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THE DEPOSITIONAL ENVIRONMENT OF UPPER ȘOMUZ FORMATION REVEALED BY HÂRTOP OUTCROPS

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Abstract: Two sedimentary successions from Hârtop (Hârtop A, B), Șomuz drainage basin, revealing middle Miocene (lower Sarmatian *sensu lato*) of Moldavian Platform deposits were analysed in order to reconstruct the depositional paleoenvironment and the local shoreline behaviour of the Central Paratethys Basin. The studied sections are mainly sandy with few silty and argillaceous interlays. The sedimentary facies analysis led to the separation of 10 sedimentary facies grouped in two Facies Associations (FA), each one describing a typical sedimentary sub-environment. The two identified Facies Associations described the upper shoreface (FA 1) and the lower shoreface (FA 2) typical for a shallow non-deltaic marginal marine depositional environment. The stacking of these facies association suggests a progradational trend of the depositional systems. The micropaleontological assemblages revealed a scarce fauna of shallow water foraminifera and ostracods specific for the neritic area, confirming the basin depth indicated by the sedimentology of the deposits.

Keywords: foreland basin system, sedimentary facies, facies association, paleoenvironment.

1. INTRODUCTION

The Sarmatian (middle Miocene) deposits from Moldavian Platform were the subject of many geological studies mainly focused in the palaeontological content of the sediments and the stratigraphical context of the area starting with Cobălcescu (1883), Simionescu, (1903), Macarovici, (1955), Ionesi B. (1968), Ionesi L. (1994), Ionesi V. (2006).

Lately, a rather great importance is given to the sedimentary basins palaeogeographical and palaeoecological evolution and to the sedimentary processes that have occurred, such studies at a large scale being proposed by Grasu et al. (2002), Miclăuș et al. (2011), Loghin (2020, 2022).

The Hârtop A section is represented by a 9.5 m thick outcrop showing predominantly sandy deposits and some siltic and argillaceous intercalations. The top of the section is marked by the presence of calcareous sandstone bed with bioclasts.

Hârtop B sections crop out a 6.8 m of well sorted sandy deposits. Both sedimentary successions are administratively located in the northern part of Hârtop commune in the village with the same name (GPS coordinates Hârtop A: N 47°30'12.06", E 26°20'48.02"; Hârtop B: N 47°30'34.23", E 26°20'30.78").

The aim of the present study is to reveal the dynamics of the sedimentary environments that led to the accumulation of two sedimentary successions outcropping in Fălticeni Plateau, Hârtop locality.

2. GEOLOGICAL SETTING

The studied outcrops are situated in the north-western part of Moldavian Platform and belong to the third sedimentation mega-cycle of this structural unit – upper Badenian – Maeotian (Ionesi L., 1994).

These deposits were accumulated in the tectonic context of a foreland basin system developed in the front of Eastern Carpathian orogenic belt (Figure 1A) during the Styric and Moldavian Orogenesis. The formation of a peripheral foreland basin was a consequence of the overthrust of the Carpathian nappes on the western part of the east-European Platform (Grasu et al., 1999, 2002).

A typical foreland basin system is characterized by the definition of four depozones (Figure 1B) which develop different sedimentation patterns being influenced by the tectonic factors and the variation of the eustatic sea-level. The four depozones are wedge-top, foredeep, forebulge, backbulge (DeCelles & Giles, 1996).

The wedge-top depozone – includes the sedimentary formations accumulated on the advancing orogenic prism, having a width of several tens of kilometres. It is characterized by alluvial or fluvial deposits in the subaerial domain or by shoreface deposits mixed with debris in the marine domain (Grasu et al., 2002; Miclăuș et al., 2011).

The **foredeep depozone** – is accumulated over distances up to tens or hundreds of kilometres wide, consisting of both subaerial (alluvial, fluvial) and aquatic (lacustrine, deltaic, marine) deposits. The source of the sediments is mainly the orogenic belt, but also the craton. The sedimentary succession can start with deposits accumulated at great depths ("flysch"), passing through deposits accumulated at shallow depths ("molasses") and ending with continental sediments. The deposits of the proximal foredeep are laterally passing into the wedge top deposits.

