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Dinosaur natural track casts from the Lower Cretaceous Hekou Group in the Lanzhou-Minhe Basin, Gansu, Northwest China: Ichnology, track formation, and distribution

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ABSTRACT

Multiple dinosaur tracksites are known from the red beds (sandstones and siltstones) of the Hekou Group in the Lanzhou-Minhe Basin in Gansu Province, China. Among these, the most famous is the Yanguoxia No. 1 & 2 tracksite, which has an abundance of tracks from a diverse ichnofauna. Here, we describe natural casts from six new tracksites including three located near the Yanguoxia No. 1 & 2 tracksites and three from more distant tracksites (located up to 40 km from Yanguoxia). The new tracksites have all yielded isolated, large dinosaur track casts, two of which are tridactyl tracks of ornithopod and/or theropod affinity, while another eight casts are pes and manus tracks of medium-to large-sized sauropods. The predominance of sauropod track casts may reflect the fact that, by simple virtue of their large size, sauropods tracks resist weathering and are easy to find. Notably, the sauropod track casts are deep natural tracks left in soft and moist substrates with a relatively high cohesiveness. They offer a glimpse into the three-dimensional foot morphology of the sauropod trackmakers and their foot movement (locomotion), and thus are an important complement to the tracks preserved as (shallow) impressions and the trackways of the Yanguoxia No. 1 & 2 tracksite. The new tracksites suggest a lower ecological diversity than would be inferred from the Yanguoxia No. 1 & 2 tracksite. However, it is assumed that this apparent low diversity is an artifact resulting from the small sample area and the fact that all the outcrops are cross-sections where bedding planes – that could reveal small tracks and more abundant tracks and trackways – are scarce and limited to small surfaces. These new sites suggest that the distribution and frequency of dinosaur tracks within the Lanzhou-Minhe Basin is much wider than previously assumed and that many more dinosaur tracksites are likely to be discovered within the basin in the future.

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1. Introduction

Dinosaur tracks can be preserved in various forms, including molds (impressions, true tracks, undertracks, overtracks), casts, and casts of deep tracks (three-dimensional tracks, preserved in convex hyporelief). The term “four-dimensional tracks” has recently been proposed for 3D tracks that show traces of movement, such as striations, during registration (Cobos et al., in press). Many dinosaur tracks are preserved as molds (convex epireliefs) exposed in plain view on bedding planes (Lockley, 1997). Casts of deep tracks, on the other hand, appear as rounded bulges protruding from the bases of sandstone beds into the underlying sediment layer (such as deformed sandstone beds, “Brontosaur Bulges”, Lockley, 2001; Lockley and Marshall, 2014). Some casts are well preserved and can easily be assigned to distinct track morphotypes. Meanwhile, such casts of deep tracks have been described for all major dinosaur groups including ornithopods (Difley and Ekdale, 2002; Currie

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et al., 2003; Xing et al., 2012; Cobos and Gascó, 2012; Lockley et al., in press), thyreophorans (Milàn, 2011; Hornung and Reich, 2014), sauropods (Milàn et al., 2005; Platt and Hasiotis, 2006; Mateus and Milàn, 2008; Romano and Whyte, 2012), and theropods (Gatesy et al., 1999; Milàn et al., 2006; Huerta et al., 2012; Avanzini et al., 2012; Ibrahim et al., 2014).

The Longzhong Basin is subdivided into the Xining Basin and the Lanzhou-Minhe Basin. The Lanzhou-Minhe Basin is situated on the boundary between the Gansu and Qinghai Provinces, and encompasses an area of 11,300 km^2. The Lanzhou-Minhe Basin is a secondary basin with the widest and most extensive Cretaceous outcrops of the Longzhong Basin. In the year 2000, collaborators from the Research Center of Paleontology of the Bureau of Geology and Resource Exploration of Gansu Province discovered ten dinosaur tracksites near Yanguoxia in the Hekou Group of the Lanzhou-Minhe Basin (Li et al., 2000; Du et al., 2001; Xing et al., 2013a). Other tracksites in the Lanzhou-Minhe Basin were discovered subsequently, such as the Zhongpu tracksite (theropod and sauropod tracks) and the Xiapujia tracksite (bird tracks). However, all of these tracksites have yet to be studied and described in detail. Since 2013, a research team led by the first author began an investigation into these tracksites. During this process, Xing LD, Lockley MG, Marty D and Peng C discovered several additional tracksites in the Lanzhou-Minhe Basin (Fig. 1). Most recently, track casts have been found in cross-sectional outcrops at roadside exposures. Herein, we present detailed descriptions of the more important examples of the Lanzhou-Minhe Basin tracks.

2. Institutional abbreviations

DC = Dianchang tracksite, Yanguoxia area, Gansu, China; LT = Litan tracksite, Yanguoxia area, Gansu, China; GDM-DC = Dianchang specimens, Gansu Dinosaur Museum, Yongjing, China; GGM = Guangoumen tracksite, Zhongpu area, Gansu, China; HT = Hutan tracksite, Guanshan area, Gansu, China; YSI = Yanguoxia No.1 tracksite, Gansu, China; ZJGM = Zhangjiagoumen tracksite, Zhongpu area, Gansu, China; ZPI = Lijiagou tracksites I, Zhongpu, Gansu, China.

3. Geological setting

The Lanzhou-Minhe Basin is a block-fault basin that developed from the Middle Qilian Uplift Zone. The red clastic rocks that dominate the basin have been assigned to a single lithological unit, 3482 m thick, and have long been regarded as part of the Hekou Group (Bureau of Geology and Mineral Resources, Gansu Province, 1997; Chen, 2013; Chen et al., 2013), which is Early Cretaceous in age (Tang et al., 2008). The Hekou Group is divided into eight informal formation-level units (Zhang et al., 2003).

The tracks herein described are primarily from three geographic areas: Guanshan, Yanguoxia, and Zhongpu (Fig. 1). The tracks of the Zhongpu area are from the lower part of the 4th or 5th informal formation-level units of the Hekou Group. The lithologies of these units are brown moderate-fine sandstones, gray-brown and gray siltstones, and silty mudstones (Chen et al., 2013), and the tracks are preserved in floodplain deposits of a meandering river system. The tracks of the Guanshan area come from the middle-lower part of the 5th informal formation-level unit, also representing fluvial facies. The tracks of the Yanguoxia area are known from the 6th informal formation-level, which is composed of shallow shore lacustrine facies of fine gray-green and gray sandstones (Chen, 2013).

4. Methodology and terminology

Compared to the documentation of dinosaur tracks preserved in negative epirelief ('impressions'), reports of three-dimensional natural track casts (track fills) are still rather scarce, even though their frequent occurrence and importance is more and more recognized in vertebrate ichnology. Describing track casts requires clear terminology and appropriate documentation methodology, because track casts frequently have a complex three-dimensional morphology and features (such as skin impressions, 3D toes and

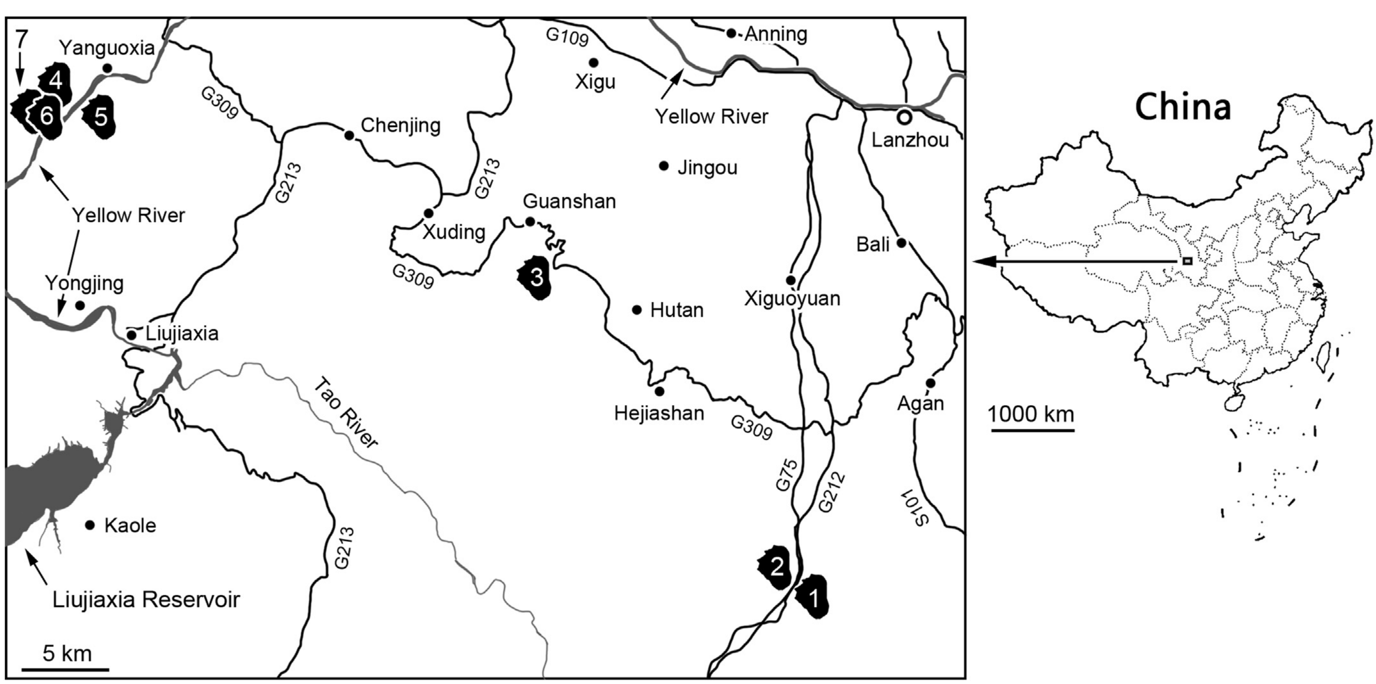

Fig. 1. Geographic positions of the Yanguoxia area, the Zhongpu area, and the Guanshan area dinosaur tracksites (footprint icon: 1. Guangoumen tracksite; 2. Zhangjiagoumen tracksite; 3. Hutan tracksite; 4. Dianchang tracksite; 5. Litan tracksite; 6. Yanguoxia SS1 tracksite; 7. Yanguoxia No.1 tracksite).

claw preservation, and kinematic indicators) that are not easy to describe and measure.

