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# Biostratigraphic re-evaluation of the lower to middle Miocene succession in the Eastern Carpathians: a case study related to the oil fields of the Diapir Fold Zone, Romania

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Romania has a long history of hydrocarbon production and tens of thousands of boreholes have penetrated Miocene strata. Many well cores or cuttings have been either lost or damaged, but lab reports containing valuable petrographic, paleontological and structural data are still available. Most of the knowledge of the subsurface relies on old descriptions and interpretations used by the oil industry. These data have not been recently updated, while research results from the last decade suggest potential changes in stratigraphy, especially for the lower to middle Miocene succession. In order to update, calibrate, and reduce uncertainties regarding the subsurface stratigraphic record, we have reviewed the lab reports and used equivalent field samples for an updated interpretation of the lower to middle Miocene succession. Core and cutting descriptions from boreholes covering an area of ~10,000 $km^2$ in the Diapir Fold Zone of the Eastern Carpathians have been selected and biostratigraphically re-evaluated based on microfossils and calcareous nannofossils. In many cases, highly uncertain ages were previously interpreted as Oligocene and early Miocene. Our recent data suggest that most of the lower Miocene is either difficult to determine or has been reinterpreted as middle Miocene (e.g., Cornu and Doftana formations). This significant change in ages requires an updated model for the timing of regional structural evolution and may open new exploration opportunities in this highly mature hydrocarbon area. This study demonstrates the need for a new complete and reliable stratigraphic framework for the whole Miocene stratigraphic record of the Eastern Carpathians.

Key words: biostratigraphy, re-evaluation, Carpathian Bend Zone, Miocene, microfossils.

## INTRODUCTION

The area known as the Diapir Fold Zone (DFZ) of the Eastern Carpathians (Figs. 1 and 2) is a highly mature hydrocarbon area with an extraction history of more than 130 years. This prolific hydrocarbon area hosts the largest onshore oil fields in Romania. Some of these fields are structurally associated with salt diapirs, and the term "diapir" was introduced by Mrazec in 1907 from this area (Mrazec, 1910; Tămaş et al., 2018).

Although the Carpathian Bend Zone (CBZ) area has a long history of exploration and production and an immense quantity of data has been recorded from the subsurface, the stratigraphic framework is currently outdated. Therefore, revision of the formal and informal stratigraphic units has become a priority.

The focus of this study is the highly uncertain lower to middle Miocene succession. We aim here to calibrate the subsurface data with respect to recent developments in both international and regional stratigraphy.

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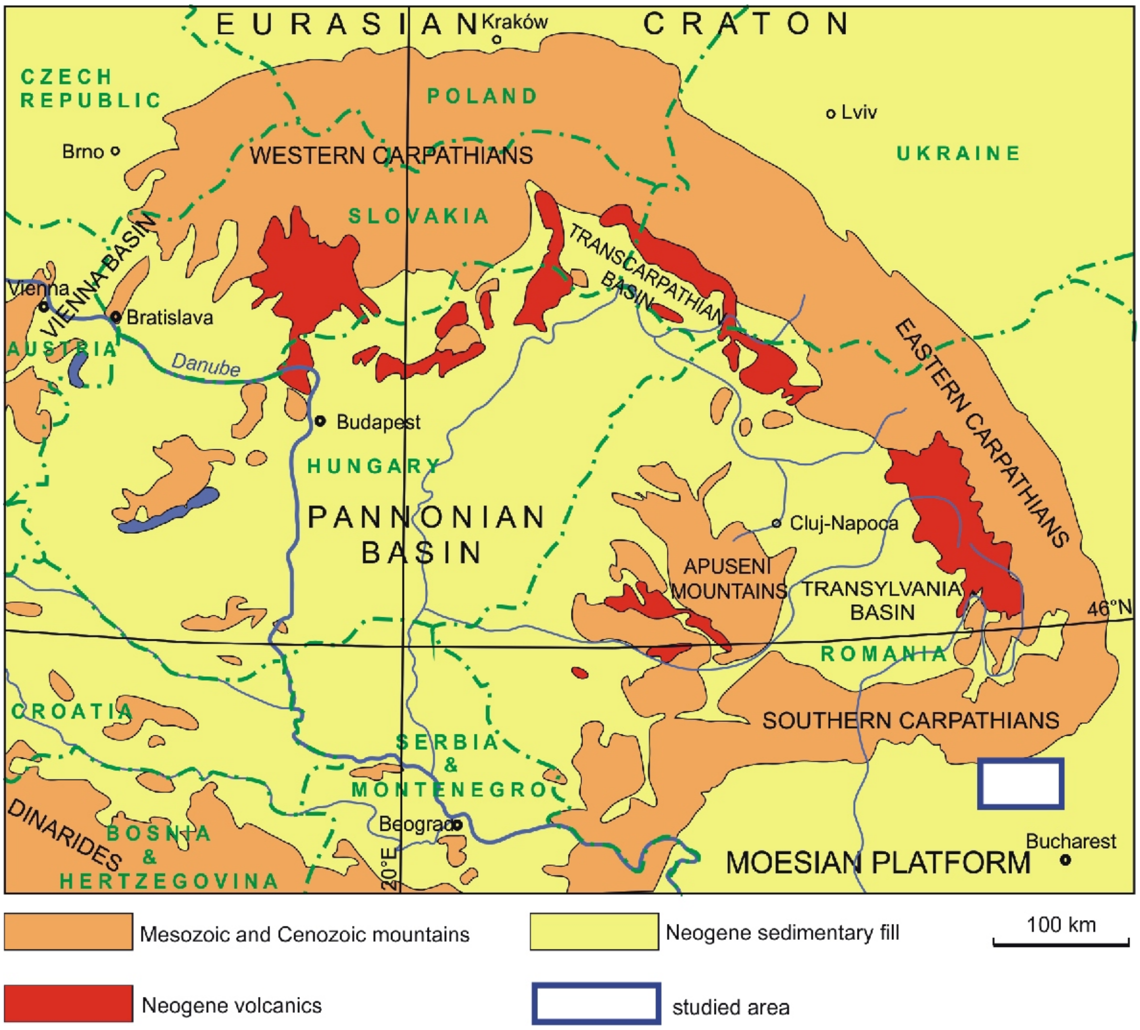



**Fig. 1. Location of the area studied**

Our biostratigraphic approach has raised questions, and offered some answers, which may impact both stratigraphic and structural interpretation of the area. In several cases, the formations proved to be much younger and, consequently, a further detailed examination of the whole region is highly recommended as a priority in order to reveal new exploration opportunities in this highly mature hydrocarbon area.

## GEOLOGICAL BACKGROUND

The Romanian Carpathians are an Alpine orogen (Fig. 1) and record the Mesozoic and Cenozoic evolution of Tethys and subsequent Paratethys (Băncilă, 1958; Săndulescu, 1984, 1988; Csontos and Vörös, 2004; Schmid et al., 2008). The first compressional event started in the late Jurassic and emplaced nappe structures of the inner Romanian Carpathians during the mid-Cretaceous (Săndulescu, 1984; Csontos and Vörös, 2004). Starting with the Burdigalian, the subduction of the Carpathian embayment created a forward-breaking sequence of nappes (convolute flysch, Macla and Audia nappes). Following the latest Burdigalian to Badenian thrusting of the Tarcău Nappe (Dumitrescu, 1948, 1952), the Subcarpathian Nappe (Mrazec and Popescu-Voiteşti, 1914; Băncilă, 1958) was thrusted over the undeformed foreland during the Sarmatian (Săndulescu, 1984, 1988; Maţenco and Bertotti, 2000; Merten et al., 2010; Maţenco, 2017). During the latest Sarmatian to early Maeotian a set of ~NW-SE dextral strike-slip faults were active in the CBZ (Maţenco and Bertotti, 2000). The Walachian deformation of the Carpathians took place during the late Miocene (Maeotian) to Holocene (Hippolyte and Săndulescu, 1996). This stage was interpreted as reflecting intra-plate compression accommodated by thick-skinned deformation (Cloetingh et al., 2004; Schléder et al., 2019). The resulting deformation was characterized by up to 4 km of uplift, erosion and out-of-sequence thrusting (Sanders et al., 1999; Merten et al., 2010). The post-Oligocene shortening in the DFZ was ~40 km during the middle Miocene (Badenian–Sarmatian) and ~1–2 km during the Wallachian phase (Schléder et al., 2019).

As this study focuses on the lower to middle Miocene stratigraphic record of the DFZ (Fig. 2), the following section describes the stratigraphy as published, without any reinterpretation.

The Carpathian Foreland Basin (CFB) developed under continuous subsidence and favoured the deposition of deep marine ("flysch type") sedimentation (Conţescu et al., 1966; Sylvester and Lowe, 2004) during the Oligocene to the early Miocene. As the subsidence rate reduced during the early Miocene, the relative sea-level in the CFB also decreased, which led to the precipitation of evaporites in this shallow marine basin (Ştefănescu, 1995; Schléder et al., 2019). The middle Miocene sequence may be syn-tectonic and mostly deposited in a piggy-back setting (Bercea et al., 2016a; Schléder et al., 2019).

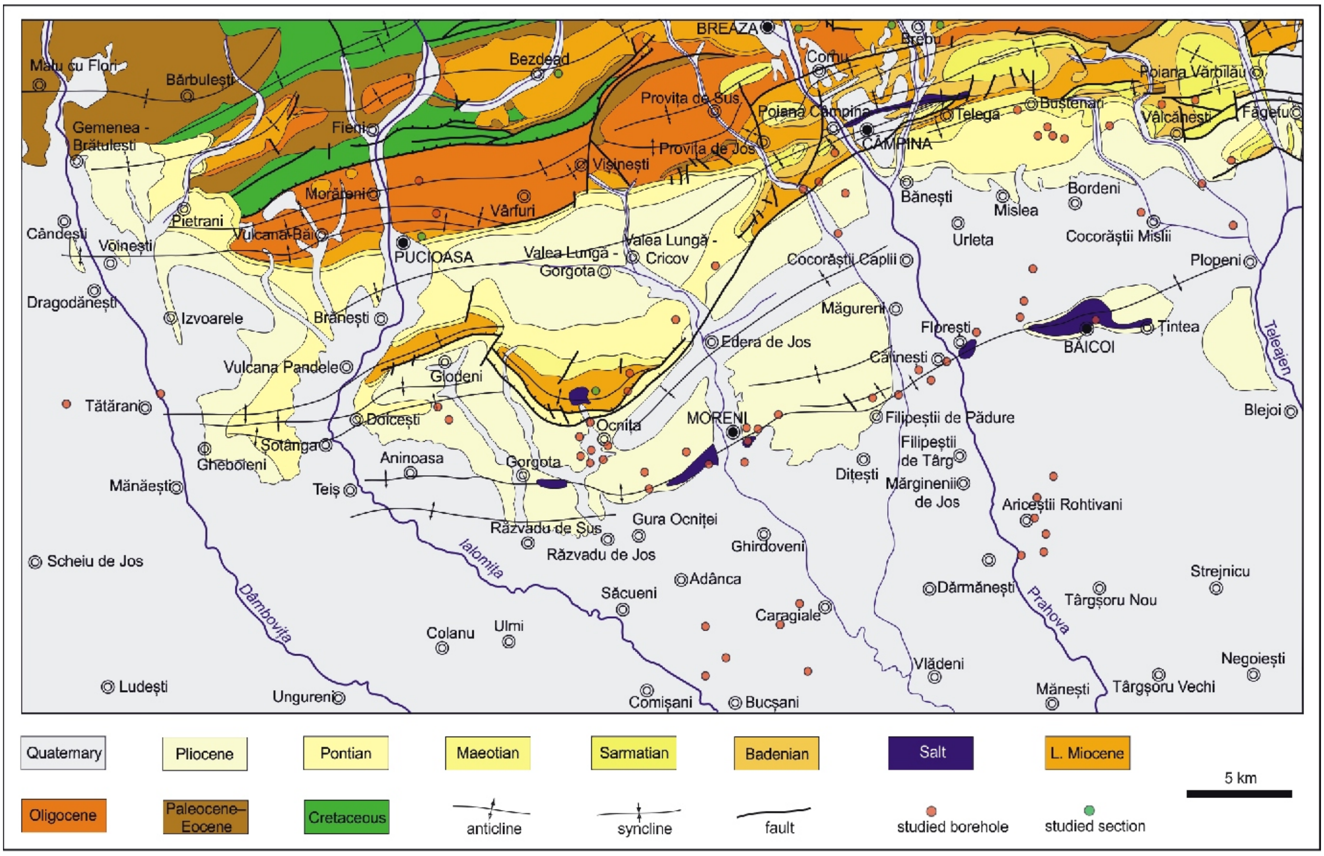



**Fig. 2. Location of the boreholes studied in the Diapir Fold Zone (based on the Geological Map of Romania, scale 1:200,000)**

During the mid-Badenian, another evaporitic event took place (i.e., de Leeuw et al., 2010). The late Sarmatian marked the end of the compression and started the evolution of the Dacian Basin (Jipa and Olariu, 2009). The upper Miocene is syn-tectonic and transgressive, deposited over a regional unconformity on the top of the Eocene, Oligocene, and Miocene strata (Ştefănescu et al., 1988; Schléder et al., 2019).

