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Early Jurassic sauropod footprints of the Southern Carpathians, Romania: palaeobiological and palaeogeographical significance

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The dinosaur footprints cf. *Parabrontopodus* isp. Lockley, Farlow et Meyer, 1994, attributed to sauropods, have been found in Hettangian (earliest Jurassic) alluvial deposits in Anina (Colonia Cehă Quarry, Reşiţa Basin), belonging to the Getic Nappe in the Southern Carpathians, Western Romania. Heteropodous pes-manus sets and one short, narrow-gauge trackway have been recognized on a large sandstone surface trampled by sauropods. A greater load was carried by the inner digits of the pes, particularly digit I, and the heel pad is deeply imprinted, which points to a sub-plantigrade pes and gravipodal posture, typical for Eusaropoda. A pentadactyl manus imprint suggests that manus digits of early sauropods might have been separate and perhaps more functional when supporting walking on unstable, sticky ground. These tracks, the first find of Jurassic dinosaur footprints in Romania, add an important site to the relatively rare record of earliest Jurassic sauropod footprints. These tracks also confirm that Pangaean islands and peninsulas around the Western Tethys were inhabited by early sauropods. These peninsulas or islands, including a hypothetical "Moesian Island", must have been at least temporarily connected with the mainland. The sizes of the Romanian footprints are similar to the Hettangian *Parabrontopodus* isp. tracks described from Poland (mainland Pangaea — Eurasian area) and Italy (Tethyan domain) and do not indicate insular dwarfism.

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INTRODUCTION

Relatively very few unequivocal examples of sauropod tracks are known in Early Jurassic strata worldwide (Lockley *et al*., 1994*b*), even though true sauropods (Eusauropoda — Upchurch, 1993, 1994) bones are known from this epoch, such as *Vulcanodon karibaensis* Raath 1972 from Africa (Raath, 1972; Cruickshank, 1975; Cooper, 1984) and fragmentary preserved remains from other continents, including *Sanpasaurus*, *Zizhongosaurus* and *Kunmingosaurus* from China (Dong *et al*., 1983; Dong, 1992), *Ohmdenosaurus* from Germany (Wild, 1978), and *Barapasaurus* from India (Jain *et al*., 1979). The most important sites with Early Jurassic sauropod footprints comprise Hettangian sites in Northern Italy (Leonardi and Lanzinger, 1992; Dalla Vecchia, 1994; Avanzini and Petti, 2008; Avanzini *et al*., 2008) and Central Poland (Gierliński, 1997; Gierliński and Sawicki, 1998; Gierliński and Pieńkowski, 1999; Gierliński *et al*., 2004). Besides Hettangian strata, sauropod tracks have been also found in Pliensbachian strata of Morocco (Ishigaki, 1989; Farlow, 1992). Finds of both body and trace fossils, scattered around the globe, suggest that Early Jurassic sauropods were geographically widespread. However, true sauropod (Eusauropoda) footprints and body fossils are absent from Early Jurassic deposits in North America (Hunt *et al.*, 1994; Olsen *et al*., 2002), suggesting the existence of a barrier situated along the Central Atlantic Rift, which prevented migration of dinosaurs to North America from the rest of Pangaea (Fig. 1). An alternative explanation would involve climatic differences, combined with habitat requirements of sauropods (drier conditions in North America), causing bioprovincialism of dinosaurs. The Hettangian time interval was an important stage in the evolution of sauropods, also in terms of principal posture changes in the fore- and hindlimbs, which influenced the shape of their footprints (Wilson and Sereno, 1998). Therefore, any find of sauropod tracks of that age is significant in answering both

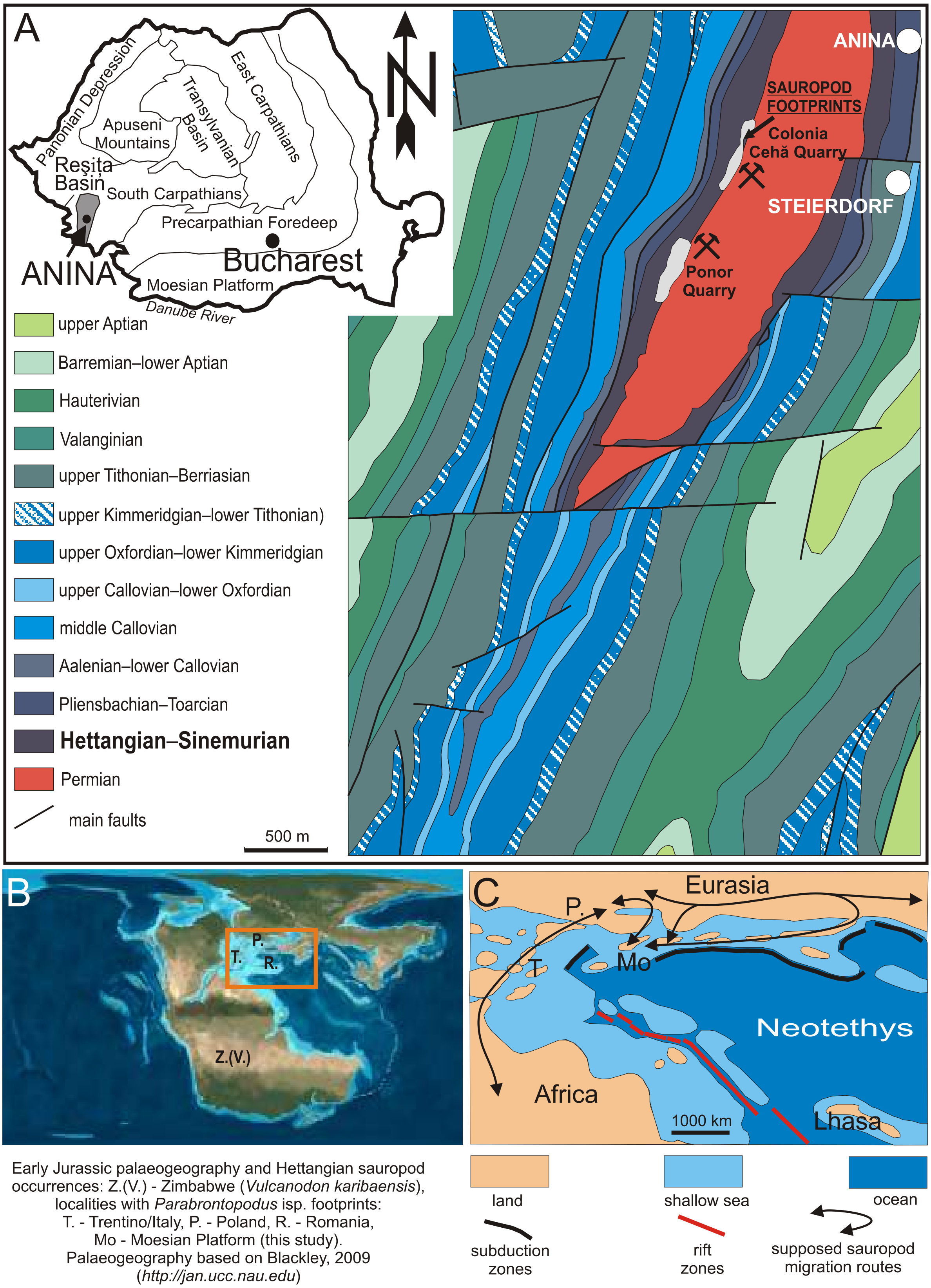

Fig. 1. A — Locations of the Reşiţa Basin and Colonia Cehă Quarry on a geological map of the Anina Anticline; B — Early Jurassic palaeogeography with major sites of Early Jurassic sauropods — bone remains (Zimbabwe) and footprints; C — outlined area of "B" showing palaeogeography of the Western Tethys with inferred sauropod migration routes

Palaeogeography after Golonka, 2004 (simplified, modified) palaeobiological and palaeobiogeographical questions of the early evolution of these animals.

