Universitatea
„Alexandru Ioan Cuza" din Iași
Facultatea de Geografie și Geologie
Școala Doctorală de Geoștiințe
Domeniul Geologie

Summary of the PhD Thesis

Depositional environments and microfaunistic assemblages from the central part of Eastern Carpathians foreland basin

Advisor:

Prof. univ. dr. Mihai Brânzilă

PhD Candidate:

Sergiu-Adi Loghin

Iași,
2022

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Introduction

The main objective of this doctoral thesis is to highlight the evolution of the depositional environments from the central part of the Moldovan Platform.

This objective is intended to be achieved by linking data obtained through sedimentological analysis of deposits with the identified microfossil assemblages.

The researches were carried out on an area that falls between the localities Mălini, Bivolari, Țigănași, Boroaia, a perimeter that from a geomorphological point of view belong within the Moldavian Plateau.

For the sedimentological analysis, 6 outcrops from the Fălticeni Plateau area were taken into account. In the analyzed sedimentary successions were identified the sedimentary facies that were determined by studying the specialized literature the sedimentary processes that led to their formation. Using genetic and lithological criteria, sedimentary facies were grouped into facies associations specific to certain fields or depositional subdomains. From the vertical stacking of these facies associations the behavior of the shoreline during the Volhinian was determined.

The deposits from the Fălticeni Plateau have accumulated in the coastal area of the Euxinic basin, in its western edge. This area was intensely affected during the Middle Miocene by the subduction of the foundation of the western part of the East European Platform under the orogenous strand of the Eastern Carpathians, being unanimously accepted the idea postulated by Grasu et al. (1999, 2002) which supports the evolution of the Moldovan Platform during the Sarmatian as a foreland basins system developed in front of the Eastern Carpathians and in which 4 distinct depots can be outlined: wedge-top, avant-garde, forebulge and backbulge. This is also reflected in the nature of the deposits accumulated in this basin as well as in the associations of macro- and microphosyls identified in these areas.

Given the fact that the stratigraphic interval contained in the sedimentary succession from the Preutești-Fălticeni- Boroaia area is quite short, their age being the lower Sarmatian (Volhynian), we turned our attention to 2 drillings in the eastern part of the Moldavian Platform: Şipote and Bivolari, boreholes where Badenian deposits were also intercepted. Thus, analyzing a series of samples from the Badenian/Sarmatian boundary, we noticed on the basis of the foraminifera, ostracod and calcareous nannoplankton fauna the ecological changes that occurred between these two stages of the middle Miocene.

Chapter. 1. Geographic settings

The study area forms a perimeter between the localities Mălini – Bivolari – Ţigănași – Boroaia in the Moldavian Plateau (fig. 1). This perimeter was divided into three research areas. The first covers the basin of the Şomuzul Mare brook from the Fălticenilor Plateau with numerous outcrops, the second one is delimited by the valleys of the Bogata and Seaca streams, a right tributary of the Moldova River. The third perimeter is located between the Jijia valley and the Prut valley, the data coming from two hydrogeological drillings with continuous logging located in Șipote and Bivolari localities.

The hydrographic basin of Şomuz, from the geomorphological point of view, has a pronounced structural character given by the Volhynian calcareous sandstone-levels sectioned on the V-E direction of the Şomuz River and its tributaries (Băcăuanu et al., 1980). From the territorial administrative point of view, the studied outcrops are located in the area of Preuteşti and Hârtop communes in Suceava county.

The sedimentary successions analyzed in the Şomuzul Mare basin were studied from east to west on the following streams, a right tributary of the river with the same name: Muscalu, Gheorghe's brook, Logofătu brook and Ciofoaia brook.

Between the valleys of the Şomuzul Mare and Şomuzul Mic rivers, 2 more outcrops were analyzed on the area of Hârtop commune, on the Pietrelor hill.

The area between Bogata and Seaca streams is located in the hydrographic basin of the Moldova River and belongs to the Piemontan Ciungi-Corni Plateau, a subunit of the Suceava Plateau, which in turn is part of the Moldavian Plateau (Băcăuanu et al., 1980). Ionesi et al. (2005), call this area the Baia Depression, as part of the above-mentioned relief units.

The main characteristic of the relief is given by the wide development of structural forms generated by the monoclinal position of the layers and by the presence of higher levels of erosion resistance (Ionesi, 2006). Thus, the relief is strongly influenced by the geomorphological processes and the hydrographic network, factors that determined the fragmentation of the Volhinian formations, predominantly represented by clays, sandy clays and sands, in which there are also some lensiform levels of calcareous sandstones.

The area where the Şipote and Bivolari drillings were executed is located in the Moldavian Plain (Băcăuanu, 1980) or the Hill Plain of Jijia (Ungureanu, 1993), a subunit of the Moldavian Plateau. From the geomorphological point of view, the Moldavian Plain is characterized by the predominance of the hills, which reach altitudes of up to 150 m (Brânzilă, 1999).

Chapter 2. Geological settings

The Moldavian platform represents the oldest platform on the territory of Romania, its foundation being consolidated in the Middle Proterozoic (Ionesi, 1994).

To the south it is delimited by the Fălciu – Munteni – Plopana fault, which separates the Moldavian Platform from the Bârlad Platform. In the northern and eastern parts, the Moldavian Platform continues with the East European Platform and to the west it is subdued under the Carpathian orogen (Ionesi, 1994).

The sedimentary deposits of the Moldavian Platform were accumulated in three mega sedimentation cycles as follows:

I – Upper Vendian Cycle – Devonian;

II- Cretaceous cycle – Paleogene – Middle Eocene;

III – Badenian Superior – Meotian.

The studied deposits belong, from the geological point of view, to the sedimentary deposits of the Moldavian Platform, more precisely to the third sedimentation cycle, namely the one carried out between Upper Badenian – Meotian (Ionesi, 1994; fig. 6).

Grasu *et al*. (1999, 2002) treats the Sarmatian deposits of the Moldavian Platform in the context of a system of foreland basins developed in front of the Eastern Carpathians following the Moldavian Tertogenesis when the Carpathian nappes were overthrusted over the edge of the East European Platform.

The accumulation of deposits from the studied sedimentary successions occurred in the Foreland Basin System in front of the Eastern Carpathians (fig. 1). It is classified in the category of perisutural accumulation areas, being developed on the continental lithosphere of the subdued plate. In its evolution, Grasu *et al*. (1999) separated two distinct stages: one of the old foreland basin – a consequence of the phenomena of convergence at the Cretaceous level – and a stage of the new foreland basin developed during the Moldavian (Miocene) tectogenesis.

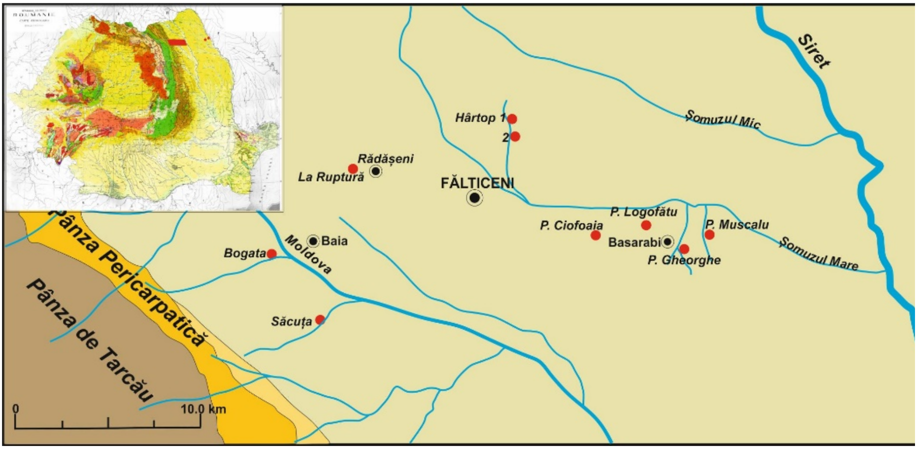


Figure 1. Geological map of the studied area with the position of the points where lithological columns were erected or samples were taken for micropaleontological analysis (Macarovici, 1955).

A foreland basin system is a depositional region located on the continental crust in front of a major orogeneous strand (DeCelles and Giles, 1996). Such a system ideally consists of four distinct depots formed under specific kinematic and subsidence conditions (fig. 2).

Wedge-top depozone – comprises the sedimentary formations accumulated on the advancing orogenic prism, having a width of several tens of kilometers. It is characterized by alluvial or fluvial deposits in the subaerian domain or by shelf deposits mixed with debrits in the marine domain.

The foredeep depozone – is accumulated over distances tens or hundreds of kilometers wide, consisting of both sub-aircraft (alluvial, fluvial) and aquatic (lake, deltaic, marine) deposits. The source of the sediments is mainly the orogenic belt, but also the cratonic plateau. Sedimentary succession can begin with deposits accumulated at great depths („flyshch"), passing through accumulated deposits at shallow depths („molases") and ending with subaerian accumulated deposits. The deposits of the proximal avant-garde pass sideways into the top wedge deposits.

Forebulge depozone – is the area of potential vaulting arranged along the cratonic limit of the foredeep. Clevis (2004) describes the forebulge area as being, a dome associated with the flexion processes that move both towards the orogenic strand and vertically ascending during active blackmail, then moving towards the hyphen and vertically descending due to isostatic readjustment after the cessation of the chamage process. This depozone is difficult to establish in fossil reservoirs, but some authors have proposed criteria for determining it on the basis of deposits accumulated in shallow conditions. Galewsky (1998), proposes such a model in which the first stages of development of submarine foreland basins, underfilled, are characterized by the installation of carbonate platforms.

In the context of the evolution of the flexion process, resulting in the strapping of the orogene over the craton, there is the migration of carbonate platforms and the withdrawal of the flexural dome in the same sense. As the potential for vertical accumulation of carbonates is exceeded by the subsidence rate and that of sea level rise, the deposition of carbonates will be stopped and the abandoned platforms will be replaced by newly initiated ones, in the area of forebulge displaced laterally.

Backbulge depot – is located behind the flexural vault (forebulge), where the subsidence rate has much lower values. The basins of this depozones are characterized by depths of up to 200 meters. The accumulation in this area depends on the amount of detritic material that must be sufficient for filling the foredeep depression and burying the flexural dome.

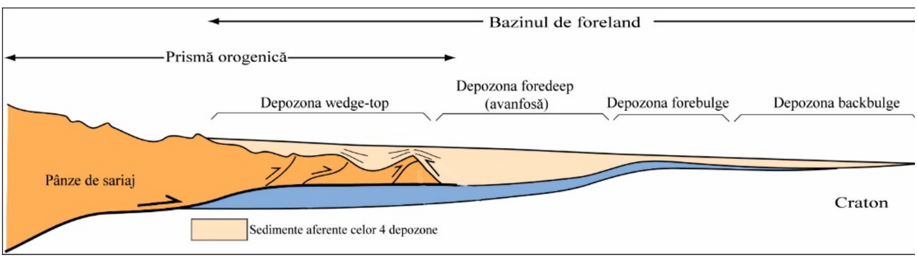


Figure 2. Schematic section indicating structural elements and depots related to a foreland basin (DeCelles and Gilles, 1996).

2.1. Stratigraphy

From the chronostratigraphic point of view, the sedimentary successions studied include a time interval starting from the upper Badenian to the upper Sarmatian (lower Bessarabian). The most extensive stratigraphic record is found Şipote and Bivolari boreholes. In the case of Şipote, it reaches at the depth of 217 meters deposits formed by gray marl of upper Badenian age (Kossovian) with a specific fauna of *Chlamys elegans*, *Bolivina dilatata*, *Uvigerina graciliformis*, etc. (Brânzilă, 1999; fig. 21). In Bivolari drilling this limit is intercepted at about 140 m.

From the chronostratigraphic point of view, the sedimentary successions that outcrops in the Fălticeni Plateau are of Volhinian age (Macarovici, 1964; Ionesi, 1968; Ionesi, 2006).

The studied outcrops belong, from the, to the Somuz Formation (after Ionesi, 2006) which also includes the calcarelus sandstones units Arghira I, Arghira II, Hârtop I, Hârtop II (fig. 3) defined by Ionesi (1968).

The analyzed sedimentary succession is predominantly sandy in the open outcrops on the Muscalu stream, Gheorghe's brook, and in the openings from Hârtop and Rădăşeni. On the other hand, on the Logofătu and Ciofoaia streams, the lithology of the deposits is predominantly silto-clayey and clayey with an abundant fossil fauna of bivalves, gastropods and foraminifera.

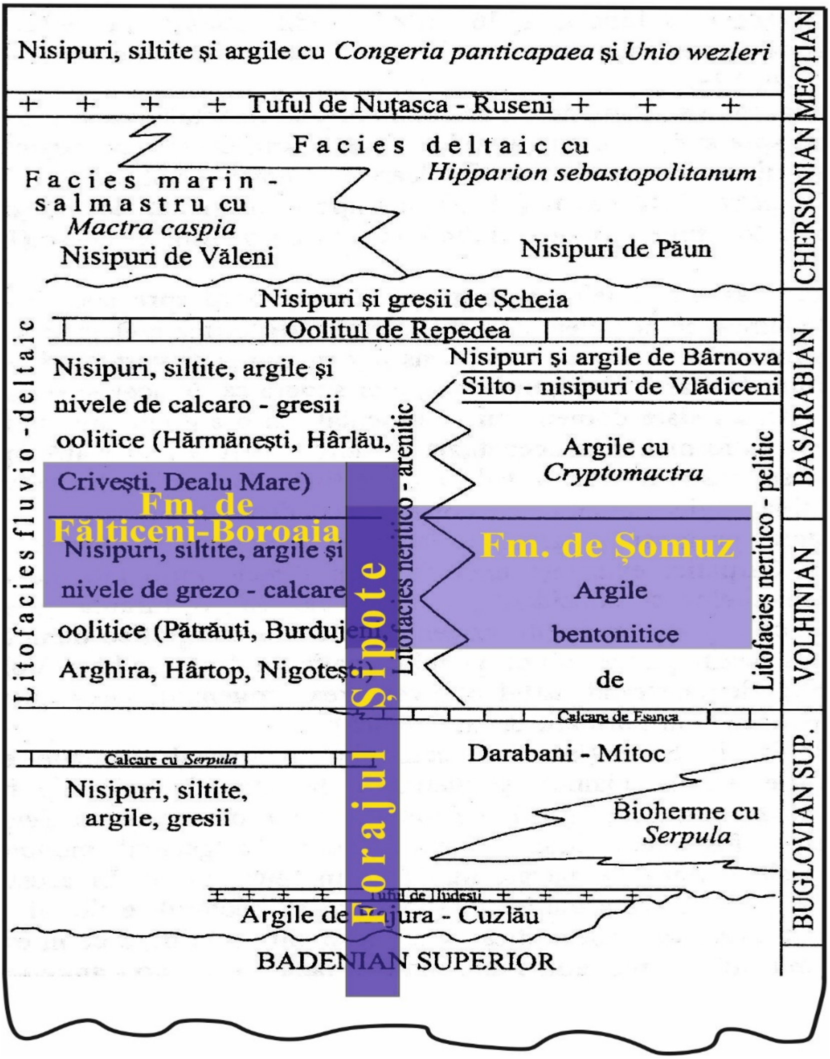


Figure 3. Lithostratigraphic units from the Middle Miocene of Moldavian Platform (after Ionesi, 1994, modified hereinn with Şomuz and Fălticeni-Boroaia Formations).

The lower Volhinian stratigraphic range in which these deposits were framed is argued by index taxa identified so far in a series of analyzed samples. Thus we determined the mollusk taxa: *Potamides nimpha* (Eichw.) and *enveloped enveloped envelope* (Eichw.) , (fig. 35, Logofătu stream), *P. Mitralis* (Eichw.) and din the taxa of foraminifera we determined *Elphidium rugosum* (d'Orb.) , *Porosononion subgranosus* (Egger), *Ammonia beccarii* (L.), *Varidentela reussi* (Bogd.). The same microfaunistic association was described by previous authors (Ionesi, 1968, 1991; Ionesi 2006). Also, after the ostracode species that we have identified, the sedimentary successions analyzed belongs within the NO-12 biozone *Neocyprideis kollmani – Aurila notata, sensu* Jiříček and Říha (1991).

The deposits that are used in Rădășeni and on the Bogata and Seaca streams, they were classified by Țibuleac (2009) in Fălticeni-Boroaia Formation (fig 3). This was attributed to the upper Volhinian on the basis of the association of mollusks with *Abra reflexa* (Eichw.) , *Lithopodolic obsoletiforma* (Mont.), *Plicatiforma plicata* (Eichw.) , *Mactra eichwaldi* (Lask.) , *M. vitaliana* (d'Orb.) , *Potamides* div. sp.

In the content of this thesis, the deposits on the Bogata and Seaca streams were also dated by us from the micropaleontological point of view being attributed to the Biozone with *Elphidium rugosum* and *Pseudotriloculina consobrina* (Ionesi, 1991), which reconfirms the upper Volhinian age of the formation.

2.2. Structural geological framework

In the crust of the Moldavian Platform, two distinct stages were observed (Ionesi, 1994):

- a labile, geosinclinal stage, in which the constituent metamorphic formations were intensely folded and crossed by igneous intrusions. The last movements occurred in the middle proterozoic, resulting in an orogene;
- a stable stage in which the orogen became rigid and was exonerated to the upper Vendian, being penetrated.

The drilling data indicate a descent to the west and south of the moldavian platform's foundation and cuvities, the largest thickness of the sedimentary deposits (Silurian, Cretaceous, Badenian, Sarmatian) being on the western side of it, which denotes that in each of the 3 cycles the sedimentation was more active or took place only on this side, for example in the Cretaceous – Eocene interval (Ionesi, 1994).

