The record of *Avetoichnus luisae* Uchman&Rattazzi, 2011 in Bisericani Formation (Eastern Carpathians, Romania)

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Abstract

The ichnogenus *Avetoichnus* and the corresponding type ichnospecies *Avetoichnus luisae* Uchman & Rattazzi, 2011 were first described based mainly on specimens from Alpine (Italy) and Carpathians (Poland) deep sea realm as complex trace fossil, horizontal and sub-horizontal, with a helical spiral string around a simple core, which can be straight or slightly curved. Ethologicaly, is interpreted as agrichnion generated by non-graphoglyptids belonging to *Nereites* Ichnofacies. In this paper is presented the occurrence of *Avetoichnus luisae* in Eocene sediments from red and green shale member of Bisericani Formation from Vrancea Nappe, Bistrita half-window, Eastern Carpathians. The studied specimens reveal a close relationship with shallow water deposits, *Cruziana* Ichnofacies, possible characterized by isolated depletion in nutrients that could induce farming behavior of the producer.

Keywords: *Avetoichnus luisae*, *Cruziana* Ichnofacies, Late Eocene, Vrancea Nappe, Eastern Carpathians.

Introduction

In 2011, Uchman and Rattazzi described and interpreted a new complex helical trace fossil build up by non-graphoglyptid farming organisms. They successfully established a new ichnogenus and ichnospecies, analyzing material from the Aveto Formation (Oligocene) in the Apennines (northwestern Italy), the Bystrica Formation (Eocene) in the Carpathians (southern Poland) with references to material from other areas. By palaeoenvironmental point of view, *Avetoichnus* occurs as part of *Nereites* Ichnofacies at the outcrop scale, considered typical for deep-sea bathyal setting. Rodrigues-Tovar and Uchman (2012) mentioned punctual occurrences in Turkey and especially Spain; for the latter they presented in detail the record of *Avetoichnus luisae*, emphasizing facies relationship and palaeoenvironmental implications. They describe this ichnospecies in well oxigenated but nutrient-

poor deep sea associated or not with *Nereites* Ichnofacies. A taphonomic study of this new ichnospecies was performed by Monaco et al. (2012) on 104 specimens from Trasimeno area (Italy), Aveto (Italy), northern Spain, and Carpathians Paleogene turbidites. The authors describe *Avetoichnus* in Trasimeno area as endichnia in turbiditic mud of deep sea. Their variable morphologic parameters are interpreted as a result of activity adjustements (agrichnial or fodinichnial) to changes of turbiditic environment.
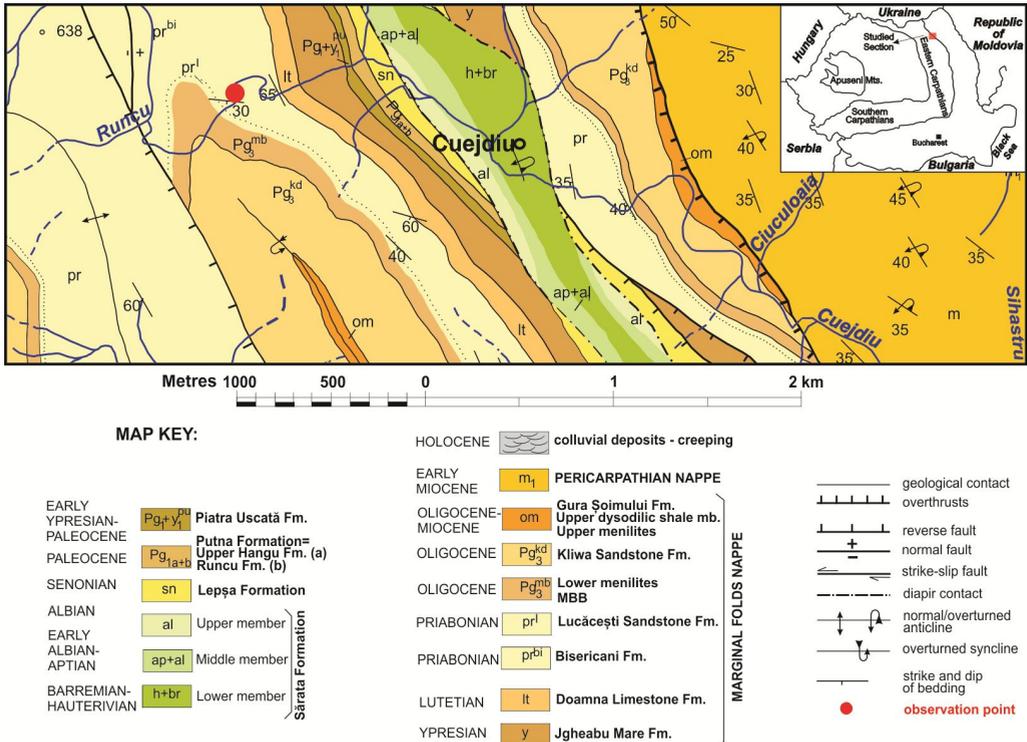
Fig. 1 Geological map with the location of the study area (after Micu, 1976).