Thus we are pleased to announce the discovery of the dinosaur footprints cf. *Parabrontopodus* isp. Lockley, Farlow et Meyer, 1994, attributed to sauropods in Hettangian (earliest Jurassic) alluvial deposits at Anina (Colonia Cehă Quarry and Reşiţa Basin), in the Southern Carpathians of Western Romania. To date, no Jurassic dinosaur footprints have been found in Romania. Reports of Cretaceous dinosaur footprints were published by Vremir and Codrea (2002) from Maastrichtian continental beds of the Sebeş area (Transylvanian Depression), while earlier Cretaceous footprints of unknown affinity were described by Koch (1900) from Neocomian beds of Lăpuş (Maramureş area). Dinosaur bones (Benton *et al*., 1997) were described from Early Cretaceous (Berriasian) beds of the Brusturi-Cornet area, northwestern Romania, while bones and eggs (Grigorescu, 2005; Grigorescu and Csiki, 2008) were described from Upper Cretaceous (Maastrichtian) beds of the Haţeg Basin (Transylvania). The small size of these dinosaur remains from the Haţeg Basin points to an insular dwarfism of these animals (Grigorescu, 2005; Grigorescu and Csiki, 2008), as well as for those of the Brusturi-Cornet area (Benton *et al*., 2006). Our new evidence, however, shows normal-sized sauropods and hence no signs of dwarfism.

GEOLOGICAL SETTING

Anina (Southern Carpathians, Western Romania), formerly known as Steierdorf, was an important coal mining locality in the South Carpathians, occurring in the central area of the Reşiţa Basin, Getic Nappe, and 35 km south of Reşiţa (Fig. 1). This area has been intensively mined since 1792 for Lower Jurassic coals, and later for refractory clays and bituminous shales, all of these activities being almost totally halted today. The mining was undertaken through vertical shafts, extensive and intricate underground works, and large open-cast mines, such as the Ponor, Colonia Cehă and Hildegard quarries (Popa, 2009). The Colonia Cehă Quarry is an important open-cast mine in the area, next to the Steierdorf old neighborhood of Anina, and was opened for the extraction of bituminous shales in the early 1980s. The dinosaur tracks cf. *Parabrontopodus* isp. Lockley, Farlow et Meyer, 1994 described in this paper were recorded from its eastern and northern flanks, along steeply inclined bedding surfaces, exposed in the uppermost levels of the quarry and cut by transverse faults (Figs. 2 and 3).

The Getic Nappe (Murgoci, 1905) represents one of the main structural units of the South Carpathians in Romania, a nappe yielding both a crystalline basement and a sedimentary cover. The Getic Nappe occurs between the Supragetic Nappe (westwards) and the Severin and Danubian units (eastwards), as parts of a nappe pile overthrust from west towards east in the South Carpathians. The Reşiţa Basin, also known as the Reşiţa–Moldova Nouă Sedimentary Zone, represents the largest sedimentary basin of the Getic Nappe, occurring in the South Carpathians, between Reşiţa and the Danube River (Fig. 1). This basin includes deposits belonging to Palaeozoic (Upper Carboniferous–Lower Permian) and Mesozoic (Lower Jurassic–Lower Cretaceous) strata, unconformably overlying the crystalline basement of the Getic Nappe. During Early Jurassic times, the Reşiţa Basin with the deposits of the whole Getic Nappe belonged to a large Moesian–Rhodope Platform, and according to palaeogeographical maps (Scotese, 2002; Golonka, 2004; Golonka *et al*., 2005; Blackley, 2009), developed on a shelf area with islands and peninsulas, including an emergent "Moesian Island", at latitudes of about 30 degrees N (Fig. 1).

The Mesozoic sedimentary succession begins with the continental Steierdorf Formation (Bucur, 1991, 1997; Popa and Kędzior, 2008; Fig. 2), unconformably overlying the crystalline basement or the Upper Palaeozoic strata, and being conformably overlain by the brackish-marine Uteriş Formation (Pliensbachian–middle Toarcian). The whole Steierdorf Formation is 250 m thick in the north, and it decreases to 50–60 m southwards, reaching about 150–160 m in thickness in the area of the Colonia Cehă Quarry. The age of the Steierdorf Formation is Hettangian–Sinemurian (Bucur, 1991, 1997; Popa, 2000*a*, *b*, 2009; Popa and Kędzior, 2008). However, because of a lack of diagnostic fossils in its lower part, the lowermost part of the Steierdorf Formation (Dealul Budinic Member, at least in its lower part) may be older (?Upper Triassic/Rhaetian). At the top of the Dealul Budinic Member, a pyroclastic layer occurs, indicating a volcanic event. Above this layer, conventionally accepted as the boundary marker between the Dealul Budinic Member and succeeding Valea Tereziei Member, the colour of sediment changes into grey. Furthermore, some 10 m above (Fig. 2), the first coal seams appear, pointing to a significant climatic change.

The sauropod tracks occur just above the pyroclastic level marking the bottom of the Valea Tereziei Member, at the top of a fine-grained sandstone (Figs. 2 and 3). The Valea Tereziei Member is late Hettangian–Sinemurian. In the Colonia Cehă Quarry, the lowermost part of the Valea Tereziei Member (including the footprint-bearing horizon) may be middle Hettangian, because this part still lacks age-diagnostic fossils; the index floral remains appear some 10 metres above, in the coal-bearing strata. The Valea Tereziei Member (except for its lowermost 10 m) is the main coal-bearing unit of the Steierdorf Formation, containing black, carbonaceous sandstones, mudstones, and clays of various types, with abundant fossil plants indicating a upper Hettangian (a range zone with *Thaumatopteris brauniana*) to Sinemurian age (an acmezone with *Nilssonia* cf. *orientalis*) — Popa (1997, 2000*a*, *b*, *c*, 2005, 2009); Popa and Van Konijnenbrug-Van Cittert (2006), Popa and Kędzior (2006). The exceptional fossil content indicates Anina as a fossil *Lagerstatte* locality, both for diversity and for degree of preservation (Andrae, 1855). The closest comparable floras to those of the Romanian Early Jurassic floras belonging to the Reşiţa, Sirinia, or other basins in the South Carpathians are the coeval assemblages of Iran and Afghanistan, which are also the closest floras palaeogeographically (Givulescu, 1998; Popa, 1998, 2000*a*). The Valea Tereziei Member contains 8 main bituminous coal seams and a characteristic refractory clay bed and shows a constant stratigraphic position and a wide lateral development in the central part of the Reşiţa Basin, thus serving as a valuable stratigraphic marker for the Hettangian-Sinemurian boundary (Fig. 2). The refractory clay bears a rich pollen and spore assemblage (Antonescu, 1973),