The **forebulge** – represents the area of potential vaulting arranged along the cratonic boundary of the foredeep. Clevis et al. (2004) describes the forebulge zone as being, from a morphological point of view, a dome associated with bending processes that moves both towards the orogenic chain and vertically upwards during active thrusting, then moving towards craton and vertically downwards due to isostatic readjustment after the cessation of the sparing process.

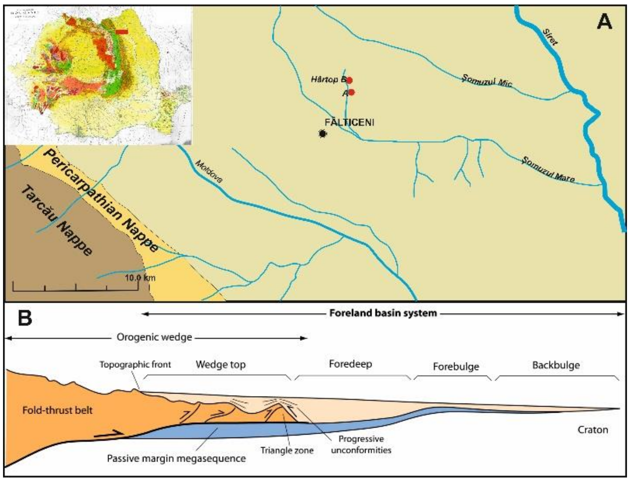

Figure 1. A – The geological setting of the Fălticeni Plateau including the studied sections (modified after Macarovici, 1955); B – schematic cross section of a foreland basin system (modified after DeCeles & Giles, 1996).

The **backbulge** depozone – is located behind the flexural vault (forebulge), where the subsidence rate has much lower values. The basins of this depozone are characterized by shallow depths.

Applying the sedimentary features described by DeCelles & Giles (1996) for the foreland basin system on the lithological particularities identified in the sedimentary successions of this study, the Hârtop sections can be placed as being accumulated in the foredeep depozone of the Eastern Carpathians Foreland Basin System *sensu* Grasu et al., (1999, 2002). The outcrops are characterized by sandy deposits with a few siltic intercalations (Table 1, Figure 5) which indicate a shallow depth of the basin.

Lithostratigraphic, the Hârtop sedimentary successions belong to the Șomuz Formation, Hârtop Member (*sensu* Ionesi V., 2006), being situated between the Hârtop I and Hârtop II calcareous horizons defined by Ionesi B. (1968). The age of the deposits is known as upper Volhynian (Figure 2), the limit Volhynian – Bessarabian being postulated above these two, in the upper part of Hârtop member namely Hârtop III – Nigotești horizon (Ionesi V., 2006).

