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REVIEW OF THE DINOSAUR RECORD FROM IRAN WITH THE DESCRIPTION OF NEW MATERIAL

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Abstract. The dinosaur record from Iran includes footprints from the Liassic Ab-e-Haji Formation of Neizar Valley (Kerman Province, central-eastern Iran), a single footprint from the Javaherdeh Formation near Zerab (Alborz Mounts, NE Iran), and skeletal remains from the Late Jurassic-earliest Cretaceous Ravar Formation of the Ab Bid Syncline (Kerman Province). Contrary to previous identifications, no footprints from the Neizar Valley belong to ornithopods; they can all be referred to theropod trackmakers. The Zerab footprint, on which the ichnospecies *Iranosauripus zerabensis* is based, is an undiagnostic theropod footprint and probably was lost. The skeletal remains are represented by bone fragments and a tooth of a mid-sized theropod, which represent the first dinosaur osteological record in this part of the Middle East. The Ab Bid Syncline has a high potential for further future discoveries.

Riassunto. Le testimonianze di dinosauri in Iran consistono in impronte rinvenute nella Formazione Ab-e-Haji (Liassico) della Valle Neizar (Provincia di Kerman, Iran centro-orientale), un' impronta singola dalla Formazione Javaherdeh nei pressi di Zerab (Monti Elburz) e resti scheletrici scoperti nella Formazione Ravar (Giurassico superiore-Cretaceo basale) della Sinclinale di Ab Bid (Provincia di Kerman). Diversamente dalle identificazioni precedenti, nessuna delle impronte della Valle Neizar appartiene agli ornitopodi, ma tutti i reperti possono essere riferiti a dinosauri teropodi. L'impronta di Zerab, sulla quale é basata l'icnospecie *Iranosauripus zerabensis*, é un'orma di teropode priva di caratteri diagnostici e probabilmente é pure andata perduta. I resti scheletrici sono rappresentati da frammenti ossei e da un dente di un teropode di medie dimensioni; rappresentano il primo rinvenimento di testimonianze osteologiche di dinosauro in questa parte del Medio Oriente. La Sinclinale di Ab Bid ha un grande potenziale per future ulteriori scoperte.

Introduction

The dinosaur record from the Middle East is rather scarce despite the great potential of several deposits particularly those of the Islamic Republic of Iran. The first dinosaur material reported from this country consists of footprints discovered in Lower Jurassic outcrops at the Neizar Valley (Kerman Province, Central-Eastern Iran) that were described by Lapparent & Davoudzadeh (1972) and a single footprint from Zerab (Alborz Mountains, NE Iran) reported by Lapparent & Sadat (1975). Given that those reports were only preliminary, subsequent authors have encountered difficulties in properly assessing them (e.g., Leonardi & Mietto 2000, p. 215).

In September 2002, an expedition lead by Alexander W. A. Kellner, Museu Nacional/UFRJ of Rio de Janeiro (Brazil), Majid Mirzaie Ataabadi, then at University of Isfahan (Iran), and Fabio M. Dalla Vecchia, at that time representing the Museo Paleontologico of Monfalcone (Italy), with the support of the Geological Survey of Iran, restudied the specimens previously reported and prospected the southern Alborz Mountains and north of Kerman for new discoveries. That survey allowed revising the dinosaur palaeoichnological record

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where new footprints were also found and leaded to the discovery of the first dinosaur osteological evidence of Iran, also reported very briefly (Kellner et al. 2003; Dalla Vecchia et al. 2003; Mirzaie Aatabadi et al. 2005). Here we provide a detailed description and interpretation of the dinosaur palaeoichnological record as well as description of the limited osteological material found so far.

Methods and terminology

For the local stratigraphic terminology and unit definition, we refer to Fürsich et al. (2009) for the Alborz Mountains and to Wilmsen et al. (2009) for the Kerman region. The English terms concerning vertebrate palaeoichnology mainly follow Thulborn (1990) and Farlow & Chapman (1997).

Measurements (L, W, A, A°) were taken mainly on the tracings because of the difficult logistic situation of the sites (e.g., bad illumination, steep inclination of the beds). Because the inner (bottom) outline of the footprints is often concealed by the sedimentary rock and sometimes obliterated by sediment collapse, measurements refer to the outer (upper) outline. The total interdigital angle (A°) was measured following the method figured in Thulborn (1990, fig. 4.5a). SL in the tracks was measured taking as reference point the proximal termination of digit III print. Speed is calculated by the equation of Alexander (1976) $V = 0.25 \times g^{0.5} \times SL^{1.67} \times h^{-1.17}$. The critical parameter in this equation is the height at the hip (h), since there are many different ways to estimate it. We have chosen the morphometric ratios method of Thulborn (1990) for h estimates (h = 4.9L, for large theropods [L > 25 cm] (for further considerations about this selection, see Dalla Vecchia & Tarlao 2000). When the longitudinal axis of the footprint is directed inward or outward with respect to the mid-line of the trackway, we will use respectively the term "inward rotation" and "outward rotation". We indicate the footprints with acronyms (e.g., NV/LHUL means Neizar Valley/Lower Horizon, upper level; T means "track"). The odontological terminology and variables used in this paper are those used several times in the literature (e.g., Currie et al. 1990; Kellner 1996).

Abbreviations for ichnological variables: A, pace angulation; A°, total interdigital angle or total divarication (II-IV); d, length of the part of digit III projecting beyond the ends of digits II and IV (see Dalla Vecchia & Tarlao 2000, fig. 2); h, height at hip; L, footprint length; P, pace; R, length of the rear of the pedal print (see Dalla Vecchia & Tarlao 2000, fig. 2); SL, stride length; V, velocity/speed; W, footprint width; II-III°, angle between digits II-III; II-IV°, angle between digits II-IV; II to IVw, maximum digit II to IV width.

Abbreviations for tooth variables: AL, apical length; CA, crown angle; CBL, crown base length; CBW, crown base width; CBR, crown base ratio (CBW/CBL); CH, crown height; CHR, crown height ratio (CH/CBL).

Institutional abbreviations: MN - Paleovertebrate Sector of the Museu Nacional/Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil.

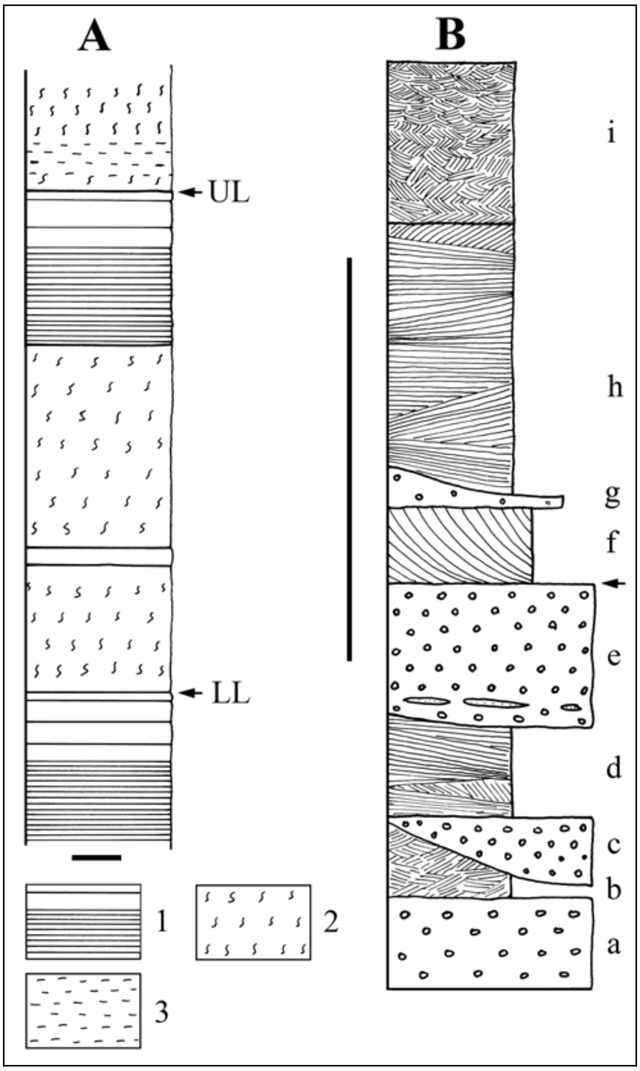

Fig. 1 - Stratigraphic sections of the fossil-bearing outcrops. A) "Upper Horizon" of the Neizar Valley; footprint-bearing surfaces are indicated by arrows; legend: LL, lower level; UL, upper level; 1, well-bedded reddish-gray sandstone; 2, very bioturbated gray-yellow sandstone; 3, coal seam. B) The tooth-bearing section at the Kuh-e-Kalleh Gav; legend: a, microconglomerate; b, fine sandstone with small-scale cross lamination (ripples?); c, lenticular microconglomerate body erosional on b; d, fine sandstone with medium-scale cross-lamination, mainly wedge-like; e, microconglomerate with small clasts and tongues of pebbly sandstone (45 cm maximum thickness); f, medium sandstone with relatively highly inclined lamination; g, sandstone body with millimeter-sized scattered clasts; h, fine sandstone with medium-scale cross bedding and lamination; i, fine sandstone with small-scale cross lamination (ripples?); tooth position is indicated by the arrow. Scale bar equals 1 meter.

