

# Micropaleontological response to the changing paleoenvironment across the Sarmatian-Pannonian boundary in the Transylvanian Basin (Miocene, Oarba de Mureş section, Romania)

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(Manuscript received June 7, 2010; accepted in revised form October 13, 2010)

**Abstract:** The Sarmatian-Pannonian transition has been investigated in Section A of Oarba de Mureş in the central Transylvanian Basin. Micropaleontological assemblages are diagnostic for different environmental settings and demonstrate a clear zonation, which was used to reconstruct the genetic units. Five stratigraphic sequences were described and subdivided based on the microfossil assemblages. Transgressive intervals were documented by five-chambered and biserial planktonic foraminifera, normal regressions by assemblages with abundant mysid, dasyclads, diatoms, and benthic rotaliid foraminifera, while the forced regressions are characterized by reworking. The Sarmatian-Pannonian boundary (11.3 Ma) is clearly documented by microfossils and is calibrated with radiometric and magnetostratigraphic data. A new interpretation for the interbasinal correlation is proposed by synchronizing the top of the Central Paratethyan Sarmatian with the top of the Eastern Paratethyan Bessarabian.

**Key words:** Sarmatian, Pannonian, Transylvanian Basin, stratigraphy, microfossils, Foraminifera, Ostracoda.

## Introduction

The Middle to Upper Miocene sedimentary succession of the Transylvanian Basin represents the upper megasequence of the basin's fill (Krézsek & Bally 2006). It mostly consists of marine siliciclastics separated into several sedimentary sequences (Krézsek & Filipescu 2005) belonging to the Badenian (Papp et al. 1978), Sarmatian (Papp et al. 1974) and Pannonian (Papp et al. 1985) regional stages of the Paratethys.

A series of large outcrops are displayed along the right bank of the Mureş River in the central part of the Transylvanian Basin (Romania). Section A from Oarba de Mureş (Sztanó et al. 2005), located at N46.45502°, E24.28598° (Fig. 1) preserves a continuous, thick succession of deep marine Sarmatian and Pannonian turbidites. For this reason, this section has been considered a very good potential candidate for a facies stratotype for the Sarmatian-Pannonian boundary.

A few independent projects have investigated the Sarmatian-Pannonian transition in Section A (Fig. 1), where the boundary was placed by Vancea (1960). Results on sedimentology were published by Sztanó et al. (2005), while Sütő & Szegő (2008) published data on biostratigraphy based on dinoflagellates. Preliminary results on magnetostratigraphy, radiometric dating, and biostratigraphy were presented by Vasiliev et al. (2006), Filipescu et al. (2009), and De Leeuw et al. (2009). An integrated study was published by Vasiliev et al. (2010). Our purpose is to present in detail the micropaleontological record for

the Sarmatian-Pannonian transition, in relation to the paleoenvironmental changes, in order to propose correlation criteria and to better understand the basin's evolution.

## Material and methods

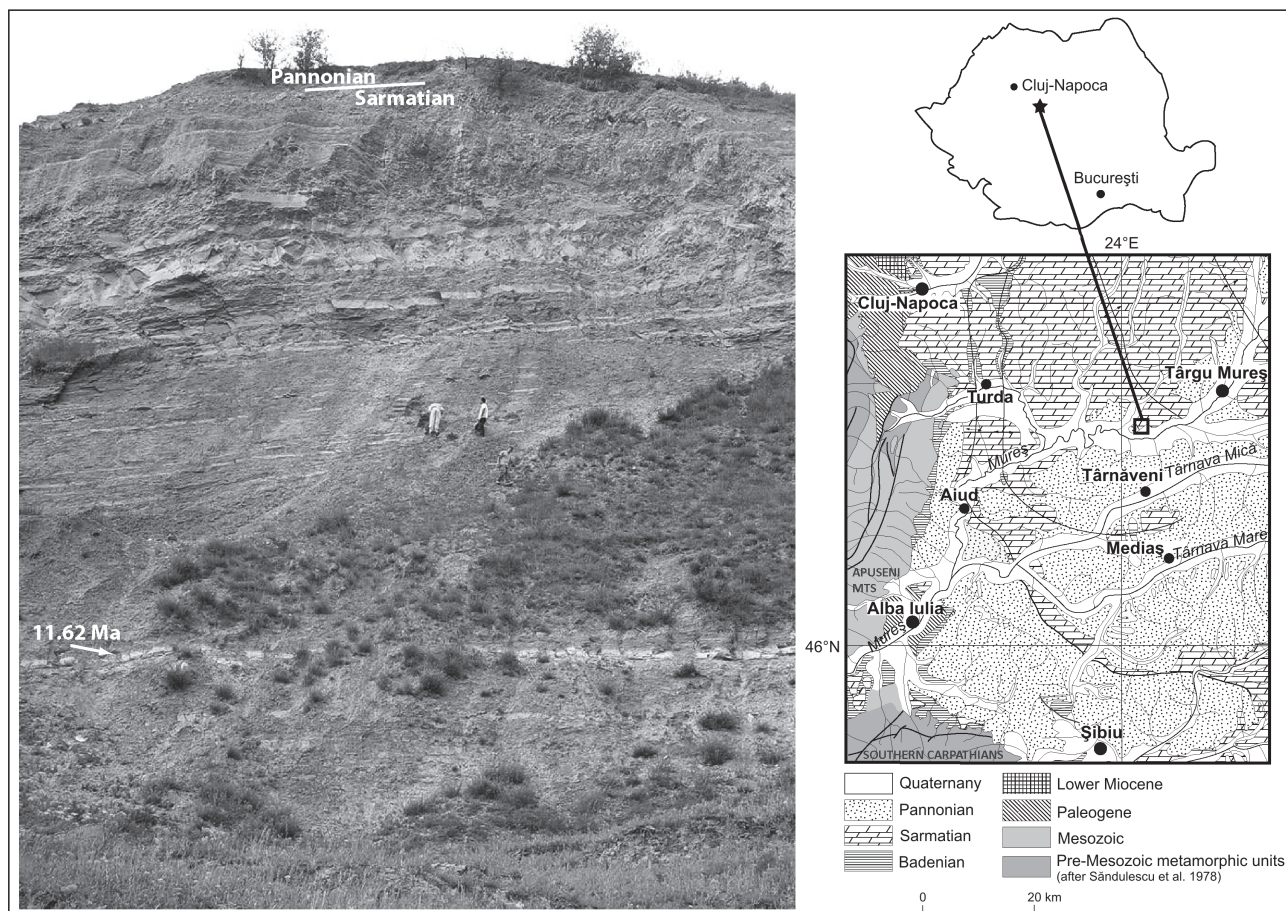
More than 120 micropaleontological samples were studied from the almost 60 m thick Section A in Oarba de Mureş. The samples were processed by standard micropaleontological methods and the microfossils were recovered from a 63 µm sieve. After a preliminary observation under stereomicroscope, the foraminifera and ostracods were examined and photographed using a scanning electron microscope (JSM-JEOL 5510 LV).

