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PALEODICTYON ASSEMBLAGE FROM FRASIN, SUCEAVA COUNTY (EASTERN CARPATHIANS, ROMANIA)

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Abstract: Hypichnia with *Strobilorharphe*, *Megagrapton*, *Spirodesmos*, *Helminthopsis*, *Treptichnus*, and the elite *Paleodictyon*, representative for „deep-sea farmers" (graphoglyptides) of the Paleodictyon ichnosubfacies, belonging to Nereites ichnofacies is described in Lower-Middle Eocene flysch deposits of Tarcău Nappe (in the north of Eastern Carpathians). The *Paleodictyon* is preserved as three superimposed networks, covering a half square meter of lower bounding surface of a Tc bed, indicating a quasi-nonerosive character of the turbidity current which exhumed the pre-depositional delicate farming traces. This paleoenvironment is supported by the agglutinated foraminifera, dominated by tubular forms (*Bathysiphon* sp., *Psammosiphonella cylindrica*, *Nothia excelsa*) collected from shale the above and below turbidite bed, accumulated in relative quiet intervals, depleted of nutrients and oxygen. Such conditions may exist in offshore, where organisms develop highly organized feeding strategies.

Keywords: *Paleodictyon carpathicum*, Nereites ichnofacies, „deep-sea farmers", Tarcău Nappe, Eastern Carpathians

1. INTRODUCTION

Paleodictyon is a trace fossil that was described for the first time by the Italian botanist, geologist, and paleontologist Giuseppe Meneghini in 1850 (Murchinson, 1850 in Baucon, 2008). It is to be consider an important ichnogenus of Nereites ichnofacies (Seilacher 1967). According to McIlroy (2004), it is Seilacher the first who, based on previous works, recognized Paleodictyon ichnosubfacies for sand-rich proximal turbidites and Nereites ichnosubfacies for mud-rich distal turbidites. The Paleodictyon ichnosubfacies is associated with low energy environmental conditions, depleted of nutrients, that induces a specialized food behavior (Seilacher, 2007).

This paper is an attempt of interdisciplinary analysis of a sandstone bed, having a large *Paleodictyon* network on its lower bounding surface, and the surrounding background finer deposit of Tazlău Formation (Tarcău Nappe, Eastern Carpathians) from Frasin, Suceava County. In an approximately 40 cm thick outcrop, we discussed micropaleontological content, sedimentary structures in terms of their processes, and the ichnological assemblage, establishing the ichnofacies and ichnosubfacies to obtain a better understanding of the sea bottom environment during the *Paleodictyon* developing time.

2. GEOLOGICAL SETTING

The Tazlău Formation, belonging to Tarcău Nappe, representative for Tazlău (central and north part of The Eastern Carpathians) Lithofacies, is a "flysch" succession overlaying Straja Formation and being overlaid by Plopu Formation (Săndulescu et al., 1981a, 1981b; Grasu et al., 1988). The deposits reflect transitional sedimentary conditions from Tarcău (internal) to Doamna (external) Lithofacies, consisting of micaceous sandstones of internal type, sandy limestones, marls, and mudstones of external lithofacies type. As lithostratigraphic entity known today, it was used for the first time by Aghiorghiesei et al., (1967), followed by Ionesi (1971). Its rich fossil assemblage indicates Lower-Middle Eocene (Ionesi, 1971, 1985). The petrographic description was first carried out by Mirăuţă (1969), who analyzed in detail the limestone content of the unit. Two decades later, Grasu et al., (1988) separated four main petrographic types (Dunham, 1962 for carbonates; Folk, 1974) as follows: a) litho-felspatho-quartzose sandstones, a Tarcău-type sandstones; b) Q-rich felspatho-quartzose and Q-rich litho-quartzose sandstones; c) calcareous mudstone, marls, and clayey marls (*sensu* Dunham, 1962); d) biosparite, sandy biosparite, and clayey biomicrite (*sensu* Dunham, 1962). Overall, the Tazlău Formation is described as a 400 m thick alternance of Tarcău-type immature and rich in muscovite sandstones, calcareous sandstones, and marls or as "an arenitic-calcareous flysch" (Mutihac & Mutihac, 2010).

Our observations were carried out on the eastern flank of the Molid Syncline (Figure 1) where, according to Ionesi (1971), the sandstone beds are thinner and more weathered than those from the western flank.