The specimens presented in this paper come from the red and green shale member of Bisericani Formation (Fig. 1), a lithostratigraphic unit defined for Vrancea Nappe in Bistriţa half-window (Eastern Carpathians); they complement the description and, on some extent, the interpretation of this complex trace fossil.

Geological setting

The Romanian Carpathians belong to the Alpine chain and are the result of the Tethys-Paratethys Ocean closure, during Cretaceous to Miocene. Several branches of this ocean developed, merged and closed during this time (e.g., Vardar-Mureş Ocean, Silesian Basin, Măgura Ocean, Ceahlău-Severin"Ocean"). From Early Cretaceous to Miocene, in external area of Ceahlău "Ocean" represented by Moldavide Realm, were accumulated deposits build up during Miocene tectonic events in Moldavide Units (Guerrera et al., 2012 and the references within).

From the internal to external area, the Moldavide Units (or Outer Carpathians) are: Convolute Flysch, Macla, Audia, Tarcău,

Vrancea (or Marginal Folds) and Pericarpathian Nappes (Săndulescu, 1984).

The Late Cretaceous-Early Oligocene sedimentary record, which characterizes the former external Moldavide Basin (Vrancea Nappe sedimentation area), consists of litho-stratigraphic units, as following (Fig.1): Sărata (Late Cretaceous), Lepşa (latest Cretaceous-lowermost Paleocene), Putna-Piatra Uscată (late early Paleocene-late Ypresian), Jgheabu Mare (latest Ypresian-Lutetian), Doamna Limestone (Lutetian) and Bisericani Formation (Priabonian-early Rupelian), generally charac-terized of marked vertical and lateral litho-facies variability (Săndulescu, 1988; Grasu et al., 1988, 1999, 2007). Considerind the paleo-geographic position in the former basin of the Vrancea Nappe sedimentation area (Miclăuş et al., 2009), it is expected to find good pre-served ichnofossils in the heterolithic units where all the necessary conditions are fulfilled (the fine-grained, organic-rich muds were food for trace fossils producers and sandy episodes covered and preserved the burrows, tracks and/or traces). There are many units of this type in the sedimentary record but in this paper we refer to lower member of the Bisericani Fm.

The trace fossils under discussion were collected from red and green shale member of Bisericani Formation deposits (late Eocene =Priabonian), that crop out on Runcu Brook (46º59'39.01"N/26º16'6.90"E), a right-hand tributary of Cuejdi River. This upper part of the unit consists of greenish mudstone and sandstones, sometime rich in glauconite, with rare, lenticular, microconglomeratic beds with green schist clasts (Grasu et al., 1988).

In some synclines and anticlines, espe-cially in the southern part of Bistriţa Half-window, the member is better exposed, the sedimentary succession beginning with red mudstone containing thin interlayers of green mudstone, going up into red and green mudstone in equal parts, then in mainly green color mudstone with sandstones, similar with the ones which host the *Avetoichnus*. The approximately 7 m of heterolithics on Runcu Brook consist of relatively monotonous color, greenish-gray, rarely whitish-gray and yellow-ish-gray mudstone with greenish sandstone interlayers.

Sedimentation was the result of three fundamental processes: gravity flows, respon-sible for accumulation of the graded beds in lower part of the log; high and low energy tractive currents resulting in cross laminated sandstones; pelagic and hemipelagic fall-out resulting in mudstones for the rest of the heterolithic column. However, in the last decade there are an increasing number of papers which proved that the fines are often accumulated by tractive currents (Schieber, 2011; Schieber et al., 2007).