All identified species were counted and the number of specimens (#/250 g of sediment) was plotted along the section (Figs. 2, 3). Several diagnostic groups of foraminifera were used for paleoenvironmental and stratigraphic interpretations.

## Results

### *Microfossil assemblages*

Fossil content and sedimentological features suggest particular environmental settings, with stratified water (brackish,



**Fig. 1.** Oarba de Mureș section and its location on the map of Romania and on the simplified geological map of the Transylvanian Basin.

oxic surface and dysoxic bottom waters) and deep-sea turbiditic systems. Poor oxygenation of the studied interval was presumed in the previous studies based on the absence of benthic molluscs (Sztanó et al. 2005), and also by the presence of greigite mineral (Vasiliev et al. 2006).

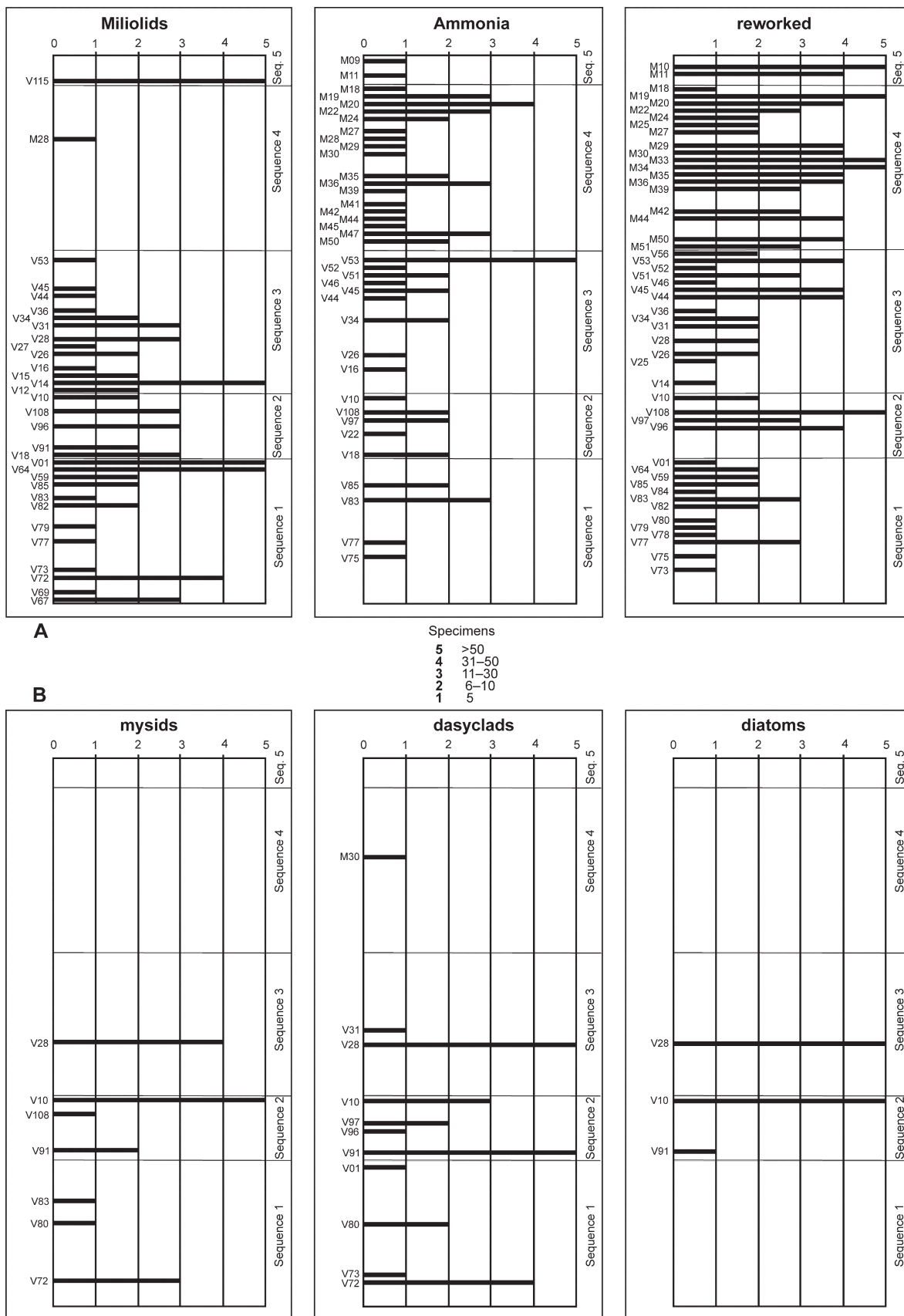
The foraminiferal assemblages are dominated by benthic species, in most cases with small juveniles, which were probably either sedimented during their early stage of life (?meroplanktonic or opportunistic taxa in seasonally unstable environments) or transported from the shallower environments by the turbiditic currents (the transport of contemporaneous taxa was more active during the regressive intervals). Rare five-chambered and biserial planktonic foraminifera have been associated with the transgressive intervals; we also presumed that the bolivinids may have had, at least temporarily, a planktonic behaviour as shown by Darling et al. (2009) and Smart & Thomas (2006, 2007).