Location and geology

Dinosaur footprints have been reported from two distinct levels of the Shemshak Formation in the Neizar Valley 20 km N of Zarand, Kerman Province, Central-Eastern Iran (Lapparent & Davoudzadeh 1972) and in a single level of the same formation near Zerab in the western Alborz Mountains, about 150 km NE of Tehran (Lapparent & Sadat 1975). According to the recent revisions of the Jurassic lithostratigraphic scheme of those regions of Iran that we follow here, a distinct Shemshak Formation does not exist anymore, having been included into the Shemshak Group (Norian-middle Bajocian).

The Neizar Valley footprints occur inside the Ab-e-Haji Formation, which reaches up to 3000 m in thickness in the Zarand area and is Hettangian-Pliensbachian in age (Wilmsen et al. 2009, p. 327). It is a silicoclastic unit containing coal seams and was mostly deposited in fluvial-coastal plain environments (Wilmsen et al. 2009).

The stratigraphical distance between the two footprint-bearing horizons of the Neizar Valley ("Lower and Upper Horizons" of Lapparent & Davoudzadeh 1972) is about 500 m, thus they have a different age. Lapparent & Davoudzadeh (1972, fig. 3) dated the "Lower Horizon" to the Sinemurian and the "Upper Horizon" to the Pliensbachian, but they did not support this with any biostratigraphic evidence. According to Lapparent & Davoudzadeh (1972, p. 8), the "Lower Horizon" occurs more than 500 m above the basal part of the unit (the former Shemshak Formation) containing a Liassic floristic assemblages in the Alborz Mountains, while the "Upper Horizon" is 250-300 m below the marine Badamu Formation that contains late Toarcian ammonites.

The "Upper Horizon" actually contains two footprint-bearing surfaces, one of which is here reported for the first time. They have a same position inside similar depositional cycles (Fig. 1A).

The upper footprint-bearing surface (Fig. 2) is at the top of a 3.5 m-thick sandstone body; the lower part of that body (~200 cm) is made of thinly, plano-parallell laminated and slaty sandstone, whereas the upper part (~110 cm) is massively bedded with ripple marks on the upper bed surfaces. The footprints are at the top of a 13 cm-thick layer of dark gray, fine sandstone, brown when weathered. The strike is 110° and dip is 65° NNE. Small-scale, slightly asymmetric ripple marks with wave lengths around 30 mm and amplitudes of 20-25 mm, and small vertical burrows are present on the surface. The footprint-bearing bed is covered by an interval of gray sandstone, which is yellowish when weathered, heavily bioturbated and scarcely cemented, with dark levels rich in organic matter.

The lower footprint-bearing surface (Fig. 3) also occurs at the top of a sandstone body with thin bedding at the base and thick beds at the top that underlies heavily bioturbated and scarcely cemented gray sandstone. The footprints are preserved at the top of a 12 cm-thick layer of gray fine sandstone whose strike is 110° and dip is 50° NNE. The surface presents small-scale and slightly asymmetric ripple marks with wave lengths around 35-40 mm and amplitudes of 20 mm.

The "Lower Horizon" corresponds to a thick body of hard, dark gray to greenish sandstone containing a few plant remains; small-scale cross lamination and wedge-like medium-scale lamination/bedding are visible in cross-section. Two footprint-bearing surfaces

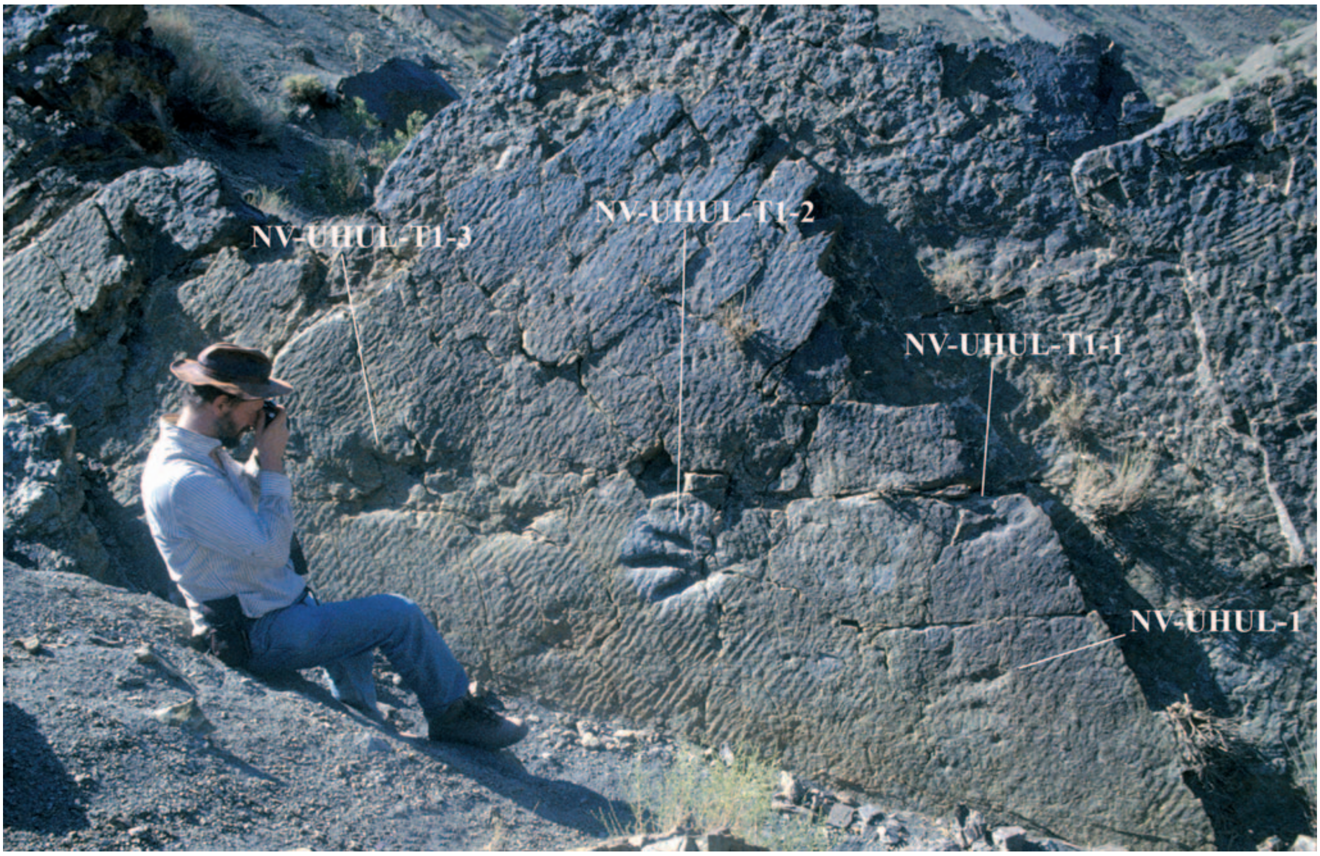

Fig. 2 - The footprints of the upper level of the "Upper Horizon", Neizar Valley.

