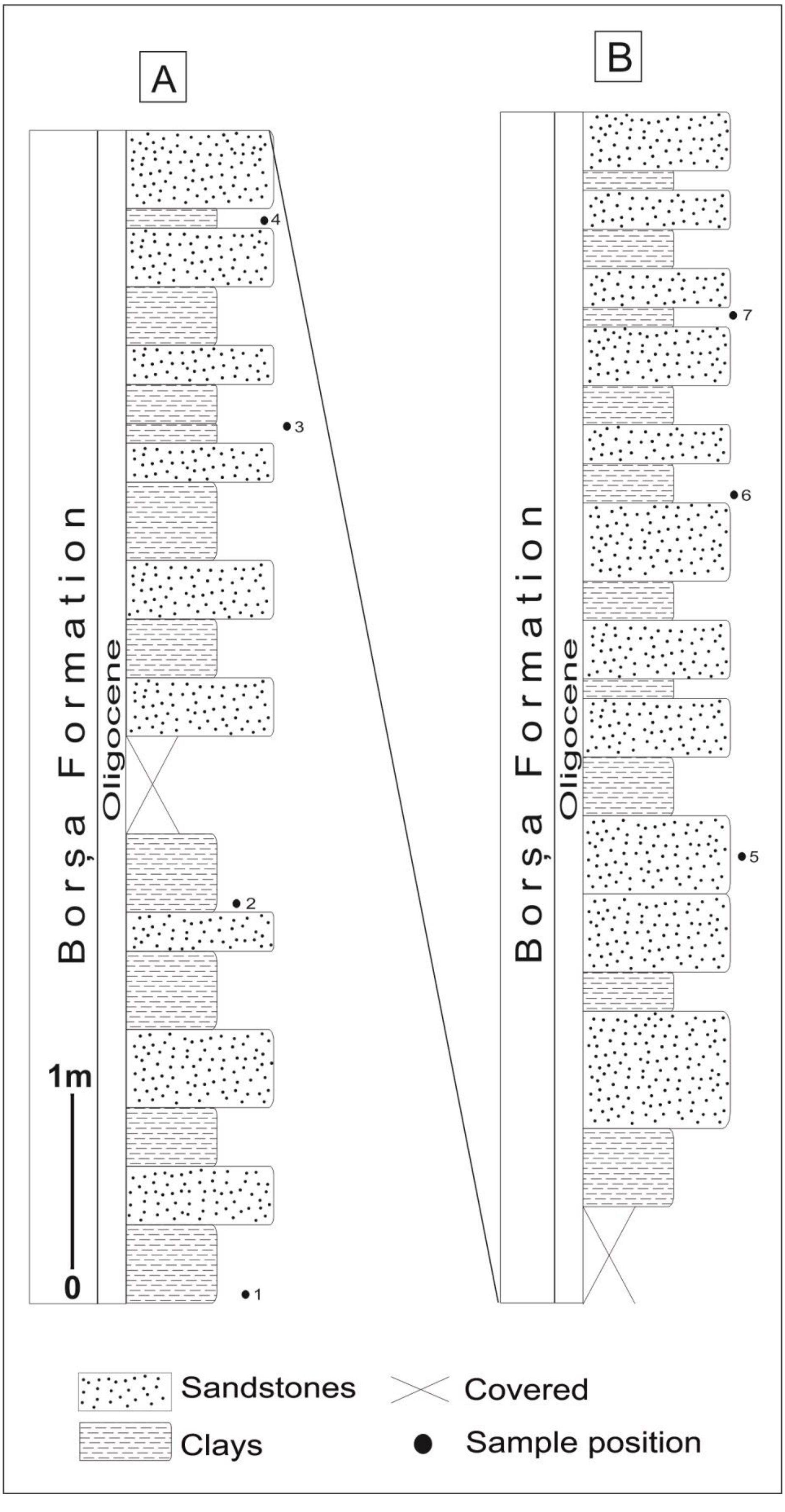

Fig. 4 Repedea section from Repedea (column B is the continuation of A).

subdivided by Mărunţeanu (1999) into two subzones (older first): *Sphenolithus dissimilis* – NN2a and *Helicosphaera kamptneri* – NN2b. The NN2a subzone contains as significant biostratigraphical markers: *Reticulofenestra pseudoumbilicus*, *Discoaster drugii* and *Sphenolithus dissimilis*, besides other long-ranging nannofossils. The NN2b subzone contains *Helicosphaera ampliaperta*, *H. kamptneri*, and all other aforementioned species, excepting *Sphenolithus dissimilis* that vanished in NN2a Subzone.

GEOLOGICAL SETTING

The studied sediments of the Borşa Formation belong to the post-tectonic cover of the Median Dacides nappes. The investigated area is located to the north of the Bogdan Vodă Fault, separating the Alcapa from Tisza-Dacia Neogene blocks (Csontos, 1995).