The abundance of microfossil groups is diagnostic for the changes in the paleoenvironment, as shown in Figs. 2 and 3. A general trend of salinity decrease can be observed along the section (Fig. 2A), which is documented by the initial dominance of the miliolids, then the dominance of the *Ammonia* spp. group and, at the top of the section, the total replacement of foraminifera by ostracods. Marginal and shallow marine assemblages suggesting highly fluctuating values of salinity

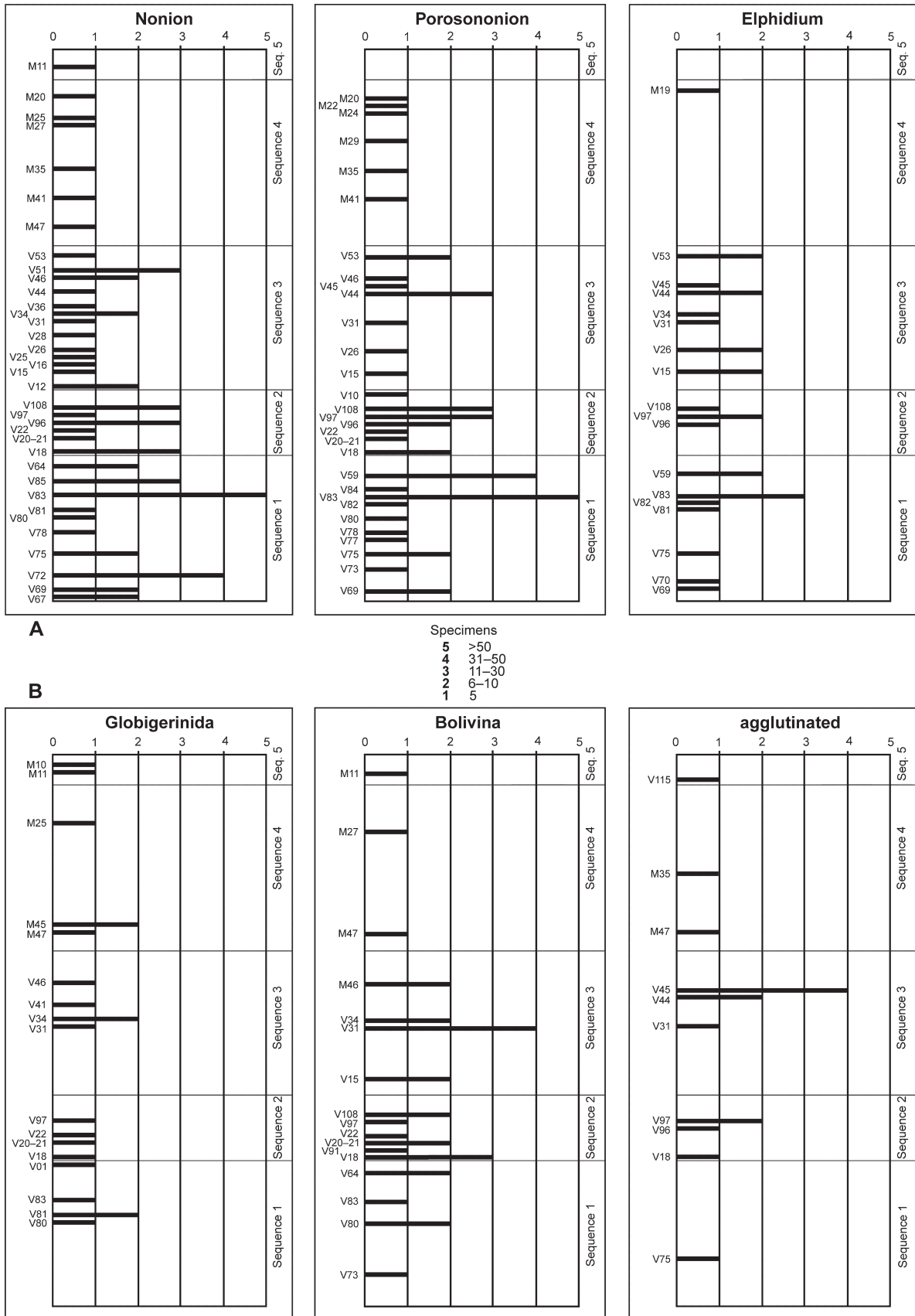
correlate with high levels of reworking (Fig. 2A). The good correlation among the groups of mysids, dasyclads, diatoms, and fish (Fig. 2B, Fig. 5) can also be used to highlight the productive areas (eutrophic environments) developed in front of the deltas. There is a good correlation between the marine benthic rotaliids (*Nonion*, *Porosonion*, *Elphidium* groups — Fig. 4), which usually display higher abundances in connection to shallowing trends or progradation (Fig. 3A). Planktonic foraminifera (species of *Globigerina*, *Tenuitellinata*, *Streptochilus* — Fig. 5) were associated with the transgressive deep-sea environments, while bolivinids and agglutinated foraminifera (Figs. 5, 6) document the colonization of the deep hypoxic to oxic environments during the early highstand and late lowstand (Fig. 3B).

