POSSIBLE MIDDLE PONTIAN AVIAN AND MAMMALIAN TRACE FOSSILS FROM THE DACIAN BASIN (SLĂNICUL DE BUZĂU VALLEY, ROMANIA)

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Abstract. The presence of bird feeding traces associated with undertracks of a small mammalian, probably similar to the European mink (*Mustela lutreola*), indicates the existence, unknown so far, of terrestrial fauna in the middle Pontian (Portaferrian) deposits from the Dacian Basin. The pecking and probing marks were probably produced by Charadriiformes and Anseriformes representatives, whose ichnospecies are known in the upper Oligocene and lower Miocene from Romania. Although there are no traces of invertebrates, usually associated with the footprints of birds and mammals, we assume that the described feeding traces and undertracks belong to the *Scoyenia* ichnofacies that is a shoreline environment with humid clay substratum and intermittent subaerian exposure.

Key words: avian feeding trace, small mammalian undertrack, Portaferrian Substage, Carpathian Foredeep

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1. INTRODUCTION

Since the late Sarmatian the Dacian Basin, located in the western part of the Eastern Paratethys, constituted the accumulation area for brackish upper Sarmatian, Pontian and lower Dacian sediments and freshwater upper Dacian - Romanian ones (Jipa and Olariu, 2009). The Pontian fauna extensive development and regional segregation was produced during the Dacian Basin isolation (Olteanu, 2006). In the middle Pontian (the Portaferrian Substage) the mollusks community increased considerably (Olteanu, 2006), with numerous new bivalve and gastropod genera and species. These have been studied over the last 130 years, especially those found in the Carpathian Foredeep area (Cobălcescu, 1883; Ciocârdel, 1943; Macarovici, 1961; Pană, 1966; Andreescu, 1977; Papaianopol, 1989; Marinescu and Papaianopol, 1989; Macaleț, 1999, 2001, and others). In the same interval, studies were performed in the Moldavian Platform lacustrine deposits with accumulations of mammalian (Ionesi *et al.*, 2005), made of post-Pontian species well represented at Mălușteni and Berești (Simionescu, 1930, 1932; Rădulescu and Samson, 1995; Rădulescu *et al.*, 2003).

As for the Dacian Basin Neogene trace fossils, the literature refers only to the borings (*Oichnus*-type, *author's note*) made by naticide gastropods on the *Viviparus* shells Romanian in age, that occurs in the Ocnița-Moreni zone (Damian, 2001). Outside the Dacian Basin, in the Banat area, borings on Sarmatian and Pontian gastropods are mentioned (Jekelius, 1944), as well as traces of lithophaga mollusks (*e.g. Lithophaga*, *Pholas, Clavagella* and *Saxicava*) in the Sarmatian limestones from the Black Sea littoral zone (Macarovici, 1969). In the fossil soils of the Romanian Plain loess, Protopopescu-Pache (1923) concisely describes crotovines, representing the rodent mammals galeries (*Cricetus, Spermophyllus* and *Arctomys*). Recently, Brustur and Jipa (2009) brought up paleoichnological arguments (rhizolithes and *Gastrochaenolithes*) for presence of a discontinuity surface in the middle Pontian deposits of the Carpathian Foredeep area, in Buzău River basin (as well as proof of the action of very strong paleowinds – see Brustur, 2016).

This paper presents, for the first time, problematic traces of animal activity (possibly, shoreline bird feeding marks and undertracks of a small-size mammalian) in the Portaferrian deposits cropping out in the Slanicul de Buzău River basin. The significance of these traces for the Dacian Basin paleogeographic evolution is discussed.

2. GEOLOGICAL SETTING

The Portaferrian deposits of the northern Dacian Basin (Fig. 1a) are well developed along the Slănicul de Buzău River in the Sârbești locality (Fig. 1c). In this area, close to a Pontian shoreline sedimentary succession (Fig. 1b,d), a sandstone block with several problematic trace fossils was identified (Fig. 1e). This outcrop corresponds to the basal part of the lithostratigraphic column presented in Jipa and Olariu (2009) (Fig. 1f).

The Sârbești middle Pontian deposits, situated on the western flank of the Berca-Arbănași anticline (Macarovici, 1961; Jipa and Olariu, 2009), are distinguished by the temporal alternance of continental and brackish-marine facies. The continental deposits are made of alluvial sediments, accumulated in alluvial channel and out-of-channel environments. The out-of-channel sediments show a variety of facies, including non-stratified, homogeneous clay (flood plain), fine grained sand with cross lamination (flood sheets), coal, clayey coal and paleosoil. The brackish-marine sediment accumulaion is represented by stratified clay and by wave-rippled sandstones (Fig. 1b,d).

According to Jipa and Olariu (2009), the Sârbești middle Pontian deposits accumulated in a delta plain environment. In this environment, the delta river canals have undergone frequent lateral migrations, allowing the accumulation of marine sediments in temporarily out of fluvial space. The lithostratigraphical context and the paleoichnological content of the Portaferrian succession of the Slănic de Buzău Valley were recently described view by Brustur and Jipa (2009).