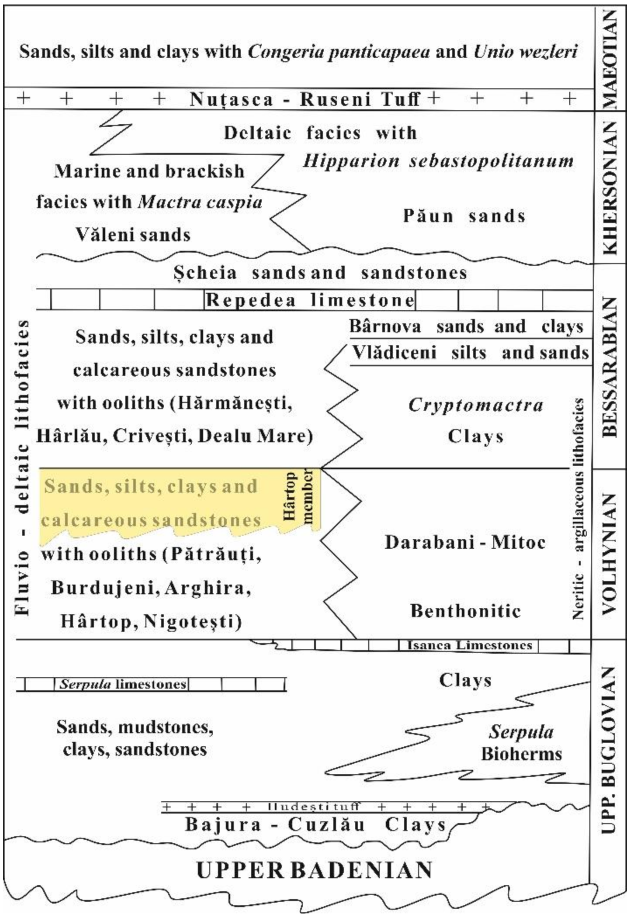

Figure 2. The stratigraphic litho-facies scheme of the Moldavian Platform (modified after Ionesi L., 1994) and the situation of the Hârtop Member within the middle Miocene sedimentary succession.

The foreland basin system of the Eastern Carpathians was accumulated in the epicontinental Paratethys Sea (Artyushkov et al., 1996; Kovac et al., 2007; Dumitriu et al., 2020) which was developed in the Old Styrian (intra-Burdigalian), New Styrian (intra-Badenian) and Moldavian (intra-Sarmatian) tectogeneses (Săndulescu, 1984; Miclăuș et al., 2011).

The lithology of the analysed sedimentary sequences is predominantly sandy with some intercalations of siltstones and grey clays (Figures 3-5). The sand is very fine to medium granular and mainly well sorted.

3. MATERIALS AND METHODS

In order to reconstruct the environmental changes that occurred during the accumulation of the studied deposits two working methods were integrated: the sedimentary facies analysis and the micropaleontological method.

The sedimentary facies analysis was realized through the field logging of the two outcrops having a stratigraphic thickness of 9.5 and 6.8 m respectively.

The data on these two sedimentary successions were collected through „bed by bed" observations on lithology, grain size, bed thickness, lateral continuity, internal sedimentary structures and eventually fossil content. All these features led to the identification and geometrical separation of the sedimentary facies in terms of their accumulation processes.

The next step was to define the facies association within the outcrops in order to characterize the depositional (sub)environment (Nemec, 1995; Reading & Collinson, 1996; Miclăuș, 2006).

The identification of facies associations, more precisely the grouping of sedimentary facies was realized considering their genetical process, spatiality and the contact in accordance with each other. The purpose of this stage is to rank the stratigraphic units in the sedimentary successions by then highlighting sedimentary processes specific to certain domains or depositional subdomains (fluvial, deltaic, shoreface, self, etc.).

The last stage of the sedimentary facies analysis supposed the interpretation of the vertical succession of facies associations. The way facies associations are stacked will indicate whether the depositional systems are pro-grading or retro grading, in this way observing the shoreline behaviour.

Additionally, 21 samples from sandy, siltic and argillaceous deposits were collected in order to identify the potential micropaleontological assemblages that could offer data on the palaeoecological features of the basin and the biostratigraphy of the deposits.

The samples were prepared by standard micropaleontological methods. The microfossil content was handpicked using a Carl Zeiss Stemi508 stereomicroscope. The determination of the species was made using the specific literature for each group of the identified organisms (van Morkhoven, 1962, 1963; Murray, 1991, 2006; Papp & Schmid, 1985).

The most representative and well-preserved microfossils were photographed using a SEM microscope from the faculty of Biology, "Alexandru Ioan Cuza" University of Iași.

The paleontological material used in this paper is deposited in the Paleontological Collection of the Museum of "Alexandru Ioan Cuza" University of Iași, Romania.