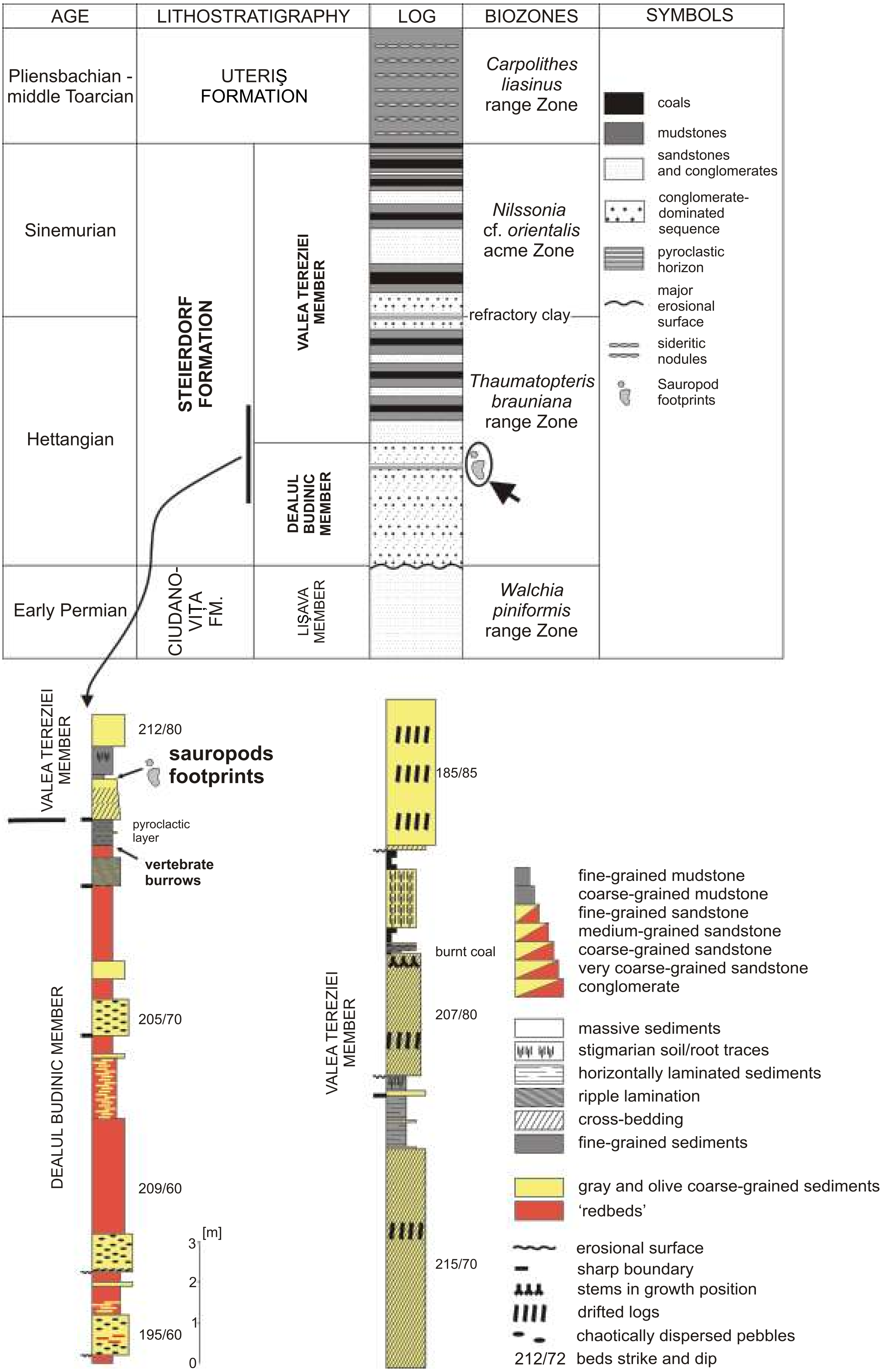

Fig. 2. Geological/sedimentological profiles of the fluvial Steierdorf Formation with position of sauropod footprints shown

and marks a temporary but widespread lacustrine sedimentation episode within a generally fluvial/alluvial plain-swamp environment. Besides rich plant fossils with preserved organs, invertebrate trace fossils as well as vertebrate tracks (*Batrachopus* cf. *deweyi*) have been found in the Valea Tereziei Member (Popa, 2000*a*, *c*, 2009).

SEDIMENTOLOGICAL BACKGROUND OF THE STEIERDORF FORMATION (HETTANGIAN–SINEMURIAN)

The lower part of the Dealul Budinic Member rests on an erosional surface, overlying either ?Permian redbeds or crystalline basement. It is mainly composed of poorly sorted, matrix-supported conglomerates and coarse-grained sandstones (Fig. 2). Pebbles (as much as 5 cm in diameter) are angular to sub-angular and are scattered throughout sandstone layers. Coarse-grained units are usually structureless, and in some places show large-scale cross stratification. Occasionally, upper surfaces of sandstone bodies have polygonal structures with secondary ferric oxide crusts, indicative of desiccation. Fine-grained deposits are subordinate, and are represented by horizontally laminated, reddish mudstones. Additionally, a fireclay horizon within this sequence has been found. These features indicate high viscosity flow, typical of alluvial fans. The age of the basal sequence of the Dealul Budinic Member cannot be precisely identified, due to the lack of fossils, so it may be either of Late Triassic (Rhaetian) or earliest Jurassic (Hettangian) age. The upper part of the member shows a transition to a more stable, lower-energy sedimentary regime. The deposits become finer, the first drifted floral remains occur, and palaeosol horizons appear. As the energy of deposition decreased, alluvial fans changed into an alluvial plain environment. In the uppermost, still reddish part of this member, vertebrate burrows have been found (Popa and Kędzior, 2006). Just above these burrows the pyroclastic level occurs, marking the boundary between the two members.

The Valea Tereziei Member is composed mainly of sandstones, with a few conglomeratic layers and subordinate mudstones, claystones and coal seams. Floral remains are very rich and well-preserved, except in the lowermost part of the member. Sandstone bodies are characterized by large-scale trough cross-bedding and parting lineations, pointing to a high energy of river flow. Ripple laminations occur at the top of some sandstone layers. Sandstone layers occurring within fine-grained deposits (attributed to crevasse-splay deposits) show horizontal or ripple-drift laminations and are strongly bioturbated by roots. Drifted logs are abundant and oriented parallel to the bedding. Tree roots and trunks in vertical, life position have also been found. Sandstone bodies show channelized geometries; they often pinch out laterally after short distances (~15 m). Traces of forest fires (frequent charcoal fragments) are also present, and the so called "burnt coal-seam" forms a local correlative horizon. These features point to a humid alluvial plain environment, with alternating fluvial and lacustrine/swamp sedimentation. Humid climate conditions during the deposition of the Valea Tereziei Member are also indicated by the floral remains (Popa, 1997, 2000*a*, *b*, *c*, 2005, 2009; Popa and Van Konijnenbrug-Van Cittert, 2006; Popa and Kędzior, 2006). It should be noted, however, that the Colonia Cehă Quarry is affected by a dense network of faults, thus different parts of the profile, involving both the uppermost Dealul Budinic and the lowermost Valea Tereziei members, occur in lateral contact with each other (Fig. 3).

The sauropod footprints, which occur at the top of the first sandstone layer of the Valea Tereziei Member, are covered by a grey mudstone containing plant roots in its topmost part. The sauropod tracks were probably left on the top of a widespread crevasse-splay/crevasse-delta layer.

