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# The longest theropod trackway from East Asia, and a diverse sauropod-, theropod-, and ornithopod-track assemblage from the Lower Cretaceous Jiaguan Formation, southwest China

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ABSTRACT

Here we report a large dinosaur tracksite from an extensive fluvial sandstone surface in the Lower Cretaceous Jiaguan Formation of Sichuan Province, China. The site contains over 250 individual tracks comprising at least 18 recognizable trackways, including the longest theropod trackway (cf. *Eubrontes*) known from China. This exceptional theropod trackway consists of 81 successive footprints covering a distance of 69 m. The tracks are well-preserved and are expressed both as true tracks on the main "upper" surface and as transmitted undertracks on a locally exposed "lower" bed. Also recorded are six other theropod trackways, including small *Grallator*-like ichnites, eight sauropod trackways (cf. *Brontopodus*), and three small ornithopod (cf. *Ornithopodichnus*) trackways with a parallel orientation, which may indicate gregarious behavior. Several trackways of a larger theropod trackmaker show pes imprints with elongated traces of the metatarsals, suggesting extramorphological (substrate-controlled) variation and/or plantigrade posture, which is here interpreted as indicating a change in gait assumed in response to deep and soft sediment. The assemblage indicates a diverse dinosaur fauna in the Lower Cretaceous Sichuan Basin with variously sized theropods, sauropods, and ornithopods. The late occurrence of footprints of the *Grallator-Eubrontes* plexus in Lower Cretaceous strata is further evidence of the extended stratigraphic range of this morphotype and the distinct palaeobiogeographic distribution of these trackmakers in East Asia.



## 1. Introduction

Prior to recent investigations into Mesozoic tracks, the known non-avian dinosaur fossil record in the Sichuan Basin was largely limited to the Middle Jurassic *Shunosaurus* fauna and the Late Jurassic *Mamenchisaurus* fauna (Peng et al., 2005). Only a few fossils from Early Jurassic prosauropods were known, and no previous dinosaur fossils from either the Triassic or Cretaceous had been described.

The track record of Sichuan Province has provided evidence of a far more complete and detailed evolutionary history. From Upper Triassic deposits of Sichuan Province (including the Sichuan and Mishi-Jiangzhou basins), archosaurian tracks such as chirotheres, *Eosauropus* (Xing et al., 2014a, 2014b), and small to medium sized *Grallator* and *Eubrontes* (theropod footprints) are known (Xing et al., 2013a; Xing et al., 2014c). From the Jurassic, dinosaur footprints are common in the Sichuan Basin, and include a high abundance of sauropod and theropod tracks, while ornithopod tracks are comparatively rare. This relative scarcity of ornithopods

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is also reflected in the skeletal fossil record (Peng et al., 2005), and has been interpreted as evidence that, during the Jurassic, the Sichuan Basin was probably an inland arid or semiarid environment (cf., Lockley et al., 1994a). During the Early Cretaceous, the tetrapod track record of the Sichuan Basin is primarily represented by sites throughout the Jiaguan and Feitianshan formations, which record an abundance of ornithopod, sauropod, theropod, bird, and pterosaur footprints (Xing et al., 2007, 2013b, 2014d, 2015a).

The tracksites described in this paper are located southwest of Hanxi Village (formerly Louge Village) of Guihua Township, in Gulin County. The location area is commonly known as "Shifengwo", which means "the stone phoenix nests" (Fig. 1). Shifengwo is a 748 m long and 50–100 m wide sandstone exposure of the Jiaguan Formation, and contains at least 270 dinosaur footprints, with additional tracks discernible amongst the moss and bamboo that covers the edges of the site. Villagers who first discovered the tracks imagined them to have been left by a phoenix. It is impossible to determine when the Shifengwo traces were first discovered; however, a local poem written in the Late Qing Dynasty (~1840–1911) made reference to the "tracks of a phoenix". A conservative estimate, therefore, puts the earliest discovery and common knowledge of the site at more than a hundred years ago. This constitutes another case of dinosaur tracks influencing the formation of Chinese legends and toponyms (Xing et al., 2011a). In July 2014, Ting Xu and the Guihua Township invited the lead authors of this paper to conduct a formal scientific investigation of the Shifengwo tracks. The aim of this paper is the first comprehensive documentation of this diverse track assemblage that includes the longest theropod trackway known from East Asia. This will also contribute to our knowledge and understanding of Early Cretaceous dinosaur communities in the region.

*Institutional and location abbreviations*. **HX** = Hanxi tracksite, Sichuan Province, China.

*Ichnological abbreviations*: **LM** = left manus; **LP** = left pes; **RM** = right manus; **RP** = right pes; **ML** = Maximum length; **MW** = Maximum width; **P'ML** = Maximum length of pes; **P'MW** = Maximum width of pes; **M'ML** = Maximum length of manus; **M'MW** = Maximum width of manus; **MP'MW** = Maximum width of metatarsal pad; **AT** = Anterior triangle; **R** = Rotation of tracks relative to midline; **SL** = Stride length; **PL** = Pace length; **PA** = Pace angulation; ***h*** = height at the hip; **WAM** = width of the manus angulation pattern; **WAP** = width of the pes angulation pattern. **MPL** = distance between center of manus to center of pes.

## 2. Geological setting

The Sichuan Basin is a Cretaceous continental sedimentary basin. Within the research area, the Sichuan Cretaceous strata consist primarily of red clastic sediments, including sandstones, mudstone inter-bedded with siltstone, marls, conglomerate, and gypsum and halite deposits (Hao et al., 1986). The sedimentary geology indicates fluvial or lacustrine facies (Hao et al., 1986). Heim (1932) named the Cretaceous strata of the Sichuan Basin as the "Jiading Series", but later changed "Jiading Series" to Jiading Group, and established

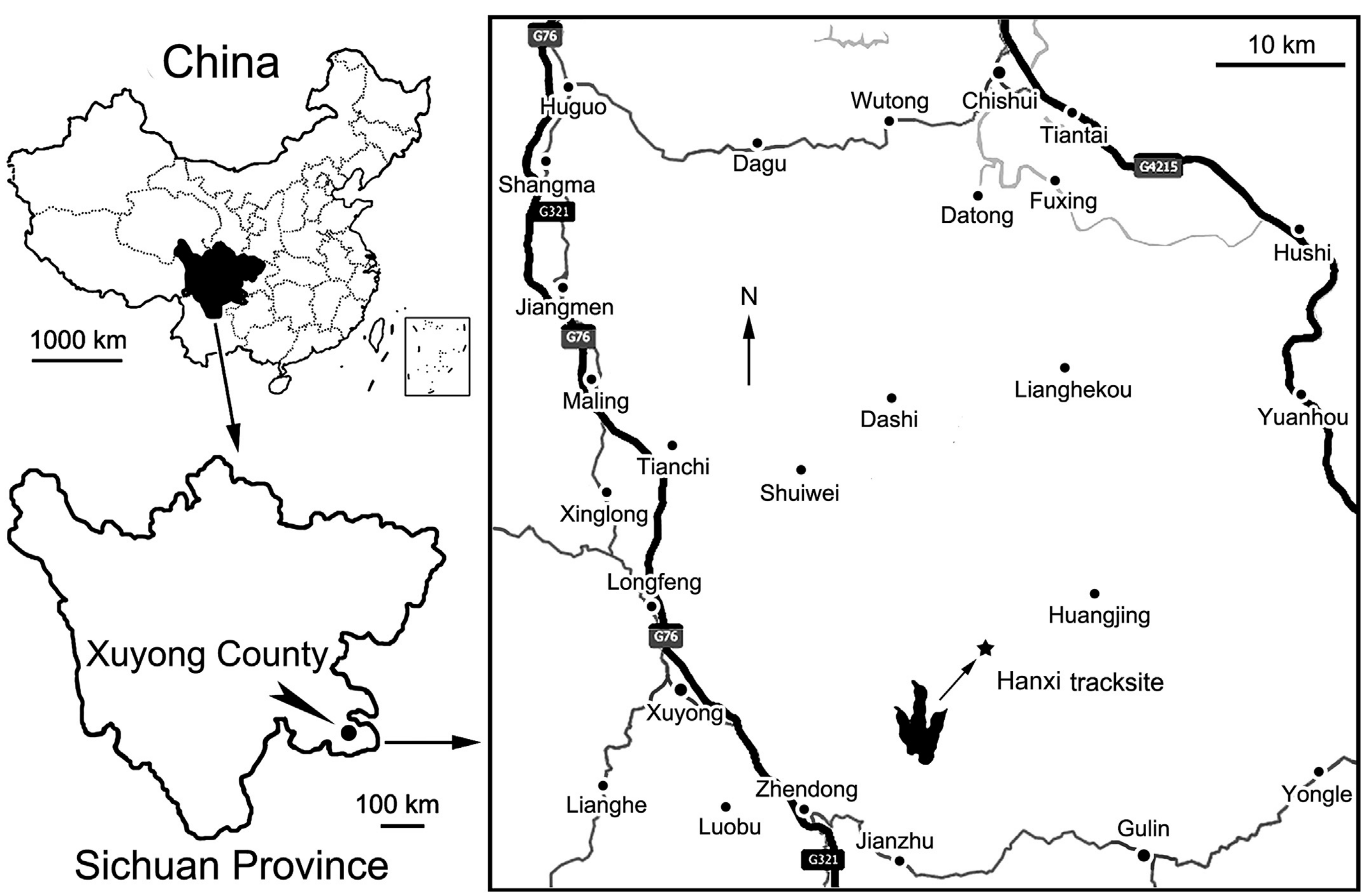


**Fig. 1.** Map showing the position of the footprint locality (footprint icon), the Hanxi tracksite, Xuyong County, Sichuan Province, China.

several stratigraphic subunits: the Lower Cretaceous Tianmashan and Jiaguan formations and the Upper Cretaceous Guankou Formation (Gu and Liu, 1997).

The Hanxi tracksite is located at the southern edge of the Sichuan Basin (GPS: 28°12′49.98″N, 105°41′3.27″E). Based on the report of a regional geological survey, Xuyong Map Sheet 1:200000 (H-48-XXXIV), the Cretaceous strata in the Hanxi area belong to the Jiaguan Formation (Fig. 2). The Jiaguan Formation is comprised of thick, brick-red, feldspathic, quartz-sandstone (Sichuan Provincial Bureau of Geology aviation regional Geological Survey team, 1976) that was deposited unconformably above the red mudstones of the Lower Cretaceous Tianmashan Formation or the Upper Jurassic Penglaizhen Formation and in conformable contact with the sandy conglomerate and mudstone of the overlying Upper Cretaceous Guankou Formation (Gu and Liu, 1997).

According to investigations by the Sichuan Provincial Bureau of Geology aviation regional Geological Survey Team (1976), the Jiaguan Formation consists of an Upper Member and a Lower Member. The Lower Member is 211–405 m thick and has a lithology of feldspathic quartz sandstone interbedded with multiple layers of mudstone, with less than 10 m thick conglomerate at the bottom and 2–10 m thick mudstone at the top. The Upper Member is 345–1000 m thick and is comprised of feldspathic quartz sandstone interbedded with thin layers of lenticular mudstone and siltstone. Cross-bedding, mud-cracks, rain-prints, and asymmetrical ripple marks are also reported. Chen (2009) argued that the bottom of the Lower Member represents alluvial fan and braided river deposits and that the Upper Member represents a meandering stream deposit interbedded with deposition from small braided rivers. The tracksite is associated with the feldspathic quartz sandstone of the Upper Member of the Jiaguan Formation. The surface of the sandstone displays current ripples, and mud cracks are common in the siltstones.

The age of the Jiaguan Formation has been variously estimated at between 117 Ma and 85 Ma (Aptian–Santonian) by Li (1995) and between 140 and 85 Ma (Berriasian–Santonian) by Gou and Zhao (2001). Recent pollen studies indicate a *Schizaeoisporites– Cicatricosisporites –Classopollis –Lygodiumsporites* assemblage suggesting a Barremian–Albian age for the Jiaguan Formation (Chen, 2009).

## 3. Tracksite description

The Hanxi tracksite is exposed on two sandstone bedding surfaces, which dip 12–15° to the north. The “upper” surface, on which the best preserved tracks are seen, is characterized by faint linguoid ripples (Fig. 3), which cover the majority of the exposure. This surface was originally covered by a mudstone unit of unknown thickness that facilitated the separation of the thick sequence of overlying sandstones from this track-bearing layer. This upper track-bearing surface lies only 2–3 cm above another “lower” surface, which is exposed in patches over about a quarter of the site (~25% of the baseline transect), where the upper surface has eroded away, and is characterized by sub-symmetric small scale ripples (wavelength ~ 3 cm) with crests consistently oriented NNW–SSE. The tracks exposed on the upper surface are sometimes represented on the lower surface as faint transmitted prints (underprints).

## 4. Methodology

After removing the withered vegetation and water from the track surface, every footprint was numbered and outlined with chalk. Then, the site was covered by a single, large, transparent plastic sheets, on which the outlines of the tracks were traced. The plastic sheets are now stored in the collections of China University of Geosciences, in Beijing. The second author (MGL) also made a field map using compass, tape, and chalk grid, and obtained representative tracings of selected trackways on clear acetate film. These tracings are catalogued as T 1654-1656 at the University of Colorado Museum (UCM).

Maximum length (ML), Maximum width (MW), divarication angle (II–IV), pace length (PL), stride length (SL), pace angulation (PA), and rotation (R) were measured according to the standard procedures of Leonardi (1987) and Lockley and Hunt (1995). Mesaxony of tridactyl tracks (the degree to which the digit III protrudes anteriorly beyond the digits II and IV) was calculated according to the methods of Olsen (1980), Weems (1992), and Lockley (2009), by measuring the ratio of the height of the anterior triangle (from base to apex at tip of digit III) over base (=width between tips of digits II and IV): i.e., height/base (L/W).