4. RESULTS ANS DISCUSSION

4.1. Sedimentary facies analysis

The sedimentary facies identified in the studied stratigraphic succession are: (1) mudstone with ripple cross lamination with brown laminae or unstructured – ***Mst***; (2) very fine sands with symmetrical ripple cross lamination – ***Swrcl***; (3) very fine sands with ripple cross lamination – ***Srcl***, (4) very fine and fine sands with hummocky convex stratification – ***Shcs***; (5) very fine and fine sands with swalley concave stratification – ***Sscs***; (6) very fine and fine sands with trough cross stratification – ***Stcs***, (7) very fine and fine sands with conchoidal stratification – ***Sctcs***; (8) very fine to medium sands with low-angle cross stratification – ***Slacs***; (9) fine to medium sands with planar parallel stratification – ***Spp***, (10) massive sandstone – ***Sst***, (11) sand with bioclasts – ***Sbtcs***.

The identified sedimentary facies were interpreted in terms of the typical physical processes that lead to their accumulation, their geometry in the outcrop, lateral continuity and the vertical development in the sedimentary succession. The most frequent sedimentary facies occurring in the studied sections are shown in Table 1.

The sedimentary facies above mentioned were grouped according to genetic criteria, lithology and geometry in 2 facies associations (FA) described and interpreted below. Each sedimentary facies have been assigned to a sedimentary process; therefore, the facies association will be represented by a sequence of sedimentary processes and will be assigned to a depositional subdomain.

Facies Association 1 – predominantly sandy (FA 1)

Description: This first association is made up from a lithological point of view of well-sorted, clean yellowish sands, in which fragments of bioclasts and

Table 1. The most frequent sedimentary facies from Hârtop A and B outcrops

Name and description of the sedimentary facies	Sedimentary processes and references	Representative photos from the outcrops
1. Weakly cemented sandstones and sands, with strangled shapes (***Sst***), without lateral continuity, with thicknesses varying from 10 cm up to 50 cm.	The genetic process leading to the accumulation of this sedimentary facies is represented by sandy, mass debritic flows (Shanmugam, 1996, 2000) that secondarily support diagenetic processes.	
2. Very fine, yellowish sands with planar parallel stratification (***Spp***) in sets of varying thicknesses from 2-3 cm up to 50-60 cm.	Unidirectional flow or oscillating traction currents in superior flow regime, on flat beds (Harms, 1979).	
3**.** Very fine, yellowish sand with hummocky convex stratification (***Shcs***) and swalley (***Sscs***) concave stratification (sets of 10-15 cm thickness).	Currents combined with an oscillating and a unidirectional component induced by storm waves followed by fair weather waves (Harms, 1979; Dott & Bourgeois, 1982; Leckie & Walker, 1982).	
4. Fine and very fine sand with trough cross stratification (***Stcs***) with or without bioclasts (sets of 10-50 cm thickness).	It is formed as a result of the migration of 3D dunes under the action of unidirectional traction currents capable of shaping their substrate (Cliffton, 1976, 2006).	
5. Very fine yellowish sand with ripple cross lamination (***Srcl***), sets of 1-5 cm thickness.	Migration of 3D current ripples under longshore current traction and unidirectional currents in low energy flow regime (Clifton, 1976, 2006; Allen, 1982a, 1982b).	
6. Yellowish, very fine sand with symmetrical wave ripple cross lamination (***Swrcl***) in sets of 4 – 5 cm.	Pure oscillating currents in the lower flow regime (Harms, 1979).	
7. Unstructured compact grey mudstone (***Mst***) of small thickness, (2-6 cm), delimited at the top by layers of very fine sand.	Settling from suspension in quiet-waters (Collinson & Thompson, 1989; Collinson et al., 2006).	

rare intercalations of grey mudstone are included. The main sedimentary facies are sands with planar parallel stratification and sands with tangential oblique stratification. Beside these, sporadically, sands with low angle cross stratification, hummocky and swalley cross stratification or oblique lamination (Figure 3) are occurring. Large-scale oblique tangential and oblique conchoid stratification are the characteristic elements of this association. Sets of Stcs are found in thicknesses from a few centimetres to 40-50 cm, sometimes associated in cosets of metric thicknesses. Srcl appears in thin sets of only a few centimetres. Granulometric, 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 sets different shell residues arranged on the layering surfaces. FA 1 occurs twice in the sequence of deposits in the Hârtop A outcrop (the base ant the top of the succession) and forms the entire sedimentary sequence in the Hârtop B column.