#### *Microfossil assemblages and potential stratigraphic sequences*

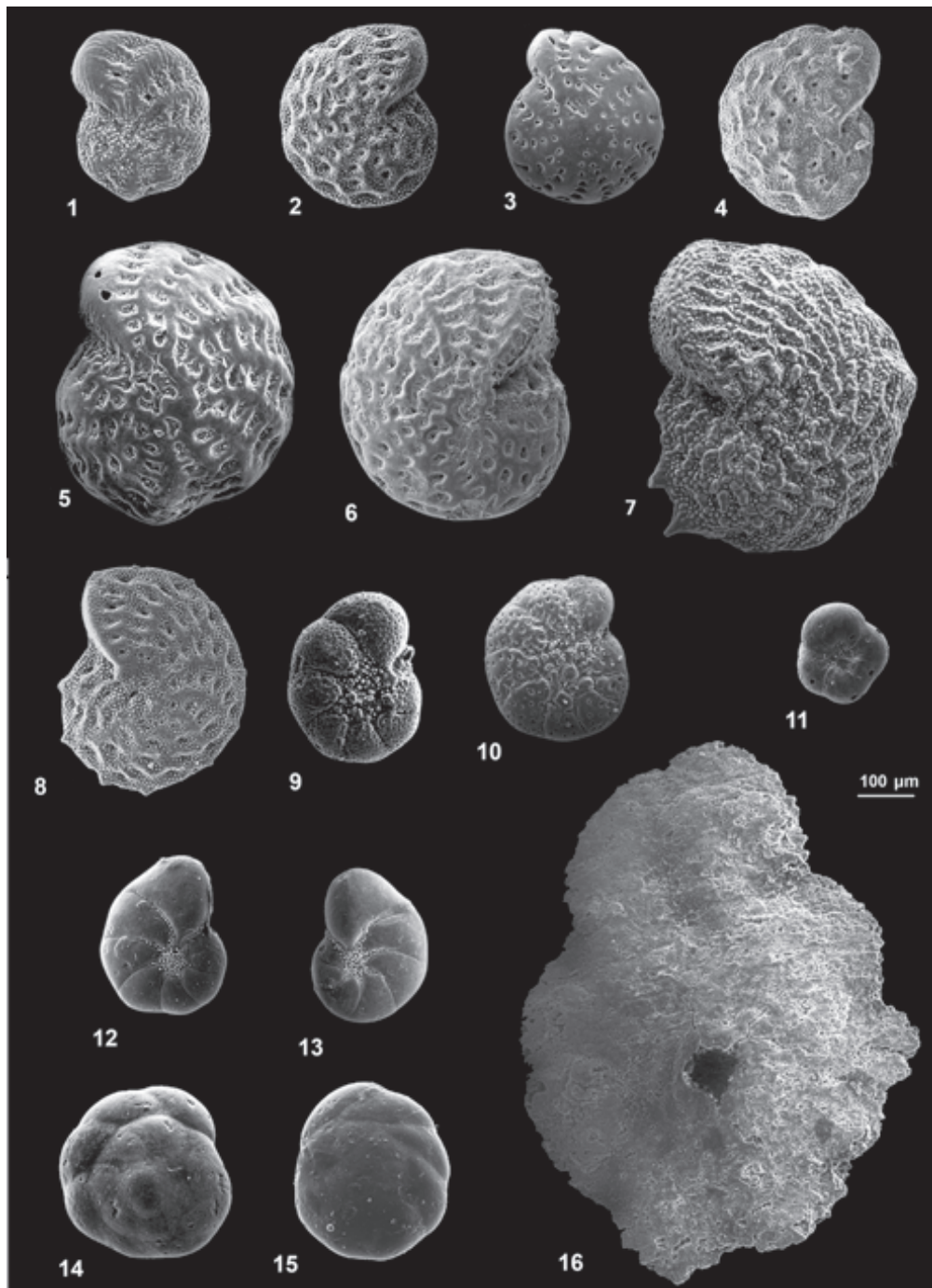
It is well-known that the sequence stratigraphy is not easy in turbiditic successions. Our investigations on the upper Sarmatian from Oarba de Mureș clearly revealed several cyclic events in the micropaleontological record, which could be linked to different stages of sea-level fluctuations and consequently to the sedimentary genetic units (systems tracts). The identified sequences (Fig. 7) are detailed below.



**Fig. 2.** Frequency of foraminiferal groups (specimens per 250 g of sediment) identified at Oarba de Mureș: **A** — groups characterizing advanced shallowing trends (strong erosion and reworking); **B** — groups documenting the eutrophication in front of deltas.



**Fig. 3.** Frequency of foraminiferal groups (specimens per 250 g of sediment) identified at Oarba de Mureș: **A** — marine foraminiferal groups characterizing the shallowing trends; **B** — marine foraminiferal groups characterizing deeper marine settings.



**Fig. 4.** Sarmatian shallow-water foraminifera from Oarba de Mureș. **1** — *Elphidium* sp. — sample V96. **2** — *Elphidium fichtelianum* (d'Orbigny) — sample V83. **3** — *Elphidium hauerinum* (d'Orbigny) — sample V44. **4** — *Elphidium* aff. *jukovi* Serova — sample V34. **5, 6** — *Elphidium grilli* Papp — 5 sample V44; 6 sample V59. **7** — *Elphidium nataliae* Popescu — sample V44. **8** — *Elphidium* aff. *aculeatum* — sample V44. **9** — *Porosonion granosum* (d'Orbigny) — sample V83. **10** — *Porosonion sarmaticum* Popescu — sample V75. **11** — *Discorbis effusus* Zhizhchenko — sample V85. **12, 13** — *Nonion bogdanowiczi* Voloshinova — 12 sample V83; 13 sample V80. **14, 15** — *Ammonia* ex gr. *beccarii* (Linné) — 14 sample V53; 15 sample M47. **16** — *Trochammina kibleri* Vengliniski — sample V115.

### 1<sup>st</sup> Sequence

Samples from the lowermost part of the section (e.g. V67) contain a few juvenile specimens of miliolids (*Articulina problema*) and rare rotaliids transported from the shallower areas by the active erosion during falling stage. The following substrate colonization, probably supported by the oxygenation produced by deltaic progradation (fish bones and mysids — *Sarmysis sarmaticus* — sample V72), must be related to the slow sea-level rise during the lowstand. The assemblage becomes progressive-

ly more diverse (samples V74–V59), with mature rotaliid foraminifera (*Elphidium flexuosum*, *Porosonion martkobi*, *P. subgranosum*, *Nonion biporus*, *N. commune*, *Fissurina bessarabica*, *Discorbis effusus*) and ostracods (*Loxococoncha* cf. *popovi*, *Amnicythere cernajseki*, *Aurila* cf. *notata*). The transgressive interval (samples V74–V81) can be documented by the presence of *Bolivina* spp. and the peak of globigerinids (Fig. 4B). The following interval (samples V82–V01) seems to be related to the highstand parasequences and is characterized by shallower taxa, mainly miliolids (*Cycloforina gracilis*, *C.*

*predkarpatica*, *Flintina georgii*, *Pseudotriloculina consobrina*, *Varidentella pseudocostata*, *V. sarmatica*).