For the trackways of quadrupeds, gauge (trackway width) was quantified for pes and manus tracks using the ratios WAP/P'ML and WAM/M'ML (see Marty, 2008 and Marty et al., 2010). Gauges were calculated from pace and stride length, assuming that the width of the angulation pattern intersects the stride at a right angle and at the approximate midpoint of the stride (Marty, 2008). If the WAP/P’ML-ratio is smaller than 1.0, the tracks intersect the trackway midline, and the trackway is considered to be narrow-gauge (see Farlow, 1992). Accordingly, a value of 1.0 separates narrow-gauge from medium-gauge trackways, whereas the value 1.2 is arbitrarily fixed between medium-gauge and wide-gauge trackways, and trackways with a value higher than 2.0 are considered to be very wide-gauge (Marty, 2008).

For calculation of hip heights and speed estimates, the methods of Alexander (1976), Thulborn (1990), and González Riga (2011) were adopted. The different values estimated from these different methods were juxtaposed but are left undiscussed.

Photogrammetric images were produced from multiple digital photographs (Canon EOS 5D Mark III), which were converted into scaled 3D textured mesh models using Agisoft Photoscan. The mesh models were then imported into Cloud Compare, where the models were rendered with accurately scaled colour topographic profiles.

## 5. Tracks and trackways

### 5.1. Theropod tracks

The Hanxi tracksite consists of seven theropod trackways: HX-T1–T7 (Figs. 4–7; Supplementary Materials), which consist of 8, 11, 81, 8, 8, 4 and 4 individual tracks, respectively.

#### 5.1.1. The longest dinosaur trackway in East Asia

*5.1.1.1. Description.* The exposed portion of the HX-T3 trackway is 69 m long and made up of 81 footprints, among which, only 57 are well-preserved on the upper surface, while others are basically undertracks being on the lower surface. The mean PA is 163°. The mean length/width ratio of the footprints is 1.4. HX-T3-L39 and R39 (Fig. 5) are the best-preserved, and 30 cm and 29.5 cm in total length, respectively. Digit III projects the farthest anteriorly, followed by digits IV and II. The average anterior triangle L/W ratio of the HX-T3 tracks is 0.37. Two distinct metatarsophalangeal pad traces can be seen: a smaller one posterior to digit II and a larger one posterior to digit IV. The former is adjacent to the trace of the first proximal pad of digit II but separated from this pad by a distinct crease. The latter is round and blunt and positioned near the axis of digit III, but closer to digit IV. The digit formula (including metatarsophalangeal pads II and IV) is x-3-3-?4-x. Each digit has a sharp claw mark, which is longest and most distinct in digit II. The interdigital divarication of II–IV is relatively wide (53° and 59°). The divarication angle between digits II and III is slightly larger than the one between digits III and IV.

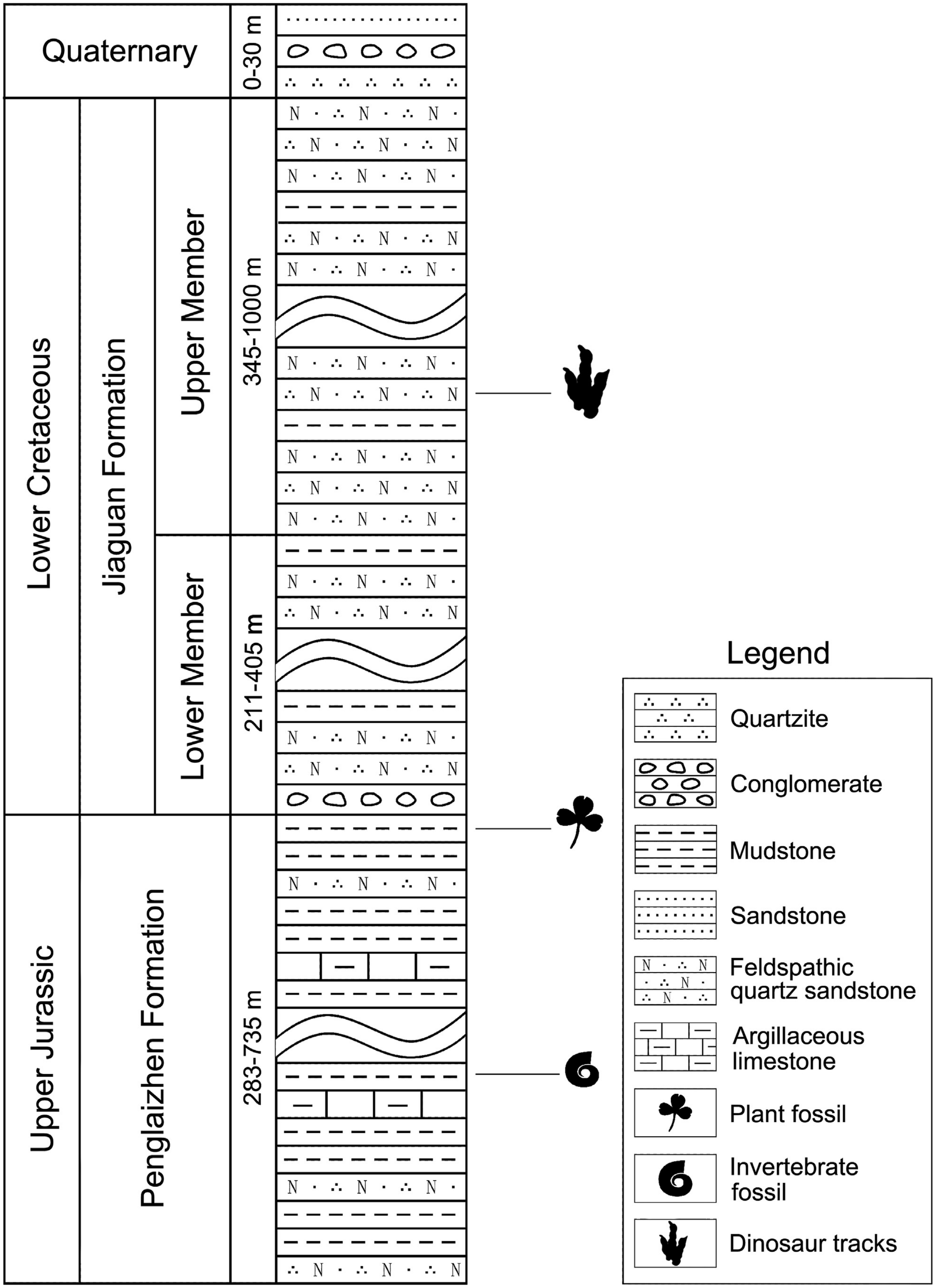


**Fig. 2.** Stratigraphic section of the Jurassic–Cretaceous in the study area with the position of footprints and plant and invertebrate body fossil remains.

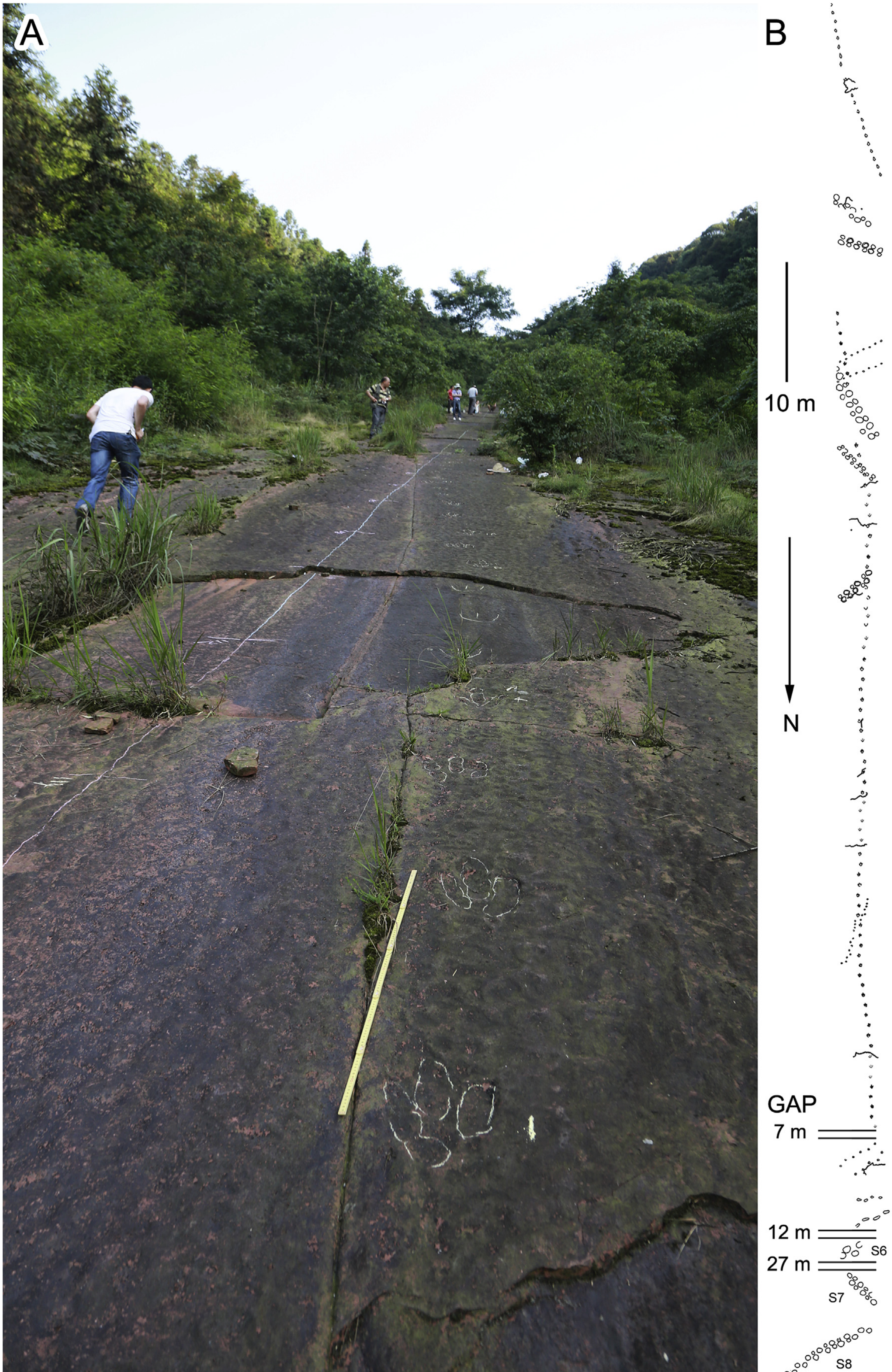


**Fig. 3.** Photograph (A) and map of track-bearing level (B) at Hanxi tracksite with trackways and isolated tracks of ornithopods and theropods.

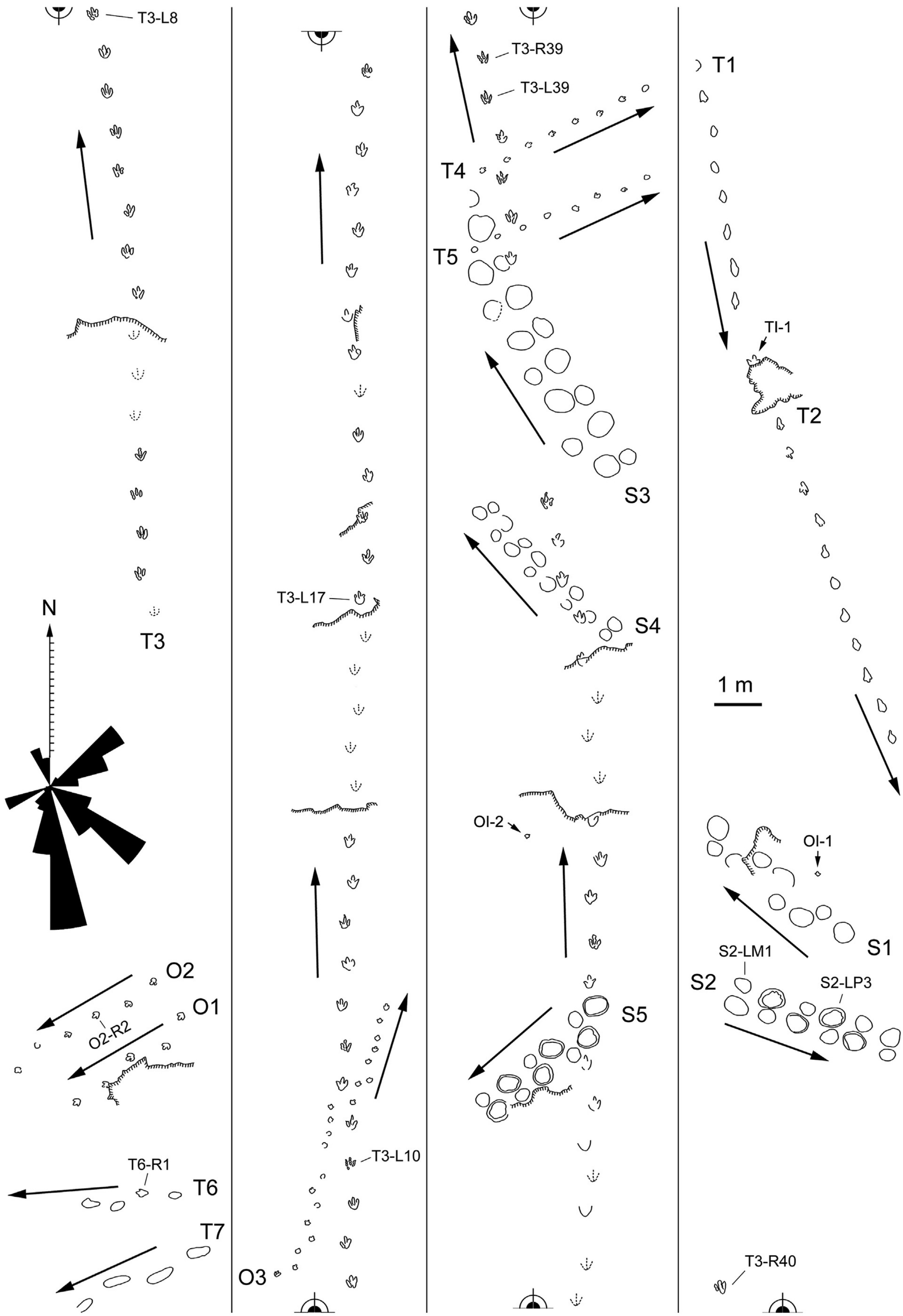


**Fig. 4.** Distribution pattern and rose diagram of the upper area of the Hanxi tracksite.

*5.1.1.2. Comparisons and discussion.* The average anterior triangle L/W ratio of 0.37 is typical of the values reported for the morphofamily Eubrontidae (Lull, 1953; Lockley, 2009). HX-T3 tracks have a distinct small metatarsophalangeal pad trace posterior to digit II. This character is common in *Eubrontes* tracks, such as the type specimen of *Eubrontes* (AC 151; Olsen et al., 1998). It appears also in the Late Jurassic non-avian theropod track *Jialingpus*; however, the type material of *Jialingpus* has a mean ML/MW ratio of 1.7 (N = 9), and a mean anterior triangle L/W ratio of 0.78 (N = 7). Values of Early Cretaceous *Jialingpus* specimens are slightly lower (1.3 and 0.61) (Xing et al., 2014e). Clearly, the ML/MW ratio and the anterior triangle L/W ratio of *Jialingpus* are much larger than in HX-T3. Therefore, the HX-T3 tracks are provisionally referred to *Eubrontes*. This suggests that, while *Eubrontes*, together with *Grallator*, *Kayentapus* and *Anomoepus,* are typical components of the Lower Jurassic ichno-associations from North America (Lockley and Hunt, 1995; Olsen et al., 1998), in China, they also occur in Middle–Upper Jurassic and even Lower Cretaceous strata (Matsukawa et al., 2006; Lockley et al., 2013; Xing et al., 2014e).