Sedimentary processes and environment: The formation of Stcs indicates the action of unidirectional traction currents in higher flow regime (Harms, 1979) as well as the migration of 3D dunes under the action of unidirectional traction currents capable of forming three-dimensional dunes with decametric heights. Two and three-dimensional dunes are common bottom shapes in contemporary shorefaces (Plint, 2010). Clifton (2006) attributes the formation of these structures to the vigorous coastal currents that form in the upper shoreface. In shorefaces characterized by fine sands, sedimentary structures of this type are preserved under the presence of underwater banks which protect them of erosion. Also, the presence of Shcs and Sscs formed by the accumulation of detrital material from suspension, highlights storm episodes followed by calmer (fair weather) periods indicated by the occurrence of oblique lamination sands (Dott & Bourgeois, 1982).

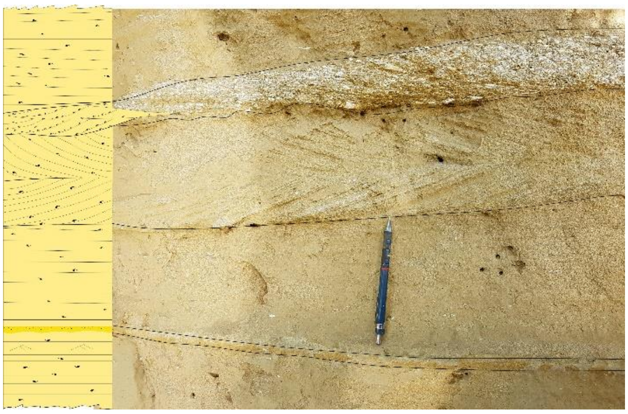

Figure 3. Facies Association 1 – Sands with plan-parallel stratification, trough cross stratification and bioclasts on Hârtop A outcrop.

Facies association 2 – sands with oblique lamination, planar parallel stratification and silt intercalations (FA 2).

Description: This association mainly groups very fine sands with planar parallel stratification, Spp and oblique stratification Srcl, interspersed with layers of mudstone with oblique lamination or unstructured (Figure 4). Sporadically, sands with low angle cross stratification (Slacs) and with hummocky convex stratification (Shcs) appear.

The thickness of the sets is variable, starting from 2-3 cm to a maximum of 20 cm in the case of sands with planar parallel stratification. FA 2 occurs only once in the sedimentary sequence of the first outcrop (Hârtop A) and measures 4 m thickness.

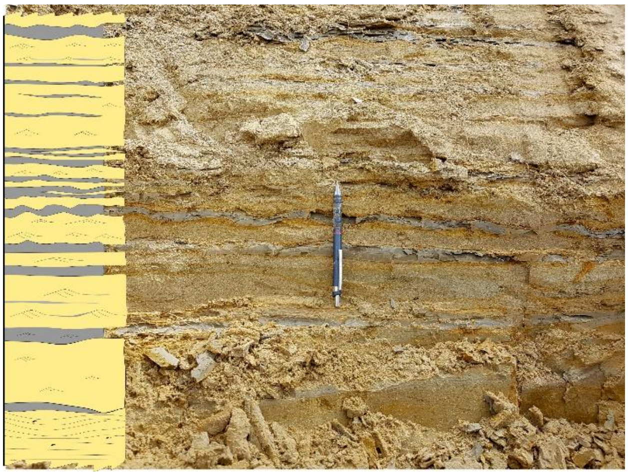

Figure 4. Facies Association 2 – Sands with ripple cross lamination, clay and silt beds and symmetrical cross lamination – Hârtop A outcrop.