The inclination of the deposits between Siret and Moldova, an area that also captures the sedimentary successions on the Şomuzul Mare valley, was measured by several authors (Ionesi, 1968; Ionesi, 2006), using landmarks such as the limits between the Sarmatian sub-floors, respectively the Buglovian/Volhinian limit and the Volhinian/Bessarabian limit (Ionesi, 2006) as well as some lithological levels, especially sandstones, which retain their relatively constant characteristics.

Having as a reference the limit between Buglovian and Volhinian identified in the Lespezi drilling and from Dorneşti-Siret, Ionesi (2006) observes an inclination of 4.7 m/km in the NV-SE direction, a value similar to that calculated by Ionesi(1968), 4-5 m/km.

The boundary between the Volhinian and the Bessarabian was identified at several points, which allowed the generation of a contact surface between these sub-floors. In this case, too, a general inclination of the layers in the nv-se direction was observed, the surface showing some slight unevenness due to the variation of the obtained values. In the case of this boundary surface, the inclination of the layers varies between 5-10 m/km (Ionesi. 2006).

Using as a reference the grezoase levels that have lateral continuity, Ionesi (2006) mentions values similar to those obtained using as a reference the limits between the Sarmatian sub-floors (inclinations that vary from 5 to 10 m/km in the NV-SE direction), somewhat lower at the level of the Buglovian deposits.

The greater thickness of the sedimentary deposits in the western part of the foreland basin and the subduction of the Moldavian Platform under the Carpathian orogen was also proved by the ash drillings that intercepted at depths of 4000 m the Sarmatian deposits. Ionesi (1994) mentions that the foundation and cuverture of the Moldavian Platform descends to the west along some fractures (fig. 4), the Paleozoic deposits appearing up to date in the bank of the Dniester and in the west near the orogene at 1734 m.

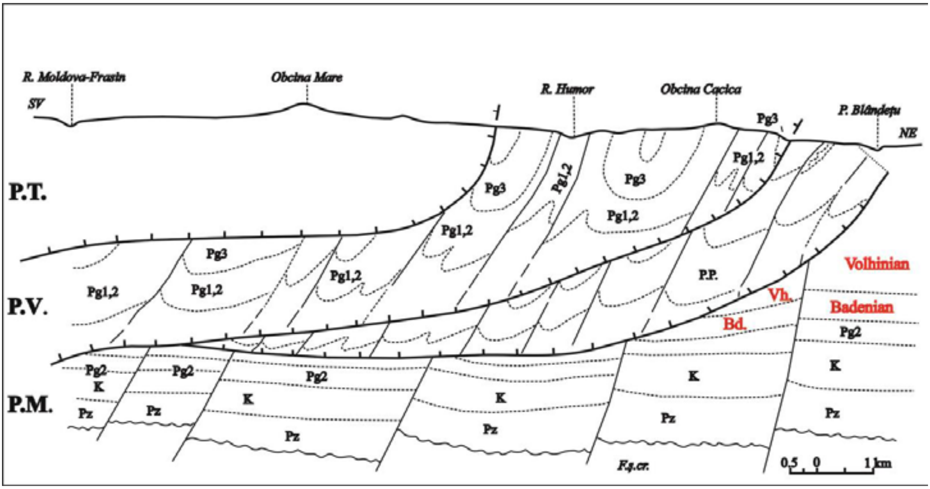


Figure. 4. The relationship of the Carpathian canvases with the Moldavian Platform between Frasin and Cacica. (after Ionesi, 1994). **PM- Moldovan Platform**; **F.ș.cr**. – crystalline shale (foundation); **Pz** – Vendian superior and Paleozoic; **K** – Cretaceous; **Pg2** – Lower and medium Eocene; **bd** – Upper Badenian; **bg-vh** – Buglovian – Volhinian; PP – **Pericarpathian Canvas**; **$m_{1,2}$** – Aquitanian, Burdigalian, Badenian; **PV** – **Canvas of Vrancea; PT – The Tarcău Canvas; sn** – Senonian; **$Pg_{1,2}$** – Paleocene and Eocene; **Pg_3** – Oligocene; **m_1** – Lower Burdigalian (Formation of Gura Șoimului).

Chapter 3. Materials and methods

3.1 Micropaleontological analysis

In order to carry out this work, 141 samples were taken from the outcrops and 25 samples from the boreholes. Some of the outcrop samples, especially the sandy ones, were taken in order to establish the granulometry of the deposits. Clay samples were taken to analyse the microphosyl content. The samples were processed by standard methods of micropaleontological sample preparation. Thus, a part of each sample (about 100 g of sediment) was dried at the oven, after which it was shredded into fragments smaller than 2 cm. The rest of the sample was stored as blank sample. The witness samples are stored in the Department of Geology of the "Alexandru Ioan Cuza" University of Iasi. The work sample was left for about 2 hours to soak in water. The clay material was subsequently removed by the method of successive washings and decantings. The residue remaining after washing was sorted by 3 sieves (0.466 mm, 0.263 mm, 0.122 mm) separating 4 fractions, each analysed subsequently. The primary determination of the microphosyls was made with the help of binocular magnifying glasses, while the detailed examination and the photographs for the drawing of the drawings were carried out under the electron microscope (fig. 5).

For the determination of microphosyl specimens, the binocular magnifying glass Carl Zeiss Jena SM XX was used. In order to make the drawings, thebest preserved xemplares were fixed on supports covered by a double-sided carbon tape and then metallized with 15 nm Au film, then photographed with the SEM Hitachi S-3400N microscope in the RAMTECH Microstructural Characterization Laboratory of UAIC, and part at the Vega/Tescan electron microscope within the UAIC Faculty of Biology.

The determined microfaunistic associations were used for the biostratigraphic dating of the studied deposits and also compared with associations from other reference areas of the Central Paratethys

(Transylvanian Basin, Vienna Basin, Avanfosa of the Western Carpathians in Poland).

Also, the associations of foraminifera and ostracode were used to determine the paleoecological conditions in the studied sections.

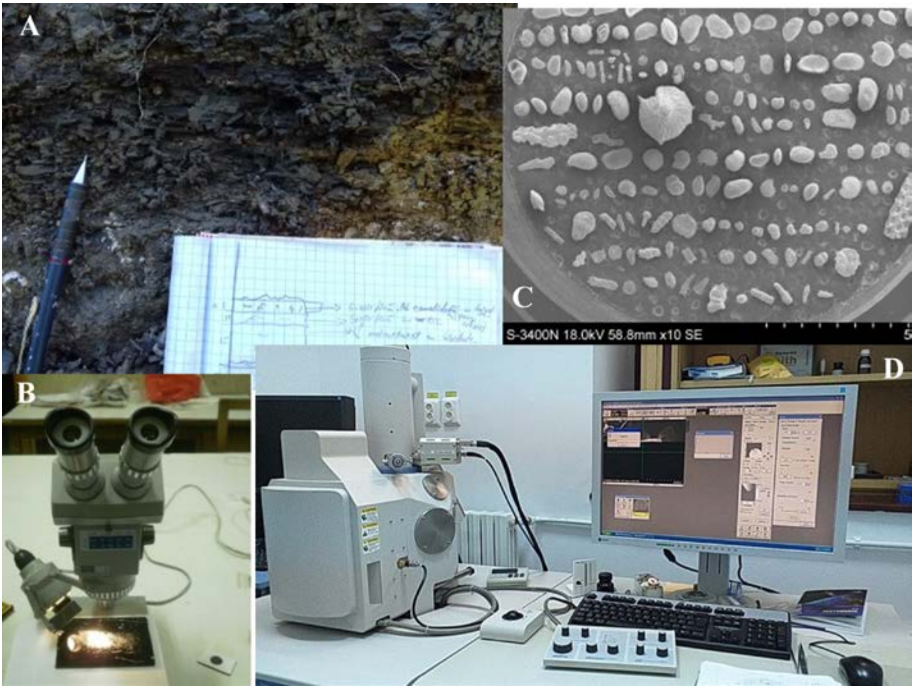


Figure 5. Apparatus and materials used in the micropaleontological analysis; A – Sampling of the material from the field (approx. 0.5 kg sample); B – Analysis of the residue washed at the binocular magnifying glass; C – Fixation of microphosyls to metal supports with double-sided carbon tape; D – Capturing photos under the scanning electron microscope (RamTech laboratory – Faculty of Physics, UAIC).

Foraminiferal Morphogroups

Foraminifera are organisms sensitive to environmental change, constituting indicators of climate change or water chemistry in a sedimentation basin. Their spread depends, among other factors, on brightness and nutrients – the factors that largely control productivity. In terms of salinity, many organisms have the ability to tolerate fluctuations in salinity between 30 – 40‰.

In view of the paleoecological reconstructions in the avanphosa of the Eastern Carpathians, we used the method of benthic foraminiferous morphogroups (Murray, 2006; Chan et al., 2017), this being one of the most effective and frequently used (Figure 6, Table 1).

The main reason for determining foraminiferous morphotypes and morphogroups is to identify the paleoambiental changes indicated by the associations of foraminifera in each sedimentary facies. The use of foraminiferous morphogroups and morphotypes has been established for benthic species, both calcareous and agglutinated by numerous authors (Jones et Charnock, 1985; Corliss et Chen, 1988; Nagy, 1992; Nagy et al., 1995; Van der Akker et al., 2000; Cetean et al., 2011; Setoyama et al., 2011; Murray et al., 2011) analyzing older deposits (Jurassic – Oligocene). For the Miocene deposits Kender et al. (2008) applied the method of analysis of foraminiferous morphogroups on some deposits in the Congo River delta and the Angolan offshore area. Although the genera present in the sedimentary successions in the Fălticeni area are slightly different, the main idea of establishing them can also be used for the middle Miocene species and genera of the Eastern Carpathians avant-garde.

Another way of interpreting the paleoecological parameters is the direct observations on the current benthic and ostracoded foraminiferous specimens. Kitazato (1988) monitored in the laboratory the behavior of foraminifera and how they move in sediments, at the surface of sediments and on the surface of Petri dishes. The observations refer to genera that we have also identified in the samples taken from the outcropsys of the Eastern Carpathians, e.g.: *Bolivina*, *Elphidium adventum*, *E.* sp. *Fissurin*, *Quinqueloculina*, *Triloculin*, *Uvigerina*. According to these observations, the foraminifera move at speeds from 20 to 100 μm/min in sediments and up to 300 μm/min in the case of Petri dishes. The author mentions in the case of infaunaous specimens that the specimens that have a single terminal aperture were moving in the direction of opening the appetizer. Species with multiple apertures have irregular direction of movement. Epiphanial specimens, in turn, have different ways of moving: either by crawling on the surface of the substrate, in which case the direction of travel coincides with that of the appetizer, or by lifting the test from the surface and moving with the help of pseudopods in various directions, in which case traces of displacement can be observed on the surface of the sediment. Comparing the travel speeds of the foraminifera through sediment with the speed of movement on the surface of petri dishes it was found that the latter can be 5 times higher.

The sediment distribution of foraminifera was analyzed by Corliss (1985). Following field and laboratory observations, it appears that in the first in 15 cm below the water/sediment interface, microhabity characteristic of different categories of species is organized. The first 2 cm of the water/sediment interface are, however, the most microfaun population.

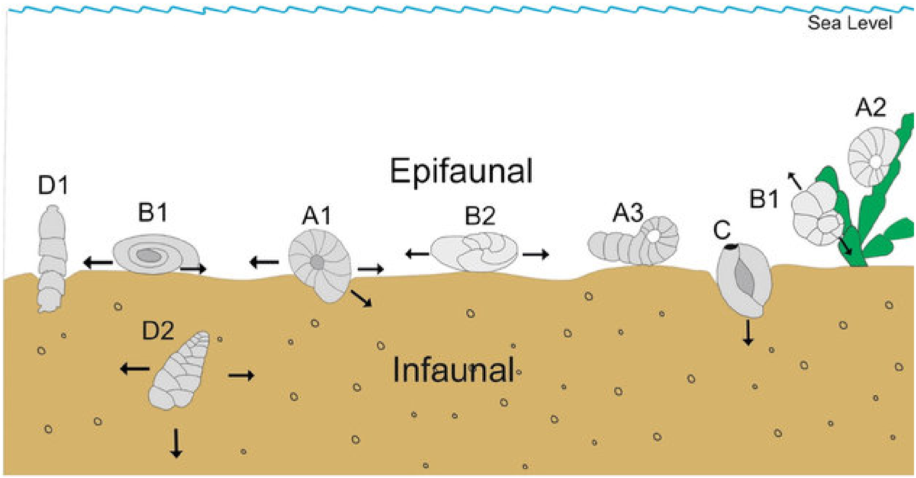
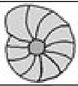
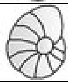
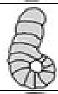
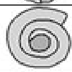
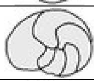
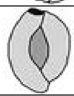
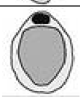
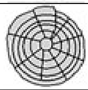


Figure 6. Way of life and position on the substrate of morphogroups of benthic calcareous foraminiferous (after Chan et al., 2017).

Ostracodes are in turn classical study tools in micropaleontology showing a greater diversity compared to other taxonomic groups having a high abundance in both normal marine waters and in brackish and sweet waters (Van Morkoven, 1963; Frenzel et al., 2005; Toth et al., 2010). Also, foraminifers and ostracodes, due to their small size, have higher chances of conservation in the fossil state and are very useful organisms in restoring the environment both now and in previous periods (Murray, 2006). The morphology of the carapace, the degree of preservation, the presence of both valves in the samples, as well as the occurrence or absence of juvenile specimens are also very important paleoambiental indicators, specifying the nature of the substrate or the energy of the currents at the water/sediment interface (Van Morkoven, 1962).

Table 1.Calcareous foraminifera morphogroups in association with agglutinated foraminifera

Morfo-grup	Morfotip		Forma testului	Poziția în timpul vieții	Genuri principale	Referințe ale exemplarelor actuale
A	**A1**		Biconvex Planspiral	Epifaunal infaunal superior	*Elphidium*	Kitazato (1981, 1988) Sturrock et Murray (1981) Corliss et Chen (1988)
	A2		Aplatizat Planspiral	Epifaunal	*Peneroplis Operculina*	Kitazato (1981, 1988) Sturrock et Murray (1981)
	A3		Nerulat Planspiral	Epifaunal	*Spirolina Cosconospira*	Murray (1991)
	A4		Tubular Planspiral	Epifaunal	*Cornuspira*	Murray (2006)
B	**B1**		Biconvex Trochospiral	Epifaunal	*Cibicides Rotalia Ammonia*	Kitazato (1981, 1988) Sturrock et Murray (1981)
	B2		Planconvex Trochospiral	Epifaunal	*Discorbinella*	
C	**C1**		Miliolid – quinqueqloculin	Epifaunal Infaunal superior	*Quinqueloculina Triloculina Sigmoilinita*	Corliss et Chen (1988) Corliss et Fois (1990) Murray (2006)
	C2		Miliolid – pyrgo (biloculin)	Epifaunal Infaunal superior	*Pyrgo*	
	C3		Miliolid fusiform la sferic	Epifaunal	*Borelis*	
D	**D1**		Cilindric uniseriat	Epifaună erectă Infaunal superior	*Stilostomella Nodosaria*	Kitazato (1981, 1988) Sturrock et Murray (1981) Murray (1991)
	D2		Aglutinat biseriat	Infaunal	*Textularia*	

As for the way of life of ostracodes, in the summer of 2019 we made some observations of our own on living specimens of *Xestoleberis* sp. collected from the Black Sea. After studying their behavior, we found that ostracodes move at higher speeds than foraminifera. As regards their relationship with the sedimentary substrate, the observed specimens shall be buried in the sand or taken shelter between the algae when threatened, while seeking food (algae or animal scraps) for the rest of the time.

3.2 Analysis of calcareous nannoplankton

Several samples taken from the studied outcropments were subjected to the analysis of the content of calcareous nannoplankton, in order to correlate the stratigraphic as accurately as possible with the other sedimentation basins. Calcareous nannophosyls were studied from the fraction of 2-30 μm that was obtained by settling from the suspension using H_2O_2 7% concentration. The material obtained was transferred to the slides that were analyzed in immersion oil at a magnification of 1200X in both transmitted light and polarized light, with an Olympus SMZ 61 microscope.

3.3 Sedimentary facies analysis

In order to determine the sedimentation conditions and the depositional domains, as well as to establish the hierarchy of the events that led to the accumulation of deposits in the Fălticeni area, we used the method of analyzing the sedimentary facies. In order to apply this method, several stages were passed that led to the recognition and differentiation of sedimentary facies and respectively of facies associations of facies.

Nemec (1995) proposes to go through three stages of work in the analysis of sedimentary facies, stages also followed in the present study:

In the first stage with the help of information obtained by direct observation in the field of deposits, the lithological columns of outcrops were made. Within these columns, from the base to the top, sedimentary facies were identified and plotted.

Geometrically, a sedimentary facies are limited both vertically and horizontally in the lithological column, its recurrent presence being normal in sedimentary successions.

The second stage of the analysis of sedimentary facies is the identification of facies associations, more precisely, the grouping of facies from a genetic, spatial and consistent point of view with each other. The purpose of this stage is to hierarchize the stratigraphic units in the sedimentary successions, then highlighting sedimentary processes specific to certain domains or depositional subdomains (fluvial, deltaic, shoreface, shelf, etc.).

The last stage of the analysis of sedimentary facies is represented by the interpretation of the vertical succession of associations of facies. Their stacking mode will indicate whether positional systems are progradational or retrograde in nature.

