

EPHEMERAL *RANA* (AMPHIBIA, ANURA) – BODY AND LOCOMOTION IMPRESSIONS AND PALEOICHOLOGICAL IMPLICATIONS

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This paper presents of ephemeral impressions belonging to the body and locomotion of *Rana* sp. (Anura). These impressions have been assigned at two distinct morphogroups, such as the jump resting and suspended hind limb impressions. This feature indicates the intimate connection between the resting impression and the jumping. These compound traces reflect without doubt a behavior difference that may be recognized in older continental deposits.

Keywords: neoichnology; ephemeral impressions; Amphibia; Anura; Suspendichnia.

INTRODUCTION

The neoichnological investigations have offered significant informations for deciphering the ichnological assemblages identified in ancient marine and continental deposits¹. In the development of the continental ichnology, important values have been added by the discovery of ichnofaunas belonging to the crustacean, insects and dinosaur group of organisms². So far, only few data have been published on the amphibian trace fossils, except those from the Paleozoic and some from Tertiary^{3,4}. Since the Devonian, only footprints of vertebrates were preserved, the impression of the whole body being rarely discovered. Recently, Lucas *et al.*⁵ reported impressions of terrestrial amphibian bodies, belonging to the *Temnocorrichnus* genus in the Lower Carboniferous deposits of USA. Impressions of median parts belonging to swimming amphibians (*Serpentichnus robledoensis*) were found in the Lower Permian from New Mexico, USA⁶. Rarely, impressions of locomotion throughout jumping gait were observed^{7,8}.

In Romania, resting traces of primitive amphibians (*Hermundurichnus patrulei*), of *Diplocaulus* type were discovered in the Permian deposits of the Apuseni Mountains⁹. Romanian contributions in the neoichnology field belong to

Protescu¹⁰, Mrazec¹¹, Marinescu¹² and Brustur^{13,14}, the investigations of the Miocene deposits from the Subcarpathian area has led to the discovery of birds and mammals footprints¹⁵⁻¹⁸. For the assignment of the identified footprints to certain taxa, the above-mentioned authors have made comparison with the footprints of aquatic birds, elephants, rhinoceros, antelopes and carnivore Actual species. The present paper is focused on the impressions of *Rana* sp. (Anura), firstly described in the neo- and paleoichnological studies.

GENERAL DATA OF THE STUDY AREA

GEOGRAPHY

The Leoata Mountains, together with the Bucegi Mountains and Pietra Craiului Massif belong to the Bucegi Mts. Group, situated in the Eastern extremity of the Southern Carpathians (Fig. 1A). The association of various landscapes and the distribution of these are characteristic for the Leota Mountains that show a massif relief, stored on various high surfaces alternating with flat levels, making an important orohydrographic node¹⁹. At the SW, towards the Dâmbovița Valley, the asymmetric hydrographic basin of the Bădeanca Valley is situated, showing a sharp right bank and a left bank with reduced slopes (Fig. 1B).

GEOLOGY

The Leaota Mountains belongs to the Getic Nappe of the Median Dacides²⁰, being mainly made by metamorphic rocks of the Leaota Group²¹. The sedimentary cover, preserved on the borders of the Leaota Massif, crop out in the Dâmbovicioara Passage, towards W, as well as in the Bucegi and Postăvaru-Piatra Mare massifs, to the E²².