The tectonical units of the Median Dacides are separated from the Inner Dacides nappes by the Main Tethyan Suture, their inner margin forming the European continental margin. The Median Dacides are built on a continental crust formed by metamorphic Precambrian and Palaeozoic units and an Upper Carboniferous - Lower Cretaceous sedimentary succession, affected by mid Cretaceous (Albian) tectonic phase (Săndulescu, 1984, 1994).

The post tectonic cover, mid Cretaceous (=late Albian) to earliest Miocene (=Aquitanian) in age, is made by two sedimentary cycles that unconformably overlies the overthrusted nappes (Săndulescu, 1994). The oldest sedimentary cycle extend within from the mid Cretaceous up to the Lower Eocene. The youngest cycle, Middle Eocene to lowermost Miocene (Aquitanian) is mainly formed by molasse deposits, deformed during the Lower Miocene (=Burdigalian) (Săndulescu, 1984). In the Maramureş region, this cover is at present preserved in several basins located on the western slope of the Median Dacides (Săndulescu, 1994).

The Borşa Formation was firstly identified and described as "Borşa Sandstone" by Zapałowicz (1886). The formation name derived from the homonymous locality and river that flows north of the Rodna crystalline massif (Bombiţă & Müller, 1999). The maximum unit thickness reaches 2,000 m (Patrulius, 1956).

Based on its stratigraphic position and lithological characters, the "Borşa Sandstone" has been considered Late Oligocene in age (Zapałowicz, 1886). The main biostratigraphical *in situ* markers are the foraminifers *Globigerina ciperoensis* Bolli and *Globigerinoides trilobus* Reuss, covering the Late Oligocene and Early Miocene, respectively (Dicea et al., 1980a,b).

Bombiţă & Müller (1999) identified in the Borşa Formation, S from the Bogdan Vodă Fault, near the village of Groşi, in the silty sandstones, the Burdigalian calcareous nannofossil zone NN2, based on the presence of *Dictyococcites (Reticulofenestra) dictyodus* (Defl.) Stradn., *Zygrablithus bijugatus* Defl., *Cyclococcolithus (Ericsonia) formosus* (Kamptn.) Wise, *Pontosphaera multipora* (Kamptn.) Roth, *Cyclicargolithus floridanus* (Roth & Hay) Bukry, *Reticulofenestra umbilica* (Lev.) Mart. & Ritzk., *Transversopontis zigzag* Lock., and *Helicosphaera kamptneri* Hay & Mohl. Most of these taxa are reworked from older deposits, i.e. *Reticulofenestra umbilica*, *Ericsonia formosa*. The upper levels of the formation, from Borşa – Moisei – Săcel, have provided a characteristic palynofacies with diatoms and palm tree pollen that are Late Oligocene to Early Miocene in age (Bombiţă & Müller, 1999).

During the Late Oligocene-Early Miocene interval, the deposition was dominated by high-density mass-flow mechanisms leading to the occurrence of mainly thick massive sandy turbidites. Paleogeographic reconstructions (Săndulescu & Micu, 1989) indicate that the source area of the Oligocene-Lower Miocene successions was situated in an inner position with respect to the Eastern Carpathians. Moreover, the paleocurrents measured from basal scours show mainly a W-E direction (Jipa, 1962).

During the Late Oligocene-Early Miocene times, a more uniform basin developed in the area deepening to the north, and elongated E-W to NE-SW. This basin had its depocentre in the Maramureş region, but it was encountered in boreholes towards W, in Hungary, in the Szolnok Basin (Györfi et al., 1999). A subsequent Early Miocene Hida Basin was oriented E-W, its depocentre being located further to the S. While the Upper Oligocene – Lower Miocene turbiditic formation ("Borşa Sandstone") is strongly deformed (folded and imbricated), the Miocene clastics belonging to the Hida Basin are only gently tilted. South of Bogdan Vodă Fault, the advancing thrust fronts of Piennide nappes and the resulting tectonic loads could have triggered in a shift of the basin axis with facies progradation towards the Transylvanian Basin. Thus, the Early Miocene Maramureş and the slightly younger Hida Basin constitutes successive migrating axis of the flexural foredeep basin, which developed during the overthrusting of Alcapa block over the Tisza-Dacia unit (Györfi et al., 1999).

MATERIAL AND METHODS

The investigated sediments have been studied from lithological and sedimentological points of view. Figs. 2, 3 and 4 show the sedimentological features of the three studied sections by using classical methods of facies analysis, such as recognition of Bouma sequences, measuring of basal scours for paleocurrent determination, lateral continuity of beds and vertical transition of sedimentary facies and turbidite environments.