In this paper, a descriptive approach is applied, i.e. the morphology of the casts is described in detail and specific measurements (length, width, depth) for clearly-defined features (such as lower and upper surfaces, digits, claws, and striations) are given according to the terminology outlined in Fig. 2 on a virtual track cast generated in Autodesk Maya 2014 sp2.

For comparison, a three-dimensional model ('virtual cast') of a sauropod manus track with overhanging track walls from the Yanguoxia No. 1 tracksite was produced by laserscanning (JiRui II, JiRui Xintian technology Co. Ltd., non-contact grating-type structured light 3D scanning system) (see 5.7).

Length: the maximum length of the track casts.
Width: the maximum width of the track casts.
Depth: the distance vertical to the upper and lower surface of the cast.
Upper surface: often smaller than the lower surface due to substrate collapse after foot withdrawal.
Lower surface: often slightly larger or significantly larger than the upper surface. May correspond to the true dimensions of the trackmaker's foot, if not considerably affected by foot kinematics (e.g., varying angle during inserting and pulling out of the foot).
Striations (entry and exit): often parallel to each other. May be caused by digits and/or toes or skin texture.

5. Description of track casts

5.1. Guangoumen tracksite, Zhongpu area

Description. The Guangoumen tracksite is located near the Guanmengou No. 4 bonebed, Zhongpu Town, Dingxi City (GPS: 35°48′34.86″N, 103°46′18.61″E) (Fig. 1), from which skeletal material of the titanosaurian sauropod *Yongjinglong* (Li et al., 2014) and the ankylosaur *Taohelong* (Yang et al., 2013) were discovered. The track-bearing strata are thick-layers of fine brick-red sandstone with thin beds of fine sandstone interlayered with brownish-red mudstone. A typical track, GGM-1 is a natural track cast (preserved

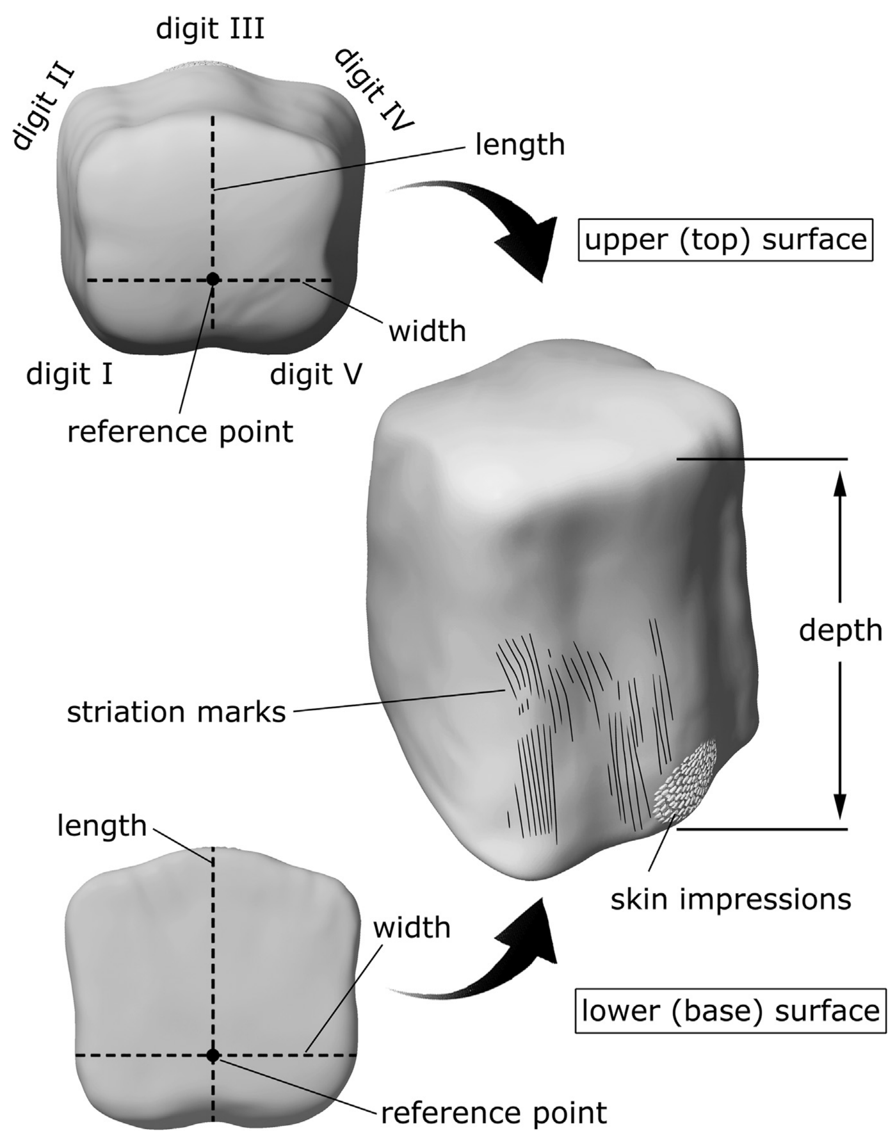

Fig. 2. Terminology of a typical and ideal 3D sauropod manus cast, based on the shape of a manus track of *Brontopodus birdi* (Farlow et al., 1989: Figure 42.5) and including the approximate alignment of digits I–III of the manus cast ZJGM-1 (see also Fig. 4). This virtual 3D cast was made in Autodesk Maya 2014 sp2.

in convex hyporelief) positioned under an overhanging ledge at the base of a sandstone bed, where it penetrates into the underlying interbedded sandstone-mudstone layers as a large sub-cylindrical sandstone filling (cast) (Fig. 3) (Table 1). GGM-1 is approximately 13 cm deep and 17 cm in length. The foot impact bent some of the finer sandstone and siltstone layers into a sub-vertical orientation.

Interpretation. The bending and great deformation (downfolding) of the sedimentary layers is typical for dinosaur track casts, and cannot be explained by sedimentary processes. The area with the pronounced bending and downfolding is associated with what we infer to be the anterior of the track cast, which makes a more acute angle than the posterior part (right and left respectively in Fig. 3). In contrast, the posterior part of the cast is flatter and the surrounding sediments are less deformed. The inferred anterior represents the distal toe region, while the posterior represents the track heel. Similar dinosaur track casts of uncertain affinity have been described from the Maastrichtian of Utah (Difley and Ekdale, 2002).

The Guangoumen specimens are all isolated and poorly preserved track casts, and the absence of any distinct (toe) morphology makes a closer identification of specific trackmakers – even a distinction between biped and quadruped – impossible. At least, this dinoturbated level indicates the presence of larger dinosaurs at the Guangoumen tracksite and in close vicinity to the Guanmengou No. 4 bonebed. The Zhongpu area has yielded *Asianopodus*-like grallatorid tracks, larger theropod tracks, sauropods tracks, and poorly defined tracks of large non-tridactyl quadrupedal dinosaurs (Xing et al., 2014a).

Table 1
Measurements (in cm) of the dinosaur tracks from Gansu tracksites.

Number.	D	L	W	II–IV	L/W
GGM-1	13.0	17.0	–	–	–
ZJGM-1	42.0	50.0	43.0	–	1.2
ZJGM-2	42.0	>40	>18	–	–
HT-1	43.0	48.0	–	–	–
HT-2	60.0	33.0	36.0		0.9
GDM-DC-1	27.0	24.0	41.0	–	0.6
GDM-DC-2	25.0	26.0	38.0	–	0.7
DC-3	3.0	23.6	20.6	65°	1.1
GDM-LT-1	7.0	29.5	23.5	–	1.3
GDM-Y-SS1-1	6.6	28.0	22.0	59°	1.3
YSI-S3-LM12A	36.0	33.0	34.0	–	1.0
YSI-S3-LM12B	8.0	45.0	68.0	–	0.7
YSI–S3-LM15	8.0	30.0	42.0	–	0.7

Abbreviations: D: Depth; L: maximum length; W: maximum width; II–IV: angle between digits II and IV; L/W: Maximum length/Maximum width.

5.2. Zhangjiagoumen tracksite, Zhongpu area

Description. The Zhangjiagoumen tracksite is situated besides the national highway G212 near Zhangjiagoumen Village, Zhongpu Town, Dingxi City (GPS: 35°48′27.37″ N, 103°45′34.69″E) (Fig. 1). Six deep sauropod track casts are preserved. As described in the former example, all specimens represent infillings by fine-grained sand of a sub-cylindrical track made in a soft substrate, thus bulging down from the bottom of a sandstone bed. This form of track cast preservation is very common in fluviatile settings and has been referred to as a type of “dinoturbation” (Lockley, 1991). The