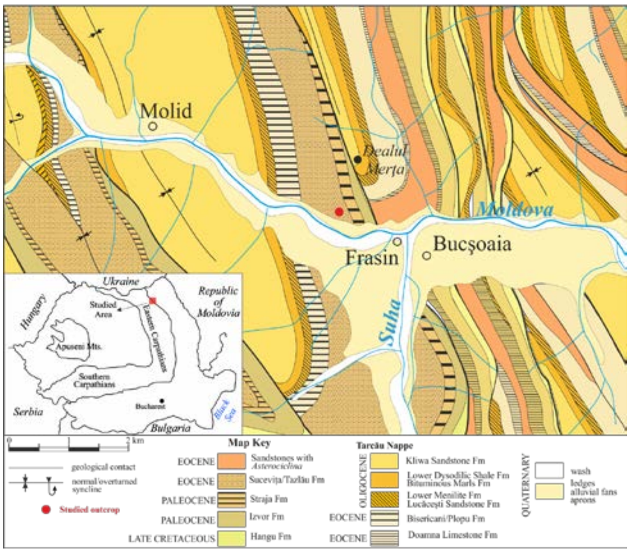

Figure 1. The location of the studied outcrop (redrawn after geological map of Ionesi, 1971)

3. MATERIAL AND METHODS

On a right-hand tributary creek to Moldova river, from under dead leafage carpet, crops out a lenticular sandstone bed, eight to twelve centimeters thick, with perfect honeycomb mesh "on top" (Figure 2a). We cleared away the debris on a surface close to half square meter to expose as much as possible from the sandstone bed to assess the ichnological content, but also to get good samples from the bellow and above mudstone for micro-paleontological analysis.

We took out from the field three sandstone samples, two of them being hosted by The Paleontology Museum of "Alexandru Ioan Cuza" University, in the Ichnology Collection (Inv. 8229, Inv. 8230). We sketched a 40 cm sedimentary log showing sedimentary structures of the sandstone layer and the position of *Paleodictyon* assemblage (Figure 2b). Two samples (around 100 g) were collected from the mudstone background for micro-paleontological analysis (P 13A and P 13B).

Figure 2a. The outcrop on Dealul Merţa (Saples13A, 13C for paleontological analysis)

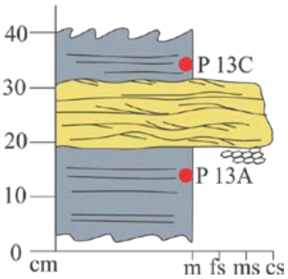

Figure 2b. Sedimentary log of the outcrop seined in fig.2a

The separation of microfossils was carried out using the water-immersion and successive decantation method. The total residue obtained by decantation was passed through three sieves (ø – 0.122 mm; 0.263 mm; 0.466 mm), and the microfossils were picked from each fraction using a Carl Zeiss Jena SM XX binocular stereo microscope. The photomicrographs were taken with a Vega/Tescan SEM microscope.

The ichnological features have been described using morphological diagnoses from Książkiewicz (1977), Uchman (1998) and Martinsson (1970) toponomical classification, while the sedimentary structures in terms of processes (Nemec, 1996). The micropaleontological content was determined using classical methods (Kaminski & Gradstein, 2005).

Paleoenvironment parameters have been deduced using the agglutinated foraminiferal morpho groups method (Nagy et al.,1995; van den Akker et al., 2000; Kaminski & Gradstein, 2005; Cetean et al., 2011; Murray et al., 2011; Setoyama et al., 2011, 2013).

4. RESULTS

4.1. Sedimentary features

The analyzed bed is a Tarcău Sandstone-type, a "coarse, micaceous, clayey-cemented sandstone" (Mutihac & Mutihac, 2010), 8-12 cm thick, lenticular shape, representing a coset of 6 sets (1.5-3.5 cm) with trough cross lamination, separated by undulated surfaces of amalgamation (Figure 3).

If these structures would have been associated with below parallel lamination, they might be considered another subdivision of Bouma Sequence (T_c), interpreted by Middleton & Hampton (1973) as the result of low regime flow of a turbiditic current. Sanders (1965) describes in detail the forming mechanism of this structure associated with turbiditic current. The author shows that they are always present in turbidites, being the result of traction of grains already settled from suspension while the current is still active.