For biostratigraphic purposes, 40 samples (Figs. 2, 3 and 4), i.e., 17 samples from Moisei, 7 samples from Repedea, and 16 samples from Crasna Vişeului – Frumuşeaua Valley were investigated for their calcareous nannofossils content. The smear slides for calcareous nannofossils were studied at LM (Light microscope), at 1000x magnification.

RESULTS

Sedimentological features

The Borşa Formation formed after the tectonic movements following Eocene transtensional cycle which affected the European continental margin (including the Median Dacides nappes) and generated several pull-apart basins, such as Borşa and Ruscova basins (Tischler et al., 2008). This formation crops out into a large area,

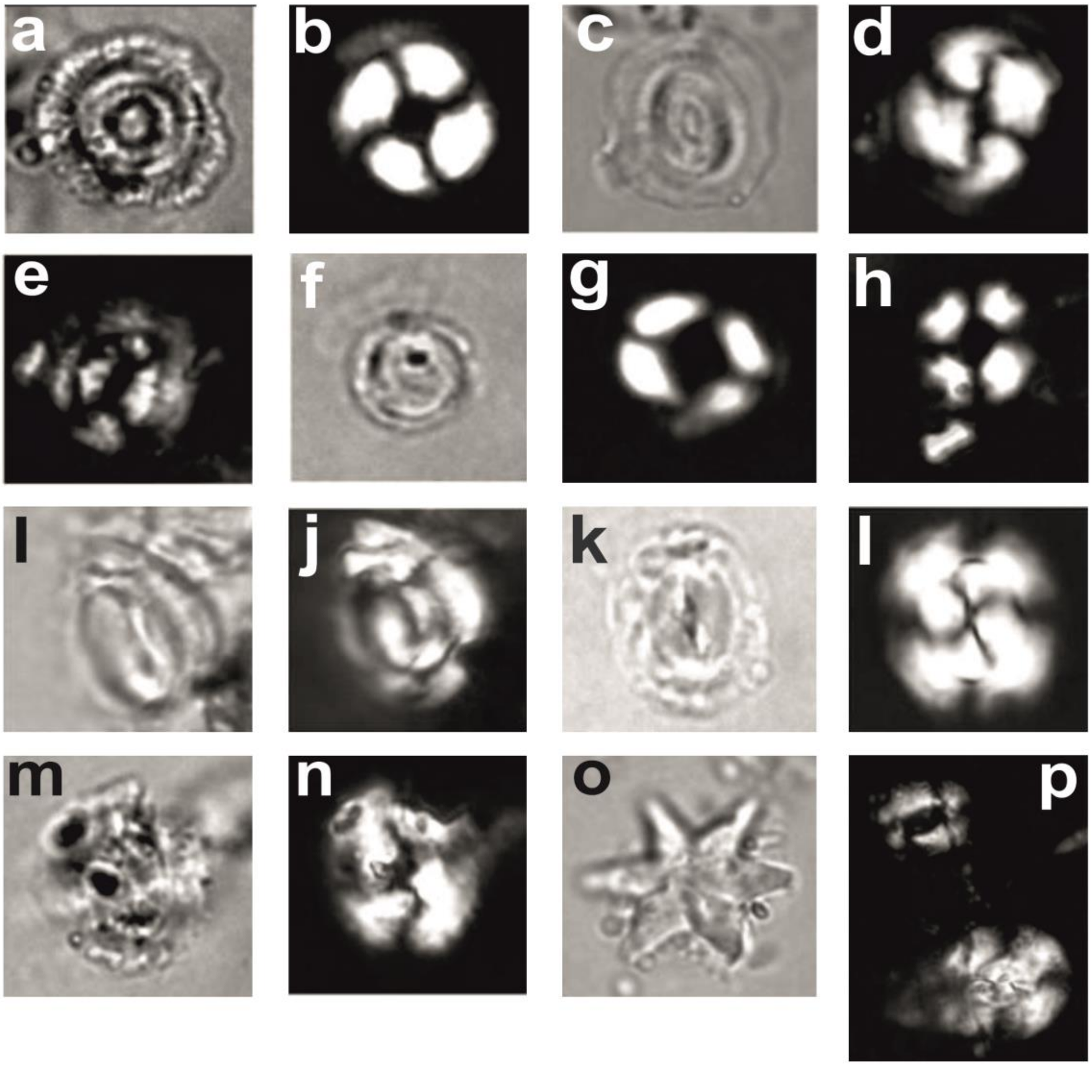

Fig. 5 Calcareous nannofossils from Moisei (X 2000). **a, b** *Coccolithus formosus* (Kamptner, 1963) Wise, 1973 (Sample 1) (a - NII, b – N+); **c, d** *Coccolithus pelagicus* (Wallich, 1871) Schiller, 1930 (Sample 3); **e** *Coccolithus* cf. *pelagicus* (Wallich, 1871) Schiller, 1930 (Sample 3); **f-h** *Coccolithus subpertusus* (Hay & Mohler, 1967) van Heck & Prins, 1987 (= *Ericsonia subpertusa* Hay & Mohler, 1967) (Sample 3) (f - NII, g – N+; h – N+); **i, j** *Helicosphaera* cf. *compacta* Bramlette & Wilcoxon, 1967 (Sample 3) (i – NII, j – N+); **k, l** *Reticulofenestra bisecta* (Hay et al, 1966) Bukry & Percival, 1971 (Sample 2) (k – NII, l – N+); **m, n** *Reticulofenestra* cf. *bisecta* (Hay et al, 1966) Bukry & Percival, 1971 (Sample 1) (m – NII, n – N+); **o** *Discoaster* cf. *strictus* Stradner, 1961 (Sample 3) (NII); **p** *Reticulofenestra dictyoda* (Deflandre in Deflandre & Fert, 1954) Stradner in Stradner & Edwards, 1968 & *R. stavensis* (Levin & Joerger, 1967) Varol, 1989 (Sample 3) (N+).