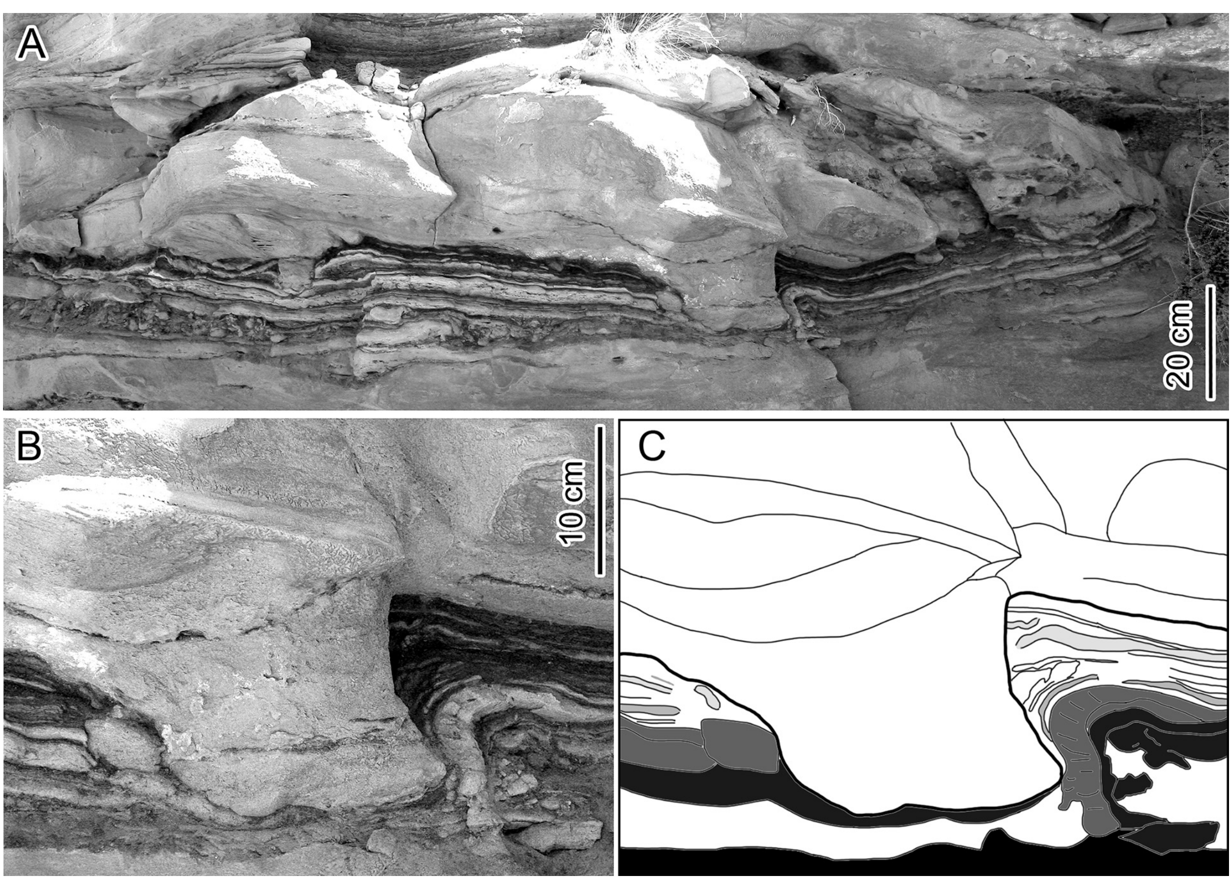

Fig. 3. The Guangoumen tracksite, overview photograph (A), close-up of dinosaur track cast (B) and interpretative outline drawing (C) highlighting the strongly bent and downfolded layer to the right of the cast, which clearly indicates that this is a deformation due to a foot impact, and it is interpreted as the anterior side of the track.

lithology of the track-bearing layer is a brick-red fine sandstone. Above are situated layers of fine sandstones intercalated with mudstones, and below the layers of purple mudstones mixed with a few thin layers of fine sandstones.

Most of the tracks are poorly preserved and appear as rounded, amorphous bulges. However, two track casts exhibit evidence of the external foot morphology and may represent a sauropod pes-manus pair (field number ZJGM-1 = manus, ZJGM-2 = pes; track casts left *in situ*) (Fig. 4) (Table 1).

ZJGM-1 is a particularly well-preserved *in situ* cast, about 42 cm in depth, with a Length/Width ratio of 1.2. It has three sub-vertical, asymmetrical digit impressions, with depths and widths of 33 & 20 cm, 38 & 21 cm, and 24 & 20 cm, respectively. All three digit impressions are rounded at the base and lack claw impressions. The base of the track is entirely exposed, uneven and sub-rounded in general shape. The posterior of the track is concave (smoothly curved), while the anterior portion is convex. ZJGM-2 contacts the medial side of ZJGM-1. ZJGM-2 is poorly preserved, not entirely exposed, and 42 cm deep. A 30 cm deep and 17 cm wide trace lateral to ZJGM-2 probably represents a digit or claw trace.

Interpretation. A semicircular, concave–convex shape is typical of sauropod manus tracks (Bonnan, 2003; Wright, 2005; Marty et al., 2010), and, for this reason, it is assumed that ZJGM-1 is a sauropod manus track cast, with the digits II, III, and IV clearly visible. The absence of claw marks on the three digit impressions furthermore indicates that ZJGM-1 is a sauropod manus rather than pes impression. In typical well-preserved manus tracks from *Brontopodus*-like sauropod trackways, digits II–IV are not isolated but are bound together in a pad that forms a deep anterior crescent, while digits I and V are slightly offset distally (e.g., Farlow et al., 1989; Marty et al., 2010). It is rare for sauropod manus impressions to have well defined digits II, III, and IV, but such sauropod tracks are known – *Polyonyx*-like trackways from the Middle Jurassic of Portugal are one example (Lockley et al., 1992; Lockley and Meyer, 2000, fig 7.12; Santos et al., 2009, figs. 4, 8).

Similar three dimensionally-preserved track casts are known from the Upper Cretaceous Tremp Formation of the La Pleta Nord, Sapeira-1, and Serraduy Sur localities, Spain that Vila et al. (2013: figs. 4d, e). These Spanish tracks have been interpreted as “undetermined sandstone moulds” of either sauropod pes or manus origin. The possibility that these Spanish track casts are ornithopod pes prints can be excluded, because ornithopod tracks are generally characterized by the greater anterior projection of digit III in relation to the lateral digits (II and IV). Deep track casts similar to ZJGM-1 and 2 are also known from the Upper Jurassic Morrison Formation, Bighorn Basin, Wyoming, USA and have been identified as those of sauropods (Platt and Hasiotis, 2006, figs. 3a, 6).

ZJGM-2 is not well exposed, but as it is in contact with the manus track casts ZJGM-1, it is likely that it represents the cast of the pes track associated with this manus track (i.e. a pes track from the same trackway). However, the identification of ZJGM-2 as a pes track cast associated with the manus track cast ZJGM-1 remains ambiguous.

5.3. Hutan tracksite from Guanshan area

Description. The Hutan tracksite is situated besides the national road G309, to the northwest of Hutan Township, Qilihe District, Lanzhou City (35°57′37.70″N, 103°38′49.40″E) (Fig. 1). Three deep

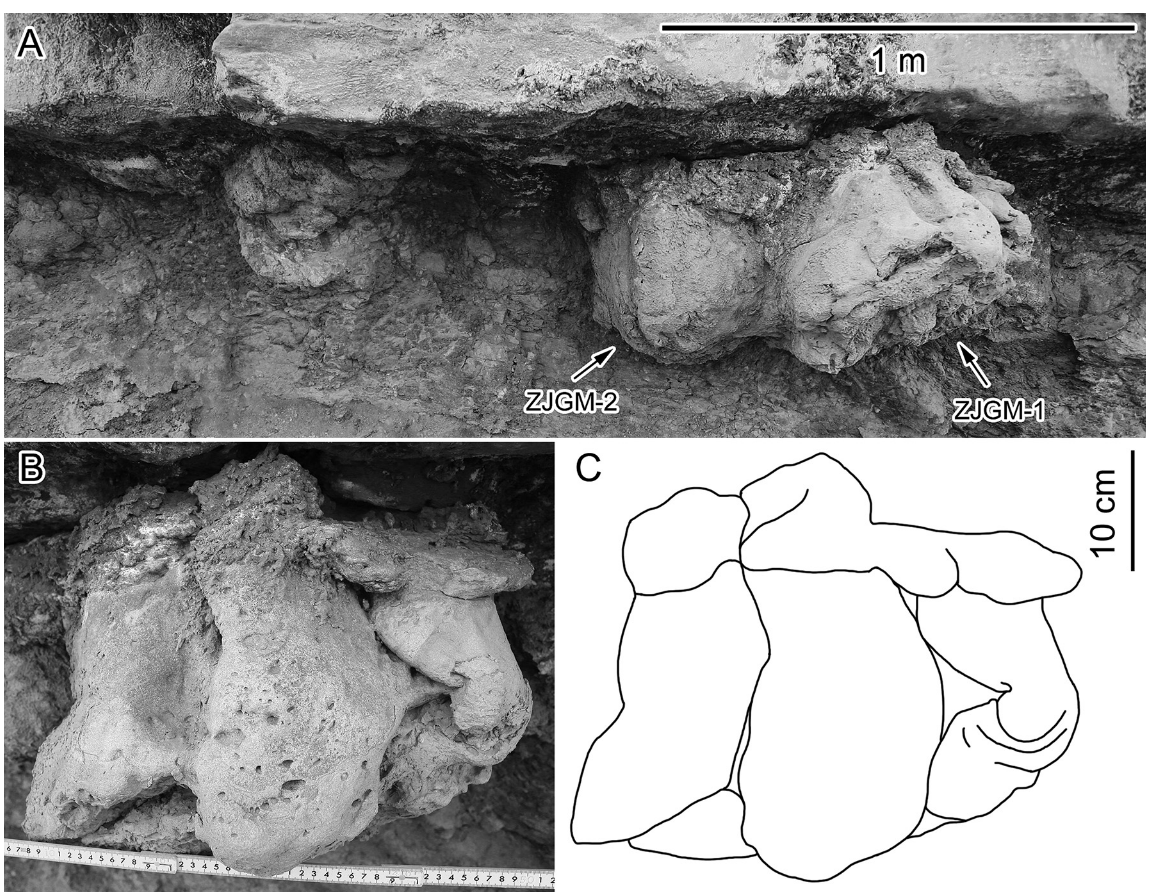

Fig. 4. The Zhangjiagoumen tracksite, overview photograph (A), close-up of sauropod track ZJGM-1 in a more anterior view (B) and corresponding interpretative outline drawing (C) showing three prominent digit impressions.

track casts were discovered at this site and were left *in situ*. The track cast-bearing layer is a brick-red, fine sandstone, of which the upper part is a thickly-bedded fine sandstone occasionally intercalated with mudstones. Some of the thinner sandstone layers show ripple laminations in cross-section. The underlying rock is a purple mudstone intercalated with a few thin sandstone layers.