Sedimentary processes and environment: The two dominant facies in this association were formed under different conditions. Sands with planar parallel stratification result from the action of unidirectional traction strong currents in the upper flow regime conditions (Harms, 1979; Reading & Collinson, 1996), while sands with ripple cross lamination are the result of the actions of the same types of currents but are formed in the lower flow regime conditions (Allen, 1982a, 1982b). These predominant facies are interspersed with layers of mudstone that have accumulated by settling from suspension in still waters (Collinson et al., 2006). The Spp facies is specific to high-energy currents, which could indicate that this association is specific to the upper shoreface, but the Srcl facies, which has an occurrence almost as high as Spp and clay drape sheets on the lamination surfaces, points more towards a lower shoreface environment. Therefore, it can be assumed that facies association 2 can be accumulated in the lower shoreface.

The defined facies associations follow one another in a coherent continuity of vertical sedimentation. Such a vertical organization of facies associations can be reconstructed in space, based on the Law of Facies Succession 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 their sedimentation.

Analysing the Hârtop A sedimentary succession and the distribution of sedimentary facies an increase in granulometry from bottom to top can be observed. In the first meters of the column (Figure 5) there is a higher frequency of mudstone and clay, which accumulated in fair weather conditions under the action of unidirectional currents (Walker &

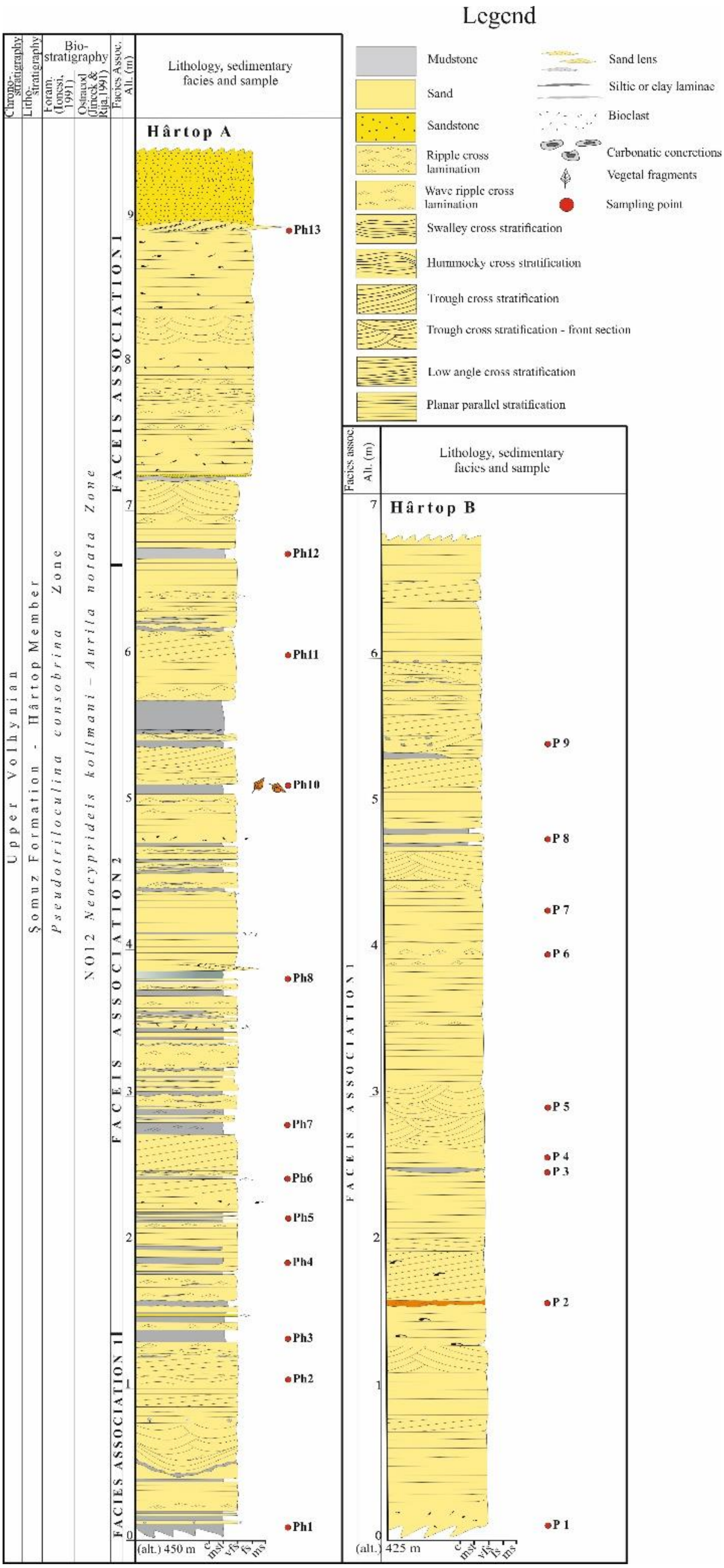

Figure 5. Sedimentological log of the Hârtop outcrops.

James, 1992) or by settling from suspension in calm waters (Collinson et al., 2006) along with very fine sands.

Towards the top of the column, the grain size of the sands increases slightly, the siltstones being almost non-existent, which suggests that the action of the currents on the sedimentary bed was more pronounced. For the characterisation of the behaviour of the depositional environments the stacking of the defined facies associations in the Hârtop A outcrop was analysed.