extending from NW Maramureş – Crasna Vişeului (Fruműşeaua Valley) and Repedea Valley – to E Maramureş, close to the village of Moisei (Vişeu Valley).
The **Moisei** section (Vişeu Valley) (Fig. 2) is about 20 m in stratigraphic thickness. It displays dm sandstone beds with abundant basal scours (mainly load and flute casts) that provide information about the main transport direction, generally oriented from W to E. The Bouma sequences are predominantly formed by Tc-Te divisions, with fine intervals represented by m-thick compact mudstones. The sandstone are litharenitic and sublitharenitic with abundant metamorphic lithoclasts, probably of Median Dacides origin, together with sedimentary siliciclastic and carbonatic grains from Eocene deposits.
The **Crasna Vişeului** section (Frumuşeaua Valley) (Fig. 3) includes m to dm-thick sandstone beds, often amalgmated or showing thin intercalations of mudstone beds. The Bouma sequences are predominantly represented by Tb-Te divisions, with rare basal scours.
In the **Repedea** section (Repedea Valley) (Fig. 4), beds of massive sandstones (up to 6 m in stratigraphic thickness) without any evident sedimentary structures are dominant. They show a very good lateral continuity, being emplaced by turbidity currents of high density. Mudstone levels are very thin or even missing in the upper part of the succession, allowing classifying them as amalgamated turbidites. This profile shows a general thickening- and coarsening-upward trend.
The Borşa Formation consists of alternations of sandstones and mudstones showing, in the lower part of the succession, a sand/shale ratio < 1 (Moisei area), with a general thickening/coarsening upward trend (Crasna Vişeului area). Massive sandstone beds, lacking or with reduced pelitic levels, are typical of the Repedea area.