Chapter 4. Sedimentological and micropaleontological analysis of some sedimentary successions in the central part of the Moldovan Platform

Depositional domains and fauna associations

In the content of this thesis were analyzed from the sedimentological and micropaleontological point of view 10 sedimentary successions from the Moldavian Platform.

The studied deposits are of Badenian superior age and lower Sarmatian (Volhinian and Lower Bessarabian), this being established on the basis of the fossil fauna of molluscs and foraminiferous (Ionesi, 1968; Ionesi, 1994; Brânzilă, 1999; Ionesi, 2006; Ţibuleac, 2009; Miclăuş et al., 2015).

The sedimentary successions studied are represented by open outcrops of tributary streams of the rivers Moldova and Şomuzul Mare, as well as by two boreholes: Bivolari and Şipote.

Some preliminary results treating paleoambiance in the sedimentation basin and biostratigraphy of deposits were presented at scientific symposiums and published in volumes of abstracts (Loghin, 2014; Miclăuş et al., 2015; Loghin et al., 2019; Loghin, 2020).

The sedimentary sequences that are the subject of the detailed study are (fig. 1):

1. Muscalu brook – 45 m;
2. Gheorghe's brook – 24 m;

3. Logofătu brook – 6.5 m;
4. Ciofoaia brook– 26 m;
5. Hârtop A outcrop – 9.5 m and Hartop B – 6.8 m;
6. Rădăşeni outcrop – 14.8 m;
7. Bogata brook – on the course of which we analyzed 6 openings;
8. Seaca brook – on the course of which we analyzed 3 openings.

In the absence of up-to-date sections that would capture the evolution of the sedimentation basin over a longer period of time, we also analyzed the samples of the carrion taken from two boreholes near the Prut River, drillings that also intercepted deposits of upper Badenian age:

9. Sipote borehole;
10. Bivolari borehole.

Of these warehouses, the openings on the streams of Gheorghe, Muscalu, Logofătu, Ciofoaia, Hârtop, Bogata and Seaca fall, according to Grasu *et al.* (1999, 2002) in the transition zone between avant-garde and forebulge of the foreland basin system of the Eastern Carpathians.

Following sedimentological, petrographic and tectonic studies, the authors identify the 4 depots of a foreland basin from east to west, framing the deposits of the Somuz valley in the forebulge depot. The authors used the calcareous-grezous levels defined by Ionesi (1968) as an argument for justifying the presence of the flexion dome formed as a result of the blackening of the Moldavian Platform under the orogene of the Eastern Carpathians. However, recent field observations show that the limestone-grezous levels Arghira I – II, respectively Hârtop I – II have an insignificant carbonate component, which are, from a petrographic point of view, closer to calcareous sandstones and have rare oolites in their mass. The nature of these sandstones, as well as their association with massive layers of clays and siltites, leads us to interpret these deposits as having accumulated in the avanphosa depot (foredeep) of the foreland basin developed in front of the Eastern Carpathians, probably in its distal area.

The Sipote and Bivolari drillings, on the other hand, comprise deposits specific to the backbulge depote of the same sedimentation basin, being characterized by stacks of predominantly pelitic sediments that describe a pelagic sedimentation and in some places calcareous intervals, even of a reef type that could have formed at shallow depths near the cardboard edge of the sedimentation basin.

Some common working methods in paleomedium reconstitutions based on microphosyls (especially foraminiferous) are based on the use of statistical parameters. One such parameter is the ratio of planktonic and benthic foraminifers - P/B (Murray, 1991; Schiebel et al. , 1997; Van der Zwaan et al., 1999) often used in estimating paleo-depth variation in sedimentation basins. From our point of view, it is necessary to use these parameters with caution, especially in the deposits accumulated in the edges of the basin, where exondations of older deposits and reshuffles of faunal associations can occur quite frequently. Also, in the coastal areas of sedimentation basins, the action of underwater currents is very intense, often remobilizing the unconsolidated stacks of sediment and transporting them, together with the fauna they contain, to the environments of greater depths.

A more appropriate approach to determine the paleo-depth of sedimentation basins is **the analysis of foraminiferous morphogroups** (Kitazato, 1981, 1988; Sturrock et Murray, 1981; Corliss et Chen, 1988; Murray, 2006), as well as direct observations on current foraminiferous genera or ostracode fauna (see Chapter 4.1)..

The micro-pharmanual content has been synthesized in a series of tables where the number of copies identified in each sample is shown. The best preserved specimens of the samples were photographed and exhibited on 12 drawings (Annex A).

The outcrops will be described from east to west, and associations of facies will be numbered in accordance with the order of their occurrence in sedimentary successions.

Muscalu Brook

The outcrop on muscalu stream is located on the territory of Arghira village, Preuteşti commune, GPS coordinates: N 47°27'0.87", E 26°28'25.19" in WGS 84 system. The opening measures 45 meters of which sedimentologically mapped 43 (fig. 7).

On the basis, the deposits are lithologically clayey and towards the upper part of the predominantly sandy outcrop, with some grezous intercalations (fig. 27).

Following the sedimentological analysis, 12 sedimentary facies were defined: (1) clay, (2) unstructured mudstone, (3) clay sand with oblique lamination, (4) very fine sand with symmetrical waving, (5) very fine sand with oblique rolling, (6) very fine sands at mediums with wide convex layerification (hummocky), (7) very fine sands with wide concave layerification (swalley), (8) sands with oblique layering tangential to concoid festonate layering, (9) sands with low-angle oblique stratification, (10) sands with plane-parallel stratification, (11) massive sands with bioclasts, (12) sands with convoluted stratification, They are also joined by an erosive form of *guttercast* type that incises a set of sands with mudstone and oblique lamination.

Sedimentary facies were grouped on genetic, lithological, and geometric criteria into three associations of facies that were interpreted in terms of depositional subsystems.

Facies Association 1 (AF 1)

Description: The association of faciesuri 1 was defined on the basis of the outcrop on the Muscalu stream and extends over 9 m in the stratigraphic sequence. AF 1 consists of 5 sedimentary facies: clays with dispersed bioclasts, mudstones with sandy lenses, clay sands with oblique lamination and some fine sand lenses with oblique lamination. Sporadically in AF 1 appear very fine sands with wide concave layering (swalley; SCS) and wide convex layering (hummocky; HCS) on a small scale.

Interpretation: The sedimentary processes that lead to clay accumulation are most often the accumulation from suspension in still waters (Collinson, 2017). Another indicator of the accumulation of clays in calm sedimentation conditions is the presence of bioclasts in the mass of clays, which are in a living position. However, the presence in AF 1a of sandy lenses and sands with oblique lamination demonstrates a coarser material intake as a result of the action of unidirectional currents. Facies with HSC and SCS with sporadic occurrence are also witnesses of higher-energy events in the sedimentation basin, hummocky stratification being a diagnostic facies for storm strata (Harms, 1979; Cheel and Leckie, 1993).

Following the analysis of sedimentary structures, lithology and fossil fauna identified, AF 1 was accumulated in generally quiet waters above the average wave base of good weather. During storms, coarse sediments are introduced into this sedimentation zone under the action of turbidic currents (Hamblin and Walker, 1979) initiated during major erosion of sediments during periods of storms (Hamblin and Walker, 1979). Based on the traits mentionedabove, we consider that the sedimentary sequence of AF 1 has accumulated in the depositional subsystem. of **transition to offshore** (Reading, 1996).

Facies Association 2 (AF 2)

Description: The association of faciesuri 2 has been identified twice in the sedimentary succession on the Muscalu stream. At the bottom of the outcross it has 11 meters and 6 sedimentary facies: very fine sands with oblique rolling, rarely with symmetrical rolling of waves, very fine sands at mediums with plane-parallel layering, fine sands with swalley concave layerification (SCS), and less often hummocky convex layerification (HSC), very fine sands at environments with tangential oblique stratification and bioclast on stratification surfaces, and some clayey drapery lenses, as well as some loamy clasts in the mass of TCS sands. The largest share in the sedimentary succession are sands with oblique rolling and sands with plane-parallel stratification.

A peculiarity of this association of facies is the presence of an erosive structure of guttercast type that incises a set of fine sands with oblique stratification and mudstone intercalations (fig 6).

Guttercast in turn has specific internal sedimentary structures represented by a pavement of bioclasts in the base with thicknesses ranging from 2-5 cm (unit A) and medium sands with oblique layering in the upper part (unit B).

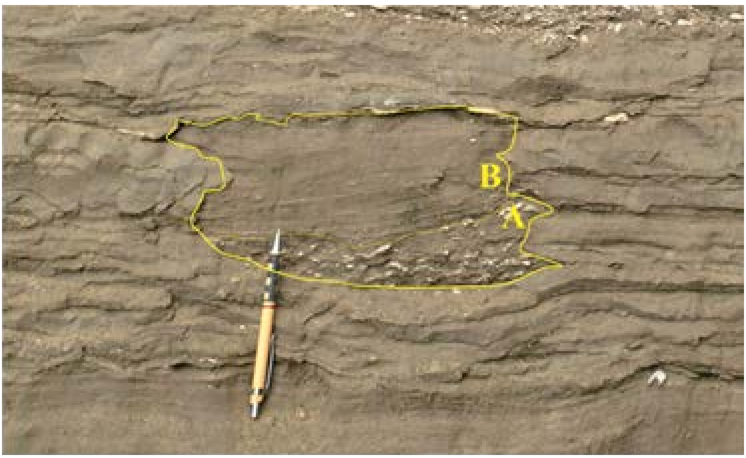


Figure 6. Guttercast erosive form

Interpretation: The presence to a large extent in the facies association 2 of sands with oblique rolling and sands with symmetrical wave lamination confirms the accumulation of deposits under the action of waves of good weather. The more energetic episodes in the sedimentation basin, e.g. storms, are evidenced by hummocky and swalley stratifications, shcs being a diagnostic sedimentary structure for storm layers, which accumulate under the action of combined high-energy currents.

The occurrence of these sedimentary facies in the outcrop on the Muscalu stream suggests the accumulation of deposits in the **lower shoreface** deposition subfield of a nondeltaic coastal system.

Facies Association 3 (AF 3)

Fine and very fine sands with tangential oblique stratification and plane-parallel stratification, sporadic, swalley concave stratification.

Description: The association of faciesuri 3 measures 11 meters and appears only once in the stratigraphic sequence on the Muscalu stream. The predominant sedimentary facies are represented by sands with tangential oblique stratification and concoid festonate. Subordinately, in AF 3 were identified sands with plane-parallel layering, hummocky and swalley with bioclasts on the stratification surfaces, two sets of 50 cm each of sands with oblique layering at a low angle, as well as 50 cm of massive sands without sedimentary structures.

Interpretation: The occurrence of sands with tangential oblique stratification and concoid festonate layering suggests the action of tractive currents on the sedimentary bed (possibly longshore ones) that lead to the migration of 3D dunes (Clifton, 1976, 2006, Saito, 2005; Miclăuş et al., 2011). As for the plane-parallel stratification, it is the product of the action of tractive currents in superior flow regime. Hummocky (HCS) and swalley (SCS) stratification are the indicators of currents combined with high energy, most likely formed by storms that affected low-depth areas in the basin (Harms, 1979).

Following the interpretation of the sedimentation processes that led to the accumulation of AF 3, we can say that they accumulated in **the upper shoreface** area of the sedimentation basin, a few meters deep, under the action of high-energy currents (longshore, and/or storms).

From the stacking of the associations of facies described above, we interpreted a behavior of the shoreline as follows: the appearance of the lower shoreface deposits and then the upper shoreface over the facies association 1 that describes the transition subdomain to the offshore, the progradation of the deposition subsystems to the sea and an upward shallowing trend of the deposits is obvious. The recurrence of AF 2 at the top of the column, however, suggests a change in the behavior of the shoreline and the beginning of its migration (retrograde) to land as a result of the generation of accommodation space either by raising the base level or by creating space following the subsidence of the platform under the orogen.

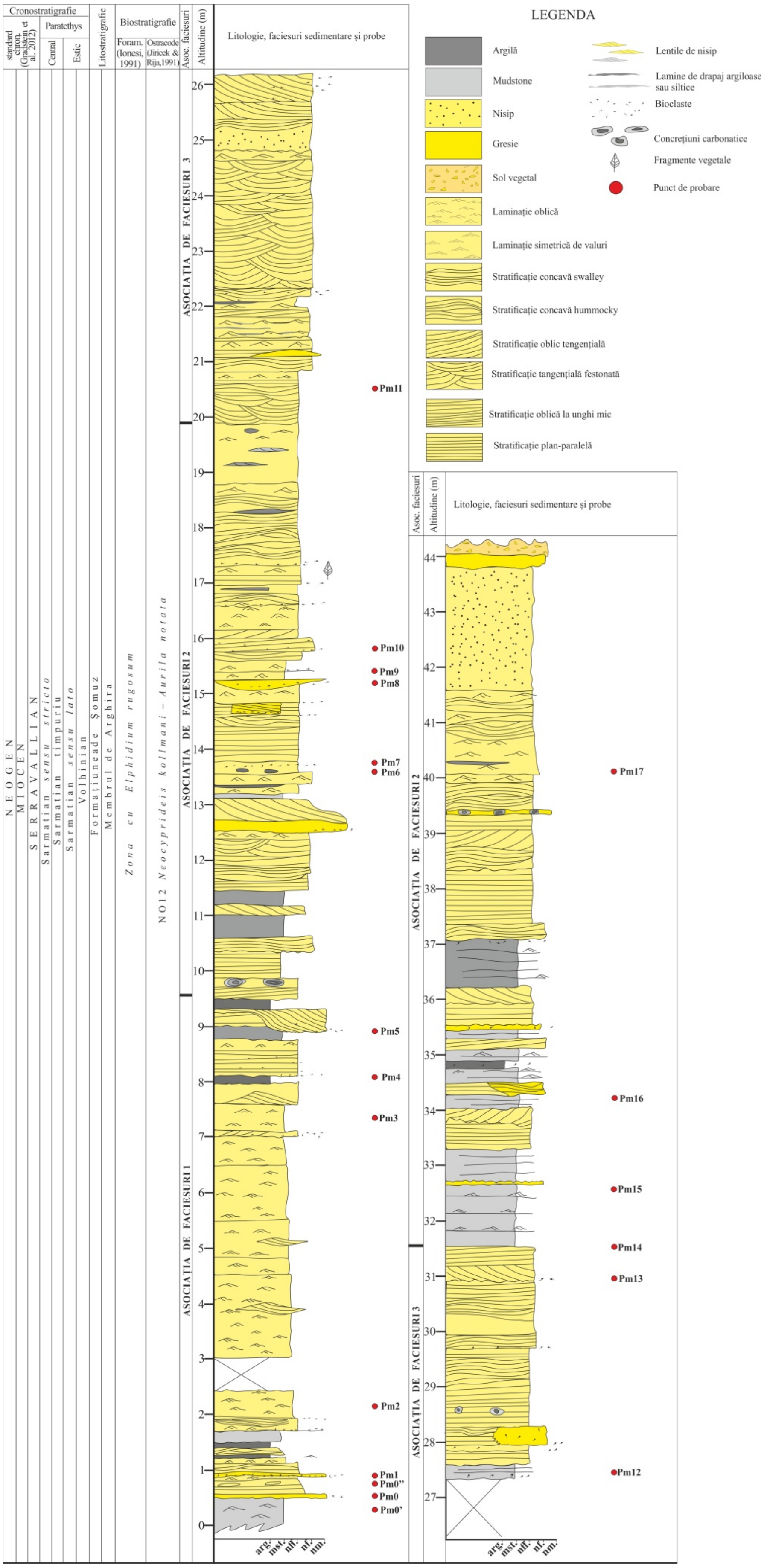


Figure 7. Sedimentological column on muscalu stream.

Microfaunistic associations

From the sedimentary sequence on the Muscalu stream, 7 samples taken from the clay or siltographic facies were analyzed from the micropaleontological point of view.

Since the association of facies 1 contains the most clayey layers, most of the samples analyzed come from these deposits. They are joined by a sample from the top of the outcrop from the second occurrence of AF 2 in the sedimentary column.

The most common species of foraminifera are *Ammmonia beccarii*, *Elphidium rugosum Porosononion subgranosus*, *Pseudotriloculin consobrina* which confirms the belonging of deposits to the Zone with *Elphidium rugosum* and *Pseudotriloculina consobrine* established by Ionesi (1991).

The ostracode association identified in the sedimentary sequence on the Muscalu stream is generally made up of *the species Cyprideis pannonica* and *Cyamocytheridea leptostigma* to which *Cytherois sarmatica* is added, a taxon identified in the upper part of the outcrop.

From the paleoecologic point of view, the dominance of *the genera Elphidium*, *Porosononion*, and *Ammonia* indicates brackish waters *A. beccarii* representing an opportunistic species that can withstand salinity variations of 10-30‰, being able to adapt even to hyposaline conditions (Murray, 1968, 2006; Dumitriu et al., 2020). Another taxon that indicates brackish waters and relatively small depths is the genus *Porosononion*, which is generally associated with salmaster to normal marine environments and increased nutrient intake . (Avnaim-Katav et al., 2013; Filipescu et al., 2014; Silye, 2015). At the same time, associations that have a low number of species of this genus indicate decreasing salinities (Culver et al., 2012).

Of the ostracode fauna, *cyprideis pannonica* species is indicators of brackish salinities (van Morkhoven, 1963) as well as taxa *Loxoconcha* and *Loxocorniculum* suggesting fluctuations in salinity (Szczechura, 2006; Toth et al., 2010).