The Miocene stratigraphic record ranges in thickness from 300 to 700 m (Patrulius et al., 1968) and is preserved in the Outer Moldavides (Săndulescu, 1984). Based on a model of Oligocene to Miocene deep marine sedimentation with basin-scale anoxic events, two lithofacies types have been described in the Tarcău Nappe (Olteanu, 1952; Popescu, 1952; Patrulius et al., 1968; Săndulescu et al., 1995): the internal Pucioasa-Fusaru (Popescu-Voiteşti, 1900 and Mrazec, 1911, fide Băncilă, 1958) and the external Kliwa (Patrulius et al., 1968; Săndulescu et al., 1995). The former was considered as belonging to the internal part of the foredeep basin, while the latter was in the external part, with a transition area in between (Săndulescu et al., 1995; Grasu et al., 2007).

The Cornu Formation (Mrazec and Popescu-Voiteşti, 1914), considered as lower Burdigalian prior to this study (Mărunţeanu, 1999) is mainly a marine siliciclastic unit containing mudstones, glauconitic sandstones, and locally gypsum and olistrostomes (Frunzescu, 2013). At the base of the Cornu Formation, the evaporitic deposits were separated as the Sărata Member (Mrazec and Popescu-Voiteşti, 1914; Patrulius et al., 1968; Ştefănescu, 1978); its equivalents are the “lower gypsum member" (Săndulescu et al., 1995; Mărunţeanu, 1999) of the Tarcău Nappe and the salt deposits in the Subcarpathian Nappe (Săndulescu et al., 1995).

The overlying Doftana Formation (*sensu* Ştefănescu and Mărunţeanu, 1980) starts with the Brebu Conglomerate followed by thick sandstones with intercalations of mudstone and gypsum (Frunzescu, 2013). It is up to ~1200 m thick (Patrulius et al., 1968) and was deposited under sub-aerial to shallow marine fan-delta conditions (Guzman, 2001). Originally, the upper sandy part was considered as early Miocene (“Helvetian”) in age (Patrulius et al., 1968), but later studies considered the whole formation as early to middle Miocene (Mărunţeanu, 1999; Melinte-Dobrinescu and Stoica, 2013).

Sedimentation continued during the middle Miocene (early Badenian) with the Câmpiniţa Formation (Crihan, 1999) or Slănic Formation (Melinte-Dobrinescu and Stoica, 2013) consisting of the Slănic Tuff interbedded with marlstones. The following evaporitic unit, correlated with the mid-Badenian salinity crisis in the Paratethys Sea, has been called the “evaporite formation” (Popescu, 1951; Olteanu, 1951; Patrulius et al., 1968; Melinte-Dobrinescu and Stoica, 2013); however, in some interpretations, only a single middle Miocene salt level is present (Athanasiu, 1916). The upper Badenian contains the radiolarian shales and pteropod (*Spirialis*) marls of the Telega Formation (Crihan, 1999). The Sarmatian Măceşu Formation (Crihan, 1999) with mudstones and a tuffitic intercalation completes the middle Miocene succession.

## MATERIAL AND METHODS

Our biostratigraphic approach has included both re-evaluation of existing subsurface data and the examination of new equivalent surface samples collected from the field. For a better understanding of the criteria used for the biostratigraphy of the CBZ, core and cutting lab reports were analysed for >900 boreholes, in order to select the best candidates. Out of these, 65 boreholes (Fig. 2), some dating back to the 1950s, have been selected based on the length of intervals suitable for biostratigraphic analysis (Tămaş, 2018). These cover an area of ~10,000 $km^2$ in the DFZ of the Eastern Carpathians. The biostratigraphic reevaluation has been based on foraminifera (which reliably characterize various marine palaeoenvironments and allow easier recognition of reworking), calcareous nannofossils and palynomorphs.

Most (54%) of selected lab reports come from core data, while the remaining come from cuttings (less reliable due to the high probability of contamination). The selection of boreholes also considered the best possible link both with the surface and with 3D seismic data.

The microfossil assemblages listed in the core and cutting descriptions were arranged in worksheets and re-interpreted for each type of microfossil and age interval. The pre-existing interpretations were imported in *Petrel* software as comment logs and were compared to the structural model.

The limitations of these types of study are given by historical descriptions, minimal access to the original material, and uncertainties regarding the correct initial identification of the taxa (because of poor preservation, limited optical resolution, the omission of the small fraction of specimens, limited literature used etc.). Whenever possible, these limitations have been further reduced by the integration of the data with surface geology, and with 3D seismic and well log correlation.

For better and more reliable stratigraphic reevaluation, we collected field samples for the representative micropalaeontological assemblages. Several representative sections were re-examined, usually located along the river valleys crossing the stratigraphic succession (e.g., Ialomiţa, Prahova, Doftana).

Field samples were processed by standard micropalaeontological methods. Fossil foraminifera were recovered from the 63 μm fraction. Representative specimens were observed and pictured using SEM. Calcareous nannofossils were observed on smear slides prepared following the standard technique (Bown and Young, 1998) and examined under a polarized light microscope at 1000 magnification.

All biostratigraphic reinterpretations were initially made separately for each major taxonomic group and subsequently were put together in order to reduce the amount of uncertainty regarding the final interpretations.

## BIOSTRATIGRAPHIC REEVALUATION

Since the early times of exploration, biostratigraphy has been one of the essential methods used for the stratigraphic and subsequent interpretations. Unfortunately, due to the particular facies, the expected index fossils could not always be found. For this reason, in specific stratigraphic intervals, the biostratigraphy has been based on irrelevant or facies-dependent endemic assemblages. Moreover, the locally developed biostratigraphic schemes have been subsequently used for interpretations of the basin-scale tectonic evolution.

By tradition, the biostratigraphy of the DFZ is based on the synthesis of Costea and Balteş (1962), which proved to be a very valuable tool for the needs of the oil industry. However, recent re-evaluation of field material in some areas (Szabo and Filipescu, 2010; Szabo et al., 2010, 2011; Bercea et al., 2016; Bălc et al., 2019) revealed the need for careful revision of the stratigraphic interval previously considered Oligocene to middle Miocene. This revision should consider both recent contributions to the biostratigraphy and the improved observation resolution offered by modern technology.

Foraminifera probably represent the most reliable group for the biostratigraphic dating of the interval studied, because of direct and indirect age indications, good resolution, and the relatively easy identification of reworked specimens. For these reasons, we gave priority to this group in our approach. Additionally, we considered the supporting information given by calcareous nannoplankton and, in some cases, by palynomorphs.

### RE-INTERPRETATION OF LAB REPORTS

The palaeogeographic evolution of the area due to the regional tectonics produced severe restrictions on the connections to the open sea in most basins in the Carpathian domain, and thus it is difficult to find the typical index taxa for the Oligocene/Miocene boundary and for the early part of the Miocene.

From the 626 revised core and cutting descriptions, only 36% yielded the same results as the originals (Fig. 3A). The rest suggest that either the specific interval clearly belongs to a different age, or the possible age range was larger (Fig. 3B). When combining the results from the different groups, special attention was given to the cutting descriptions and the position of the casing shoe at the time of sampling, in order to reduce the uncertainties arising from sample contamination.

In the case of the lower Miocene upper Kliwa Formation, which is still considered "Oligocene" by some hydrocarbon companies (i.e., Munteanu et al., 2014; Fig. 2A), 90% of the strata previously ascribed to the Oligocene proved to be younger. Furthermore, most changes occurred for the lower Miocene formations, as 95% of the lab reports analysed suggested different ages compared to the initial interpretations (Fig. 3).

#### FORAMINIFERA

Foraminiferal assemblages, containing both benthic and planktonic taxa, have been considered as characteristic of the "mid to upper Oligocene" Pucioasa Formation and "upper Oligocene" Muereasca Formation (Costea and Balteş, 1962). The dominant suboxic benthic taxa (buliminids – Kaiho, 1994) in this interval suggest moderate depths and restricted circulation or communication of the basin with the open sea (the bituminous facies suggest even more restricted conditions). It is challenging to create a reliable biostratigraphic framework for this interval due to the rare planktonic taxa and their specific wide stratigraphic range. However, the presence of *Globigerina bulloides* d'Orbigny and *Globigerinoides trilobus* (Reuss)[1] in the lab reports raises serious questions regarding stratigraphic age due to their known first occurrences, which is early Miocene for *G-des trilobus* and late early Miocene for *G. bulloides* in the Paratethys (Cicha et al., 1998). Furthermore, in the type section of the Pucioasa Formation, we identified specimens of *Globigerinoides quadrilobatus* (d'Orbigny), considered as middle Miocene. In the Ukrainian part of the Carpathian Foredeep, the "upper menilites" are considered as lower Miocene based on the presence of *G-des trilobus* (Andreyeva-Grigorovich et al., 1997).

Starting with the Burdigalian, biozones were established based on the most common occurrence of foraminifera assem-

[1] The recent taxonomy uses the name *Trilobatus trilobus* (Reuss)

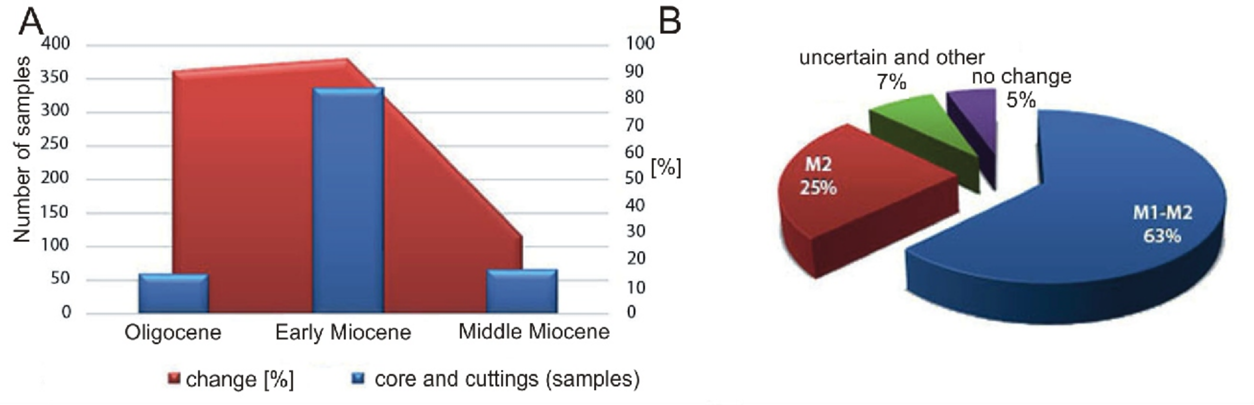



**Fig. 3. Statistics of the biostratigraphic re-evaluation of the lab reports**

**A** – age changes trend (red) and number of revised samples (blue); **B** – ages resulting from the re-interpretation of lab reports (M1 – early Miocene, M2 – middle Miocene)

blages. The Cornu Formation contains very diverse benthic and planktonic taxa with wide stratigraphic ranges, very similar in aspect to the typical marine Miocene assemblages of the surrounding basins. Among other planktonic species, *G-des trilobus* and *G. bulloides* are mentioned in the lab reports; while the former has its first occurrence during the early Miocene and has been largely used for defining the early Miocene biozone in Romania (even if it is also common in the middle Miocene), the latter suggests a middle Miocene age.