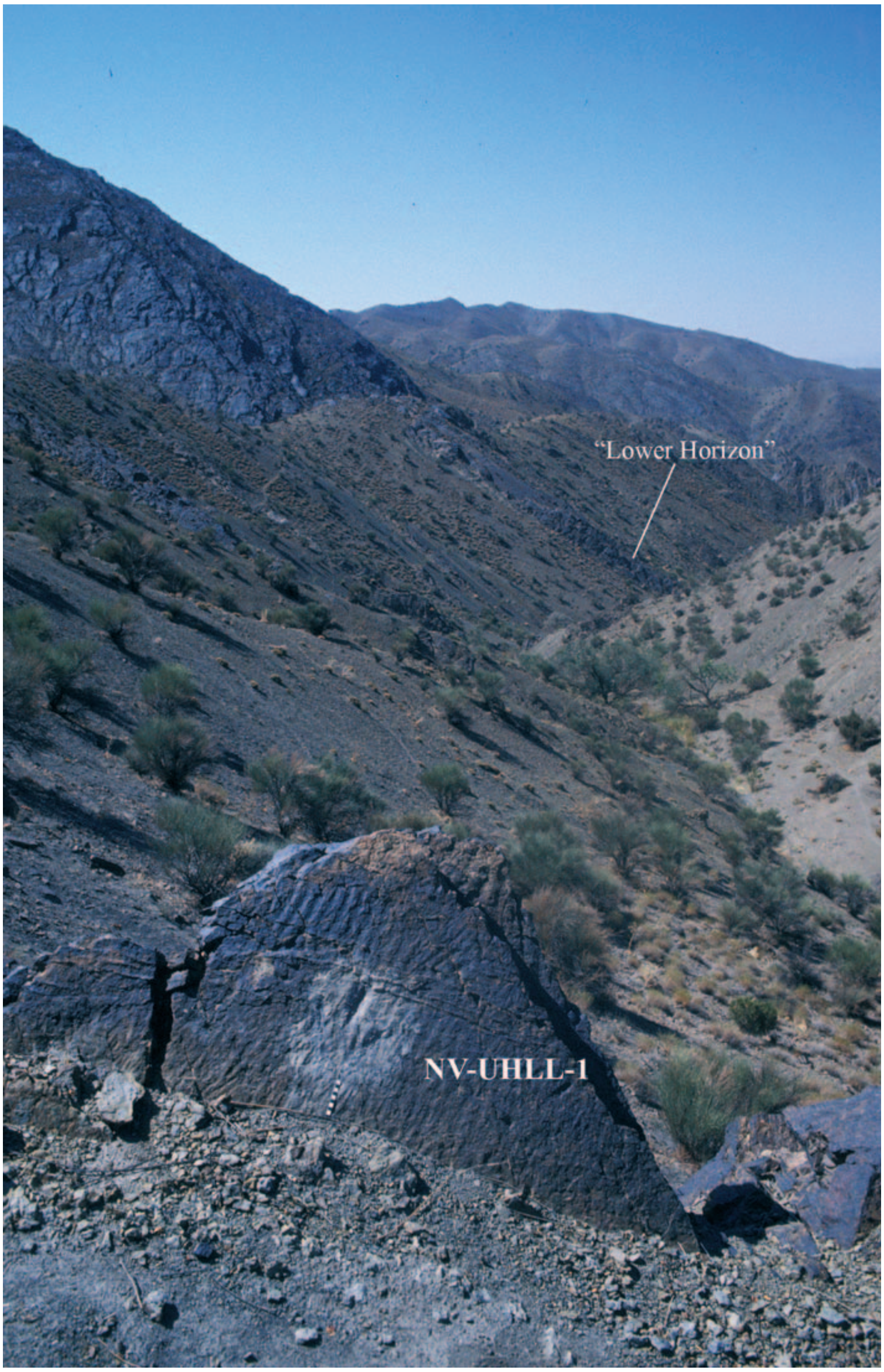

Fig. 3 - The lower level of the "Upper Horizon" with the footprint NV/UHLL-1; the "Lower Horizon" is in the background. Scale bar equals 10 cm.

have been identified. The lower surface is at the top surface of a 65 cm-thick bed of greenish sandstone with wedge-like medium-scale lamination, covered by a 10 cm-thick tabular bed of greenish sandstone with small-scale cross lamination. Bed strike is 85° and dip is 50°N. The upper surface is at the top of a 15 cm-thick tabular bed of laminated sandstone and shows narrow asymmetric ripple marks. It is less than 1 metre above the lower surface.

The stratigraphical relocation of the Zerab footprint is more problematic because the revised lithostratigraphic schemes regard the central-eastern Alborz Mountains (Fürsich et al. 2009), while Zerab is in the western Alborz Mountains. For Lapparent & Sadat (1975, p. 161), the specimen comes from the "upper part of the Lower Liassic, which is 200 m-thick". According to the stratigraphic scheme by Fürsich et al. (2009), the finding locality should be in the fluvial Javaherdeh Formation (Hettangian-Bajocian), being located in the northern part of the Alborz Mountains. However, it cannot be totally excluded a provenance from the Alasht Formation (Hettangian-Toarcian), which is also fluvial but more distal, and is comparable to the Ab-e-Haji Formation of the Zarand area (Wilmsen et al. 2009).

The dinosaur skeletal remains were discovered along the western flank and foot of the Kuh-e-Kalleh Gav (Kuh is the Farsi name for mount) close to the southwestern margin of the Lut Desert (Dasht-e-Lut) in the Ab Bid syncline, 35 km south of Ravar and 95 km north of Kerman. The remains were found in the upper part of the Bidou Formation following the Geological Map of Iran (Daneshmand 1995). However, according to the recent revision of the Jurassic stratigraphy of the southern Tabas Block (Wilmsen et al. 2009) they come from the Ravar Formation. A marked angular unconformity exists between the bone-bearing unit and the overlaying Cretaceous units ($K^{c,s}_1$ - $K^{l,m}_2$ sequence in the sheet Zarand of the Geological Map of Iran at scale 1:100.000, Daneshmand 1995). The Ravar Formation is Late Jurassic- early Early Cretaceous in age based on the age of the under and overlaying units (Wilmsen et al. 2009; the overlaying strata are dated to the Barremian-Aptian).

The bone-bearing section is characterized by sandstone bodies with microconglomerate intercalations, usually 2 to 5 m-thick and forming well-projecting ledges because they are harder than the intervening marl and thinly laminate, slaty sandstone. The bedding strike is around 110-115° and dip is 60°-70° NNE. The microconglomerate beds have lenticular cross-sections, and are usually 5-6 meters wide and 10-50 cm-thick, with a concave, erosional bottom. The clasts are usually millimeter-sized, angular, often without a clear pattern of orientation and without structures (gradation, lamination etc.). Sandy matrix is from totally absent to abundant and coarse, with iron oxydes. The specimens have been found in the microconglomeratic beds and, much rarely, at the base of sandstone beds with pebbles. Bones are found as scattered and often rolled clasts, which can be distinguished because of their whitish color contrasting with the prevailing dark brown, dark reddish or pinkish color of the other clasts that are mainly made of sandstone, and less frequently chert and metamorphic rocks, or are clay chips. The microconglomerate beds are often covered by 15-40 cm-thick, tabular sandstone bodies with sigmoid or highly sloping foresets. The surfaces of the sandstone beds are usually smooth and ripple marks are rare. Interference ripples were observed only in a single case and asymmetric ripples were found in the upper surface of a 50 cm-thick microconglomerate bed. Mud-cracks are extremely rare. Macrofossil evidence includes only a few invertebrate ichnofossils, vertebrate skeletal fragments, and some poorly preserved plant remains. The theropod tooth has been found inside a sandstone-microconglomerate body about five meters-thick (Fig. 1b). It was preserved at the top surface of a lenticular body of microconglomerate with abundant coarse sand matrix and iron oxides that reaches a maximum thickness of 45 cm and a lateral width of only a few meters. The surface bearing the tooth is covered by a tabular body of medium sand with relatively highly inclined lamination.