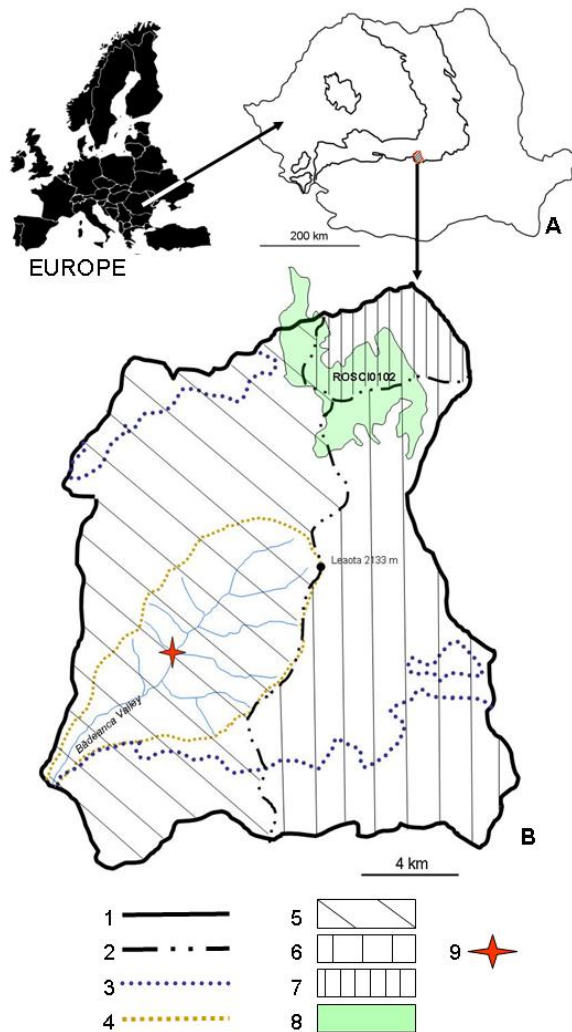


Fig. 1. A. Geographical framework of *Rana* impressions from Leaota Mountains; B. Leaota Mountains (simplified after Murătoreanu, 2008, with written permission): 1. Leaota Mountains boundary; 2. Water-parting; 3. Sedimentary-metamorphic boundary; 4. Bădeanca Valley catchment area; 5. Dâmbovița catchment area; 6. Ialomița catchment area; 7. Olt catchment area; 8. NATURA 2000 ROSCI0102 site; 9. Location of the *Rana* impression site.

Close to the Dâmbovița River (Fig. 2A), the mid Cretaceous deposits, *i.e.* Upper Albian and confluence of the Bădeanca Valley with the Cenomanian, are discordantly disposed on the

Leaota Group metamorphites; the latter rocks belongs to the Călușu and Voinești Series, Late Precambrian in age²³.

CLIMATOLOGY

The Leaota Mountains are characterized by a continental temperate climate, influenced by the relief and altitude; in this area, low temperatures, high level of precipitations and significant wind are to be expected. The yearly precipitation average is 900–1000 mm, with the highest level during the summer, when strong storms²⁴.

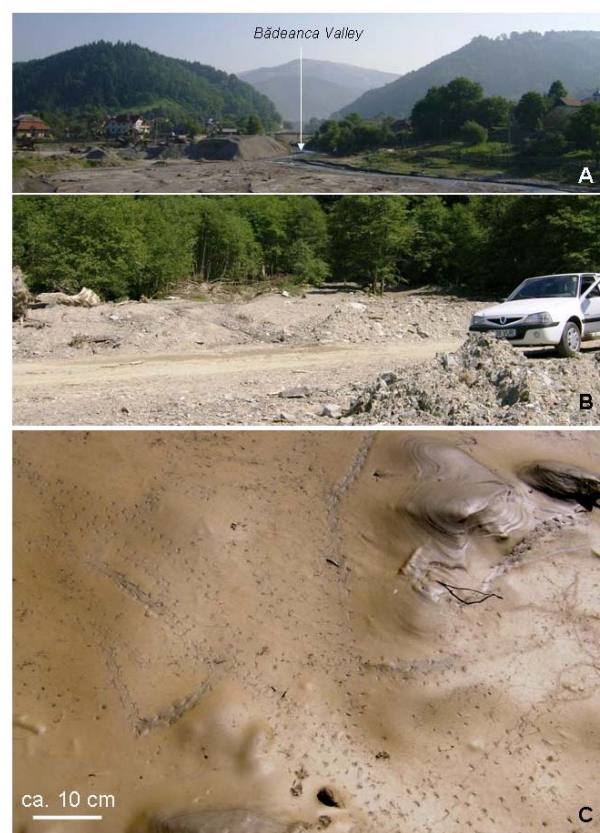


Fig. 2. A. Valea Bădeanca Valley at the confluence with Dâmbovița Valley; B. Coarse alluvia brought by torrents; C. Very fine brown-reddish mud with numerous *Rana* and insect impressions (Photo: T. Brustur).