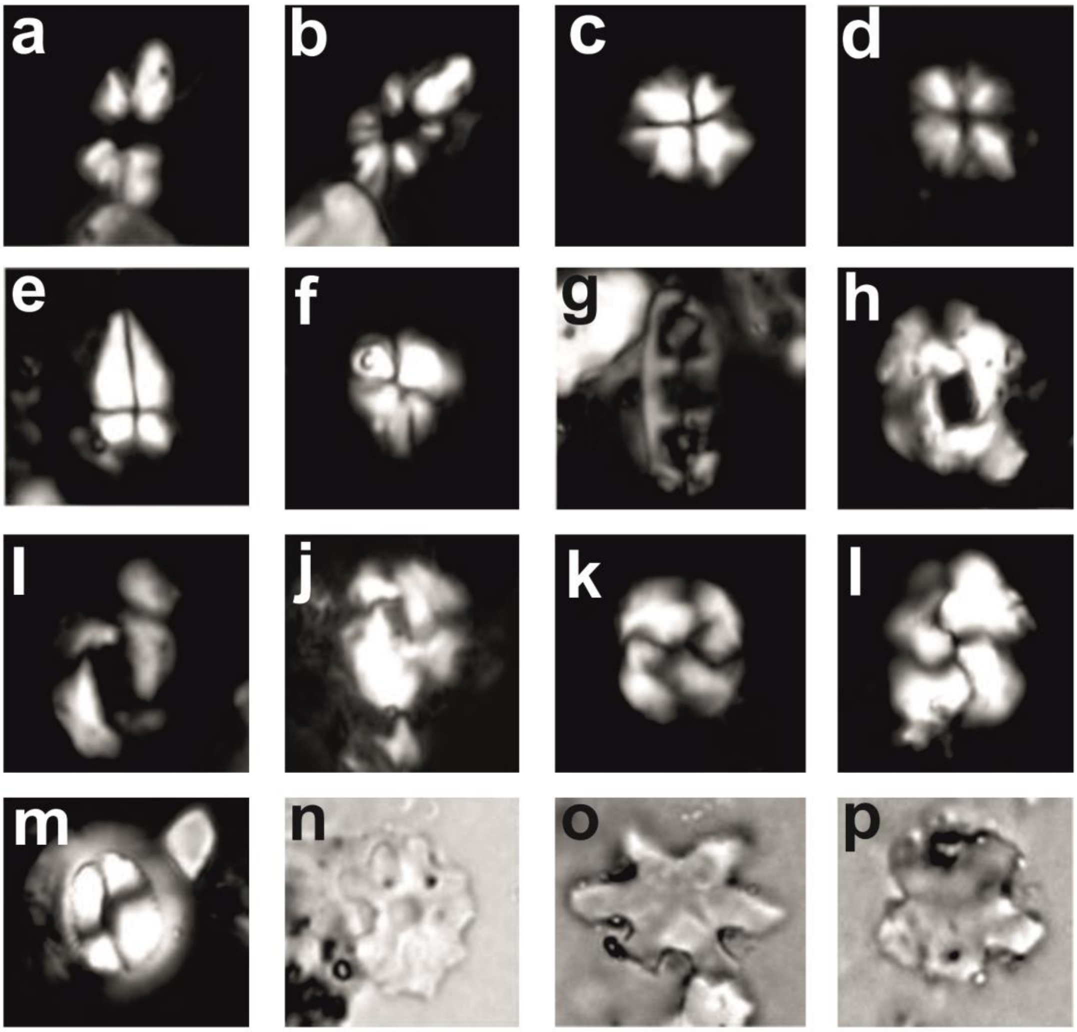

Fig. 6 Calcareous nannofossils from Frumuşeaua Valley – Crasna Vişeului (X 2000). **a, b** *Sphenolithus* cf. *conicus* Bukry, 1971 (Sample 14) (a - 90°, b - 45° - N+); **c, d** *Sphenolithus moriformis* (Bronnimann & Stradner, 1960) Bramlette & Wilcoxon, 1967 (Sample 14, 5) (N+); **e** *Sphenolithus anarrhopus* Bukry & Bramlette, 1969 (Sample 7) (N+); **f** *Sphenolithus conicus* Bukry, 1971 (Sample 7) (N+); **g** *Isthmolithus recurvus* Deflandre in Deflandre & Fert, 1954 (Sample 7) (N+); **h** *Reticulofenestra dictyoda* (Deflandre in Deflandre & Fert, 1954) Stradner in Stradner & Edwards, 1968 (Sample 14) (N+); **i, j** *Reticulofenestra* cf. *dictyoda* (Deflandre in Deflandre & Fert, 1954) Stradner in Stradner & Edwards, 1968 (i - Sample 7, j - Sample 5) (N+); **k** *Reticulofenestra* cf. *bisecta* (Hay et al, 1966) Bukry & Percival, 1971 (Sample 5) (N+); **l** *Reticulofenestra bisecta* (Hay et al, 1966) Bukry & Percival, 1971 (Sample 7) (N+); **m** *Coccolithus* cf. *eopelagicus* (Bramlette & Riedel, 1954) Bramlette & Sullivan, 1961 (Sample 7) (N+); **n** *Discoaster* sp. (Sample 7) (NII); **o, p** *Discoaster* cf. *druggii* Bramlette and Wilcoxon, 1967 (Sample 7) (NII).

Detailed facies analysis suggest a turbiditic depositional environment of outer fan in the lower part of the succession and of mid and inner fan in the upper part, in which the sediments emplaced by turbulent flows are interbedded with very thin fine grained hemipelagic deposits.

Calcareous nannofossil assemblages

Moisei (Vişeului Valley)

In this section, the nannofossil assemblages are dominated by taxa of the genera *Reticulofenestra* and *Helicosphaera*. The oldest two investigated samples (Samples 1 and 2 in Fig. 2) contain scarce calcareous nannofossil assemblages with long-ranging species, like *Coccolithus formosus* (NP12 - NP21, Ypresian – Rupelian interval) (Fig. 5, a,b) and *Reticulofenestra* cf. *bisecta* (NP17 – NN1, Late Eocene-basal Miocene) (Fig. 5, m,n). A probable age is Lower Oligocene (NP21).