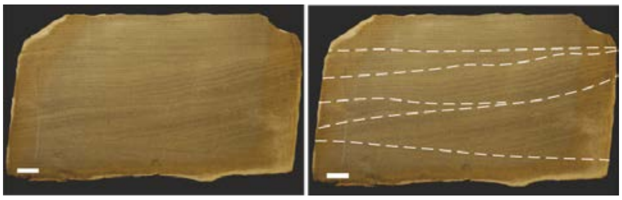

Figure 3. Sedimentary structures on the polished cross-cut surface of sandstone sample (scale bar 1 cm)

The result may be subcritical to critical climbing cross lamination, due to variation of the angle of climb versus the angle of the stoss slope. As ripples move down current, they truncate the upper parts of the ripples accumulated bellow, resulting often in preservation of the basal part of them (Collinson et al., 2006). But Sanders (1965) clearly specified that this mechanism is valid only for fine to very fine sediments, while the coarser deposits are the result of tractive accumulation. For Shanmugam (2006) they represent materials first accumulated throughout turbiditic current and reworked by tractive bottom currents.

If a unit, characterized only by T_c subdivision, must be related to turbiditic current, Middleton (1993) suggest that it must have erosive basal surface, sole marks, and centimeters in thickness as it is this sandstone bed.

4.2. Ichnology

The lower bounding surface of the analyzed sandstone bed shows convex and concave hypichnia (Figure 4.1), revealing the fact that during its sedimentation the shallow part of the muddy substrate was washed out, and the organism traces were exhumated. The sole marks are absent, indicating the current which exhumed the delicate traces was weak enough not to erode them. As such, several trace fossils representing an assemblage of deposit feeder activity are preserved (Figure 4.1). Some of them were identified at genera (*Spirodesmos, Helminthopsis, Treptichnus*), while other at species level (*Megagrapton irregulare, Paleodictyon carpathicum,* and *Strobilorhaphe clavata*).

“The star of the show” is *Paleodictyon*, which is an important representative for the graphoglyptides. The “Graphoglyptids” (German Graphoglypten) term was introduced by the Austrian geologist and paleontologist Fuchs (1895) as an informal name for a diverse group of ornamental trace fossils observed always on the soles of flysch sandstones. Seilacher (2007) uses it in sense of an ichnofamily with *Paleodictyon* as the best representative ichnogenus.

Paleodictyon Meneghini, 1850 diagnosis feature is a “honeycomb-like network of ridges in hyporelief, consisting of remarkably regular hexagonal polygons; may be also 4- to 8-sided; reticulate pattern of considerably varying size (incomplete along margins) but diameter of meshes constant within individual net (from less than 1 mm to about 50 mm); walls of meshes 0.5 to 2mm wide and occasionally consisting of small circular or oval “pimples” closely arranged in rows which may cross one another regularly; networks may cover large areas up to about 1 m^2; polygons sometimes elongated due to current action” (Häntzschel, 1975). This description seems to agree with the specimens found here, except the last part regarding strong currents responsible with deformation of the honeycomb-like structures. This absence suggests the presence of the low energy current responsible for the sedimentation of the sand layer which later became sandstone with hypichnia.

In the past, *Paleodictyon* was considered algae (Kushlin, 1982), sponge, coral, spawn, or even frog eggs (Ilie, 1937). It is preserved as positive hyporeliefs and represents shallow-tier farming structures produced by vermiform organisms although some authors proposed that small, elongated, endobenthic crustaceans may be the responsible organisms (Garlick & Miller, 1993). The simple forms are explained by passive trapping of mobile and dissolved food within the sediment, while multiple openings presence suggests active farming (Seilacher, 1977a).

The classification, functional morphology, ethology, and significance of the graphoglyptids were reviewed by Seilacher (1977a), and the common ground is that they occur in flysch and deep-water or anoxic environment, being the result of highly organized behavior. The so-called “graphoglyptid family” may be divided in three main topologic configurations: homeomorphic to line, tree, and network. By comparing the environmental characteristics of these configurations, Gong & Huang (1997) established that from line to network, the anoxia degree of the producer environment decreases, but the bottom current energy increases.