According to the formula of Alexander (1976), the HX-T3 trackmaker was walking at a speed of 4.25 km/h. It is worth noting that HX-T3 shows consistent step lengths without any significant changes. This implies that the trackmaker was travelling at constant speed.

Dinosaur trackways with a length greater than 50 m can be considered very long by global standards and are extremely rare. At present only a handful of other such trackways are known:

1) The longest dinosaur trackway known is that of a small theropod from the Upper Cretaceous Cal Orcko tracksite near Sucre in Bolivia. It has a length of 581 m (Lockley et al., 2002a; Meyer and Thüring, 2006). Due to collapse of a part of the Cal Orcko quarry wall, the complete extent of this trackway can no longer be seen.
2) Lockley et al. (1996), Meyer and Lockley (1997), and Meyer (1998) described a 311 m long trackway of a large theropod (*Megalosauripus*) from the Upper Jurassic of Turkmenistan. This is considered the world's second longest dinosaur trackway, and the longest known from Asia. Also, this is the longest trackway of a large theropod dinosaur. From the same site Fanti et al. (2011) report two trackways that are about 220 m long and four trackways more than 95 m long.
3) Two giant theropod trackways (T13 and T80), provisionally attributed to *Megalosaurus*, from the Ardley Quarry of Oxfordshire in central England, both in excess of 180 m and comprising approximately 100 prints each (Mossman et al., 2003; Day et al., 2004). Unfortunately, due to a landfill, parts of this quarry have been covered, and the trackways are no longer accessible.
4) The longest sauropod trackway measures 155 m and comes from the Upper Jurassic Plagne tracksite (Département de l'Ain) of the Jura Mountains in France. It was excavated during several years by the University of Lyon but it is currently covered up in order to protect it. The pes tracks have a diameter of over 1 m and are surrounded by huge displacement rims, making these tracks very impressive (Mazin and Hantzpergue, 2010, pers. comm. 2012).
5) The Galinha (Fatima) tracksite in Portugal is considered to exhibit the second longest sauropod trackway (ichnogenus *Polyonyx*), with a length of 142 m (Santos et al., 1994, 2009).
6) A bipedal dinosaur trackway from Carenque (Portugal, middle Cenomanian) spans 127 m, but the footprints are poorly preserved and probably undertracks. (Santos et al., 1992).
7) During excavations that were part of the "Palaeontology A16" project, two very long and parallel sauropod trackways (105 m and 115 m) of medium-sized individuals were discovered in the Jura Mountains of Canton Jura, in northwestern Switzerland along Highway A 16. They occur in the Upper Jurassic (Kimmeridgian) on track level 515 of the Courtedoux–Béchat Bovais tracksite (Marty et al., 2010).
8) A 90 m long sauropod (*Brontopodus*) trackway from the Lommiswil tracksite (NW Switzerland, Upper Jurassic) (Meyer, 1990), and also a 90 m long sauropod trackway from the Münchehagen site in northern Germany (Lower Cretaceous) (Fischer, 1998).
9) A Cretaceous ornithopod trackway from Chudo Island Korea, measured at 84 m in length (Lockley et al., 2012c).
10) The Upper Cretaceous Fumanya tracksite exhibits several wide-gauge (*Brontopodus*, titanosaur) trackways longer than 50 m, with the longest being about 80 m in length (Schulp and Brokx, 1999). Early pictures taken by Viladrich indicate that the latter was even longer originally (~100 m). Afterwards, part of the early exposures of that trackway were covered by mining debris rubble. This is discussed in a review paper by Vila et al. (2008).
11) The Upper Jurassic Purgatoire River site (Colorado, USA) exhibits sauropod (*Brontopodus*) trackways with lengths of about 50–60 m (Lockley, 1986; Lockley et al., 1997).

In China, trackway lengths are often not reported. The longest theropod trackway so far known was the No. TT trackway from the Chabu No.7 tracksite (Lower Cretaceous) in Inner Mongolia, which is about 65 m long (based on Azuma et al., 2006: Fig. 3). The No. TT theropod footprints are about 35 cm in length. The longest Chinese sauropod trackway is probably the No. SA trackway, from Yanguoxia tracksite (Lower Cretaceous) in Gansu Province, which stretches 44 m in length (Li et al., 2006). Therefore, the 69 m-long HX-T3 theropod trackway is the longest dinosaur trackway in China, and the longest theropod trackway reported from East Asia.

### 5.1.2. Other theropod tracks

*5.1.2.1. Description.* HX-T1–T2 likely belong to the same trackway, but three tracks are not preserved from the middle of the sequence. All tracks remain *in situ*. These trackways can be divided into three types: HX-T1, T2, T6, and T7 (Fig. 6) have poorly-preserved medium–large-sized tridactyl pes imprints that show a trace of the metatarsal pad; HX-T3 (Fig. 5) has medium-sized tridactyl imprints; and HX-T4–T5 (Fig. 7) have small-sized tridactyl pes imprints.

The tracks and trackways of HX-T1, T2, T6, and T7 share the typical theropod features, such as a strongly forward projecting digit III, high pace angulation (162°–175°), and a relatively high length/width ratio (1.8–2.1 on average). Among all these tracks, digit III is more distinct and more deeply impressed than digits II and IV, which are often poorly preserved by shallow impressions that show large extramorphological variation. The well-preserved tracks, such as T2-R1, L2, R5, show an elongated, club-shaped "heel" or trace of the metatarsal. The MP'MW/P'MW ratio is 0.3–0.4. Poorly preserved tracks, such as T7-R2, have a trace of the metatarsal that is heavily weathered and broader, with an MP'MW/P'MW ratio of 0.6. Generally, the metatarsal pad region of all these tracks show relatively indistinct borders, evidently due to an originally soft and wet substrate.

#### 5.1.2.2. Comparisons and discussion

*5.1.2.2.1. Tracks with metatarsal pads.* Well-developed metatarsal pad traces usually appear in resting or crouching theropod and basal ornithischian dinosaurs tracks (e.g. Milner et al., 2009; Lockley et al., 2003), when the metatarsals contacted the ground. Deep and soft sediments can cause extramorphological variation in