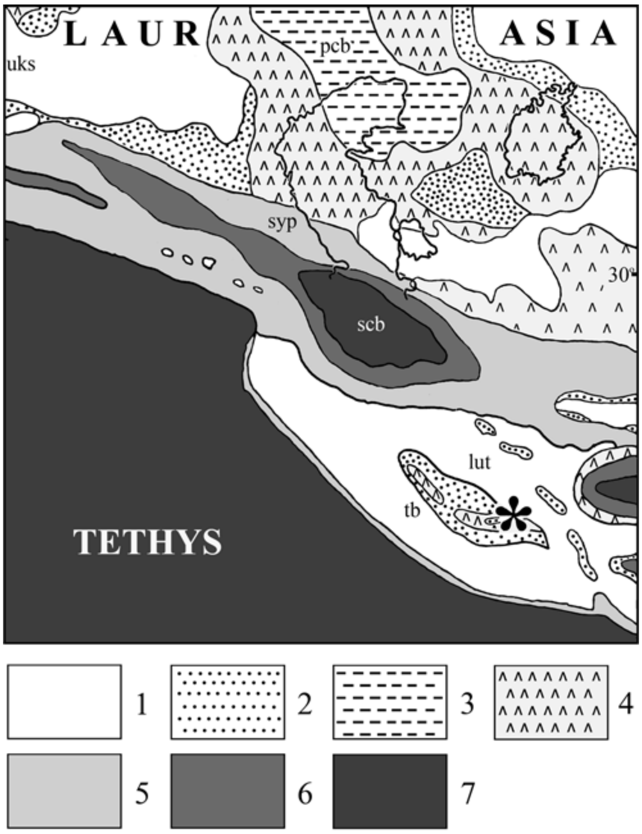

Fig. 4 - Tithonian palaeogeographic map of a portion of the southern margin of Laurasia. Legend: 1, emergent land without deposition (including volcanic arcs); 2, fluvio-lacustrine facies; 3, deltaic facies; 4, evaporitic platform or basin; 5, shallow sea; 6, slope and deep marine basin; 7, oceanic basin; Lt, Lut Block; pcb, Pre-Caspian Basin; scb, south Caspian Basin; syp, Scythian Platform; tb, Tabas Block; uks, Ukrainian Shield. The asterisk marks the position of the Ab Bid syncline. The coastline of the present-day Caspian and Aral seas is reported. Redrawn and modified after Barrier & Vrielynck (2008).

The 400 m-thick Ravar Formation deposited in a sabkha-type environment (Wilmsen et al. 2009). According to the latest Jurassic palaeogeographic maps of the Tethys, Peri- Tethys, and MEBE programs (Cecca et al. 1993; Thierry et al. 2000; Thierry, Barrier et al. 2000; Fourcade et al. 1993; Barrier & Vryelinck 2008), Central-Eastern Iran was a wide island very close to the southwestern Asian continental margin (Fig. 4). The zone yielding the bone remains correspond to a basin with fluviodeltaic sedimentation in the central part of the island (Fig. 2). A generally dry climate was present in the region during Late Jurassic times (Thierry, 2000a, b) as suggested by the presence of evaporites and the absence of coal seams in the Ravar Formation, which are instead found in the two other Jurassic continentalparalic units of the same area (the Liassic Ab-e-Haji Formation and the Middle Jurassic Hodjek Formation).

Footprint description

Neizar Valley, "Upper Horizon"

The upper footprint-bearing layer of the "Upper Horizon" of the Neizar Valley, figured in Lapparent & Davoudzadeh (1972, fig. 5) presents a track segment (NV/UHUL-T1) and a single tridactyl footprint (NV/UHUL-1) (Figs. 2, 3, 4). We have been unable to identify footprint n. 5 of Lapparent & Davoudzadeh (1972, fig. 5). All the footprints are negative (concave) epireliefs. Footprint variables are reported in Tab. 1.

The track NV/UHUL-T1 is made of three consecutive tridactyl footprints. The first is a right footprint and is only partly preserved; the second is the best preserved of the three and is complete; the third is only partly preserved. Although belonging to a same track, the three footprints have markedly different morphologies.

NV/UHUL-T1-1 (Fig. 5A1) preserves the impression of the proximal part of digit III and that of digit II. The digit II has two rounded pad marks and possibly a third, proximal pad mark. Considering also the latter pad mark, the length of the digital impression is 270 mm. The distal end of the digit is curved medially and is pointed, but it is still filled with sedimentary rock, thus the termination of the digital print could have been incorrectly interpreted as rounded. A shallow round depression posterior to the digital impression III and separated from it could be the posterior termination of digit IV mark.

The next footprint, NV/UHUL-T1-2 (Fig. 5A2), is deeper than T1-1 (depth = 25 mm). Its length is 390 mm, less than the 420 mm reported by Lapparent & Davoudzadeh (1972). All digital impressions are long and narrow, and digit III print is slightly sigmoid. The distal termination is slightly curved medially and there is evidence of a relatively short claw mark slightly facing medially and still filled with rock. Thus, this distal end seems blunt at first sight, but it is not. There are probably four pad marks and a low medial expulsion rim. The deepest part of the print is still filled with rock. Digit II print is straight and has at least three pad marks and the distal end is pointed and also filled with rock, with a fracture starting from it and extending on the bed surface. The filling is made of thin sandstone laminae similar to those of the footprint-bearing bed; for this reason the distal part of the digital mark can appear as blunt. The impression of digit IV is straight, with a maximum width at the hypex with digit print III; it ends posterior to the impression of digit II. Two pad marks can be identified in the portion of the digital print distal to the well-marked hypex with digit III; one occurs proximally and probably corresponding to the phalangeal-metatarsal pad. The distal end of the digit is pointed, but the point is still obliterated by sedimentary rock. The posterior termination of the footprint is damaged by fractures and there is no evidence of the "well developed, asymmetrical heel which indicates that the animal walked on the sole of its foot" reported by Lapparent & Davoudzadeh (1972, p. 12). The supposed

Footprint	L	W	W/L	A°	III-IV°	III-II°	R/d	II	IIw	III	IIIw	IV	IVw
UHUL-T1-1	-	-	-	-	-	-	-	270	-	-	-	-	-
UHUL-T1-2	390	290	0.74	53°	21	32	2.00	205	~50	270	45	280	~50
UHUL-T1-3	?355	-	-	-	-	-	-	-	-	>195	-	-	-
UHUL-1	~350	-	-	-	-	-	-	-		-	-	-	-
UHLL-1	215	220	1.02	71	34	37	2.03	95	40	132	40	160	~40
UHLL-2	>230	-	-	-	-	-	-	130	37	210-230	-	-	-
LHUL-1a	280	190*	0.68*	55*	28*	27*	-	-	-	-	-	-	-
LHUL-1b	220	205*	0.93*	66*	29*	37*	-	-	-	-	-	-	-
LHUL-2	290	190*	0.65*	52*	22*	30*	-	-	-	-	-	-	-
LHUL-3	~300	205	0.68	55	20	35	1.61	~150	70	>190	70	210	57
LHUL-4	265	210	0.79	52	31	21	-	137	55	167	48	-	-
LHUL-5	285	225	0.79	58	26	32	1.58	130	53	195	-	200	55
LHUL-6	>210	190	<0.90	26	20	6	-	-	-	-	-	-	-
LHLL-T1-1	210	170	0.81	58	27	31	1.80	93-125	33	140	40	160	42
LHLL-T1-2	195	157	0.80	51	24	27	?1.95	?110	30	130	35	125	30

Tab. 1 - Variables of the footprints from the Neizar Valley. Lengths are in millimetres and angles in degrees. *taken from Lapparent & Davoudzadeh (1972).