Seilacher (2007) has dedicated the “Deepsee Farmers” chapter to the meandering and the

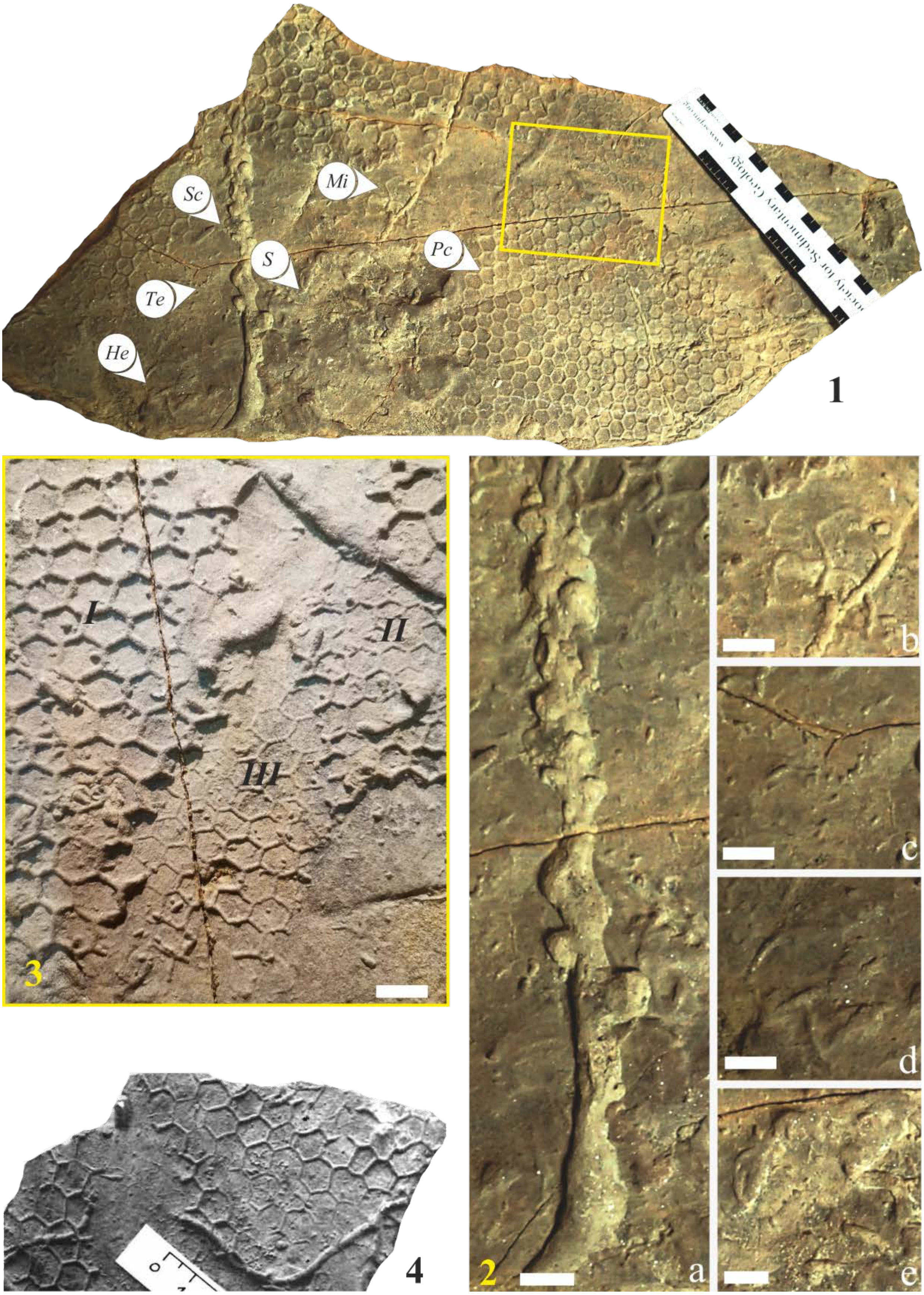

Figure 4. 1 Convex and concave hypichnia of *Paleodictyon* assemblage. *Paleodictyon carpathicum* (*Pc*); 2a *Strobilorhaphe clavata* (*Sc*);2b *Megagrapton irregulare* (*Mi*); 2c *Treptichnus* (*Te*); 2d *Helminthopsis*(*He*); 2e *Spirodesmos*(*S*)*;* 3. Three superposed levels of *Paleodictyon carpathicum* (scale bar 10 mm); 4. *Paleodictyon carpathicum* Matiasovszky. Lubomierz, Beloveza Beds (from Książkievicz, 1977)