The next three samples (Samples 3-5 in Fig.2) contain more diversified calcareous nannofossils assemblages, with *Coccolithus pelagicus* (Fig. 5, c,d) (Paleocene-Present), *Coccolithus* cf. *pelagicus* (Fig. 5, e), *C. eopelagicus* (Eocene-Oligocene), *Reticulofenestra bisecta* (Fig. 5, k,l) (Eocene–basal Miocene), *Reticulofenestra minuta* (Paleogene –Pleistocene); *R. stavensis* (NP15–NN1, Middle Eocene to basal Miocene) (Fig. 5, p), *Helicosphaera compacta* (Fig. 5, i, j) (NP16–NP24) (Lutetian – Chattian), *Coronocyclus nitescens* (Paleogene-Middle Miocene), *Cyclicargolithus floridanus* (NP15-NN7 Middle Eocene-Middle Miocene), *Sphenolithus mori-*

formis (Eocene–Late Miocene). Reworked taxa from Paleocene and Eocene are also present: *Sphenolithus.* cf. *anarrhopus*, *Reticulofenestra dictyoda*, *R. reticulata*, *Coccolithus subpertusus* (Fig. 5, f-h), *Discoaster* cf. *strictus* (Fig. 5, o), a.o. A presumably age is Lower Oligocene.

Samples 6 to 8 are almost barren, but samples 10 and 11 are very abundant in calcareous nannofossils and contain *Zygrablithus bijugatus* (Paleocene–basal Miocene), *Helicosphaera* cf. *compacta* (NP16–NP24), *Reticulofenestra umbilica* (NP17-NP23, Late Eocene-Early Oligocene), *Pontosphaera pulchra*, *D.* cf. *nodifer*, *S.* cf. *moriformis* (Eocene–Upper Miocene), *Coccolithus pelagicus* (Paleogene-Present), *Thoracosphaera* sp., and ascidian spicules. Reworked Eocene taxa also occur: *Discoaster distinctus*, *D.* cf. *sublodoensis*, *D. multiradiatus* and *Sphenolithus anarrhopus*. This assemblage possibly belongs to the Lower Oligocene depositional interval.

The next two samples are barren in calcareous nannofossils. Samples 14 and 15 contains reticulofenestrids (*Reticulofenestra dictyoda, R. minuta*, a.o.), *Sphenolithus* cf. *spiniger*, *S.* cf. *editus*, *Pontosphaera multipora*, *Discoaster multiradiatus* that most probably are reworked from Middle Eocene deposits. The next sample contains no nannosfossils, while the youngest one (sample 17) contains: *Coccolithus pelagicus*, reticulofenestrids, *Helicosphaera seminulum* (NP15–NP23), *H.* cf. *compacta*, *Sphenolithus* cf. *moriformis*, ascidian spicules and rarely Cretaceous taxa. This assemblage, containing long-ranging taxa, is considered Early Oligocene in age.

Rare foraminifera have been observed at Moisei, most of them reworked from Paleogene deposits. The occurrence of reworked foraminifera assemblages in this section confirm the turbiditic origin of the related deposits, as indicate also by the reworked nannofossils. Thus, a transitional depositional setting from outer slope to bathyal can be inferred. The bituminous shales prove an anoxic environment, improper for the benthic life.

Crasna Vişeului (Frumuşeaua Valley)

On Frumuşeaua Valley, the succession belong to the NP25 biozone (after Martini (1971) biozonation) (Upper Oligocene), with *Sphenolithus ciperoensis*; the succession extends up to the NN2a subzone (Lower Miocene), with *Sphenolithus dissimilis* (after Mărunţeanu, 1992).

The oldest investigated samples (Sample 1 in Fig. 2) contain few calcareous nannofossils, with a long range, such as *Zygrablithus bijugatus* (NP11-NN1, Eocene - basal Miocene), *Isthmolithus recurvus* (NP19 – NP22, Late Eocene–Early Oligocene) (Fig. 6, g), *Coccolithus pelagicus* (Paleocene-Present), *C.* cf. *eopelagicus* (Fig. 6, m), *Reticulofenestra* cf. *stavensis* (Upper Eocene-basal Miocene, NP17 to NN1), *R.* cf. *bisecta* (Fig. 6, k), *R. bisecta* (Fig. 6, l), *Sphenolithus moriformis* (Paleocene-Early Pliocene), thoracospheres and ascidian spicules. Rarely, Cretaceous taxa are also present. This sample also contains *Sphenolithus ciperoensis*, which have its FO in the Upper Oligocene (Chattian stage). In the upper part of the section, sphenoliths are present, such as: *Sphenolithus* cf. *conicus* (NN1-NN3) (Fig. 6, a,b,f), *Sphenolithus conicus* (Fig. 6, f), (NP24-NN3) (Rupelian – Burdigalian), *S. moriformis* (NP12-NN9) (Fig. 6, c,d), *S. anarrhopus* (Fig. 6, e), reticulofenestrids: *Reticulofenestra dictyoda* (Fig. 6, h), *Reticulofenestra* cf. *dictyoda* (Fig. 6, i,j), as well as *Helicosphaera recta* (NP24-NN1, Chattian-Aquitanian); the later species crosses the Oligocene-Miocene boundary. Besides, discoasterids, such as *Discoaster* cf. *druggii* (NN2-NN5 - Lower Miocene) (Fig. 6, o,p), *D*. sp. (Fig. 6, n), and calcispheres were encounterd. This assemblage proves the existence of the Upper Oligocene – Lower Miocene (Upper Chattian – Lower Aquitanian) depositional interval. *Discoaster* cf. *druggii* indicates the presence of the NN2a Subzone (after Mărunţeanu, 1992). Taking into account the aforementioned data, a Late Oligocene to Early Miocene age may be assigned.