In similar assemblages from the Getic Depression, *Globigerina subcretacea* (Lomnicki), another middle Miocene species, has been noted in the lab reports from the "lower salt formation". The field samples also suggest a middle Miocene age for this unit.

Other problems occur in dating the "upper Burdigalian" Brebu Conglomerates from the boundary between the Subcarpathian and Getic depressions, where middle Miocene *Orbulina* specimens are noted in the lab reports. Due to the restricted stratigraphic range of *Orbulina* (Cicha et al., 1998), the early Miocene age originally suggested cannot be supported regardless of whether the specimens are in place or reworked.

Biostratigraphic characterization is also difficult for the "Helvetian" (an obsolete geochronological unit used on the Geologic Map of Romania, scale 1:200,000, corresponding to the late Burdigalian). Nevertheless, middle Miocene *Orbulina* species have been noted in reports from the upper "Helvetian" of the Subcarpathian Depression. For this reason, an early Miocene age cannot, again, be supported.

Usually, there is no conflict with the ages given for the base of the middle Miocene (Badenian), because the occurrence of *Orbulina* seems to be a clear marker. Other planktonic species, which were also common in the stratigraphic interval below, do not help in improving the resolution.

The assemblages from the salt breccia ("upper salt level" – Olteanu, 1951; Popescu, 1951; Iorgulescu, 1953) contain taxa that are similar to the ones considered as "early Miocene", thus suggesting that the units may be stratigraphically equivalent.

The upper Badenian "radiolarian shales" placed above the "upper salt", are dominated by radiolarians, while the foraminifera are less diverse and contain no index species. More diverse assemblages are present in the "Spirialis marls" that ended open marine middle Miocene sedimentation. Together with pteropods, diverse benthic and endemic planktonic (e.g., *Velapertina* – Popescu, 1976, 1979) species are present, allowing dating and regional correlation.

For the uppermost part of the middle Miocene (Sarmatian), biostratigraphic results in the lab reports usually match our revisions if reworking is considered in particular cases. This is due to the evident change in assemblages' composition as an effect of the reduced connections with the global ocean produced by regional tectonics.

In considering the consistency of the data in the lab reports, *Globigerina bulloides, Globigerinoides trilobus* and *Orbulina suturalis*, among other species, are usually easy to identify and we can assume that most taxa were correctly diagnosed by the experienced lab workers involved.

### CALCAREOUS NANNOFOSSILS

Due to the high reworking potential of calcareous nannofossils, we mainly focused on the core samples. We discount the presence of Cretaceous and Paleogene reworked species, and rely on those relevant for Miocene biostratigraphy.

Most of the ages of cores have been reinterpreted based on the standard biozonations of Martini (1971) and Perch-Nielsen (1985), correlated with other schemes developed for different latitudes (Okada and Bukry, 1980; Fornaciari et al., 1996; Backman et al., 2012).

Usually, the early Miocene age given by the lab reports is based on species with wider stratigraphic ranges, such as *Helicosphaera ampliaperta* (Bramlette and Wilcoxon) ranging from the Aquitanian to Langhian, or *Sphenolithus heteromorphus* (Deflandre) ranging from the Burdigalian to Serravallian (Lourens et al., 2004). These species occur together at many sites from the Paratethys, Mediterranean and Atlantic regions (e.g. Shafik et al., 1998; Mărunţeanu, 1999; Rögl et al., 2002; Ćorić et al., 2004; Faris et al., 2016; Melinte-Dobrinescu and Stoica, 2013; Sant et al., 2019; Ukpabi et al., 2020) as markers for the late Burdigalian NN4 (Martini, 1971) or MNN4a (Fornaciari et al., 1996) zones.

In several samples, the absence of *Helicosphaera ampliaperta* and the presence of *Sphenolithus heteromorphus* restricted the age to the middle Miocene NN5 Zone (Martini, 1971; Perch-Nielsen, 1985), CN4 Zone (Okada and Bukry, 1980) or upper part of the CNM7 Zone (Backman et al., 2012).

For these reasons, we conclude that there is no clear evidence in the lab reports for an early Miocene age of the samples reviewed.

PALYNOMORPHS

Even if the early to middle Miocene biostratigraphy of the Alpine – Carpathian region relies on dinoflagellate cysts (Jiménez-Moreno et al., 2006; Köthe and Piesker, 2007; Bakrač et al., 2012), the lab reports did not offer enough data to compare the record with the usual zonations. The core and cutting lab reports had a fair content of botanical determinations, but counts of pollen grains were absent in more than half of the lab reports. This made biostratigraphic re-evaluation very difficult but allowed some palaeoecological and palaeoclimatic interpretations, which also suggest a probable age (i.e., Jiménez-Moreno et al., 2005; Ţabără, 2008; Ţabără and Chirilă, 2012).

The palynological assemblages noted in the lab reports consist both of continental taxa (spores, pollen) and aquatic phytoplankton (dinoflagellate cysts and prasinophyte algae). Of these two groups of palynomorphs, the continental palynoflora (gymnosperms and angiosperms) is dominant in the boreholes studied.

Paleogene to early Miocene ages seem commonly to be based on reworked taxa (e.g., *Plicatopollis plicatus* Potonié, *Cicatricosisporites* sp., *Alisporites* sp., *Cordosphaeridium inodes* Klumpp, *Wetzeliella clathrata* Eisenack, *Deflandrea phosphoritica* Eisenack). A few taxa give clear middle-upper Miocene ages, such as *Achomosphaera crassipellis* Deflandre and Cookson, *A. alcicornu* Eisenack, *Palaeocystodinium miocaenicum* Strauss et al., and *Phtanoperidinium mucronatum* Hope (Lubenescu et al., 1986; Köthe and Piesker, 2007; Bakrač et al., 2012). Several samples, previously assigned in lab reports to the Oligocene to early Miocene interval, contain palynological assemblages typical of middle to upper Miocene deposits of the Dacian Basin (Roman and Papaianopol, 1982; Ţabără, 2008, 2014, Casas-Gallego et al., 2020a), mainly gymnosperms (*Pinuspollenites*, *Piceapollis*, *Abiespollenites, Taxodiaceae*) and angiosperms (e.g., *Tricolporopollenites*, *Caryapollenites*, *Quercopollenites*, *Faguspollenites, Sabalpollenites, Tiliapollenites, Alnipollenites, Chenopodiaceae*). Among the spores considered as markers for the early Miocene, *Mecsekisporites mioceanicus* Nagy mainly occurs in the middle Miocene (Badenian) of the Pannonian Basin (Nagy, 2005; Mandic et al., 2019).

The palaeoclimatic conditions revealed by the middle-upper Miocene palynomorph assemblages suggest a warm-temperate climate, with arid phases, as indicated by some thermophile species (e.g., palm pollen, *Sapotaceae*), xerophytic grassy vegetation (*Chenopodiaceae*), and pollen belonging to mid- and high-altitude forest (various *Pinaceae*). Approximately the same climatic regime (with mean annual temperature values ranging from 14 to 16.5°C) was estimated for the Badenian – Pontian interval of the Dacian Basin (Ţabără and Chirilă, 2012; Casas-Gallego et al., 2020b).

BIOSTRATIGRAPHY OF THE FIELD SAMPLES

Several exposures were sampled for biostratigraphy in order to clarify the ages of equivalent subsurface units described in the lab reports. These exposures are located along the Ialomiţa, Prahova, and Doftana rivers, in the area of the Pucioasa, Bezdead, Ocniţa, Cornu, de Sus, and Brebu localities (Figs. 4–8). In our quest for representative locations, unfortunately, not all samples contained relevant microfossils. Therefore, the analyses and interpretations refer to a limited number of samples, but representative enough to draw some general conclusions.

PUCIOASA SECTION

The section studied, >300 m thick, is part of the northern limb of the Valea Lungă syncline (Bercea et al., 2016; Schléder et al., 2019) extending between the Ialomiţa and Prahova rivers (Fig. 4 – 45°04'44"N, 25°26'58"E).

Following our previous study of the Pucioasa and Fusaru formations (Szabo and Filipescu, 2010; Szabo et al., 2010, 2011), we focused on the Miocene ($m_{1+2}$ on the Geological Map of Romania, scale 1:50,000) piggy-back succession. The section consists of offshore, shoreface, and deltaic deposits, with a shallowing upwards trend (Fig. 5A, B). The tectonic activity pro-

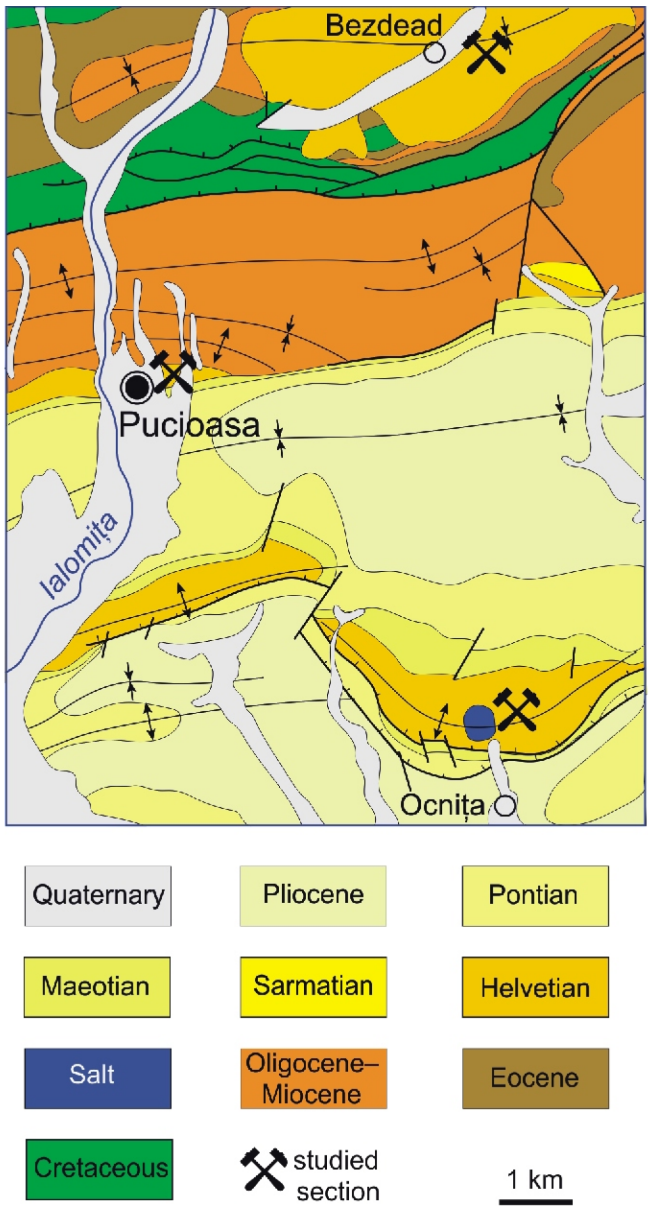



**Fig. 4. Location of the sections studied and exposures in Pucioasa, Ocniţa and Bezdead, on a simplified geological map (modified after the Geological Map of Romania, scale 1:200,000, preserving the original ages)**