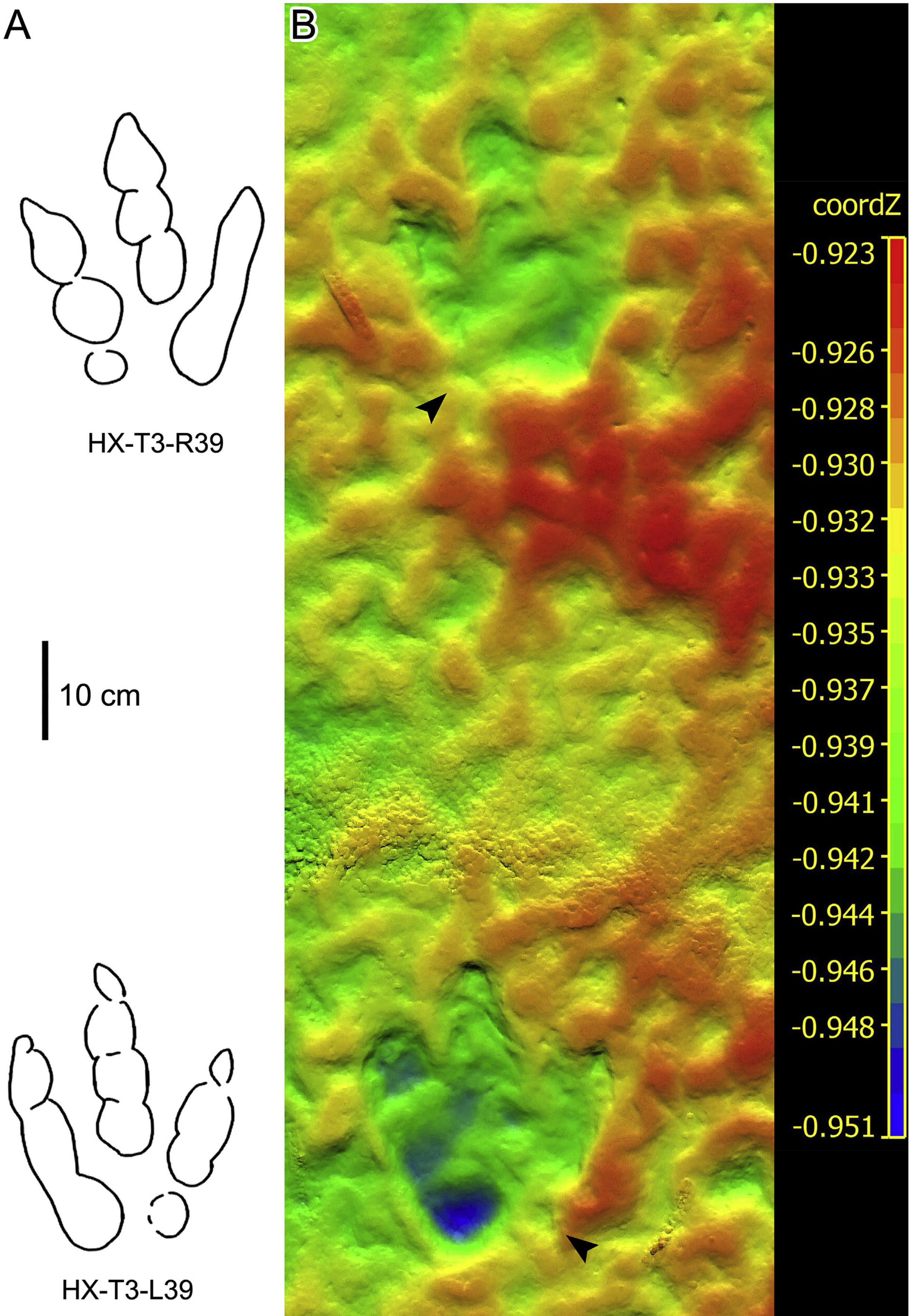


**Fig. 5.** Interpretative outline drawing (A) and 3D model (B) of HX-T3-L39 and R39 from Hanxi tracksite.

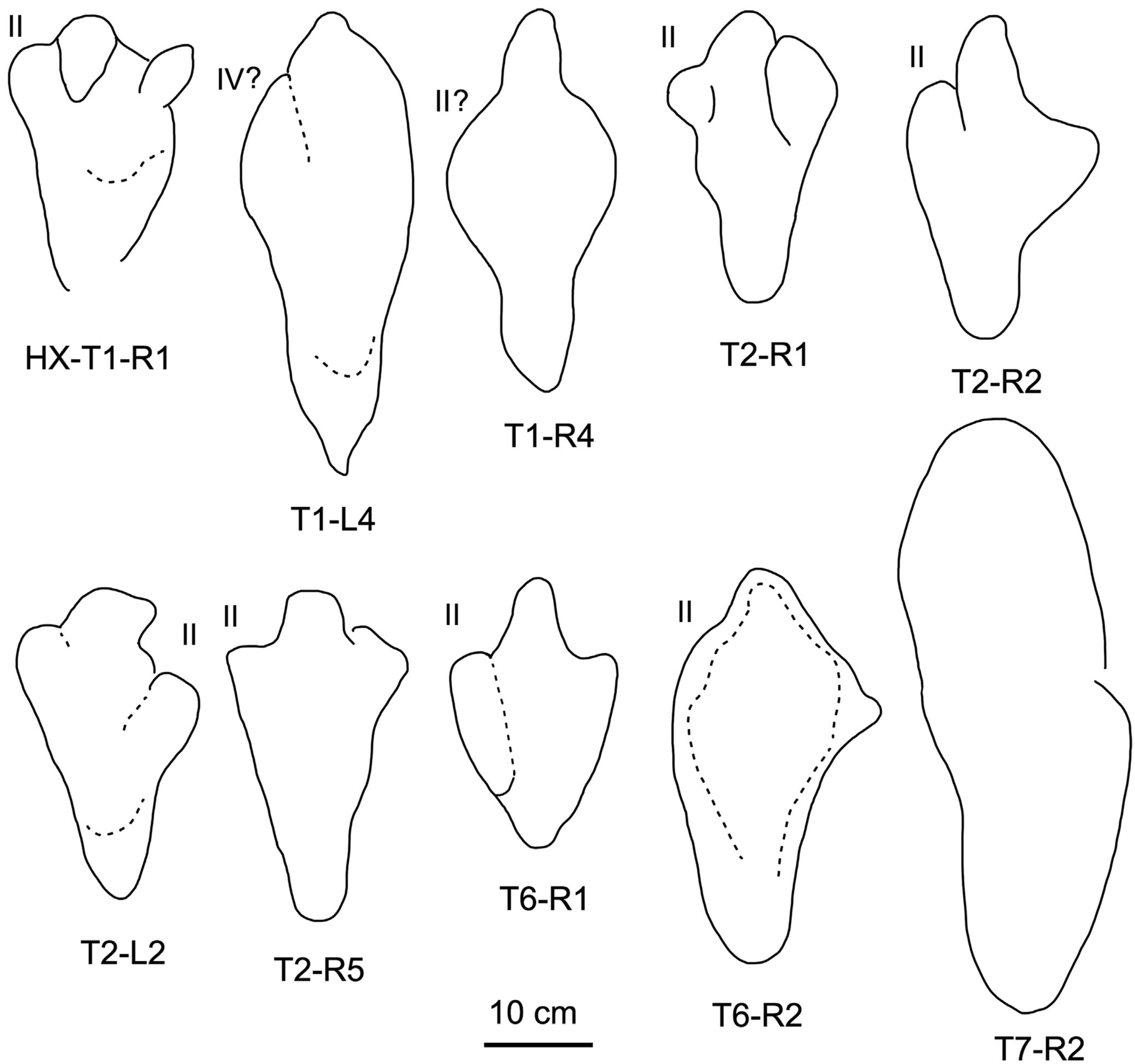


**Fig. 6.** Interpretative outline drawings of theropod tracks with metatarsal pad from Hanxi tracksite.

footprints, including the presence/absence of metatarsophalangeal pad traces (Gatesy et al., 1999; Xing et al., 2014f). However, trackways such as HX-T1, T2, T6, and T7 (Fig. 6), which are composed largely or entirely of footprints with accompanying metatarsal prints, suggest that some bipedal dinosaurs, at least at times, walked in a plantigrade or quasi-plantigrade manner (Kuban, 1989). Other trackways include consistent metatarsal pad impressions, such as those of *Moraesichnium barberenae* from the Lower Cretaceous Sousa Formation of Paraíba, Brazil (Leonardi, 1979), theropod trackways from the Lower Cretaceous Glen Rose Formation of Glen Rose, Texas (Kuban, 1989), and cf. *Irenesauripus* isp. trackways from the Lower Cretaceous Jiaguan Formation of Baoyuan, China (Xing et al., 2011b). The PA values of these trackways are similar: 162°–175° in HX specimens, ~154° in *Moraesichnium barberenae* (Leonardi, 1979), 140° (average, n = 13, range 119°–167° based on Kuban, 1989: Fig. 2 IIW1–15) in Glen Rose specimens, and 165° in Baoyuan specimens (Xing et al., 2011b).

Like cf. *Irenesauripus* isp. (Xing et al., 2011b), which is also from the Jiaguan Formation, HX-T1, T2, T6, and T7 have well-developed metatarsal pad traces, except that cf. *Irenesauripus* isp. shows more details, such as digit pads and occasionally preserved traces of digit I. Compared with the well-preserved HX-T6-R1, the size of cf. *Irenesauripus* isp. from the Baoyuan tracksite is smaller (average 17 cm, range 13.8–19.5 cm [excluding the metatarsal pad], vs. 26 cm in T6-R1), and the length/width ratio (average 1.1, range 1.0–1.5, vs. 1.8 from T6-R1) is rather low, while the interdigital divarication II–IV (average 55°, range 45°–78°, vs. 48° from T6-R1) is similar.

Kuban (1989) observed that, when moist mud slumps back into a depression, it generally does so about equally from all sides (including the three digits and the heel). Digit III of most HX specimens is better preserved than the outer digits, which is probably due to its greater length and deepness.

Some large living birds still contact the ground when they are resting, for example, the marabou stork (*Leptoptilos crumeniferus*)

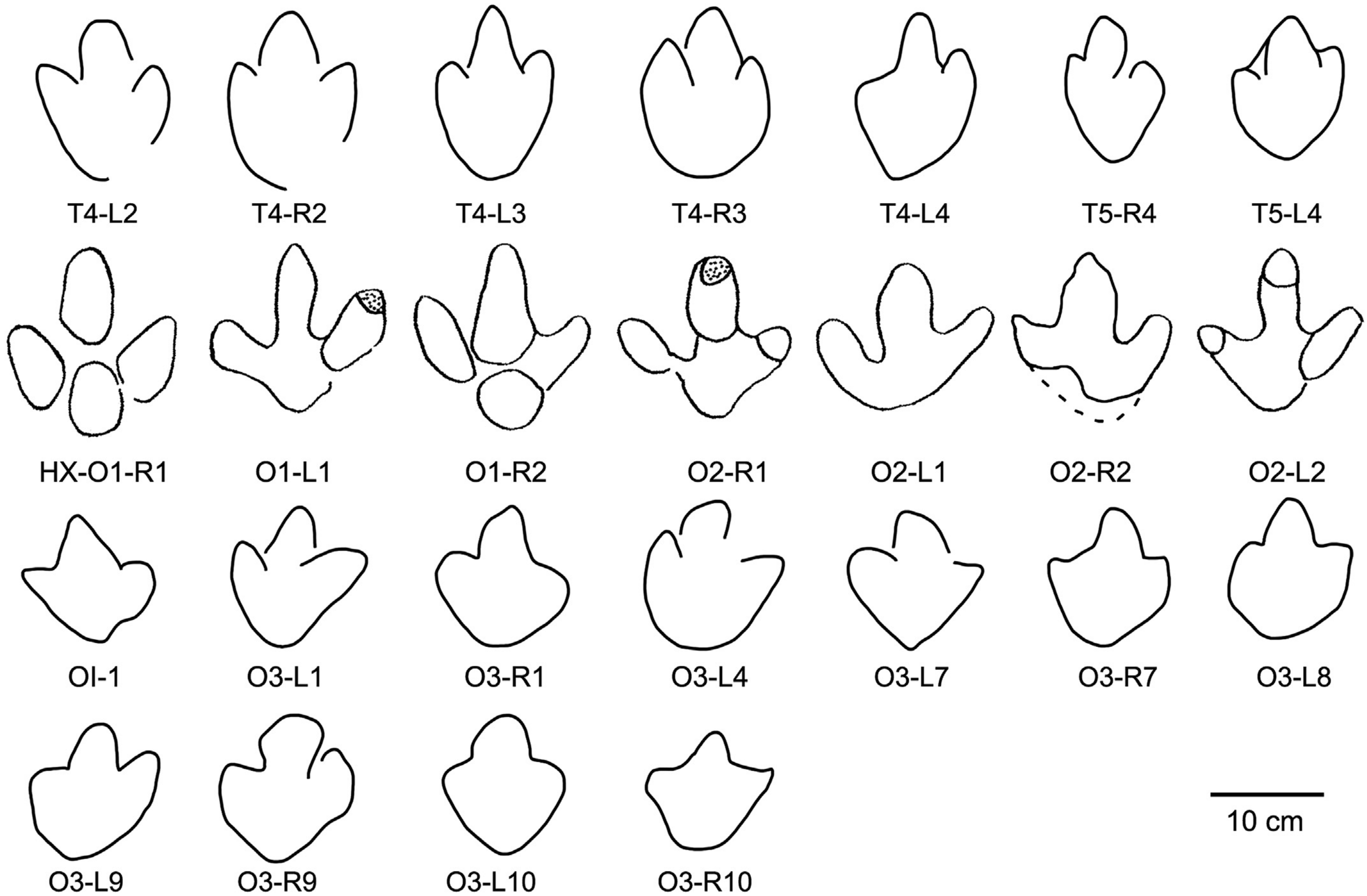


**Fig. 7.** Interpretative outline drawings of ornithopod and theropod tracks from Hanxi tracksite.

often poses in this way (Liebenberg, 1990; personal observation from Shanghai Zoo). There is hardly any bird, however, that walks in this way under normal healthy conditions. Like birds, bipedal dinosaurs have been viewed as strict digitigrade walkers. Explanations for the metatarsal impressions of these and other theropod tracks include the possibility that the trackmaker foot sank deeply into extremely soft sediment. Kuban (1989) considered two hypotheses: 1) soft and slippery sediment may have forced the trackmaker to lower its metatarsals in order to gain firmer footing and balance during walking; 2) some trackmakers may at times have walked with a special gait, holding their metatarsals in a more horizontal position, thereby contacting the ground.

Based on the Baoyuan specimens (Xing et al., 2011b), these HX footprints with metatarsal traces were probably preserved in soft sediment with high water content. The trackmakers were nevertheless plantigrade or quasi-plantigrade, moving at normal speeds between walking and trotting. For example, in the "normally" preserved HX-T6-R1, (differentiated into typical footprint and short metatarsal pad portions), the hip height $h = 4 \times$ foot length (Henderson, 2003), and the relative stride length (SL/h) of T6 is 1.44, suggesting that the trackmaker was actually walking. However, if this theropod trackmaker was walking with a plantigrade gait, then its leg length would have been functionally reduced. The formula of Henderson may not be entirely appropriate, as the hip height was probably less than $4 \times$ foot length. Based on Henderson (2003: Fig. 1) the hip height of the plantigrade trackmaker = ~$3 \times$ foot length (excluding the metatarsal pad), and the relative stride length (SL/h) of T6 is ~1.91, suggesting that the trackmaker was still walking, but close to trotting. Therefore, the trackmaker of HX-T6 appears to have been walking with a distinctive gait on the extra-soft sediment, and it seems that this gait did not significantly limit its speed.

*5.1.2.2.2. Trackways of small-sized tridactyl trackmakers.* Early Cretaceous small theropod tracks from China are dominated by the *Grallator* morphotype, which includes *Jialingpus* (Xing et al., 2014e). Among the HX theropod tracks, the ML/MW ratio of T4 and T5 (1.6 and 1.5) are close to the widely-discovered Early Cretaceous *Grallator* morphotype (1.1–1.5, Xing et al., 2014e). However, the weak mesaxony of T4 and T5 (0.46) is slightly lower than that of the *Grallator* morphotype from China (0.54–0.68, Xing et al., 2014e).

HX-T4 and T5 tracks are similar to MGCM H5 from the Lower Cretaceous Tugulu Group of Xinjiang, China (ML/MW ratio and anterior triangle L/W ratio are1.3 and 0.49, respectively) (Xing et al., 2011c), and Morphotype A theropod tracks from the Upper Cretaceous Xiaodong Formation of Anhui Province, eastern China (ML/MW ratio and anterior triangle L/W ratio are 1.3 and 0.49, respectively) (Xing et al., 2014g). Anhui Morphotype A specimens belong to coelurosaurs (Xing et al., 2014g). Skeletal fossils of coelurosaurs indicate that they were the prominent theropods throughout China, during the Late Jurassic and Cretaceous (Huh et al., 2006), and they have proportionately wider feet than less derived theropods (Lockley, 1999; Snively et al., 2004). Therefore, we tentatively attribute HX-T4 and T5 to coelursosaurs.

Compared to ornithopod and sauropod dinosaurs, records of theropod trackmakers walking in parallel (which can provide ichnologic support for gregariousness) are rather rare. These include two parallel theropod trackways from the Lower Cretaceous of Chile (Rubilar-Rogers et al., 2008) and parallel tyrannosaurid trackways (*Bellatoripes fredlundi*) from the Upper Cretaceous of British Columbia, Canada (McCrea et al., 2014). Li et al. (2007) also reported six parallel trackways of dromaeosaurids (ichnogenus *Dromaeopodus*) from the Lower Cretaceous of Shandong.

### 5.2. Ornithopod tracks

#### 5.2.1. Description

The Hanxi tracksite includes three ornithopod trackways, catalogued as HX-O1–O3. These trackways consist of 5, 6, and 20 tracks respectively, and two isolated ornithopod tracks are also preserved, catalogued as HX-OI-1–2 (Figs. 7–9, Supplementary Materials). All tracks remain *in situ*.

HX-O1–O3 pes traces are mesaxonic, functionally tridactyl and plantigrade with a length estimated at 13–15 cm and average and median ML/MW ratios of 0.9–1.0. The pes HX-O2-R2 (Fig. 9) is one of the best-preserved tracks. Based on the 3D photo, the ML/MW ratio is 0.9, while the anterior triangle L/W ratio is 0.39. Digit III is the longest. The trace of digit II is slightly shorter than that of digit IV. Digital pads are absent. All the distal part of the digit impressions are deep, the claw marks are round and blunt. The heel is sub-triangular. The interdigital divarication of II–IV is 85°. The pes traces HX-O1-R2 and R3 show quadripartite morphology, consisting of impressions of three digits and a heel pad separated by pronounced ridges. Based on trackways O1and O2, there is consistent inward rotation ranging from 15 to 20° (mean ~17°). Step length averages 74.8 cm in HX-O1 (or 4.8 × footprint length), 69.9 cm in HX-O2 (or 5.1 × footprint length), and 36.2 cm in HX-O3 (or 2.7 × footprint length). The average PA of these well-preserved trackways is 153° (range between 138° and 167°) for HX-O1 and 163° (range between 150° and 170°) for HX-O2.

In contrast to HX-O1–O2, trackway HX-O3 is poorly preserved, but the tracks are similar in size to those of HX-O1 and HX-O2 and are also roughly as wide as long (ML/MW 1.1). Well-preserved tracks, such as HX-O3-L1 and HX-O3-R9 are similar to HX-O1 and HX-O2 in most respects. Tracks from HX-O3 show considerable morphological variation, which is probably due to the original substrate having been wet and slippery. The average PA of HX-O3 is 133° (range between 101° and 171°). In the middle of the O3 trackway, the PA of R5–L8 changes conspicuously. It first increases (115°–171°) and then decreases (165°–104°), which may be due to a confrontation with the T3 theropod trackmaker.