Fig. 3. Front and lateral view of the track-bearing layer at the Colonia Cehă Quarry

Note transverse faults exposing different stratigraphic levels; v.b. — vertebrate burrows of the uppermost Dealul Budinic Member (Popa and Kędzior, 2006); s.t. — sauropod tracks shown on Figure 4; s.tw. — sauropod trackway shown on Figure 5 — the surface is densely trampled by sauropods

SYSTEMATIC DESCRIPTION OF THE DINOSAUR FOOTPRINTS

cf. *Parabrontopodus* isp. Lockley, Farlow et Meyer, 1994 (Figs. 4, 5) (type ichnosp. *Parabrontopodus mcintoshi* Lockley, Farlow et Meyer, 1994)

M a t e r i a l. — Two plaster casts LPB III ICH 76 (pes-manus set) and LCB III ICH 77 (two-steps trackway) of original surfaces in the Colonia Cehă Quarry (Fig. 3), reposited at the University of Bucharest, Faculty of Geology and Geophysics, Laboratory of Palaeontology, 1, N. Balcescu Ave., 010041, Bucharest, Romania.

D e s c r i p t i o n. — LPB III ICH 76 — pes-manus sets (Fig. 4) and LCB III ICH 77 (Fig. 5) — a short, narrow-gauge sauropod trackway. Pes and manus footprint of small size, pes *ca*. 40 cm long, 25 cm wide, manus *ca*. 15 cm wide and 10 cm long. Pes is oval, strongly narrowed in its posterior (heel) part. Manus oval (Fig. 4) or star-like, pentadactyl (Fig. 5). Pronounced heteropody, manus/pes area ratio 1:5 or less. Pes imprints show outwardly rotated claw (or ungual) impressions corresponding to digit I, II, III and IV. Digit I is robust, greater than the other digits. Leading margin of the pes print (the medial side of the pes) is deeper that the trailing (lateral) margin of the pes. Heel pad is distinctly impressed. All the tracks are surrounded by displacement rims.

The trackway (Fig. 5) is narrow-gauged, and shows marked heteropody. Both pes and manus are rotated outwardly, the second pes-manus spacing is shorter. Footprints are deeply impressed, the first pes is surrounded by a high displacement rim, the second one was filled by upwelling, saturated sediment. The first pes is 32 cm long, the second one lacks a clear heel pad because of obliteration caused by sediment upwelling. The first manus is preserved as an undertrack (upper part of the sandstone layer is missing); second manus well preserved and more or less pentadactyl in shape. The inferred midline of the trackway is curved, perhaps due to progression on an unstable surface. The pes stride length for the step is *ca*. 80 cm, measured between the middle points of two pedal imprints and the pes divergence angle, relative to the inferred midline, is irregular, from 0° (posterior pes) to 38° (anterior pes).

D i s c u s s i o n. — The track-bearing sandstone surface at the base of the Valea Tereziei Member is densely trampled by sauropods, which makes indentification of individual tracks and trackways difficult. However, in two places (Fig. 3) the last generation of tracks allow one to recognize two probable pes-manus sets inferred to represent a narrow-gauge trackway (Figs. 4 and 5). Particularly, one pes footprint with digit imprints is diagnostic (Fig. 4, where pes-manus set no. 2 is in the middle). The pronounced heteropody may also be diagnostic of *Parabrontopodus* isp. Lockley, Farlow et Meyer, 1994 — here tentatively labelled cf. *Parabrontopodus*. The best preserved pes no. 2 (Fig. 4) shows other characteristic features. A robust digit I is typical of the Eusauropoda, which can also point to a large first ungual (Wilson and Sereno, 1998). Moreover, Wilson and Sereno (1998) mentioned that the assymetrical robustness of pedal digits must be related to the unequal weight distribution across the sub-plantigigrade pes in Eusauropoda. Indeed, in the LPB III ICH 76 specimen (Fig. 4), digit I is the dominant digit of the pes and the medial (inner) side of the pes is deeper, while the heel pad is substantial. These features are also observed in trackways produced by eusauropods (Pittman and Gilette, 1989) and may reflect how a greater load was carried by the inner digits of the pes of these sauropods. The significance of these features is that the collapse from digitigrade to a sub-plantigigrade (or gravipodal) posture was an important turnover in the evolution of sauropods as the Eusauropoda evolved from basal Sauropoda in the Early Jurassic times (Wilson and Sereno, 1998). Early and middle Hettangian sauropod footprints from Poland (Gierliński, 1997; Gierliński and Sawicki, 1998; Gierliński and Pieńkowski, 1999; Gierliński *et al*., 2004; Pieńkowski, 2004) show substantial heel pad and conspicuous traces of pes digit I. There is also a difference in depth between the deeper medial and shallower lateral parts of pedal imprints in several tracks. Such a difference is not clear in the photographs of sauropod tracks from Italy, where pes prints suggest rather symmetrical distributions of pressure (Leonardi and Lanzinger, 1992; Leonardi and Avanzini, 1994; Dalla Vecchia, 1994; Avanzini and Petti, 2008; Avanzini *et al*., 2008). The Romanian footprints are similar in age to the Italian ones (middle–late Hettangian) and are somewhat younger than most of those from Poland. Romanian finds suggest that a sub-plantigrade (gravipodal) posture of sauropods developed probably by middle Hettangian times.

The narrow-gauge trackway (LCB III ICH 77, Fig. 5) is short, inferred to be composed of only two manus-pes sets, and was left in soft, saturated sediment, as shown by deeply-impressed tracks, high sediment-displacement rims, and in one case infilling of the track with saturated sediment. Because of the irregular step, one might infer a changing pes divergence angle, and the bent midline of the short trackway. However, precise measurements of trackway parameters could not be taken. Irregularity of the trackway may perhaps point to an irregular progression of the trace producer, caused by a soft, unstable substrate. The track-bearing layer could be further distorted by early diagenesis. The first or proximal pes is very deeply impressed, and the corresponding manus is represented by an undertrack as the upper part of the sandstone layer is missing in this part of the trackway. The next pes is incomplete (due to sediment upwelling), whereas the second manus is well preserved and has retained a pentadactyl shape with impression of digits. Digit imprints in sauropod manus tracks are rarely preserved (Lockley *et al*., 1994*a*), although noted from several localities (Lockley *et al*., 1992; Santos *et al*., 1994; Leonardi and Avanzini, 1994; Gierliński and Sawicki, 1998; Avanzini and Petti, 2008; Avanzini *et al*., 2008; Santos *et al*., 2009). Gierliński and Sawicki (1998) and Gierliński and Pieńkowski (1999) illustrated early Hettangian sauropod trackways of both adult and juvenile sauropods, and in the adult sauropod trackways, some of the manus imprints were clearly pentadactyl. The manus described herein bears resemblance also to the Late Triassic *Eosauropus* isp. (Lockley *et al.*, 2006), produced by members of the Sauropodomorpha (Hunt and Lucas, 2007). Dalla Vecchia (1999) and Dalla Vecchia and Tarlao (2000) suggested three sauropod manus morphotypes based on the configuration of digit I — the manus described herein is most similar to their Morphotype A, which comprises manus prints with a well-developed impression of digit I (see also Lockley *et al*., 1992, their fig. 2: print 3). Assuming a soft and saturated substrate, such preservation might suggest that manual digits of early sauropods might occasionally separate or be splayed, perhaps providing better support on unstable terrain. Several authors believe the sauropod manus probably functioned as a single, rigid, block-like structure with no intermetacarpal movements (McIntosh, 1990; Upchurch, 1994; Bonnan, 2003), but the non-tubular, primitive manus of earliest sauropods might have functioned in a different way.