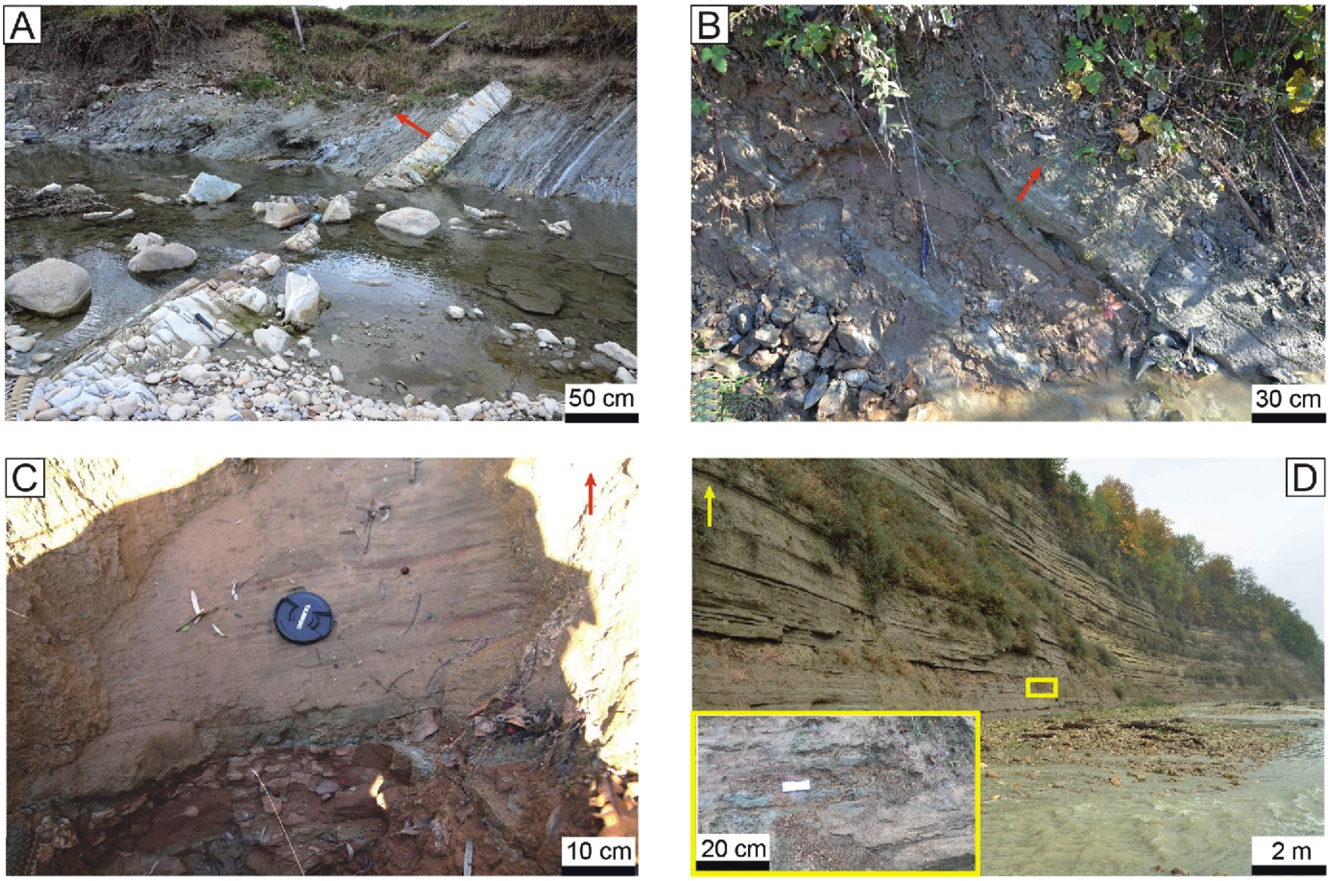



**Fig. 5A – lower part of the Pucioasa section (middle Miocene: upper Badenian), that consists of grey mudstones with cm/dm-thick fine sandstones, tuff (white – centre of the picture), and gypsum; B – upper part of the Pucioasa section (Middle Miocene: upper Sarmatian), made of brown-reddish and grey mudstones with thin clayey siltstones and very fine sandstone intercalations; C – Ocniţa section in the Doftana Formation: brown-reddish mudstones eroded by dm-thick, amalgamated, normally graded, coarse (rare) to very fine sandstones with climbing ripples (+ brown reddish muddy drapes); D – Bezdead section in the Doftana Formation: stacked dm/m-thick, fine to medium, normally graded very fine pebbly sandstones/sandstones with brown reddish dm/m-thick mudstones (yellow rectangle); arrow shows the way-up of the strata**

duced local evaporitic basins during the transition from foredeep to piggy-back settings (Bercea et al., 2016).

One characteristic feature of >50 samples collected from this turbiditic succession is the consistent reworking.

The calcareous nannofossil assemblages are characterized by low diversity, fluctuating abundance, and poor to moderate preservation due to unstable palaeoenvironments and strong currents related to regional tectonics. The taxa identified (Fig. 6N, O) suggest the presence of the NN4-NN5 zones (Martini, 1971; Perch-Nielsen, 1985) or the MNN4a Zone (Fornaciari et al., 1996), and therefore a suggested age range from Burdigalian to Serravallian.

The rare specimens of foraminifera are small and mainly reworked from Cretaceous to Miocene (Fig. 6). Beside the reworked specimens, some samples include taxa which are characteristic of younger ages than expected: even from the lower stratigraphic part of the section, rare species characteristic to the middle Miocene (probably late Badenian) are present (Fig. 6A, B, F). Furthermore, Motaş (1948, fide Motaş, 1952) identified early to mid Badenian molluscs and corals in this area, between the Pucioasa-Fusaru lithofacies and the Maeotian. Towards the top of the section, species characteristic of the late Sarmatian, such as evolved miliolids (Fig. 6K–M), have also been identified. Their state of preservation may indicate transport or possible reworking; therefore, the topmost part of the section cannot be older than late Sarmatian.

It is challenging to identify in-situ foraminifera assemblages. However, it is certain that Badenian and Sarmatian taxa are present. Thus, the Pucioasa section representing the base of the "Helvetian" (or $m_{1+2}$ on the Geological Map of Romania, Scale 1:50,000) deposits cannot be older than middle Miocene (Badenian + Sarmatian).

### OCNIŢA

On the southern flank of the Valea Lungă syncline, exposures around Ocniţa (Fig. 4; 45°00'23"N, 25°33'11"E) display mudstones with thin intercalations of sandstones (with asymmetrical ripples and HCS structures; Fig. 5C), and massive gypsum. They were deposited in a shallow marine setting, as in the Pucioasa section. Ştefănescu et al. (1988) considered these shallow marine deposits as part of the Doftana Formation. The Ocniţa exposure also hosts a salt diapir, so far considered to be surrounded by lower Miocene deposits (Murgeanu et al., 1968).

All 15 samples investigated, collected from the mudstones cropping out around the salt diapir, show strong reworking. Together with Paleogene and early Miocene taxa, some species common in late Badenian strata have also been identified: *Bogdanowiczia pocutica* Pishvanova, *Cornuspira involvens* (Reuss), *Lenticulina inornata* (d'Orbigny), and *Bolivina antiqua* d'Orbigny (Fig. 7A–D). Additionally, *Streptochilus latum*

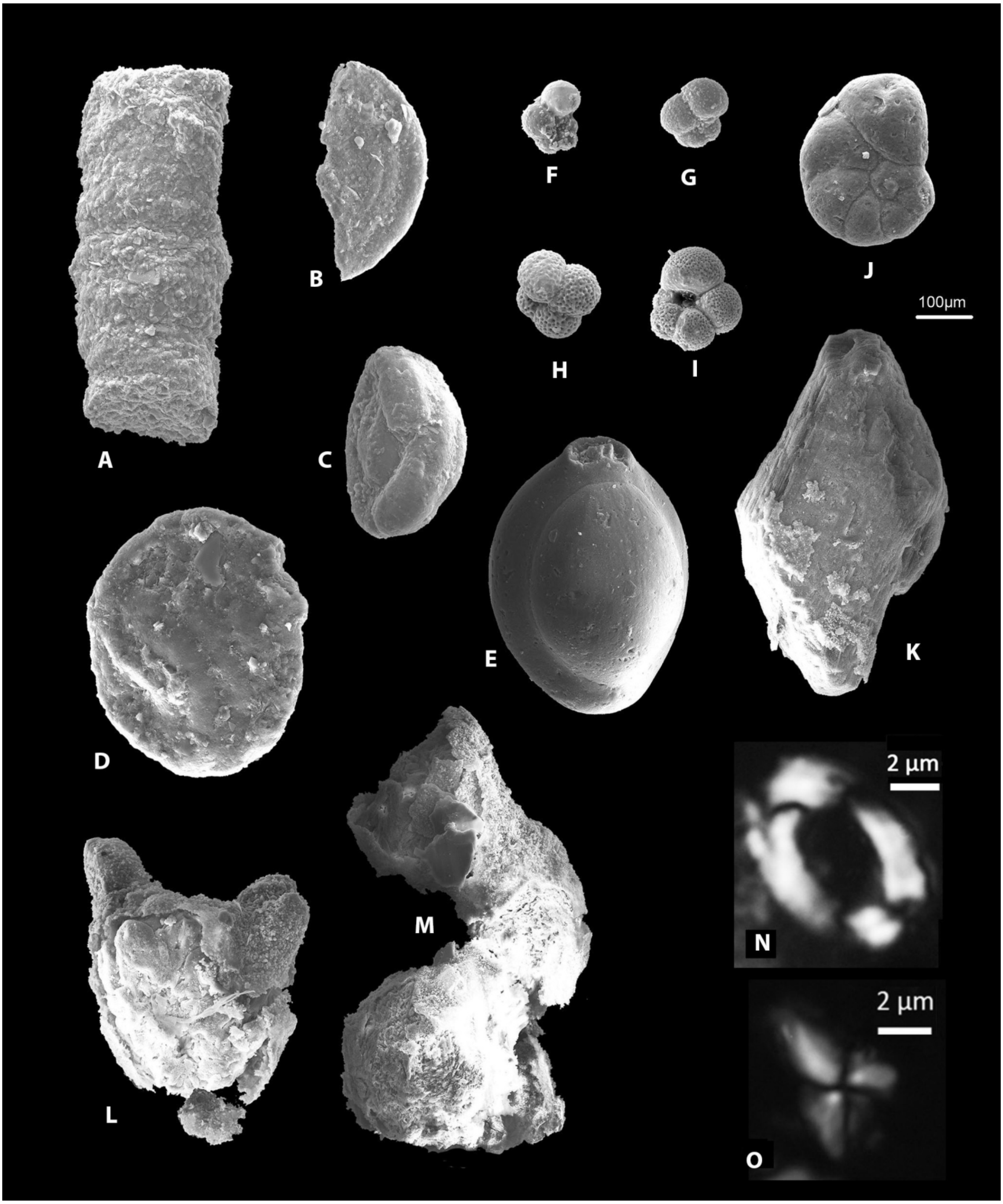



**Fig. 6. Foraminifera (A–M) and calcareous nannofossils (N, O) from Pucioasa section**

**A** – *Bogdanowiczia pocutica* Pishvanova (late Badenian); **B** – *Ammodiscus* sp.; **C** – *Glomospira charoides* (Jones & Parker) (Cretaceous–Miocene); **D** – *Glomospira* sp.; **E** – *Pyrgo clypeata* (d'Orbigny) (Badenian); **F** – *Globigerina subcretacea* Lomnicki (mid to late Badenian); **G** – *Tenuitella munda* (Jenkins) (Oligocene to early Miocene); **H** – *Dipsidripella danvillensis* (Howe & Wallace) (Eocene to Oligocene); **I** – *Paragloborotalia nana* (Bolli) (Oligocene to early Miocene); **J** – *Valvulineria palmarealensis* (Nuttall) (Oligocene to early Miocene); **K** – *Affinetrina voloshinovae* (Bogdanowicz) (late Sarmatian); **L**, **M** – *Sinzowella novorossica* (Karrer & Sinzow) (late Sarmatian); **N** – *Helicosphaera ampliaperta* (Bramlette & Wilcoxon); **O** – *Sphenolithus heteromorphus* (Deflandre)