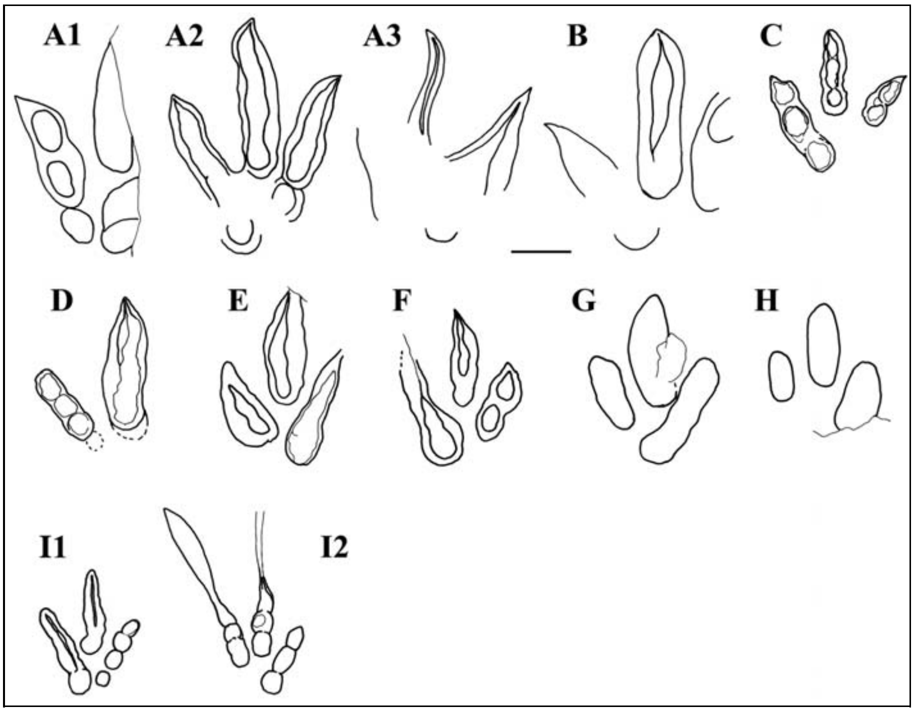

Fig. 5 - Footprints from the Neizar Valley. A1) NV/UHUL-T1-1; A2) NV/UHUL-T1-2; A3) NV/UHUL-T1-3; B) NV/UHUL-1; C) NV/UHLL-1; D) NV/UHLL-2; E) NV/LHUL-3; F) NV/LHUL-4; G) NV/LHUL-5; H) NV/LHUL-6; I1) NV/LHLL-T1-1; I2) NV/LHLL-T1-2. Scale bar equals 10 cm.

"asymmetrical heel" is actually the posterior end of digital print IV.

Regarding NV/UHUL-T1-3 (Fig. 5A3), its original morphology has been misunderstood by Lapparent & Davoudzadeh (1972). The posterior portion and the impression of digit II are missing because the part of the bed containing them has split away, leaving a hole. The impression of digit IV is rather deep, straight, tapering distally and with a triangular outline. The distal extremity of the impression is still filled with rock. A shallow print in the posterior part of the footprint could be the posterior end of the digit. If the case, the footprint would be 355 mm long. The impression of digit III is sigmoid and very narrow because of its nearly total closure caused by the collapse of the waterlogged sediment after foot withdrawal. The slit-like digital print is still filled with rock. The digit III impression is 195 mm long, but the proximal part is missing. Possibly, only a segment of the medial margin of digit II is still preserved. Footprints have a slight outer rotation, A is 157°, and the stride is 253 cm; stride/footprint length is 6.49. The midline of the trackway makes with the ripples an angle of 62-71°.

The single, isolated tridactyl footprint NV/UHUL-1 (Fig. 5B) is very shallow and can be identified only with low-angle light. The margins of the digital prints are blurred and it is difficult to trace their actual extension. The footprint is about 350 mm long, so the trackmaker had approximately the same size of that producing NV/UHUL-T1. The distal part of the impression of digit III (10 mm deep) is the deepest part of the footprint. The impression appears wide, but the actual bottom outline was much narrower and it is concealed by the sedimentary rock. The impression slightly widens distally; the distal end is slightly pointed, but no claw mark can be seen. Only the distal and proximal extremities of digit IV are clearly identifiable; the distal extremity is curved laterally and its termination is pointed. Only a shallow mark of two or three pads is visible in digit II.

The lower footprint-bearing surface is scarcely exposed. Two footprints have been identified and both are negative (concave) epireliefs.

NV/UHLL-1 (Fig. 5C) is tridactyl, slightly wider than long with a relatively high A° and R/d (Tab. 1). It forms an angle of 12° with the ripples. The impression of digit III is 20 mm deep at maximum and is the deepest; it has three, possibly four, faint pad impressions and its distal end is pointed, with a possible narrow and small claw mark still filled with rock. Laminae of sandstone also fill the bottom of the footprint. The print of digit II shows two pad impressions mostly still filled with rock; its distal end is sharply pointed. The impression of digit IV is the shallowest of the three, partly filled with laminate sandstone, and shows at least three pad impressions.

NV/UHLL-2 (Fig. 5D) occurs about 10 m away from NV/UHLL-1. It is bidactyl, and the right digital impression (corresponding to digit III) is the deeper, particularly the distal part, that has a small and narrow claw mark. The posterior part is much shallower and its proximal termination is unclear. The digit is 210-230 mm long and its width cannot be accurately measured since the outer margins are unclear. The long axis of the digit forms with the ripples an angle of 70°. The outer impression is possibly that of digit II; its distal end is blunt and there are at least three pad marks, the distal two completely filled with rock.

Neizar Valley, "Lower Horizon"

We were able to locate two of the footprint-bearing bed surfaces described by Lapparent & Davoudzadeh (1972) in the "Lower Horizon" of the Neizar Valley. All the footprints are negative (concave) epireliefs.

The "main slab" of Lapparent & Davoudzadeh (1972) corresponds to our 'upper footprint-bearing surface'. Three footprints of the "main slab" (n. 1-3 of Lapparent & Davoudzadeh 1972; NV/LHUL-2 and NV/LHUL-1a-b here) have taken away from the site in 1970 and are now exposed in the Museum of the Geological Survey of Iran, Tehran. Because of the excessive weight of the three slabs containing the specimens, their arrangement in the exhibit and the scarce illumination, it was not possible to make a detailed drawing of them. NV/LHUL-2 is the best preserved of the three and has been figured by Lapparent & Davoudzadeh (1972, fig. 1-2). The impression of digit III is markedly longer than those of the other two and its distal end is pointed. There seems to be the remnant of a narrow claw mark closed by the sediment collapse and still filled with rock. One digital impression (digit IV) is longer posteriorly than the other (digit II) and there is no mark of a true heel. A° is rather low, probably much less than 60° (Lapparent & Davoudzadeh 1972, report 52°, but their method to measure angles differs from the one used here). The actual margins and the bottom outline of the footprint are somewhat concealed by the partial retention of thin sandstone laminae, mainly in the proximal (posterior) part. The 160 mm-long, deep mark lateral to the impression of digit IV ("trace no. 8" in Lapparent & Davoudzadeh 1972) is probably the single, isolated impression of a digit (digit III?) and does not belong to the footprint NV/LHUL-2.

NV/LHUL-1a-b consists of two consecutive footprints (i.e., it is a footprint pair), now preserved in two distinct slabs. NV/LHUL-1b most resembles NV/LHUL-2 having a similar size, relatively slim digital impressions, digit III markedly more projecting anterior than the other two, digit IV longer posteriorly than digit II, absence of a true heel impression, and relatively low A° (55° according to Lapparent & Davoudzadeh 1972). The actual morphology of the footprint is partly concealed by the laminated sandstone, mainly at the posterior part of the footprint. The margins of the digital prints of NV/LHUL-1a are unclear and their real extension is difficult to be traced. Apparently, the digital prints are shallow, rounded and short depressions blurring into the bed surface, with a much deeper and groove-like central part. This footprint is decidedly shorter (220 mm) than NV/LHUL-1b and A° is higher (66° according to Lapparent & Davoudzadeh 1972). Four tridactyl footprints of the "main surface" are still present in situ (footprints n. 4-7 of Lapparent & Davoudzadeh 1972). They occur in couples: NV/LHUL-3 and NV/LHUL-4 are close, roughly parallel to each other and with the same direction, and NV/LHUL-5 and NV/LHUL-6 show the same arrangement (see Lapparent & Davoudzadeh 1972, fig. 6).

NV/LHUL-3 (Fig. 5E) is the best preserved and deepest footprint. It belongs to the right side and has almost the same length of LHUL-1a and LHUL-2. The impression of digit III lacks the distal termination and is 35 mm deep; it is narrow at the bottom and sharply pointed distally, suggesting the presence of a claw. The impression of digit II tapers distally and, as the previous one, the impression is narrow at the bottom because of sediment collapse. The impression of the digit IV ends more posterior than that of digit II and is pointed distally. It is mostly filled with laminated sandstone and presents shallow expulsion rims along the left (medial) side of digit III and II.

