# SYNFORM SEDIMENTARY STRUCTURES AND MAMMALIAN FOOTPRINTS OF THE ALMAŞU SANDSTONE (BURDIGALIAN) FROM GÂRCINA FLOODPLAIN PALEOSURFACE (NORTH PIATRA NEAMŢ, EAST CARPATHIANS, ROMANIA)

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**Abstract.** This contribution examines the presence of synform small-load structures on the typical green siltstones, as well as several extramorphological features of the plantar/palmar surfaces of *Pecoripeda*, and harmonizes the turbid surface currents hypothesis (*sensu* Panin, 1964, 2022) within the conceptual framework of floodplain paleosurfaces (*sensu* Smith, 1993, and Groenewald *et al.*, 2023).

**Key words:** Synform sedimentary structures, Mammalian footprints, Almaşu Sandstone, Burdigalian, Gârcina Floodplain Paleosurface (or Panin Paleosurface), East Carpathians

## 1. INTRODUCTION

Occupying a large part of the Subcarpathian Nappe of the Eastern Carpathians, the Lower Miocene molasse is also found in the Marginal Fold Nappe of central Moldova (Slănic-Oituz and Bistriţa half-windows), as well as in the Slănic and Drajna synclines of Muntenia. The sedimentation of the molasse proper begins with the deposition of the Lower Salt Formation and continues until the terminal part of the Lower Miocene, when the Schlier lithofacies is installed, up to the base of the Middle Miocene, i.e., Badenian (Săndulescu, 1984). According to Săndulescu *et al.* (1980), the sandy and conglomerate molasses follow the Lower Salt Formation in an area limited to the outside by an active relief that edged the foreland, which discharged important quantities of coarse material, accumulated in the form of large dejection cones (*e.g.*, the Pietricica, Pleşu, Almaşu Conglomerates). This facies is replaced gradually by sandy molasse (=Red Formation), followed by the Gray Formation with gypsum, inland and from north to south.

From a paleoichnological point of view, the Burdigalian sandstone molasse, represented by the Red Formation and the Grey Formation, as well as the Almaşu Sandstone within the conglomerate molasse, were of particular interest. In these lithostratigraphic entities, most of the bird and mammal footprints associated with current traces were identified in the ichnofossil sites of Vrancea (Paucă, 1942, 1952; Panin, 1961; Panin & Avram, 1962; Kordós & Prakfalvi, 1990), Gârcina-Piatra Neamţ (Panin, 1964), Teleajen (Panin *et al.*, 1966; Grujinschi, 1969) and Brebu-Doftana (Panin & Ştefănescu, 1968). A review of bird and mammal footprints from Miocene ichnosites can be found in the works of Brustur (2012, 2018) and Panin (2022).

This paper examines for the first time the presence of synform small-load structures on the typical green siltstones, several extramorphological features of the plantar/palmar surfaces of *Pecoripeda*, and harmonizes the turbid surface currents hypothesis (*sensu* Panin, 1964, 2022) within the conceptual framework of floodplain paleosurfaces (*sensu* Smith, 1993, and Groenewald *et al.*, 2023).

## 2. STRATIGRAPHY AND SEDIMENTOLOGY

### 2.1. Stratigraphy and geological setting

According to Săndulescu & Dimitrescu (2004), the major geological ensembles of the East Carpathians are: the Crystalline-Mesozoic Zone, the Flysch Zone and the Subcarpathians. The innermost units of the Flysch Zone are grouped into the Outer Dacides, while the Moldavides are grouped together within the outer part of the Flysch Zone, including also the Subcarpathian Nappe, which is the outermost overthrust unit of the East Carpathians. The Moldavides nappes (Teleajen, Macla, Audia, Tarcău, and Marginal Folds) include Cretaceous, Paleogene and Lower–Middle Miocene sedimentary formations. In the Marginal Folds Nappe (= Vrancea Nappe), the Lower Miocene Salt Formation occurs mostly in the outer part of the Bistriţa and Vrancea half-windows. The Red Molasse (= the Hârja Formation) and the Green Molasse are locally developed (Săndulescu *et al.*, 1981a, b).

In the Bistriţa Half-window (in the Piatra Neamţ region), the Miocene deposits in molassic facies overlie formations developed in an Oligocene bituminous facies. In the northern part of this structural unit, the molassic sedimentation begins in the Oligocene as a green, sandy-conglomeratic facies, longitudinally and transversally interfingered with the bituminous facies with Kliwa Sandstone (Micu, 1982). The molassic deposits situated between the Salt Formation and the Grey Formation belongs to two synchronous heterotopic lithofacies: Hârja lithofacies (red coloured = Borzeşti Molasse), and Almaşu lithofacies, respectively, a gritty-conglomeratic, green coloured lithofacies (Micu, 1982). North of Piatra Neamţ city, on Cuejdiu Valley, near Gârcina, the Almaşu lithofacies developed in the Almaşu Antiform (Fig. 1a, b). According to Micu (1976c, 1982), in this area, a stratigraphic succession shows, from the base to the top (Fig. 1c): Bălţăteşti Sandstone (= Condor Sandstone), Lower Almaşu Conglomerates (thick-bedded conglomerate banks, containing mainly greenschists elements of variable sizes and roundness in a green silty-sandy matrix), Almaşu Sandstone