#### 2<sup>nd</sup> Sequence

A possible tectonic uplift produced a forced regression and associated coarse sediment above sample V01 (volcanic ash connected to active tectonics and coarse sediment of the erosional falling stage FSS2). The lowstand interval following the minimum sea-level (samples V2–V07) continues the regressive trend and only contains very rare rotaliid and miliolid foraminifera. A distinct change in the assemblage can be observed starting with sample V18, probably determined by a transgression; the migration of planktonics and deeper sea benthics into the basin came in several stages (probably deepening-upwards parasequences) with abundant *Bolivina* (*B. pseudoplicata*, *B. moldavica*, *B. sarmatica*) and other buliminids (*Buliminella elegantissima*, *Caucasina* sp.). Prograding highstand deltas installed just below sample V110, as proven by abundant populations of mysids (*Sarmysis sarmaticus*), dasyclad algae (*Halicoryne moreletti*), and diatoms (*Coscinodiscus* sp.). Stable environments generated by the high sea-level persisted up to the interval represented by sample V11. Diverse and mature foraminifera (*Elphidium flexuosum*, *Porosonion hyalinum*, *P. subgranosum*, *Nonion bogdanowiczi*, *Ammonia beccarii*, *Articulina* sp., *Pseudotriloculina consobrina*) occur together with ostracods (*Amnicythere cernajseki*, *Loxoconcha* sp.). Locally abundant bolivinids, agglutinated foraminifera, and mysids are in relation with parasequences.

#### 3<sup>rd</sup> Sequence

Another falling stage with associated forced regression (FSST 3) supplied coarser sediments (samples V12–V14) and very shallow foraminiferal assemblages with miliolids (*Varidentella reussi*, *Varidentella sarmatica*). The following diversification (samples V16 to V26) of the ostracods (*Xestoleberis* sp.; *Amnicythere cernajseki*, *Loxoconcha* cf. *popovi*), and foraminifera (*Ammonia beccarii*, *Porosonion subgranosum*, *Elphidium* spp., *Bolivina* spp.) is related to the lowstand deepening in shallow marine environments. Prodeltaic assemblages (dasyclads, diatoms, mysids, fish bones — sample V28) are followed by deeper marine taxa (*Bolivina* aff. *arta*, *B. sarmatica*, *B. moldavica*, *B. pseudoplicata*, *Streptochilus* sp. — samples V31, V34) associated with the transgression. The highstand persisted up to sample V58, with sea-level fluctuations documented either by shallower benthic foraminifera (*Cycloforina predkarpatica*, *Pseudotriloculina consobrina*, *Quinqueloculina fluviata*, *Nonion bogdanowiczi*, *Porosonion markobi*, *Porosonion subgranosum*, *Elphidium flexuosum*, *Elphidium* aff. *nataliae*, *Elphidium subangulatum* — samples V34–V40, V47–V58) and ostracods (*Aurila merita*, *Aurila* cf. *schreteri*, *Graptocythere omphalodes*, *Cyprideis* cf. *pannonica*, *Amnicythere* spp.) or deeper marine foraminifera (*Glomospira charoides*, *Ammodiscus miocenicus*, *Bolivina* spp., globigerinids — samples V43–V45). Very shallow brackish environments with *Ammonia* flourished at the top of the sequence (samples V53–V58).

#### 4<sup>th</sup> Sequence

Planktonics and deeper-water foraminifera (five-chambered globigerinids and *Bolivina* spp.) are present again in the samples following the interval with thick coarse sediments (?FSST4–LST4) above sample V58. These correlate with progressively less reworking and lower abundances of shallow water taxa (e.g. *Ammonia* spp.), therefore we interpreted this interval as another transgressive interval (TST4 — samples M45–M25). As the progradation became more active during the highstand (HST4 — samples M24–M15), shallower foraminifera and ostracod assemblages became more abundant (*Ammonia beccarii*, *Ammonia tepida*, *Amnicythere* sp., *Cyprideis pannonica*).

#### 5<sup>th</sup> Sequence

The sandy interval close to the top of the section (55 m) has been interpreted as the lower part of the last sequence (FSST5). The shallow marine miliolid-dominated assemblage (*Articulina sarmatica*, *A. problema*, *A. bidentata costata*, *A. vermicularis*, *Sarmatiella moldaviensis*, *S. prima*, and agglutinated *Trochammina kibleri* — sample V115) was probably associated with the late lowstand (LST5), while the last few globigerinids document the last marine incursion at the Sarmatian/Pannonian boundary (TST5 — samples M10–M11). These occur just below the volcanic ashes (Bazna Tuff) near the top of Section A, which were probably deposited in connection with a tectonic event. The associated higher sedimentary input (HST5 — samples M09 and above) and possible change of salinity determined an abrupt change in the micropaleontological assemblages (extinction of Sarmatian foraminifera and radiation of Pannonian ostracods — sample M09).

### Stratigraphic calibration

The Sarmatian/Pannonian boundary was placed by Vancea (1960) at the last level of volcanic ash in Section A. The Pannonian Biozone with *Lymnocardium praeponticum* was identified in the lower part of the Section B, and correlated with the dinoflagellate *Mecsekia ultima* Biozone and polarity Zone C5r (12–11 Ma; Magyar et al. 1999; Sztanó et al. 2005). Based on dinoflagellate assemblages, Sütő & Szegő (2008) placed the boundary at 3.4 m below the top of Section A, at the massive occurrence of *Mecsekia ultima*, although they showed that the index species for the Pannonian (*Spiniferites bentonii pannonicus*) occurs at 1.4 m below the top.