Two well-preserved track casts, named HT-1 and HT-2, were found (Fig. 5) (Table 1). HT-1 is 43 cm deep, 48 cm long, oval in shape, and located at the base of the track-bearing layer. The lateral surface is poorly preserved but seven grooves are visible. These grooves are vertical, parallel, and approximately 10 cm long and 3–4 mm wide. HT-2 was not *in situ* and it found at the base of the outcrop. Its lithology is very similar to HT-1, and it is assumed that HT-2 comes from the same stratigraphic position, i.e. the base of the sandstone layers. HT-2 is 60 cm deep, has a U-shaped morphology, and the L/W ratio of the cross-section is 0.9. The shapes of the top and the base are generally consistent in morphology. Narrow, closely spaced, parallel, vertical striations that each measure 3–4 mm run from the top of HT-2 to the bottom of the heel.

Interpretation. Although there are no details of toe impressions visible, the oval and elongated shape of HT-1 is typical of a sauropod pes cast. The U–shaped morphology of HT-2 is typical for a manus track of *Brontopodus*-like sauropod trackways (Farlow et al., 1989; Santos et al., 2009). The striations are interpreted as marks made by raised areas of coarsely-textured skin. Similar striations have been described from manus track casts from the Late Jurassic of Portugal, and were interpreted as striation marks resulting from skin texture and recording the movement of the manus as it vertically entered and left the substrate, with little or no horizontal movement (Mateus and Milàn, 2008).

On the posterior part of the manus cast of HT-2, is a shallow concavity with two internal molds of small bivalves with distinct concentric striations. These bivalves may either have been living within the sediment and disturbed by the foot impact, they may already have been dead prior to track formation, or they may have been transported into the track after track formation. Bivalves disturbed by sauropod tracks have been reported from the Upper Jurassic Morrison Formation of Colorado (Lockley and Hunt, 1995; Lockley et al., 1997).

5.4. Dianchang tracksite. Yanguoxia area

Description. The Dianchang (=power plant) tracksite is situated in a small river valley to the south the local power plant of Yanguoxia Town, Yongjing County, Linxia Hui Autonomous Prefecture (36° 4′1.74″N, 103°16′34.95″E) (Fig. 1). Two deep sauropod track casts and one tridactyl track cast (Figs. 6, 7A, B) (Table 1) were discovered at the bottom of the valley, so that their precise stratigraphic origin is not known. The sauropod specimens are cataloged as GDM-DC-1 and 2, and they are housed at the Gansu Dinosaur Museum. The tridactyl track was cataloged as DC-3 but was not collected.

The upper surfaces of both GDM-DC-1 and 2 track casts are U–shaped, and the L/W ratios are 0.6 and 0.7, respectively. In both tracks, the lower surface is much larger than the upper surface.

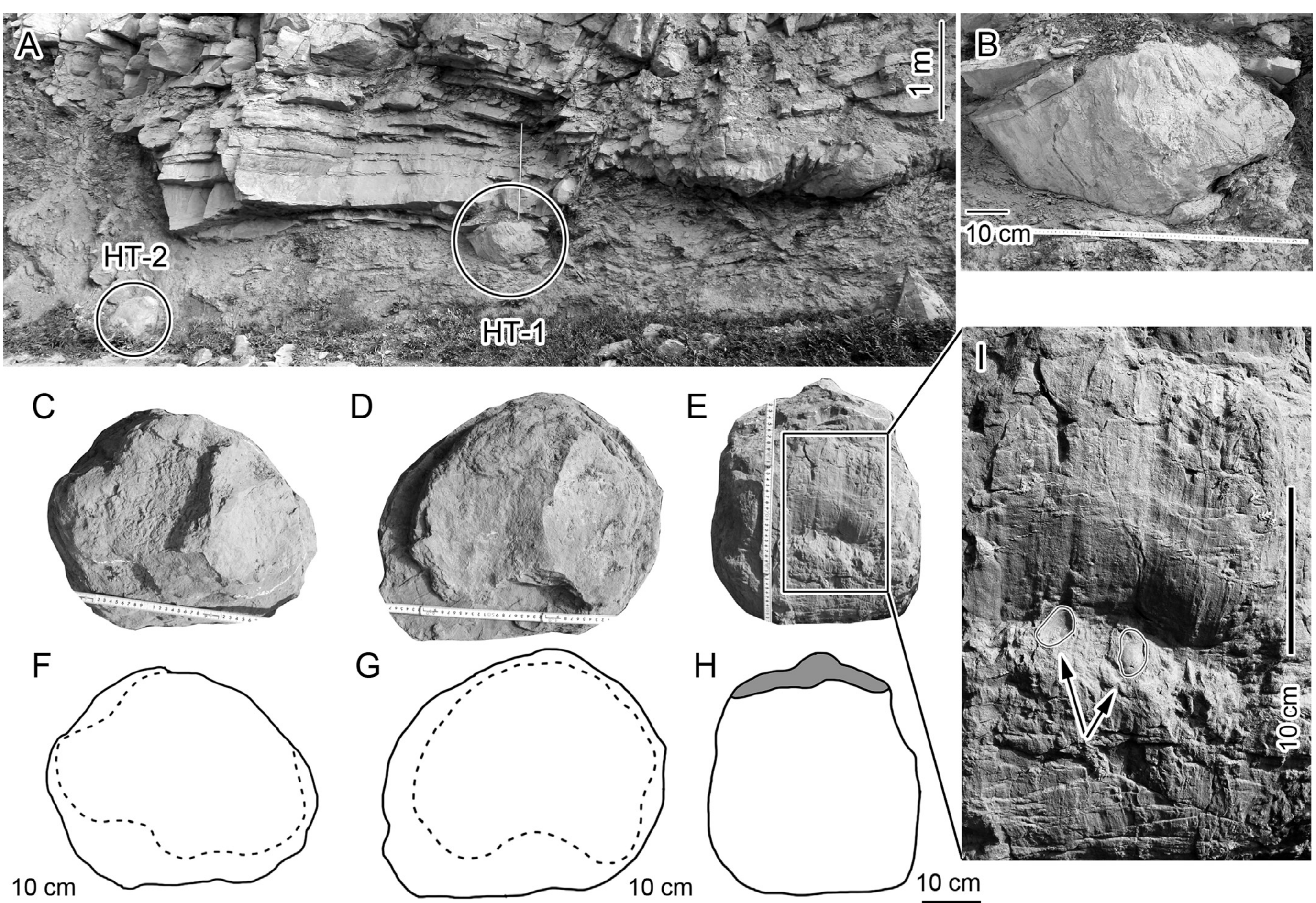

Fig. 5. The Hutan tracksite, overview photograph of the road outcrop (A), close-up of the sauropod pes track cast HT-1 (B), sauropod manus track cast HT-2 in upper (top) (C), lower (base) (D), and posterior (E) views and corresponding outline drawings (F–H), close-up of the posterior view of HT-2 with arrows indicating two internal molds of small bivalves (I).

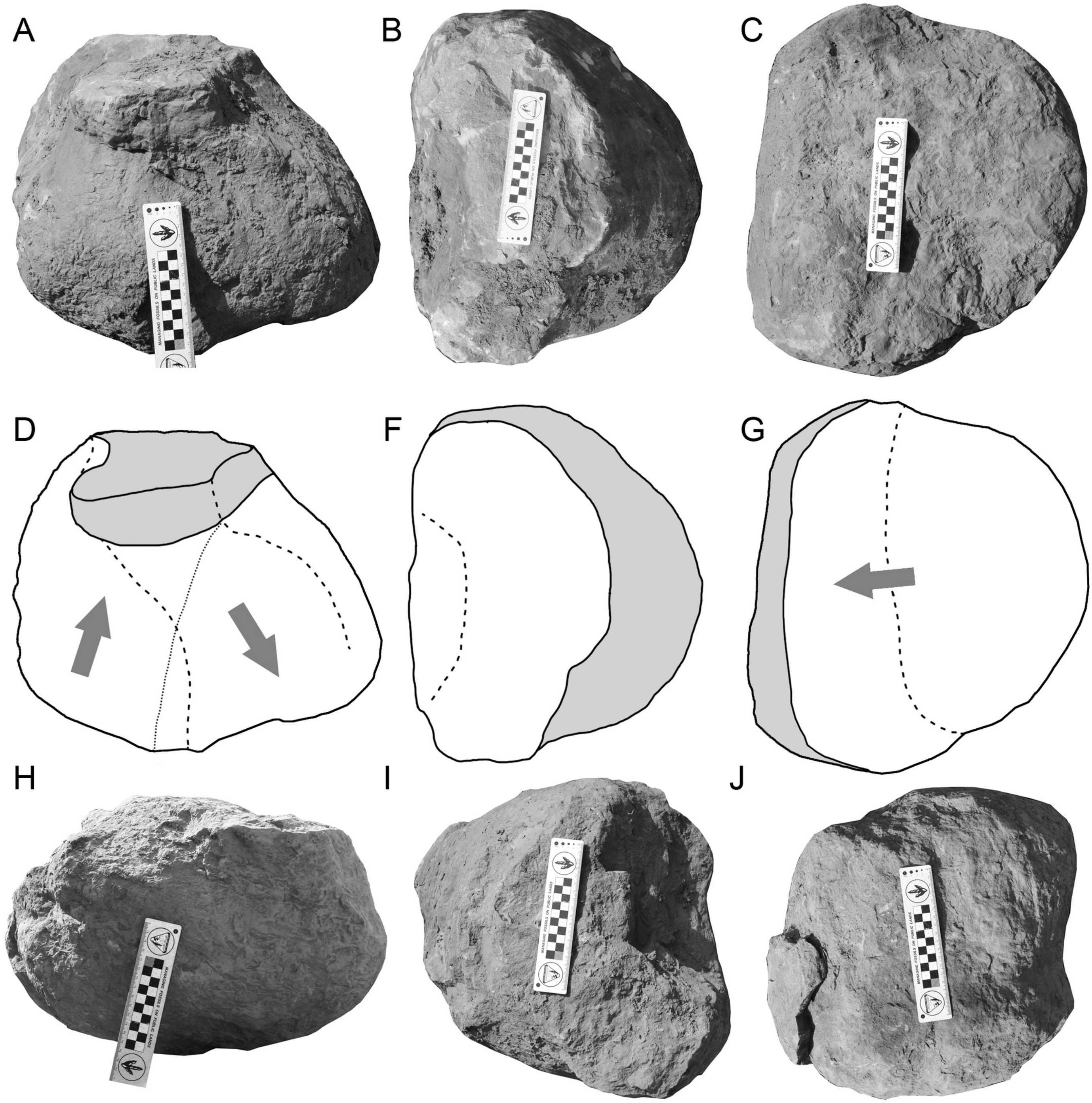

Fig. 6. Sauropod manus track casts from the Dianchang tracksite. GDM-DC-1 in lateral (A), upper (top) (B), and lower (base) (C) views and corresponding outline drawings (D–G); GDM-DC-2 in lateral (H), upper (top) (I), and lower (base) (J) views. Arrows indicate likely moving directions of the trackmaker's foot.