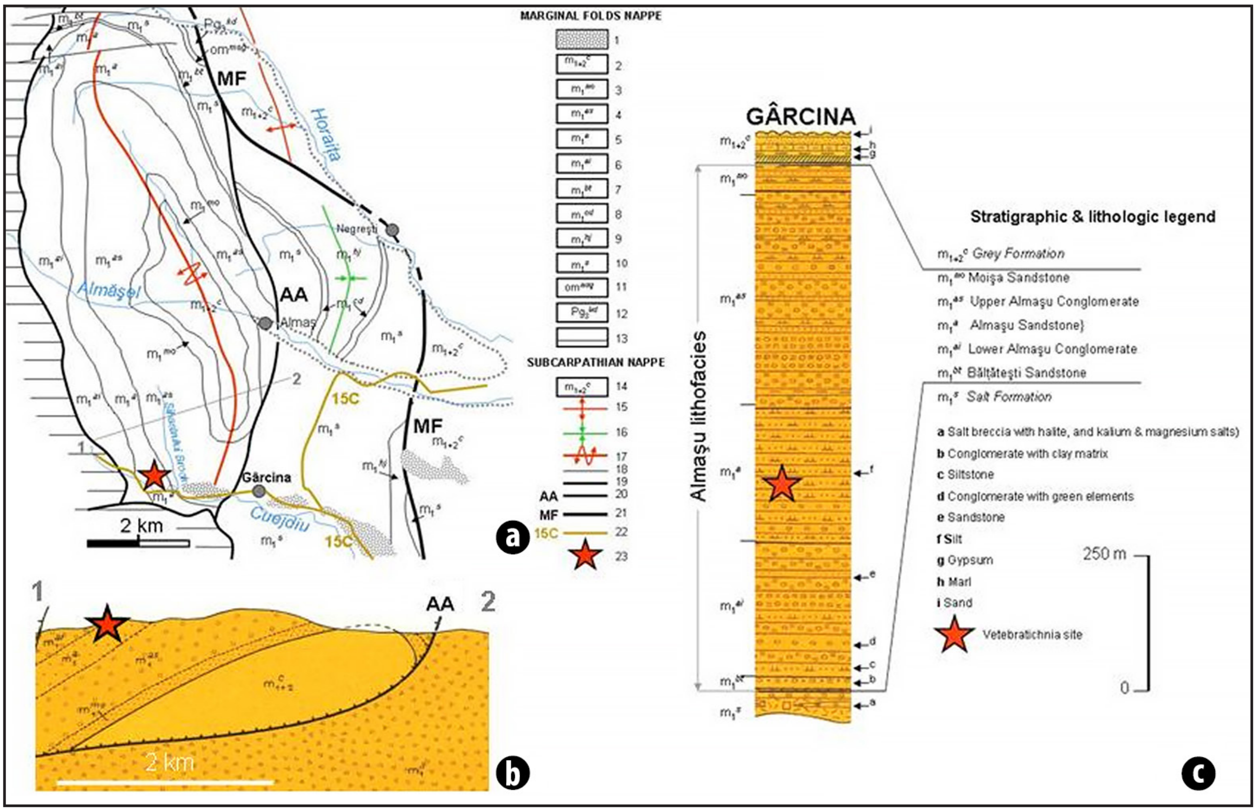


**Fig. 1.** Schematic geological map (**a**), cross-section (**b**) and stratigraphic log of the Almaşu lithofacies (**c**) (after Micu, 1976a,b, simplified). **1**. Quaternary (alluvial terace); **Marginal Folds Nappe** – *Middle Miocene* – **2**. Grey Formation; *Lower Miocene* – **3**. Moişa Sandstone; **4**. Upper Almaşu Conglomerate; **5**. Almaşu Sandstone; **6**. Lower Almaşu Conglomerate; **7**. Bălţăteşti Sandstone; **8**. Condor Sandstone; **9**. Hârja Formation; **10**. Salt Formation; *Oligocene-Lower Miocene* – **11**. Upper Menilite and Gura Şoimului Formation; *Oligocene* – **12**. Kliwa Sandstone, Upper Dysodiles; **13**. Cretaceous-Upper Eocene; **Subcarpathian Nappe** – **14**. Grey Formation; *Simbols*: **15**. Anticline; **16**. Syncline; **17**. Almaşu Antiform; **18**. Normal fault; **19**. Reverse fault; **20**. Frontal line of the Almaşu Antiform (AA); **21**. Frontal line of the Marginal Folds Nappe (MF); **22**. National road 15C; **23**. Ichnofossiliferous site.

(named by Mirăuţă & Mirăuţă, 1964), consisting of massive or graded sandstones and green siltstones, frequently interbedded with microconglomerates (with numerous ripple marks, rain prints, avian and mammalian footprints, coexisting together with current markings of different types), Upper Almaşu Conglomerates (showing practically the same characteristics as the lower conglomeratic succession), Moişa Sandstone (youngest part of the Almaşu lithofacies), and the Grey Formation, occur in in the core of the Almaşu Antiform (Fig. 1a, b).

### 2.2. Sedimentary petrography and sedimentology of the Almaşu Sandstone

#### *2.2.1. Sedimentary petrography*

The petrographic analysis of the Almaşu Sandstone, exposed in an overturned succession, over a thickness of 560 m, in the Cuejdiu Valley, downstream of the confluence with the Sihastru stream (Fig. 2a,b), carried out by Grasu *et al.* (1999) indicates the participation of lutitic terms (sandy-silty clays with low calcareous content and marls), subordinate to arenitic-silty ones (lithic wacke sandstones, quartzous wacke and chlorite-quartz-sericite siltstones) (Fig. 2d). In the lower part of the succession, these rocks constitute gray-blackish clay films and laminae, in the middle part, they become marly, in millimetric to centimetric plates, interstratified with sandstones, and in the terminal part, the typical, grey-green, muscovite and slightly satiny clays frequently occur, alternating with fine sandstones or siltstones. The sandstones are greenish-grey, with perfectly flat separation, include wacke and siltstones with subsiltic chlorite-sericite binder, arranged in dm-thick layers or in cm-thick plates (Fig. 2a).

The chlorite-quartz-sericite siltstones form cm-sized layers; they are composed of an intimate mixture of chlorite, quartz and sericite, along with feldspars and frequently pyrite. They have a satiny appearance and a bluish-gray or greenish colour (Fig. 2d). According to Grasu *et al.* (1999), these rocks constitute the petrographic type that contains the ichnofauna reported by Panin (1964) and in which the authors identified bird tracks (unpublished), downstream of the Sihastrului stream, a location where we identified several *Charadriipeda recurvirostra* tracks.

#### *2.2.2. Sedimentology*

After the first observation of the association of current traces with bird and mammal footprints in Vrancea (Panin, 1961), followed the discovery of the ichnofossil site at Gârcina, confirming their coexistence with current mechanical traces. This sedimentological reality substantiated the concept of "turbid surface currents" in flysch-like molasse deposits (Panin, 1964). From the Almaşu Sandstone at Gârcina and its surroundings, several types of mechanical sedimentary structures have been reported by different authors, a situation summarized in Table 1. Most of these have only been cited, rarely depicted (Panin, 1964), *"sometimes being found on the same side of the layer together with vertebrate traces"* (Panin, 1964).