Repedea (Repedea Valley)

The outcrop from Repedea contains scarce Paleogene (Oligocene) calcareous nannoplankton and thoracospheres. Some of the identified nannofossils are long-ranging taxa.

CONCLUSIONS

Three sections from Maramureş region (N Romania), namely Moisei, Crasna Vişeului (Frumuşeaua Valley) and Repedea, have been studied for their potential to point out the Paleogene/Neogene boundary. The most significant section for biostratigraphic studies is that from Frumuşeaua Valley, because it includes the transition from Oligocene to Miocene.

The Oligocene to Lower Miocene Borşa Formation consists of a progradational clastic sequence of sandstones and mudstones originating in a turbiditic depositional environment of outer fan in the lower part (Moisei) and of mid and inner fan in the upper part (Crasna Vişeului, Repedea). Paleocurrent analysis, together with petrographic composition of sandstones, suggests a west-east transport direction with the source area and sediment supply probably located to south-west, in present-day Preluca and/or Meseş massifs.

The calcareous nannofossils and foraminifera from all the three sections were analyzed. The foraminifera content was too poor for reliable results. Based on identified calcareous nannoplankton, only the presence of the Oligocene was demonstrated at Moisei: lower Oligocene (Rupelian) (NP21 biozone), with probably reworked Upper Eocene species. Paleogene calcareous nannofossils are almost absent in the Repedea section.

At Crasna Vişeului, a Late Oligocene to Early Miocene age was identified based on the observed calcareous nannofossils assemblage: NP24 biozone (Upper Oligocene – Chattian), in the lower part of the section, NP25 (uppermost Oligocene - upper Chattian), and NN2, respectively NN2a Subzone (Lower Miocene - upper Aquitanian), in its upper part.

In conclusion, the age of the Borşa Formation, based on calcareous nannoplankton, is assigned to the Oligocene – Early Miocene. This age is in agreement with the evolution of the foredeep depocenter from SE to NW, probably linked to the tectonics of the Pieninds (Petrova and Leordina nappes), located north of the Bogdan Vodă Fault. Transtensional tectonics during Oligocene and the advancing thrust front of Petrova and Leordina nappes during Early Miocene played a crucial role in controlling the deep-water facies distribution into the Borşa and Ruscova Basins.

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REFERENCES

Andreyeva-Grigorovich, A. & Gruzman, A.D. 1994. The biostratigraphic basis of the Paleogene -Neogene boundary in the Central (Ucrainian Carpathians) and Eastern (Black Sea Depression, northern Caucasus) Paratethys. Geologica Carpathica, 45 (6): 333-342.

Beddow, H. M., Liebrand, D., Sluijs, A., Wade, B. S., Lourens, L. J., 2016. Global change across the Oligocene-Miocene transition: High resolution stable isotope records from IODP Site U1334 (equatorial Pacific Ocean). Paleoceanography, 31: 81–97, doi: 10.1002/2015 PA 002820.

Beddow, H. M., Liebrand, D., Wilson, D. S., Hilgen, F. J., Sluijs, A., Wade, B. S., and Lourens, L. J., 2018. Astronomical tunings of the Oligocene–Miocene transition from Pacific Ocean Site U1334 and implications for the carbon cycle, Clim. Past, 14, 255-270, https://doi.org/10.5194/cp-14-255-2018.

Bombiţă, G. & Müller, C., 1999. Geological data and events from the Romanian Maramureş with emphasis on the Palaeogene System. GEO-ECO-MARINA, 4: 81 – 105. Proc. Intern. Workshop on "Modern and Ancient Sedimentary Environments and Processes" in Moeciu, Romania, 1998.

Csontos, L. 1995. Cenozoic tectonic evolution of the Intra-Carpathian area: a review. Acta Vulcanologica, 7: 1-13.

Dicea, O., Duţescu, P., Antonescu, F., Mitrea, G., Botez, R., Donos, I., Lungu, V. & Moroşanu, I., 1980a. Contributii la cunoaşterea stratigrafiei zonei transcarpatice a Maramureşului. D. S. Inst. Geol. Rom., LXV, 4: 21-85.

Dicea, O., Duţescu, P., Antonescu, F., Mitrea, G., Botez, R., Donos, I., Lungu, V. & Moroşanu, I., 1980b. Contribuţii la cunoaşterea stratigrafiei zonei transcarpatice a Maramureşului. D. S. Inst. Geol. Rom., LXV, 5: 35-53.