#### 5.2.2. Comparisons and discussion

Small-sized ornithopod and theropod trackways are sometimes difficult to tell apart since they are both comprised of tridactyl footprints. Generally speaking, one of the criteria for distinguishing theropod and ornithopod trackmakers has been the presence/absence of manus traces, which suggests a quadrupedal or bipedal trackmaker (Castanera et al., 2013). However, the manus traces of ornithopods are often shallow and may not be recorded at all, depending on the firmness of the sediments. When manus traces are absent, other telling characters that suggest an ornithopod origin are a low ML/MW ratio, low anterior triangle L/W ratio, short steps, and the inward rotation of the pes prints (such as Lockley, 2009; Lockley et al., 2009; Lockley and Wright, 2001; Castanera et al., 2013; Lockley et al., 2014). The ornithopod tracks from Hanxi have low ML/MW ratios (0.9–1.1), moderately low AT (mesaxony) values (0.39), and a wide interdigital divarication II–IV (85°). All of these characteristics are within the range of values for ornithopod tracks (0.28–0.47, Lockley, 2009) and are similar to those of typical ornithopod trackways, such as *Ornithopodichnus* (Lockley et al., 2012a; Xing and Lockley, 2014) or *Iguanodontipus*? *oncalensis* (Castanera et al., 2013). The Hanxi

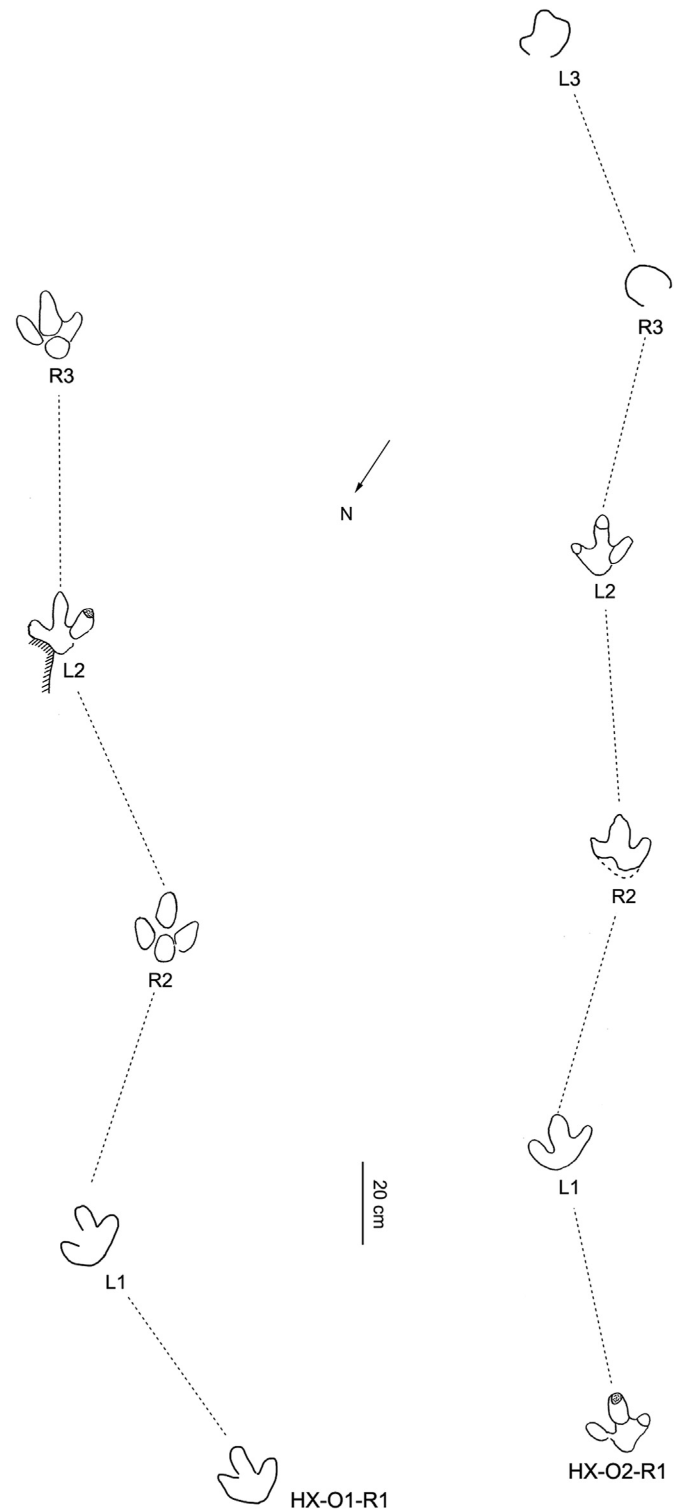


**Fig. 8.** Interpretative outline drawings of ornithopod trackways HX-O1 and O2 from Hanxi tracksite.

tracks also exhibit a transverse shape and consistent tendency towards inward rotation as is typical for ornithopod tracks and trackways.

The only Early Cretaceous small-sized ornithopod tracks previously discovered in China are *Ornithopodichnus* (~15 cm) from Zhaojue, Sichuan Province (Xing and Lockley, 2014) and small-sized

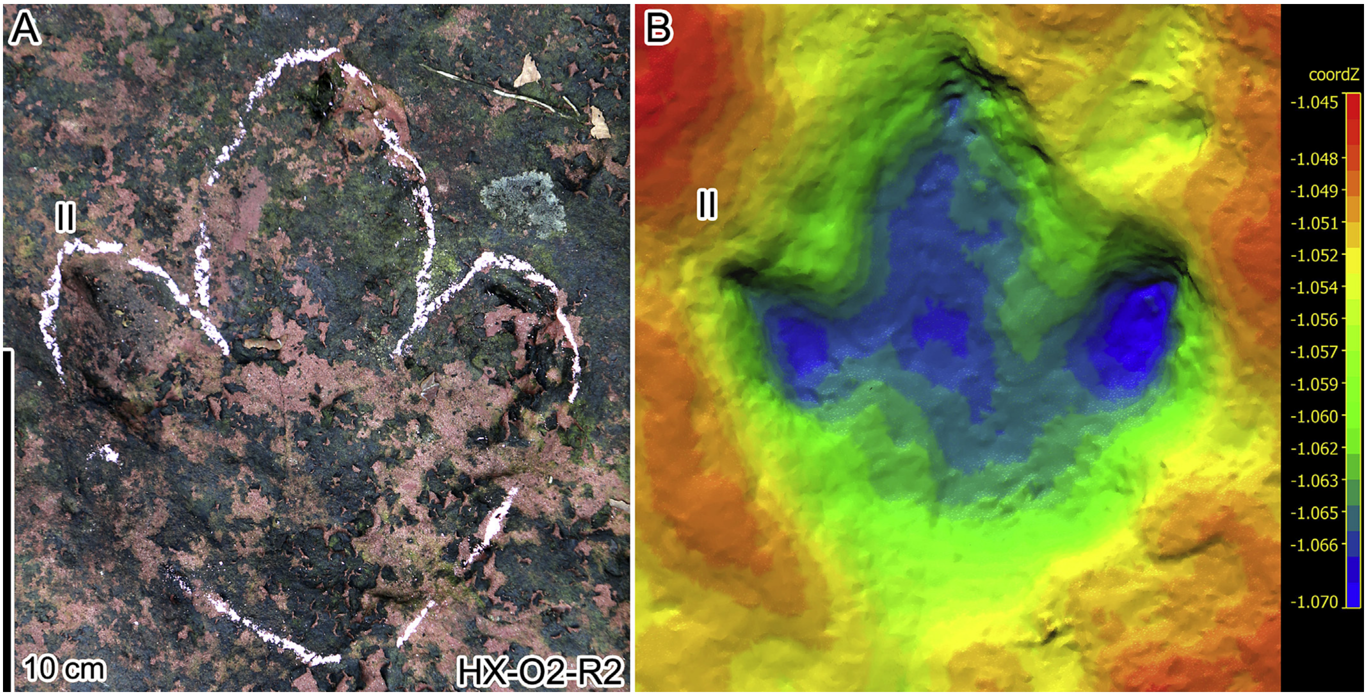


**Fig. 9.** Photograph (A) and 3D model (B) of ornithopod track HX-O2-R2.

*Caririchnium lotus* (19–23 cm) from Qijiang, Chongqing City (Xing et al., 2007). Among these tracks, the Hanxi ornithopod trackways HX-O1–O2 have a similar AT value (0.38) to the small-sized *Caririchnium lotus*, but the latter has a higher ML/MW ratio (~1.2), a quadripartite morphology consisting of impressions of three digits, a heel pad separated from the digit traces (II–IV) by pronounced ridges, and thicker, broader U-shaped toe impressions in distal portions of digits II and IV. HX-O1–O2 tracks are similar in size and shape to *Ornithopodichnus* tracks (mean ML/MW ratio = 0.90, Xing and Lockley, 2014), especially to those of the *Ornithopodichnus* trackways from South Korea (Kim et al., 2009; Lockley et al., 2012a) and Zhaojue, China (Xing and Lockley, 2014). However, typical *Ornithopodichnus* has weak mesaxony (0.21) in comparison with other ornithopod ichnotaxa (~0.40) (Lockley, 2009), whereas the mesaxony values of the Hanxi tracks fall in between (0.39). Therefore, we tentatively assign the Hanxi ornithopod tracks to cf. *Ornithopodichnus*.

Lower Cretaceous ornithopod trackways are well-known from Europe, North America, and East Asia. Other than *Caririchnium lotus* and *Ornithopodichnus*, there are typical small-to medium-sized ornithopod ichnotaxa such as *Dinehichnus* (Lockley et al., 1998), *Neoanomoepus* (Lockley et al., 2009), and *Iguanodontipus? oncalensis* (Castanera et al., 2013). *Neoanomoepus* represents a quadruped, with tetradactyl pes (Lockley et al., 2009), which is conspicuously different from the HX-O1–O2 tracks. Though the ML/MW ratio of the Late Jurassic *Dinehichnus* (1.0) and Early Cretaceous *Iguanodontipus? oncalensis* (1.01) are similar to that of the HX-O1–O2 tracks, their AT (0.45–0.51 and 0.44) is relatively higher than that of the HX-O1–O2 tracks. *Dinehichnus* typicaly has much sharper ungual traces than *I? oncalensis*, and *Dinehichnus* PA (155°) and inward rotation values (10–15°) are similar to those measured in the HX-O1–O2 tracks. The current status of tracks assigned to medium-sized ornithopods from the Late Jurassic–Early Cretaceous interval is not well understood (Castanera et al., 2013). Thus, we cannot rule out the possibility that HX-O1–O2 tracks could be assigned to cf. *Dinehichnus*, or even juvenile *Iguanodontipus*.

It is evident that small ornithopod trackmakers often travelled in groups, as recorded by parallel trackways. For example, small *Ornithopodichnus* trackways from South Korea record a small group of six individuals (Lockley et al., 2012a); at least four individuals are represented at the Zhaojue tracksite (Xing and Lockley, 2014), six individuals at the type locality of *Dinehichnus* in North America (Lockley et al., 1998), and two or three individuals represented by small-sized *Caririchnium lotus* at the type locality (Xing et al., 2007). The Hanxi ornithopod trackways HX-O1 and HX-O2 also exhibit parallel orientations.

Because of the natural weathering and substrate condition, HX-O3 shows strong extramorphological characteristics. Therefore, HX-O3 cannot be assigned to a particular ichnogenus. The record of small ornithopod trackways in China may support the inference that Lower Cretaceous ichnofaunas from Asia are regionally distinctive (Lockley et al., 2012b).

#### 5.2.3. *Speed estimates*

For small ornithopods (P'ML < 25 cm), Thulborn (1990) suggests that h = 4.6 P'ML. The relative stride length (SL/h) may be used to determine whether the animal is walking ($SL/h \leq 2.0$), trotting ($2 < SL/h < 2.9$), or running ($SL/h \geq 2.9$) (Alexander, 1976; Thulborn, 1990). The SL/h ratios of the Hanxi ornithopod trackways HX-O1–O2 range from 2.06 to 2.20 (Table 1) and accordingly suggest a trotting gait. In HX-O3 this value is 1.06 (Table 1) suggesting a walking gait. Using the formula of Alexander (1976), the speed of HX-O1–O2 ranges from 7.96 to 8.35 km/h and the speed of HX-O3 is 2.41 km/h (Table 1). By contrast, the small ornithopod trackways

**Table 1**
Estimated data of the speed of Hanxi ornithopod trackmakers.

| No. | SL/h | S (km/h) |
|---|---|---|
| HX-O1 | 2.06 | 7.96 |
| HX-O2 | 2.20 | 8.35 |
| HX-O3 | 1.06 | 2.41 |

Abbreviations: SL/h, relative stride length; S = absolute speed.