**Table 1.** Scour, tool, ripple and load casts from Almaşu Sandstone (adapted after Miclăuş, 2006)

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<tr><th colspan="5">Author's</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th></tr>
<tr><td rowspan="5">scour marks; fluid made marks</td><td colspan="2">obstacle marks</td><td colspan="2">crescent casts</td><td></td><td></td><td></td><td></td><td></td><td>■</td></tr>
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<tr><td colspan="4">transverse scours</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td rowspan="5">tool marks, tool casts</td><td rowspan="2">Continue [groove]</td><td colspan="3">groove marks, groove casts</td><td></td><td>■</td><td>■</td><td></td><td></td><td>■</td></tr>
<tr><td colspan="3">chevron marks, chevron casts</td><td></td><td></td><td>■</td><td></td><td></td><td>■</td></tr>
<tr><td rowspan="3">Discontinue [impact]</td><td rowspan="2">single</td><td>prod marks</td><td>prod casts</td><td></td><td></td><td></td><td></td><td>■</td><td></td></tr>
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<tr><td colspan="5">ripple-marks</td><td>■</td><td>■</td><td>■</td><td>■</td><td>■</td><td></td></tr>
<tr><td colspan="5">load casts</td><td></td><td>■</td><td></td><td></td><td>■</td><td>■</td></tr>
<tr><td colspan="5">Raindrops</td><td></td><td></td><td>■</td><td></td><td></td><td></td></tr>
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**1**. Athanasiu, 1916; **2**. Mirăuţă & Mirăuţă, 1964; **3**. Panin, 1964; **4**. Micu, 1976c; **5**. Grasu *et al.*, 1999; 6. this paper

## 3. MATERIALS AND METHODS

The fossil material, collected from the scree (talus deposits, rock fall) on the left slope of the Cuejdiu Valley (Fig. 1a), is represented by samples deposited in the collection of the Paleontology Laboratory of the University of Bucharest, and contains *Pecoripeda* traces (Fig. 4b - no. LPBIIIich092, Fig. 4c - no. LPBIIIich093, Fig. 4d - no. LPBIIIich094, Fig. 4f - no. LPBIIIich095). All materials were photographed in the laboratory with a Canon IXUS 180 camera. The linear dimensions (mm) and angular dimensions (sexagesimal degrees) were measured with electronic digital calliper PowerFix, respectively Digital angle finder PowerFix. For the observation of morphological details, the Auriol® Magnifier lighted reading magnifier was used, and computer digital manipulation of colours and contrast to enhance the structural deformation of sedimentary structures, and the *Pecoripeda* plantar imprints. When analyzing erosive and deformative sedimentary structures, the criteria recommended by Dżulyński (1996, 2001), Allen (1982), Picard & High (1973) and De Clercq & Holst (1971) were used.

## 4. RESULTS

### 4.1. Synform sedimentary structures (Fig. 3)

The sedimentary sequence of the Almaşu Sandstone, two outcrops located at the confluence of the Cuejdiu Valley with the Sihastru stream (Fig. 2a, b), open two stratigraphic levels conventionally called the *Charadriipeda* level and the *Canipeda* level, named after the frequency of the appearance of bird and mammal footprints (Fig. 2c). The identification of a lower surface of a layer belonging to the green-blue chlorite-quartz-sericite siltstones (Fig. 2d), at about 150 m downstream of the confluence, on the left slope of the Cuejdiu Valley, offered the possibility to examine some particularly interesting structures. Most of them have a wrinkled appearance (Fig. 3a-d, f), so they were initially attributed to the "wrinkle structure" type, especially after consulting the atlas edited by Schieber *et al.* (2007). Not convinced that the reasoning is correct, I turned to the expertise of Dr. James Hagadorn (USA) and Dr. Brian Pratt (Canada), who suggested the solution (*ex litteris*, January 30, 2023, and February 6, 2023 respectively) for the correct interpretation of these structures whose hyporelief must be classified as load structures. In context, Dr. James Hagadorn indicated that "...they look like very small-scale load structures", and Dr. Brian Pratt specified that "If they are on bed soles then I would not call them wrinkles. Instead, you might call them load structures, although that is not a great term because it implies simple gravitational deformation which might not explain all examples".

Thus, in the analyzed case (Fig. 3), the deformational structures are represented by probable load-casted ripples (Fig. 3a) associated with linear ridges with "pillow"-like structures (Fig. 3a1), irregular scaly (Fig. 3a2), and dendritic ridges (Fig. 3a3), dendritic longitudinal ridges (Fig. 3b), polygonal structures (Fig. 3b1), and irregular scaly or "vermicular" structures (Fig. 3f1). Shallow-water load-cast deformational structures *(e.g.* longitudinal ridges and furrows, scaly pattern of imbricated flute-like moulds), similar to those depicted by us, associated with footprints of wading birds (Ralidae) have been reported in the Upper Oligocene subalpine molasse of Switzerland (De Clercq & Holst , 1971). The identified erosional structures belong to the following types: obstacle scours (Fig. 3c) associated with longitudinal ridges (Fig. 3c1), groove casts (Fig. 3d), rill casts (Figs. 3e, f), and uninterrupted-type chevron casts (Fig. 3g). It is worth mentioning that, in the Lower Cretaceous formations of the Eastern Carpathians, both sedimentary structures of the rill-marks type (Patrulius, 1969), as well as load casts and wrinkle marks (Grasu *et al.*, 2012). have been reported.

### 4.2. Mammalian footprints

#### *4.2.1. Pecoripeda (Fig. 4)*

The ichnological sites of the Lower Miocene molasses of the Romanian Subcarpathians have provided a rich inventory of Artiodactyl and bird footprints. Initially, the shallow cloven-hoofed tracks from Vrancea area were attributed to antelopes that moved on a relatively hard substrate (Panin, 1961). Later, the ichnospecies *Pecoripeda amalphea* and *Pecoripeda gazella* described with distinct morphology (Panin & Avram, 1962), being also present at Gârcina, but poorly preserved (Panin, 1964). With some details of the movement (*e.g.* widely spread hoof tips, spur impressions), the pecoripedes from the Teleajen area are presented, associated with "drag"- and "prod"-marks (Panin *et al.*, 1966). In the southern part of the Eastern Carpathians, around the Brebu locality, Panin & Ştefănescu (1968) schematically depict the traces of two ichnospecies, suspecting the presence of females with cubs, tacking into account the coexistence of large-sized traces and small ones. Grujinschi (1969) signals the presence of the ichnospecies *Pecoripeda gazella* in the Slănic Syncline, with traces deepened in the substrate, associated with drying cracks. Later, Kordós & Prakfalvi (1990), describe in detail the trace of *P. (Gazellipeda) gazella* Vialov 1965 from Vrancea region (Bozului stream), stating that "The trace of part around the hoof imprint can only be presumed, surrounding both parts as a narrow rim". We assume that the remark refers to the incipient deformation of the substrate that circumscribes the plantar impression, a dynamic process that we discuss below.

Thus, in a *Pecoripeda amalphaea* trace, the presence of a narrow semicircular wrinkle, not exceeding 3.26 mm, two symmetrical ungual areas, positioned at the anterior part, were identified (Fig. 4b). Complications begin to appear at the *Pecoripeda amalphaea* trace, where, in addition to the two wrinkles adjacent to the ungual area, two semicircular fractures are very clearly distinguished delimiting many sectors of displaced sediment (Fig. 4c), a situation amplified in the case of the *Pecoripeda gazella* trace, with three semicircular sectors (Fig. 4d).