The sedimentary facies identified at the base of the Hârtop A outcrop are indicating a retrogradational character of the shoreline. This behaviour is described by a deepening upward trend with the first occurrence of the sand with planar parallel stratification and trough cross stratification (upper shoreface FA 1) followed by the overlaying of finer low energy accumulated sands with ripple cross lamination, mud and silt intercalations (lower shoreface FA 2) in the sedimentary succession).

The upper part of the sedimentary succession from Hârtop A outcrop reveals a progradational behaviour of the depositional domain and the shoreline respectively. This is indicated by the presence in the sedimentological column of a shallowing upward trend – the FA 1 upper shoreface deposits are stacked on top of the lower shoreface FA 2.

In the Hârtop B outcrop, the existence of the upper shoreface depositional subdomain accumulated in high energy conditions can be confirmed.

All these deposits identified in the Hârtop sedimentary successions are representing subsystems of the non-deltaic coastal depositional domain.

4.2. Micropaleontological analysis

The micropaleontological assemblages are represented by most frequent foraminifera and a scarce number of ostracods. Among the ostracod species *Loxocorniculuim schmidi* (Cernajsek), *Cyprideis pannonica* (Mehés), *C. sublitoralis* Pokorny are the most representative taxa.

The foraminiferal assemblages identified in the studied section (Figure 6) namely *Ammonia beccarii* (L.), *Elphidium hauerinum* (d'Orb.) *Porosononion subgranosus* (Egger), are typical for shallow water environments (inner to outer neritic) and brackish to normal marine salinity conditions (Filipescu et al., 2014; Silye, 2015) with an eventually decreasing salinity for low species-richness assemblages (Culver et al., 2012). The ostracod assemblages constitute by cytheracean ostracods (*Cyprideis* species) present in the analysed samples are indicating a well oxygenated sea bottom (Whatley, 1995) and a shallow basin depth ranging at few dozen meters. Additionally, the *Cyprideis* taxa could indicate a mesohaline water and a littoral environment (Gross et al., 2008) with a progradational shoreline.