The foraminiferal assemblages from Oarba de Mureş contain evolved *Porosonion* species (*Porosonion aragviensis*, *P. hyalinum*, *P. sarmaticum*), therefore we included the whole interval opened by Section A into the Sarmatian *Porosonion aragviensis* Biozone (Popescu 1995). Beside the evolved species of *Porosonion*, the foraminiferal assemblages contain all common Bessarabian taxa (*Trochammina kibleri*, *Articulina problema*, *A. sarmatica*, *A. tamanica*, *Bolivina moldavica*, *B. sarmatica* etc. — see Didkovski & Satanovskaya 1970; Venglini 1975), and for this reason we consider that the Sarmatian sensu Suess (1866) must be



**Fig. 5.** Sarmatian micropaleontological assemblages from Oarba de Mureș. **1** — *Bolivina moldavica* Didkovski — sample V18. **2** — *Bolivina* aff. *arta* Macfayden — sample V34. **3** — *Bolivina sarmatica* Didkovski — sample V34. **4** — *Bolivina dilatata* Reuss — sample V46. **5** — *Bolivina pseudoplicata* Heron-Allen & Earland — sample V34. **6** — *Bolivina hebes* Macfayden — sample V46. **7, 8** — *Streptochilus latum* Brönnimann & Resig — **7** sample V28; **8** sample V18. **9** — *Streptochilus globulosum* (Cushman) — sample V72. **10** — *Buliminella elegantissima* (d'Orbigny) — sample V18. **11, 12** — *Tenuitellinata pseudoedita* (Subbotina) — **11** sample V80; **12** sample V12. **13** — *Tenuitellinata selleyi* Li, Radford & Banner — sample V56. **14** — *Tenuitella clemenciae* (Bermúdez) — sample V51. **15** — *Cyprideis pannonica* (Méhés) — right valve, sample V53. **16** — *Graptocythere omphalodes* (Reuss) — right valve, sample V53. **17** — *Aurila merita* (Zalányi) — right valve, sample V45. **18** — *Amnicythere* sp. — left valve, sample V52. **19** — *Loxoconcha* cf. *popovi* Stancheva — right valve, sample V73. **20** — *Amnicythere cernajseki* Stancheva — right valve, sample V16. **21** — *Coscinodiscus* sp. — sample V28. **22** — *Halicoryne moreletti* (Pokorný) — sample V28. **23–25** — Fish skeletal fragments: otolith (**23**) and fish teeth (**24, 25**) — sample V28. **26** — *Sarmysis vancouveringi* (Voicu) — sample V91. **27** — *Sarmysis sarmaticus* (Khalilov) — sample V28.



**Fig. 6.** Sarmatian foraminiferal assemblages from Oarba de Mureş. **1** — *Ammodiscus miocenicus* Karrer — sample V44. **2** — *Glomospira charoides* (Jones & Parker) — sample V44. **3** — *Varidentella latecunata* (Vengliniski) — sample V01. **4** — *Varidentella reussi* (Bogdanowicz) — sample V64. **5** — *Varidentella sarmatica* (Karrer) — sample V01. **6** — *Flintina georgii* Bogdanowicz — sample V01. **7** — *Sinuoloculina consobrina* (d'Orbigny) — sample V28. **8** — *Cycloforina predkarpatica* (Serova) — sample V45. **9** — *Articulina problema* Bogdanowicz — sample V115. **10–11** — *Articulina tamanica* Bogdanowicz — sample V115. **12** — *Articulina sarmatica* (Karrer) — sample V115. **13** — *Sarmatiella costata* Bogdanowicz — sample V115. **14** — *Articulina vermicularis* Bogdanowicz — sample V115.

correlated with the Volhynian and the whole Bessarabian stages of the Eastern Paratethys.

The Sarmatian-Pannonian boundary can be very clearly traced on the basis of microfossils due to the very distinctive assemblages of Sarmatian foraminifera vs. Pannonian ostracods. The boundary must be traced at the first occurrence of ostracod assemblages containing deep-water species of *Amplocypris-Candona* group (Fig. 8), at about 2.3 m from the top of Section A (sample M10, Fig. 4), just below the ash layers of the Bazna Tuff (Vancea 1960; not “Oarba Tuff” as

considered by Vasiliev et al. 2010). Our boundary can be very clearly traced between the boundaries of Vancea (1960) and Sütő & Szegő (2008).

No type species for the base of Zone A of the Pannonian (large *Amplocypris* ostracods or *Congerina ornithopsis* bivalve) have been found. Among the ostracods, *Loxococoncha* (*Loxococoncha*) *dudichi* and *Candona* (?*Typhlocypris*) aff. *lunata* are known from the Pannonian Zones B–C, while *Candona* (*Lineocypris*) *transilvanica* (Héjjas) are found in Zones B–D. The absence of typical taxa for Zone A could be