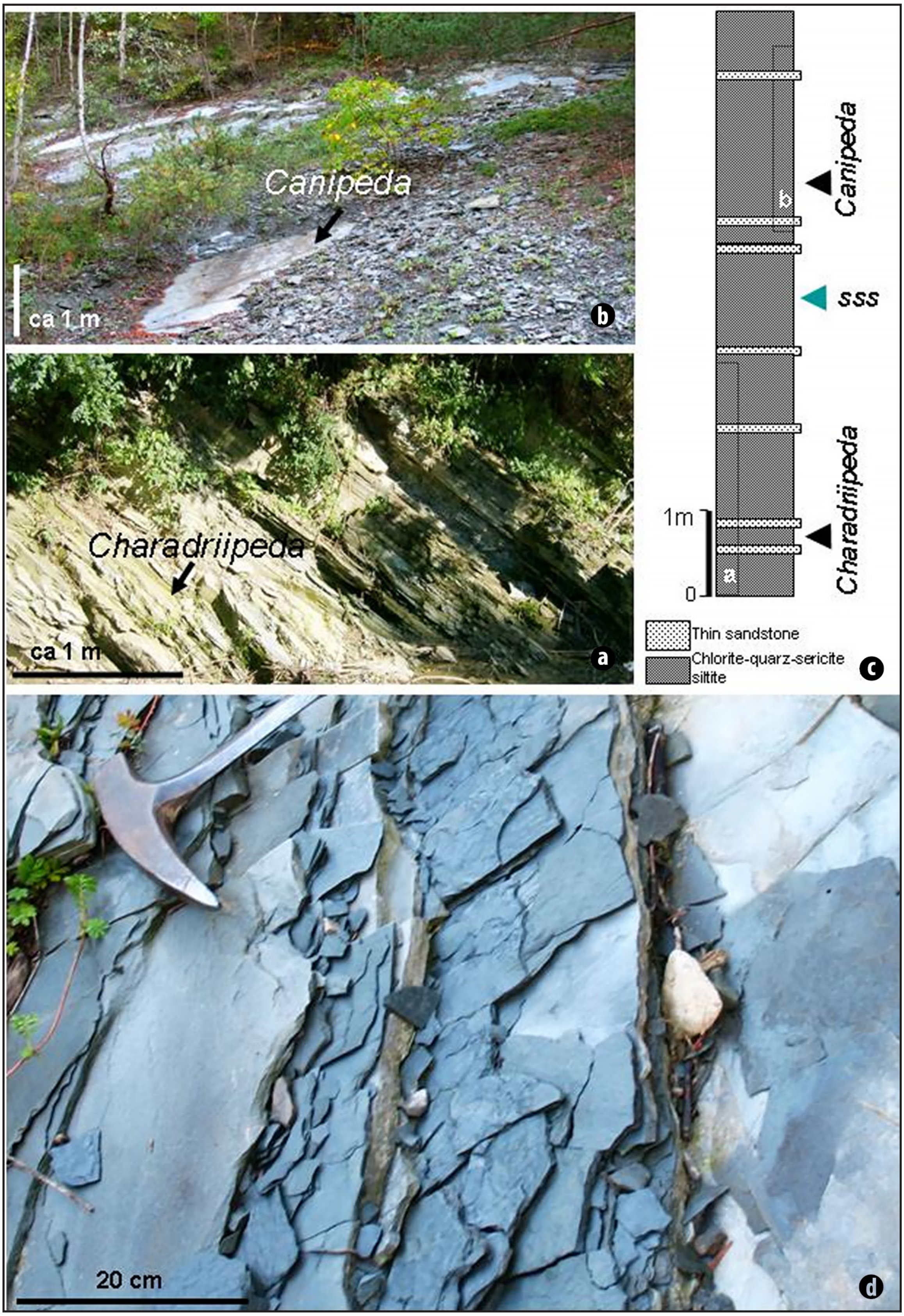


**Fig. 2.** Almaşu Sandstone at Sihastrului Brook with Gârcina Valley confluence: **a, b.** Outcrops with *Charadriipeda* and *Canipeda* ichnofaunal levels; **c.** Schematic lithostratigraphic log with a and b outcrops, and synform sedimentary structure location; **d.** Typical chlorite-quartz-sericite siltite (= green siltstones) with small-load structures (see Fig. 3) (photos T. Brustur, August 2015).