Thus, the above-mentioned authors indicate that the friable sandy deposits with more than one *rhizoliths* occurring in this succession point to the presence of paleosoils affected by variations of the hydrostatic level, indicating a local/regional regression surface. After the middle Pontian continental depositional interval, a marine transgression developed. This is indicate by a relatively numerous *Gastrochaenolites*, ichnogenus usually associated with occasional erosional exposure of older sediments, which implied sea level variations.

3. MATERIAL AND PRESENTATION OF DATA

The trace fossil data derive from a set of larger-scale and detailed pictures the most representative being selected for the paleoichnologic analysis (Fig. 2). The longitudinal parallel grooves (Fig. 2b) may be assigned to a small size mammal, but this interpretation is not relevant for the bilobated specimens in large number on the bed surface (Fig. 2a). Morphologically speaking, size and resemblance with similar traces described in the literature, the bilobate features probably belong to feeding shoreline birds.

3.1. Avian trace (beak marks)

The examination of the bed surface with hypichnial punctiform-hemispheric and bilobated marks (Fig. 2a,b) indicates the presence of two types of tracks that might indicate a shorebird feeding activity. The similar size tubercles row (Fig. aa$_1$) suggests a pecking feeding activity of the superficial mud substrate less than 1-2 mm in depth. In contrast, the bilobated marks (Fig. 2b) highlight the lobes asymmetry. Some specimens show longer upper lobes, less curved and covering the shorter and more curved lower lobes (Fig. 2bb$_1$). Other specimens have apparently equal size lobes and straight (Fig. 2bb$_2$) or curved (Fig. 2bb$_3$) median furrow. The lobe surface has no ornaments. The size of several specimens (number of specimens n=9) ranges between 10.7 and 21.5 mm (mean = 14.2 mm) in lengthwise and from 7.7 to 16.0 mm (mean = 11.5 mm) in width (Fig. 2c). The length to width ratio (L/w) is 1.25. Some specimens are almost isometric, less than 10 mm in size.

According to the above characteristics, the specimens described herein are almost identical to the Abbassi *et al.* (2015b, fig. 13A) morphotypes. We consider that the larger lobe corresponds to the upper part of the beak and the smaller lobe to its lower part. In our interpretation, these morphotypes represent a one-probe mark of the substratum. An extensive discussion on the bird feeding marks is offered by Falk *et al.* (2010, 2014) (Lower Cretaceous Haman Formation, South Korea) and Fiorillo *et al.* (2011) (Upper Cretaceous deposits from Alaska, USA). Possible bird probing and pecking marks are presented by Zonneveld *et al.* (2011) from Sumatra Oligocene deposits. From Holocene sediments (Dakota de Sud, USA) Falkingham *et al.* (2010) show numerous semicircular site marks, which are considered bird feeding marks, without indicating the number of marks.

3.2. Mammalian tracks

On the layer surface with many marks assigned to bird feeding tracks, two oblique deep undertracks are visible Fig. 2d). These features are probably produced by a 30° angle sliding (Fig. 3a) of the, most probably, front limbs into the sufficiently consistent substratum mud (Fig. 3b). This setting allowed the conservation of the longitudinal striations made by the straight claws and by the hairs of the front limbs, or grains of sand on the sole of the foot (Fig. 3c). After the limbs were retrieved from mud (Fig. 3bb$_1$), the created mould was covered with a fine grained parallel laminated sand layer that also shows *Skolithos*-type structures (Fig. 3bb$_2$).

The sizes of the undertracks are the following: d$_1$ trace: 98 mm length and 90 mm width; d$_2$ trace: 109.8 mm length and 98 mm width; 240.6 mm distance between traces; angle of divarication from midline = 8-9° (Fig. 3e). Thre is a small difference between the percentual values (24.9% *vs* 21.43%) of ratio between the distance between traces (240.6 mm – Fig. 2d; 14 mm – Fig. 2f, after Sidorovici, 2001, p. 135, fig. 2) and the distance between d$_1$ and d$_2$ tracks (60 mm between – Fig. 2d; 3 mm – Fig. 2f, after Sidorovici, 2001, p. 135, fig. 2). The ≈4% differentiation could represent measurement errors on the photographic images.