BIOGEOGRAPHY

In the Leaota Mountains, the highest surfaces are occupied by beech forests, up 1,200 m altitude, followed by mixing forests of beech and conifers, reaching 1400 m altitude, the highest level being that of spruce forests. At highest altitudes, over 1,700 m, subalpine brushes and alpine meadows develop²⁴. Towards NNE of the de Bădeanca Valley

is located the site NATURA 2000 Leaota Mountains ROSCI0102 (Fig. 1B). In this site, the amphibians are represented by only one protected species, the yellow-bellied toad

(*Bombina variegata*), along with the fire salamander, the European green toad (*Bufo viridis*), the European toad (*Bufo bufo*), the European treefrog (*Hyla arborea*) and the common frog (*Rana temporaria*) occur²⁴. According to the amphibian distribution map in Romania²⁵, in the Leaota Mountains the abundance of this group reaches the value of 12, on a scale comprises between 3 and 16.

MATERIAL AND METHODS

On the July 21, 2006, after a pouring rain, a torrent formed in the right bank of the Bădeanca Valley (Fig. 1B) transported in the river bed a significant volume of coarse up to fine-grained sediments (Fig. 2B); the fine-grained sediments formed a thin layer of homogenous mud, yielding

tens of *Rana* sp. impressions (Fig. 2C), which are placed in a small temporary depression from where has been extracted ballast (Fig. 3A). The tracking surface, of around 5 m², contains resting and locomotion impressions; several pictures have been taken on these, with a digital camera CANON EOS 400D; some representative impressions have been selected for the study (Figs. 4 and 5), which the dimensions have been obtained by measuring the length and width (Figs. 3B, 4 and 5).

RESULTS

Based on the substratum consistency, which the granulometry and water content is directly controlling the morphology and the preservation of the animal activity traces²⁶⁻³⁰, the *Rana* sp. impressions from the Bădeanca Valley have been assigned to two morphotypes: jumping resting impression (Cubichnia) and impression of the suspended hind limbs.

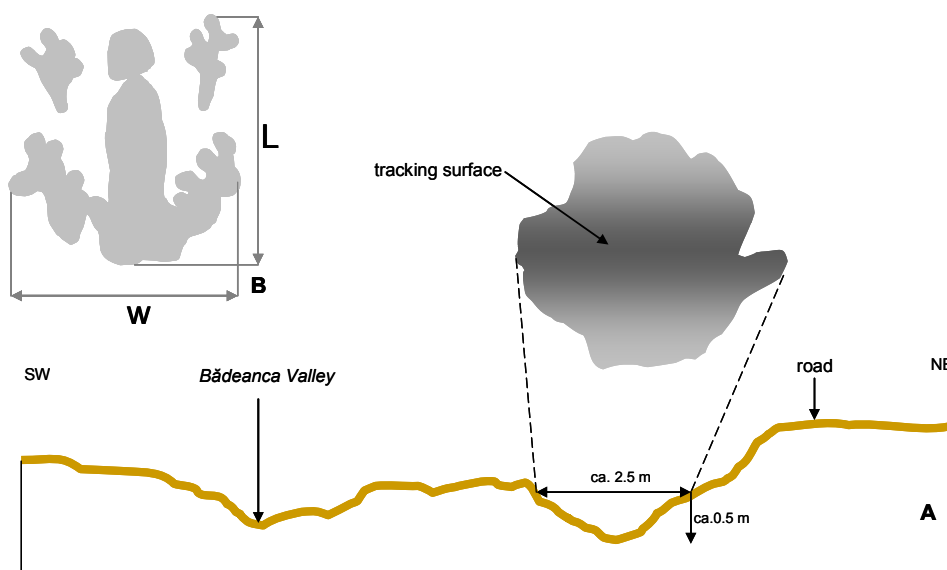


Fig. 3. A. Cross-section of the temporary site with *Rana* impressions and approximate surface outline (not drawn to scale); B. *Rana* resting impression dimensions (L = length; w = width).