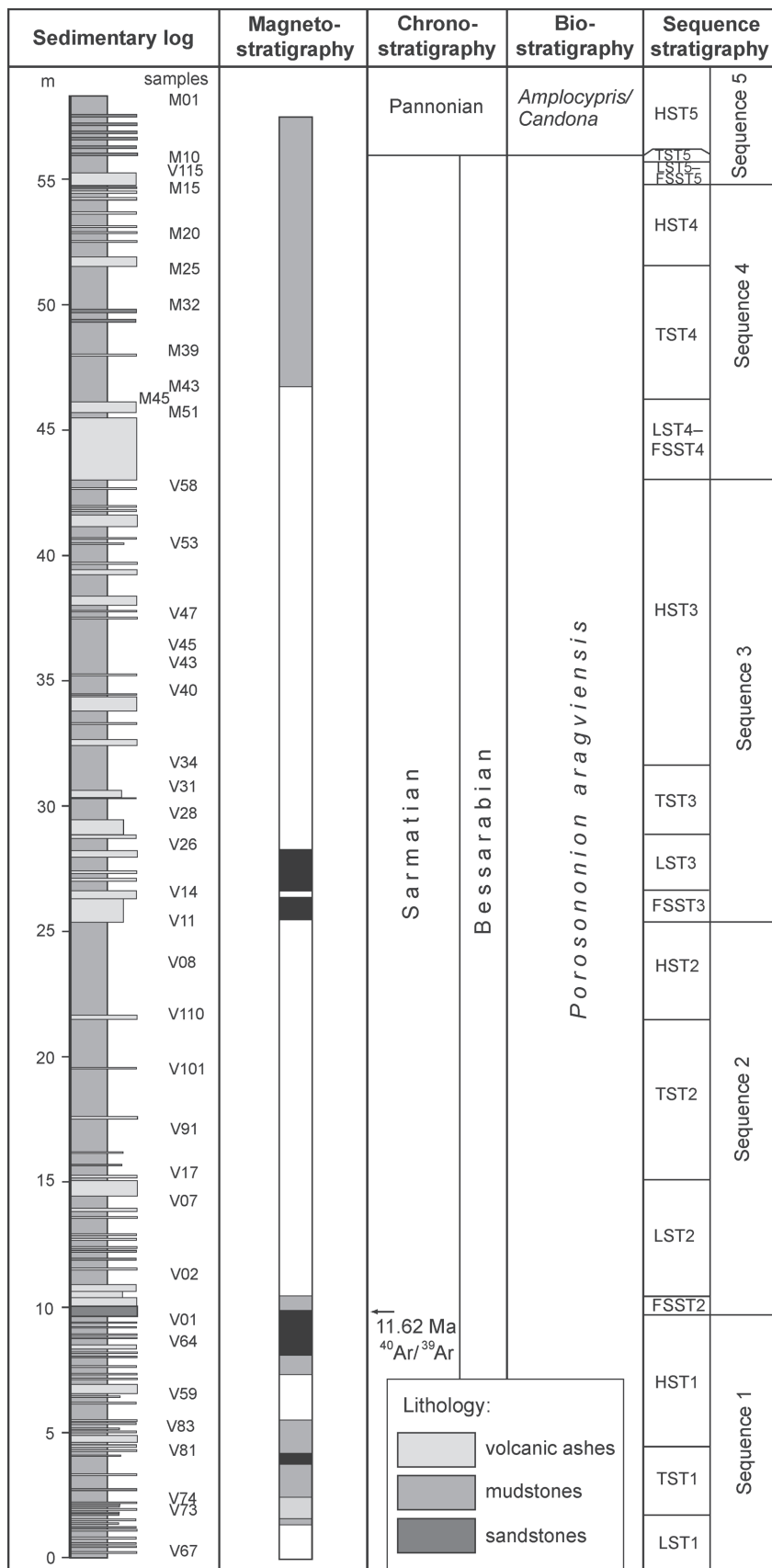
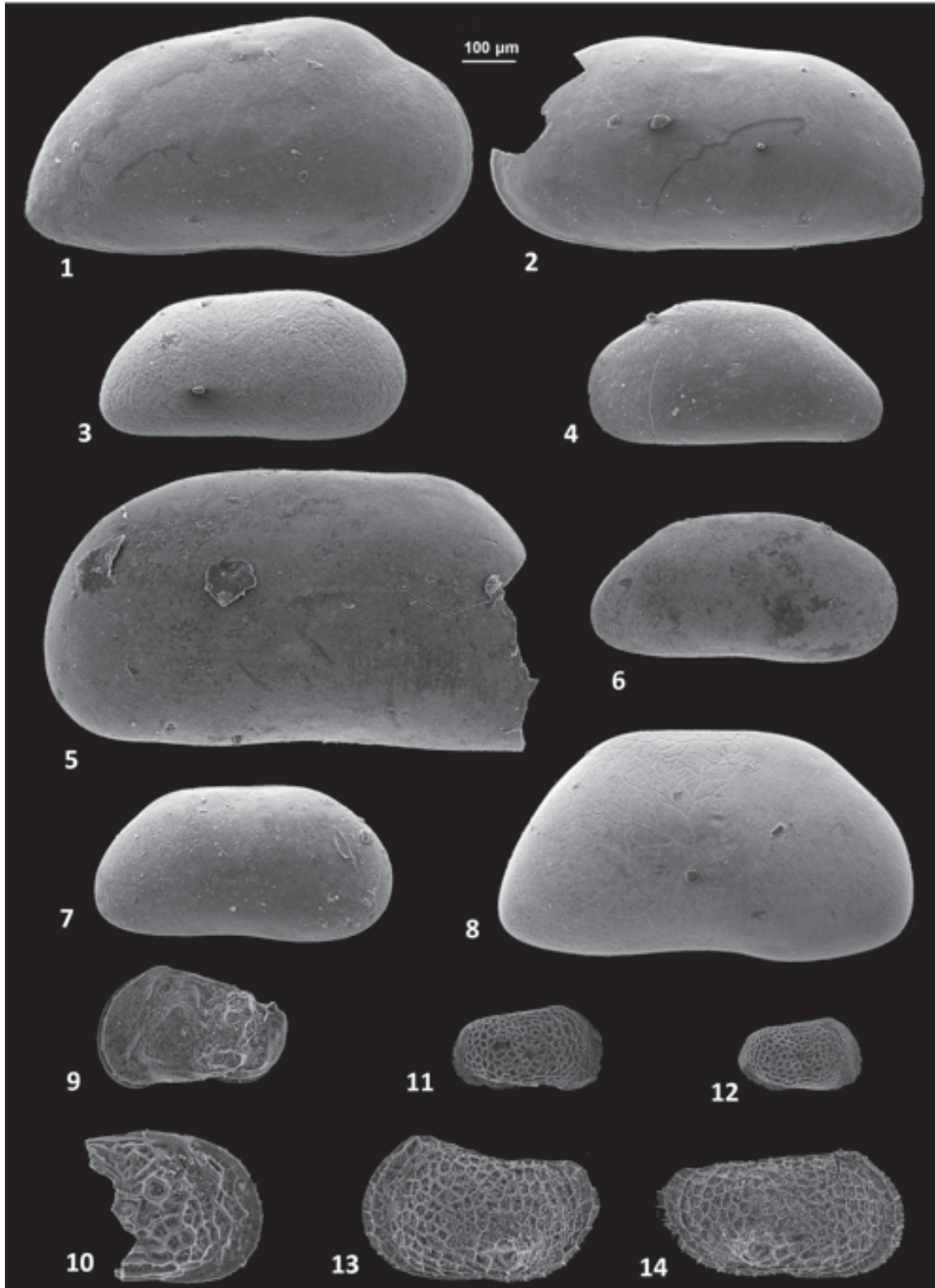


Fig. 7. Stratigraphic position of Sarmatian-Pannonian boundary at Oarba de Mureş (magnetostratigraphic and isotopic data from Vasiliev et al. 2010).