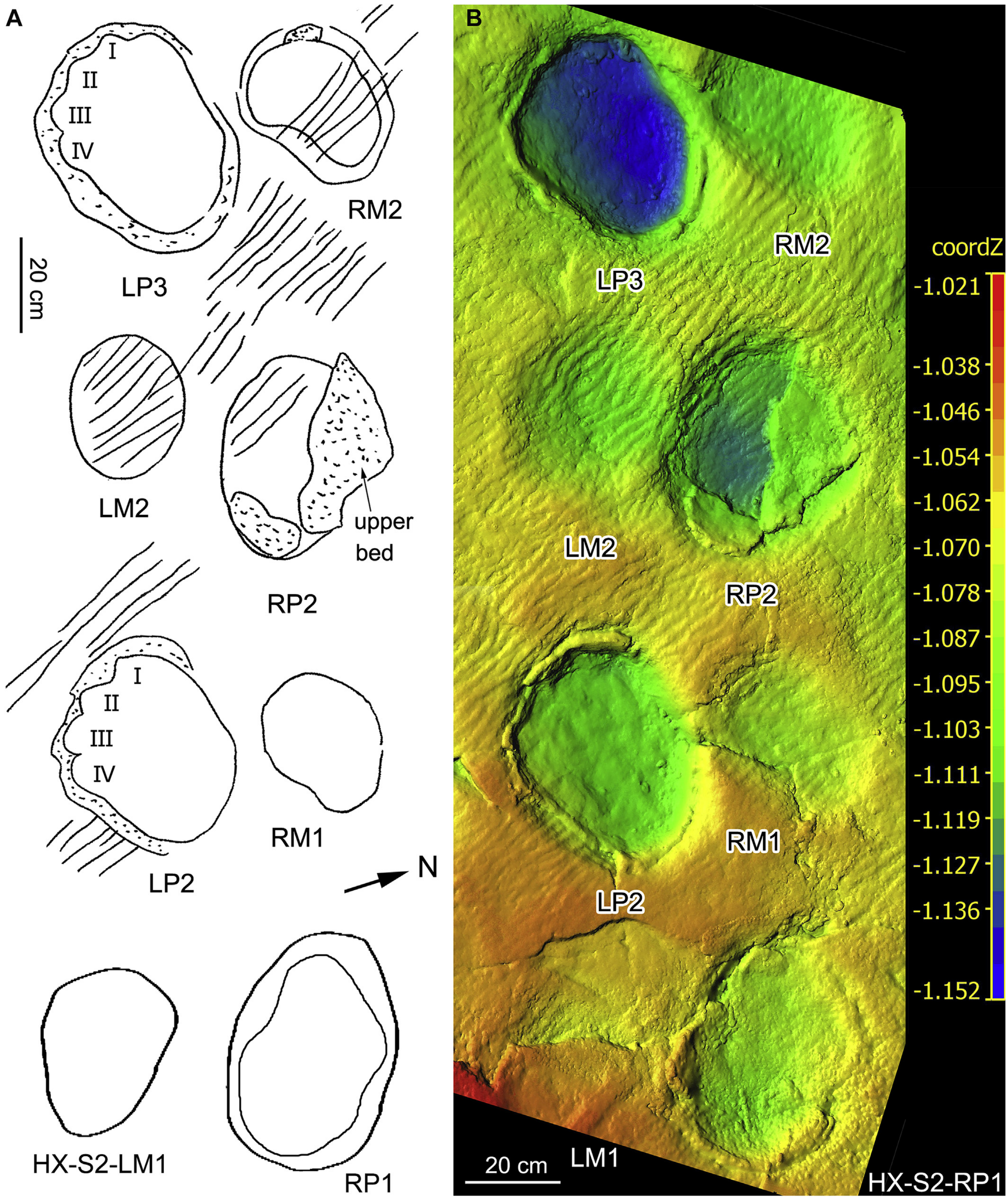


**Fig. 10.** Interpretative outline drawing (A) and 3D model (B) of HX-S2 from Hanxi tracksite. Note that ripple marks occur on lower surface. Upper surface remnants adhere to the track floor and walls in a few places.

ZJIIN-O1 and ZJIIN-O2, from Zhaojue, indicate a walking speed of 3.31 and 3.56 km/s, respectively (Xing and Lockley, 2014).

### 5.3. Sauropod tracks

#### 5.3.1. Description

The HX tracksite preserves eight trackways of middle-to large-sized quadrupeds: HX-S1–S8 contain 9, 12, 16, 14, 11, 4, 10, and 20 tracks respectively (Figs. 3 and 10, Supplementary Materials). All tracks remain *in situ* and are recorded in detail, except HX-S6 – which is poorly preserved. Most trackways preserved easily-distinguishable manus and pes tracks, although individual digit traces are only recognizable in a few cases. The lengths of most pes tracks are between 40 and 50 cm (Fig. 11).

Among all the trackways, the best-preserved is HX-S2. Digit traces I, II and III of some of the best preserved pes traces (LP2, LP3) have recognizable claw marks (Fig. 10). Digit IV traces have small marks or depressions made by small unguals or foot callosities. The metatarsophalangeal pad region is smoothly curved. The manus traces are usually oval or U-shaped, with rounded marks of digits I and V, as in RM1. The average outward rotation of S2 is 59° in the manus and 33° in the pes. The ratio of manus to pes size is ~1:2. Some of the manus traces show a diagnostic semicircular outline, rather than a more generalized oval shape (Fig. 10). It is also clear that this trackway was made on the upper surface with underprints transmitted through to the lower surface, which reveals characteristic small scale ripple marks. In some areas around the track margin, remnants of the upper bed are sharply bent downwards towards the track floor. Other remnants of the upper bed adhere to the track floor (Fig. 10).

The other trackways only preserve an oval outline of the pes, with no recognizable manus traces. Otherwise, the other trackways are similar to S2 in the morphology. The smallest pes trace seen in S4, which only 25.7 cm in length and may belong to a juvenile trackmaker.

#### 5.3.2. Comparisons and discussion

The pes and manus morphology and trackway configuration of the HX quadruped trackways is typical of sauropods (Lockley, 1999, 2001; Lockley and Hunt, 1995). Most sauropod trackways in China are wide- (or medium-) gauge and are therefore referred to the ichnogenus *Brontopodus* (Lockley et al., 2002b). The HX sauropod trackway characteristics are similar to those of *Brontopodus*, for example, the pes tracks are longer than wide, large, and outwardly directed, and the manus prints are U-shaped. However, the low heteropody (~1:2) of the HX sauropod trackways is significantly less than in *Brontopodus birdi* (1:3) or *Parabrontopodus macintoshi* (1:4 or 1:5) (Lockley et al., 1994b). Thus the HX heteropody is more similar to *Polyonyx gomesi* with a low heteropody of 1:2 (Santos et al., 2009). The HX sauropod trackways are all narrow- and medium-gauge (WAP/P'ML ratio of 0.9–1.1, Marty, 2008), while *Brontopodus* is wide-gauge and *Parabrontopodus* is narrow-gauge (Lockley et al., 1994b). Therefore, we refer the HX sauropod trackways to cf. *Brontopodus*.

Low heteropody appears in many Early Cretaceous *Brontopodus* trackways, as is generally the case for a majority of Cretaceous sauropod trackways (Lockley et al., 1994b). For example, ratios of 1:2.1 from the Yanguoxia tracksite in Gansu Province (Zhang et al., 2006: Fig. 11), 1:2.3 from the Zhaojue tracksites in Sichuan Province (Xing et al., 2014d), and 1:1.5 from the Linsu tracksite of Shandong Province (Xing et al., 2013c) have been reported. Except for the HX specimens, all these trackways are medium-gauge and wide-gauge.

The wide-gauge of the *Brontopodus*-type trackways suggests that the tracks were left by titanosaurian sauropods (Wilson and Carrano, 1999; Lockley et al., 2002b). Narrow-gauge and medium-gauge trackways may be left by more basal sauropods. In this respect the HX sauropod trackways could be attributed to basal forms. However there are, as yet, no corresponding skeletal fossils in Southwest China.

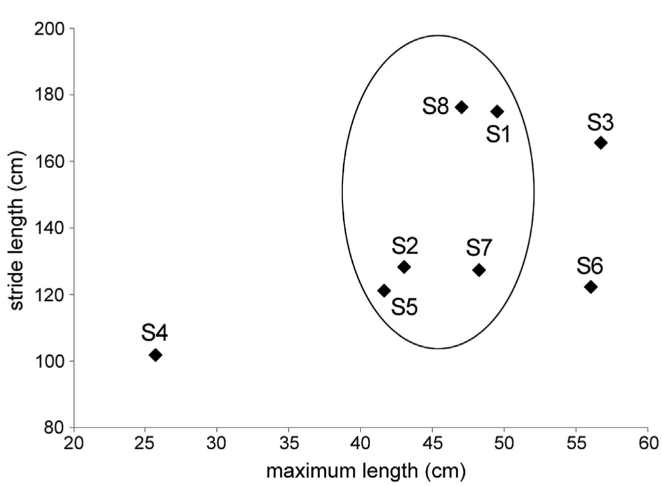


**Fig. 11.** Scatter diagram of Hanxi sauropod tracks.

#### 5.3.3. Speed estimates

For sauropods, Alexander (1976) first suggested that hip height $h = 4 \times$ foot length, whereas, later, Thulborn (1990) estimated $h = 5.9 \times$ foot length. The relative stride length (SL/h) may be used to determine whether the animal is walking ($SL/h \leq 2.0$), trotting ($2 < SL/h < 2.9$), or running ($SL/h \geq 2.9$) (Alexander, 1976; Thulborn, 1990). The SL/h ratios of the HX sauropod trackways are between 0.37–0.67 and 0.55–0.99 (Table 2) and accordingly suggest walking. Using the equation to estimate speed from trackways (Alexander, 1976), the mean locomotion speed of the trackmaker is between 0.97 and 2.20 km/h and 1.55–3.49 km/h.

## 6. Dinosaur faunas from Sichuan and Mishi-Jiangzhou basins

### 6.1. Sichuan Basin

#### 6.1.1. Geographic and stratigraphic distribution

The Cretaceous system in Sichuan Province and Chongqing Municipality is mainly distributed in the west and south of the Sichuan Basin and Panxi region (Gu and Liu, 1997) (Fig. 12). The Cretaceous system in the Sichuan Basin can be divided into three areas: the northern area (Tongxi–Bazhong region), the western area (Chengdu–Ya'an region), and the southwestern area

**Table 2**
Estimated data of the speed of Hanxi sauropod trackmakers.

| No. | F = 5.9 | | F = 4 | |
|---|---|---|---|---|
| | SL/h | S (km/h) | SL/h | S (km/h) |
| HX-S1 | 0.60 | 2.05 | 0.89 | 3.24 |
| HX-S2 | 0.51 | 1.44 | 0.75 | 2.27 |
| HX-S3 | 0.50 | 1.58 | 0.73 | 2.52 |
| HX-S4 | 0.67 | 1.80 | 0.99 | 2.81 |
| HX-S5 | 0.50 | 1.37 | 0.73 | 2.16 |
| HX-S6 | 0.37 | 0.97 | 0.55 | 1.55 |
| HX-S7 | 0.45 | 1.26 | 0.66 | 1.98 |
| HX-S8 | 0.64 | 2.20 | 0.94 | 3.49 |

Abbreviations: F, hip height conversion factors; SL/h, relative stride length; S = absolute speed.

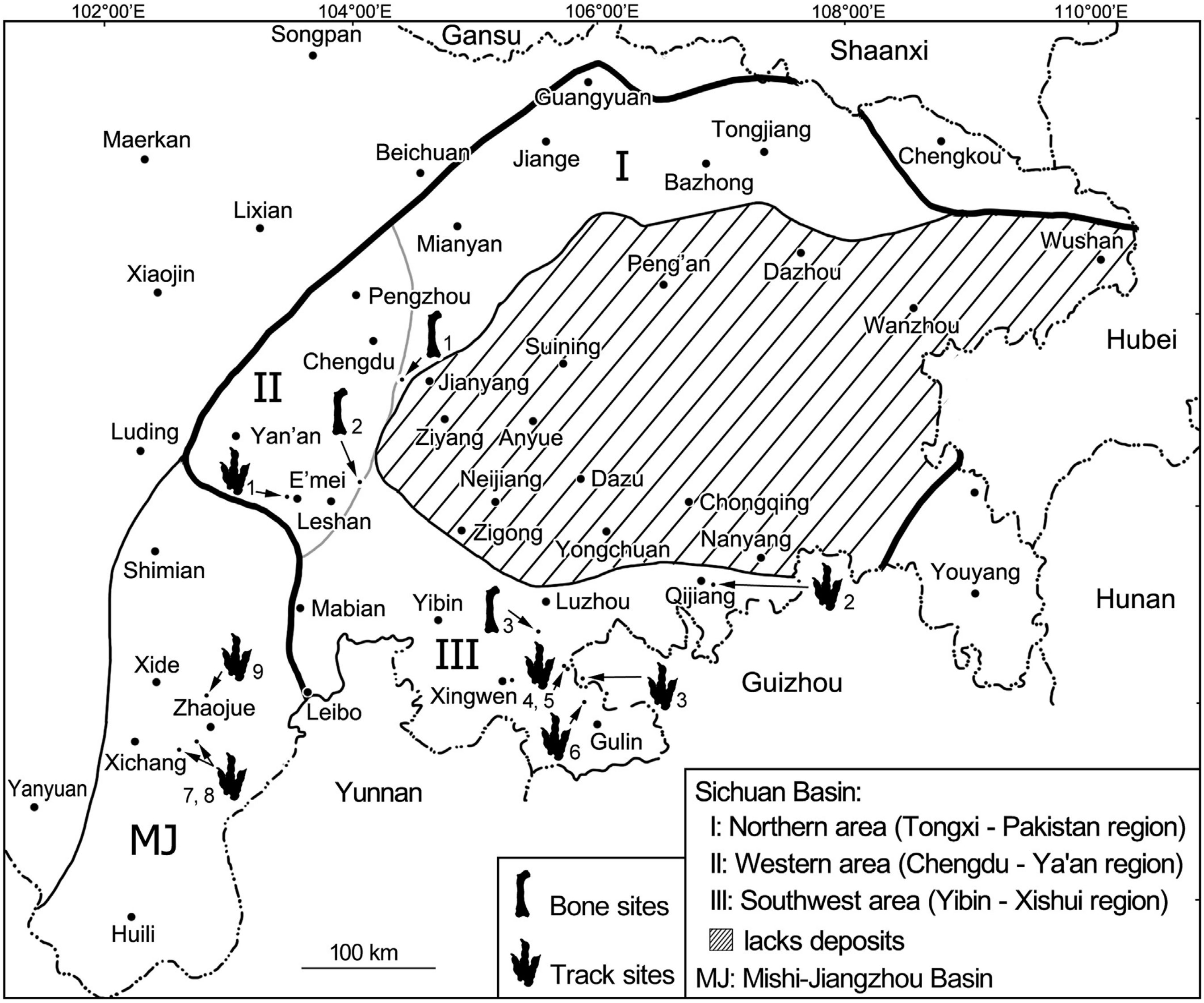


**Fig. 12.** Cretaceous sections and dinosaur footprint and bone distribution of Sichuan Basin (after CGCMS, 1982; SBGMR, 1991). Tracksites: 1, Emei tracksite (Zhen et al., 1994); 2, Lotus tracksite (Xing et al., 2007); 3, Baoyuan tracksite (Xing et al., 2011b); 4 and 5, Xinyang and Longjing tracksites (Xing et al., 2015b); 6, Hanxi (this text); 7 and 8, Zhaojue tracksites (Xing et al., 2014d, 2015a) and Jiefanggou tracksite (Xing et al., 2015c); 9, Yangmozu tracksite. Bone sites: 1, Sanxing site; 2, Renshou site; 3, Naxi site (Wang et al., 2008).