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Ichnological analysis implies the assess-ment of (Seilacher, 1978; Ekdale et al., 1984; Bromley 1996): (1) the size distribution of trace fossils; (2) the geometries of ichnofossils; (3) the association with other trace fossils; (4) the sedimentary deposits characteristics; (5) the frequency and density of ichno-structures; (6) the presence or absence of burrow wall ornamentation/lining; (7) the infilling type compared with the sediment burrowed and any other clues that indicate if it was a passive (by gravity collapse) or active (backfilling by the organism) infill; (8) the positions of the trace fossils relative to a specific deposit; and (9) the cross-cutting relationships. For the description of trace fossil we used simultaneously ethological (Ekdale et al., 1984) and toponomic classifi-cations (Martinsson, 1970).

In the analyzed log we observed on two whitish-gray mudstone surfaces a high abundance of dark colored, horizontal, slightly curved, zip-like trace fossils of various sizes (Fig. 2). According to Uchman and Rattazi (2011), this trace fossil represents a new ichnospecies, *Avetoichnus luisae* Uchman& Rattazi, 2011, a complex ichnofossil charac-terized by a helical spiral structure with a simple, straight or curved, central core (Fig. 3a). Specimens described by the named authors are up to 35 mm long and over 3 mm

wide (diameter) and appears as two rows of dots (1.0–2.0 mm in diameter) alternatively arranged along a central horizontal to sub-horizontal axis. These axes are nothing more than sections of horizontal helical spirals and the zip-like shapes are the expressions of the same horizontal sections. Each whorl of the

helical spiral was preserved as pair of dots, so it is possible to establish the number of them as well as the degree of the coiling. Monaco et al. (2012), in their study on morphologic parameters variability, measured lengths between 7 and up to 75 mm and widths (diameters) from less than 3 to more than 7 mm.
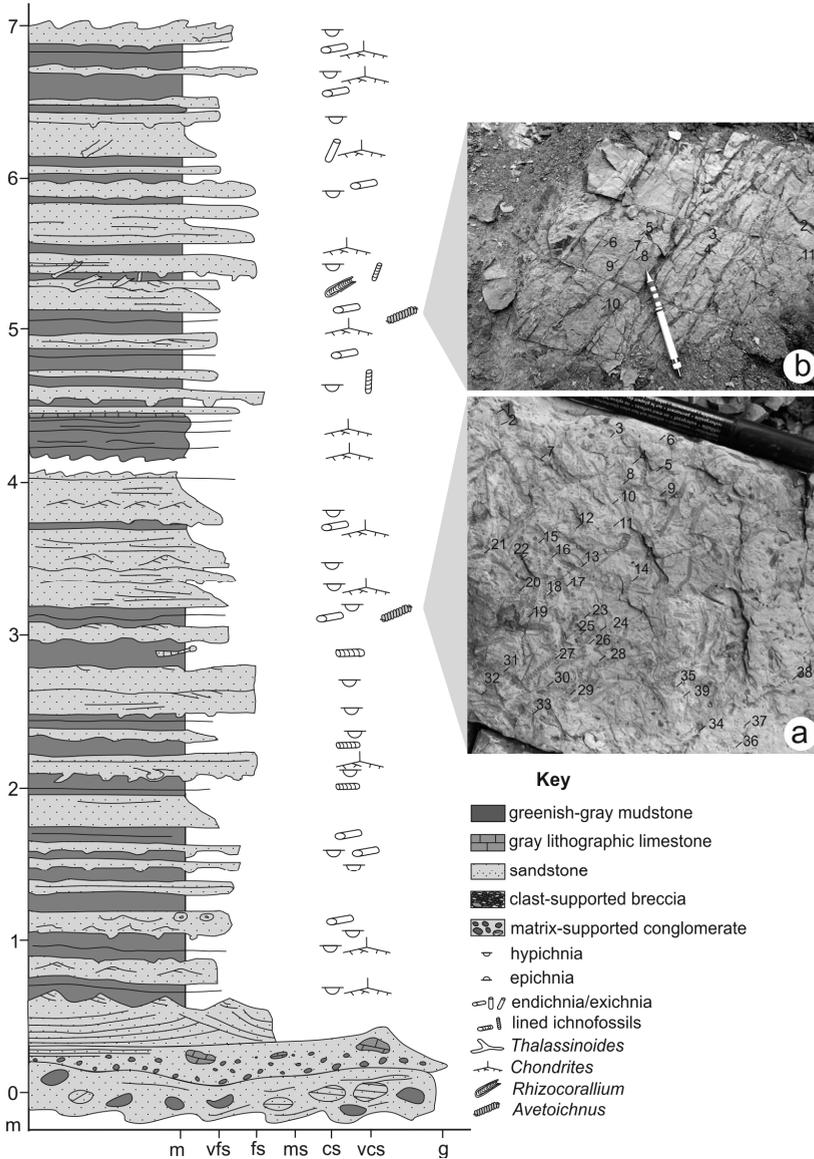
Fig. 2 Upper part of red and green shale member of Bisericani Formation (Runcu Brook log) with the position of *Avetoichnus luisae* Uchman&Rattazzi, 2011 beds.