graphoglyptids produced by organisms that use to live in extreme diet conditions, due to the lack of light. Despite that, starting in the Precambrian, their diversity has increased above shallow-marine ichnocoenoses by late Cretaceous- Early Tertiary time. The general idea is that such burrows normally occur on distal turbidites soles, in flysch (Seilacher, 1962, 1977a, b; Crimes & Fedonkin, 1994; Bromley, 1996; Seilacher & Gishlick, 2014), but they are found in other environments, such as non-marine deposits (Archer & Maples, 1984; Pickerill, 1990), neritic (Hantzpergue & Branger, 1992; Stanley & Pickerill, 1993) or lithographic limestones of offshore (Wetzel, 2000).

In Romanian literature, eight ichnospecies (*Paleodictyon isp*., *P. tellini*, *P. regulare*, *P. minimum*, *P. majus*, *P. carpathicum*, *P. miocenicum*, *P. gomezi*) from different formations (Paleozoic, Mesozoic, and Tertiary in age) were described, most of them from Outer East Carpathians (Joja, 1955; Alexandrescu & Brustur, 1980; Alexandrescu & Brustur, 1990; Brustur, 1995).

Paleodictyon carpathicum Matyasovszky, 1878 (*Pc*)

The ichnospecies was identified based on the similarities with the Książkiewicz's (1977) description from Beloveza Beds (Figure 4.4).

Description: about 2 mm subcylindrical bordering riblets in width and highs, with hexagonal meshes 7-8 mm long, sometimes smaller than 7. The nets are of considerable size, in this case covers an area of approximately a third of a square meter (fig. 4.1). As Książkiewicz (1977) observed, the riblets appeared to usually be subcylindrical, but we have not, as he did, detached a riblet to observe the cylindrical profile. We have observed a subtle rise of grains size compared to the host sandstone. At least three superposed levels of *Paleodictyon* can be recognized, suggesting the special feature of the ichnogenus (Figure 4.3). The first layer (the bottom one) shows larger, higher riblets (up to 2 mm), while the second layer have smaller, lower riblets (1.5 mm), the third being almost faded (0.5 mm high).

The Książkiewicz's (1977) description is like the features we observed on our sample: the dimensions are similar (length of the meshes no longer than 8 mm). The contour of the meshes are mostly hexagonal. The network is usually covering a wide area. In this case a half square meter. The sediments of the riblets are slightly coarser than that of the host rock.

Deposit: fine-grained sandstone soles of 8-12 cm thick, representing a coset of 6 sets (1.5- 3.5 cm) with trough cross lamination (Figure 3). Most likely the nets had been developed on flat, even soles. If we admit that these structures' producers prefer a muddy sediment, then these three levels from figures 4.1 and 4.3 are proof of unique conditions of conservation.

Strobilorhaphe clavata Książkiewicz, 1968 (*Sc*)

Diagnosis: "Hypichinial full burrow consisting of a thin stem passing into a cone composed of round or subelliptical knobs which vary in size, arranged obliquely in relation to the axis of the burrow" (Książkiewicz, 1977).

Description: The specimen that we have found (*Sc* in fig. 4.2a) is 17 cm long and up to 3 cm wide, while the supporting stem is 1.5 cm wide, thicker to the base (up to 3 cm). It is ramified into short knobs, isolated or closer to one another, and even overlapped to the top. They are 1 cm long and 5 mm high.

Megagrapton irregulare Książkiewicz, 1968 (*Mi*)

Diagnosis: hypichnial string-sized full burrows, straight or weakly curved, branching at irregular intervals mostly at approximately right angles and forming incomplete irregular polygons (Książkiewicz, 1977; Uchman, 1998).

Description: This specimen consists of cylindrical strings 1.5 mm wide and up to 1 mm high, branching at various interval at approximately right angles. The abrupt breaks of the string may be due to descending of the producer into the mud, progressively abandoning the previous interface. The trace fossil from figure 4.2b is assigned here with some doubts, perhaps this deserves to be classified as distinct ichnospecies of *Paleodictyon* (*Mi* in Figure 4.1., detail in Figure 4.2b).