JUMPING RESTING IMPRESSION

This morphotype is characterized by the footprint of the body ventral part, of the member pairs (*manus* = m; *pes* = p) and the fingertip (Fig. 4). The Fig. 4 (images A–K) shows the variability of these anatomic details, produced before or after jumping, linked to the substratum consistency that progressively decreases from

stiffground to softground. Some almost complete impressions of the abdominal and cephalic regions may be observed, with the four members completely visible, having 5 fingers to the posterior members and 4 fingers to the anterior ones (Figs. 4A to 4H). Some of the impressions preserved striations of the sucker effect (*sensu* Sarjeant & Leonardi³¹) (Figs. 4B and 4J), due to the complete rising of the abdomen. This one could

imprint either an oval-elongated shape with numerous tubercles, as those situated on the ventral part of *Bufo bufo* (Fig. 4C), a median rid (Fig. 4F) or an elongated depression, having two parallel marginal rids (Figs. 4D and 4G).

Sometimes, the abdomen impression is weak expressed, with an acicular form showing a spatulate posterior part (Fig. 4H). On a soft substratum, the abdomen impression is significantly elongated (Fig. 4I), or, by contrary, exaggerated widened with two striations of oblique suction, *i.e.* a shorter anterior one and a longer posterior striation; both of these striations mark two lift sequences before the jumping (Fig. 4J). On a very soft substratum, the ventral impression is unclear, only the member footprints are visible Fig. 4K).

By marking the ventral morphology of the producer (in this case *Rana* sp.), the jumping resting impression morphotype corresponds to the ethological category Cubichnia. For the resting impressions (n = 21) that fit in a rectangle, which

circumscribe the fingertips of the anterior members, the length (L) is comprises between 18.3 and 56.6 mm (the average = 31.4 mm) and the width (w) between 21.6 and 44.5 mm (the average = 29.8 mm), while the ratio L/w is 1.05.

COMPOUND LOCOMOTION IMPRESSION

The type of locomotion throughout jumping is known from many species of Arthropoda (*e.g.* Orders Araneae, Sipnona-ptera, Orthoptera), but also to some vertebrates, especially (Anura), kangaroos (Macropodida) and a few small rodents (Rodenta). In case of our findings, the locomotion impressions are considered to be compound, resulting from the coupling of the jumping impressions with the suspended hind limb impressions (Figs. 5A to 5D), resulting the combination of two different compartments in one impression (*sensu* Seilacher³²).