DC-3 is a tridactyl track cast with "fleshy" digits, an L/W ratio of 1.1, and a moderate mesaxony (Fig. 7A, B). Invertebrate traces are preserved on the bottom of the cast. The digits are poorly preserved, with indiscernible phalangeal pads and claw marks. Digit III is the longest and largest digit, and its anterior portion has a pad with a pronounced trapezoidal shape.

Interpretation. The U-shaped form of both GDM-DC-1 and 2 are typical of sauropod manus tracks. The differential surface of the top and base of the manus track casts offers some clues to the history of the track formation and preservation. First, the manus pushed downward into a soft substrate (mud) with a higher cohesiveness and lower moisture content at the base, which permitting the formation of a 3D cast that did not collapse at the base. When the foot was pulled out, a large "heel" trace was formed, while the upper portion of the track collapsed back slightly – resulting in the cast's smaller upper surface. Therefore, only the dimensions of the lower surface of the track represents the true size of the trackmaker's manus.

Similar sauropod tracks are known from the Upper Cretaceous North Horn Mountain of the Wasatch Plateau, Central Utah (Difley

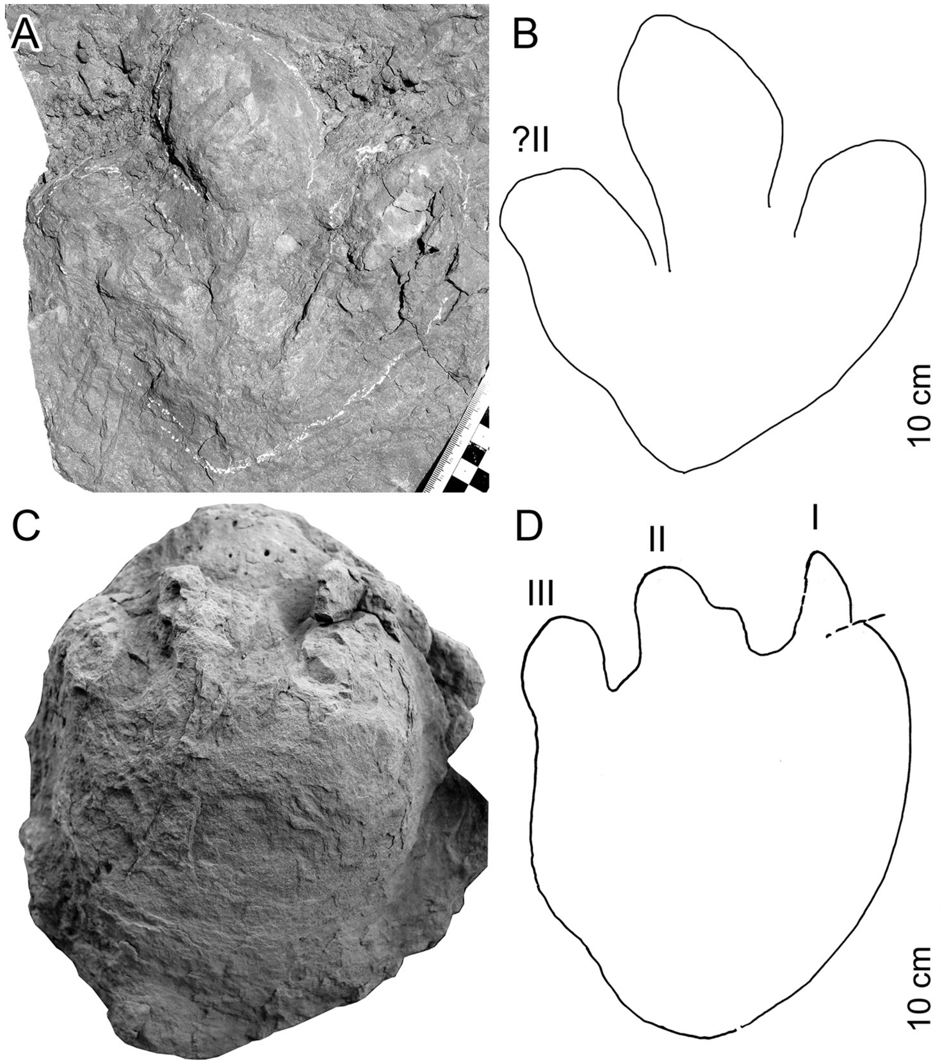

Fig. 7. Track cast DC-3 of theropod affinity from the Dianchang tracksite, photograph (A), and corresponding outline drawing (B), note the fleshy toes; Medium-sized sauropod pes track cast with prominent digits interpreted as dI, II, and III from the Litan tracksite, photograph (C), and corresponding outline drawing (D).

and Ekdale, 2002, fig. 7A). The absence of striations (contrary to HT-2 described above) suggests that the substrate was too moist at the time of track formation. Tracks left in moist (but not water-saturated) and cohesive fine-grained substrates generally best preserve anatomical details, including striation marks or skin impressions (e.g., Lockley, 1986; Nadon, 1993; Marty et al., 2009).

Due to its poor preservation, DC-3 is difficult to attribute to a specific trackmaker. However, based on comparison with other dinosaur track morphotypes at the Yanguoxia No.1 tracksite (Zhang et al., 2006) and the presence of a pad on digit III and deep hypicies, DC-3 is best attributed to a theropod trackmaker.

5.5. *Litan tracksite, Yanguoxia area*

Description. The Litan tracksite is situated at the southern bank of the Yellow River at Litan Township, Yongjing County, Linxia Hui Autonomous Prefecture (36° 3′51.14″N, 103°16′53.89″E) (Fig. 1). One medium-sized sauropod pes cast (GDM-LT-1: Fig. 7C, D) (Table 1) was discovered here. The track cast LT-1 has an oval shape, with three well-marked, anteriorly-oriented, round, and blunt digit impressions with claw marks visible on digits I and II. The claw mark of digit I is well-defined, whereas the claw mark of digit II is blunt. Digit III is small and its terminal end is damaged. The heel is well developed and located posterior to the axis of digit II. The L/W ratio of the track cast is 1.3.

Interpretation. The general morphology including the three round and blunt digit impressions of LT-1 is similar to medium-sized pes tracks of quadrupedal sauropod trackways from Malingshan, Jiangsu Province (Xing et al., 2010a), Linshu, Shandong Province (Xing et al., 2013b), Zhucheng, Shandong Province (Xing et al., 2010b), Yanqing, Beijing (Zhang et al., 2012; unpublished data), and Zhongpu, Gansu (Xing et al., 2014a). Impressions of digits IV and V are only faintly observable on the specimens from Yanqing (Zhang et al., 2012) and Linsu (Xing et al., 2010b), while the only known specimen ZP1-S2 from Zhongpu exhibits weak but clear impressions of digit IV and V. It is thus assumed that the three digits of LT-1 correspond to digits I–III of a pes track of sauropod with weakly-developed digits IV and V. A stegosaurian origin for this track cast is ruled out, even though it resembles the stegosaurian ichnogenus *Deltapodus* (Whyte and Romano, 2001; Mateus et al., 2011; Xing et al., 2013c).

5.6. *Yanguoxia SS1 tracksite, Yanguoxia area*

Description. Yanguoxia SS1 (SS = small site) is situated at the edge of a valley at Dinosaur Bay (former Tiger Mouth), Yongjing County, Linxia Hui Autonomous Prefecture (36° 3′24.69″N, 103°15′19.84″E) (Fig. 1), approximately 250 m away from the Yanguoxia No.1 main tracksite. The Yanguoxia SS1 tracksite has yielded two tridactyl ornithopod pes track casts (Fig. 8) (Table 1). One specimen was collected, cataloged as GDM-Y-SS1-1, and is now housed at Gansu Dinosaur Museum. The other track is preserved *in situ*. The lithology of the track cast is a yellow fine sandstone. The strata of the area consists of brick-red, fine sandstones intercalated with gray–green and red mudstones.

GDM-Y-SS1-1 is a well-preserved tridactyl track with relatively strong mesaxony (L/W of anterior triangle 0.38 *sensu* Lockley, 2009), an L/W ratio of 1.3, and a typical quadripartite track morphology (three digital and one heel pad). All three digits have blunt claw marks. The heel pad has a triangular form. In GDM-Y-SS1-1, the anterior end was embedded in the strata, while the posterior end was exposed. A second, uncollected ornithopod track was preserved in the same manner, approximately one meter away from GDM-Y-SS1-1.