The material is consistent in terms of shape and size with known Hettangian *Parabrontopodus* isp. trackways reported from Northern Italy (Leonardi and Lanzinger, 1992; Dalla Vecchia, 1994; Avanzini and Petti, 2008; Avanzini *et al*., 2008) and Central Poland (Gierliński, 1997; Gierliński and Sawicki, 1998; Gierliński and Pieńkowski, 1999). Recently, Santos *et al*. (2009) discussed Sauropodomorpha ichno-morphotypes — most of the features of our material (narrow-gauge trackway, pes shape and its outwardly directed claw marks, high heteropody) fits the Parabrontopodus-like morphotype. Furthermore, the single pentadactyl manus imprint would rather fit their new Polyonyx-like morphotype (Santos *et al*., 2009).

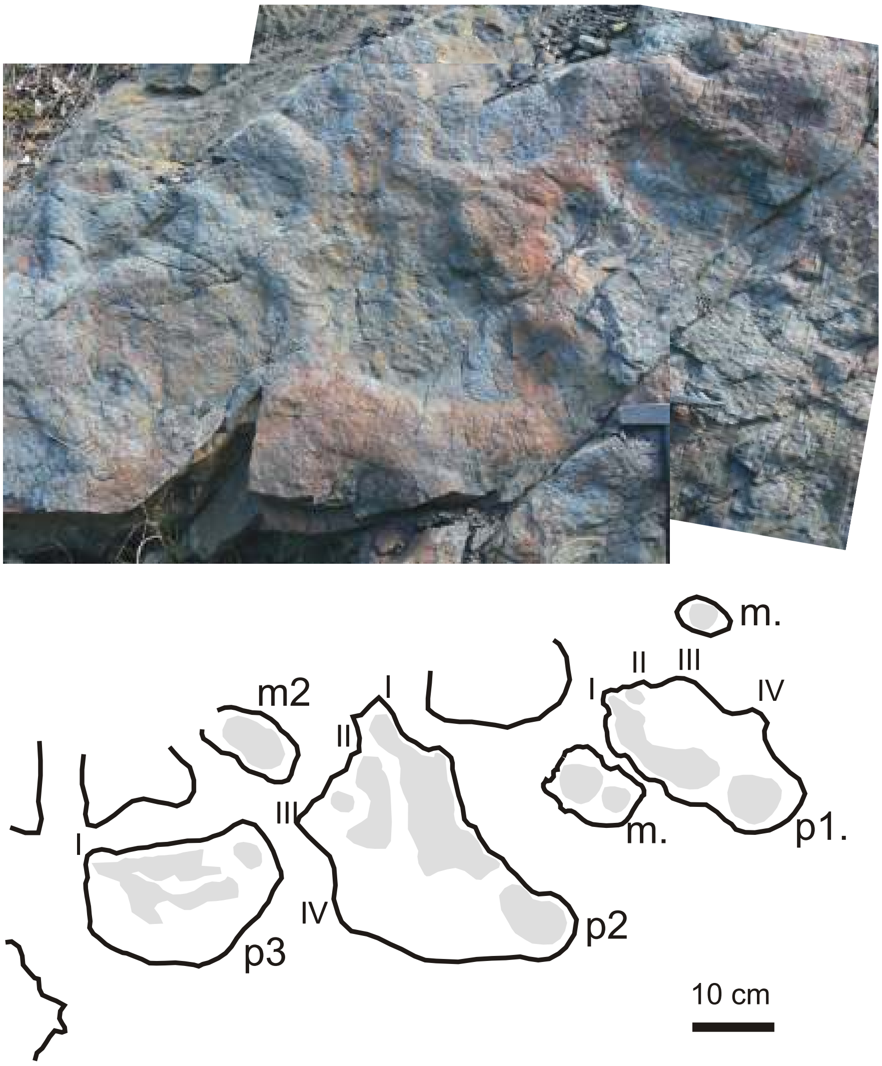

Fig. 4. Isolated sauropod tracks (last track generation on the heavily trampled surface), deeper parts of the footprints shadowed: note the pes-manus set (p2–m2), pes with four digits imprinted, and prominent digit I; medial (inner) part of the pes is significantly deeper, as in all pes tracks on the surface, and were produced by different sauropod individuals

PALAEOGEOGRAPHIC IMPLICATIONS

The palaeoclimatic and palaeogeographic interpretation is based largely on the rich Early Jurassic (Hettangian–Sinemurian) flora found in the coal-bearing Valea Tereziei Member. Givulescu (1998) referred the floral assemblage to various coeval environments of Iran and Afghanistan (northern Tethyan rim). This author also suggested that the palaeovegetation in Anina occurred along seashores and beaches, although generating coals in pure limnic, freshwater conditions. Semaka (1962) and Givulescu (1998) emphasized the paralic features of the Steierdorf Formations, following previous geological works (Răileanu *et al*., 1957) describing the coal measures of the Steierdorf Formation as Gresten-type deposits. However, any features supporting seashore proximity were not demonstrated by the authors. The first unequivocal marine influences in the Mesozoic of the Reşiţa Basin occur in the Uteriş Formation (Pliensbachian–Middle Toarcian interval — Bucur, 1991, 1997; Popa, 2000*a*, 2009). Therefore, an interpretation of a continental intramontane (limnic) basin was proposed by Popa (2000*a*) and Popa and Kędzior (2008). According to these authors, during Hettangian times, the basins of the Getic Nappe (Reşiţa) and of the Danubian Units (Sirina, Presacina and Cerna-Jiu) were continental, closely related to each other at a short distance.

Popa (1997, 1998), Popa and Van Konijnenburg-Van Cittert (2006) and Givulescu (1998) indicated that the flora of Anina belongs to the Eurosinian Region, European Province *sensu* Vakhrameev (1991). Popa and Van Konijnenburg-Van Cittert (2006) interpreted the palaeolatitude of the Reşiţa Basin as between 20° and 30° north. Mateescu (1958) recorded secondary xylem tissues with pseudo-annual growth rings in fusains from Rudăria, in the Sirinia Basin, Danubian Unit, a neighbor basin of the Reşiţa Basin in the Hettangian, citing similar features in wood tissues from Anina, Doman (Reşiţa Basin) and from the Vulcan-Codlea area (Holbav Basin). These rings indicate monsoonal conditions at this time, an appropriate model for the northern frame of the Tethys realm. Such pseudo-annual growth