**Fig. 8.** Pannonian ostracods from Oarba de Mureș. **1, 2** — *Amplocypris* cf. *reticulata* (Héjjas) — 1 right valve, sample M3; 2 left valve, juv. sample M07. **3** — *Candona* (*Caspiocypris*) cf. *aspera* (Héjjas) — right valve, juv. sample M05. **4** — *Candona* (?*Typhlocypris*) *lunata* (Méhes) — left valve, juv. sample M07. **5** — *Candona* (*Caspiocypris*) *aspera* (Héjjas) — left valve, sample M07. **6** — *Candona* (?*Propon-toniella*) sp. — right valve, juv. sample M05. **7, 8** — *Candona* (?*Lineocypris*) *transilvanica* (Héjjas) — 7 right valve, juv. sample M07; 8 right valve, sample M05. **9, 10** — *Callistocythere* (*Euxinocythere*) cf. *bituberculata* Sheremeta — 9 left valve, sample M05; 10 right valve, sample M07. **11, 12** — *Loxoconcha* (*Loxoconcha*) cf. *dudichi* Zalányi — right valves, sample M07. **13, 14** — *Loxoconcha* (*Loxocorniculina*) *hodonica* Pokorný — 13 left valve, sample M05; 14 right valve, sample M03.

caused by a longer persisting marine facies compared to the Pannonian Basin, due to a later closure of the Transylvanian Basin.

Considering the radio-isotopic age of the ash layer from the lower part of Section A (11.62 Ma) and the magnetostratigraphic calibration of the top of the section (Vasiliev et al. 2010), we have a good age approximation for the Sarmatian-Pannonian biostratigraphic boundary, that is close to 11.3 Ma. This is approximately 300 kyr younger than the age of the Sarmatian-Pannonian boundary traced by Piller et al. (2007) and about 100 kyr younger than the boundary traced by Lirer et al. (2009).

## Discussion

A major paleoenvironmental change occurred at the Sarmatian-Pannonian boundary. The newly established restrictive conditions produced very distinctive changes of biota (e.g. marine foraminifera replaced by brackish ostracods) about 11.3 Myr ago (Vasiliev et al. 2010). This biotic boundary seems to be younger compared to other Central Paratethyan basins (e.g. Piller et al. 2007; Lirer et al. 2009), suggesting a different position of the Sarmatian-Pannonian boundary due to persisting marine conditions in the Transylvanian Basin (possible longer-lasting connections to the open seas).

Indications for a transgressive event (planktonic foraminifera) could be identified even in the vicinity of the Sarmatian-Pannonian boundary and probably this event can be correlated with the early Ser4/Tor1 cycle of Hardenbol et al. (1998). The sea-level rising trend was probably stopped by active tectonics (higher sedimentary input and volcanic ashes can be observed just above the boundary).

It seems that the cyclicity observed in the sedimentary and micropaleontological record could have been produced by a combination of tectonic and climatic factors. The influence of compressional tectonics could be inferred by the presence of volcanic ash in the section, while the climatic/seasonal cyclicity can be presumed by the repeated abundances of the assemblages with diatoms, mysids, dasyclads, fish bones, and local abundances of opportunistic groups living in an seasonally unstable environment.

## Conclusions

Different microfossil taxa and their frequency (Figs. 2, 3) reflect with fidelity the environmental changes around the Sarmatian-Pannonian boundary. Particular micropaleontological assemblages were used to distinguish several cyclic events. The fossil mysids, diatoms, calcareous algae and fish bones were probably stimulated by eutrophic intervals associated with active deltas. The globigerinid assemblages were associated with transgressive intervals, while the presence of *Bolivina* species could have been related to the deep environments of the early highstand and late lowstand. Diverse rotaliids and miliolids (the shallowest) are characteristic of normal regressive intervals during the highstand and lowstand, while strong reworkings were probably associated

with forced regressions. Linking the particular micropaleontological assemblages to sea-level changes allowed the separation of five stratigraphic sequences (Fig. 7) with their particular genetic units, which support the increase of stratigraphic resolution for the Upper Sarmatian. The sequences identified in Section A at Oarba de Mureş seem to be lower order cyclicities within the Ser4-Tor1 cycle (Hardenbol et al. 1998), influenced by regional tectonics and climate.

A clearly marked Sarmatian-Pannonian boundary has been traced on the basis of very distinctive foraminiferal and ostracod assemblages. Based on foraminiferal assemblages, we consider that the Central Paratethyan Sarmatian should be correlated with the Volhynian and the whole Bessarabian of the Eastern Paratethys. Due to the continuous sedimentation and good calibration given by biostratigraphy, magnetostratigraphy, radiometric data and sequence stratigraphy, the section of Oarba de Mureş seems to be a very good candidate for the facies stratotype of the Sarmatian-Pannonian boundary.

**Acknowledgments:** The authors are grateful to S.N.G.N. Romgaz S.A. and University of Utrecht for funding the study, to Dr. Csaba Krézsek, Dr. Katarína Holcová, and Dr. Jarosław Tyszka for the useful comments. We also thank Claudiu Chendeş, Florin Borbei, and Josh Ball for helping with sample processing.

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