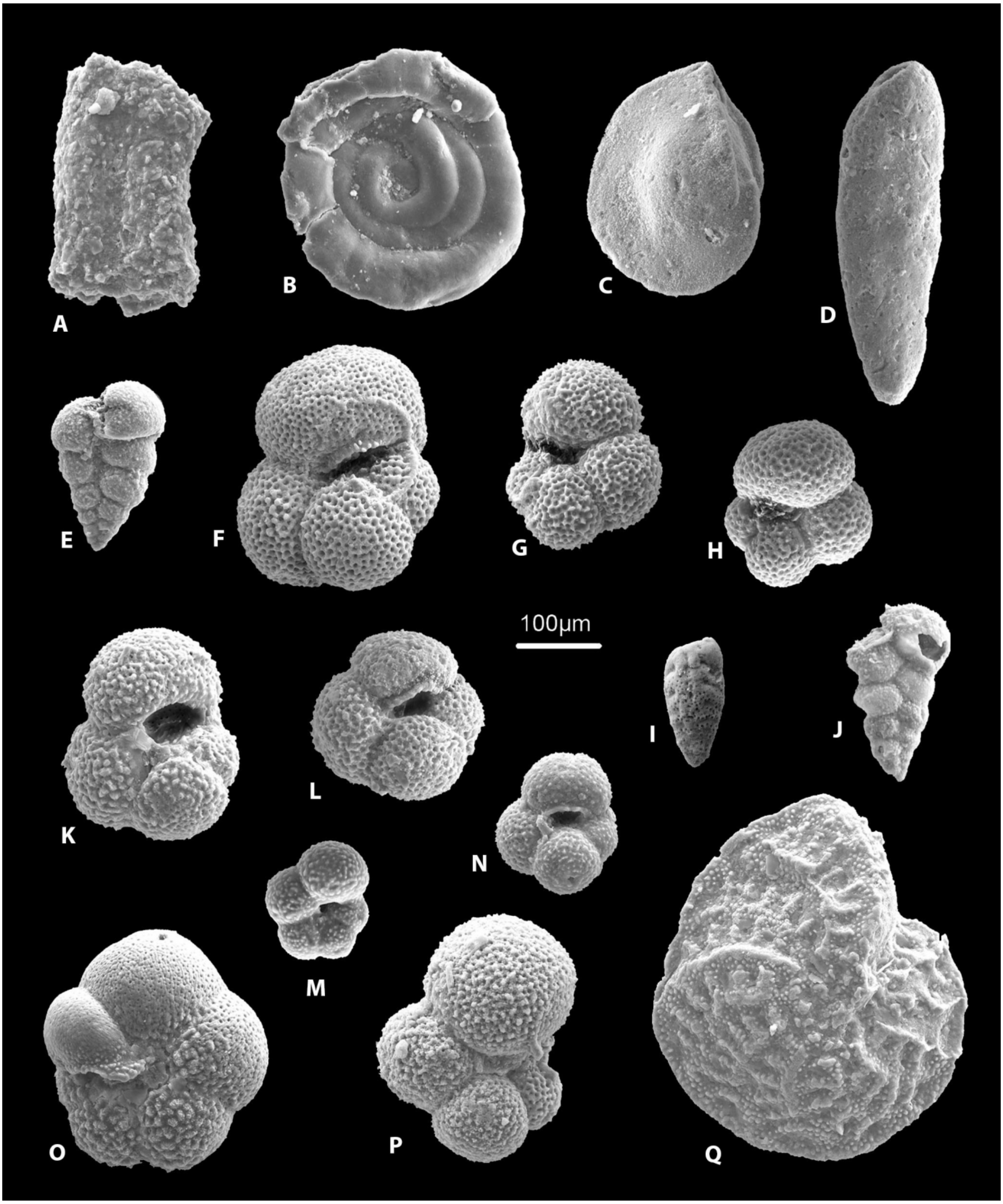



**Fig. 7. Foraminifera of the Doftana Formation**

**A**–**H** – from Ocniţa: A – *Bogdanowiczia pocutica* Pishvanova; B – *Cornuspira involvens* (Reuss); C – *Lenticulina inornata* (d'Orbigny); D – *Bolivina antiqua* d'Orbigny; E – *Streptochilus latum* Brönnimann & Resig; F – *Subbotina hornibrooki* (Brönnimann); G – *Paragloborotalia pseudocontinuosa* (Jenkins); H – *Paragloborotalia nana* (Bolli); **I**, **J** – from Cornu de Sus: I – *Bolivina euzona* Hofmann; J – *Streptochilus* cf. *pristinum* Brönnimann & Resig; **K**–**P** – from Lunca Mare: K – *Globigerina bulloides* d'Orbigny; L – *Globoturborotalita bulloidea* (Crescenti); M – *Tenuitellinata angustiumbilicata* (Bolli); N – *Globigerinita uvula* (Ehrenberg); O – *Turborotalita quinqueloba* (Natland); P – *Globigerinella obesa* (Bolli); **Q** – from Brebu, Morăroasa Valley, *Elphidium grilli* Papp.

Brönnimann and Resig (Fig. 7E), a small and rare planktonic species identified in the Paratethys (Filipescu and Silye, 2008) is known to have its first occurrence in the Tortonian (i.e. late Sarmatian), therefore its presence in the samples from Ocniţa cannot give ages older than late Sarmatian.

The Sarmatian age from Ocniţa supports the ages from the northern part of the syncline in Pucioasa and would continue more naturally the transition to the Maeotian above. These results also show that the salt diapir in Ocniţa is in contact with Sarmatian deposits rather than lower Miocene, as previously considered. This has a far-reaching consequence: the dating of the salt as lower Miocene becomes questionable and needs careful re-evaluation.

BEZDEAD

At Bezdead, the exposure sampled (Fig. 4; 45°09'22"N, 25°31'54"E) belongs to the Doftana Formation and represents a westward extension of the structures of the "Slănic Syncline". It consists of stacked thick fine-medium normally graded sandstones and brown mudstones (Fig. 5D). Some channels with cross-bedded sandstones have been observed cutting the graded sandstones. The overall depositional environment may be related to a marine brackish delta front associated with a fan-delta (Guzman, 2001). The settings explain the very considerable amounts of reworking in the samples and the absence of in-situ typical marine assemblages.

The foraminifera identified are reworked and range from the Paleogene (e.g., flysch-type agglutinated forms) to middle Miocene (e.g., *Globigerina bulloides*). This strong reworking and lack of in-situ typical marine assemblages were probably caused by the characteristic progradational trend established before the end of the Badenian. Therefore, considering the facies and micropalaeontological record, we can infer that the age of this formation at Bezdead may be Sarmatian, but definitely not older than late Badenian.

CORNU DE SUS

The Sărata Member from Cornu de Sus was sampled close to the European road E60 (Fig. 8; 45°10'24"N, 25°41'19"E) from dark grey shales interbedded with cm-thick gypsum (Fig. 9A), probably deposited in a restricted coastal/shallow marine setting.

The calcareous nannofossil record includes species of Cretaceous, Paleogene, and Miocene age. Even if the youngest index species is *Sphenolithus belemnos* (Bramlette and Wilcoxon), which suggests the Burdigalian NN3 Zone (Martini, 1971; Perch-Nielsen, 1985), we have to consider the calcareous nannofossils' high potential of reworking.

Unfortunately, the foraminiferal samples are almost sterile, except for poorly preserved reworked foraminifera, mainly from the Oligocene (Fig. 7I), ?lower Miocene (Fig. 7J), and even middle Miocene (e.g., *Globigerina bulloides*). Therefore, a reliable age cannot be estimated directly, but it is probably not older than mid or late Badenian.

DOFTANA VALLEY

Along the Doftana valley, the Cornu and Doftana formations were sampled in the area of the Podu Cheii and Lunca Mare localities.

The Cornu Formation sampled, northwest of Podu Cheii (Fig. 10A; 46°12'41"N, 25°44'43"E) consists of dark grey mudstones with thin fine sandstone intercalations, mudstone rip-up clasts, and thin gypsum intercalations, all deposited in a typical marine environment.

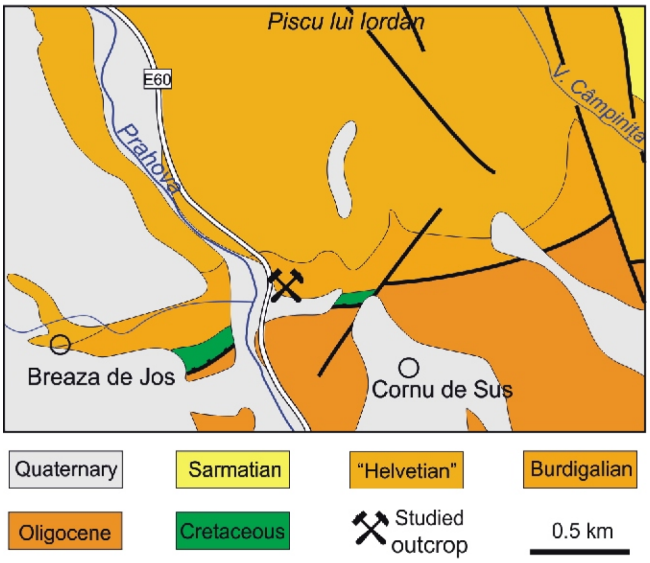



**Fig. 8. Location of the exposure studied at Cornu de Sus on a simplified geological map (modified after the Geological Map of Romania, scale 1:50,000, preserving the original ages)**

Samples collected from the grey mudstones (Fig. 9B) have variable micropalaeontological content, but clear indication of the age has been determined. Even the scarce assemblages of foraminifera include planktonic specimens (Fig. 11). Together with several species having a wide stratigraphic range, some are diagnostic for the Badenian: *Globigerina bulloides* d'Orbigny, *Globoturborotalita bulloidea* (Crescenti) and *Globoturborotalita apertasuturalis* Jenkins (Cicha et al., 1998). Moreover, there are specimens of *Velapertina indigena* (Luczkowska), well known as an index taxon for the late Badenian (Popescu, 1976, 1979). Similar assemblages were noted by Crihan and Mărunţeanu (2006) from the Telega Formation in the Meliceşti Syncline.

Samples collected from greenish rip-up clasts included in the dark mudstones (Fig. 9B) contain assemblages with remarkably well-preserved planktonic foraminifera belonging to the genera *Subbotina* and *Catapsydrax* (Fig. 11P, Q), ranging from the Paleogene to the early Miocene; however, most taxa are probably of Oligocene to (?) early Miocene age. This sample, which is among the very few yielding well-preserved pre-Badenian assemblages, documents the start of active erosion in the source area during the late Badenian, which probably removed an important part of the Oligocene and lower Miocene deposits.

The Doftana Formation was sampled north of Lunca Mare (Fig. 10B; 45°12'25"N, 25°44'26"E), just above the Brebu Conglomerate. The sequence includes normally graded fine-medium sandstones, with asymmetrical ripples and cross-bedding, together with silty clays (Fig. 9C), probably representing a shallow marine delta front (Guzman, 2001), apparently similar to the settings at Bezdead.

The distal marine reddish silty clays contain an assemblage with smaller benthic and planktonic foraminifera, including many reworked taxa. Considering the presence of smaller planktonic forms (Fig. 7M–P), the age may be latest Badenian (see comparable assemblages in Filipescu and Silye, 2008), or somewhere around the Badenian/Sarmatian transition if a large amount of reworking is considered.

The dark clays from above, which suggest deep deltaic environments, preserve a few planktonic species that are common in the Badenian: *Globigerina bulloides* d'Orbigny and