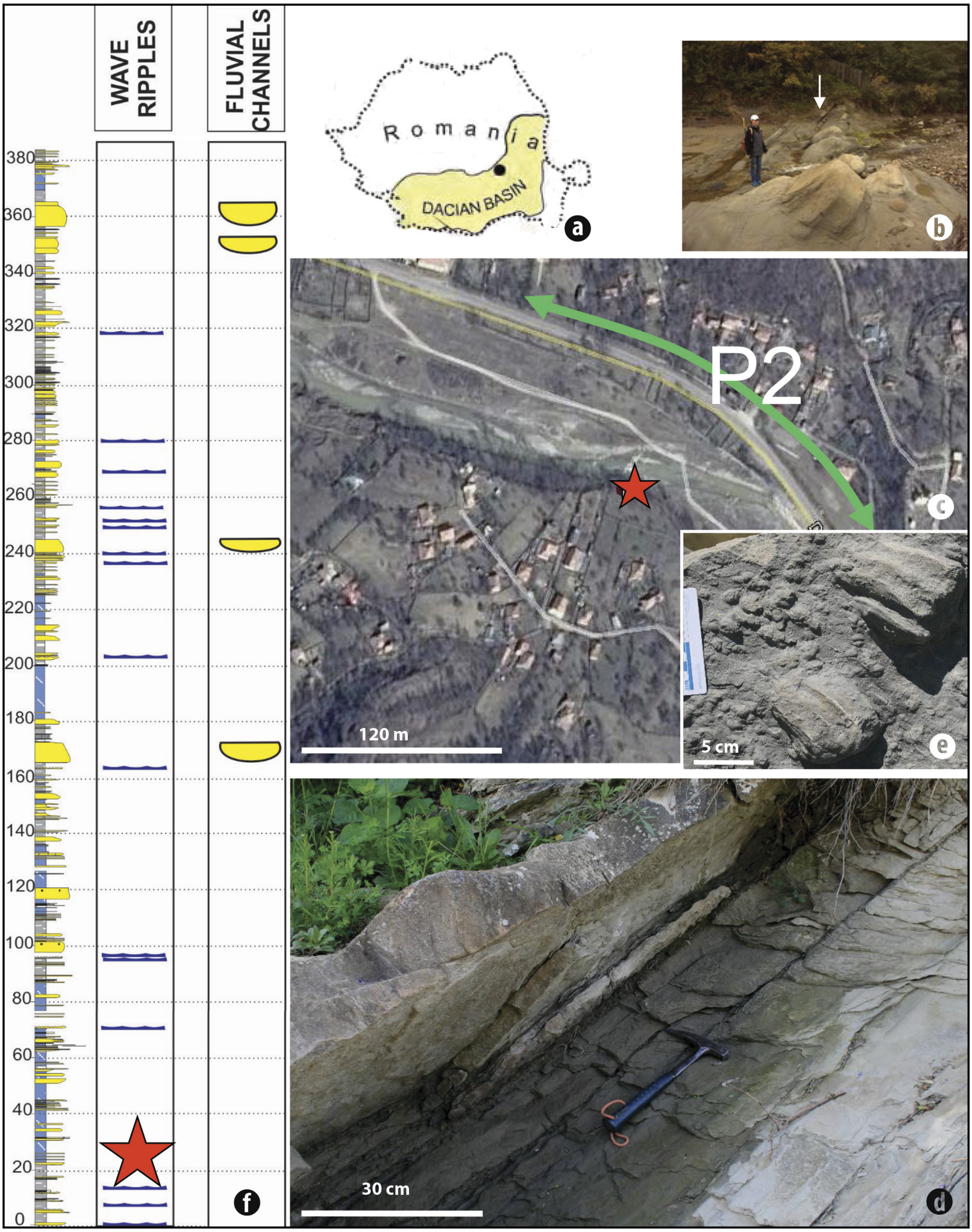

Fig. 1. a. Location of the area with middle Pontian (Portaferrian) deposits from Sârbești, in the Dacian Basin (after Jipa and Olariu, 2009); **b**. View of the Portaferrian site (white arrow) outcrop on the Slănicul de Buzău Valley (photo Jipa, June 2009); **c**. Location of the ichnofossiliferous in the Portaferrian deposits (P2 – green line); **d**. Detailed view outcrop B, showing the sandstone bed with decimetric wave ripples and current lamination (photo Brustur, November 2012); **e**. Partial view of the sandstone block with the problematic trace fossils (photo Jipa, 2009); F. Middle Pontian stratigraphic log with the wave ripples and alluvial channel occurrences (modified from Jipa and Olariu, 2009; the red star shows the position of the outcrop and the provenance of the sandstone block with problematic trace fossils)