The new ichnotaxon definition was based on the analysis of 21 Cenozoic specimens, collected from the T_e subdivisions of turbidite beds or at the transition from turbiditic sandstone to shale or marls from the Apennines (Italy), the Carpathians (Poland), northern Spain and Turkey. It was first described from Aveto Formation in the Apennines, hence the ichnogenus name. For its occurrence it was also proposed a stratigraphic range of latest Palaeocene-early Oligocene (Uchman and Rattazzi, 2011).

What we describe here is a situation of high abundance, not mentioned until now, i.e., 39 specimens on the lower bed (Fig. 2a – surface A of about 0.02 m²) and 11 on the upper one (Fig. 2b – surface B of 0.07 m²), more than twice than it was carefully studied for documentation of this new ichnospecies. We must assume that the number may be much higher if more of the two surfaces would be exposed.

The bioturbated surface A (Fig. 2a) occurs in the top part of a composite bed (12 cm thick) which have the following characteristics: sharp lower bounding surfaces with small hypichnia trace fossils; 7–8 cm sandstone coset consisting of 4 trough cross laminated sets having *Planolites* with glauconite infilling on set's bounding surfaces; undulated upper bounding surface draped by 2–3 cm coarse mudstone with large *Planolites* (8 mm wide) and small *Chondrites*; 0.2 cm of finer mudstone with *Avetoichnus luisae*, covered by 0.5–1 cm thick mudstone layer with large *Chondrites* and oxidized *Planolites* detachable infillings. The bioturbated surface B (Fig. 2b) occurs in a thinner bed with similar features.

The length of the largest specimens described so far is not more than 75 mm, while the width is up to 6 mm (Monaco et al., 2012), in the studied section, some specimens being close to these sizes (Fig. 3h). Among the 50 ichnofossils on the two surfaces, a few individuals were selected to be described (Fig. 3). In some cases, they appear as two rows of oval (Fig. 3a, b, c, e, g) or circular (Fig. 3d, h, i) dots, flanking an either straight (Fig. 3b, c, e, g, i) or slightly curved (Fig. 3a, d, f, h),

central, horizontal to subhorizontal axis. In other cases, when the cross-section of the spiral is not a perfect twin-cut, only a single row of dots can be seen (Fig. 3f left), exposing the lower or upper marginal part of the spiral.

The dots are enhanced by the strong color contrast (Fig. 3e, g). This is not the case for the central core, which is a little lighter than the dots, but still darker than the host rock (Fig. 3g) and rarely observed due to poor preservation (Uchman and Rattazzi, 2011).

The ovalness of the dots in the single rows depends of the position where the spiral was sectioned. The closer to the axis the section is, the greater the ovalness.

Regardless they are paired or single rows, the dots are 0.7 to 1.5 mm in diameter. When they are paired, they represent cross-sections of horizontal helical spiral with whorls coiled at 1 to 2 mm apart. The number of whorls varies from 6 (Fig. 3c) to over 42 (Fig. 3h). The dots don't have the same sizes across the whole length of the specimen. The width of some specimens from both surfaces decreases toward one end. This might be due to: 1) whorl diameters decrease; 2) subhorizontal position of the specimens related to the lamination surface; 3) crossing at small angle between axial section plane and exposed section plane. Some specimens seem to be branched (Fig. 3g). Monaco et al. (2012) describe specimens with branches either at 45º or 90º. The example in Figure 3g is closer to 90º.