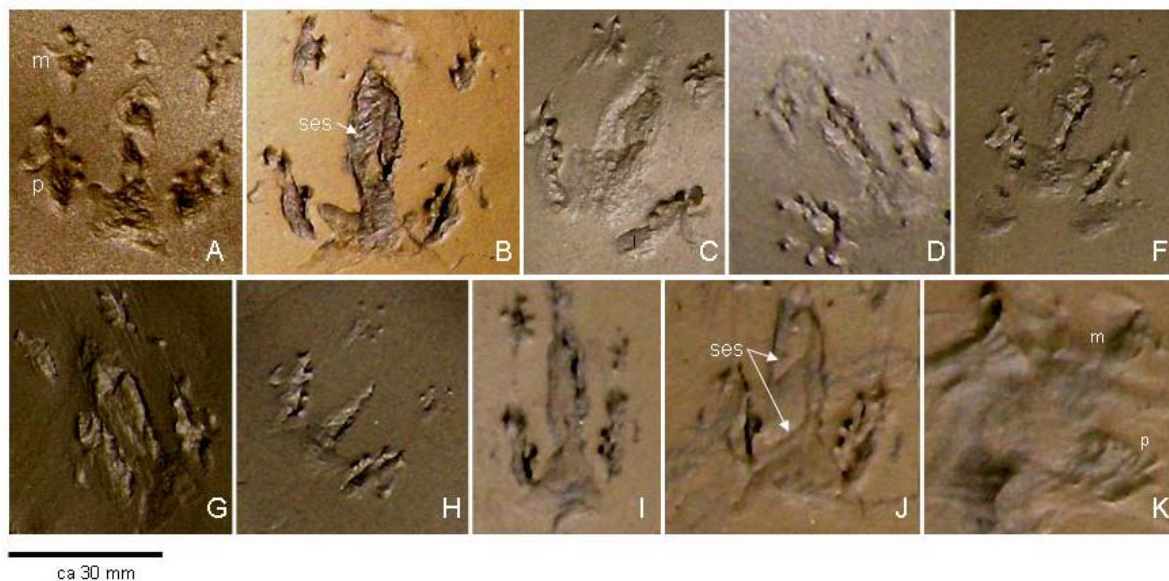


Fig. 4. *Rana* sp. (A–K). Resting impressions (Cubichnia) on the mud surface with various degrees of consistence. There are visible impressions of the abdomen, head, anterior members (m = manus), posterior members (p = pes) and the effect of the suction striations (ses).

Jumping impressions

These are represented by resting impressions of the jumping, above-described, in the § 4.1. This kind of traces is considered typical for this locomotion mode³³⁻³⁶. After Sarjeant³⁵, the four impressions of the members that are not overlapping have formed together a group, or, we consider forming the resting impression with the four footprints at which the impression of the

abdomen is added, with or without cephalic region. These impressions are repeated along the locomotion route of the animal at various intervals, depending of the length of the jumping.

Impression of the suspended hind limbs

This type of impression, not mentioned so far in the ichnological literature, credible illustrates the action of the posterior members on the substratum,

during the jumping (Figs. 5A to 5E). Therefore, during a short jump this type of impression is missing (Fig. 5A, 1-2; A4-5; Fig. 5F), while in the longer jumps (around twice the length of the resting impression), this impression usually occur as arc shaped with convex-arms (Figs. 5A to 5D) or double arc shaped with concave-arms (Fig. 5E), in respect with the locomotion axis. The radius of the arch may be big, and in this case the pair of arms are parallel (Fig. 5A, 2-3) or parallel quasi (Fig. 5B, 1-3; 5D, 1) or smaller, leading to the occurrence of double arch shaped biconvex (Fig. 5C, 1-3; 5D, 2) or biconcave (Fig. 5E, 1-3). The proximal part of these impressions, similar to the resting impressions of the posterior members is monofilar, while the distal part is slightly bold and sharpening (Fig. 5A,

2, 3; 5B, 1-3) or polifilar (Fig. 5C, 2); the later aspect indicates the finger sprawle of the posterior members before the landing.

At the compound locomotion impression ($n = 14$), the distance between the resting impressions is between 4.9 and 66 mm (average = 36.5 mm), while the length ($n = 7$) of the suspended posterior member impressions varies between 32 and 60 mm (average = 42.2 mm). The length of the arch pairs may be equal (Figs. 5A, 2; 5B 3), different (Figs. 5B1, 2; 5C1, 3) or one of the arms is missing (Fig. 5A 3). At a jump twice longer than the resting impression length, both arms are missing (Fig. 5A 4, 5). The morphotype of the suspended posterior member impressions is illustrated in Fig. 5C, 2.