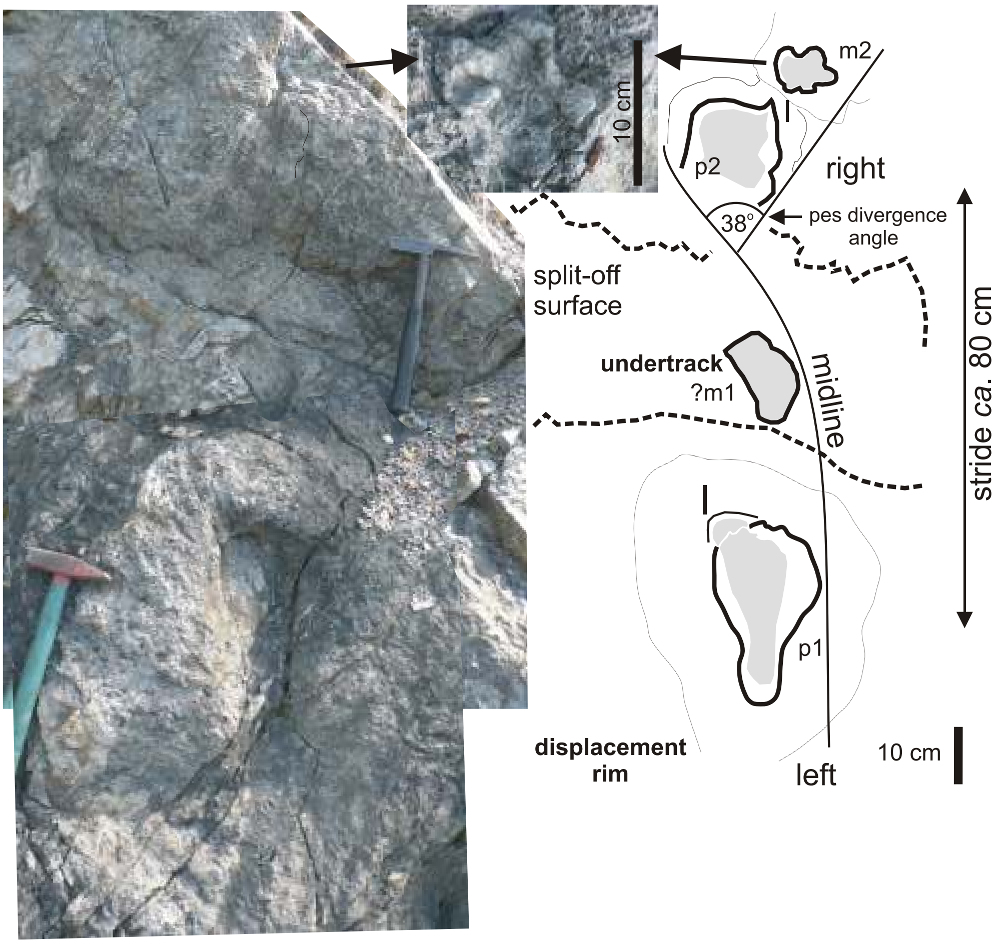

Fig. 5. Short, one-step (two manus-pes sets) trackway with inferred midline, distorted in the soft, saturated sediment

Note bent midline, changing stride and divergence angle (probably resulting from progression on an unstable surface) and deeply impressed footprints with high sediment displacement rims; pentadactyl manus of the second set (m2) shown in the insert photo

rings were also recorded in permineralized conifers from Holbav, Holbav Basin, part of the Getic Nappe, indicating a similar climate. Popa (1998, 2000*a*) concluded that the Early Jurassic flora of the Reşiţa Basin occurred on the northern frame of the Tethys realm, within a typical limnic intramontane depression, without paralic influences, whereas paralic influences were stronger in the basins of the Danubian Units.

The sauropod tracks come from the lowermost 10 m of the Valea Tereziei Member. This part of the section does not contain coal seams, thus, the climatic conditions of Romanian sauropods could have been somewhat drier than the conditions prevailing during deposition of the main coal measures in the Reşiţa Basin. Likely, it could have been a warm and humid subtropical (monsoonal) climate, perhaps with a drier season.

Although relatively few unequivocal narrow-gauge sauropods trackways are recorded from Early Jurassic strata worldwide (Hettangian: Leonardi and Lanzinger, 1992; Dalla Vecchia, 1994; Gierliński, 1997; Gierliński and Sawicki, 1998; Gierliński and Pieńkowski, 1999; Avanzini and Petti, 2008; Avanzini *et al*., 2008, and Pliensbachian strata of Marocco: Ishigaki, 1989; Farlow, 1992; see also Lockley *et al*., 1994*b*), it is clear that sauropods roamed this region, in both the Pangaean (African, Eurasian) mainland and supposed island/peninsula areas within the western/northern Tethys domain (Fig. 1). The palaeogeographic reconstructions of Blackley (2009), Golonka (2004) and Golonka *et al*. (2005) show that the area which is now the Romanian Carpathians included large islands, embracing both Hungarian and Romanian coal-bearing formations (Fig. 1). The palaeogeographic map of Scotese (2002) shows a rather peninsular area, but this map is much more generalized. As mentioned above, in the Early Jurassic, the Getic Unit would belong, together with the Danubian Units, to the larger Moesian Platform, including the "Moesian Island" of Golonka (2004). Such an island could provide a habitat for lush subtropical plants and animals, but this hypothetical island must have been at least temporarily connected to mainland Pangaea to allow migration of sauropods. Migration routes of sauropods would cross the western and northern frames of Western Tethys, including Africa and Eurasia (Fig. 1). Moreover, the size of the sauropod cf. *Parabrontopodus* isp. footprints from Romania is typical of Early Jurassic sauropods and does not differ from those from Poland (mainland Pangaea — Eurasia) and Italy (Tethyan carbonate platform/sea shore). Thus, the size of the Romanian footprints would speak against insular dwarfism, with the latter condition expected in the case of long-lasting island conditions. This is contrary to the finds of Maastrichtian dinosaurs of the "Haţeg Island" in Romania, where dinosaur bone remains clearly indicate insular dwarfism (Bojar *et al*., 2005; Csiki and Grigorescu, 2008). Polish and Romanian Early Jurassic sauropod footprints come from a continental alluvial environment, whereas Italian and Moroccan ones come from carbonate tidal flat facies. This suggests a wide spectrum of environments roamed by early sauropods and a great mobility of these animals. Assuming this mobility and the varied environments, one can suppose that the absence of sauropods from North America in the earliest Jurassic times was rather caused by a permanent obstacle (rift) between this part and other parts (Africa, Eurasia) of the fragmenting Pangaean landmass.

CONCLUSIONS

Early Jurassic cf. *Parabrontopodus* isp. tracks and an inferred narrow-gauge trackway described herein represent the first Jurassic dinosaur footprints described in Romania. Romanian footprints are of similar age to Italian sauropod tracks (middle to upper Hettangian) and they are somewhat younger than the early to middle Hettangian tracks from Poland. Asymetrically impressed pes prints with substantial heel pads indicate that a greater load was carried by the inner digits of the pes of sauropods during walking. This points to a sub-plantigrade (gravipodal) posture of the trace maker, and suggests that such a posture of sauropods (Eusauropoda) developed from digitigrade to a sub-plantigrade by the mid Hettangian. The pentadactyl manus may indicate that the manus digits were occasionally functional in Eusauropoda, perhaps providing a better support when walking on unstable, sticky ground. In the earliest Jurassic, the "Moesian Island" was at least temporarily attached to the Pangaean (Eurasian) mainland. Moreover, the normal sizes (for Hettangian times) of the Romanian sauropod footprints speak against insular dwarfism of these animals. Based on our find and on those of other sauropod tracks in the region, sauropods roamed both the northern and the southern rim of Western Tethys. This wide palaeogeographic and palaeoenvironmental distribution of sauropod footprints indicates that the absence of sauropod footprints observed in Early Jurassic strata of North America was perhaps caused by an geographical obstacle (rift), rather than by climatic factors.

Lastly, we expect that this find of dinosaur footprints can contribute to the development of geotourism and to the local economy in this part of Romania. Perspectives of geotourism depend on future scientific research on dinosaur tracks and on other fossils such as plant and invertebrate remains in the region.