According to Uchman and Rattazzi (2011), a specimen can be represented by a sequence of horizontal spiral whorls with different orientation, built at different levels, connected through short vertical to oblique fatter spiral whorls. Consequently, the same individual can be seen at several levels in a bed of few millimeters thick. If this is the situation, it means that Figure 3b might display a three-dimensional individual observed at two different levels and not different specimens for each level.

As mentioned before, *Avetoichnus luisae* occurs at least two times in the red and green member of Bisericani Formation from Runcu

Brook. In both cases this ichnospecies co-occurs with small *Chondrites intricatus* and *Planolites*, but they are not coeval, possible being part of different ichnoguilds.
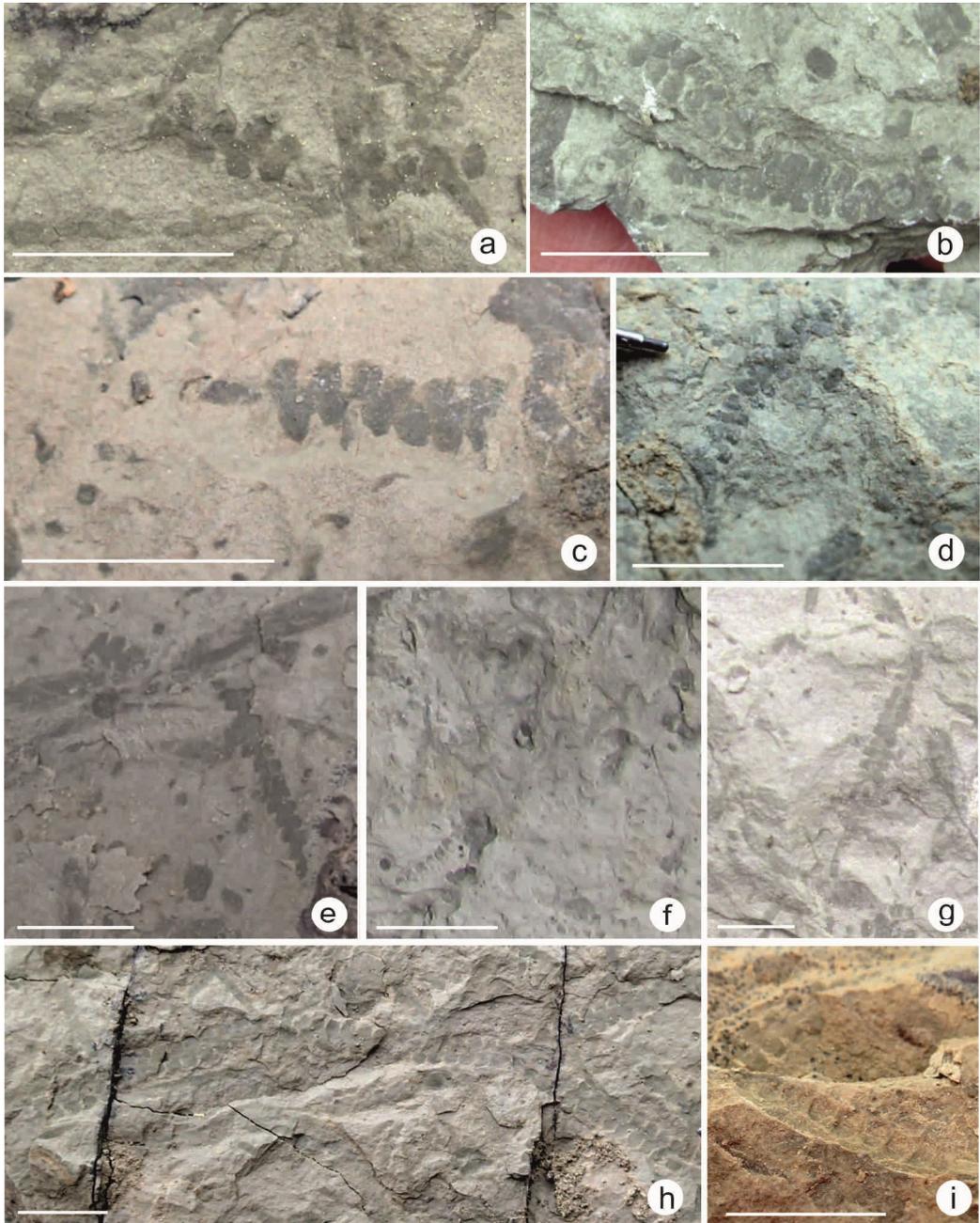
Fig. 3 *Avetoichnus luisae* from the upper part of red and green shale member of Bisericani Formation. The white scale bar is 5 mm long. See the text for explanations.