As for the depth of the basin, the genus *Cytherois* is predominantly epi-neritic, preferring environments with marine vegetation and rather sandy substrate (van Morkhoven, 1963). In addition, the species *Loxoconcha minima* was identified by Muller (1894) in the waters of the Gulf of Naples at a few meters deep and the representatives of the genus *Callistocythere* usually does not exceed the depth of 100 m, being abundant at about 70 m (Bonaduce et al., 1976).

Gheorghe brook

The opening on Gheorghe's creek is 24 meters thick and is mostly made up of sands (fig. 8). From the territorial administrative point of view, Gheorghe's brook is located on the territory of the Basarabi village in the preuteşti commune, GPS coordinates: N 47°26'29.60", E 26°27'22.78"E coordinate system WGS 84.

On the basis of the outcrop is worth about 1 m of silt and clay deposits with intercalations of very fine sands. In the top of the analyzed sedimentary succession we also identified a layer of 1 m of coarse sandstones, poorly consolidated with oolites.

In total, 10 sedimentary facies were identified as follows: (1) gray clays, (2) siltites with oblique rolling or without sedimentary structures, (3) very fine sands with oblique lamination, (4) sands with symmetrical wave lamination, (5) sands with hummocky convex layering, (6) sands with swalley concave layering. (7) sands with tangential oblique stratification, (8) sands with low angle oblique layering, (9) sands with plane-parallel layering, (10) sandstone with rare oolites.

The 10 identified sedimentary facies were classified on lithological and genetic criteria into 3 associations of facies, each being specific to a deposition subdomain.

Facies Association 1 (AF 1)

Description: AF 1 is located at the base of the sedimentary succession on Gheorghe's creek and sums up 1 m of heterolitic deposits formed by alternations of clays and siltites with sandy lenses and with intercalations of very fine sands with oblique lamination. Most likely this association of facies continues in depth, its outcropping starting right from the thalweg of the creek. In the content of clay and silage intercalations, fragments of bioclasts are also observed, as well as brown lamines that have an oblique lamination appearance. In the intercalations of sands can most often be distinguished oblique lamination, loamy drapery lamines, and a few reddish brown lamines.

Interpretation: How to accumulate clays by decanting from suspension in still waters (Collinson et al., 2006; Collins et al., 2017) suggests a depositional field of greater depths. The recurrent existence of the intercalations of sands with oblique rolling in AF 1 is proof of the contribution of sandy material from the shore following the action of unidirectional currents of low energy, which led to the formation of corrugation trains with high conservation potential. Also, the sitites in AF 1 are witnessing the accumulation of fine sediments in still waters.

The predominance of fine sediments in AF 1 and their association with lenses or intercalations of very fine sands with oblique lamination suggest the accumulation of deposits in **the transition zone to offshore** of a non-metallic coastal system (Reading, 1996).

Facies Association 2 (AF 2)

Description: This association of facies has a stratigraphic extension of 14 meters in the column on Gheorghe's creek. It is predominantly sandy, having a single mudstone interlacing and several levels of heavily consolidated sandstones. Af 2 consists of 8 sedimentary facies: sands with symmetrical rolling of waves, sands with oblique lamination, very fine and fine sands with hummocky and swalley layering on medium scale, sands with plane-parallel layering, sands with concoid stratification festonate, mudstone with oblique lamination, and on set of coarse sands with tangential layerification on a large scale, with a wavelength of 20 m showing clayey and bioclassed clasts on the stratification surfaces (Fig. 31).

Of the 8 sedimentary facies listed, 3 are prevalent in AF 2. The largest share is held by sands with symmetrical rolling of waves that are most often presented in baskets with thicknesses of 20-70 cm, with clayey drapery manholes in the saddles of ripples, and with rare bioclasts (fig. 32). A significant share in AF 2 is also held by hummocky and swalley sands at medium scale, with wavelengths of 0.8-1.2 m. Also, sands with parallel plane layerification have a recurrent occurrence in AF 2.

Interpretation: The predominance of symmetrical wave lamination in AF 2 indicates the accumulation of deposits under the action of oscillating currents (waves) on the sedimentary bed. The fact that the charts of sands with symmetrical wave rolling are in erosive contact with storm layers such as hummocky and swalley stratification, indicates frequent episodes of high energy that eroded pre-existing ripple sets.

The dominance of very fine sands with oblique rolling in combination with hummocky convex stratification and swalley concave stratification suggests the accumulation of AF 2 in the **lower shoreface** deposition subfield, with the sedimentary bed frequently affected by storms. The presence in AF 2 of coarse sands with large-scale tangential tangential oblique stratification witness a high-energy event, most likely a unidirectional current that caused the formation of a large underwater dune.

Facies Association 3 (AF 3).

Description: AF 3 measures 9 meters in the stratigraphic sequence on Gheorghe's creek and is exclusively sandy, except for a layer of sandstone with oolites in thickness of 1 m that is at the top of the sedimentary column.

The AF3 consists of 7 sedimentary facies: fine sands at mediums with swalley concave stratification, hummocky convex layerification, tangential oblique stratification, parallel plane layerification, sporadic, very fine sands with symmetrical wave lamination and oblique lamination as well as oolite sandstone. The predominant facies in AF3 are hummocky and swalley sands with wavelengths of 1.5-2 m and sands with tangential oblique layering. They appear in sets that reach thicknesses of up to 1.8 m. Sporadically, in the content of AF 2 are present mowers of 2-3 sets of very fine sands with symmetrical lamination of waves, with clayey drapery manholes. Sands with plane-parallel stratification also appear subordinate, in sets of 10-30 cm, with bioclasts on the stratification surfaces.

Interpretation: Sands with tangential oblique stratification indicate the action of high-energy tractive currents on the sedimentary bed (possibly those of longshore type) that determine the migration of 2D dunes (Clifton, 1976, 2006, Saito, 2005; Miclăuş et al., 2011). Sands with plane-parallel layering are the product of the action of tractive currents in superior flow regime, the high energy of the current causing the realization of a flat bed on which layers of millimeter thicknesses are successively accumulated.

The dominance of fine sands in hummocky (HCS) and swalley (SCS) layered environments indicates the action of combined high-energy currents on the sedimentary bed, currents most likely formed by storms that affected areas of low depths in the basin (Harms, 1979). Sporadic ranges of sands with oblique stratification are witnesses of periods of calm in the sedimentation basin, with coffin tops or thinner sets most likely being pickled by high-energy currents.

Considering the geometrical arrangement of the sedimentary facies in AF 2, as well as the accumulation processes that involve the action of the high-energy currents in the basin, we interpreted the deposits from AF 3 as being accumulated in **the upper shoreface** area of a nondeltaic coastal depositional system.

Following the outlining of the associations of facies from the outcrop on Gheorghe's creek, one can observe the way of stacking them in the sedimentary succession and observe the behavior of the shoreline as follows: the depositional subfield of transition to the offshore over which the lower shoreface deposits are accumulated. Over the latter, deposits are accumulated describing the upper shore-sided area, which indicates the existence of a deposition system.

Microfaunistic Association

Given the predominantly sandy nature of the deposits on Gheorghe's creek and the facies describing episodes with high energy in the basin, from this outcrop, 2 samples were taken into account for micropaleontological analysis (Table 6). In the analyzed samples, we identified foraminiferous taxa (the most numerous) and ostracode. Among the foraminiferous predominate species of *Ammonia*, *Porosononion* and *Elphidium*, and of the ostracode, the most common species are *Cyprideis pannonica*, *Henryhowella asperima*, *Amnicythere*. *Tenuis*.

The Porosononion species indicate, as in the deposits on the Muscalu stream, a decrease in salinity in the basin due to the low number of species existing in the association (Culver et al., 2012) as well as small depths of the waters (Filipescu, 2014; Silye, 2015). Also, *loxoconcha* and *Amnicythere* ostracode taxa are indicators of brackish waters and shallow depths (Muller, 1894).

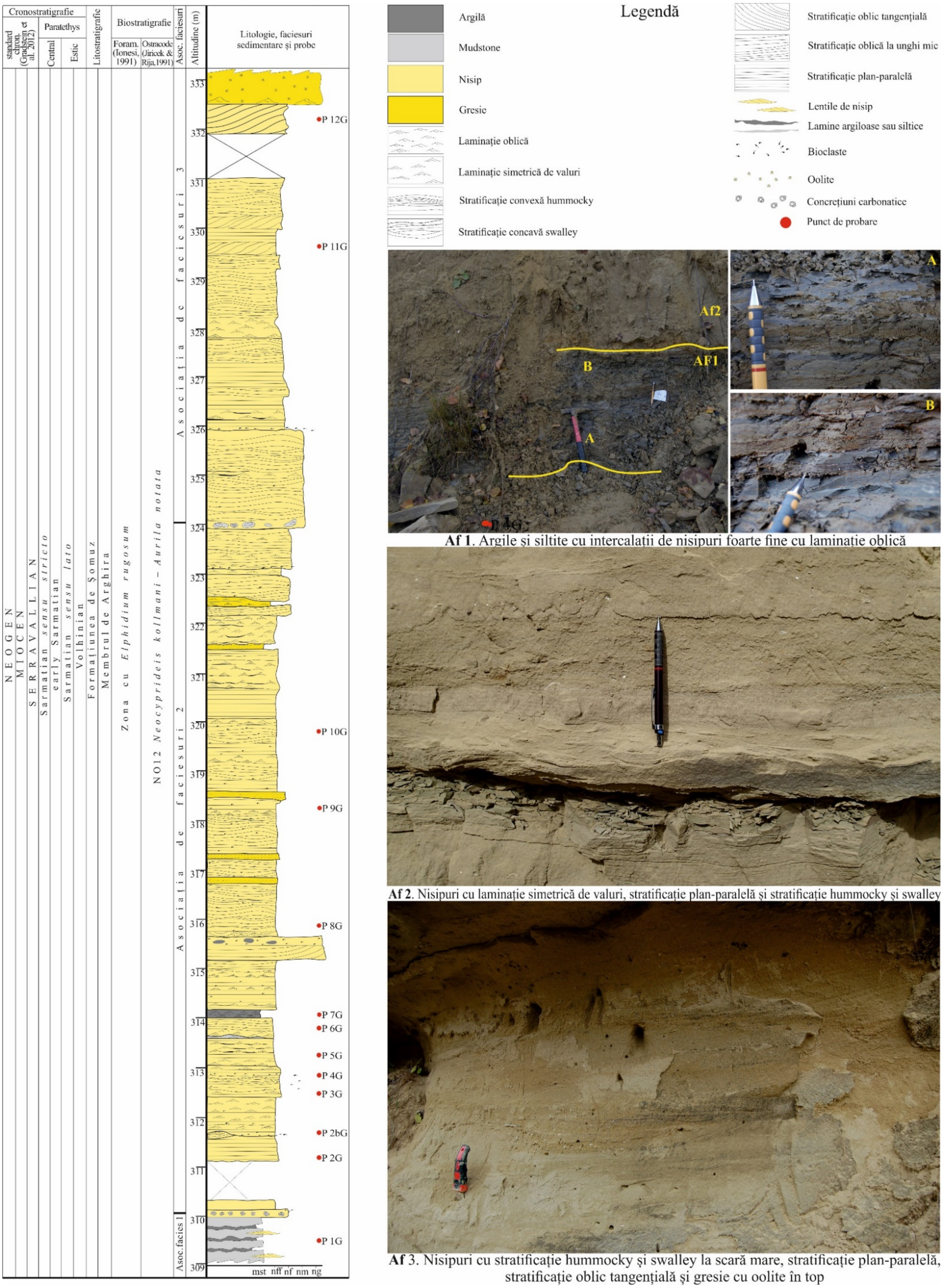


Figure 8. Sedimentological column on Gheorghe's creek.

Logofătu brook

The opening on the Logofătu stream includes a sedimentary succession of about seven meters consisting predominantly of clays and sands. It is located between basarabi and preuteşti villages (GPS coordinates: N 47°27'8.91", E 26°25'47.00").

Sedimentologically, 9 facies were separated according to lithology, texture and sedimentary structure (tab. 7, fig. 31): (1) fatty clay, (2) mudstone (silt) unstructured with brown lamines, (3) very fine sands with symmetrical rolling waves, (4) sands with oblique rolling, (5) sands with swalley layering, (6) sands with tangential oblique stratification, (7) sand or fine sandstone on average with bioclasts, (8) fine sands with plane-parallel stratification, (9) coal.

Facies Association 3 (AF. 3).

Description: Medium sands with tangential oblique stratification and swalley concave stratification. The predominant facies in AF. 3 is represented by sands with tangential oblique layering that appears in sets of 30-80 cm, with remnants of bivalves and gastropods on the lamination surfaces, with inclinations of the lamines of 20-25 °. The swalley stratification appears subordinated in Af 3 on logofătu stream, being identified in a single intercalation (fig. 9).

Interpretation: Tangential oblique stratification is formed under the action of high-energy unidirectional currents that lead to the migration of dunes from the upper shoreface area, with the base of storm waves located at depths of 5-20 m. Also, the presence of swalley stratification also highlights episodes of storms that led to the action of the combined currents on the sedimentary substrate (Harms, 1979). The dominance of sedimentary facies specific to high-energy currents confirms that the deposits in the association of facies 3 have accumulated in the upper shoreface area of the sedimentation basin.

Association of facies 4 (AF. 4)

Description: Siltites devoid of sedimentary structures and subordinate sands with symmetrical rolling waves with clayey drapery manholes, and clay levels without sedimentary structures. In the top Af 4 is opened a layer of sandy clay with bioclasts followed by a layer of coal with a thickness ranging from 2 to 7 cm. Over the coal is erosively arranged a layer of bioclasts belonging to the genus *Potamides*. The siltites appear in a compact layer with a thickness of about 1.5 m. in their content are also sandy lenses with bioclasts. Symmetrical wave lamination occurs in mowers with thicknesses of 15-20 cm, having clayey drapery manholes. Sands with plane-parallel layering are poorly represented, with thicknesses of 5-10 cm, rarely having bivalve shells on the lamination surfaces. Clays have thicknesses of 5-10 cm, and show a demanding behavior when breaking.

Interpretation: Bioclast silts without sedimentary structures accumulate in still waters (Collinson et al., 2006, Collins et al., 2017). It is worth mentioning that in micropaleontological samples taken from Af. 4 appears in high frequency ammonia . *bulbs* species (20000 specimens

/ 100 g sediment), taxon that supports extensive variations in salinity. The frequency of predominantly loamy facies in Af. 4 and their accumulation in still waters suggest the backshore area.

Facies Association 1 (Af. 1).

Description: This association of facies presents on the basis of a layer of very fine sands with plane-parallel layering, symmetrical rolling of waves and silts with bioclasts, without sedimentary structures.

Interpretation: The appearance of bioclast silts and the lack of sedimentary structures indicate an accumulation in still waters, the possible sedimentary structures being removed as a result of sediment bioturbation. Sets of sands with symmetrical lamination of better developed waves indicate long periods of good weather. Also, in the pre-washed micropaleontological samples from Af1 on the Logofătu stream, we identified a high frequency of the foraminiferous species *Quinqueloculina reussi*, a taxon that has a bathymetric spread of 150-200 meters ((Łuczkowska, 1974), depths corresponding to the offshore-transition area.

Analyzing the stacking mode of the associations of separate facies on the outcrop on the logofătu square, the location af 3 (upper shoreface) below af 4 (backshore) indicates an initial progradational behavior of the shoreline. Subsequently, the stacking of the deposits with microfossils that populate waters of high depths over the backshore deposits (retroplaja) indicates a transgression in the sedimentation basin, an event that had as a response the migration of the shoreline to the land and the installation of a depositional transitional domain to the offshore.

The occurrence of the *genus Ammonia* in a very high number in the samples analyzed on the Logofătu stream suggests the existence of mediums with low salinity and shallow depths (Murray, 2006; Cimerman and Langer, 1991; Hayward and Hollis, 1994, Filipescu et al., 2014), Also, *A. beccarii* was identified in holocene deposits in the Black Sea at salinities of 7-8 ‰ where they form monospecific associations (Briceag and Ion, 2014).