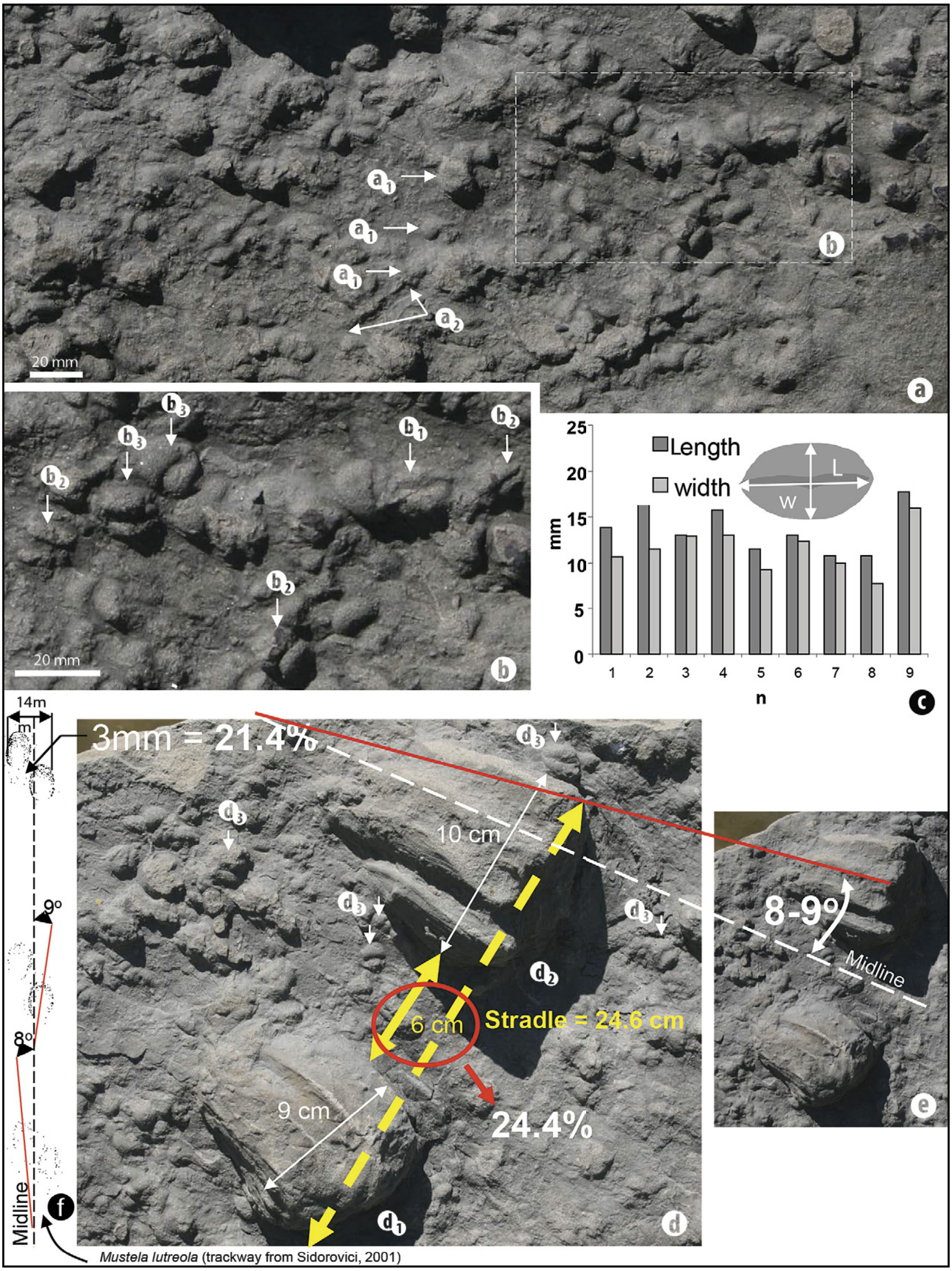

Fig. 2. a. Punctiform pecking traces (a$_1$) along a trackway ending with a curve segment (a$_2$ – *sensu* Abbassi *et al.*, 2015b). **b**. Bilobate probe marks. Detail from Fig. 2a outlining the bilobate specimens with double arched groove (b$_1$), straight (b$_2$) and curved (b$_3$). **c**. The diagram of the bilobate specimen lengths and widths variation (number of specimens, n = 9). **d**. The undertracks (d$_1$, d$_2$) produced by limps sliding into substratum together with probing signs (d$_3$). **e**. The angle of foot divarication from midline (8-9º). F. *Mustela lutreola* trackway (after Sidorovici, 2001).