The ichnoguild concept was developed on ecological "guild" significance which was best stated by Root (1967) as "a group of species that exploit the same class of environmental resources in a similar way". Later on, Bambach (1987) separated three general criteria for grouping species of a community characterized by the same *bauplan* (reproduction, development, growth and physiology), foods source (suspended matter, detritus, plants or animals) and space utilization (pelagic, epifauna or infauna).

Bromley (1996) adapted Bambach's three factors by: 1) removing taxonomic restriction from the bauplan and categorizing the mobility of the tracemakers that lead to a specific ichnostructure; 2) considering the food source in terms of feeding behavior, and 3) using space in terms of tiering. The latter concept is not employed as it should be, yet, but hopefully some universal ichnoguilds will be established in order to add valuable information to paleoenvironmental interpretations.

As concern the tiering, if normal oxygen content at water-sediment interface is considered, the shallowest tier is represented by *Planolites* that is built in soft superficial deposit, while *Chondrites* tracemaker characterizes deeper, stiffed sediment (Ekdale and Bromley, 1991). The distribution of organism and their traces below the sediment-water interface is the definition of tiering (McIlroy, 2004). Its preservation relies upon rapid death of the community because of different environmental changes, considering that the deeper burrows tend to overprint shallower ones with continuing deposition. It is considered to be the result of separation of the infaunal realm into different niches, each one being characterized by similar feeding strategies and grouped into "ichnoguilds" (*senso* Bromley, 1996).

Chondrites structure makers follow the sea floor aggradation and, at some point, populate the levels already colonized with *Planolites*, usually deformed due to their burial. When dysoxic conditions characterize the water-sediment interface, *Planolites* tracemakers are inhibited, therefore the association with younger *Chondrites* is not possible.

According to previous studies (Uchman and Ratazzi, 2011; Rodrigues-Tovar and Uchman, 2012; Monaco et al., 2012), *Avetoichnus luisae* is a mid-tier trace fossil, consequently when it co-occurs with *Planolites* and *Chondrites* (Fig. 4a) we can assume that *Avetoichnus* is younger than *Planolites* and older than *Chondrites*. Figures 3a and 4a show *Planolites* clearly crossed by *Avetoichnus*, proving that they are not coeval, while in Figure 3g *Chondrites* it is seen to cross-cut *Avetoichnus*.
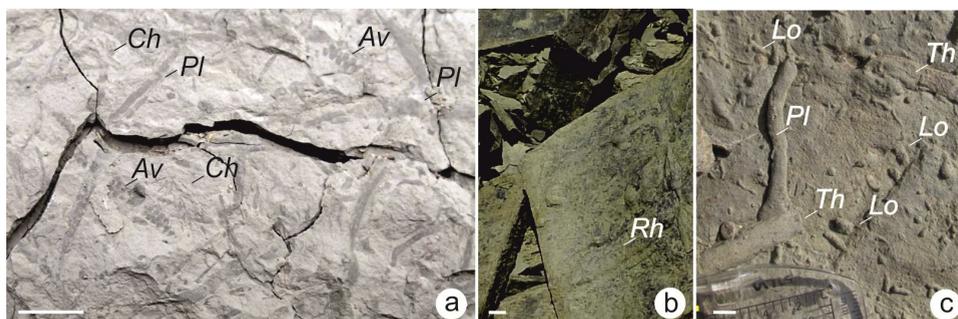
Fig. 4 *Avetoichnus luisae* co-occurences. a – *Planolites* crossed by *Avetoichnus*; b, c – associated trace fossils at the outcrop scale. *Ch – Chondrites; Pl – Planolites; Av – Avetoichnus luisae; Rh – Rhizocorallium; Lo – Lockeia; Th – Thalassinoides*. The white scale bar is 5 mm long.