Interpretation. A quadripartite track morphology is typical of ornithopod pes tracks and of the ornithopod tracks of the Yanguoxia tracksites (primarily No. 1, 2, 6). The mesaxony of GDM-Y-SS1-1 is substantially less pronounced than in the ornithopod tracks of the Yanguoxia tracksites. For example, another ornithopod track cast from Yanguoxia tracksite No. 1, has an L/W ratio of 1.3, and the length/width ratio of the anterior triangle is 0.41 (Zhang et al., 2006: fig. 12). Zhang et al. (2006) argued that the ornithopod trackmakers of the Yanguoxia tracksites were walking bipedally. However, the tracks resemble those from both bipedal and quadrupedal trackways attributed to the ichnogenus *Caririchnium* (Matsukawa et al., 1999; Xing et al., 2014b).

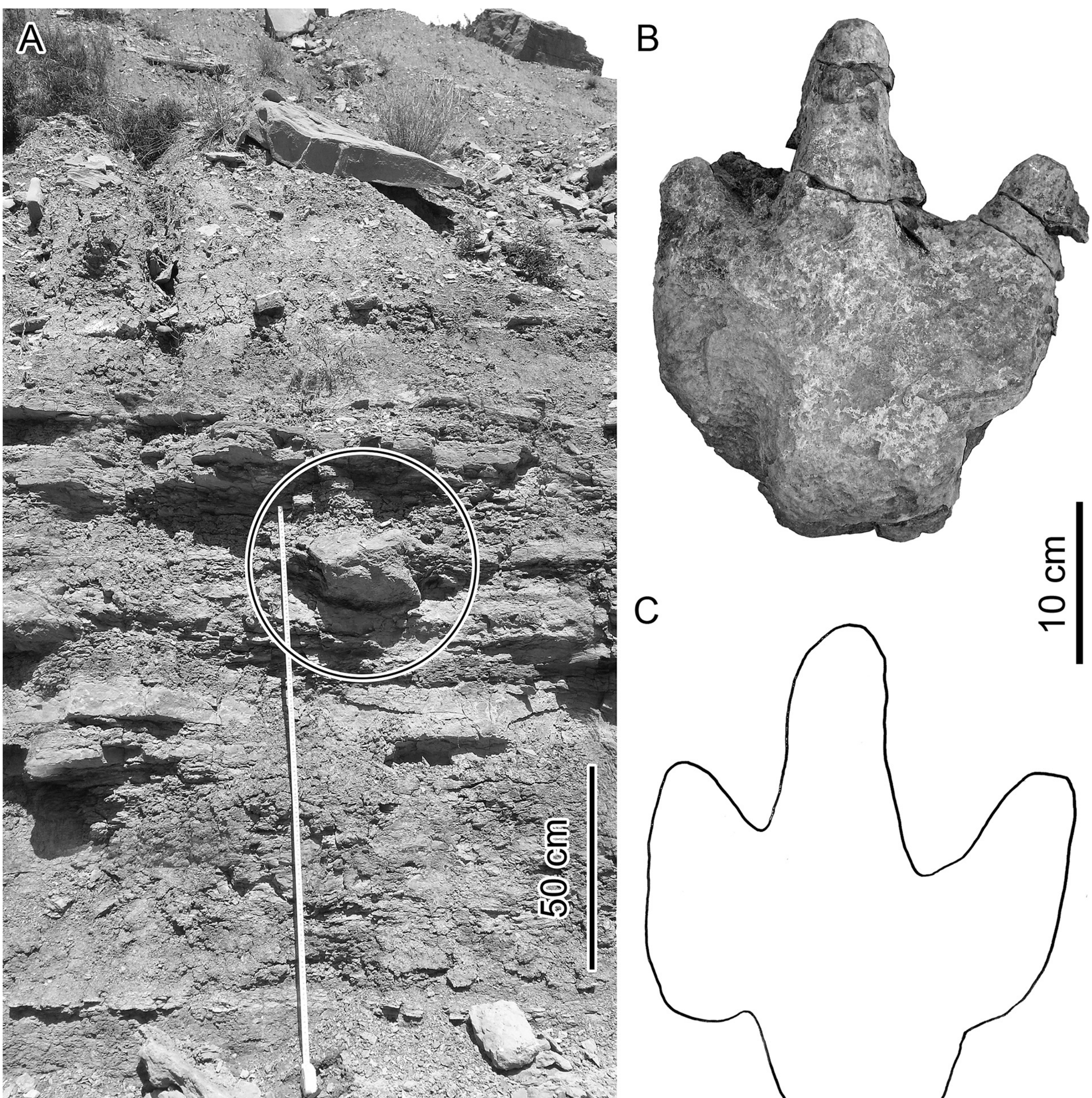

Fig. 8. The Yanguoxia SS1 tracksite, overview photograph (A), close-up photograph of the ornithopod track cast GDM-Y-SS1-1 (B) and corresponding outline drawing (C).

5.7. Yanguoxia No.1 tracksite, Yanguoxia area

Description. Yanguoxia No.1 tracksite is situated at Dinosaur Bay (former Tiger Mouth), Yongjing County, Linxia Hui Autonomous Prefecture (GPS: 36° 3′17.95″N, 103°15′13.52″E). The sauropod trackway YSI-S3 is well preserved (the details of the YSI-S3 trackway will be published elsewhere), and in front of the pes track LP12, two manus tracks, LM12A and LM12B, are preserved. LM12B is only approximately 8 cm deep and seriously deformed. LM12A is unusually deep, approximately 36 cm, (Fig. 9A) (Table 1), with overhanging track walls that obscure the track details (toe and claw impressions). To observe and describe these obscured details, a resin mold of the track YSI-S3-LM12A was made, and the molds were scanned to obtain a 3D model (Fig. 9B–F). YSI-S3-LM12A is U–shaped and the L/W ratio of the lower surface is 1.0. On the 3D model of the track, digits I–V and a concavity between digit II and III can be observed, while the border between digits III and IV is indiscernible. From these observations, the manus appears slightly obliquely inserted at the floor of the track. The insertion angle of digits II–IV resembles that of ZJGM-1 from the Zhangjiagoumen tracksite (Zhongpu area, described above).

Interpretation. The U-shape and low L/W-ratio of YSI-S3-LM12A is consistent with the general morphology of YSI-S3-LM12B and LM15 from the same trackway, and it is typical of manus tracks of *Brontopodus*-like sauropod trackways (Farlow et al., 1989; Santos et al., 2009). The overhang was formed by a partial collapse of the substrate after foot withdrawal, but this collapse did not

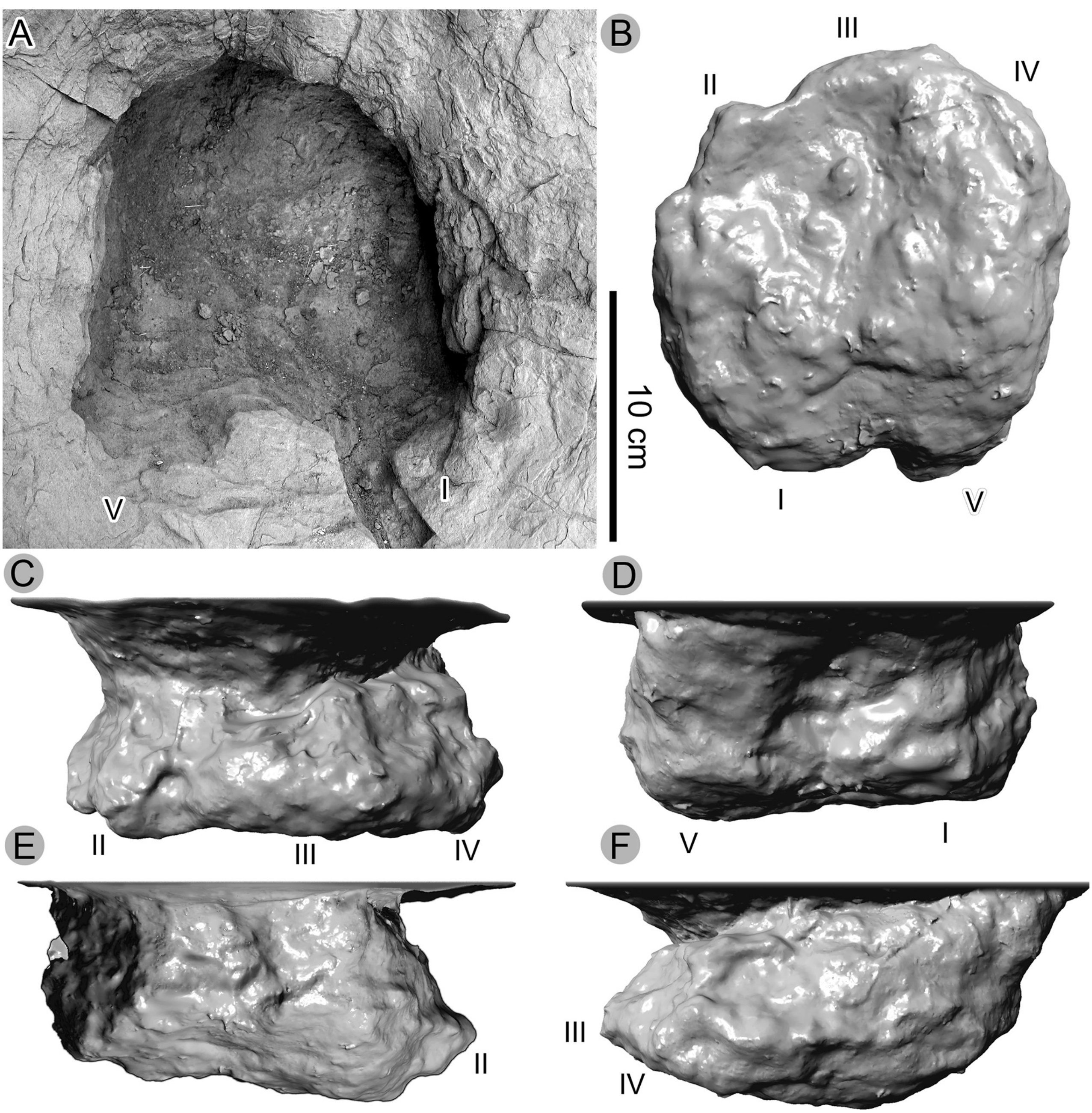

Fig. 9. Sauropod manus track YSI-S3-LM12A from the Yanguoxia No.1 tracksite. Overview photograph in plain view (A), 3D models ('virtual' track cast) in ventral (B), anterior (C), posterior (D), medial (E), and lateral (F) views. Note the presence of five digits in (B).

entirely cover the base of the track, possibly because the substrate had a higher cohesiveness and lower moisture content at the base. This results in a smaller upper than lower surface, as was also observed on the sauropod manus casts GDM-DC-1 and 2 from the Dianchang tracksite (Yanguoxia area) described above.