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REFERENCES

ANDRAE C. (1855) — Beitrage zur kenntniss der fossilen Flora Siebenburgens und des Banates. Abhandlungen der K. K. geologischen Reichsanstalt, **3** (4): 1–48.

ANTONESCU E. (1973) — Quelques donnees sur la palynologie du Lias sous facies de Gresten de Roumanie. 3rd International Palynological Conference, Moscow: 13–17.

AVANZINI M., FRANCESCHI M., PETTI F. M., GIRARDI S., FERRETTI P. and TOMASONI R. (2008) — New Early Jurassic (Hettangian–Sinemurian) sauropodomorph track from the Trento carbonate Platform (Southern Alps, Northern Italy). Studi Trent. Sc. Nat., Acta Geol., **83**: 317–322.

AVANZINI M. and PETTI F. M. (2008) — Updating the dinosaur tracksites from the Lower Jurassic Calcari Grigi Group (Southern Alps, Northern Italy). Studi Trent. Sc. Nat., Acta Geol., **83**: 289–301.

BENTON M., COOK E., GRIGORESCU D. and TALLODI E. (1997) — Dinosaurs and other tetrapods in an Early Cretaceous bauxite-filled fissure, northwestern Romania. Palaeogeogr., Palaeoclimat., Palaeoecol., **130**: 275–292.

BENTON M., MINTER N. J. and POSMOŞANU E. (2006) — Dwarfism in ornithopod dinosaurs from the Early Cretaceous of Romania. In: Tributes to the Career of Prof. Dan Grigorescu (ed. Z. Csiki): 79–87. Ars Docendi, Bucharest.

BLACKLEY R. C. (2009) — Global palaeogeography. http://jan.ucc.nau.edu/rcb7/

BOJAR A.-V., GRIGORESCU D., OTTNER F. and CSIKI Z. (2005) — Palaeoenvironmental interpretation of dinosaur- and mammal-bearing continental Maastrichtian deposits, Haţeg basin, Romania. Geol. Quart., **49** (2): 205–222.

BONNAN M. F. (2003) — The evolution of manus shape in sauropod dinosaurs: implications for functional morphology, forelimb orientation and phylogeny. J Verte. Paleont., **23**: 595–613.

BUCUR I. I. (1991) — Proposition pour une nomenclature formelle des depots paleozoiques et mesozoiques de la zone de Reşiţa-Moldova Nouă (Carpathes Meridionales, Roumanie). Stud. Univ. Babeş-Bolyai. Geologie, **36** (2): 3–14.

BUCUR I. I. (1997) — Formaţiunile mesozoice din zona Reşiţa-Moldova Nouă. Cluj-Napoca.

COOPER M. R. (1984) — Reassessment of *Vulcanodon karibaensis* Raath (Dinosauria: Saurischia) and the origin of the Sauropoda. Palaeontol. Africana, **25**: 203–231.

CRUICKSHANK A. R. I. (1975) — Origin of sauropod dinosaurs. South African J. Sc., **71**: 89–90.

CSIKI Z. and GRIGORESCU D. (2008) — The "Dinosaur Island" — new interpretation of the Haţeg Basin after 110 years. Sargetia, **20**: 5–26.

DALLA VECCHIA F. M. (1994) — Jurassic and Cretaceous sauropod evidence in the Mesozoic carbonate platforms of the Southern Alps and Dinarids. Gaia, **10**: 65–73.

DALLA VECCHIA F. M. (1999) — A sauropod footprint in a limestone block from the Lower Cretaceous of northeastern Italy. Ichnos, **6**: 269–275.

DALLA VECCHIA F. M. and TARLAO A. (2000) — New Dinosaur track sites in the Albian (Early Cretaceous) of the Istrian peninsula (Croatia). Parte II — Paleontology. Mem. Sc. Geol., **52**: 227–292.

DONG Z. (1992) — Dinosaurian Faunas of China. Springer-Verlag, Berlin.

DONG Z., ZHOU S. and ZHANG Y. (1983) — The dinosaurian remains from Sichuan Basin, China. Palaeontol. Sinica, **162** C(23): 1–145.

FARLOW J. O. (1992) — Sauropod tracks and trackmakers: integrating the ichnological and skeletal records. Zubia, **10**: 89–138.

GIERLIŃSKI G. (1997) — Sauropod tracks in the Early Jurassic of Poland. Acta Palaeont. Pol., **42** (4): 533–538.

GIERLIŃSKI G. and PIEŃKOWSKI G. (1999) — Dinosaur track assemblages from Hettangian of Poland. Geol. Quart., **43** (3): 329–346.

GIERLIŃSKI G., PIEŃKOWSKI G. and NIEDŹWIEDZKI G. (2004) — Tetrapod track assemblage in the Hettangian of Sołtyków, Poland, and its Paleoenvironmental Background. Ichnos, **11** (3–4), *William A. S. Sarjeant (1935–2002) A Celebration of His Life and Ichnological Contribution.* Spec. Issue: Part 3, 195–213.

GIERLIŃSKI G. and SAWICKI G. (1998) — New sauropod tracks from the Lower Jurassic of Poland. Geol. Quart., **42** (4): 477–480.

GIVULESCU R. (1998) — Flora fosilă a Jurasicului inferior de la Anina. Editura Academiei Române, Bucureşti.

GOLONKA J. (2004) — Plate tectonic evolution of the southern margin of Kurasia in the Mesozoic and Cenozoic. Tectonophysics, **381**: 235–273.

GOLONKA J., KROBICKI M. and TOMAŚ A. (2005) — Paleogeografia Karpat centralnych i wewnętrznych — ujęcie rotacyjne. In: Wapienie organiczne i organodetrytyczne w Karpatach Zewnętrznych i ich znaczenie dla rekonstrukcji paleogeograficznych (eds. M. Cieszkowski, J. Golonka): 41–45. Seminarium naukowe, Kraków, 21.04.2005.

GRIGORESCU D. (2005) — Rediscovery of a “forgotten land”. The last three decades of research on the dinosaur-bearing deposits from the Haţeg Basin. Acta Palaeont. Romaniae, **5**: 191–204.

GRIGORESCU D. and CSIKI Z. (2008) — A new site with megaloolithid egg remains in the Maastrichtian of the Hateg Basin. Acta Palaeont. Romaniae, **6**: 115–121.

HUNT A. P. and LUCAS S. G. (2007) — Late Triassic tetrapod tracks of western North America. In: Triassic of the American West (eds. S. G. Lucas and J. A. Spielmann). New Mexico Mus. Natur. History Sc. Bull., **40**: 215–230.

HUNT A. P., LOCKLEY M. G., LUCAS S. G. and MEYER C. A. (1994) — The global sauropod fossil record. Gaia, **10**: 261–279.

ISHIGAKI S. (1989) — Footprints of swimming sauropods from Morocco. In: Dinosaur Tracks and Traces (eds. D. D. Gilette and M. G. Lockley): 83–86. Cambridge Univ. Press. Cambridge.

JAIN S. L., KUTTY T. S., ROYCHOWDHURY T. and CHATTERJEE S. (1979) — Some chararacteristics of Barapasaurus tagorei, a sauropod dinosaur from the Lower Jurassic of Deccan India. Procced. 4 International. Gondwana Symp., Calcutta, **1**: 204–216.