Fornaciari, E. & Rio, D. 1996. Latest Oligocene to early Middle Miocene quantitative Calcareous Nannofossil Biostratigraphy in the Mediterranean region. Micropaleontology 4: 11–36.

Gherasi, N., Bombiţă, G., Vasilescu, A. & Kräutner, H., 1967. Geological map of Romania, scale 1:200.000, sheet 3-Baia Mare. Institute of Geology, Bucharest.

Györfy I., Csontos L. & Nagymarosy A. 1999. Early Tertiary structural evolution of the border zone between the Pannonian and Transylvanian Basins. In: Durand B, et al., (Eds.): The Mediterranean Basins: Tertiary Extension within the Alpine Orogen. Geological Society of London, Special Publications, 156: 251 – 267.

Jipa, D., 1962. Direcţii de aport în gresia de Borşa (Maramureş). Com Acad. R.P.R., 12: 1363-1368 (in Romanian).

Martini, E. 1971. Standard Tertiary and Quaternary calcareous nannoplankton zonation. In: Proceeding of the 2nd Planktonic Conference, Roma: 739–785.

Mărunţeanu, M. 1992. Distribution of the Miocene calcareous nannofossils in the Intra- and Extra- Carpathian areas of Rumania. Knihovnicka ZPN, 14b (2): 247-261.

Mărunţeanu, M. 1999. Litho- and Biostratigraphy (Calcareous Nannoplankton) of the Miocene deposits from the Outer Moldavides. Geologica Carpathica, 50 (4): 313-324.

Melinte, M.C. 2005. Oligocene palaeoenvironmental changes in the Romanian Carpathians, revealed by calcareous nannofossil fluctuation. In: Tysza, J., Olikwiewicz – Miklasinska, M., Gedl, P. & Kaminski, M.A. (Eds.), Methods and Applications in Micropaleontology. Studia Geologica Polonica, 124: 15–27.

Melinte-Dobrinescu, M. & Brustur, T. 2008. Oligocene – Lower Miocene events in Romania. Acta Palaeontologica Romaniae, Iaşi, VI: 203-215.

Mészáros, N. 1992. Nannofossil Zones in the Paleogene and Miocene deposits of the Transylvanian Basin. Knihovnicka ZPN, 14b (2): 87-92.

Patrulius, D., 1956. Contribuţii la studiul geologic al Maramureşului, bazinul Ruscova. D.S. Inst Geol. Rom., XL: 68-84.

Patrulius, D., Bombiţă, G., Kräutner, H. G. & Kräutner, F., 1968. Geological map of Romania, scale 1:200.000, sheet 4-Vişeu. Institute of Geology, Bucharest.

Săndulescu M., 1984. Geotectonica Romaniei. Ed. Tehnica Bucuresti, 336 pp.

Săndulescu M. & Micu M. 1989. Oligocene Paleogeography of the east Carpathians. In The Oligocene from the Transylvanian Basin. Cluj-Napoca: 79-86.

Săndulescu M., Visarion M., Stănica D., Stănica M. & Atanasiu L. 1994. Deep Structure of the inner Carpathians in the Maramureş - Tisa zone (East Carpathians). Romanian Journal of Geophysics, 16: 67-76.

Steininger F.F., Aubry M.P., Berggren W.A., Biolzi M., Borsetti A.M., Cartlidge J. E., Cati, E Corfield, R. Gelati, R. 1accarino, S. Napoleone, C. Otmer, E., Rögl, F., Roetzel, R., Spezzaferri, S., Tateo, F., Villa, G. & Zevenboom D., 1997. The Global Stratotype Section and Point (GSSP) for the base of the Neogene. Episodes, 20(1): 23-28.

Tischler, M., Maţenco, L., Filipescu, S., Gröger, H.R., Wetzel, A. & Fügenschuh, B., 2008. Tectonics and sedimentation during convergence of the ALCAPA and Tisza-Dacia continental blocks: the Pienide nappe emplacement and its foredeep. In: Siegesmund, S., Fügenschuh, B., Froitzheim, N. (eds). Tectonic Aspects of the Alpine-Dinaride-Carpathian System. Geological Society, London, Special Publication, 298: 317-334.

Zachos, J. C., Flower, B. P. & Paul, H., 1997. Orbitally paced climate oscillation across the Oligocene/

Miocene boundary. Nature, 388: 567-570.
Zachos, J. C., Shackleton, N.J., Revenaugh, J.S., Pälike, H. & Flower, B.P., 2001. Climate response to orbital forcing across the Oligocene/Miocene Boundary. Science, 292: 274-278.
Zapałowicz, H., 1886. Eine geologische Skizze der oestlichen Theile der Pokutisch-Marmaroscher Grenz-Karpaten. Jahrb. d. k. k. geol. Reichanst., XXXVI: 361-504, Wien.