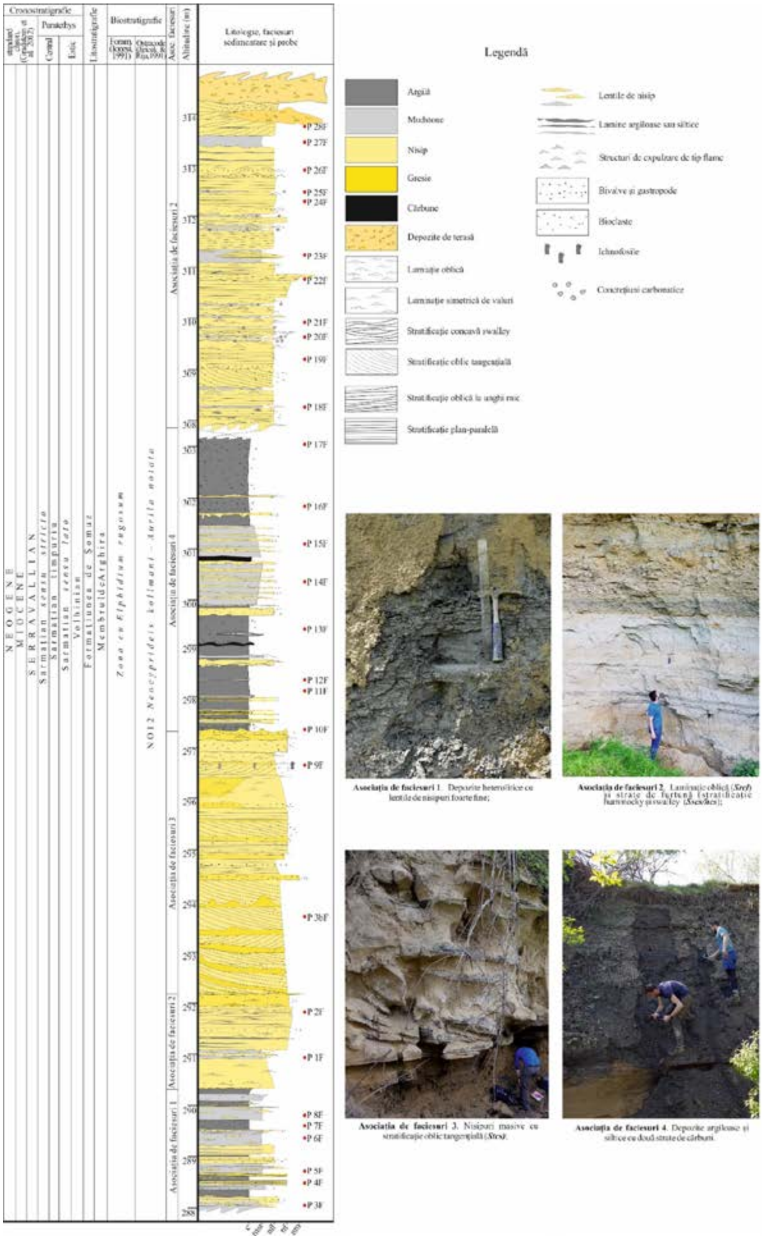


Figure 9. Sedimentological log on Logofătu brook

Ciofoaia brook

The studied deposits are located in the village of Preutești (GPS coordinates: N 47°26'47.55", E 26°25'4.85") and are mainly represented by sands between which there are heterolitic intervals, one of them having two coal layers of centimeter thickness (fig. 10).

In the sedimentary succession on the Ciofoaia stream, 15 sedimentary facies, 12 syndepositional and 3 post-positional facies were identified (tab. 9). The syndepositional sedimentary facies are: (1) coal, (2) fatty clay, (3) silttites, (4) sands with symmetrical wave rolling, (5) sands with oblique rolling, (6) sands with hummocky convex layerification, (7) sands with swalley concave layerification, (8) sands with tangential oblique stratification, (9) sands with low angle oblique layering, (10) sands with parallel-plane layering, (11) sands with bioclast lenses, (12) massive sands and sandstones. They are followed by postdepositional facies: (13) sands with pillars and flame structures, (14) clay pseudonodules (loadcasts), (15) concretions or carbonate crusts.

Sedimentary facies have been described, and figured out in Table 6 where the sedimentary processes that led to their accumulation are also presented.

The separate and described sedimentary facies in the previous subchapter were grouped on genetic criteria into four distinct associations of facies.

Association of facies 1 - wavy and lenticular heterolithic.

Description: This association takes place on about two meters, appearing only once in the column, being represented by unstructured clays or with hardly observable structures, with sandy lenses that have oblique rolling waves and oblique rolling current. In this association of facies the fine, loamy fraction dominates. On some surfaces of order 1, bioclasts (whole shells of bivalves and gastropods) are found.

Interpretation: The lack of sedimentary structures in the clays of this association can be attributed to several factors, among which, the rapid and homogeneous sedimentation from the suspension or the destructive activity of various agents such as the attested bioturbation and the presence of bioclasts (Collinson et al., 2006) or diagenetic factors. Sandy lenses with oblique structures indicate the episodic and totally subordinate action of unidirectional tractive currents with higher energy. Background accumulation in conditions with moderate to low energy is interrupted by energy episodes in which coarser material accumulates in centimeter lenses or thin layers with some lateral continuity. In this context, the remnants of mollusks quartered in fine deposits can be considered native. All this places the sediments in The Af. 1 in the offshore transition subfield **.**

Association of facies 2 – Sands with oblique lamination and storm layers.

Description: The main component facies in this association are sandy ones with plane-parallel stratification (Spp), oblique layering at low angle (Slacs), and with oblique lamination (Srcl). In combination with oblique lamines, brown films with plant material can be observed clayey drapery lenses. In some places there are hummocky structures (Shcs) (H = 20-25 cm, L = 40-50 cm) and swalley (Sscs) (H = 5 cm, L = 25 cm), diagnosis for storm layers. A peculiarity of this association is the presence of post-positional structures such as carbonate concretions (blamed on the isolated precipitation of carbonates in solutions), structures for the expulsion of water of *pillars, flame* and *load cast* type (due to the rapid burial against the background of the high sedimentation rate). Clays participate entirely subordinately in the composition of this association.

Interpretation: The parallel plane stratification is the result of the tractive currents acting in the superior flow regime producing the flattening of all the irregularities already on the sedimentary bed, continuing with the thickening of the sedimentary bed and the formation of plane-parallel lamines with bioclasts on the stratification surfaces (Harms, 1979). In isolation, parallel plane stratification is associated with low-angle oblique stratification suggesting the transition from a moderate energy to a large one (Walker and Plinth, 1992).

Hummocky and Swalley-type structures are rare, each occurring only once in the lithological column and have as a genetic process stormy events that, although short-lived, produce relatively significant deposits in the sedimentary sequence. The mechanism underlying the formation of these structures is constituted by the combined currents of high energy (Walker and Plinth, 1992).

The oblique rolling together with the symmetrical oblique rolling of waves indicates both the presence of unidirectional currents acting in the **lower shoreface** area, with the intake of sediments from offshore, and the presence of oscillating currents formed by the waves in the upper shoreface area. (Reading., 1996; Walker and Plinth, 1992).

Description: This association is constituted on the basis, of a level of 205 cm, represented by sands and sandstones without structures, with bioclasts arranged chaotically. Within this level one can distinguish a structure, apparently of the large-scale TCS type, the stratification of which is composed of intercalations of sandstones with sandstones; this facies supports in the top a candle level (L). Above this level of 205 cm follows unstructured sands (Ss), sands with tangential/sigmoidal oblique stratification (Stcss) and subordinated sands with plane-parallel layering (Spp), in some places sands with oblique rolling mills of RCL and WRCL type are present. This association consists only of medium sands, fine and very fine, more or less consolidated.

Interpretation: The massive sands on the basis of these associations are attributed to the differentiated cementation resulting from diagenetic processes (Miclăuș., 2006). The high frequency of bioclasts and the total lack of structures may indicate an intense bioturbation.

The fossiliferous level with bioclasts arranged chaotically from the top of the layers mentioned above has as a mechanism of formation oscillating currents during stormy events, which reorganize the arrangement of bioclasts. Above in the sedimentary succession, unstructured sands and sandstones predominate. Then two layers with tangential and sigmoidal oblique stratification, respectively, which suggest the action of the tractive currents (possibly those of longshore type) that lead to the migration of the 3D dunes (Clifton, 1976, 2006, fide Miclăuș et al., 2011). As for the plane-parallel stratification, as we have also said before in the previously described facies association, it is the product of the action of tractive currents in superior flow regime. Finally, RCL-type oblique lamination indicates the presence of currents in the lower flow regime, that is, short periods of calm. Given the predominance of high-energy sedimentary facies in this association of facies, we can conclude that the deposits in AF 3 have accumulated in the **upper shoreland** area of a nondeltaic coastal marine system.

Association of facies 4 – dominantly muddy, with fleshy levels

Description: This association is lithologically dominated by unstructured clays, with rare intercalations of sands and sandstones with RCL. The particular element of this association is the presence of two levels of coal (lignite - after Țabără and Chirila, 2011).

The sedimentary facies present in this association are: the facies of the unstructured clays (M), with the wave ripple cross laminateion (Mwrcl), with the sand intercalations (Ms) with bioclasts arranged on the lamination surfaces (Mb), the facies of the unstructured sands/sandstones (Ss) and the carbunous facies (C). Af.4 is composed of "greasy" clays, mudstones and very fine sands, present both as thin lamines of maximum 2 cm and as individual layers up to 15 cm.

Interpretation: The sedimentary processes responsible for the accumulation of unstructured clays, represented by slow decanting from the suspension associated with intense bioturbation, indicate conditions with low basin energy. The two layers of lignite present in this association suggest an accumulation in the swamps behind the non-mapical coastal zone beach (***the backshore*** subdomain) in the composition of which can also come a sand barrier source of sediment from the marine domain, thus explaining the sandy intercalations in this association (Reinson E.G., 1992).

Analyzing the sedimentological column from the base to the top we separate at least two trends of the shoreline: a regressive one in which the sediment stack has a ShU tendency (shallowing upward – deep deposits from the shallower ascending in the column – offshore-transition → lower shoreface → superior shoreface → backshore) and a transgressive trend in which the sediment stack has a DeU tendency (deepening upward – deeping upwards – deposits of increasing depth upwards in the column – backshore → shoreface upper → shoreface lower).

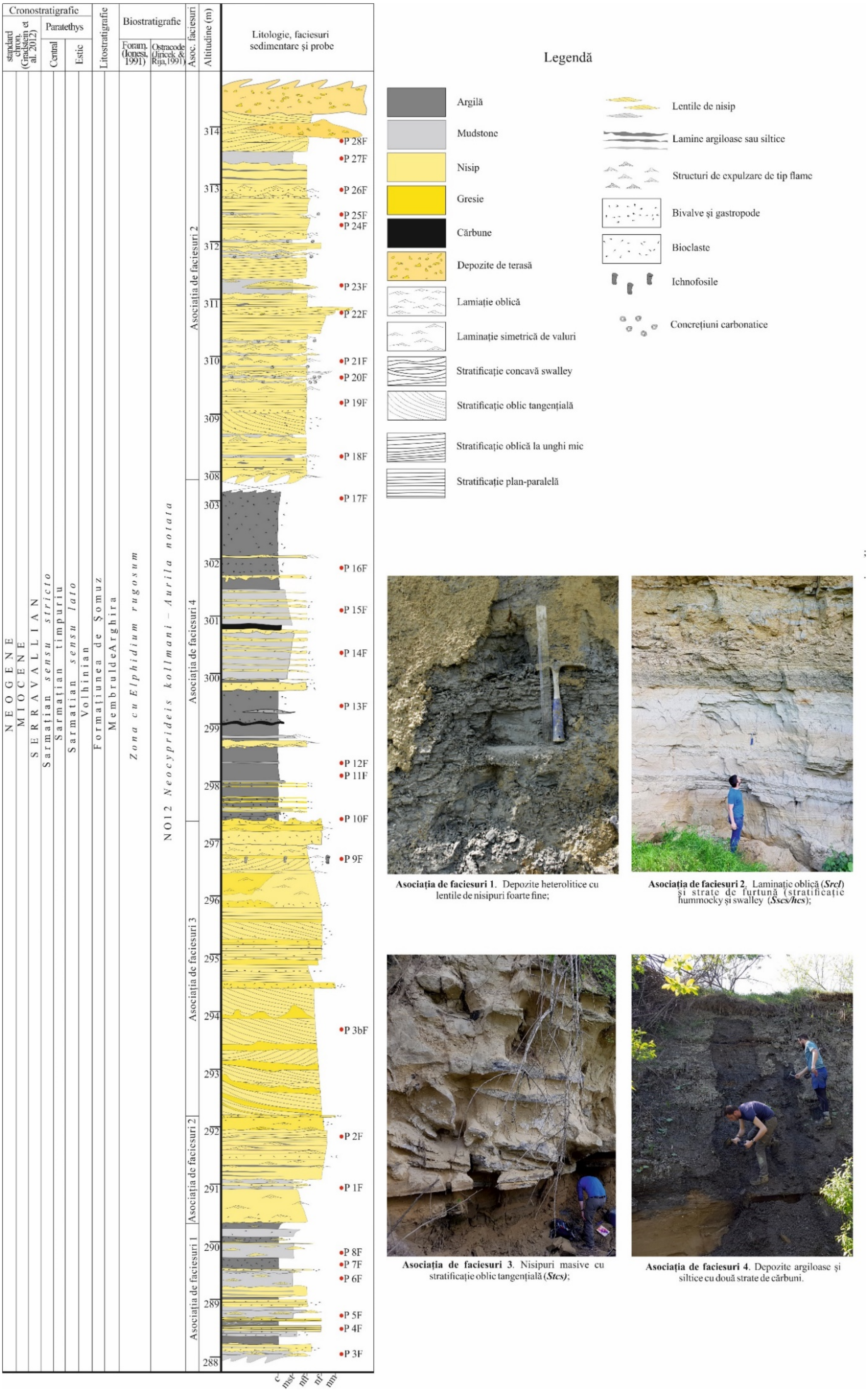


Figure.10 Sedimentological column on the Ciofoaia brook.

Microfaunistic associations

From the analyzed samples we identified 22 species of foraminiferous, 13 taxa of ostracode and 9 of calcareous nannoplankton. Of the foraminiferous *Elphidium rugosum, E. antonium, Varidentella reussi, Porosononion subgranosum, Ammonia beccarii*, confirm the early Sarmatian (Volhinian) age of the studied deposits. In fact, the abundant taxa belong to the genera *Elphidium*, *Ammonia*, *Porosononion*, *Quinqueloculina* followed by *Bulimina* and *Globigerina.* Among the species of ostracode *Aurila denotata*, *Loxoconcha minima*, *Cyprideis pannonica*, *C. sublitoralis* and *Hehryhowella asperrima* are the most representative.

The presence of *the species Aurila notata* frames the deposits studied in the Biozone NO 12 – *Neocyprideis kollmani – Aurila notata* defined by Jiřìček and Rija (1991) for the Lower Sarmatian in the Vienna Basin. The ostracode fauna is clearly subordinated to that of foraminiferous

Three samples were subjected to the analysis of calcareous nannoplankton in order to establish the age of the deposits by classifying them in specific biozones and/or highlighting the degree of reshuffle (according to Martini, 1971; Roth and Thierstein, 1972). One of the samples dedicated to the investigation of calcareous nannoplankton was sterile. Most of the taxa identified in the other two are considered reshuffled from older d epozites (Upper Cretaceous, Eocene). A number of taxa, however, frame the deposits studied in the Middle Miocene (Upper Badenian – Upper Sarmatian): the first occurrence of the species *Calcidiscus macintyrei* - NN6 - Pliocene and the last occurrence of the species *C. pataecus* NP23 - NN11.

Hârtop A, and Hartop B outcrops

Hârtop A and B outcrops represent 2 natural openings of 9.5 and 6.8 m respectively formed by predominantly sandy deposits with rare silt intercalations. They are administratively located in the northern part of Hârtop commune in the village with the same name

In view of the fact that the distance between them is about 1 km are relatively close and that they describe similar deposits in terms of lithology, texture and sedimentary structures, the sedimentological columns of the outcrops were sketched on the same figure (Fig 13).

Following the field mapping of the openings, 11 sedimentary facies were identified for which we presented in table 7 characteristics, depositional processes responsible for their formation and suggestive photographs. From a lithological point of view the deposits are predominantly sandy, with thin intercalations and isolated ash mudstones and less often silts or grezous levels.

The sedimentary facies identified are: (1) unstructured ash silts or obliquely laminated, (2) sands with symmetrical rolling rolling of waves, (3) sands with oblique rolling milling, (4) sands with hummocky convex layerification, (5) sands with swalley concave layering, (6) sands with tangential oblique stratification, (7) sands with oblique stratification festonate, (8) sands with oblique stratification at low angle, (9) sands with plane-parallel stratification, (10) massive sandstone, (11) sand with nested bioclasts.

Associations of facies

The sedimentary facies described above are grouped according to genetic criteria in 2 associations of facies described and interpreted below. Each sedimentary facies has been assigned a sedimentary process, therefore, the association of facies will be represented by a suite of sedimentary processes and will be assigned to a depositional subdomain.

Association of facies 3 – dominantly sandy (Af.3)

Description: This first association is lithologically made up of well-sorted, clean sands, which contain fragments of bioclasts and rare gray mudstone intercalations. The constituent sedimentary facies are sands with plane-parallel stratification and sands with tangential oblique stratification. They are sporadically joined by sands with low-angle oblique stratification, hummocky stratification, and swalley stratification or oblique lamination (fig 11). Tangential oblique stratification and large-scale concoid obliquely are the characteristic elements of this association. Stcs sets are found in thicknesses from a few centimeters to 40-50 cm, sometimes associated in mowers of metric thickness. Srcl appears in thin sets of just a few inches. Grain size, the deposits are made up of very fine and fine sands with a good sorting. Spp sets appear in thicknesses starting from 4-5 cm, up to 50-60 cm, having in some places remnants of shells arranged on the stratification surfaces.

Af 1 occurs twice in the sequence of deposits in the first outcrop (Hartop A) and forms the entire sedimentary succession in the Hârtop B column.

Figure 11. Association of facies 1- dominantly sandy

Interpretation: Stcs formation indicates the action of unidirectional tractive currents in superior flow mode (Harms, 1979) as well as the migration of 3D dunes under the action of unidirectional tractive currents capable of forming three-dimensional dunes with decimetric heights. Two- and three-dimensional dunes are common bottom forms in contemporary shorefaces (Plinth, 2010). Clifton (2006) blames the formation of these structures on the vigorous coastal currents that form in **the upper shoreface**. In shorefaces characterized by fine sands, sedimentary structures of this type are preserved in the conditions of the presence of underwater banks to protect them. Also, the presence of Shcs and Sscs formed by the accumulation of detritic material from the suspension, highlights storm episodes followed by calmer periods indicated by the occurrence of sands with oblique lamination (Dott and Bourgeois, 1982).