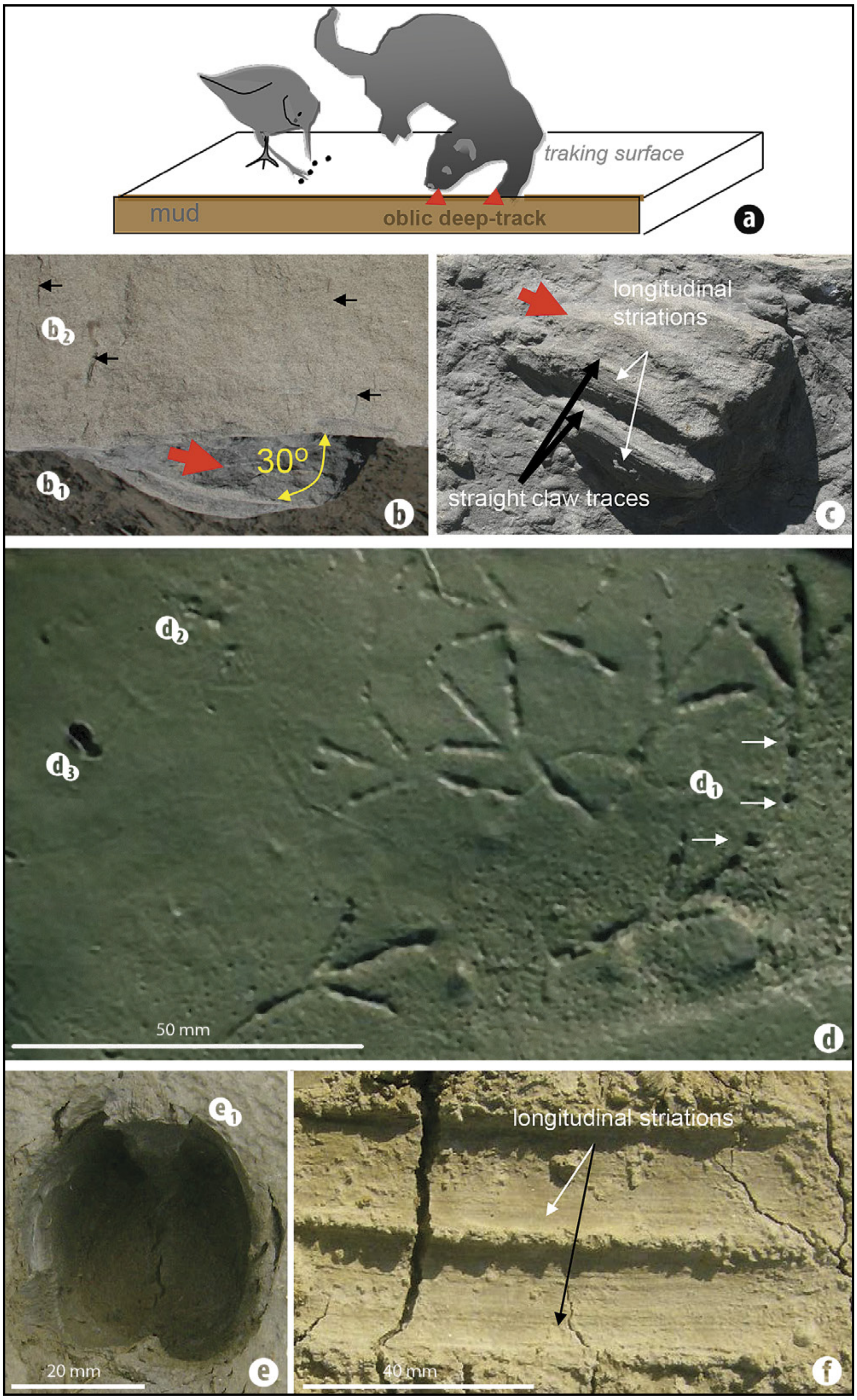

Fig. 3. a. Production of the oblique undertracks by slipping to the edge of the pelitic sediment surface (the animal silhouette modified from https://www.google.com); **b**. The oblique substrate mould (b_1) under an angle of about 30º resulting by coverage with fine-grained sand (b_2), which shows *Skolithos* vertical tubes (black arrows); **c**. Undertracks with the marks of the claws and the fine longitudinal striations produced by the hair of the front limbs (photo D. Jipa, 2009); **d**. Modern traces of *Motacilla alba* with feeding signs (probing d_1, d_2 and dumbbell-shaped figure-of-eight – d_3, *sensu* Fiorillo *et al.*, 2011) (photo T. Brustur, 2016, Slănicul de Buzău Valley, near the Dogari bridge); **e**. *Ovis aries* – vertical deep-undertrack with extruded prism (e_1); **f**. *Ovis aries* - slipping track on dry mud with longitudinal striations (photo T. Brustur, 2008, The Mud Volcanoes Pâclele Mari).

In view of these characteristics, we can assume that these traces belong to a small mammalian, probably from the Carnivora order (Mustelidae family). This mammalian is quite close to the European mink (*Mustela lutreola*), whose head and trunk measures 35-40 cm, tail 13-14 cm and weight 550-800 g (Murariu, 1993).

Presently, in Romania, the mink is mainly found in the Danube Delta, but also throughout the country, especially, along rivers and ponds. Interestingly, the finning membrane that joins fingers, does not appear in the pattern of the trace, as is the case of the European otter (*Lutra lutra*) (Rosetti-Bălănescu, 1961).

4. DISCUSSIONS

Referring to the fossil ornithofauna, the literature does not record the presence of the footsteps of birds in Pontian. The synthesis of the Cenozoic birds in Europe (Mlíkovský, 2002) records the birds footstep traces in the Oligocene (MP 25-30), from Câmpul lui Neag, the Petroșani Basin (Rădan and Brustur, 1993) and the lower Miocene (MP 3-4), in various localities of the Subcarpathian Moldavia and Muntenia regions (Grozescu, 1918; Paucă, 1942, Panin 1961, 1964, Panin and Avram 1962, Panin *et al.*, 1966).