Treptichnus (*Te*)"

Diagnosis: "Shallow, sub-horizontal burrow consisting of one series of down bowed or J- to U--shaped segments joined near or at their ends in a uniserial pattern that may be irregular, zigzag, or arcuate" (Uchman et al., 1998).

Description: Straight and curved row of very short individual burrows of equal length; eight "dots" with 2-3 mm in diameter, and 1mm high, making a loop-like shape (*Te* in Figure 4.1, detail in Figure 4.2c).

The trace fossils' assemblage was formed in muddy substrate but preserved on the sole of the sandstone bed due to moderate to low energy current that washed away a shallow part of the surficial sediment. The trace fossils described are a part of Nereites ichnofacies, namely Paleodictyon ichnosubfacies (*sensu* Uchman, 2009).

Helminthopsis (*He*)

Diagnosis: "Hypichnial string- or rope-sized full burrow, loosely winding with a tendency to meandering. Meanders irregular and variable in shape" (Książkiewicz, 1977; Uchman, 1998).

Description: Here the burrow is 4 mm wide and 3 mm high. The meanders are of variable height (7, 8, 10 mm), high and narrow, with a tendency of a loop-like shape, but in some parts follow a straight course. The surface of the burrow seems smooth (*He* in Figure 4.1, detail in Figure 4.2d).

Spirodesmos Andreé, 1920 (*S*)

Diagnosis: "Large spiral-shaped form, diameter up to 30 cm; it consists of individual parts 2 to 3 cm long and up to 10 mm wide. Individual loops are developed close to each other, slightly eccentrically but following and overturning an earlier loop. Most commonly, traces are found frequently overrunning and intersecting each other "(Książkiewicz, 1977).

Description: Here we have a spiral-shaped form with a diameter no larger than 12 cm, with individual parts of 3-4 cm long, 10 mm wide, and up to 5 mm high. Some parts of the outer coils are displaced inward almost 90 degrees one to the other. (*S* in Figure 4.1, detail in Figure 4.2e).

4.3. Micropaleontology

The microfossils in the two samples (Figure 2) are exclusively agglutinated foraminifers with different morphologies. As such, sample 13C, from above the sandstone bed (Figure 2), contains few tubular forms, while sample 13A contains a variety of forms (tubular, globular, trochospiral etc). The morphology of agglutinated tests is used to infer paleo-environmental conditions.

The morphogroup analysis assumes that species with different test shape prefer different habitats and have different feeding strategies, consequently the variations of the morphogroups' relative abundance reflecting environmental changes (Corliss, 1985; Jones & Charnock, 1985; Murray et al., 2011). Several morphogroups are recognized and codified from M1 to M4. The morphogroup M1 (tubular forms) is very rare in the shelf environments, but increases in abundance with water depth, reaching the maxima in the middle and lower bathyal zones (Nagy et al., 1995; Kaminski & Gradstein, 2005). M2a (forms with globular chambers) is very common in the bathyal and abyssal environments, while M2b (rounded trochospiral and streptospiral) and M2c (elongated keeled) are more characteristic for shelf to deep marine environments. M3a (flattened trochospiral, planspiral, and streptospiral forms) occurs commonly in lagoon to abyssal environments (Nagy et al., 1995), whereas M3b (flattened irregular) and M3c (flattened streptospiral) are characteristic of deep-water environments (Cetean et al., 2011). M4 morphogroup, both M4a (rounded planspiral) and M4b (elongated multiserial forms), is commonly found in inner shelf to upper bathyal environments.