Association of facies 2 – sands with oblique lamination and plan-parallel stratification (Af. 2)

Description: This association groups mainly very fine sands with parallel plane stratication, Spp, and with oblique stratification Srcl, interspersed by mudstone layers with oblique or unstructured lamination (fig. 12). Sporadically, sands appear with oblique layering at a low angle, Slacs and with convex layering hummocky, Shcs. The thickness of the sets is variable, starting from 2-3 cm to a maximum of 20 cm in the case of nipples with parallel plane layerification.

Af. 2 occurs only once in the sedimentary sequence of the first outcropment (Hartop A) and measures 4 m. In the upper part of Af 2, it highlights a level of mudstone rich in fragments of plant tissue.

Interpretation: The two dominant facies in this association were formed under different conditions. Sands with parallel plane layering result from the action of unidirectional tractive currents in superior flow mode (Harms, 1979), while sands with RCL are the resulted of the same types of currents but are formed in inferior flow regime (Allen, 1982).

These predominant facies are interspersed by mudstone layers that have accumulated by settling out of the suspension in still waters (Collinson, 2006).

The Spp facies are specific to high-energy currents, which might indicate that this association is specific to the upper shoreface, but the Srcl facies, which has a weight almost as high as spp and clay drapery manholes on the lamination surfaces, points more towards a lower shoreface. Therefore, we can say that the association of facies 2 can be accumulated in the lower shoreface.

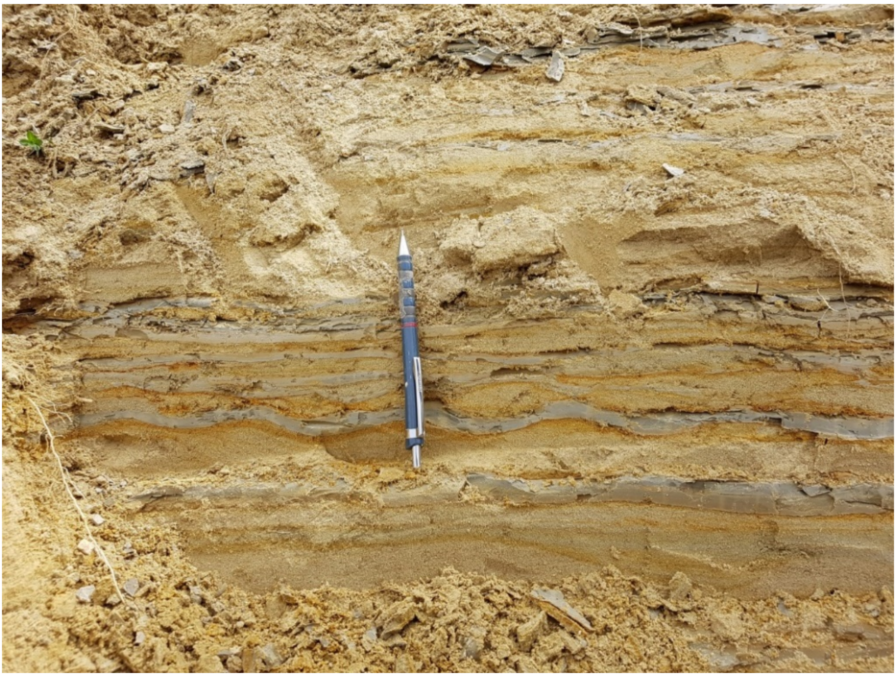


Figure 12. Association of faciesuri 2 – sands with Spp and Srcl

The 11 sedimentary facies were grouped according to genetic criteria into associations of facies corresponding to a depositional subdomain, namely:

Association of facies 3 – dominantly sandy specific to the deposition subfield of upper shoreface;

Association of faciesuri 2 – sands with oblique lamination, silts and plan-parallel stratification. describing the lower shorescreen deposition subfield.

The defined associations of facies follow each other in the continuity of vertical sedimentation. Such a vertical organization of facies associations can be reconstructed in space, based on the Law of Succession of Facies proposed by Walther (1894). Thus, the depositional domains that lie above each other in the sedimentary succession were at one time in the vicinity of each other during sedimentation. In parallel, in the column of the first outcrop is observed increase in granulometry from the bottom up. In the first half of the column there is a higher frequency of mudstones, which have accumulated in good weather conditions under the action of unidirectional currents (Walker and James, 1992) or by decanting from the suspension in quiet waters (Collinson, 2006) along with very fine sands. Towards the top of the column, the grain size of the sands increases slightly, the sitites being almost non-existent, which suggests that the action of the currents on the sedimentary bed was more pronounced.

From the point of view of the trend of the depositional domain, we can say on the basis of the vertical stacking of facies associations in the Hârtop A outcropment that the shoreline initially had a retrograde character described by a deepening uppward trend (lower shoreface deposits over those of superior shoreface). Subsequently, the behavior of the depositional domain became progradational, in the sedimentological column being observed a shallowing uppward trend (the upper shoreface deposits are stacked over the lower shoreface ones).

In the Hârtop B outcropment it is only possible to confirm the existence of the upper shoreface deposition subfield. All these deposits identified in the openings at Hârtop represent subsystems of the nondeltaic coastal deposition domain.

Microfaunistic associations

Given the predominantly sandy nature of the outcrops as well as the identification of sedimentary facies that describe the action of high-energy currents in the basin, we analyzed from the Hârtop A outcrop, 2 samples from mudstone intercalations (tab. 12).

The identified microfauna is quite rare and contains a low diversity of species. However we can attribute the upper Volhinian age of deposits, based on the association of foraminiferous with *Ammonia beccarii*, *Porosononion subgranosus* and *P. martkobi*

Regarding paleoecologic indicators, *loxocorniculum schmidi* occurrence may indicate to some brackish waters, which is also confirmed by the foraminiferous taxa *Porosononion* and *Ammonia* (Filipescu et al., 2019; Dumitriu et al., 2020).

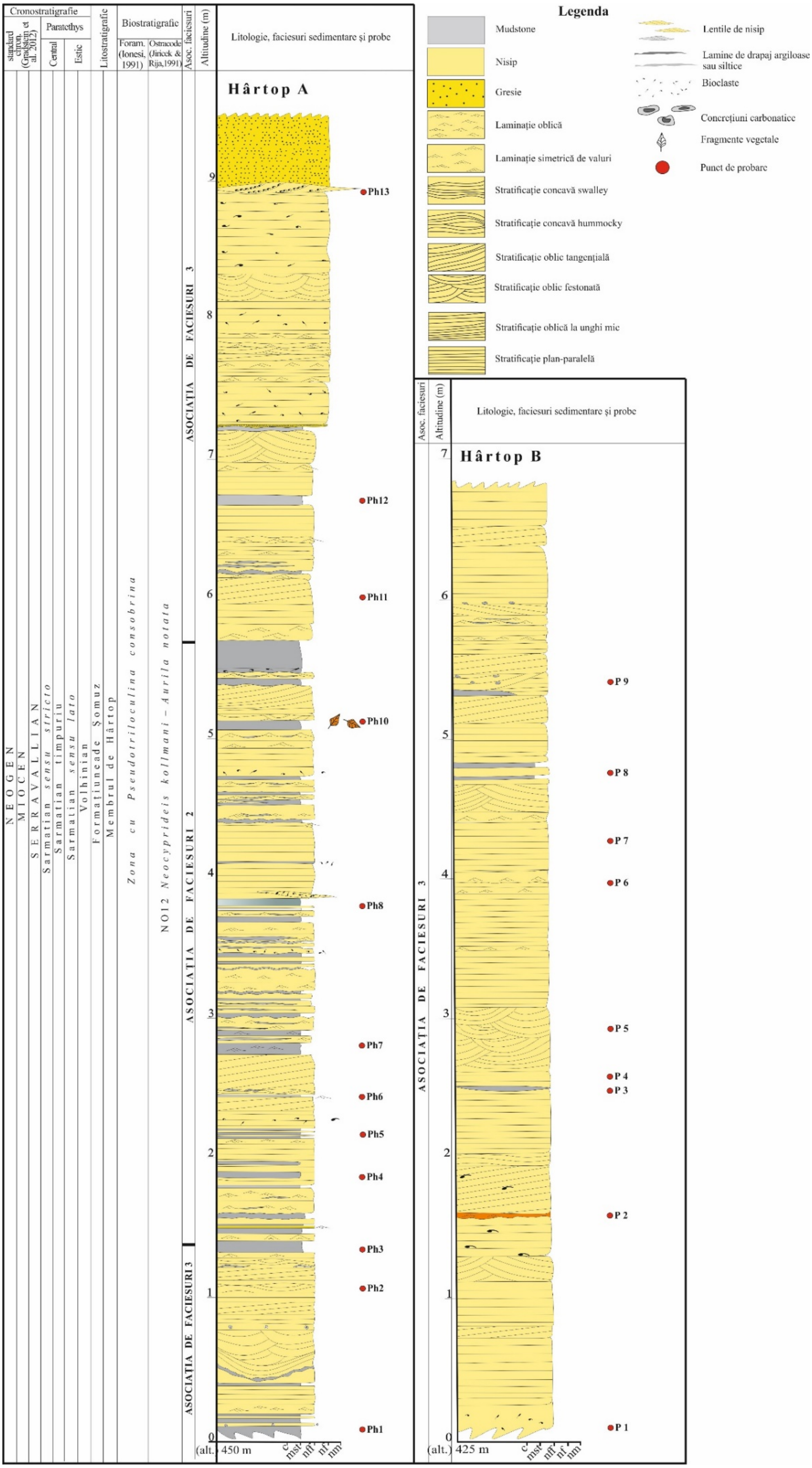


Figure 13. Sedimentological column of the outcrops from Hârtop.

Rădăşeni Hill – Outcrop La Ruptură

The outcrop from Rădășeni is located in the western part of the Rădășeni village, a location called by the locals "La Ruptură", GPS coordinates: N 47°28'22.85", E 26°14'17.68", WGS 84 coordinate system.

The sedimentary sequence from Rădășeni measures 11.5 m thick and is mostly made up of sands (fig. 14). On the basis of the outcrop, a higher share of fine sediments (siltites and sandy clays) interspersed with very fine sands is observed.

In total, 11 sedimentary facies have been identified: (1) gray mudstone , (2) sands with symmetrical rolling of waves, (3) sands with oblique lamination, (4) sands with hummocky convex layering, (5) sands with concave swalley layering, (6) sands with concoid oblique layering, (7) sands with low angle oblique stratification, (8) sands with parallel-plane stratification, (9) massive sands with bioclasts, (10) sands with bioclast lenses, (11) medium sands with gravel. They are joined by 2 other post-positional facies (12) clayey loadcast compaction structures and (13) carbonate concretions.

Facies associations

In the sedimentary succession from Rădășeni, the 11 identified sedimentary facies were separated according to geometry, sedimentary structures and lithology into 2 associations of facies, coherent with each other (fig. 44), each being specific to a depositional subdomain.

Facies Association 2 (Af 2)

Description: Af 2 develops on a thickness of about 3.5 m based on the stratigraphic sequence and on 1 m in its top. In case of occurrence on the basis of the outcrop, the deposits have at the bottom of Af 2 a layer of medium sands with gravels, clayey and bioclast clasts. Over it is arranged a layer of 5 cm of fine sands with oblique rolling and calcareous concretions. The sedimentary facies that sums up the largest thickness (2/3 of the thickness) is sand with a plane-parallel layer. Other 2 sedimentary facies well represented in Af 2 are very fine silts and sands with oblique rolling. They form a heterolithic alternation about 1 m thick. The hummocky and swalley stratification also appears in Af 2.

Interpretation: Sands with parallel plane stratification result from the action of unidirectional tractive currents in superior flow mode (Harms, 1979), while laminated sands are the result of tractive currents in lower flow regime. To these are added the mudstone intercalations that have accumulated by decanting from the suspension in still waters (Collinson, 2006).

Considering that the sands with parallel plane stratification represent event strata and that in Af 2 an important share is also held by the siltites and sands with oblique rolling, we can say that the deposits from the base of the sedimentary succession from Rădășeni have accumulated in the **lower shoreface** area, being often affected by energetic episodes, most likely storms that led to the accumulation of event-type layers such as the parallel plane stratification and hummocky stratifications and the hummocky stratifications and swalley.

Association of facies 3 (Af 3)

Description: Af 3 is almost entirely sandy, showing only a few centimeter intercalations of silts or clayey clasts in its contents. The predominantly sedimentary facies are sands with parallel plane stratification and sands with tangential oblique stratification. Also towards the top are flattened clay claws or with irregular structures.

Interpretation: The formation of tangential oblique stratification and parallel plane stratification indicates the action of unidirectional tractive currents in superior flow mode (Harms, 1979) as well as the migration of 3D dunes under the action of unidirectional tractive currents capable of forming three-dimensional dunes with decimetric heights. Two- and three-dimensional dunes are common bottom forms in contemporary shoreface areas (Plinth, 2010).

Taking into account the exclusive presence of sedimentary facies that describe high energy and shallow depths in the basin, we can say that the Af 3 identified in the outcrop from Rădășeni has accumulated in the upper shoreface area of a nondeltaic coastal system.

From the vertical succession of the associations of facies we can follow a progradational character of the shoreline (lower shoreface under upper shoreface deposits) followed by the beginning of a transgression suggested by the occurrence of Af 2 in the top of the column.

Microfaunistic associations

Also in Rădășeni, the fine sediment intercalations are quite poorly represented in the stratigraphic sequence, which led to the analysis of 2 samples from a micropaleontological point of view (tab. 14).

Regarding the peleoecological conditions indicated by the identified taxa, the genera *Porosononion* and *Ammonia* indicate brackish waters with shallow depths and significant nutrient intake (Avnaim-Katav et al., 2013; Filipescu et al., 2014; Dumitriu, et al., 2020). The association of these genera of foraminiferous with the *taxon Cyprideis pannonica* reinforces the above statement. The presence in the microfaunistic association of *the Ilyocypris brady* ostracode species specific to freshwater media (van Morkhoven, 1963), together with seeds and other plant residues, can only indicate the proximity of the shoreface depositional domain described in Rădășeni with lagoons populated by these ostracodes.

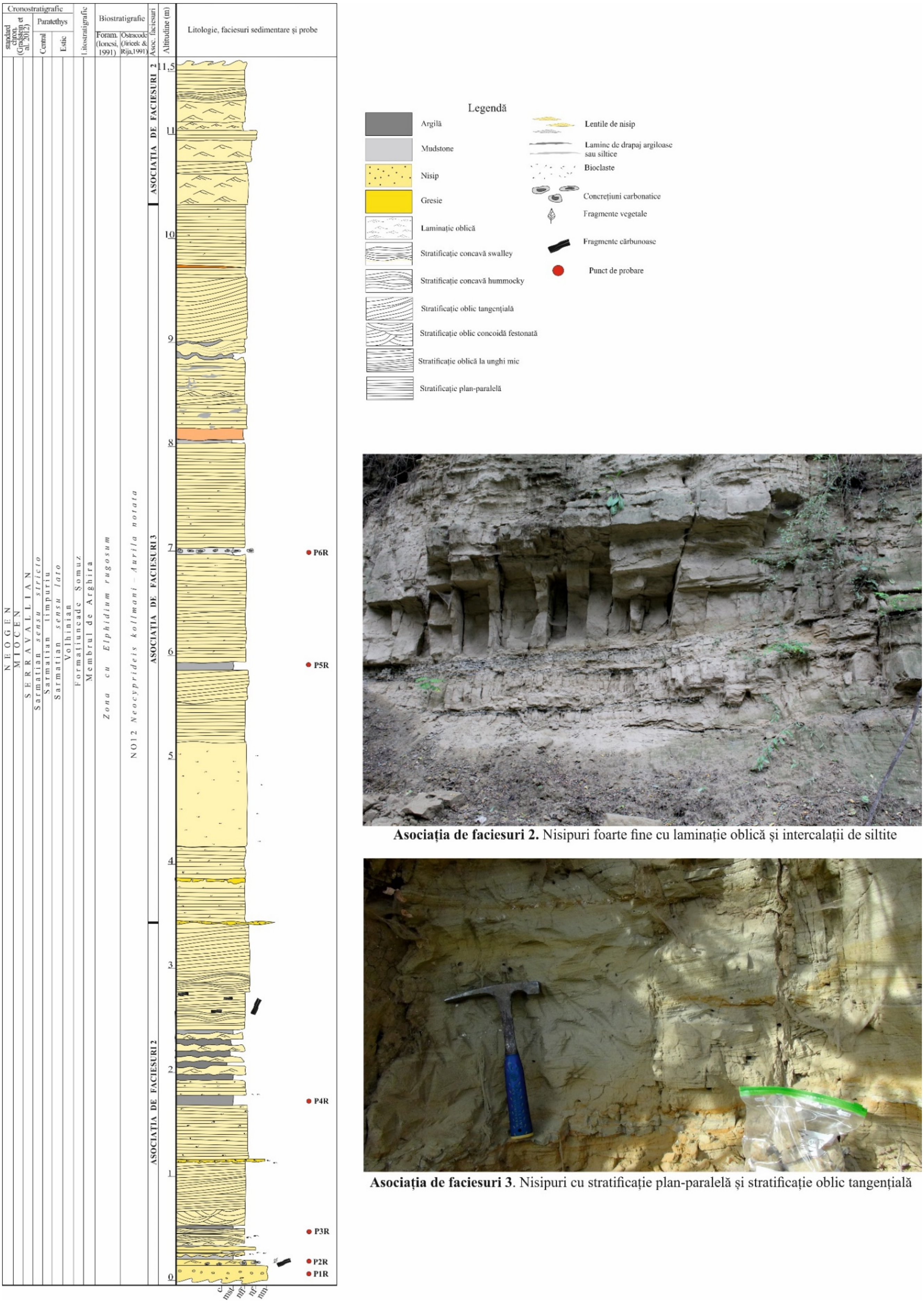


Figure 14. The sedimentological column of the outcrop from Rădăşeni.