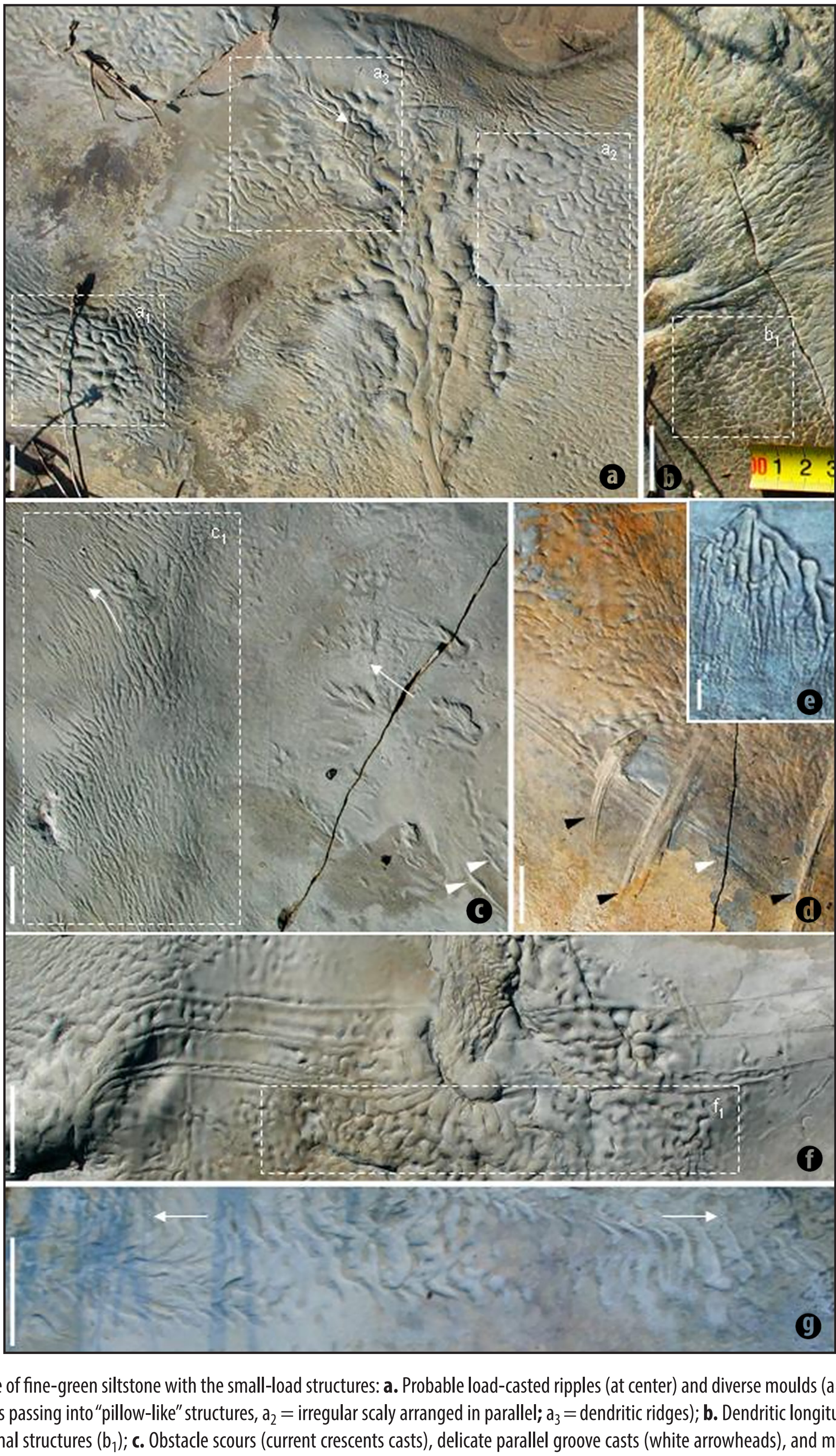


**Fig. 3.** Base of fine-green siltstone with the small-load structures: **a.** Probable load-casted ripples (at center) and diverse moulds ($a_1$ = probable linear ridges passing into "pillow-like" structures, $a_2$ = irregular scaly arranged in parallel**;** $a_3$ = dendritic ridges); **b.** Dendritic longitudinal ridges and polygonal structures ($b_1$); **c.** Obstacle scours (current crescents casts), delicate parallel groove casts (white arrowheads), and mould of dendritic ridges ($c_1$); **d.** Longitudinal ridges and two generations of groove casts (white arrowhead , older; black arrowheads, newer); **e.** Moulds of dendritic ridges**; f.** Rill casts with irregular scaly structures or "vermicular" structure ($f_1$); **g.** Chevron casts (direction of currents indicated of white arrows) (photos T. Brustur, 2015). All scale bars = 20 mm.

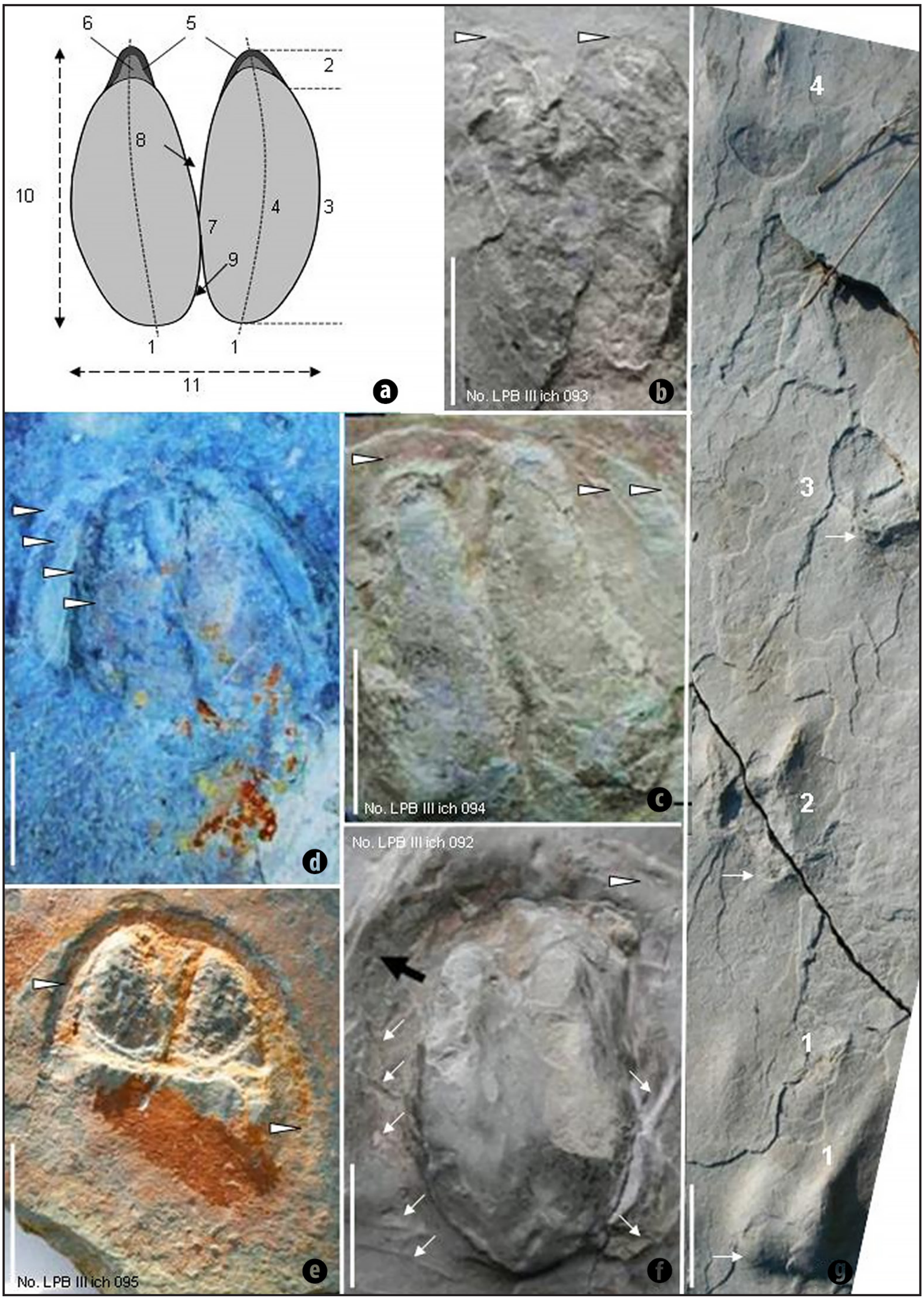


**Fig. 4.** Palmar/plantar views of *Pecoripeda*: **a.** Schematic palmar/plantar views of Artiodactyla (acc. to Oliva & Arragui, 2018, and /Campos-Medina *et al.*, 2022, adapted and modified): **1**. digital apex; **2**. ungular/clavular area; **3**. digital region; **4**. digital-pad; **5**. toenail; **6**. sole; **7**. interdigital septum; **8**. interclavular gap/anterior cleft; **9**. heel-noth/posterior cleft; **10**. length; **11**. width; **b-e.** *Pecoripeda* plantar footprints revealed of displaced material in *marginal ridge* (sensu Allen, 1997) or *concentric rings of distortion* (*sensu* Brown, 1999) (black-rimmed yellow arrowheads); **f.** Slightly asymmetrical (black arrow) *Pecoripeda gazella* undertrack with semi-complete rings and radial fracture of displaced sediments (small white arrows); **g.** Trackway of the *Pecoripeda gazella* Vialov ($g_1 \rightarrow g_{4;}$; white arrows indicated of heel position) (photos T. Brustur, 2005, 2015). All scale bars = 20 mm.