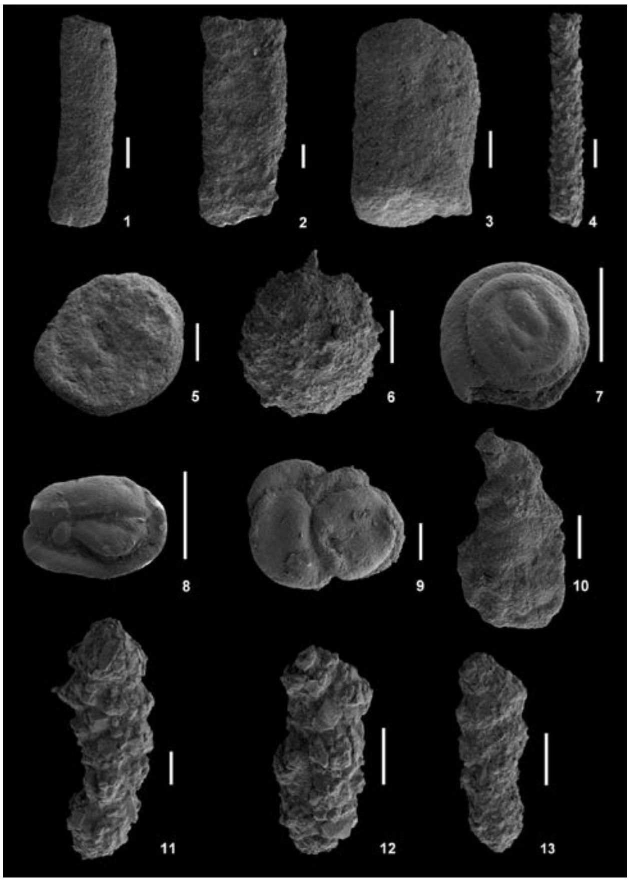

Figure 5. 1 – scale bar 100 μm Sample13A: 1 - *Bathysiphon sp.*; 2 - *Nothia excelsa* (Grzybowski); 3 - *Nothia excelsa* (Grzybowski); 4 - *Psammosiphonela cylindrica* (Grzybowski); 5 - *Nothia excelsa* (Grzybowski); 6 - *Saccammina grzybowskii* (Schubert); 7 - *Glomospira charoides*; 8 - *Paratrochamminoides gorayskii* (Grzybowskii); 9 - *Paratrochamminoides irregularis* (White); 10 - *Reophax*; 11 - *Karrerulina* (Brady); 12 - *Karrerulina* (Brady);13- *Amobaculites* Cushman

As we mentioned above, in the sample 13 C (Figure 2a) just a few forms belonging to M1 morphogrup have been recovered. Sample 13 A (Figure 5) contains 70% M1 (*Bathysiphon* sp., *Psammosiphonella cylindrica*, *Nothia excelsa*), 16% M4b (*Karrerulina* sp.), 2-7% M2a (*Saccammina grzybowskii*), M3a (*Glomospira div.* sp), and M3c *(Paratrochamminoides*, *Trochamminoides*).

According to Kaminski et al., (1996), the dominant tubular forms develop in a restrictive environment depleted of nutrients characterized by low oxygen level. These observations agree with sedimentological features and ichnological assemblage.

5. DISCUSSIONS AND CONCLUSIONS

For the first time in the Frasin area the *Paleodictyon carpathicum* was described by Alexandrescu & Brustur (1980) from Moldovița Sandstone of Middle Eocene age. The second mention about this trace fossils is in the Lower-Middle Eocene flysch deposits from Tazlău Lithofacies of Tarcău Nappe, Tazlău Formation, together with other trace fossils (this paper). It is the first assessment of its context based on sedimentological and micropaleontological analysis.

Paleodictyon occurs on lower surface of a turbidite bed characterized by only Tcd subdivisions of Bouma Sequence.

Ichnological analysis showed ichnospecies and ichnogenera, ethologicaly grouped in pasichnia and agrichnia types. These behaviors relate to an environment characterized by scarce nutrients and low bottom currents energy where Nereites ichnofacies develop. This environment is also supported by the agglutinated foraminifera, dominated by tubular forms such as: *Bathysiphon* sp., *Psammosiphonella cylindrica*, *Nothia excelsa*, which were found in the samples collected from the above and below shales.

The entire assemblage is associated with pre-turbidite background deposits, accumulated in relative quiet intervals, depleted of nutrients. Due to extreme diet conditions and to the lack of light, this environment coerces a highly organized feeding behavior.

The chance of the *Paleodictyon* assemblage preservation on such large surfaces suggested that only the topmost part of the basin floor was slightly eroded to exhume this spectacular traces. Moreover, the presence of at least 3 levels of superimposed meshes justifies the assumption that these low energy and calm conditions in distal area of a sedimentation basin floor were repeatedly disturbed by discrete currents. They were strong enough to gently swab the basin floor and week enough to preserve this unique trace fossils. Their presence was more frequent than one may anticipate.

Based of the sedimentary structures and micropaleontological content, together with ichnological analysis these deposits had been accumulated in an offshore environment.

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