NV/LHUL-4 (Fig. 5F) is a left footprint, slightly shorter and broader than NV/LHUL-3. The impression of digit III has a pointed distal termination and ends proximally with a rounded pad mark. The impression of digit II preserves two pad marks and a small, triangular distal point. The impression of digit IV print is incompletely preserved distally, ending proximally more posterior than that of digit II. An accurate R/d cannot be obtained, but it was probably similar to that of NV/LHUL-4. A shallow expulsion rim borders the medial side of the footprint.

NV/LHUL-5 (Fig. 5G) is much shallower than NV/LHUL-3 and NV/LHUL-4 and no expulsion rims are present. It is as broad as NV/LHUL-4 but slightly shorter. All digital prints have a rounded outline and somewhat vague margins. The impression of digit III is partly concealed by sedimentary rock. The impression of digit IV is much longer than that of digit II and ends more posterior.

NV/LHUL-6 (Fig. 5H) is a right footprint even shallower than NV/LHUL-5, without expulsion rims and quite low A°. The margins of the digital impressions blur into the bed surface, consequently the digital impressions appears wide and rounded. It is an underprint or more probably an overprint (sensu Paik et al. 2001). The impression of digit IV ends more posterior than that of digit II; digit III projects more forward than the prints of the outer digits.

All footprints of the 'upper footprint-bearing surface' are more or less parallel to the ripples direction.

The lower footprint-bearing surface preserves a pair of consecutive tridactyl footprints with P = 550 mm, that correspond to footprints n. 18-19 in Lapparent

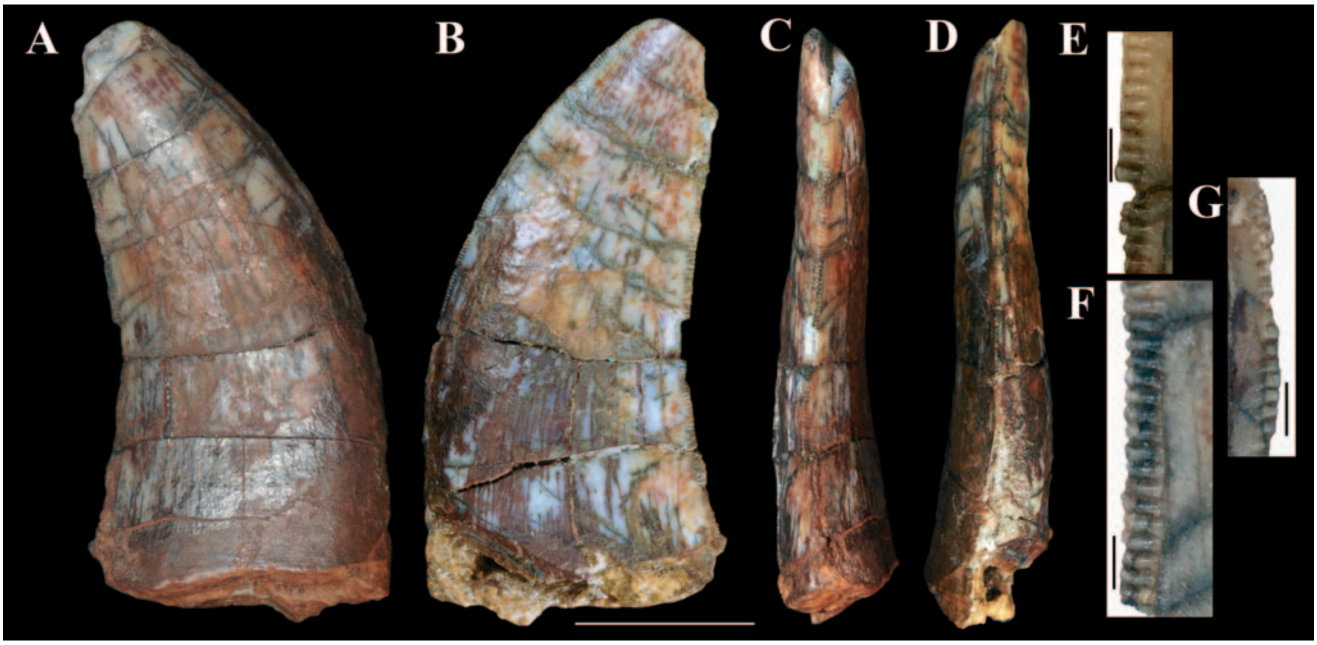

Fig. 6 - Theropod tooth (MN 7271-V) recovered from the Ab Bid region. A) labial; B) lingual; C) posterior; and D) anterior views. Details of the denticles of the E) apical region of the anterior carina in labial view; F) middle portion of the anterior carina in labial view; G) apical portion of the posterior carina in labial view. Scale bar of A-D equals 10 mm; scale bar of E-G equals 1 mm.

& Davoudzade (1972). Both specimens are smaller than those preserved in the upper footprint-bearing surface and rather shallow, what limits the observation of digital features.

NV/LHLL-T1-1 (Fig. 5I1) is a left footprint. The impression of digit III is slightly sigmoid and its distal portion presents a longitudinal groove at the bottom. The proximal end has a rounded pad mark and the distal one is slightly tapered but not pointed. The impression of digit II is 93 or 125 mm long, depending on the inclusion or not of the small posterior pad mark that is separated from the distal digital print. The latter is straight and shows three rounded pad marks, and blunt the distal end. The impression of digit IV has a rounded proximal pad mark, a blunt distal end, and a long longitudinal groove at the bottom.

NV/LHLL-T1-2 (Fig. 5I2) is a right footprint. The impression of digit III presents three pad marks and is still partly filled with rock in the middle; the distal end is pointed and presents a slit-like claw mark that was closed by the collapse of the sediment; a long, narrow and shallow depression starts from the point of the digital mark. The impression of digit II has three pad marks; the shape of its distal end cannot be determined because it fades distally into a very long and narrow depression. The origin of this depression as that similar occurring at the end of digit III is unclear. The impression of digit IV has three pads, a relatively blunt distal termination and ends proximally much posterior than the print of digit II. R/d is possibly 1.95, but this value is biased by the uncertainty about the actual termination of digit II.

We were unable to locate the footprints above the "main" slab reported by Lapparent & Davoudzadeh (1972).

Zerab (Alborz Mountains)

The single footprint found near Zerab, is the holotype of *Iranosauripus zerabensis* de Lapparent & Sadat, 1975. According de Lapparent & Sadat (1975, p. 161), it has been carried to Tehran and should be in the Museum of the Geological Survey of Iran of Tehran (M. Mirzaie Atabaadi, pers. obs.). However, the specimen cannot be found there and should be considered lost.

Skeletal elements

In their original paper, Lapparent & Davoudzadeh (1972, p. 7) hinted the possibility of finding dinosaur osteological material as they wrote: "These sandstone and the marly-sandy Jurassic rocks were examined north of Ravar, near Darband, and again east of Ravar in the Miyanrud Valley, but there was not sufficient time to examine the similar rocks in the Ab Bid syncline. The red sandstones are rather coarse-grained and do not seem to be very favorable for the preservation of dinosaur footprints. On the other hand, bones or teeth may be present in them, particularly in the microconglomeratic beds: experience in the Sahara has shown that similar facies are often fossiliferous".

Most of the osteological material recovered (GPS coordinates: N 30°55'07.5"/ E 56°58'47.3") consists of isolated remains (all housed at the Geological Survey of Iran) that due to their fragmentary nature could not be identified (Mirzaie Ataabadi et al. 2005). At least one of the specimens represents the cortex of a long bone that due to its comparatively small thickness most likely belonged to a medium-sized theropod dinosaur.

The main element collected in the 2002 expedition is a tooth (MN 7271-V) collected in a conglomeratic level (GPS coordinates: N 30°55'07.9"/ E 056°58'47.2"). Overall it is well preserved but in some parts the enamel was broken away most likely during the transportation process. The specimen is not a shed tooth because it is broken basally and does not show any evidence of root reasorption.