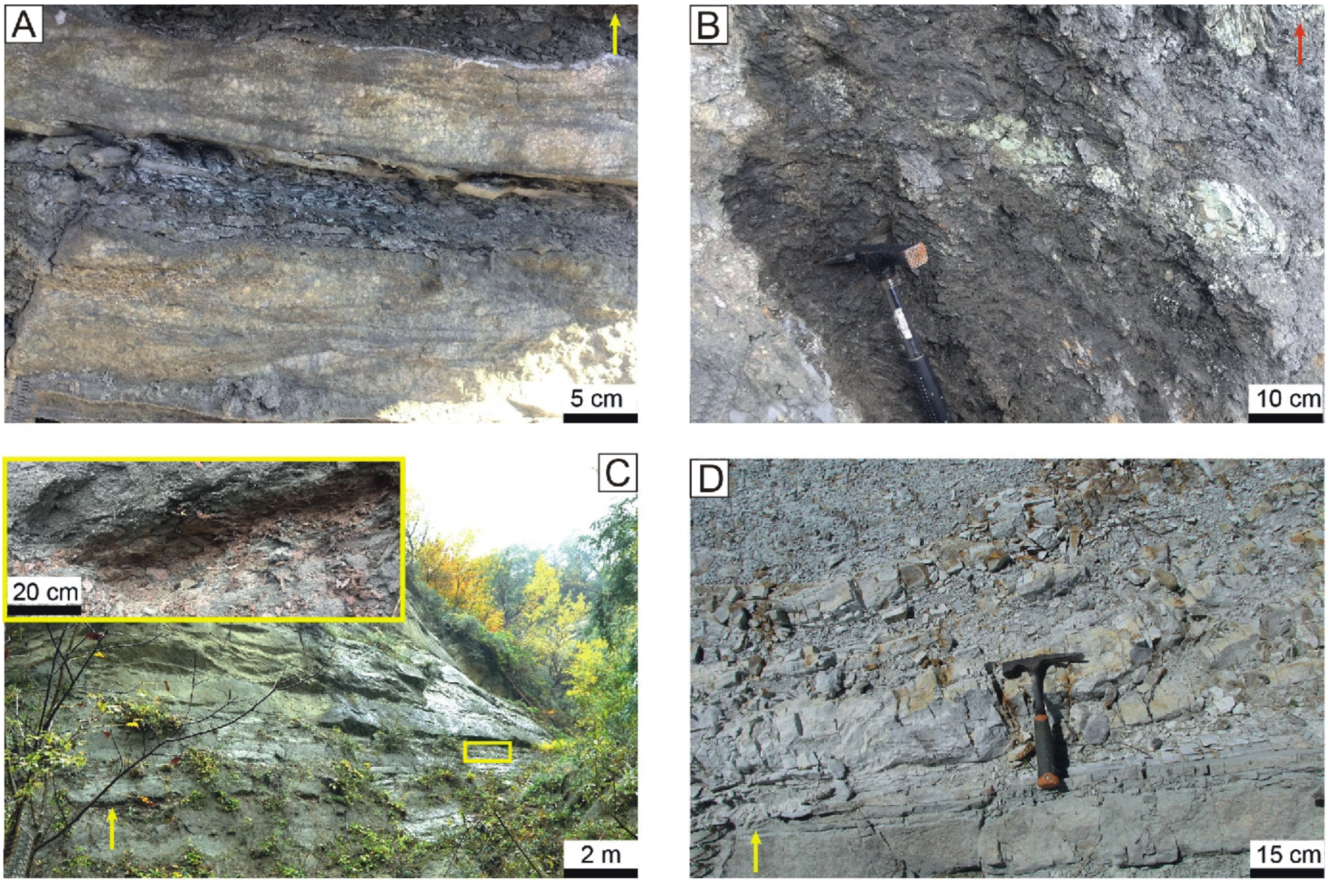



**Fig. 9A – Cornu de Sus exposure (close to the E60 road, middle Miocene): cm-thick sand/granule size gypsum reworked as asymmetrical ripples (with mud drapes) interbedded with cm-thick black mudstones (some fissility); B – NW of Podu Cheii exposure in the Cornu Formation: dark grey, black mudstones with thin very fine sandstones and deformed white mm/cm gypsum (can be massive), white cm-thick mudstones developed as rip-up clasts; C – Lunca Mare exposure in the Doftana Formation: metre-thick fine-medium massive and normally graded sandstones, very fine pebbly sandstones (can be amalgamated) with mm/cm-thick brown-reddish mudstones (yellow rectangle); D – exposure in the Purcaru Valley in the "Slănic Formation", made of alternations of massive volcanic tuff, laminated tuffite and light grey massive mudstone; arrow shows the way-up of the strata**

*Globoturborotalita bulloidea* (Crescenti) (Fig. 7K, L). The specimens' size and stage of preservation suggest selective transport and reworking within prograding deltaic systems, probably around the Badenian – Sarmatian transition.

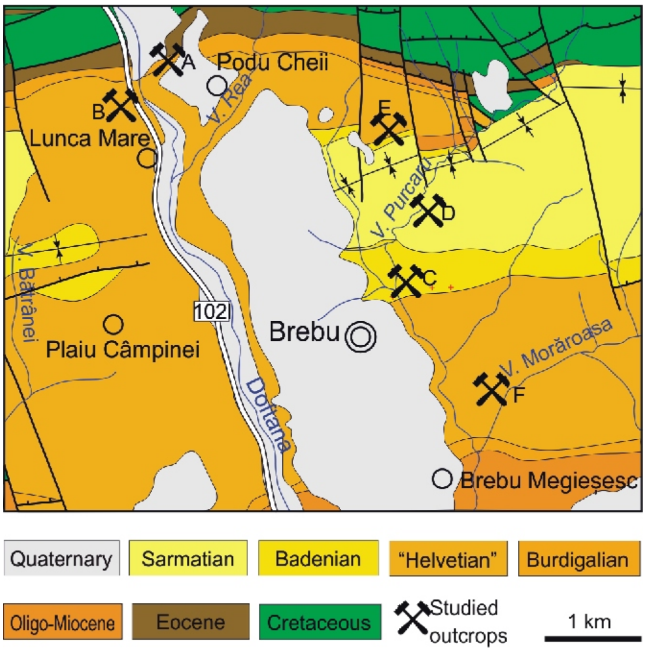
BREBU

The section from the Purcaru Valley (northeast of Brebu), a left-side tributary of Doftana (Fig. 10C–E) is part of the "Slănic Syncline". It opens a long Miocene stratigraphic section, starting from the lower Badenian and ending in the Sarmatian.

In the sample collected in the area of the volcanic tuff (Figs. 9D and 10C; 45°11'08"N, 26°46'31"E), which seems to

**Fig. 10. Location of the exposures studied in the Doftana Valley on a simplified geological map (modified after the Geological Map of Romania, scale 1:50,000, preserving the original ages)**

**A** – Podu Cheii; **B** – Lunca Mare; **C** – Brebu – tuff and salt breccia; **D** – Brebu – "Sarmatian"; **E** – Brebu – Doftana Formation in the Purcaru Valley; **F** – Brebu – Doftana Formation in the Morăroasa Valley)



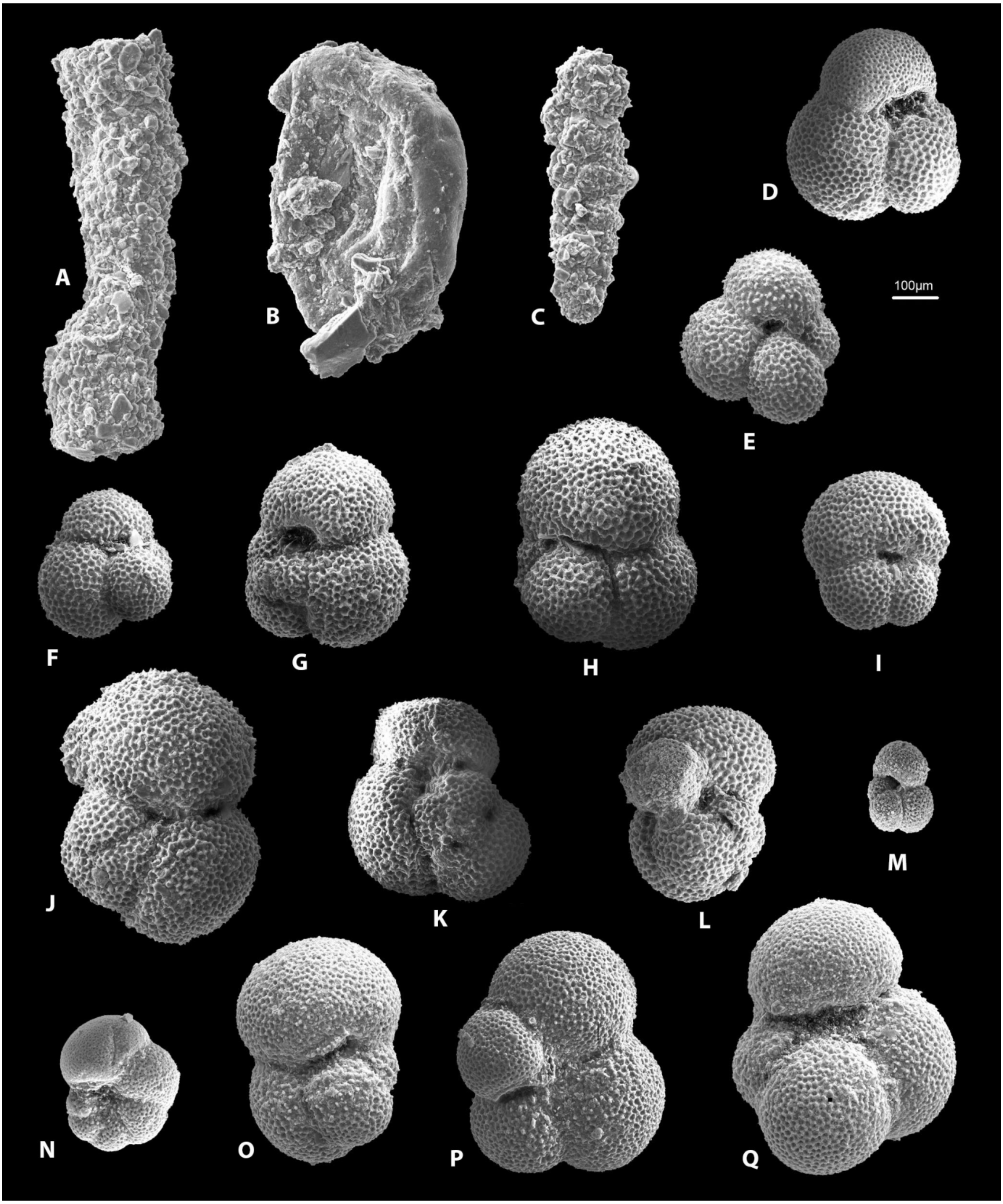



**Fig. 11. Foraminifera of the Cornu Formation from Podu Cheii**

**A** – *Rhizammina* sp.; **B** – *Ammodiscus peruvianus* Berry; **C** – *Karrerulina conversa* (Grzybowski); **D** – *Globoturborotalita bulloidea* (Crescenti); **E** – *Globoturborotalita apertasuturalis* Jenkins; **F** – *Trilobatus quadrilobatus* (d'Orbigny); **G**, **H** – *Trilobatus trilobus* (Reuss); **I** – *Trilobatus bisphericus* (Todd); **J**–**L** – *Velapertina indigena* (Łuczkowska); **M** – *Globigerina bulloides* d'Orbigny; **N** – *Paragloborotalia mayeri* (Cushman & Ellisor); **O** – *Subbotina angiporoides* (Hornibrook); **P** – *Catapsydrax unicavus* (Bolli, Loeblich & Tappan); **Q** – *Subbotina gortanii* (Borsetti)