The presence of punctiform and bilobate traces at the lower part of the Sârbești middle Pontian sedimentary succession (Jipa and Olariu, 2009, fig. 5.32) indicates the activity of feeding shorebirds, probably, at the edge of some permanent or temporary lakes. Examples of this type of setting are reported in various areas and in geological formations of different ages: Korea, Lower Cretaceous (Falk *et al.*, 2010, 2014); USA , Upper Cretaceous (Fiorillo *et al.*, 2011), Eocene (in Hunt and Lucas, 2007); Argentina, Late Eocene (Melchor *et al.*, 2013), and Iran, Neogene (Abbassi *et al.*, 2015b).

Thus, Melchor *et al.* (2006) and Genise *et al.* (2009) mentioned the presence of small epichnial rounded pits on bed surfaces that preserve the bird footprints, interpreted as

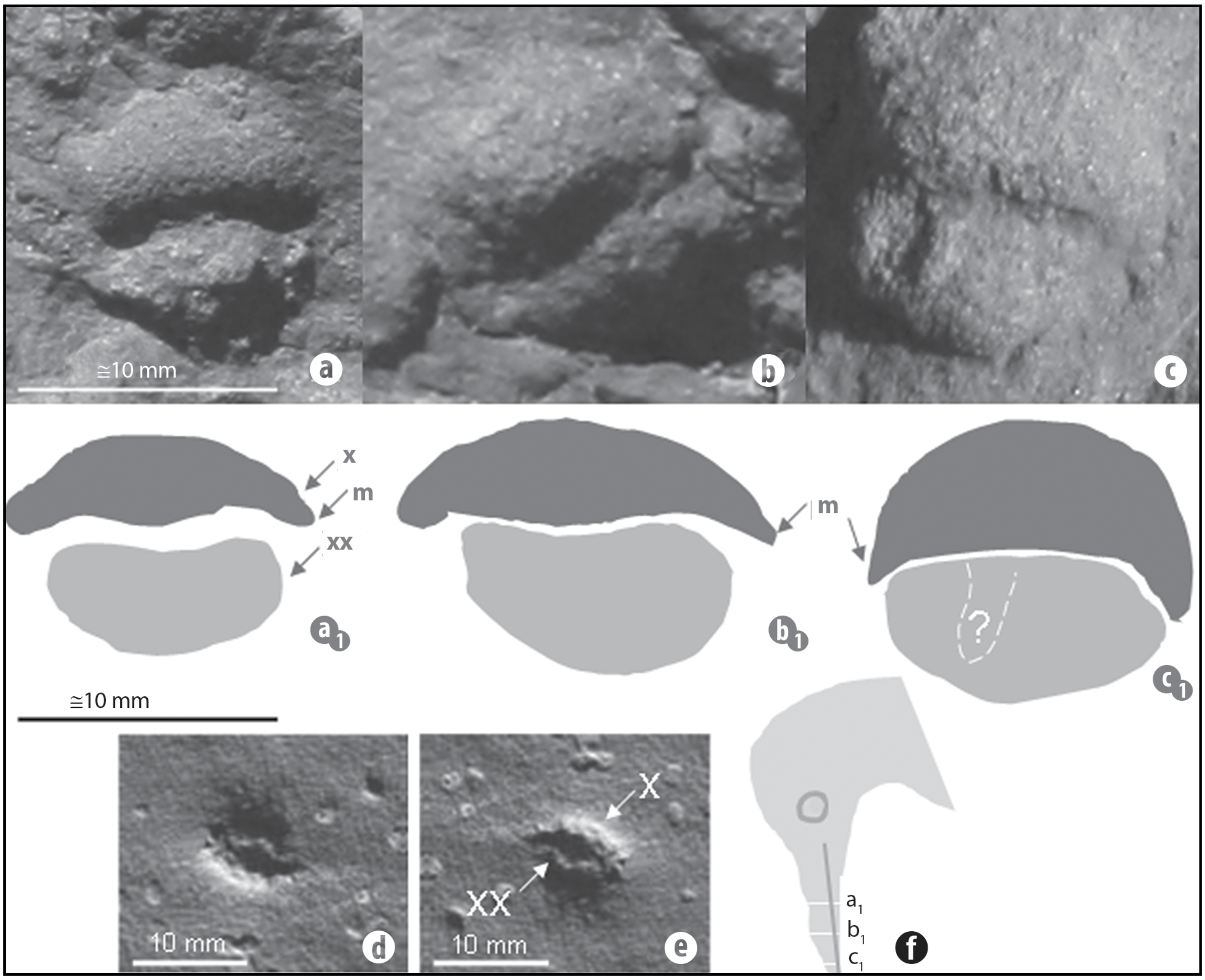

Fig. 4. a-c. Bilobate bill trace (convex hyporeliefs) with longitudinal incisions along the sagittal plane (*sensu* Abbassi *et al.*, 2015b). **a**$_1$-**b**$_1$. Silhouettes of bilobate traces rotated 180º (x = upper part of the bill); xx = lower part of the bill; m = marginal jaw; **c**$_1$. Silhouette in normal position; **d**. Bill-probe marks - concave epichnial relief (after Fiorillo *et al.*, 2011, Fig. 13B); **e**. Figure d rotate at 180º - convex hypichnial relief, similar with figures a-c; **f**. Penetration of the beak into the substrate at different depths, corresponding to a_1-c_1 (not to scale).

pecking marks. In our case, the marks are preserved as convex hypchnial relief, visible in Fig. 2aa$_1$. Beside these traces, there is a structure called by Abbassi *et al.* (2015b) „curviform trace fossil" (Fig. 2aa$_2$), that derived from the preceding traces, but was generated by „continuous and undulating drag of the bill through the sediment" (Abbassi *et al.*, 2015b, p. 11). An important category is formed by the bilobate structures, which we attribute to probing marks, quite numerous on the surface of the track-bearing bed surface (Fig. 2a, b: Fig. 3a).

The details of some of the specimens (Fig. 4a-c) indicate the presence of unequally developed lobes corresponding to the upper mandible (Fig. 4a$_1$x), the lower mandible (Fig. 4a$_1$xx) and the maxillary edges (Fig. 4a$_1$-c$_1$m). By comparing our specimens with the probing sign preserved as a negative epichnial relief (Fig. 4d), depicted by Fiorillo *et al.* (2011, Fig. 13b) and using a geometric artifact, rotating with 180° figure 13b, the image of the convex hyporelief (Fig. 4e) is very close to the marks of the Portaferrian probing, corresponding to the penetration of the beak in the substrate, at different depths (Fig. 4f).