Seaca brook

The outcrops studied on the Seaca stream are composite, the Sarmatian deposits being opened on quite small portions of its bed and of a tributary, Săcuţa. Thus, from the Seaca stream we mapped 5 points (fig. 15) from which we took 14 samples from clay and sandy deposits, as well as from a layer of coal.

Figure 15. Location of the samples on the Seaca and Săcuţa streams

From the first opening (47°20'25.29"N, 26°18'42.38"E) we took sample 1 sandy, with no visible traces of fossils. At 50 meters upstream, there is a layer of clay sand from which we took samples 2 and 3 and after 30 meters from the thalweg of seaca creek we took sample number 4 formed by mudstone. Advancing into the stream bed, after about 150 meters, we identified the next opening from which we took samples 5, 6 and 7. Made up of gray clay with coal intercalations.

The last and most important outcrop on the Seaca stream is about 50 meters upstream of samples 5, 6 and 7. It consists of sandy gray clay in the base, followed by intercalationsof pietrish and clay sand, on top of whichthe rora is worth a layer of coal with a thickness of about 30 centimeters (samples 8, 9, 10; Figure 16).

Samples 11, 12, 13, 14 are predominantly sandy and were collected from an open outcrop by the sacuța stream bed and have no fossil fauna.

Figure 16. Opening the outcrop with coal layers on the Seaca stream.

Following the micropaleontological analysis of the 14 samples collected from the field, 8 of them showed fossil content. A total of 27 microfossil taxa were identified in the analysed samples, including 10 foraminiferous taxa, 10 ostracodes and 7 molluscs.

Among the foraminifera, the best represented are *Porosononion martkobi*, *P. subgranosus* and *P. subgranosus umboelata*, followed by *Ammonia beccarii* and *Quinqueloculina minakovae ukrainica* (tab. ...).

Ostracode fauana is best represented by *the species Cyprideis pannonica*, *C. mataschensis* and *Loxoconcha minima*.

Of the mollusks, the most common taxa belong to *the species Hydrobia uniratamense*, *Valvata soceni* and *V. moesiensis*.

From a biostratigraphic point of view, the deposits on the Seaca stream can be attributed to the upper part of the Volhinian, the most abundant taxa being *Porosononion subgranosus*, *Ammonia beccarii* and *Elphidium macellum*, typical foraminiferous for the Area with *Ammonia beccarii* and *Quinqueloculina consobrina* (Ionesi, 1991; Ionesi, 2006).

Regarding the paleoecology of sediments, the association of foraminifera in samples 1-7 indicates waters with low salinities and low depths of the sedimentary medium, as well as a significant intake of organic matter. The same is confirmed by the fauna of ostracode

Regarding the occurrence of the massive coal layer, it was also quoted by Ionesi and Țibuleac (1996), the authors recording on the Seaca stream alternations of marine environments and lakes with specific fauna.

Comparing the microfaunistic association identified by us with the one mentioned by Ionesi and Țibuleac (1996) we consider that until sample 7 (which contains specimens belonging exclusively to the *porosononion* genus) the analyzed deposits belong to the penultimate marine-brackish interval over which they prograded retroplaj deposits , probably coastal plains in which peatlands have been installed in which the 30 cm coal layer identified by us has accumulated.

Bogata brook

During the field mapping we identified several openings on the Bogata stream (fig. 17) from which we could take 14 micropaleontological samples from 9 sampling points.

Figure 17. Sampling points on Bogata stream

Point A (Samples 1, 2 and 3 of WGS coordinates 84: N47º 24' 19.00" E26º 10' 17") consists of the gray clays in the base (sample 1) which are opened for a thickness of about 1.5 m. At 10 m upstream are opened on about 0,5 m gray siltites from which the sample was taken2. They are covered by about 1 m of very fine sands over which follows about 1 m of brown silts from which sample 3 was taken.

Point B (Sample 4 of WGS coordinates 84: N47º 24' 19.00" E26º 10' 17") consists mainly of coarse sands open in the stream bed on a thickness of about 1 m in which we identified terrestrial gastropods (*Helix* – Figure 18).

Figure 18 a, b. Mudstone with *Helix* – sample 4

Point C, probe 5 (coordinates: N 47º 24' 13.00", E 26º 08' 19") has on the basis conglomerates on a thickness of about 0.5 m over which about 2 m of gray clay with bioclast residues are spread.

Point D (Sample 6, N 47º 24' 02" E 26º 08'03") consists of about 1.5 m of eggplant clays in the base followed by very fine sands with organic matter.

Point E -Samples 7 and 8 (N 47º 24' 036" E 26º 07'53.5") opens 1m of the greenish gray clays.

Point F is about 50 m upstream of point E and opens about 2 m of the outcrop and is based on gravel and sands (0.35 m) over which follows a layer of coarse clay sands at mediums of greenish color (0.6 m) above which follows 0.3 m of very fine clay sands of reddish color, 0.2 m of very fine sands with parallel plane layering, 0.2 m of very fine reddish sands, and in the top 0.3 m of very fine sand with oblique rolling (fig. 19). From this point they were taken (probes 9, 10 and 11).

Point G, probe 12 de (N 47º 23' 58,77", E 26º 07'45,48") consists of an opening of 2 m of clay sands in which we have identified several specimens of macrofauna (*Helix)*. In the upper part of the outcrop, 20 cm of yellowish sands are observed.

Point H, probe 13 (coordinates WSG 84: N47º 23' 52,06" E26º 07' 28,89") consists of an opening of 50 cm of yellowish gray sand clay from which we have taken a sample.

Point I, probe 14 (N 47º 23' 39,13", E 26º 07'14,02") comprises a succession of 2 m of very fine sands and ash clays.

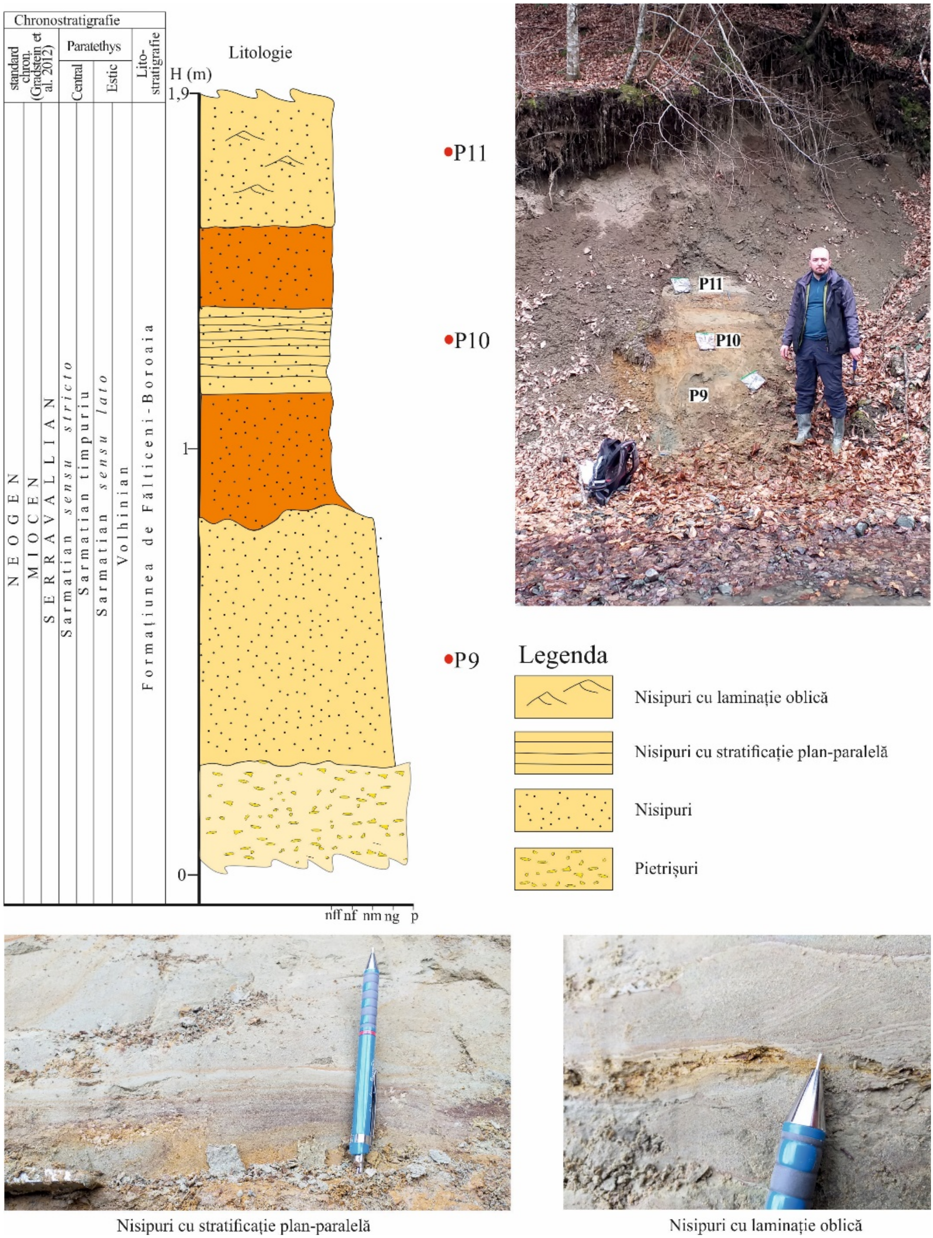


Figure 19. Point F of probation on Bogata creek.

At about 200 m upstream of point I, we identified an opening with well sorted medium gravel, with coarse sand lenses with oblique lamination. These deposits we have assigned to the Asoc.of facies 5.

Association of facies 5 – Gravel and sands with oblique stratification

Af. 5 presents sets of 30 to 100 cm of medium sorted gravel nested with intercalations of coarse sands with planar oblique layering (fig. 20).

Interpretation

Nested gravels with obliquely planar stratification indicate high-energy events in the minor riverbed of a small river (Miall, 1985, 1992, 2014) that led to the progradation of the isles. Sands with oblique planar stratification are witnesses of calmer events during which the migration of the transverse dunes on the flow bed took place and the material intake was continuous, which allowed their degradation.

This association of facies has been interpreted as having been accumulated in the river depositional domain.

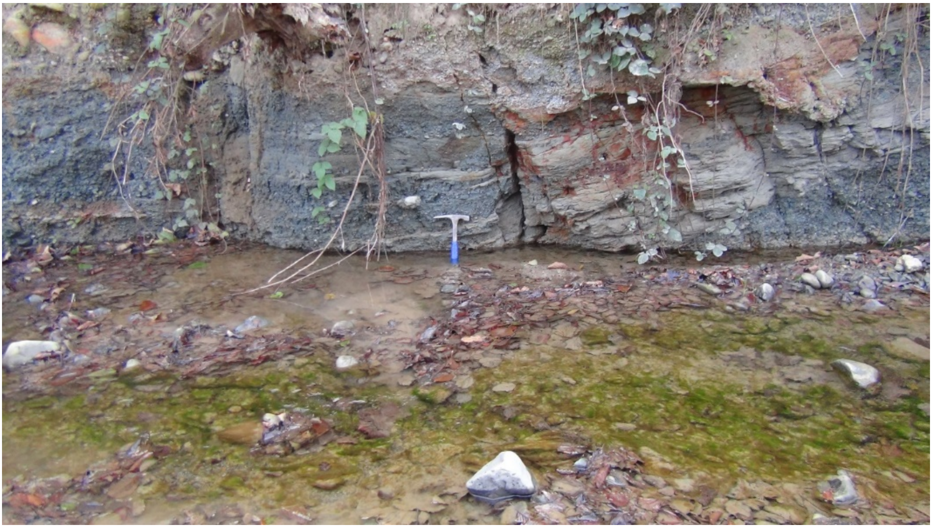


Figure 20. Association of facies 5 – Gravels and sands with oblique planar stratification.

Microfaunistic associations

First of all, there are some taxa of benthic foraminiferous that can be considered markers for the Volhinian: *Pseudotriloculina consobrina* and *Quinqueloculina* cf. *reussi virgata,* according to the biozonation made by Ionesi (1991). However, there are also some taxa of benthic foraminiferous that can be considered markers for older deposits (bugloviene): *Cibicides lobatulus* and *Quinqueloculina fluviata.*

As can be seen from the determined micropaleontological association there is a mixture of planktonic and benthic foraminiferous that raises some problems regarding the biostratigraphic interpretation of the deposits on the Bogata stream

Following the altitudinal distribution of the taxa in the studied outcrops, it is noticed that there is no stratigraphic order in which such a distribution is likely to occur, and then we can think about the possibility of reshuffles of taxa from older deposits. This is also reinforced by the presence in a large number of planktonic foraminifera that some researchers (Ionesi, 1968, Ionesi, 2006) consider reshuffled from Badenian deposits. It should be noted, however, that lately, some opinions have also emerged on the in-situ storage of planktonic foraminifera as a result of a higher salinity water intake from basins adjacent to Parathethys (Harzausher and Piller, 2007; Dumitriu et al., 2017).

However, in the present case, the first variant is more acceptable because there are also some elements that on the contrary show an even sharper decrease in salinity because we have some ostracode taxa (*Fabaeformiscandona pokorniy*) that indicate almost fresh waters as well as terrestrial gastropods (*Helix* sp.) that indicate the proximity to a hydrographic network and the installation of a coastal plain in the edge of the basin. In the conclusions, we consider that on the basis of the micropaleontological association determined by us, the analyzed deposits belong to the Volhinian, most likely to the Upper Volhinian if we consider the principle that in the case of a mixture in which traceable fossils appear, the age is given by the newest taxa (*Pseudotriloculina consobrina*).

Sipote Drilling

From the Şipote drilling, 23 core samples were analyzed in order to establish the micropaleontological content and the reconstitution of the paleoambiance in the Paratethys basin (fig. 21). in total, 57 foraminifera taxa and 19 ostracodes were determined (tab. 17). Although the probation interval is an extended one, in this study we have focused our attention only on the boundary between Badenian and Sarmatian and the paleoambiental changes that occurred during this interval.

It is unanimously accepted that Badenian represents the last stratigraphic interval in Paratethys in which normal marine conditions developed

In contrast, the Sarmatian is mainly characterized by the installation of endemic fauna in the Basins of Paratethys, the deposits in the foreland of the Eastern Carpathians being specific to some brackish salinities (Ionesi, 2006, Dumitriu et al., 2020).

The transition interval between Badenian and Sarmatian was interpreted as a catastrophic episode in Paratethys (BSEE – Badenian – Sarmatian Extinction Event) which led to the extinction of over 90% of Badenian foraminiferous species (Harzhauser and Piller, 2007) and most ostracode taxa (Toth et al., 2010).

Analyzing the association of benthic foraminifera in the upper Badenian deposits in the Sipote drilling, we noticed a significant number of buliminids, bolivineids, uvigerinides, milliliides like *Sigmoilinite* to which *cibicides*, *Heterolepa* and others are added.

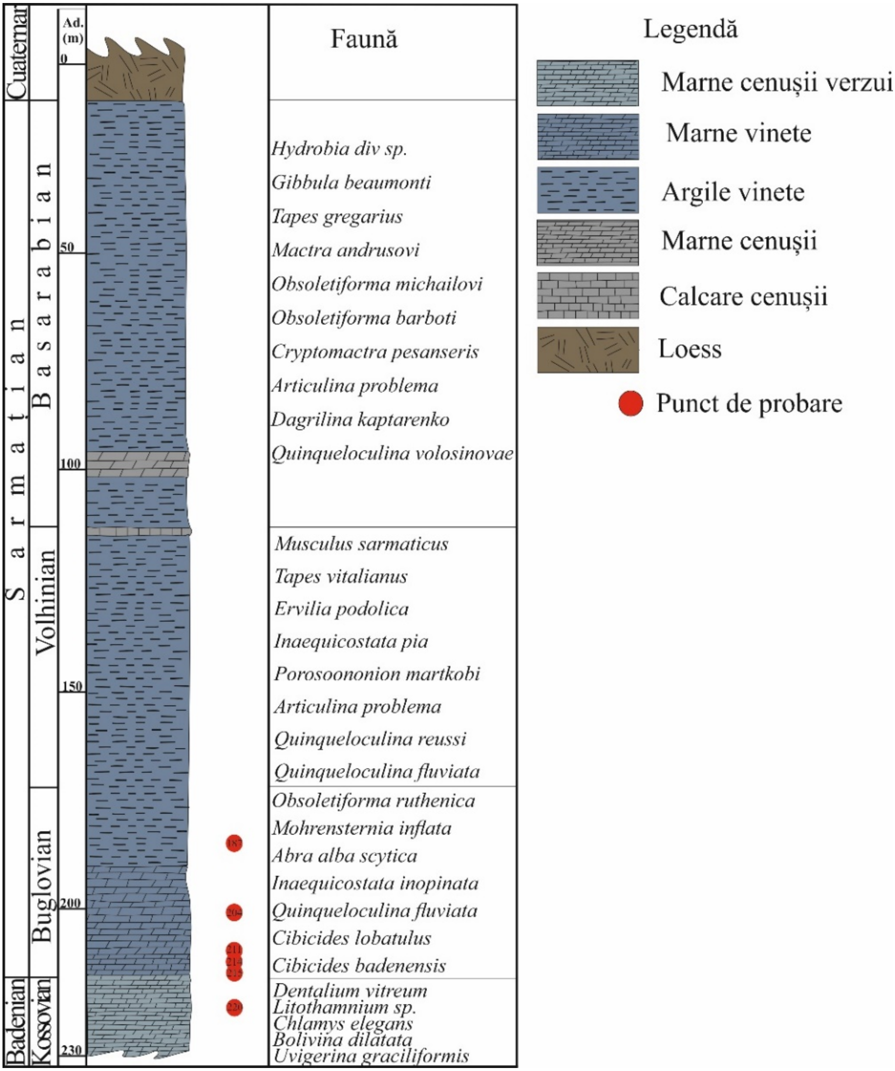


Figure 21. Lithostratigraphic column of the Şipote drilling (after Brânzilă, 1999)

The large number of infaunaous taxa of relatively deep water, e.g. buliminides, bolivinides and uvigerinides, indicates a significant intake of nutrients, sediments rich in organic matter and sedimentary substrate with oxideficiency in the genus (Murray, 1991; Sen Gupta and Marchain-Castillo, 1993; Jorissen et al., 1995; Kováčová et al., 2009; Dubicka et al., 2014; Drinia et al., 2016; Pezelj et al., 2016) and normal salinity of waters (Van der Zwaan, 1982; Peryt, 2013; Peryt et al., 2014).