(Yibin–Xishui region) (CGCMS, 1982). There is no track record in the northern area, only a sparse skeletal record consisting of several fragments of small-sized theropod and sauropod limb bones (Sanxing Township in Jianyang, Wang et al., 2008). In the western area, the Emei tracksite (Zhen et al., 1994) and several skeletal fragments of small-sized theropods in Renshou Township in Meishan have been reported (Wang et al., 2008). The southwestern area is by far the richest ichnologically with the Lotus (Xing et al., 2007), Baoyuan (Xing et al., 2011b), Hanxi (this text), Xinyang, and Longjing tracksites (Xing et al., 2015b), along with several incomplete small-sized theropod and sauropod skeletons in Naxi Township in Luzhou City (Wang et al., 2008).

In the northern area of the Sichuan Basin, the Lower Cretaceous Chengqiangyan Group can be divided (from bottom to top) into the Cangxi, Bailong, Qiqusi and Gudian formations. The Cretaceous formations in the western area are divided into the Lower Cretaceous Tianmashan and Jiaguan Formations and the Upper Cretaceous Guankou Formation (Gu and Liu, 1997). The Cretaceous formations in the southwestern area are divided into the Wotoushan, Daerdang, Sanhe and Gaokanba formations (SBGMR, 1991). However, the Wotoushan–Gaokanba Formation and the Jiaguan–Guankou Formation are equivalent (CGCMS, 1982). For example, when Gao and Chen (2000) reviewed the lithostratigraphy of the Sichuan Basin, they considered the Woshantou Formation and Jiaguan Formation to be homonyms. As such, the Cretaceous dinosaur trackways found in the western and southwestern parts of the Sichuan Basin are all within the Jiaguan Formation.

### 6.1.2. Palaeoenvironment and palaeoclimatology

The Jiaguan Formation in the west and southwest of the Sichuan Basin is generally regarded as a fluvial facies deposit (Cao et al., 2008; Chen, 2009), however some researchers (such as Jiang et al., 2003; Wang et al., 2008) consider it to have been a desert environment during the “mid”-Cretaceous, with eolian sandstone accumulations characterized by parallel bedding and huge cross bedding. By contrast, in the western area, there is only a small southern region of desert sedimentation, which may be attributable to a local river-floodplain depositional environment. Such environments were maintained by seasonal floods flowing into the northern and western areas, which resulted from seasonal precipitation on the windward slope of the Longmen Mountains (Wang et al., 2008). The desert environment in the southwestern area was hot and dry with regional, intermittent river environments and a few oases (Wang et al., 2008). Based on sporopollen evidence, Chen (2009) considered the climate of the Jiaguan Formation to be generally tropical and subtropical to semiarid, with two short periods of extreme aridity.

### 6.2. Mishi-Jiangzhou Basin

#### 6.2.1. Geographic and stratigraphic distribution

The southwestern area of Sichuan Province, consisting of Liangshan Autonomous Prefecture and Panzhihua City, is commonly known as the Panxi (Panzhihua–Xichang) region. The Panxi region is situated at the eastern end of the Himalayan mountain range and the Southeastern corner of the Tibetan Plateau, and covers the area between the Central Yunnan Basin and the Sichuan Basin. The Panxi region is where the Cretaceous system is most widely distributed, besides the Sichuan Basin. The largest basin in this area is the Mishi (Xichang)-Jiangzhou Basin (Luo, 1999).

The Cretaceous system in the Mishi-Jiangzhou Basin is divided into the Lower Cretaceous Feitianshan and Xiaoba formations and the Upper Cretaceous Leidashu Formation (Gu and Liu, 1997). Though no skeletal fossil were found in the Feitianshan Formation, several tracksites were discovered, including Zhaojue tracksite I, II and IIN (Xing et al., 2013a,b,c, 2014d, 2015a; Xing and Lockley, 2014), the Jiefanggou tracksite (Xing et al., 2015c), and the Yangmozu tracksite. Sauropod and theropod trackways have been found in the Xiaoba and Leidashu formations, though they have not yet been described (personal communication, Yang G from Sichuan Bureau of Geological Exploration and Development of Mineral Resources). The Feitianshan Formation matches the Tianmashan Formation or Chengqiangyan Group in the Sichuan Basin, and the Lower Member of the Xiaoba Formation matches the Jiaguan Formation (CGCMS, 1982).

#### 6.2.2. Palaeoenvironment

The Lower Member of the Feitianshan Formation, which is 517 m thick, is categorized as fluvial and lacustrine delta facies. The Upper Member, which is 604 m thick, belongs to a lacustrine delta facies (Xu et al., 1997). *Scoyenia* ichnofacies from the Zhaojue tracksite indicate intermittent emergence and shallow flooding in low-energy non-marine facies, typical for river floodplains or lakeshore regions (Yang et al., 2004).

### 6.3. Comparison

Based on the stratigraphy and geologic ages, the Feitianshan Formation (Berriasian–Barremian, Tamai et al., 2004) is older than the Jiaguan Formation (Barremian–Albian, Chen, 2009), as such, the dinosaur trackways in the Panxi region are younger than those from the Sichuan Basin. The dinosaur fauna of the Jiaguan and Feitianshan formations are similar (Table 3). Both contain records of highly diverse theropods, including *Minisauripus* which is rarely found in the Upper Cretaceous of China, and large- and small-sized ornithopod trackmakers. However, both also show some unique ichnospecies, e.g., *Velociraptorichnus* and *Wupus* from the Jiaguan Formation, and *Siamopodus* from the Feitianshan Formation. Based on trackways gauge, sauropods in the Jiaguan Formation appear to be more primitive than in the Feitianshan Formation.

**Table 3**
Tetrapod tracks from Jiaguan and Feitianshan Formations.

| Tetrapod | Jiaguan Fm. | Feitianshan Fm. |
|---|---|---|
| non-avian | *Grallator* | *Grallator*- type |
| theropod | *Eubrontes* | *Eubrontes*- type |
| | *Minisauripus* | *Minisauripus* |
| | cf. *Irenesauripus* | – |
| | *Velociraptorichnus* | – |
| | coelurosaurs tracks | – |
| | – | *Siamopodus* |
| bird | *Wupus* | – |
| sauropod | cf. *Brontopodus* | *Brontopodus* |
| ornithopod | *Caririchnium* | *Caririchnium* |
| | cf. *Ornithopodichnus* | – |
| | – | *Ornithopodichnus* |
| pterosaur | *Pteraichnus* | *Pteraichnus* |

## 7. Conclusions

The Hanxi tracksite represents one of the largest accessible exposures of a track-bearing sandstone bedding plane (paleosurface) in Sichuan Province, and is less vulnerable than the large Zhaojue quarry exposures that have already been largely destroyed by ongoing quarrying and collapse (Xing et al., 2014d; Xing and Lockley, 2014). The Hanxi tracksite is typical of many red-bed dinosaur dominated ichnofaunal assemblages in having a large proportion of saurischian (theropod and sauropod) tracks, the latter referred to as cf. *Brontopodus*. However, as with the Zhaojue sites, some ornithopod tracks are also present, and are referred tentatively to *Ornithopodichnus*. Most of the tracks are moderately well preserved, but a few theropod trackways show metatarsal traces indicating substrate conditions leading to sub-optimal preservation.

Due to the large size of the site, it is possible to trace a single very long theropod trackway for a distance of 69 m, and observe differential preservation on two different ripple marked surfaces. This is the longest trackway hitherto reported from China, or from anywhere in East Asia. The Hanxi site is one of a rapidly-growing number of tracksites reported from sandstone-dominated Cretaceous sequences in Sichuan. This suggests that the dinosaur dominated ichno record of the region is more abundant than previously supposed and has until recently been largely overlooked.

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## References

Alexander, R.M., 1976. Estimates of speeds of dinosaurs. Nature 26, 129–130.
Azuma, Y., Li, R., Currie, P.J., Dong, Z.M., Shibata, M., Lu, J., 2006. Dinosaur footprints from the Lower Cretaceous of Inner Mongolia, China. In: Memoir of the Fukui Prefectural Dinsaur Museum, 5, pp. 1–14.
Cao, K., Li, X.H., Wang, C.S., 2008. The Cretaceous Clay Minerals and Paleoclimate in Sichuan Basin. Acta Geologica Sinica 28 (1), 115–123.
Castanera, D., Pascual, C., Razzolini, N.L., Vila, B., Barco, J.L., Canudo, J.I., 2013. Discriminating between Medium-Sized Tridactyl Trackmakers: Tracking Ornithopod Tracks in the Base of the Cretaceous (Berriasian, Spain). PLoS One 8 (11), e81830. http://dx.doi.org/10.1371/journal.pone.0081830.
Chen, H.X., 2009. Research of Paleoenvironment and Paleoclimate of Cretaceous in Ya'an Area of Western Sichuan Basin. Chengdu University of Technology, China (in Chinese).

Compiling Group of Continental Mesozoic Stratigraphy and Palaeontology in Sichuan Basin of China (CGCMS), 1982. Continental Mesozoic Stratigraphy and Palaeontology in Sichuan Basin of China. Chengdu: People's Publishing House of Sichuan, pp. 1–405.

Day, J.J., Norman, D.B., Gale, A.S., Upchurch, P., Powell, H.P., 2004. A Middle Jurassic dinosaur trackway site from Oxfordshire, UK. Palaeontology 47 (2), 319–348.

Farlow, J.O., 1992. Sauropod tracks and trackmakers: integrating the ichnological and skeletal record. Zubia 10, 89–138.

Fanti, F., Contessi, M., Nigarov, A., 2011. New data on two large dinosaur tracksites from the Middle Jurassic of Eastern Turkmenistan, Central Asia. SVP Annual Meeting, Program and Abstracts, 107.

Fischer, R., 1998. Das Naturdenkmal Saurierfährten Münchehagen, 37. Mitt. Geol. Inst. Univ. Hannover, p. 125.

Gao, Z.J., Chen, K.Q., 2000. The Lithostratigraphic Dictionary of China. China Geological University Press, Beijing, pp. 1–628.

Gatesy, S.M., Middleton, K.M., Jenkins, F.A., et al., 1999. Three-dimensional preservation of foot movements in Triassic theropod dinosaurs. Nature 339, 141–144.

González Riga, B.J., 2011. Speeds and stance of titanosaur sauropods: analysis of Titanopodus tracks from the Late Cretaceous of Mendoza, Argentina. Anais da Academia Brasileira de Ciências 83 (1), 279–290.

Gou, Z.H., Zhao, B., 2001. The Cretaceous and Tertiary systems in Dayi and Chongzhou regions, Sichuan. Journal of Stratigraphy 25 (28–33), 62.

Gu, X.D., Liu, X.H., 1997. Stratigraphy (Lithostratic) of Sichuan Province. China Univ. Geosci. Pr., Wuhan, p. 417.

Hao, Y.C., Su, D.Y., Li, Y.G., Wang, N.W., 1986. The Chinese Cretaceous. The Geological Publishing House, Beijing, p. 301.

Heim, A., 1932. Bergsturz und Menschenleben. Zürich, Fretz und Wasmuth; 218. English translation by Skermer NA. 1989. Landslide and human lives. BiTech Publishers, Vancouver, B.C.; 195.

Henderson, D.M., 2003. Footprints, trackways, and hip heights of bipedal dinosaurs – testing hip height predictions with computer models. Ichnos 10, 99–114.

Huh, M., Paik, I.S., Lockley, M.G., others, 2006. Well-preserved theropod tracks from the Upper Cretaceous of Hwasun County, southwestern South Korea, and their paleobiological implications. Cretaceous Research 27, 123–138.

Jiang, X.S., Xu, J.S., Pan, Z.X., 2003. The surface features of the quartz sandgrains from the Cretaceous desert in the Sichuan Basin. Sedimentary Geology and Tethyan Geology 23 (1), 60–65.

Kim, J.Y., Lockley, M.G., Kim, H.M., Lim, J.D., Kim, S.H., Lee, S.J., Woo, J.O., Park, H.J., Kim, H.S., Kim, K.S., 2009. New dinosaur tracks from Korea, *Ornithopodichnus masanensis* ichnogen. et ichnosp. nov. (Jindong Formation, Lower Cretaceous): implications for polarities in ornithopod foot morphology. Cretaceous Research 30, 1387–1397.

Kuban, G., 1989. Elongate Dinosaur Tracks. In: Gillette, David D., Lockley, Martin G. (Eds.), Dinosaur Tracks and Traces, 1989. Cambridge University Press, Cambridge, pp. 57–72.

Leonardi, G., 1979. Preliminary note on six Ornithischia dinosaur trackways from Bacia do Rio do Peixe, in Sousa, Paraíba, Brazil. Anais da Academia Brasileira de Ciências 51 (3), 501–516.

Leonardi, G., 1987. Glossary and manual of tetrapod footprint palaeoichnology. Departamento Nacional de Producão Mineral, Brazil, p. 75.

Li, Y.L., 1995. Daxi conglomerate and its geological time, 22. J. ChengduUniv. Technol., pp. 11–14

Li, D., Azuma, Y., Fujita, M., Lee, Y.–N., Arakawa, Y., 2006. A preliminary report on two new vertebrate track sites including dinosaurs from the early Cretaceous Hekou Group, Gansu province, China. Journal of the Paleontological Society of Korea 22, 29–49.

Li, R.H., Lockley, M.G., Makovicky, P.J., Matsukawa, M., Norell, M.A., Harris, J.D., Liu, M.W., 2007. Behavioural and faunal implications of Early Cretaceous deinonychosaur trackways from China. Naturwissenschaften 95, 185–191.

Liebenberg, L., 1990. A Field Guide to the Animal Tracks of Southern Africa. David Phillips Publishers, Cape Town, p. 320.

Lockley, M.G., 1986. North America's largest trackway site: Implications for Morrison Formation paleoecology. Geological Society of America bulletin Geological Society of America 97, 1163–1176.

Lockley, M.G., 1999. The Eternal Trail: A Tracker Looks at Evolution. Perseus Books, Cambridge, pp. 1–334.