The order of emplacement of the burrows is very important in palaeoenvironmental analysis along with the recognition of successive cross-cutting palaeocommunities associated with the same sedimentary unit. In Figure 5, we propose a scenario for the

observed co-occurence of *Planolites*, *Avetoichnus* and *Chondrites*, enhancing their cross-cutting relationships for better understand the colonization history. At T1 the trace producers colonize the sediment at their favorite niches, seen as tier levels. With continuing deposition (sea floor aggradation), as seen at T2 and at T3, the deeper burrows tend to overprint the shallower ones. So, the earlier mentioned assumption that *Avetoichnus* is younger than *Planolites* and older than *Chondrites* rises as a fact.
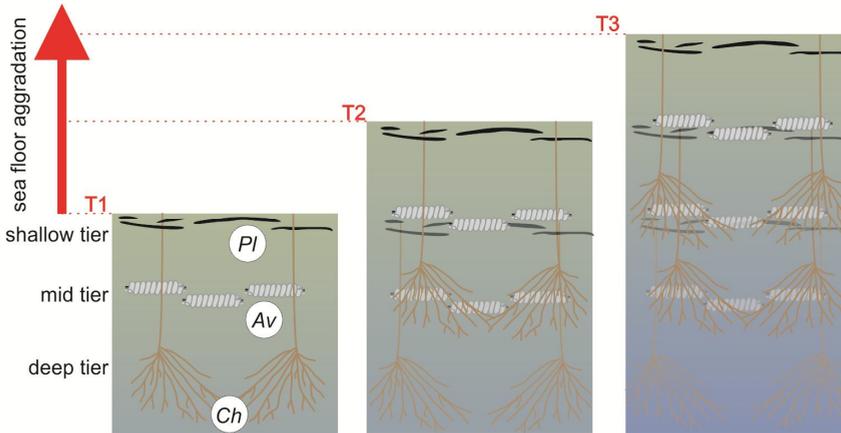
Fig. 5 A possible scenario of the co-occurrence of *Planolites*, *Avetoichnus*, and *Chondrites* based on tiering level (see the text for explanation): *Pl-Planolites*; *Av-Avetoichnus*; *Ch-Chondrites*; T1, 2, 3 - sea floor at time 1, 2, 3.

In this model we did not take into consideration neither the compaction of sediment with burial deepness due to continuous accumulation, nor the deformation of the shallow tiered trace fossils. There are some situations when the substrate consistency at bioturbation time can be established by evaluating the degree of deformation or detachment of the traces (Schieber, 2003). In Figure 4a, for example, *Planolites* specimens are completely flattened, indicating the sediment was soft, even soupy, when was bioturbated. In the same time, the negative reliefs of A*vetoichnus* in Figures 3d and 3i are nothing more than the casts of detached trace fillings made in a deposit characterized by some consistency (probably stiffed).

Avetoichnus luisae Uchman&Rattazzi, 2011 in *Cruziana* Ichnofacies

At the outcrop scale (Anistoroae, 2014), *Avetoichnus luisae* co-occurs with trace fossils such as (Fig. 2) *Lockeia*, *Thalassinoides*, and

Planolites (Fig. 4c), and especially *Rhizocorallium* (Fig. 4b). According to Seilacher (2007), *Rhizocorallium* is a feeding burrow without an established behavioral genealogy. For Knaust (2013), the same ichnogenus is a component of the *Cruziana* Ichnofacies, characterizing the marine realm from closely above the fair-weather wave base to the storm wave base, namely an area ranging from the lower shoreface to the lower offshore in wave-dominated seas (Buatois and Mangano, 2011). *Cruziana* Ichnofacies includes deep-tier as well as shallow-tier traces and the general aspect of the assemblage varies with the degree of bioturbation that, in turn, varies with the degree of community maturity (Bromley, 1996). This ichnofacies consists of all ethological type trace fossils, mainly horizontal and subhorizontal (Frey and Seilacher, 1980; Seilacher, 2007; Buatois and Mangano, 2011; Knaust, 2013).

All sandstone bed sets are characterized by trace fossils of epichnia, hypichnia and exichnia types, while the mudstone beds,

some siltstones and thin sandstones are characterized by endichnia and rare exichnia. The specimens of *Avetoichnus* are endichnia type trace fossils (Martinsson's terminology, 1970), related by the light greenish-gray mudstone, which at the time of their bioturbation had some consistency as it is proven by positive (Fig. 3b, d) and negative (Fig. 3i) relief of some of them.