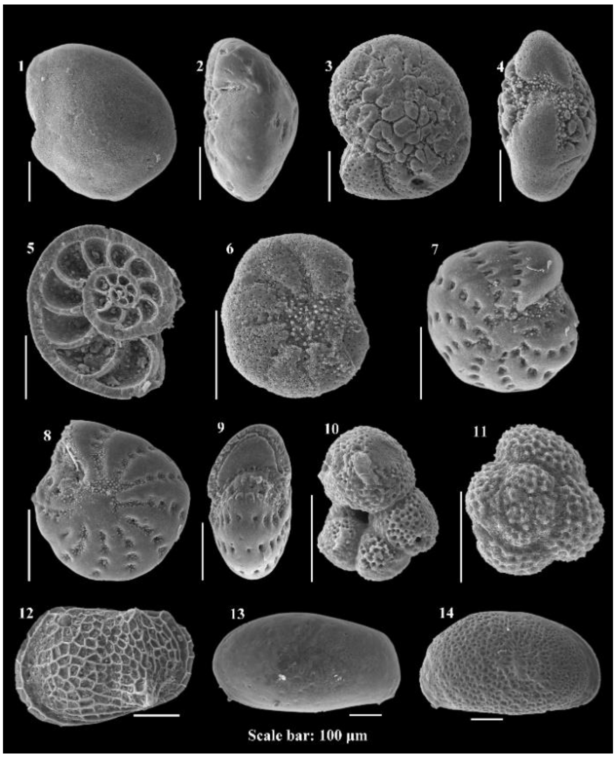

Figure 6. Micropaleontological assemblages identified in the Hârtop A outcrop (FA 2 – Lower shoreface). 1, 2 – *Ammonia beccarii* (Linné, 1758); 3, 4, 5 – *Porosononion subgranosus* (Egger, 1857); 6 – *Porosononion martkobi* (Bogdanowicz, 1947); 7, 8, 9 – *Elphidium hauerinum* (d'Orbigny, 1846); 10, 11 – *Globigerina bulloides* d'Orbigny, 1826; 12 – *Loxocorniculum schmidi* (Cernajsek, 1974) left valve, lateral view; 13 – *Cyprideis pannonica* (Méhes, 1908) left valve, lateral view; 14 – *Cyprideis sublittoralis* Pokorný, 1952 right valve, lateral view.

The *Cyprideis pannonica* ostracod species was previously described by Dumitriu et al. (2021) in the Sarmatian deposits from Moldavian Platform as indicating a rich nutrient supply in a shallow and well oxygenated environment with water salinity varying from brackish to normal (van Morkhoven, 1963).

5. CONCLUSIONS

Analysing two outcrops of 9.6 and 6.8 meters respectively we could distinguish 11 sedimentary lower shoreface facies with typical accumulative processes.

The identified sedimentary facies were divided in two facies associations:

FA 1 – predominantly sandy describing an upper shoreface environment;

FA 2 – very fine sand, silts and clay intercalations – typical for a lower shoreface environment.

The stacking of facies association in the Hârtop A outcrop allowed the separation of two depositional trends of the shoreline. A deepening upward (DeU) trend revealed by the positioning of lower shoreface deposits (FA2) over upper shoreface (FA1) and a shallowing upward trend in the upper part of the outcrop confirmed by the reappearance of upper shoreface (FA 1) on the top of the outcrop stacked over the lower shoreface FA2.

The shallowing upward trend displayed in the sedimentary succession suggests that the sediment source was closer and closer to this section area, filling the accommodation space and migrating the shoreline basinward in a progradational stacking pattern.

Comparing the depositional pattern from our sections with the large-scale sea-level fluctuations (Popov et al, 2010) at Badenian (Konkian) - lower Sarmatian (Volhynian) stratigraphic interval a small regressive episode can be observed in Eastern Paratethys basin. This is followed by a transgression marked by a +40 hold up during middle-late Volhynian, and a rise up to +80 in middle Bessarabian. The progradational pattern of the upper part of Hârtop A outcrop is confirming the same model of basin evolution.

The micropaleontological analysis revealed a representative fauna for the Volhinian stage of the Moldavian Platform.

The foraminiferal assemblages are suggesting a brackish to normal marine salinity and neritic paleoenvironmental depths.

The ostracod fauna is typical for littoral conditions and well oxygenated sea-floor.

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