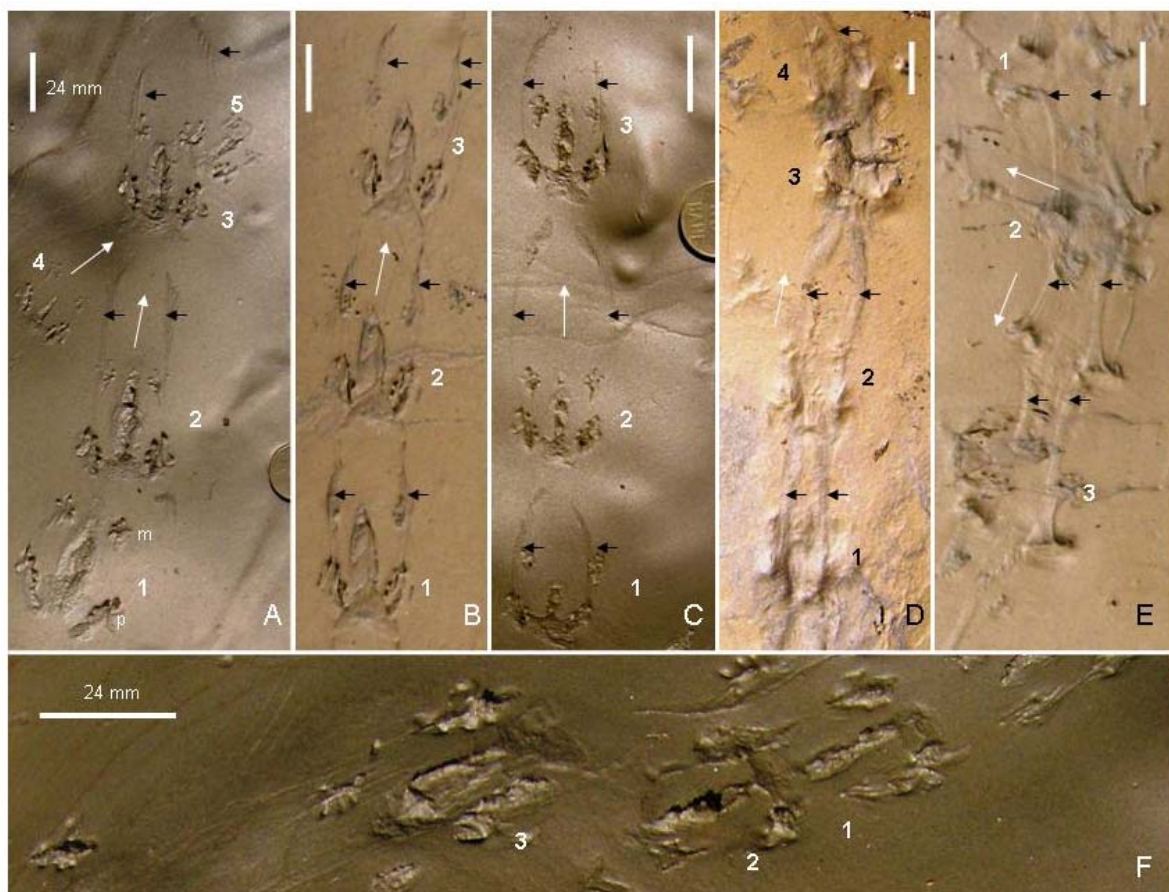


Fig. 5. A–F. *Rana* sp.: Compound locomotion impressions. The white arrows indicate the locomotion direction, while the black arrows indicate suspended hind limbs impressions. The numbers (1–5) show resting impressions succession.

DISCUSSION AND CONCLUSIONS

The amphibians or batrachians represent a less numerous group of vertebrates, occupying an intermediate position between fish and superior

cordates. The amphibians are divided in three distinct orders: Urodela (salamanders and newts), Anura (frogs, toads and green frogs) and Gymnophiona, the later without representatives in the temperate climate zones³⁷. The amphibian taxa

are present in the fresh-water and terrestrial environment, being spread in Romania from the coastal region of the Black Sea up to the Carpathian belt, at altitudes over 2,000 m³⁷. This group of organisms displays 18 fingers, 5 fingers at the each posterior member and four ones at each anterior member; additionally, the posterior members show digging adaptations (*Pelobates*, *Bufo*), climbing (*Hyla*) or swimming (*Rana*, *Bombina*)³⁷. The Anura representatives (frogs without tail) are represented in Romania by 5 families and 13 species, as follows (Murariu)³⁸: Discoglossidae (*Bombina bombina*, *B. variegata variegata*), Pelobatidae (*Pelobates fuscus fuscus*, *P. syriacus balcanicus*), Ranidae (*Rana ridibunda ridibunda*, *R. esculenta*, *R. dalmatina*, *R. temporaria temporaria*, *R. arvalis arvalis*, *R. arvalis wolterstorffi*), Bufonidae (*Bufo bufo bufo*, *B. viridis viridis*) and Hylidae (*Hyla arborea arborea*). The up to date taxonomy of the *Rana* genus recognized the species *R. ridibunda*, *R. lessonae* and a morphotype between the two above-mentioned, namely *R. esculenta*, as well as the *Rana arvalis* with the subspecies *R. arvalis arvalis* and *R. arvalis wolterstorffi*^{37,25}. In Europe, including the Romanian territory, the hybridization between the species *Bombina bombina* and *Bombina variegata* was reported³⁹.