Avetoichnus luisae usually co-occurs with *Chondrites*, *Planolites*, *Thalassinoides* and *Zoophycos* but also with ichnogenera typical for the *Nereites* Ichnofacies including *Nereites*, *Paleodictyon*, and *Spirorhaphe*, some of them belonging to graphoglyptids (Uchman and Rattazzi, 2011; Rodrigues-Tovar and Uchman, 2012). *Nereites* Ichnofacies with its sophisticated graphoglyptids (e.g., *Paleodictyon*, *Spirorharphe*) and grazing trails (e.g. *Nereites*) is associated with deep sea settings where the nutrients are poor. Consequently, the trace makers develop different strategies to feed themselves, the commonest being farming and grazing (references in Buatois and Mangano, 2011). In addition, the delicate structures of *Nereites* Ichnofacies use to preserve on thin turbidite soles which also are considered to indicate deep sea. The occurrence of *Avetoichnus* in such association brought Uchman and Rattazzi (2011) to an ethologic interpretation of it.

According to them, this ichnospecies can be considered a composite trace fossil of a non-graphoglyptid tracemaker that stashes the organic rich surface sediment inside a deep burrow. The stored sediment is the start source of a bacteria farm, consequently *Avetoichnus luisae* being an agrichnia type.

However, the red and green member of Bisericani Formation trace fossil's content suggests either a different ethologic interpretation or the same ethology in restricted poor nutrient time spans.

The co-occurrence of *Rhizocorallium* with *Avetoichnus* in analyzed section suggests shallower settings than initially established. It is possible the ichnogenus under discussion to be a cross facies and if this is the case the ethological diagnose might be different. Although *Paleodictyon*

miocenicum (*pleudodictyonoides* form) was previously mentioned in Bisericani Formation on Nechit Brook (Brustur, 1995 in Brustur, 1995; table 1), no details about its co-occurence or position in the outcrop were given.

In the same time, the defined farming behavior might be induced by occasionally low nutrients availability, if we consider its rare occurrence in the studied log. A similar situation where *Avetoichnus* occurs in sedimentary successions characterized by mottled ichnotexture, suggesting benthic food availability punctuated by absence of trace fossils, is mentioned by Rodrigues-Tovar and Uchman (2012). In this case, where it is not related by deep sea *Nereites* Ichnofacies, its occurrence would be explained by punctual nutrients depleted conditions, affecting macrobenthic environment which determined the farming strategy of *Avetoichnus* trace makers.

Conclusions

In the red and green shale member of Bisericani Formation (late Eocene), on two light greenish-gray mudstone surfaces, we counted 50 specimens of *Avetoichnus luisae* Uchman&Rattazzi 2011, an ichnospecies which is described for the first time in Eastern Carpathians' "flysch" deposits. The analyzed sedimentary succession is characterized by high abundance but moderate diversity of trace fossils, such as *Planolites*, *Chondrites*, *Thalassinoides*, *Lockeia*, *Rhizocorallium*, and other horizontal and subhorizontal ichnostructures pointing to *Cruziana* Ichnofacies.

The original interpretation of this ichnospecies links the tracemakers by deep sea settings, together with ichnofossils belonging to *Nereites* Ichnofacies (*Nereites*, *Paleodictyon* and *Spirorhaphe*) consisting of graphoglyptids and grazing trails (Uchman and Ratazzi, 2011).

Here is presented a situation when *Avetoichnus luisae* co-occurs with trace fossils rather indicating *Cruziana* Ichnofacies usually associated with shelf environment. In the bed by bed analyzed section no graphogliptides or grazing trails were found. Therefore, the previously suggested ethological interpretation

as agrichnia may be just one of the possibilities.

If the ethological aspects are difficult to establish, the tiering ones may be used to separate ichnoguilds and deduce the dynamics of sea floor aggradation. We propose a scenario to explain the co-occurrence of *Planolites*, *Avetoichnus* and *Chondrites*, especially when they cross-cut each others. Based on their known or supposed tiering levels, we suggest that when they are together in the same level, this is the result of upward migration of the producers which keep peace with sea floor aggradation. In this way, in the association *Planolites*, *Avetoichnus* and *Chondrites*, they might not be coeval, but the oldest is the first one, while the youngest is the last one.

Avetoichnus luisae is an intriguing trace fossil and needs further investigation in terms of its complex ethology as well as ichnofacies affinity.

Acknowledgements

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