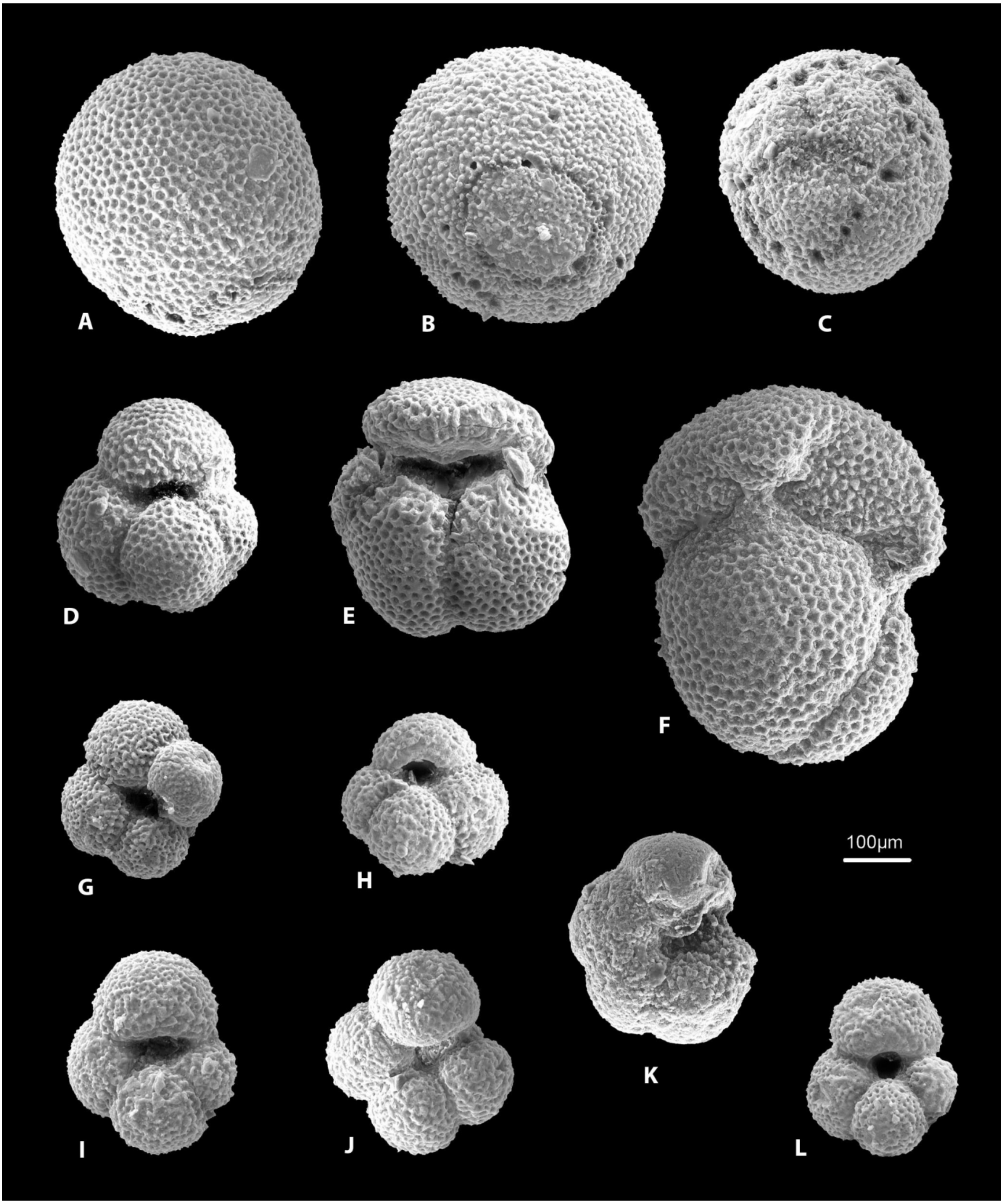



**Fig. 12. Badenian foraminifera from the Purcaru Valley section in Brebu**

**A** – *Orbulina suturalis* Brönnimann (specimen resembling *Velapertina sphaerica* Popescu); **B** – *Orbulina suturalis* Brönnimann (transitional specimen to *Orbulina universa* d'Orbigny); **C** – *Praeorbulina circularis* (Blow); **D** – *Trilobatus quadrilobatus* (d'Orbigny); **E**, **F** – *Dentoglobigerina altispira* (Cushman & Jarvis); **G** – *Globigerina falconensis* Blow; **H** – *Globigerina officinalis* Subbotina; **I** – *Globigerina praebulloides* Blow; **J** – *Globigerina subcretacea* Lomnicki; **K** – *Globorotalia transsylvanica* (Popescu); **L** – *Globigerina lentiana* Rögl

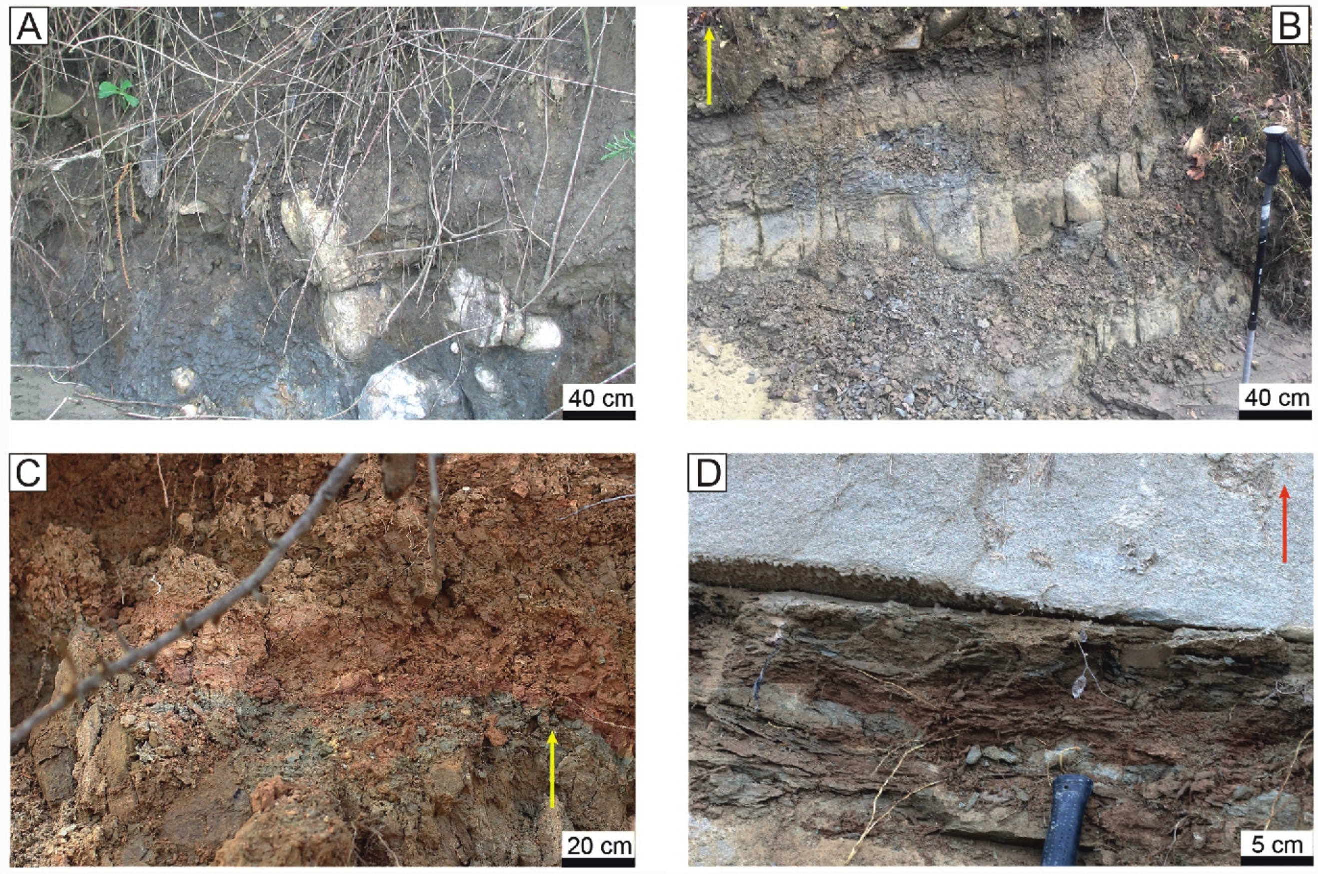



**Fig. 13A – "salt breccia" exposure in the Purcaru Valley made of grey massive mudstones with extraclasts of cobbles; B – light grey mudstones with cm/dm-scale fine and rare medium massive/normal graded sandstones in the middle part of the Purcaru Valley section; C – upper part of the section of the Doftana Formation in the Purcaru Valley: cm/dm-thick brown-reddish mudstones interbedded with rare mm/cm-thick grey mudstones; D – Morăroasa Valley exposure in the Doftana Formation with alternating cm/dm-thick brown-reddish and grey mudstones with dm/m-thick fine/medium massive sandstones; arrow shows the way-up of the strata**

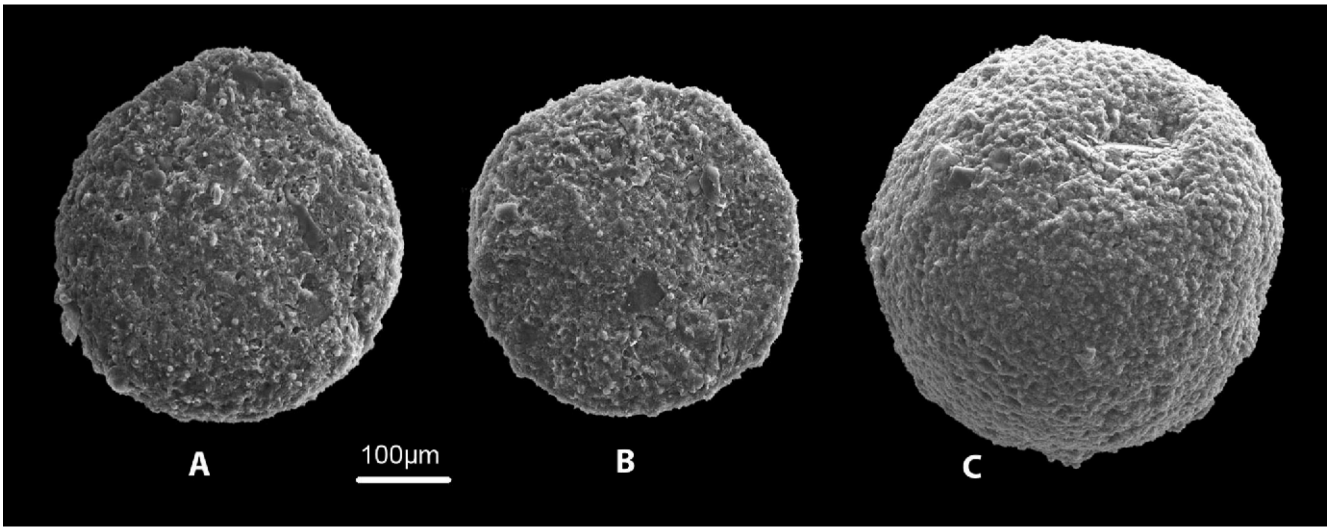



**Fig. 14. Thecamoebians from the Purcaru Valley section in Brebu: A–C – *Silicoplacentina majzoni* Kovary**

have been tectonically emplaced above the Doftana Formation, abundant early Badenian planktonic foraminifera have been found (Fig. 12C, E, F, K), including *Praeorbulina circularis* (Blow), *Orbulina suturalis* Brönnimann and *Globorotalia transsylvanica* (Popescu). The volcanic tuff extends eastwards, and together with the micropalaeontological assemblage, may represent a very useful regional marker. This age agrees with the data featured on the geological maps and with the results published by Sant et al. (2019).

A few metres upstream, in the vicinity of a salty spring and elements of "salt breccia" (Fig. 13A), a very abundant assemblage with siliceous testate amoebas (thecamoebians) belonging to the genus *Silicoplacentina* Kőváry has been identified (Fig. 14). *Silicoplacentina* was noted by Kőváry (1956), Schreiber et al. (1985), Fuchs and Schreiber (1988), Gagić (1992), and Paruch-Kulczycka (1999) from the upper Miocene, while Cicha et al. (1971) reported it from the lower Miocene. We also identified it in the upper Sarmatian of the Transylvanian Basin. Therefore, its stratigraphic value is questionable but more important seems to be its palaeoecological significance because it suggests euryhaline environments (Asioli et al., 1996). This assemblage, clearly placed in a higher stratigraphic position relative to the volcanic tuff, may either belong to the mid Badenian restrictive environments or even to the lowermost upper Badenian Radiolarian shales (as other siliceous organisms have been recorded from this unit by Popescu, 1979).

The sample collected from the presumed lower to middle Sarmatian (Figs. 10D and 13B; 45°11'40"N, 25°46'48"E) in the same valley contains a few taxa common in the lower and middle Miocene, but a detailed examination indicated a late Badenian age (*Velapertina* Zone, see discussions and Fig. 12A, B), which completes the normal Badenian succession.

Samples collected from the upper section (Doftana Formation; Figs. 10E and 13C; 45°12'03"N, 25°46'33"E), contain only a few small-sized reworked specimens, which are difficult to determine. The interval is probably related to a significant progradational phase and the assemblages resemble those in Bezdead, Cornu de Sus, and Lunca Mare.

Another section was studied in the Morăroasa Valley (east of Brebu), a left-side tributary of Doftana, south of Purcaru (Fig. 10F; 45°10'32"N, 25°47'12"E). The sedimentological characters (Fig. 13D) show a strong continental influence, mainly of deltaic environments, also reflected in the very sparse micropalaeontological record, as most samples proved to be barren or contained just a few poorly preserved reworked specimens. The samples were collected from fine sediments intercalated in a succession of conglomerates, sandstones, gypsum, and volcanic tuffs presumed as belonging to the lower to middle Miocene. Only one sample, placed meters above the Brebu Conglomerate included the benthic foraminifer *Elphidium grilli* Papp (Fig.7Q) which is usually common in the Sarmatian and rarely noted from the late Badenian (Cicha et al., 1998). Although we need additional evidence based on these results from other locations, it seems that the deposits may not be older than Sarmatian.

## DISCUSSION

### AGES BASED ON LAB REPORTS

Some general observations need to be outlined for the assemblages reviewed from the lab reports.