The various species of frogs use different ways of locomotion, such as jumping, running, walking, swimming, burrowing, climbing and gliding. Most of the frogs locomotion is jumping, except for the toads (*Bufo*)³³, even those also can jump³⁶. The toads have the posterior legs longer than the anterior ones, being moved by strong muscles; throughout extension, the frog may jump on distance that consistently overcomes the body length. The anterior legs are also used for a slow walk on short distances, and for supporting the anterior body part in the moment of landing at the end of each jump³³.

When the frog confronted a predator, the length of the jump depends on the jump angle, while a series of small jumps allow changing direction and speed, leading to the maneuverability increase, and therefore the chance of escape⁴⁰.

The reduced dimensions of the resting impressions and of suspended hind limbs (Figs. 4 and 5) indicate the presence of the juvenile specimens of *Rana*. These are generally going on straight itineraries, with small jumps on a soft substratum that allows the preservation of some of distinct anatomical details (Fig. 4A to 4K; Fig. 5A to 4E).

PALEOICHOLOGICAL IMPLICATIONS

During some neoichnological experiments with amphipods and isopods, Uchman & Pervesler (p. 389)²⁹ pointed out that “*in practice, it is difficult to distinguish between resting and jumping, the comparison material is insufficient for elaboration of diagnostic criteria to distinguish these behaviors*”. Lockley *et al.* (p. 61, and Fig. 9)⁸ described traces of a rodent, made by 5–6 pairs of fingerprints made by the anterior and posterior legs, indicating that the variable distance „*as a result of differences in behavior (length of hop) not preservation*”.

The existence of the arch shaped impressions to certain fossil impression categories was described since long time in the ichnological literature. These types of impressions are produced by the tail drag⁴¹, or forelimbs toes as for the trackway of *Rogerbaletichnus aguilerai* identified in Patagonia in Triassic deposits⁴². Sometimes, linear impressions of manus drag marks have been recognized; these were attributed to small rodents⁴³ or to posterior members of amphibians, as assumed by Lockley *et al.*⁸ At the Actual toads from USA, for example, drag impressions of the fingers has been identified, linked to the number of the finger touching the substratum; to some species (*Rana pipens*, *R. sylvatica*) the jumping action produced the impression of the anterior members in face of the posterior one, the footprints of the straddle also depending on age and species³⁶. Murie³⁴ reported impressions of toads on a dusty substratum with feet dragging, while at the bull frog (*Lithobates catesbeianus*) the impressions of the posterior members are almost parallel with the body, while the anterior members are face to face.

As shown above, in the §4.2.2., the impressions of the suspended posterior members show an arch shape, being placed in front of the resting impression (Fig. 6A and 6B). This setting shows the intrinsic connection between the resting footprint and the jumping that is the missing link invoked by Uchman & Pervesler²⁹, and which materializes the behavior difference described by Lockley *et al.*⁸, but in *this case preserved on the substratum*.

The Figs. 6A and 6B illustrates the two generated ways of the locomotion impressions related to the type of the convergent or divergent movements of the posterior members during the jumping. Hence, the convergent movement (Fig. 6A) produces an impression of a biconvex arch shape, while at the divergent movement

(Fig. 6B), the shape is of a biconcave arch. It is to assume that the two different arched impressions are related to different modes in which the two ranid species straddle or unite the posterior legs during the jumping.