As common in theropod teeth, this specimen is laterally compressed and shows an oval base. The tooth is broken at the base and lacks the tip of the crown. Observed from mesial or distal view, this tooth is slightly asymmetrical, with the labial surface more convex than the lingual one.

A marked depression is observed on the lingual surface, close the apical region of the mesial margin (Fig. 6B). Although it is known that the preservation processes can strongly affect the interpretation of a fossil (e.g., Kellner 2010), based on the fact that the enamel in this area is intact, this feature is here not regarded as a taphonomic artifact but likely occurred during the lifetime of this dinosaur. Although the cause of this depression is unknown it might have been the result of some injury resulted during the feeding process. It does not appear to be a wear facet due to the occlusion of an opposite tooth (which, if the case would allow the identification of MN 7271-V as an upper left tooth).

The crown height (CH) and apical length (AL) are 36 mm and 38 mm, and the crown base length (CBL) and crown base width (CBW) are 17 mm and 7 mm, respectively. The crown height ratio (CH/CBL) is 2.12 and the crown base ratio (CBW/CBL) is 0.41. The crown apex is directed posteriorly, with the anterior border convex and the posterior border concave. Anterior and posterior carinae are serrated, showing 3.5 and 3 serrations per mm, respectively. Like in several theropod teeth, the denticles of the anterior margin are more wore down than those from the posterior one, but they show the same basic morphology: straight, longer than wide, and chisel-like. Blood grooves are present as faint impressions, curved towards the basal part of the tooth.

Due to the overall shape of the tooth and the position of the anterior carina, MN 7271-V can be interpreted as a lateral tooth from either the left upper or the right lower jaw.

Discussion

Regarding the palaeoichnological material, the influence of the substrate condition on the morphology of the Iranian footprints is evident in the described specimens, as is the frequent presence of the original sedimentary rock that fill the footprints. Probably, many are 'overprints' to various degrees, i.e. they are not the original pedal impressions, but a more blurred depression in the thinly laminated sandstone that filled the original one.

Lapparent & Davoudzadeh (1972, p. 14) referred NV/LHLL-T1-1 and NV/LHLL-T1-2 to "coelurosaurian theropods" and all the other footprints to ornithopods. However, they did not consider the bias of the original substrate conditions on the final form of the footprint. Furthermore, they did not realize that the incomplete weathering of the original sediments that were filling up of the true footprint influenced its morphology. One good example are the claw marks, that are narrow and often still filled with rock and overlooked by Lapparent & Davoudzadeh (1972).

All described footprints were made by medium to large-sized bipedal dinosaurs. Because of the Liassic age of the sample and based on our knowledge of the Liassic dinosaur fauna obtained from the osteological record, the possible track makers can be restricted to basal sauropodomorphs ('prosauropods'), bipedal ornithischians, and theropods.

Basal sauropodomorphs are the most common and widespread non-carnivorous dinosaurs during the Liassic (North America, Argentina, southern Africa, India, Antartica, and China; Galton & Upchurch 2004; Weishampel et al. 2004) and most were probably facultative bipeds (Galton & Upchurch 2004; Van Herdeen 1997). The pes of heavy forms like *Yunnanosaurus* did very probably leave tetradactyl footprints with a very scarcely projecting digit III print. Gracile forms like *Anchisaurus* and the Triassic *Sellosaurus* had slender digits and a digit III more projecting forward, but the relatively well-developed digit I would have probably impressed a trace. NV/LHUL-2 has a fourth impression near those of digits II-IV, but it is lateral to digit IV, thus it could only be the trace of pedal digit V, which is usually reduced in bipedal dinosaurs.

Footprints referred to basal sauropodomorphs are different from those found in the Liassic of Iran (cf. Thulborn 1990) and those dinosaurs are very improbable makers for the Iranian footprints described so far. Liassic skeletal remains of bipedal ornithischians were found mainly in southern Africa and North America; Norman et al. 2004a-c; Weishampel et al. 2004). They were small animals only one to two meters long that produced footprints much smaller than those found so far in Iran. Bone remains of larger ornithischians are unknown in the Liassic, and their possible existence in the Early Jurassic is based only on ichnological record (see Leonardi & Mietto 2000). Theropods of all sizes are much more represented in the Liassic osteological record than ornithischians, and are widespread, being reported in several parts of Europe (United Kingdom, France, Germany, and Italy), northern and southern Africa, India, China, North America, and Antarctica (Weishampel et al. 2004; pers. obs.).

The large footprints NV/UHUL-T1 and NV/UHUL-1 have been referred to "typical ornithopod dinosaur" by Lapparent & Davoudzadeh 1972, p.14) on the base of a "broad well-marked heel", "widely spread lateral digits" and the "absence of claws". Actually NV/UHUL-T1-1, 3 and NV/UHUL-1 do not preserve the heel print at all and the 'heel' print of the best preserved specimen (NV/UHUL-T1-2) is the proximal termination of the impression of digit IV. A° is more in the range of "theropod" footprints than in that wider of "ornithopod" footprints (Thulborn 1990; Dalla Vecchia & Tarlao 2000; Dalla Vecchia et al. 2002). The apparent absence of claw marks can be an artifact of preservation and claw marks are present at least in the footprints of NV/UHUL-T1. The impression of digit IV of NV/UHUL-1 is pointed and also probably was clawed.

Furthermore, the digital prints in NV/UHUL-1 and above all NV/UHUL-T1-2 are more slender than those attributed to "large ornithopods", with a relatively low W/L (Thulborn 1990). Additionally, outer rotation is unusual in "large ornithopods" trackways (e.g., Thulborn 1990). All those evidences strongly indicate that those footprints were made by a theropod dinosaur.

The estimate h considering NV/UHUL-T1 produced by a theropod is 191 cm and SL/h is 1.32, indicative of a moderately fast walk (Thulborn 1990), with V of 6.2 km/hour. The trackmaker was probably moving from a zone with relatively hard sandy substrate (first footprint, shallow) to one softer (third footprint, deep or with digital print closure). The direction with respect to the slightly asymmetric ripple marks suggests it was moving nearly in the direction of the water stream and possibly to relatively deeper waters (e.g., crossing diagonally a shallow tidal channel).

Lapparent & Davoudzadeh (1972, pp. 12, 14) consider NV/LHUL-1a, b to 4 as ornithopod on the same basis as those from the "Upper Horizon", but belonging to a "different "species" because of the smaller size and older geological age. They consider NV/LHUL-5 and NV/LHUL-6 from the same surface as a separate ornithopod footprint "type" characterized by very broad digits ("coarse", p. 14), high total divarication and broad heel.

As a general consideration, all other footprints are smaller (195<L<300 mm) than NV/UHUL-T1 and NV/UHUL-1, but they are decidedly larger than those that could have been made by the Liassic bipedal ornithischians known from skeletal material. NV/LHUL-2 does not have any heel print, presents pointed and slender digital prints and a relatively low A°. NV/LHUL-1a, b are very different from each other despite appearing to belong to the same track. NV/LHUL-1a resembles more NV/LHUL-6 than NV/LHUL-1b. This suggests a strong sedimentological and/or preservational bias on the footprint shape. The long and relatively narrow digital prints in NV/LHUL-1b is more consistent with a theropod than to an ornithopod.

The "pairs" formed by NV/LHUL-3 and NV/LHUL-4, and NV/LHUL-5 and NV/LHUL-6 are not the prints of two standing still individuals as could appear at first sight, because both footprints of the "pair" NV/LHUL-5 and NV/LHUL-6 are from the right side. Furthermore, NV/LHUL-3 is a right footprint but is positioned on the left side of the "pair". Both NV/LHUL-3 and NV/LHUL-4 have a low A° that is more in the range of the theropod than of the "ornithopod" footprints (Thulborn 1990; Dalla Vecchia & Tarlao 2000). Their digital marks are relatively slender and pointed distally, with the impression of digit III that is notably more projecting forward than those of digits II and IV, and no true heel mark could be observed. All those features led to the conclusion that those footprints belonged to theropod dinosaurs.