The abundant presence of epiphaunaal taxa with biconvex and planconvex assay (*Cibicides, Heterolepa*) as well as myliolides such as *Sigmoilinite* indicates moderate to high oxygenation at the water/sediment interface (Van der Zwaan, 1982; Peryt, 2013; Peryt et al., 2014) Complementary, the genera *Bulimina* and *Bolivina* indicate greater water depths (Murray, 1991; Dumitriu et al., 2020)

The ostracode fauna identified in badenian samples is composed of species such as *Henryhowella asperrima*, *Krythe* sp. Taxa which indicate normal salinity and relatively large depths (van Morkhoven 1963; Zorn, 2003; ter Borgh et al., 2014).

Above in the sedimentary succession of the Sipote drilling (starting with 215 m deep) major changes are observed in the associations of foraminifera. The dominant species in the samples are *Elphidium reginum*, *E. aculeatum* and *E fichtelianum* taxa which indicate low depths (0-50 m) and a high degree of oxygenation of water (Murray, 2006; Gedl et al., 2016). The ostracode association is composed of *Cytheridea* *hungarica*, *C. acuminata*, *Loxoconcha rhomboidea*, taxa who are found in neritic infralitoral environments (Breman, 1975).

Given the characteristics of the associations of foraminifera and ostracode identified in the Sipote drilling, we can mark the Badenian/Sarmatian boundary between the depth of 215 m and 217 m. Following observations on the morphogroups of foraminifera, it can be inferred that in the backbulge depot of the existing foreland basin in late Baden the depth of the water was greater than at the beginning of the early Sarmatian.

Bivolari Drilling

From drilling Bivolari were analyzed 2 samples from the limit zone Badenian / Sarmatian respectively 138 m – Lower Sarmatian; 145 m – Upper Badenian (Brânzilă, 1999). The sample from 145 m has a poor fossil content represented by 3 species of foraminifera: *Bulimina elongata*, *Ortomorphina dina* and *Fissurina isa*, as well as one species of ostracod (*Xestoleberis dispar)*. This sample was also analysed for the determination of the nannoplankton content and proved to be sterile. The sample at 138 m shows several specimens of *Elphidium fichtelianum* and *Cycloforina fluviata*. Although the micropaleontological content in these samples is low, the species identified show the same characteristics of the upper Badenian and Sarmatian lower deposits as those presented in the Shipote boreholes. Thus, the genus *Bulimina* indicates higher depths of the pelvis, with oxygen deficiency in the sedimentary substrate and normal salinity (Murray, 2006; Toth et al., 2010; Peryt, 2013). The occurrence in the Sarmatian deposits of the species of *Elphidium* and *Cycloforina* supports the existence of fewer depths in the lower Sarmatian.

Conclusions

Of the 10 sedimentary successions studied for the thesis, 6 were analyzed from the sedimentological point of view. In all 6 studied outcrops, 12 sedimentary facies were identified. Sedimentary facies were grouped according to genetic and geometric criteria into 5 associations of facies corresponding to one depositional subdomain. Following the vertical succession of the associations of facies we determined the behavior of the depositional domain and the fluctuations of the sea level at the level of the Volhinian in the Fălticeni area.

On the Muscalu stream, a progradational behavior of the deposits is observed, from the base to the top of the outcrop, the deposits presenting a ShU trend: offshore-transition → lower shoreface → superior shoreface;

On Gheorghe's brook, the sedimentary succession has the same behavior as on the Muscalu brook, the deposits in this opening being only of shoreface: the lower shoreface → the median shoreface → the upper shoreface;

The outcrop on Logofătu creek registers a ShU trend: upper shoreface → backshore. Over the backshore deposits, following a rise in sea level, Af. 5 – offshore-transition has been accumulated.

In the opening on the Ciofoaia brook we were able to determine two trends of the warehouses, starting from the base a ShU trend (offshore-transition → lower shoreface → superior shoreface → backshore) and towards the top a DU trend (backshore → superior shoreface).

The Hârtop A outcrop describes on the basis a DU trend – the lower shoreface superior shoreface (the deposits in the Hârtop B column being interpreted as located in the base of those from Hârtop A), followed by a tred ShU (lower shoreface → upper shoreface).

From the succession of facies associations on the outcrops of the basins of the Somuzul Mare valleys, a porgradational trend of the shoreline is observed, with the migration to the sea of the shoreface deposits up to installation of some backshore conditions in which the coal layers described on the Ciofoaia stream and Af. 4 on the Logofătu stream have been accumulated. This progradational trend is specific to the periods of HST, which is also supported by Popov et al. (2010) for the Volhynian age in the Paratethys basin.

In the outcrops opened by the Săcuța and Bogata streams, the sedimentation is much more dynamic, the fluvial and backshore facies alternating with the marine ones.

As for the occurrence of the massive coal layer, it is positioned transgressively over the penultimate marine-brackish interval over which backshore deposits have prograded, probably coastal plains in which peatlands have been installed in which the 30 cm coal layer identified by us has accumulated.

On Bogata brook we identified a mixed fauna with foraminiferous typical of Badenian and Sarmatian. Following the analysis we consider that based on the micropaleontological association determined by us, the analyzed deposits belong to the Volhinian, most likely to the upper Volhinian if we take into account the principle according to which in the case of a mixture in which marking fossils appear, the age is given by the newest taxa (*Pseudotriloculina consobrina*).

Also on Bogata brook we identified the Facies Association 5 (gravel and sands with oblique planar stratification) which was interpreted in terms of fluvial deposits that degraded over the coastal plains at the level of the upper Volhynian.

From the Sipote drilling, 23 carrion samples were analyzed in order to establish on the basis of the micropaleontological content the paleoambience changes in the Paratethys basin at the border between Badenian and Sarmatian.

For the Badenian range in the large number of relatively deep water infaunal taxa, e.g. buliminides, bolivinides and uvigerinides indicate a significant intake of nutrients, sediments rich in organic matter and sedimentary substrate with oxigenus deficiency and normal salinity. In addition, the ostracode fauna identified in Badenian samples is composed of species that indicate normal salinity and relatively larger depths of the bazin.

In the lower Sarmatian deposits in the Sipote borehole (starting from 215 m deep) major changes are observed in the associations of foraminiferous. The dominant species in the samples are *Elphidium reginum*, *E. aculeatum* and *E fichtelianum* taxa which indicate low depths (0-50 m) and a high degree of oxygenation of water. Also, the ostracode assemblages is composed of *Cytheridea hungarica*, *C. acuminata*, *Loxoconcha rhomboidea*, taxa who are found in infralitoral environments.

Although the micropaleontological content in Bivolari borehole is scarce, the identified species show the same characteristics of the upper Badenian and Sarmatian lower deposits as those presented in the Sipote drilling. Thus, the genus *Bulimina* identified in the Badenian deposits indicates higher depths of the pelvis, with oxygen deficiency in the sedimentary substrate and normal salinity while the occurrence in the Sarmatian deposits of the species of *Elphidium* and *Cycloforin* supports the existence of fewer depths in the lower Sarmatian.

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Annex A. Plates:

Plate 1 – The microfaunistic association in the Sipote 201 drilling
Fig. 1,2,3 – *Cytheridea hungarica*; 1-VS lateral view, 2 - VD side view, 3 - VS internal view; P 211.5
Fig. 4, 5 – *Xestoleberis fuscata*; 4- VS lateral view; P 215,5-view dorsal both valves; P211.5
Fig. 6 – *Hemicytheria omphalodes* VD lateral view; P211.5
Fig. 7 – *Aurila* cf. *cicatricosa*; VS side view; P211.5
Fig. 8 – *Aurila mehesi*; VD side view; P215
Fig. 9 – *Loxocorniculum schmidi*; VD side view; P209
Fig. 10 – *Hemicytheria omphalodes*; VS side view; P211
Fig. 11 – *Cnestocythere lamellicosta*; VD side view; P 215
Fig. 12 – *Costa* sp. VD side view; P215
Fig. 13 – *Polycope orbicularis*; VS side view; P 211

Plate 2 – The microfaunistic association in the Sipote 201 drilling
Fig. 1,2,3 – *Cibicides lobatulus*; 1– lateral view, 2– umbilical vision, 3– apertural vision; P215
Fig. 4 – *Elphidium reginum*; side view, P215
Fig. 5, 6 – *Elphidium aculeatum*; 5 – P215, 6 – P211.5
Fig. 7 – *Elphidium obtusum*; P 211.5
Fig. 8 – *Elphidium macellum* var. *tumidocamerale*; P 211.5
Fig. 9 - *Quinqueloculina* sp. P 215

Plate 3 - The microfaunistic association in the sipote 201 drilling
Fig. 1 – *Moldovan bolivina*; P 215
Fig. 2 – *Bolivina* sp. P 215
Fig. 3 – *Bolivina* cf. *Sarmatica*; P 211.5
Fig. 4 – *Nodosaria rudis*; P 214
Fig. 5 – *Nodosaria gutifera*; P 214
Fig. 6 – *Bulimina* sp.
Fig. 7, 8 – *Nonion serenus*; P 187
Fig. 9 – *Predcarpathian cycloforin*; P 187
Fig. 10, 11 – *Lagena striata*; P 203
Fig. 12 – Fish coast; P 205
Fig. 13 - 17 – fish teeth; P 204.

Plate 1

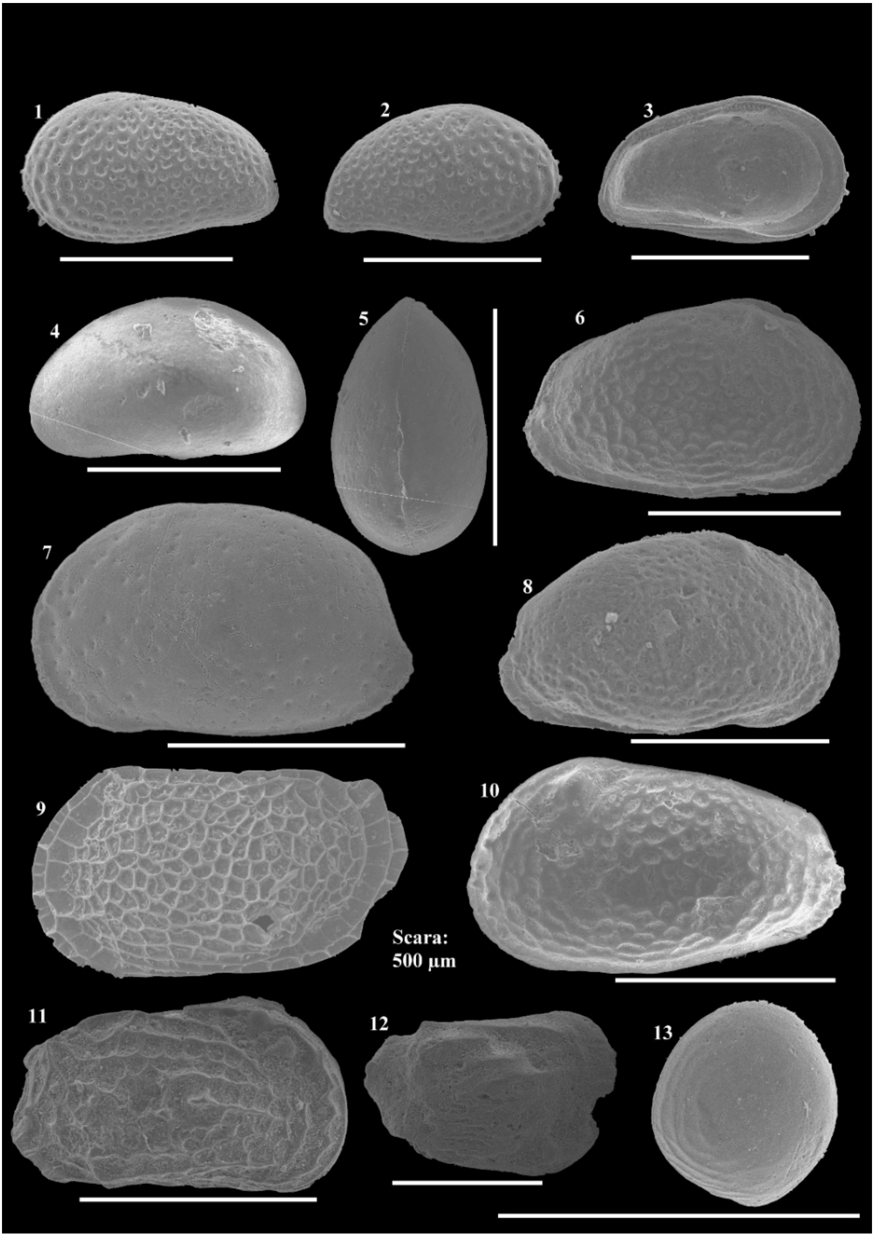

Plate 2

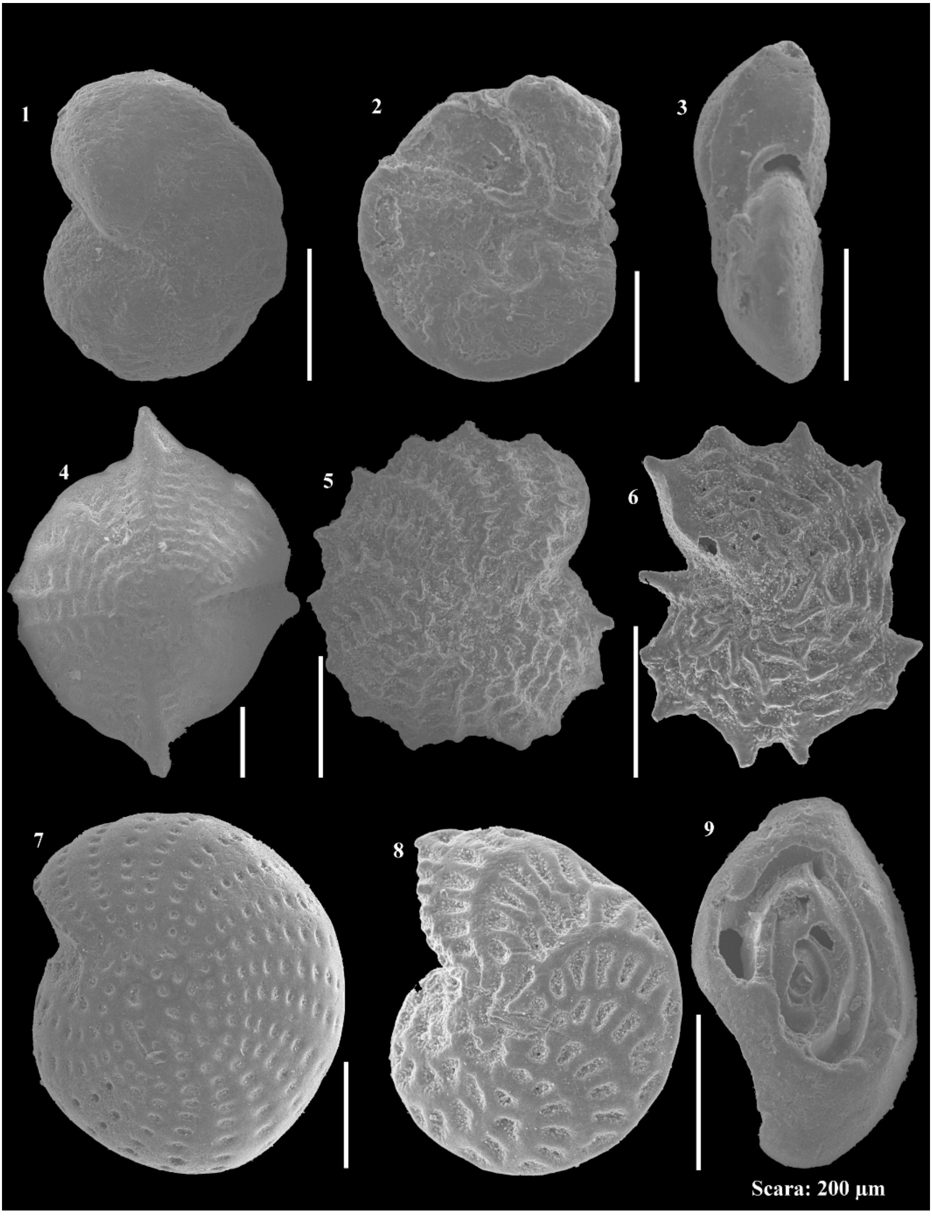

Plate 3