A possible interpretation for the double manus track may be that the trackmaker stepped into soft and unstable substrate, became mired, lost its balance, and quickly braced itself with an extra manus step – leaving two manus tracks. Another hypothesis is that LM12A pertains to another trackway, of which other tracks were too shallowly impressed to be preserved.

6. Discussion

In China, the Lanzhou-Minhe Basin is becoming increasingly well-known for its abundance and high diversity of dinosaur tracks. The Yanguoxia No.1 tracksite is the most representative of the known ichnofauna of the region, and includes well-preserved sauropod, ornithopod, dromaeosaur, theropod, pterosaur, and bird tracks and trackways (Zhang et al., 2006; Xing et al., 2013a). In the Zhongpu and Guanshan areas, some non-avian dinosaur and bird tracks were discovered by a crew, led by Li DQ, searching for osteological dinosaur fossils. While track casts are not scarce, they had been overlooked and/or neglected in previous field investigations.

The natural casts tracks of the Lanzhou-Minhe Basin are generally found at the base of (massive) sandstone beds, within the sandstone beds (i.e. on accretion surfaces), or as sandy casts within mudstone levels. The well-preserved track ZJGM-1 is inferred to reveal the rare impressions of digits II–IV of a sauropod manus, while the posterior part of ZJGM-2 is probably a pes track that may be associated with the manus (possible pes–manus pair). Manus tracks HT-2 and YSI-S3-LM12A reveal that the trackmaker moved its feet only over a very short horizontal distance during entering and exiting the sediments, i.e. it stepped in and retracted in a (sub-) vertical manner.

The sauropod manus track casts GDM-DC-1 and 2, as well as the manus track YSI-S3-LM12A from the Yanguoxia No. 1 tracksite, represent tracks where the upper part of the track partially collapsed over the lower part, resulting in a smaller upper surface (diameter) and, in the case of a track in negative epirelief (impression), obscuring important track details such as the digit and claw impressions. These details were revealed in the manus track impression YSI-S3-LM12A by laserscanning and subsequent generation of a three-dimensional ‘virtual cast’.

LT-1 is the first discovery of a medium-sized sauropod track from the Lanzhou-Minhe Basin, comparable with coeval tracks in East and North China. The well-preserved ornithopod track GDM-Y-SS1-1 resembles the medium-sized ornithopod tracks that are commonly found at the Yanguoxia No. 1 tracksite.

The large Yanguoxia No. 1 & 2 tracksites reveal a high abundance of tracks and trackways and a diverse ichnofauna represented by well-preserved tracks and at least one, or in some cases several, track morphotypes of theropods, sauropods, ornithopods, pterosaurs, and birds. In contrast, the small, new tracksites described herein suggest a low diversity and low abundance of tracks for the studied area. On the one hand, this could indicate a general low diversity and the Yanguoxia No. 1 & 2 tracksites would then represent an exceptional (‘atypical’) track abundance with an unusual high ichnodiversity. On the other hand, the lower diversity indicated by the new tracksites may be artificial and simply the result of both the small sample area and the fact that all of these outcrops are cross-sections where bedding planes – that could reveal abundant tracks and trackways – are scarce and limited to small surfaces. This perceived low diversity may further be enhanced by the disproportionate predominance of large tracks that are resistant to weathering and easy to spot. If large-scale excavation of bedding planes could be conducted at these new sites, they could conceivably yield a similar track abundance and diversity as observed at the Yanguoxia No. 1 & 2 tracksites. This latter conclusion may also be valid in more general terms, for any track-bearing sedimentary sequence.

7. Concluding remarks

The new discoveries of abundant natural track casts show that the distribution and frequency of dinosaur tracks within the Lanzhou-Minhe Basin is much greater than previously recognized. Probably because of their tremendous individual size and depth, sauropod tracks dominate the preserved natural cast record. Although all of the currently known natural cast sites contain relatively few tracks and each spans a relatively small area, the sites collectively add data from a large geographical area and offer new clues to the reconstruction of the local terrestrial Cretaceous ecosystem. Moreover, because natural casts record the three-dimensional foot morphology and the locomotive kinematics of the trackmakers, they provide an important complement to the information that can be gained from tracks and trackways preserved as shallow impressions on single bedding surfaces. For these reasons, it is important to systematically document small tracksites and occurrences of natural track casts.

In the near future, more dinosaur tracksites (impressions and casts) are likely to be discovered at the base of sandstone ledges, ribbons, fins, and within the mudstone beds of the Lanzhou-Minhe Basin. These future finds will help confirm if the low diversity so far recorded from the natural cast record is an artifact or if the ichnofauna of the whole area is as diverse as indicated by the exceptional Yanguoxia No. 1 & 2 tracksites. It is our hope that the terminology and methodology here outlined will be adopted and built upon by future studies of dinosaur natural casts, both with the Lanzhou-Minhe Basin and abroad.

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References

Avanzini, M., Piñuela, L., García-Ramos, J.C., 2012. Late Jurassic footprints reveal walking kinematics of theropod dinosaurs. Lethaia 45 (2), 238–252.

Bonnan, M.F., 2003. The evolution of manus shape in sauropod dinosaurs: implications for functional morphology, forelimb orientation, and phylogeny. Journal of Vertebrate Paleontology 23, 595–613.

Bureau of Geology and Mineral Resources, Gansu Province, 1997. Stratigraphy (Lithostratic) of Gansu Province. China University of Geosciences Press, Wuhan, pp. 194–198.

Chen, J., 2013. Sedimentary Characteristics and Paleogeography of the Hekou Group in Lanzhou-Minhe Basin in the Early Cretaceous. China University of Geosciences, Beijing, 73p. Master Thesis.

Chen, J., Liu, Y.Q., Kuang, H.W., Liu, Y.X., Peng, N., Xu, H., Dong, C., Liu, H., Xue, P.L., Xu, J.L., 2013. Sedimentary characteristics and their basin analysis significance of the Lower Cretaceous Hekou Group in Zhongpu area of Lanzhou-Minhe Basin, Gansu Province. Journal of Palaeogeography 15 (2), 155–168.

Cobos, A., Gascó, F., 2012. Presencia del icnogénero Iguanodontipus en el Cretácico Inferior de la provincia de Teruel (España). Presence of the ichnogenus Iguanodontipus in the Lower Cretaceous of the Teruel province (Spain). Geogaceta 52, 185–188.