NV/LHUL-5 seems to be a footprint similar to NV/LHUL-3 and NV/LHUL-4, but shallower and generally in a poorer state of preservation. All that can be said of NV/LHUL-6 is that the blurring margins of the digital prints and absence of expulsion rims suggest that it is scarcely representative of the details of trackmaker foot morphology. Probably it was produced by a foot with the same general morphology of the one that produced NV/LHUL-2 and NV/LHUL-3 on a less soupy, fine sandy substrate, or is a partly cancelled footprint, since footprints in sandy substrates are more easily wiped out by currents than those in mix and more cohesive sandy-muddy substrates. A° is not very high and no true heel print is visible. Therefore in unlikely was made by an ornithopod dinosaur, but represents a poorly preserved theropod footprint like NV/LHUL-3.

NV/LHLL-T1-1 and NV/LHLL-T1-2 have relatively slender digital marks, with the impression of digit III that is notable more projected forward than those of digits II and IV, and shows no true heel mark. The impression of digit III of NV/LHLL-T1-2 presents also a claw mark. Thus, we agree with Lapparent & Davoudzadeh (1972) suggestion that it belongs to a theropod trackmaker. However, the referral to *Grallator* cannot be endorsed. According to Olsen et al. (1998,

p. 595) *Grallator* is <15 cm long, W/L is near 0.5 or lower and total divarication is 10°-30°. We think that the imperfect state of preservation of the Iranian footprints and the small sample size do not permit reliable comparisons to the best-defined Liassic theropod ichnotaxa *Grallator*, *Anchisauripus* and *Eubrontes* (Olsen et al. 1998).

The comparatively small NV/UHLL-1 has a higher total divarication than the others and it is as wide as long. However, the digital prints are narrow and pointed, thus it is also here tentatively referred to theropods.

It is not very unusual to find footprints without the mark of one or two toes like NV/UHLL-2 (see Dalla Vecchia & Tarlao 2000). This does not mean that the foot of the trackmaker was didactyl; the presence of only two digital impressions in NV/UHLL-2 is most probably the consequence of a relatively hard substrate. The claw mark in the impression of digit III suggests it is also a theropod footprint.

According to the original description, the diagnosis of *Iranosauripus zerabensis* is as follows: tridactyl footprint of mid-size (L = 230 mm); spindly toes, very elongated, ending with a pointed claw; toes very angled; well-marked, oval heel (de Lapparent & Sadat 1975, translated from the French). It is clear today that any ichnotaxon must be based on a sample and cannot be described on the base of a single footprint, unless clearly defined by undisputable diagnostic features. It is evident from the footprints of the Neizar Valley, as also from other larger samples (see for example Dalla Vecchia & Tarlao 2000), that footprint shape can vary dramatically in the same track due to several variables. Therefore, taken those differences individually they would lead to the paradox of having different ichnotaxa for consecutive footprints of the same trackmaker. Furthermore, none of the characters mentioned in the diagnosis of *Iranosauripus zerabensis* is actually unique to that footprint. Narrow toe marks are common to many medium-sized tridactyl footprints and are often rather the result of the sediment collapse after foot withdrawal than to an actual marked narrowness of the toes. A° can be biased by contingent factors (e.g., gait and sediment conditions), and a large sample is needed to support this feature as a unique morphological characteristics of an ichnotaxon. Considering the probable total extension of digit IV print, A° that we obtain from the drawing of de Lapparent & Sadat (1975) is relatively high (73°, similar to the 78° published) and unusual for tridactyl footprints of that size, but not a rare case (see for example, Dalla Vecchia & Tarlao 2000; Dalla Vecchia et al. 2001). Probably there was not a true heel mark, but just the impression of the proximal termination of digit IV, the metatarsal-phalangeal pad mark whose posterior margin is often well- impressed in mid-sized tridactyl footprints.

Based on the available evidence, we conclude that the ichnotaxon *Iranosauripus zerabensis* is not valid. As presented above, the pointed end of the toe print, the narrowness of digital prints (even if possibly increased by sediment collapse), the asymmetry of the posterior part of the footprint with a hint of an indentation posterior to the impression of digit II (indicated as digit IV by de Lapparent & Sadat 1975), suggest a theropod as the trackmaker, as already suggested by de Lapparent & Sadat (1975).

Regarding the osteological material, unfortunately the collected specimens are too fragmentary to allow any systematic classification or general statements, although more information of Iranian dinosaurs are needed to be able to address several relevant information, such as biogeographic discussions (e.g., Jacobs et al. 2011; Bittencourt & Langer 2011). Notwithstanding, there are a few comments that can be made regarding the tooth (MN 7271-V).

Although several attempts have been made do identify theropod taxa or groups based on isolated teeth (e.g., Currie et al. 1990; Smith et al. 2005), the fact of the matter is that presently there are no sufficient data available to provide a more comprehensive classification of theropod dinosaurs based on dental characters. However, some general comparisons restrain the possibilities to which theropod clade the Iranian specimen can be referred.

The tooth MN 7271-V clearly does not belong to a member of the Spinosauridae (or Spinosauroidea) that lack or display only thinly serrated carinae (e.g., Kellner & Mader 1997; Kellner et al. 2011). Furthermore, spinosauroid teeth show a sub-circular transverse section, quite distinct from the Iranian specimen.

The transverse section of MN 7271-V also differs from the wider teeth observed in tyrannosaurids (e.g., Smith et al. 2005) that show a distinctive D-shaped basal section (e.g., Erickson 1995).

The Iranian material lacks the developed transverse wrinkles on the labial and lingual surfaces that are commonly observed in teeth attributed to carcharodontosaurids (e.g., Sereno et al. 1996; Kellner & Campos 2000; Veralli & Calvo 2004). Additionally, the number of serrations in MN 7271-V varies from 3.5 and 3 per mm that is higher than the 1.6 to 2.8 serrations per mm reported in carcharodontosaurids from Argentina (Veralli & Calvo 2004) and the 1.3 to 1.5 serrations per mm reported in one carcharodontosaurid from Niger (Sereno & Brusatte 2008).

The Iranian tooth is also larger than the ones of derived maniraptorans, particularly Dromeosauridae and Troodontidae (e.g., Currie et al. 1990; Fiorillo & Currie 1994), including unenlagiinids (Gianechini &

Apesteguía 2011; Agnolin & Novas 2011). Within the Dromeosauridae, MN 7271-V lacks the strong disparity in size of the denticles present in the anterior and posterior carinae of the Velociraptorinae (Currie et al. 1990). Furthermore, the serrations of the Iranian specimen are not hook-shaped as reported for several troodontids (Currie et al. 1990). Overall, the size of the serrations in dromeosaurids and troodontids are also proportionally larger than in the Iranian specimen.

Regarding Abelisauroidea, distinctions regarding the Iranian material are more difficult to be established. In one abelisauroid from Brazil, the density of the serrations is also lower than in MN 7271-V, varying between 1.8 and 2 (Bittencourt & Kellner 2002), but in some African abelisaurids this value can reach up to 3 (e.g., Sereno & Brusatte 2008). This difference is not conclusive and we cannot completely rule out that MN 7271-V does not represent an abelisauroid or a closely related taxon.

Conclusions

Despite the potential of several Mesozoic deposits in Iran, the record of fossil vertebrates, particularly dinosaurs, is almost non-existent. The most important evidences so far are the footprints found in the Neizar Valley. Contrary to the original reports (Lapparent & Davoudzadeh 1972), all of the palaeoichnological record of that region represents theropod footprints. Furthermore, the ichnotaxon *Iranosauripus zerabensis* described from the Alborz Mountains by Lapparent & Sadat (1975) is here regarded as undiagnostic and should therefore be regarded as *nomen dubium*.

Regarding the limited osteological record, the best specimen so far is one isolated tooth (MN 7271-V) that represents a middle-sized theropod. Although the taxonomic identity cannot be established with certainty, it does not represent a species of the following clades: Spinosauroidea, Tyrannosauridae, Dromeosauridae, Troodontidae and Carcharodontosauridae. Distinctions with abelisauroids are more difficult to be made and despite the fact that differences exist (e.g., number of serrations per mm), the classification of the Iranian tooth in that theropod clade cannot be discarded.

Although meager, the recovered osteological record is the first dinosaur skeletal evidence from the Islamic Republic of Iran and indicates that further prospection in the Ab Bid syncline and surrounding area has great potential for new discoveries.

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