In both cases, the total width of the displaced area does not exceed 1.6 cm. A particular situation presents the *Pecoripeda gazella* trace doubled by a semiparabolic marginal sector, slightly deepened, suggesting a *Hippipeda*-type trace (Fig. 4e). The undertrack of *Pecoripeda gazella* (Fig. 4f), slightly asymmetrical, with a well-marked marginal wrinkle, is accompanied by numerous radial fractures. A sequence of a trackway (Fig. 4g) shows a succession of *Pecoripeda* tracks, with the heel prominent and the hoof tips widely separated, signs of running, probably on an uneven ground. A similar situation was reported by Panin *et al.* (1966) for the *Pecoripeda gazella* tracks found in the Brebu Conglomerates in the Teleajen basin. (Fig. 4g3). The presence, in one of the tracks, of an oval depression, with an obvious marginal border, very similar to the one shown in Fig. 4f, is noticeable.

## 5. DISCUSSION AND FINAL REMARKS

The presence of current and interface sedimentary structures (scour, tool, ripple, and load casts) in the stratigraphic succession of the Almaşu Sandstone raises the question of the existence of so-called *true substrates*, as recently defined by Davies & Shillito (2018), preserved at the sediment-water or sediment-air interface at the time of deposition, surfaces that provides *in situ* fossilization of topography at the microscale of geological time. Some of these are notable for their sedimentary and paleontological records that provide true windows of geological history. It should be noted that all current and interfacial casts on the lower face of the layer are included by French geologists in the term *hyporelief* (cf. Foucault & Raoult, 1980). According to Owen (2003), load structures are deformations of soft sediments at an interface: both load casts and pseudonodules (= synform structures), or flame and diapir structures (= antiform structures). They form in response to unstable density contrasts or lateral variations in load, when the sediment becomes liquidized or loses its strength.

An extensive discussion of the coexistence of erosional structures and deformational structures on a bed surface was made by Dżułyński (1996), followed by the publication of an excellent atlas of sedimentary structures in the Carpathian turbidites, with the mention that "*they are not limited to any specific facies*" (Dżułyński, 2001). A particularly important clarification, was supported by Miclăuş (2006), who considers that the interpretation of mechanoglyphs should be *limited to the process* and not to the event or depositional domain (turbidites or sediments deposited at the base of floodplains). According to Dżułyński (1996), erosional structures are produced by the action of the current flow or the impact of objects (tools) on a cohesive substrate, and deformational structures result from the interaction of current deposits and substrate or by the mutual interpenetration between the different density of soft sediments and kinematic viscosity.

Regarding the traces of even-toed mammals, we consider that it is useful to present the palmar/plantar scheme of Artiodactyls (see Fig. 4a), a somewhat neglected descriptive element, but which was pointed out by Oliva & Arregui (2018), Fig. 2, and completed by Campos-Medina *et al.* (2022). The above-mentioned authors used the modifications of the clavular region to establish the ichnopathology of some Holarctic ungulates from the Upper Pleistocene of South America and, respectively, to identify the traces of Upper Pleistocene camelids from Chile. The production of imprints with distinct morphological characteristics, related to events during locomotion are generated, according to Thulborn & Wade (1989), in three phases: a) the touch-down phase T, when the foot touches the substrate, b) the weight-bearing phase W, when the foot sinks into the substrate and c) the kick-off phase K, when the foot withdraws from the substrate. In reality, the movement phases are much more complex, representing a continuum between limbs and substrate (cf. Gatesy, 2003), by involving the granulometry of the substrate in the pre-track and post-track stages (Gatesy, 2003). The detailed study of the member–substrate relationship (especially in the case of dinosaur tracks) led to the establishment of a standard terminology, starting from Lockley's (1991, in Milàn & Bromley, 2006) definition of true track and undertrack, concepts later discussed by Allen (1997), Brown (1999), Bromley (2001), Fornós *et al.* (2002), Milàn (2003), Milàn *et al.* (2007), Marty (2008), Marty *et al.* (2016), and others. If Bromley (2001) viewed substrate dislocation "...as micro- and nannotectonics, at a centimeter and a millimeter scale", Graversen *et al.* (2007) compare the kinematics of dinosaur undertrack production with "crustal-scale tectonics associated with plate tectonics and foreland fold-thrust belts", of course an exaggeration, but not without a perfect analogy. The abovementioned features demonstrate the complex dynamics of the formation and preservation of tetrapod fossil tracks, the ideal condition for their study consisting in their location on a "tracking surface" (*sensu* Fornós *et al.*, 2002), as is the case of the well-preserved tracks of the ruminant goat *Myotragus balearicus* on the Upper Pleistocene carbonate aeolianites of the island of Mallorca (cf. Fornós *et al.*, 2002). For the camel tracks, located on the Quaternary eolian oolites of the island of Rhodes, Milàn *et al.* (2007) reported the presence, around them, of the prominent marginal wrinkle, as well as of concentric and radial fractures. Moreover, according to Manning (2004), this particularity constitutes an important criterion necessary for the determination of surface tracks. These considerations lead to the assumption that the extramorphological aspects of vertebrate tracks (in our case the tracks of *Pecoripeda*; Fig. 4b-g) may be present or absent, depending on the consistency of the substrate at the time of their production, but also on the attention with which they are observed in the outcrop or in the laboratory.

Since the first decades of the 20th century, the geological literature in Romania has recorded a significant number of works referring to the Miocene deposits in the Subcarpathian area of the Eastern Carpathians, regarding their stratigraphy, tectonics, age, and genesis. The existence in the lower Miocene red molasse of traces of waves, hieroglyphs, raindrops (Preda, 1917) and of impressions of bird footprints (Grozescu, 1918) demonstrated the formation of these deposits near the shore or beaches, at very shallow depths, in warm climate conditions, sometimes remaining uncovered by water, as mentioned by Athanasiu (1916) at Gârcina. Later, Mirăuţă & Mirăuţă (1964), Panin (1964), Micu (1976c), Grasu *et al.* (1999) identify in the unit of the Almaşu Sandstone numerous types of single mechanical traces (Table 1) or associated with bird and mammal footprints. The coexistence of flysch-type textures with vertebrate footprints, initially recognized in Vrancea (Panin, 1961) and apparently "difficult to resolve in relation to the genesis of these deposits" (Panin, 1964), is masterfully interpreted by the same author, by invoking "turbidity surface currents". These are the main factors in the formation of the rhythmic succession with a flysch appearance, imprinted by the turbidity character of the *flood currents*, which propagated on an alluvial-deltaic field in conditions of very shallow water and even emergence; between floods, the plains were visited by animals and raindrops were imprinted, wave traces were formed in the places covered by water, and with a new flood, when a new arenite-lutite rhythm was formed (Panin, 1964).