The originally given "Oligocene" ages for the deep parts of the boreholes studied need to be carefully reconsidered because the core samples do not contain diagnostic Oligocene foraminifera. Moreover, the local presence of *Globigerina postcretacea* Mjatliuk, *Globigerina praebuloides* Blow, *Globigerinoides trilobus* (Reuss), and *Globorotalia praescitula* Blow suggest a Miocene age, while *Globorotalia scitula* (Brady), *Globigerina bulloides* d'Orbigny, and *"Nonion granosum"* [probably either *Porosononion granosum* (d'Orbigny) or *Porosononion subgranosus* (Egger)] are middle Miocene forms (Kennett and Srinivasan, 1983; Cicha et al., 1998).

The "lower Miocene" *Globigerina bulloides* d'Orbigny, *Globigerina subcretacea* Lomnicki, *Globorotalia bykovae* (Aisenstat), *Globorotalia mayeri* (Cushman and Ellisor), *Globorotalia menardii* (Parker, Jones and Brady), *Globorotalia praemenardii* Cushman and Stainforth and *Globorotalia scitula* (Brady), have their first occurrence in the middle Miocene (Kennett and Srinivasan, 1983; Cicha et al., 1998). Therefore, the "early Miocene" age given by specific planktonic taxa is questionable.

A typical Badenian age is usually given by the presence of *Orbulina suturalis* Brönnimann (early Badenian) and *Velapertina* Popescu (late Badenian). In some cases, the *"Orbulina universa"* listed may be in fact evolved specimens of *Orbulina suturalis,* as shown by the closely similar morphological characters.

If the above-mentioned assemblages and the ones described by Costea and Balteş (1962) from the whole interval between Oligocene and middle Miocene are carefully analysed, it is difficult to find significant differences between the planktonic assemblages, except for the presence of *Orbulina* and *Velapertina*. For this reason, these similar assemblages suggest a common history, including the possibility of reworking.

The Sarmatian has been dated based on endemic assemblages, which, together with a clear distinction of reworked taxa, makes the biostratigraphy of some Sarmatian intervals quite straightforward.

### AGES BASED ON SURFACE LOCALITY DATA

In the upper section of the Purcaru Valley at Brebu (Fig. 10D), considered as Sarmatian, a preliminary observation by light microscope showed the presence of *Orbulina suturalis* Brönnimann, which is clear indication of an early Badenian age. Subsequent examination of specimens by SEM revealed a particular situation. The specimen in Fig. 12A shows the test architecture and surface structure characters of both *Orbulina suturalis* figured by Kennett and Srinivasan (1983: pl. 20, no. 1) and *Velapertina sphaerica* figured by Popescu and Crihan (2011: plate 6, no. 17). Apart from the taxonomic affiliation, it is evident that the test architecture is more evolved (a more fully embracing last chamber) compared to the typical early Badenian *Orbulina suturalis* and, therefore, we assume that the specimen belongs to a stratigraphically younger assemblage, i.e., to the *Velapertina* Zone of the late Badenian. This assumption may be supported by the surface characters of the specimen in Figure 12B, which seems to be transitional to the typical spherical, smooth, and densely perforated *Orbulina universa* d'Orbigny (having its first occurrence in the Mediterranean during the Serravallian – the equivalent of the late Badenian – but not clearly proven so far in the Paratethys). For the reasons above, we consider that the assemblage in discussion is not early, but late Badenian. This seems to be supported by the position of the sampled unit, between the mid-Badenian and Sarmatian units seen in the Purcaru section. This type of assemblage demonstrates the need for very careful revision of the Badenian biostratigraphic zonation of the "Slănic Syncline" and the whole Eastern Carpathian area.

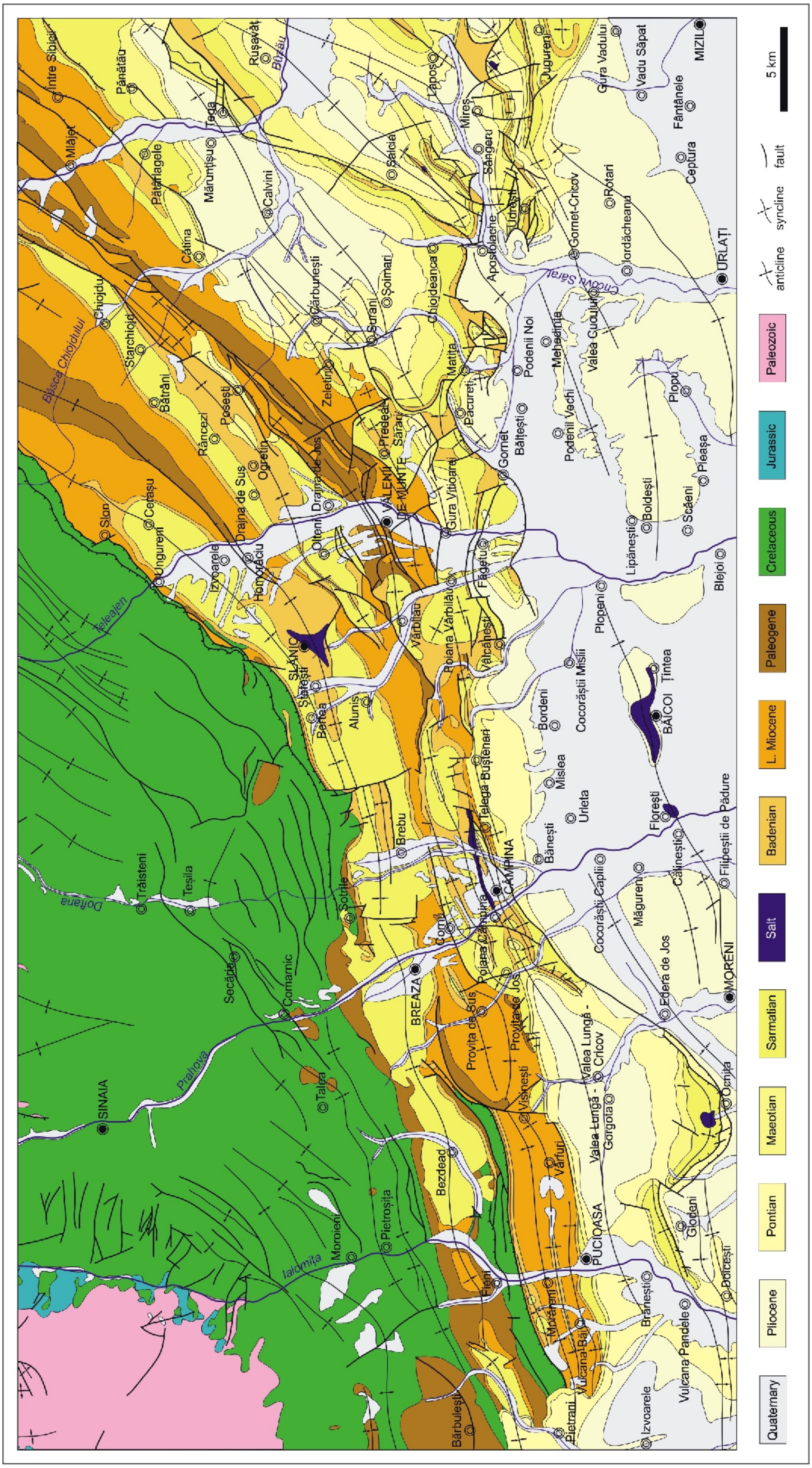



**Fig. 15. Simplified geological map of the DFZ with the revised ages**

See Figure 2 for comparison (modified after the Geological Map of Romania, scale 1:200,000)

Different types of assemblage observed in the Sarmatian of the Măceşu and Doftana formations probably occur in relation to different palaeoenvironmental settings, with brackish shallow marine areas (Măceşu, dominated by in-situ specimens) crossed by deltaic systems (Doftana, dominated by reworked specimens). Further studies on these formations would refine the position of their boundaries and the distribution in space and time of specific facies.

#### RELEVANCE OF BIOSTRATIGRAPHIC DATA TO REGIONAL EVOLUTION

Due to the salt tectonics, the structure of the "Slănic Syncline" seems to be more complex than currently thought. While Mărunţeanu (1999) and Melinte-Dobrinescu and Stoica (2013) suggested earlier ages, Bojar et al., (2018) calculated the age of Slănic Tuff at 13.7 Ma, which corresponds to the late Badenian according to the classification of Hohenegger et al. (2014). This seems to be supported by the foraminifera and calcareous nannofossil assemblages occurring below the tuff (Bojar et al., 2018), which do not look older than mid-Badenian. The Slănic Tuff may be the result of a different eruption than that which formed the tuff outcropping at Brebu (Purcaru Valley), which is of an early Badenian age, as shown by our foraminifera assemblages. Therefore, the lithological correlation potential of the volcanic tuffs in the area needs to be carefully constrained using biostratigraphy. It seems that the mid Badenian salt from Slănic reaches the surface as a diapir surrounded by salt breccia and followed by not lower, but upper Badenian (Slănic Formation on the map) and Sarmatian (Doftana Formation on the map), therefore the structure around the diapir must be an anticline, bordered by synclines, as shown on the revised geological map proposed in Figure 15.

At the moment, we have no proof that any of the outcropping salt diapirs cross pre-middle Badenian formations. Our results show that an overestimated biostratigraphic age may be a reliable option for the interpretation of younger ages calculated for the lower Miocene salt in the Carpathian Foredeep (Léost and Férraud, 2001; Wójtowicz et al., 2003). At least for the DFZ, a more natural stratigraphic position for the "lower salt" would be in the mid Badenian (as a well-known and widely distributed unit in the Paratethys), while the much thinner "upper salt" may have formed by the same body which reached the surface, probably not before the late Sarmatian, and flowed into the peripheral synclines. Regardless of the salt age, this seems to be a viable mechanism in the area, as already discussed by means of seismic interpretation and analogue modelling (Schléder et al., 2019; Tămaş et al., 2019).

The upper Cornu Formation together with the lower Doftana Formation (Brebu Conglomerate) preserve evidence of an important erosional phase related to regional tectonics, active around the Badenian/Sarmatian boundary. This may be correlated with the erosional phase identified in the upper Badenian of the Transylvanian Basin (Krézsek and Filipescu, 2005; Krézsek et al., 2010). By this means, we may have clearer evidence of a regional tectonic phase, previously considered as Burdigalian (Săndulescu, 1988).

## CONCLUSIONS

The Oligocene to Miocene formations in the CBZ developed under particular palaeoenvironmental settings, and so the standard biozones have not always been identified. This promoted forced local biozonations, which became the basis for the reconstruction of Carpathian evolution with all the consequences for science and exploration of natural resources.

Re-evaluation of lab reports on cores considered as lower Miocene and additional examination of field samples collected from the Cornu and Doftana formations showed clear evidence of different ages. This study indicates that the Cornu Formation ($m_1^{Cn}$ on the Geological map of Romania, scale 1:50,000) is middle Miocene (upper Badenian) and contains exotic clasts of Oligocene and lower Miocene age. The lower and middle Miocene Doftana Formation ($m_{1+2}$ on the Geological map of Romania, scale 1:50,000) seems to represent a part of the middle Miocene, mainly the Sarmatian. The rare occurrence of index species and strong reworking are probably related to the specific environmental settings, associated with highly progradational systems controlled by regional tectonics.

Due to salt tectonics, the structure of the "Slănic Syncline" seems to be more complex than currently considered. The salt outcrops as a diapir surrounded by upper Badenian deposits, therefore the structure around the diapir must be an anticline, bordered by synclines to the north and south. The different ages of the Slănic Tuff and its previously considered equivalents suggest the need for careful revision of their basinal and regional correlation potential.

At the moment, we have no proof that any of the outcropping salt diapirs penetrated pre-middle Badenian formations. As stratigraphic relationships are the primary source for the salt age in the CBZ, younger ages demonstrated for the surrounding formations may have a significant impact on interpretation of the depositional history and structural evolution of the area.

An important erosional phase related to regional tectonics has been demonstrated around the Badenian/Sarmatian boundary, which probably needs to considered as part of the intra-Burdigalian phase with all the consequences for the evolution of the Carpathians.

Our results suggest that the stratigraphy and structural relations between the formations of the CBZ need to be fundamentally reconsidered. Further evidence and a careful check on how our results fit with the field reality outside the investigated area and with the existing subsurface data will be necessary to allow a revised model of Carpathian evolution.

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