KOCH A. (1900) — Systematische Ubersicht der fossilien Wilbertierreste der Lander der Ungarischen Krone. Magyar Orv. Es Term-Visg. Vandorgy Munkatalai, **30**: 526–566.

LEONARDI G. and AVANZINI M. (1994) — Dinosauri in Italia. In: Il tempo dei dinosauri (ed. G. Ligaube). Le Scienze Quaderni, **76**: 69–81.

LEONARDI G. and LANZINGER M. (1992) — Dinosauri nel Trentino: venticinque piste fossili nel Liassico di Rovereto (Trento, Italia). Paleocronache, **1**: 13–24.

LOCKLEY M. G., FARLOW J. O. and MEYER C. A. (1994*a*) — *Brontopodus* and *Parabrontopodus* ichnogen. nov. and the significance of wide- and narrow-gauge sauropod trackways. Gaia, **10**: 135–145.

LOCKLEY M. G., LUCAS S. G. and HUNT A. P. (2006) — *Eosauropus*, a new name for a Late Triassic track: further observations on the Late Triassic ichnogenus *Tetrasauropus* and related forms, with notes on the limits of interpretation: In: The Triassic-Jurassic Terrestrial Transition (eds. H. D. Harris, S. G. Lucas, J. A. Spielmann, M. G. Lockley, A. R. C. Milner and J. I. Kirkland). New Mexico Mus. Natur. Hist. Sc. Bull., **37**: 193–198.

LOCKLEY M. G., MEYER C. A., HUNT A. P. and LUCAS S. G. (1994*b*) — The distribution of sauropod tracks and trackmakers. Gaia, **10**: 233–248.

LOCKLEY M. G., SANTOS V. F., RAMALHO M. M. and GALOPIM DE CARVALHO A. M. (1992) — Novas jazidas de pegadas de dinossáurios no Jurássico superior de Sesimbra (Portugal). Gaia, **5**: 40–43.

MATEESCU I. (1958) — Studiul petrografic al cărbunilor de la Rudăria (Svinecea Mare). Anuarul Comitetului Geologic, **31**: 5–49.

McINTOSH J. S. (1990) — Sauropoda. In: The Dinosauria (eds. D. B. Weishampel, P. Dodson and H. Osmólska): 345–401. Univ. California Press, Berkeley.

MURGOCI G. M. (1905) — Sur l’existence d’une grande nappe de recouvrement dans les Carpathes meridionales. C. R. Acad. Sc., **7**.

OLSEN P. E., KENT D. V., SUES H-D., KOEBERL C., HUBER H., MONTANARI A., RAINFORTH E. C., FOWELL S. J., SZAJNA M. J. and HARTLINE W. (2002) — Ascent of dinosaur linked to an iridium anomaly at the Triassic-Jurassic boundary. Science, **296**: 1305–1307.

PIEŃKOWSKI G. (2004) — The epicontinental Lower Jurassic of Poland. Pol. Geol. Inst. Spec. Pap., **12**.

PITTMAN J. G. and GILETTE D. D. (1989) — The Briar site: a new sauropod dinosaur tracksite in Lower Cretaceous beds of Arkansas. In: Dinosaur Tracks and Traces (eds. D. D. Gilette and M. G. Lockley): 313–332. Cambridge Univ. Press, Cambridge.

POPA M. E. (1997) — Corystospermal pteridosperms in the Liassic continental deposits of Romania. Acta Palaeont. Romaniae, **1**: 81–87.

POPA M. E. (1998) — The Liassic continental flora of Romania: systematics, stratigraphy and paleoecology. Acta Bot. Horti Bucurestensis, (1997–1998): 177–184.

POPA M. E. (2000*a*) — Early Jurassic land flora of the Getic Nappe. Univ. Bucharest, Bucharest, unpubl. PhD Thesis,.

POPA M. E. (2000*b*) — Aspects of Romanian Early Jurassic palaeobotany and palynology. Part III. Phytostratigraphy of the Getic Nappe. Acta Palaeont. Romaniae, **2**: 377–386.

POPA M. E. (2000*c*) — First find of Mesozoic tetrapod tracks in Romania. Acta Palaeont. Romaniae, **2**: 387–390.

POPA M. E. (2005) — Aspects of Romanian Early Jurassic Palaeobotany and Palynology. Part VI. Anina, an exceptional locality. Acta Palaeont. Romaniae, **5**: 375–378.

POPA M. E. (2009) — Late Palaeozoic and Early Mesozoic continental formations of the Reşiţa Basin. Editura Universităţii din Bucureşti, Bucharest.

POPA M. E. and KĘDZIOR A. (2006) — Preliminary ichnological results on the Steierdorf Formation in Anina, Romania. In: Mesozoic and Cenozoic vertebrates and paleoenvironments (ed. Z. Csiki): 197–201. Bucureşti.

POPA M. E. and KĘDZIOR A. (2008) — High resolution paleobotany and sedimentology of the Steierdorf Formation, Reşiţa Basin. In: Annual Scientific Session “Ion Popescu Voiteşti” (eds. I. Bucur and S. Filipescu): 57–59. Cluj Univ.yPress, Cluj-Napoca.

POPA M. E. and VAN KONIJNENBURG-VAN CITTERT J. H. A. (2006) — Aspects of Romanian Early–Middle Jurassic palaeobotany and palynology. Part VII. Successions and floras. Progress in Natur. Sc., **16**: 203–212.

RAATH M. A. (1972) — Fossil vertebrate studies in Rhodesia: a new dinosaur (Reptilia: Saurischia) from near the Trias-Jurassic boundary. Arnoldia, **5**: 1–37.

RĂILEANU G., NĂSTĂSEANU A. and MUTIHAC V. (1957) — Cercetări geologice n regiunea Anina — Doman (zona Reşiţa–Moldova Nouă–Banat). Ann. Ins. Geol. Roum., **2**.

SANTOS V. F., LOCKLEY M. G., MEYER C. A., CARVALHO J., GALOPIM DE CARVALHO A. M. and MORATALLA J. J. (1994) — A new sauropod tracksite from the Middle Jurassic of Portugal. Gaia, **10**: 5–13.

SANTOS V. F., MORATALLA J. J. and ROYO-TORRES R. (2009) — New sauropod trackways from the Middle Jurassic of Portugal. Acta Palaeont. Pol., **54**: 409–422.

SCOTESE C. R. (2002) — Palaeomap project; www.scotese.com

SEMAKA A. (1962) — Flora Liasică de la Anina (Banat). Anuarul Comitetului Geologic, **32**: 527–569.

UPCHURCH P. (1993) — The anatomy, phylogeny, and systematics of the sauropod dinosaurs. PhD. Thesis, Univ. Cambridge.

UPCHURCH P. (1994) — Sauropod phylogeny and palaeoecology. Gaia, **10**: 249–260.

VREMIR M. and CODREA V. (2002) — The first Late Cretaceous (Maastrichtian) dinosaur footprints from Transylvania (Romania). Stud. Univ. Babe–Bolyai, Geologie, **47** (2): 93–104.

WILD R. (1978) — Ein Sauropoden-Rest (Reptilia, Saurischia) aus dem Posidonienschiefer (Lias, Toarcium) von Holzmaden. Stuttgart. Beitr. Natur., (B), **41**: 1–15.

WILSON J. A. and SERENO P. C. (1998) — Early Evolution and Higher-level Phylogeny of Sauropod Dinosaurs. J. Vertebrate Paleont., 18, Supplement to No., **2**: 1–68.