Cobos, A., Gascó, F., Royo–Torres, R., Lockley, M.G., Alcalá, L., 2014. Exquisite dinosaur footprint preservation reveals the four dimensional dynamics of track making. In press. In: Richter, A., Falkingham, P., Marty, D. (Eds.), Dinosaur Tracks. Next Steps. Indiana University Press.
Currie, P.J., Badamgarav, D., Koppelhus, E.B., 2003. The first Late Cretaceous footprints from the Nemegt locality in the Gobi of Mongolia. Ichnos 10, 1–13.
Difley, R.L., Ekdale, A.A., 2002. Footprints of Utah's last dinosaurs: track beds in the Upper Cretaceous (Maastrichtian) North Horn Formation of the Wasatch Plateau, Central Utah. Palaios 17, 327–346.
Du, Y., Li, D.Q., Peng, B.L., Bai, Z., 2001. Dinosaur footprints of Early Cretaceous in Site 1, Yanguoxia, Yongjing County, Gansu Province. Journal of China University of Geosciences 12, 2–9.
Farlow, J.O., Pittman, J.G., Hawthorne, J.M., 1989. *Brontopodus birdi*, Lower Cretaceous dinosaur footprints from the U.S. Gulf Coastal Plain. In: Gillette, D.D., Lockley, M.G. (Eds.), Dinosaur Tracks and Traces. Cambridge University Press, Cambridge, pp. 371–394.
Gatesy, S.M., Middleton, M.K., Jenkins Jr., F.A., Shubin, N.H., 1999. Three-dimensional preservation of foot movements in Triassic theropod dinosaurs. Nature 399, 141–144.
Hornung, J.J., Reich, M., 2014. *Metatetrapous valdensis* Nopcsa, 1923 and the presence of ankylosaur tracks (Dinosauria: Thyreophora) in the Berriasian (Early Cretaceous) of northwestern Germany. Ichnos 21, 1–18.
Huerta, P., Fernández-Baldor, F.T., Farlow, J.O., Montero, D., 2012. Exceptional preservation processes of 3D dinosaur footprint casts in Costalomo (Lower Cretaceous, Cameros Basin, Spain). Terra Nova 24, 136–141.
Ibrahim, N., Varricchio, D.J., Sereno, P.C., Wilson, J.A., Dutheil, D.B., Martill, D.M., Baidder, L., Zouhri, S., 2014. Dinosaur Footprints and Other Ichnofauna from the Cretaceous Kem Kem Beds of Morocco. PLoS One 9 (3), e90751.
Li, L.G., Li, D.Q., You, H.L., Dodson, P., 2014. A New Titanosaurian Sauropod from the Hekou Group (Lower Cretaceous) of the Lanzhou-Minhe Basin, Gansu Province, China. PLoS One 9, e85979.
Li, D.Q., Du, Y.S., Gong, S.Y., 2000. New discovery of dinosaur footprints of the Early Cretaceous from Yanguoxia, Yongjing County, Gansu Province. Earth Sciences Journal of China University of Geosciences 25, 498–525.
Lockley, M.G., 1986. The paleobiological and paleoenvironmental importance of dinosaur footprints. Palaios 1, 37–47.
Lockley, M.G., 1991. Tracking Dinosaurs: A new Look at an Ancient World. Cambridge University Press, Cambridge, pp. 1–238.
Lockley, M.G., 1997. The paleoecological and paleoenvironmental utility of dinosaur tracks. In: Farlow, J.O., Brett-Surman, M.K. (Eds.), The Complete Dinosaur. Indiana University Press, Bloomington, pp. 554–578.
Lockley, M.G., 2001. A Field Guide to Dinosaur Ridge. Friends of Dinosaur Ridge and University of Colorado at Denver Dinosaur Trackers Research Group, Denver, Colorado, pp. 1–34.
Lockley, M.G., 2009. New perspectives on morphological variation in tridactyl footprints: clues to widespread convergence in developmental dynamics. Geological Quarterly 53, 415–432.
Lockley, M.G., Fillmore, B., Marquardt, L., 1997. Dinosaur lake: the story of the Purgatoire Valley dinosaur tracksites area. Colorado Geological Survey. Special Publication 40, pp. 1–64.
Lockley, M.G., Hunt, A.P., 1995. Dinosaur Tracks and Other Fossil Footprints of the Western United States. Columbia University Press, New York, pp. 1–338.
Lockley, M.G., Marshall, C., 2014. A Field Guide to the Dinosaur Ridge Area, 4th edition. Friends of Dinosaur Ridge, Morrison Colorado, pp. 1–40.
Lockley, M.G., Meyer, C.A., 2000. Dinosaur Tracks and other fossil footprints of Europe. Columbia University Press, New York, pp. 1–323.
Lockley, M.G., Santos, V.F., Ramalho, M.M., Galopim, A., 1992. Novas jazidas de pegadas de dinossaurios no Jurassico superior de Sesimbra, (Portugal). Gaia 5, 40–43.
Lockley, M.G., Xing, L.D., Lockwood, J., Pond, S., 2014. A review of large ornithopod footprints with special reference to their Ichnotaxonomy. Biological Journal of the Linnaean Society. In press.
Matsukawa, M., Lockley, M.G., Hunt, P.A., 1999. Three age groups of ornithopods inferred from footprints in the mid-Cretaceous Dakota Group, eastern Colorado, North America. Palaeogeography, Palaeoclimatology, Palaeoecology 147, 39–51.
Marty, D., Belvedere, M., Meyer, C.A., Mietto, P., Paratte, G., Lovis, C., Thüring, B., 2010. Comparative analysis of Late Jurassic sauropod trackways from the Jura Mountains (NW Switzerland) and the central High Atlas Mountains (Morocco): implications for sauropod ichnotaxonomy. Historical Biology 22 (1–3), 109–133.
Marty, D., Strasser, A., Meyer, C.A., 2009. Formation and taphonomy of human footprints in microbial mats of present-day tidal-flat environments: implications for the study of fossil footprints. Ichnos 16 (1–2), 127–142.
Mateus, O., Milàn, J., 2008. Sauropod forelimb flexibility deduced from deep manus tracks, 52th Paleontological Association Annual Meeting. 18th–21st December 2008, pp. 67–68.
Mateus, O., Milan, J., Romano, M., Whyte, M.A., 2011. New finds of stegosaur tracks from the Upper Jurassic Lourinhã Formation, Portugal. Acta Palaeontologica Polonica 56, 651–658.
Milàn, J., 2011. New theropod, thyreophoran, and small sauropod tracks from the Middle Jurassic Bagå Formation, Bornholm, Denmark. Bulletin of the Geological Society of Denmark 59, 51–59.
Milàn, J., Christiansen, P., Mateus, O., 2005. A three-dimensionally preserved sauropod manus impression from the Upper Jurassic of Portugal: implications for sauropod manus shape and locomotor mechanics. Kaupia 14, 47–52.
Milàn, J., Avanzini, M., Clemmensen, L.B., Garciá-Ramos, J.C., Piñuela, L., 2006. Theropod foot movement recorded from Late Triassic, Early Jurassic and Late Jurassic fossil footprints. New Mexico Museum of Natural History and Science Bulletin 37, 352–364.
Nadon, G.C., 1993. The association of anastomosed fluvial deposits and dinosaur tracks, eggs, and nests: implications for the interpretation of floodplain environments and a possible survival strategy for ornithopods. Palaios 8, 31–44.
Platt, B.F., Hasiotis, S.T., 2006. Newly discovered sauropod dinosaur tracks with skin and foot-pad impressions from the Upper Jurassic Morrison Formation, Bighorn Basin, Wyoming, U.S.A. Palaios 21, 249–261.
Romano, M., Whyte, M.A., 2012. Information on the foot morphology, pedal skin texture and limb dynamics of sauropods: evidence from the ichnological record of the Middle Jurassic of the Cleveland Basin, Yorkshire, UK. Zubia 30, 45–92.
Santos, V.F., Moratalla, J.J., Royo-Torres, R., 2009. New sauropod trackways from the Middle Jurassic of Portugal. Acta Palaeontologica Polonica 54 (3), 409–422.
Tang, Y.H., Dai, S., Huang, Y.B., Zhu, Q., Fang, X.M., Hu, H.F., Liu, J.W., Kong, L., Zhao, J., Liu, X., 2008. The early Cretaceous tectonic uplift of Qilian mountains, evidence from the sedimentary facies and susceptibility of rocks of the Hekou group, Lanzhou-Minhe basin. Earth Science Frontiers 15 (2), 261–271.
Vila, B., Oms, O., Fondevilla, V., Gaete, R., Galobart, A., Riera, V., Canudo, J.I., 2013. The Latest Succession of Dinosaur Tracksites in Europe: Hadrosaur Ichnology, Track Production and Palaeoenvironments. PLoS One 8 (9), e72579.
Whyte, M.A., Romano, M., 2001. Probable stegosaurian dinosaur tracks from the Saltwick Formation (Middle Jurassic) of Yorkshire, England. Proceedings of the Geologist's Association 112, 45–54.
Wright, J.L., 2005. Steps in Understanding Sauropod Biology: The importance of sauropod tracks. In: Curry Rogers, K.A., Wilson, J.A. (Eds.), The Sauropods. University of California Press, Oakland, pp. 252–280.
Xing, L.D., Harris, J.D., Jia, C.K., 2010a. Dinosaur tracks from the Lower Cretaceous Mengtuan Formation in Jiangsu, China and morphological diversity of local sauropod tracks. Acta Palaeontologica Sinica 49 (4), 448–460.
Xing, L.D., Harris, J.D., Wang, K.B., Li, R.H., 2010b. An Early Cretaceous Non-avian Dinosaur and Bird Footprint Assemblage from the Laiyang Group in the Zhucheng Basin, Shandong Province, China. Geological Bulletin of China 29 (8), 1105–1112.
Xing, L.D., Bell, P.R., Harris, J.D., Currie, P.J., 2012. An unusual, three-dimensionally preserved, large hadrosauriform pes track from "mid"-Cretaceous Jiaguan Formation of Chongqing, China. Acta Geologica Sinica (English edition) 86, 304–312.
Xing, L.D., Li, D.Q., Harris, J.D., Bell, P.R., Azuma, Y., Fujita, M., Lee, Y., Currie, P.J., 2013a. A New *Dromaeosauripus* (Dinosauria: Theropoda) ichnospecies from the Lower Cretaceous Hekou Group, Gansu Province, China. Acta Palaeontologica Polonica 58 (4), 723–730.
Xing, L.D., Lockley, M.G., Marty, D., Klein, H., Buckley, L.G., McCrea, R.T., Zhang, J.P., Gierliński, G.D., Divay, J.D., Wu, Q.Z., 2013b. Diverse dinosaur ichnoassemblages from the Lower Cretaceous Dasheng Group in the Yishu fault zone, Shandong Province, China. Cretaceous Research 45, 114–134.
Xing, L.D., Lockley, M.G., McCrea, R.T., Gierlinski, G.D., Buckley, L.G., Zhang, J.P., Qi, L.Q., Jia, C.K., 2013c. First record of *Deltapodus* tracks from the Early Cretaceous of China, Cretaceous Research. Cretaceous Research 42, 55–65.
Xing, L.D., Li, D.Q., Lockley, M.G., You, H.L., Klein, H., Zhang, J.P., Marty, D., Persons, W.S.I.V., Peng, C., 2014a. Theropod and sauropod track assemblages from the Lower Cretaceous Hekou Group at Zhongpu, Gansu Province, China. Acta Palaeontologica Sinica 53 (3), 381–391.
Xing, L.D., Lockley, M.G., Zhang, J.P., Klein, H., Persons, W.S.I.V., 2014b. Diverse sauropod-, theropod-, and ornithopod-track assemblages and a new ichnotaxon Siamopodus xui ichnosp. nov. from the Feitianshan Formation, Lower Cretaceous of Sichuan Province, southwest China. Palaeogeography, Palaeoclimatology, Palaeoecology 414, 79–97.
Yang, J.T., You, H.L., Li, D.Q., Kong, D.L., 2013. First discovery of polacanthine ankylosaur dinosaur in Asia. Vertebrata PalAsiatica 51 (4), 265–277.
Zhang, H.F., Lin, Q.X., Zhang, Z.Y., Gu, Y.S., Cai, X.F., Yan, X.Q., 2003. Study on the sedimentary sequence and sedimentary facies of the Early Cretaceous Hekou Group in Lanzhou-Minhe Basin. Geological Science and Technology Information 22 (4), 21–26.
Zhang, J.P., Li, D.Q., Li, M.L., Lockley, M.G., Bai, Z., 2006. Diverse dinosaur, pterosaur and bird–track assemblages from the Hakou Formation, Lower Cretaceous of Gansu Province, northwest China. Cretaceous Research 27, 44–55.
Zhang, J.P., Xing, L.D., Gierliński, G.D., Wu, F.D., Tian, M.Z., Currie, P.J., 2012. First record of dinosaur trackways in Beijing, China. Chinese Science Bulletin (Chinese version) 57, 144–152.