A similar situation was recognized in the Teleajen Valley basin, where torrential deposits belonged to a young hydrographic network that flowed directly into the sea (Panin *et al.*, 1966). To explain the traces of this type in the Slănic Syncline, recorded over extensive areas, Grujinschi (1969) assumes the action of strong winds that released water from the aquatic basins, a stage in which the animal tracks were imprinted. Subsequently, heavy rainfall transported large quantities of sediments redistributed by turbid surface currents, moments favorable to the formation of current structures, but also to the preservation of biological trace imprints. Recently, Panin (2022) shows that deposits with traces of vertebrates and traces of undulations and/or mechanical effects due to strong currents *cannot be considered flysch deposits*, as they are spread over an alluvial-deltaic area, subject to periodic flooding.

Referring to the Miocene Salt Formation in the Cuejdiu and Almaşu basins, Athanasiu (1916) first noted the *reversed succession* of the lower series which, in the current sense, also includes the Almaşu Sandstone, whose sequences of chlorite-quartz-sericite siltstones in cm-thick layers are relatively well exposed on the left slope of the Cuejdiu valley, downstream the confluence with the Sihastrului stream. Nevertheless, a few outcrops of a limited extent offer the observation of the hyporelief of the synform sedimentary structures and the cast or impressions of mammal tracks. This particularly favorable circumstance refers us to what Davies & Shillito (2021) call a *state of stasis* of ancient sedimentary systems, in which the true substrates are faithful and valuable archives of high-resolution paleoenvironmental and temporal information, possibly equivalent to the so-called "primordial surfaces" emerging after a regression of Cobălcescu (fide Tufescu, 1947). These contributions, having as key words current traces, vertebrate footprints, redistribution currents (turbid, flood), hydrographic networks, alluvial-deltaic plain, and emergence, lead, in our opinion, to their integration into the *concept of paleosurfaces*, an aspect that will be discussed below.

According to Widdowson (1997), the concept of paleosurface includes a wide range of geological and geomorphological phenomena that make it difficult to attempt a definition that encompasses all their fields of study, except for the fundamental distinction between exogenous and endogenous surfaces. In its broadest sense, the term paleosurface, which designates an *ancient surface*, is interpreted by geologists who approach the Earth's surface systems in a depositional or constructive (endogenous) framework, considering the whole variety of types of surfaces, formed by erosion or other unconformities, as an integral and fundamental part of the stratigraphic record, preserved in both subaerial and subaqueous sequences, originating from erosional and depositional processes (Widdowson, 1997). By integrating fundamental geological, geomorphological and climatic events recorded stratigraphically, a paleosurface can be any surface recognized in the lithological record, from small-scale stratiform ones to regional hiatuses that preserve important climatically or tectonically controlled events. Without being an exhaustive definition, not limited to subaerial surfaces, Widdowson (1997) proposes that the term palaeosurface should indicate *"an identifiable topographic surface of either endogenic or exogenic origin, recognizable as part of the geological record or otherwise of demonstrable antiquity, which is, or was, originally of regional significance, and which as a consequence of its evolution, displays the effects of surface alteration resulting from a prolonged period of weathering, erosion, or non-deposition"*. Within the continental depositional systems, old deposits frequently mark important moments of emergence, those belonging to the fluvial system, which is controlled and defined by the distribution of the hydrographic network (cf. Anastasiu *et al.*, 2007).

In a broad sense, a floodplain paleosurface is an ancient, buried land surface that was once a floodplain, preserving evidence of hydrographic network dynamics, depositional processes, and paleoclimatic conditions. Formed by the accumulation of sediments deposited by rivers during floods, such deposits, protected and preserved as silts and clays, contain fossils, ichnofossils and drying cracks, showing evidence of climate-influenced river dynamics (*e.g.*, point-bar surfaces, crevasse splay deposits), as well as paleosols. Relatively recently, river-floodplain systems have been integrated into the Flood Pulse Concept (FPC) by Junk *et al.* (1989), applicable to large, tropical rivers. Later, the concept was adapted to the rivers from mid-latitudes (Junk & Wantzen, 2004) and also from the lacustrine domain (Wantzen *et al.*, 2008). In summary, the FPC defines the following aspects: a) floodplains represent the Aquatic/Terrestrial Transition Zone (ATTZ); b) a long-term pulse is characteristic of large rivers; c) the flood pulse maintains the ATTZ in dynamic equilibrium; d) the aquatic and terrestrial productivity of river-floodplain systems depends on the state of water nutrients, climate and the flood pulse; e) the FPC is dominant over the River Continuum Concept (RCC) in floodplain systems (ATTZ), when the pulse is regular and long-term; f) floodplain processes do not depend on inefficient processing of upstream organic matter; g) the FPC contributes to the hydroecological understanding of river-floodplain systems.

Considering the spread of ichnosites with vertebrate traces in Romania and western Ukraine, over a distance of about 550 km, between the Olanu Valley (N Târgovişte) and the Delyatin–Dobrotov area (SE of Ivano-Frankivsk), it can be assumed that the possible Lower Miocene (Burdigalian) flood paleosurface marked a regional-scale paleogeographic and paleoclimatic event, controlled by the intra-Burdigalian Styric tectonic phase, when "halogen moments were followed by unconformities that determined sedimentation and/or erosion gaps" (Săndulescu, 1984). It is worth mentioning that, about 370 km west of Delyatin-Dobrotov, the Lower Miocene of the post-tectonic cover of the Gemeride and Veporide units in the Western Carpathians includes the fluvial Zagyvapálfalva Formation, with flood-plain sedimentation (Bartkó, 1985), which hosts the famous vertebrate ichnofauna from Ipolytarnóc. This ichnofauna, admirably protected within the Novohrad-Nógrád UNESCO Geopark, is the subject of Kordós (1985) monograph, partially revised recently, as an important contribution for late Burdigalian age of "the footprint bearing-sandstone beds", ranging between 18.5±0.5 and 17.0-17.5 M.y. (Botfalvai *et al.*, 2022).