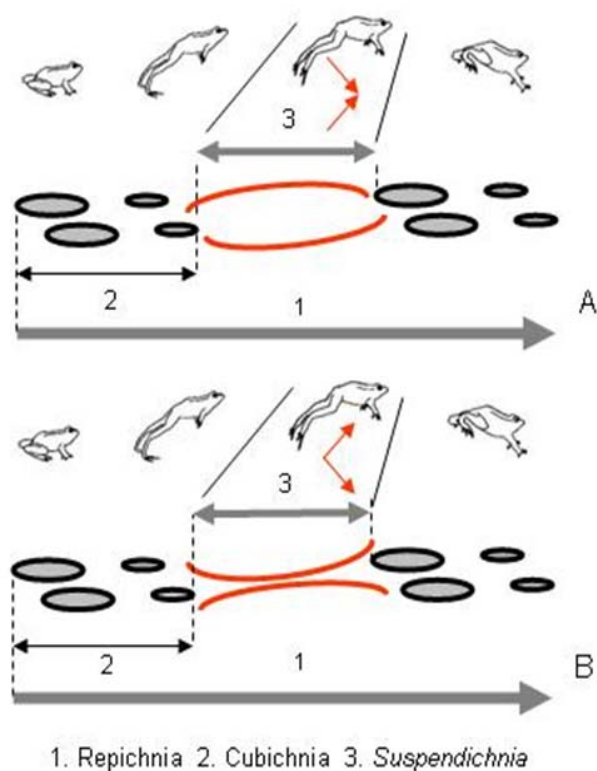


Fig. 6. A. The jumping chart showing the convergent movement of the legs (*biconcave impression*); B. The chart of the jumping showing the divergent movement of the legs (*biconvex impression*). Jumping frog silhouette from Mackean & Mackean (2013*, with written permission in January, 2014).

Following the recommendation of Vallon *et al.*⁴⁴, regarding the integration of distinct behaviors in different ethological sub-categories, herein we proposed the term of *Suspendichnia* to describe the fossil locomotion impressions that point out the proved *dynamic link* between two static impressions (Cubichnia) as part of locomotion footprints at Repichnia belonging, in this case, to Anura.

The paleontological published data indicate that the ancestor of the Anura Order (*Triadobatrachus*) firstly appeared in the Early Triassic, in Madagascar, while the ranid group, belonging to the

above-mentioned order, occurs much later in Europe, within the Middle Eocene⁴⁵. In Romania, Ilie⁴⁶ assumed that the reticular network, *Paleodictyon* (syn. *Batracoidea nidificans*) found in various Tertiary deposits, was produced by batrachian eggs. Later, Joja⁴⁷ contradicts this hypothesis, as the taxa of the Anura Order, living in a fresh-water aquatic environment could not generate traces in marine sediments; the above-mentioned author could not explain the absence of such kind of traces in fresh-water sediments of the Pliocene sediments from Romania, interval in which most probably this group of organisms was abundant. Recently, amphibian bones belonging to the genera *Urodela* and *Anura* were discovered in the Upper Cretaceous deposits from the Hațeg Basin⁴⁸⁻⁵⁰, in the Oligocene of the NW Transylvanian Basin, near Cluj-Napoca town⁴⁷, as well as in the Lower Pleistocene from Betfia (Oradea), from where the genera *Bombina*, *Pliobatrachus*, *Pelobates*, *Bufo*, *Hyla* and *Rana* were identified⁵¹.

The presence in various regions of Romania of continental deposits, from the Paleozoic up to the Quaternary, has offered conditions for the preservations of different terrestrial organism trace fossil, such as dinosaurs discovered in the Banat region, SW Romania⁵² and Transylvanian Basin⁵³, birds in the Upper Oligocene deposits from the Petroșani Basin⁵⁴, mammals and birds in the Lower Miocene deposits of the Eastern Carpathians^{15-18, 55}. Probably, many trace fossils – including batrachians – not yet discovered are to be found in the Miocene, Pliocene and Pleistocene fluvial and lacustrine deposits⁵⁶ of the Eastern Paratethyan Dacic Basin from Romania, and especially those to be found at the recently traced discontinuity surface located in the Early Pliocene, *i.e.* Middle Pontian⁵⁷.

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* Mackean D.G., Mackean I. (2013) *Characteristics of Amphibia, an introduction*. In: Resources for biology education by D.G. Mackean [http://www.biology-resources.com/amphibia.html].

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