This way of substratum probing is common to many present-day bird species, an example is the white wagtail (*Motacilla alba*) which explores the mud covered with an algal biofilm by single-time pecking, (Fig. 3dd$_1$) or by clustered pecking (Fig. 3dd$_2$), or probing in substrate, leaving a "8"-sign, according to how much opened the beak is (Fig. 3dd$_3$).

Noteworthy is the striking resemblance between the trace with the double-curved median groove (Fig. 2bb$_1$) and the paratype of the ichnospecies *Osculichnus labialis*, described by Demircan and Uchman (2010, text-fig. 3) from the Mezardere Formation (upper Eocene–lower Oligocene) of Turkey, but with larger dimensions (L = 44 mm, w = 28 mm, L / w = 1.57). This ichnospecies is interpreted as the praedichnion of a predatory fish that has sank its head (vertically or obliquely) into the sediment, with its mouth more or less open. This type of structure ("bioprint" type - *sensu* Rindsberg and Kopaska-Merkel, 2005) was recently recognized in the Lower Devonian of Poland and attributed to *Osculichnus tarnowskae* (Szrek *et al.*, 2016). In the studied marks from Romania, the association of the bilobate traces, presumed to be bird feeding traces, with the pair of traces of a small mammalian, excludes the possibility of fish activity.

Being a prehensil organ, the beak serves a variety of goals, with feeding being the most important. Depending on the adaptations to different types of food, the beaks are named differently according to the shape and appearance (Cătuneanu *et al.*, 1978). Without detailing, and given the morphological features of the pecking and probing traces discussed above, we assume that the marks were produced by Charadriiformes (limnic birds with long and thin beak), and Anseriformes (probably *Anas*, with lamellar beak and jaw edges). Although in the Dacian Basin upper Miocene deposit no skeletal remains, were recorded so far, footprints or traces of feeding birds have been reported, in the lower Miocene the different ichnospecies of the two orders are well represented, being described in classics (Panin, 1961, 1964; Panin and Avram, 1962; Panin *et al.*, 1966).

Recently, Lockley and Harris (2010, p. 34) have shown that in the feeding behaviour of fossil birds the interference between the footprints and beak marks can be infered, and three eloquent examples were presented: a) legs shuffling (e.g. *Ignotornis*) that were stirring in search of food; b) a series of signs of "dabble marks" (ex. *Presbyornithiformipes*); c) "sweep" signs, consisting of finely arched or semicircular zigzag-shaped grooves, associated with the trackway (ex. *Hwangsanipes*). It is important to note that distinct and repetitive morphology (*sensu* Melchor *et al.*, 2012) of the feeding signs represents the trace of the beak while probing the mud substrate.