In this context, the sedimentology and ichnology of the Almaşu Sandstone succession can be included, in what we can call the *Burdigalian flood paleosurface of the Gârcina type* or the *Panin paleosurface* (in honor of the discoverer of the ichnosite, the author of the hypothesis of "turbid surface currents"). This paleosurface is comparable to two instructive examples from the Upper Permian, described by Smith (1993) and, respectively, Groenewald *et al.* (2023) within the Beaufort Group of the Karoo Basin of South Africa. The authors identify several types of paleosurfaces, showing point bar sequences, proximal and distal floodplain facies, with trackways of arthropods, synapsid reptiles and current structures (Smith, 1993), respectively, the Dave Green paleosurface, of about 600 $m^2$, with numerous ichnofossils, including traces of tetrapods (temnospondyls) and fish swim-trails (Groenewald *et al.*, 2023). In both cases, numerous synform sedimentary structures and unidentifiable plant remains, similar to the algal filaments depicted by Smith (1993), are present, as in Gârcina, probably indicating the presence of the distal facies of the flood paleosurface on which they are distributed. At a reduced scale, some segments of the Gârcina floodplain are very similar to a convex bank of the minor riverbed from which the water withdrew after a flood pulse.

It is interesting to note the resemblance of ancient ichnosites to some modern synform sedimentary structures, algal mats, vertebrate traces and invertebrate burrows, described on the banks of the Dâmboviţa Valley, near the locality of Malu cu Flori (Fig. 5).

From the data presented above, in this study, emerges the scientific significance of the Gârcina ichnosite, which must be urgently protected by law, as has already been proposed (Brustur, 2003, 2015). Further, there is a need to carry out highly detailed sedimentological studies (lithological columns "layer by layer" and "centimeter by centimeter", sequential analyses and facies analyses), as well as detailed paleoichnological investigations. These steps are needed to decipher the formation conditions of the Almaşu lithofacies in general, and of the Almaşu Sandstone in particular. Based on the aforementioned considerations, the other ichnosites known in Romania should also benefit from similar investigations (Brustur, 2012, 2018; Panin, 2022). In the future, it is the duty of geological scientists to provide new and pertinent answers to the questions of their predecessors, especially those who studied the fascinating Tertiary formations of the Romanian Carpathians and Subcarpathians.

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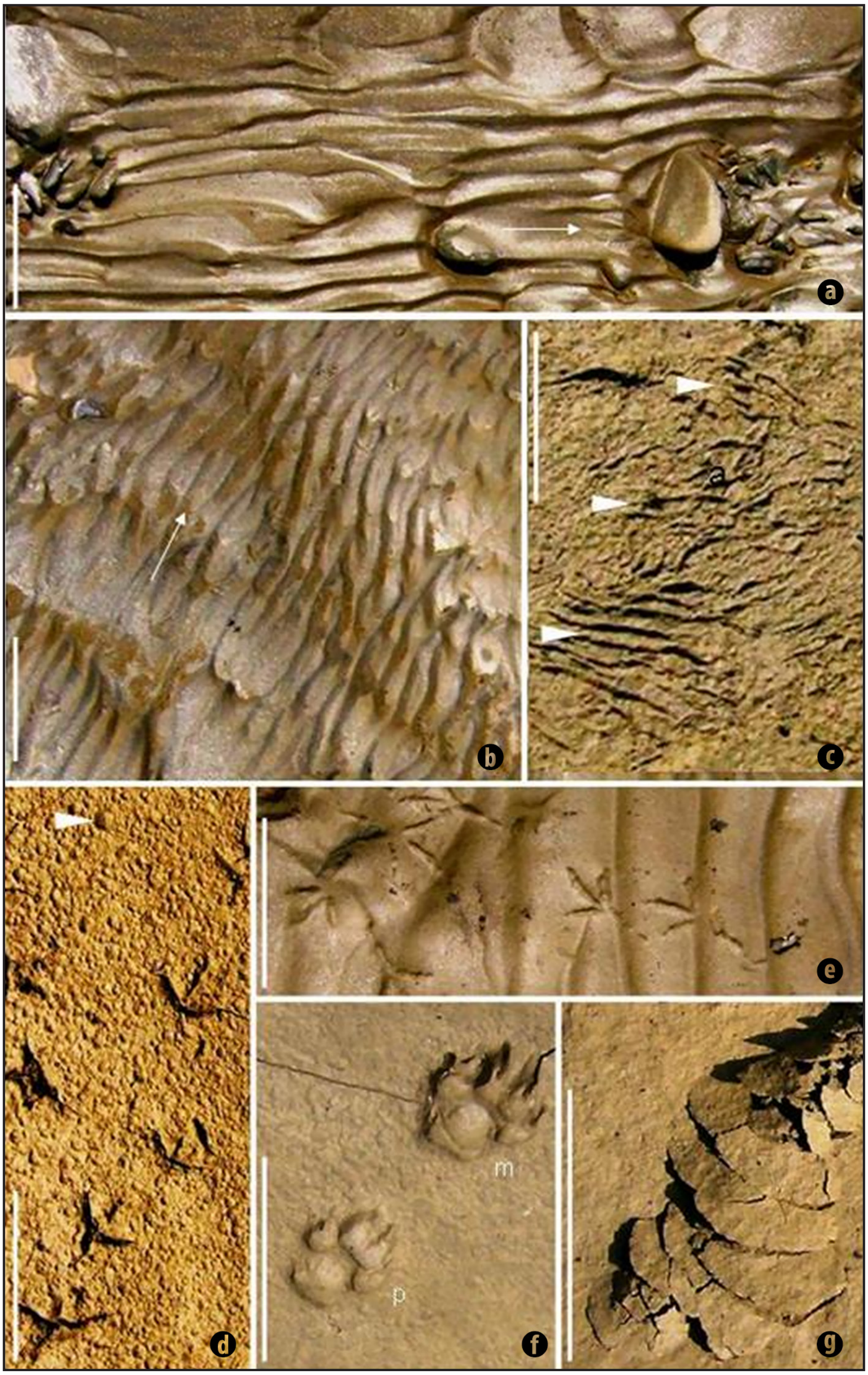


**Fig. 5.** Modern synform sedimentary structures, algal mat, vertebrate tracks and invertebrate burrow on river bank of Dâmboviţa Valley, nearly Malu cu Flori locality: **a**. Longitudinal ridge**; b.** Longitudinal ridges and moulds of irregular scale; **c.** Microbial mat wrinkles; **d.** Avian (probable *Motacilla* sp.) trackway on mud with raindrops imprints (white head arrow); **e.** Avian (probable *Corvus* sp. or *Columba* sp.) tracks on ripple mud; **f.** *Canis domestica* tracks (m = *manus;* p = *pes)*; **g.** Variegated mud-loving beetle-like burrow (*sensu* Chamberlain, 1975) (probable *Gryllotalpa gryllotalpa*) (current direction indicated of white arrows) (photos Diana Căpitanu (d, e) and T. Brustur (a-c, f, g; August 2006). All scale bars approx. 20 mm.

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