From the above-presented data, we consider that the marks of the middle Pontian's bird feeding traces is important, because it extends the shorebird extension area from the Dacian Basin to Spain (along with the mammalian musterid undertracks). From Spain, of avian trackways (*Antarctichnus, Iranipeda, Roepichnus*) are known, associated with artiodactyle (*Pecoripeda*) traces in the Messinian Sorbas Basin (Doyle *et al.*, 2000). In Italy, the Messinian (MN 13) contains only a carnivore association, represented by Viveridae, Hyaenidae, Felidae, Mustelidae (*Mellivora beinfieldi* Hendey, *Plesiogulo crassa* Kurtén) and Canidae (Sardella, 2008).

In the Dacian Basin Pontian deposits, mammalian fauna was practically unknown until now, excepting the Meotian *Hipparion* fauna (Macarovici, 1967). In the post-Sarmatian area of the Dacian Basin, the oldest skeletal remains of fossil mustelids are represented by two species (*Mustela* I, II indet.) from the Dacian of Moldavia, at Bereşti (Rădulescu and Samson, 1995). In the Romanian Stage deposits, three species (*Mustela* 1-3 indet.) were described, from Măluşteni and an undetermined species from Lupoaia, in Oltenia (Rădulescu *et al.*, 2003). From the Quaternary (upper Pleistocene), *Martes martes* is known from cave deposits (Macarovici, 1967).

In the "Unio wetzleri Schichten" in the Pontian of Hungary fossil mustelide remains are known near Lake Balaton, at Sümeg and Polgárdi. From Polgárdi the *Paramartes pococki* species is cited belong to the MN 12-13 mammal zone (Rabeder, 1989). South of the Danube, in Bulgaria, in the Pontian deposits there are only large-sized mammals (Nikolov, 1989). In the synthesis of McDonald *et al*. (2007) footprints of Mustelidae are mentioned in: USA (Texas, upper Eocene – *Phacelopus therates*; Hungary (Ipolytarnoc, lower Miocene – *Mustelipeda punctata*; *Paruusipeda gemmea*); USA (California, Pliocene-Pleistocene – *Mustelidichnum vallecitoensis*; Tennessee, Pleistocen – mustelide).

The way of forming and preserving undertracks that we assign to a small mammal (in the present case a mustelid) is known, especially in the case of large animals such as, for example, (Milán *et al.*, 2004) and in the middle Jurassic in Denmark (Milán and Bromley, 2005). Often, vertical and oblique undertracks retain the anatomical details of the limbs that penetrated into the substratum. In case of sliding on/in the substratum, multiple longitudinal striation due to claws or scales can be preserved (see Thomson and Lovelace, 2014), and also due to the sliding of sand grains. A neoichnnological example is the production by artiodactyles (ex. *Ovis aries*) of the vertical deep-undertrack which preserves the extrusion prism (*sensu* Martin, 2009) (Fig. 3ee$_1$), or the longitudinal striations due to the sliding on the clay substrate (Fig. 3f).

The association of traces of mammalian steps with the footprints of shore birds is known in regions and geological formations (lakes, rivers, flood plains, marine marginal environments) of different ages. Thus, the oldest associations of this kind are known from the upper Triassic-lower Jurassic? from Argentina (Genise *et al.*, 2009); in the USA, traces of birds and perissodactyles in Eocene (Mustoe and Hopkins, 2013), traces of birds and mammals in the middle Miocene (Scrivner and Bottjer, 1986). From Iran there are reports of Eocene charadriiformes and perissodactyles (Abbassi and Lockley, 2004), traces of Oligocene charadriiformes, perissodactyles and large carnivores (Abbassi *et al.*, 2015a) and Miocene traces of charadriiformes and carnivores (Abbassi and Shakeri, 2005). Upper Eocene-Lower Miocene traces of charadriiformes, ciconiiformes and artiodacyles are known from Spain (Astibia *et al.*, 2007).

At present, reffering only to two significant examples, we mention the association of the birds probing (*Larus, Corvus*) with the American mink (*Mustela vison*) in the fluvial ambiance of the Saint John River in Canada (Lawfield and Pickerill, 2006) and traces of bird scrambling with traces of *Mustela vison* in the tidal and supratidal environments of Georgia, USA (Frey and Pemberton, 1986).

5. CONCLUSIONS

Based on the data of the present study it can be concluded that:

a) the presence of bird feeding traces associated with undertracks of a small mammalian, probably similar to the European mink (*Mustela lutreola*), indicates the existence, unknown so far, of terrestrial fauna in Portaferrian deposits from the Dacian Basin;
b) the pecking and probing marks were probably produced by Charadriiformes and Anseriformes representatives, whose ichnospecies are known in the upper Oligocene and lower Miocene from Romania;
c) although there are no traces of invertebrates, usually associated with the footprints of birds and mammals, it can be assumed that the described feeding traces and undertracks belong to the *Scoyenia* ichnofacies (shoreline environment with humid clay substratum and intermittent subaerian exposure);
d) the lack of a sample and / or moldings of the specimens designated as holotypes did not allow the denomination and description of these traces as distinct ichnogenera and ichnospecies.

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