Lockley, M.G., 2001. Trackways and dinosaur locomotion. In: Briggs, D.E.G., Crowther, P. (Eds.), Palaeobiology II: A Synthesis. Blackwell Science, Oxford, pp. 412–416.

Lockley, M.G., 2009. New perspectives on morphological variation in tridactyl footprints: clues to widespread convergence in developmental dynamics. Geological Quarterly 53 (4), 415–432.

Lockley, M.G., Hunt, A.P., 1995. Dinosaur tracks and other fossil footprints of the western United States. Columbia University Press, New York, p. 338.

Lockley, M.G., Wright, J.L., 2001. Trackways of large quadrupedal ornithopods from the Cretaceous: A review. In: TankeK Carpenter, D.H. Mesozoic vertebrate life. Indiana University Press, Bloomington and Indianapolis, pp. 428–442.

Lockley, M.G., Hunt, A.P., Meyer, C.A., 1994a. Vertebrate Tracks and the Ichnofacies Concept: implications for Paleoecology and Palichnostratigraphy. In: Donovan, S. (Ed.), The paleobiology of trace fossils. Wiley and Sons, Inc, New York, pp. 241–268.

Lockley, M.G., Farlow, J.O., Meyer, C.A., 1994b. *Brontopodus* and *Parabrontopodus* ichnogen. nov. and the significance of wide- and narrow-gauge sauropod trackways. Gaia 10, 135–145.

Lockley, M.G., Meyer, C.A., Schultz-Pittman, R., Forney, G., 1996. Late Jurassic dinosaur tracksites from central Asia: a preliminary report on the world's longest trackways. In: Morales, M. (Ed.), The Continental Jurassic. Museum of Northern Arizona Bulletin 60. Museum of Northern Arizona, Flagstaff, pp. 137–140.

Lockley, M.G., Fillmore, B.J., Marquardt, L., 1997. Dinosaur Lake – The Story of the Purgatoire Valley Dinosaur Tracksite Area, Colorado Geological Survey. Special Publication No. 40.

Lockley, M.G., Santos, V.F., Meyer, C., Hunt, A., 1998. A new dinosaur tracksite in the Morrison Formation, Boundary Butte, Southeastern Utah. In: Carpenter, K., Chure, D., Kirkland, K. (Eds.), The Upper Jurassic Morrison Formation: An interdisciplinary study. Modern. Geology, 23 (2), 317–330.

Lockley, M.G., Schulp, A.S., Meyer, C.A., Leonardi, G., Kerumba Mamani, D., 2002a. Titanosaurid trackways from the Upper Cretaceous of Bolivia: evidence for large manus widegauge locomotion and gregarious behaviour. Cretaceous Research 23, 383–400.

Lockley, M.G., Wright, J., White, D., Li, J.J., Feng, L., Li, H., 2002b. The first sauropod trackways from China. Cretaceous Research 23, 363–381.

Lockley, M.G., Matsukawa, M., Li, J.J., 2003. Crouching theropods in taxonomic jungles: ichnological and ichnotaxonomic investigations of footprints with metatarsal and ischial impressions. Ichnos 10, 169–177.

Lockley, M.G., McCrea, R.T., Matsukawa, M., 2009. Ichnological evidence for small quadrupedal ornithischians from the basal Cretaceous of SE Asia and North America: implications for a global radiation. In: Buffetaut, E., Cuny, G., Le Loeuff, J., Suteethorn, V. (Eds.), Late Palaeozoic and Mesozoic Ecosystems in SE Asia. The Geological Society, 315, pp. 255–269. London, Special Publications.

Lockley, M.G., Huh, M., Kim, B.S., 2012a. *Ornithopodichnus* and pes-only sauropod trackways from the Hwasun tracksite Cretaceous of Korea. Ichnos 19, 93–100.

Lockley, M.G., Lucas, S.G., Matsukawa, M., Harris, J.D., 2012b. Cretaceous tetrapod footprint biostratigraphy, biochronology and ichnofacies. Journal of Stratigraphy 36, 503–550.

Lockley, M.G., Huh, M., Gwak, S.G., Hwang, K.G., Paik, I.S., 2012c. Multiple tracksites with parallel trackways from the Cretaceous of the Yeosu City area Korea: implications for gregarious behavior in ornithopod and sauropod dinosaurs. Ichnos 19, 105–114.

Lockley, M.G., Li, J.J., Li, R.H., Matsukawa, M., Harris, J.D., Xing, L.D., 2013. A review of the tetrapod track record in China, with special reference to type ichnospecies: implications for ichnotaxonomy and paleobiology. Acta Geologica Sinica (English edition) 87 (1), 1–20.

Lockley, M.G., Xing, L.D., Lockwood, J.A.F., Pond, S., 2014. A review of Large Cretaceous ornithopod tracks, with special reference to their ichnotaxonomy. Biological Journal of the Linnean Society 113, 721–736.

Luo, C.D., 1999. The Danxia landforms in southwest Sichuan. Economic Geographya 19, 65–70.

Lull, R.S., 1953. Triassic life of the Connecticut Valley, 181. Bull. Connect. Geol. Nat. Hist. Surv., pp. 1–331

Mazin, J.M., Hantzpergue, P., 2010. Les traces de dinosaures des sites jurassiques français (Coisia, Loulle, Plagne). La frontière franco-suisse: un petit pas pour les dinosaures. Colloque scientifique, Porrentruy 29.-30.10.2010, abstract book, Billon-Bruyat, J.-P. (coord.), Porrentruy, pp. 15–16.

Matsukawa, M., Lockley, M.G., Li, J.J., 2006. Cretaceous terrestrial biotas of East Asia, with special reference to dinosaur-dominated ichnofaunas: towards a synthesis. Cretaceous Research 27, 3–21.

Marty, D., 2008. Sedimentology, taphonomy, and ichnology of Late Jurassic dinosaur tracks from the Jura carbonate platform (Chevenez–Combe Ronde tracksite, NW Switzerland): insights into the tidal-flat palaeoenvironment and dinosaur diversity, locomotion, and palaeoecology. GeoFocus. 21. University of Fribourg, Fribourg, p. 278. PhD Thesis.

Marty, D., Paratte, G., Lovis, C., Jacquemet, M., Meyer, C.A., 2010. Extraordinary sauropod trackways from the Late Jurassic Béchat Bovais tracksite (Canton Jura, NW Switzerland): implications for sauropod locomotor styles, 8th Annual Meeting of the European Association of Vertebrate Palaeontologists, 7.-12.06.2010, Aix-en-Provence, France, p. 56.

Meyer, C.A., 1990. Sauropod tracks from the Upper Jurassic Reuchenette Formation (Kimmeridgian, Lommiswil, Kt. Solothurn) of Northern Switzerland, 82/2. Ecl. Geol. Helv., pp. 389–397

Meyer, C.A., 1998. Jura- und kreidezeitliche Dinosaurierfährten aus Zentral-Asien (Usbekistan, Turkmenistan). Natur und Museum 128/12, 393–402.

Meyer, C.A., Thüring, B., 2006. A marriage between geotechnique and paleontology: three dimensional visualization of a geological monument for scientific exploration and geotechnical conservation (Cal Orcko, Sucre, Bolivia), 4th Swiss Geoscience Meeting, 25.11.2006, Berne, Switzerland, abstract volume, pp. 133–134.

Meyer, C.A., Lockley, M.G., 1997. Jurassic and Cretaceous dinosaur tracksites from central Asia (Usbekistan and Turkmenistan). In: Yang, S.Y., Huh, M., Lee, Y.N., Lockley, M.G (Eds.), International Dinosaur Symposium for Uhangri Dinosaur Center and Theme Park in Korea, pp. 77–92. Journal of the Paleontological Society of Korea Special Publication 2. Paleontological Society of Korea, Chonnam.

McCrea, R.T., Buckley, L.G., Farlow, J.O., Lockley, M.G., Currie, P.J., Matthews, N.A., Pemberton, S.G., 2014. A 'Terror of Tyrannosaurs': The First Trackways of Tyrannosaurids and Evidence of Gregariousness and Pathology in Tyrannosauridae. PLoS One 9 (7), e103613.

Milner, A.R.C., Harris, J.D., Lockley, M.G., Kirkland, J.L., Matthews, N.A., 2009. Birdlike anatomy, posture, and behavior revealed by an Early Jurassic theropod dinosaur resting trace. PLoS One e4591.

Mossman, D.J., Brüning, R., Powell, H.P., 2003. Anatomy of a Jurassic theropod trackway from Ardley, Oxfordshire, U. K. Ichnos 10, 195–207.
Olsen, P.E., 1980. Fossil great lakes of the Newark Supergroup in New Jersey. In: Manspeizer, W. (Ed.), Field Studies of New Jersey Geology and Guide to Field Trips. Rutgers University, New Brunswick, pp. 352–398.
Olsen, P.E., Smith, J.B., McDonald, N.G., 1998. Type material of the type species of the classic theropod footprint genera *Eubrontes, Anchisauripus* and *Grallator* (Early Jurassic, Hartford and Deerfield basins, Connecticut and Massachusetts, U.S.A.). Journal of Vertebrate Paleontology 18 (3), 586–601.
Peng, G.Z., Ye, Y., Gao, Y.H., Shu, C.K., Jiang, S., 2005. Jurassic DinosaurFaunas in Zigong. People's Publishing House of Sichuan, Chengdu, p. 236 (in Chinese, with English abstract).
Rubilar-Rogers, D., Moreno, K., Blanco, N., Calvo, J.O., 2008. Theropod dinosaur trackways from the Lower Cretaceous of the Chacarilla Formation, Chile. Revista Geológica de Chile 35 (1), 175–184.
Schulp, A., Brokx, W.A., 1999. Maastrichtian sauropod footprints from the Fumanya site, Bergueda, Spain. Ichnos 6 (4), 239–250.
Santos, V.F. dos, Lockley, M.G., Moratalla, J.J., Galopim de Carvalho, A.M., 1992. The longest dinosaur trackway in the world? Interpretations of Cretaceous footprints from Carenque, near Lisboa, Portugal. Gaia 5, 18–27.
Santos, V.F., Lockley, M.G., Meyer, C.A., Carvalho, J., Galopim De Carvalho, A.M., Moratalla, J.J., 1994. A new sauropod tracksite from the Middle Jurassic of Portugal. Gaia 10, 5–13.
Santos, V.F., Moratalla, J., Royo-Torres, R., 2009. New sauropod trackways from the Middle Jurassic of Portugal. Acta Palaeontologica Polonica 54 (3), 409–422.
Sichuan Provincial Bureau of Geology aviation regional Geological Survey team, 1976. Geological Map of the People's Republic of China. Xuyong Map Sheet 1: 200000 (H-48-XXXIV).
Sichuan Bureau of Geology and Mineral Resources (SBGMR), 1991. Regional Geology of. Sichuan Province. Geological Publishing House, Beijing, p. 264.
Snively, E., Russell, A.P., Powell, G.L., 2004. Evolutionary morphology of the coelurosaurian arctometatarsus: descriptive, morphometric and phylogenetic approaches. Zoological Journal of the Linnean Society 142, 525–553.
Tamai, M., Liu, Y., Lu, L.Z., Yokoyama, M., Halim, N., Zaman, H., 2004. Palaeomagnetic evidence for southward displacement of the Chuan Dian fragment of the Yangtze Block. Geophysical Journal International 158 (1), 297–309.
Thulborn, R.A., 1990. Dinosaur Tracks. Chapman and Hall, London, p. 410.
Vila, B., Oms, O., Marmi, J., Galobart, À., 2008. Tracking Fumanya Footprints (Maastrichtian, Pyrenees): historical and ichnological overview. Oryctos 8, 115–130.
Wang, Q.W., Liang, B., Kan, Z.Z., Li, K., 2008. Paleoenvironmental reconstruction of mesozoic dinosaurs fauna in Sichuan basin. Geological University Press, Beijing, pp. 1–197.
Weems, R.E., 1992. A re-evaluation of the taxonomy of Newark Supergroup saurischian dinosaur tracks, using extensive statistical data from a recently exposed tracksite near Culpeper, Virginia. In: Sweet, P.C. (Ed.), Proceedings 26th Forum on the Geology of Industrial Minerals, 119. Virginia Division of Mineral Resources Publication, pp. 113–127.
Wilson, J.A., Carrano, M.T., 1999. Titanosaurs and the origin of "wide-gauge" trackways: a biomechanical and systematic perspective on sauropod locomotion. Paleobiology 25, 252–267.
Xing, L.D., Lockley, M.G., 2014. First report of small *Ornithopodichnus* trackways from the Lower Cretaceous of Sichuan, China. Ichnos 21, 213–222.
Xing, L.D., Wang, F.P., Pan, S.G., Chen, W., 2007. The Discovery of Dinosaur Footprints from the Middle Cretaceous Jiaguan Formation of Qijiang County, Chongqing City. Acta Geologica Sinica (Chinese edition) 81 (11), 1591–1602.
Xing, L.D., Mayor, A., Chen, Y., Harris, J.D., Burns, M.E., 2011a. The Folklore of Dinosaur Trackways in China: Impact on Paleontology. Ichnos 18 (4), 213–220.
Xing, L.D., Harris, J.D., Gierliński, G.D., Wang, W.M., Wang, Z.Y., Li, D.Q., 2011b. Middle Cretaceous Non-avian Theropod trackways from the Southern Margin of the Sichuan Basin, China. Acta Palaeontologica Sinica 50 (4), 470–480.
Xing, L.D., Harris, J.D., Jia, C.K., Luo, Z.J., Wang, S.N., An, J.F., 2011c. Early Cretaceous Bird-dominated and Dinosaur Footprint Assemblages from the Northwestern Margin of the Junggar Basin, Xinjiang, China. Palaeoworld 20, 308–321.
Xing, L.D., Klein, H., Lockley, M.G., Chen, W., Ye, Y., Matsukawa, M., Zhang, J.P., 2013a. Earliest records from China of theropod and mammal-like tetrapod footprints in the Late Triassic of Sichuan Basin. Vertebrata PalasiAtica 51 (3), 184–198.
Xing, L.D., Lockley, M.G., Zhang, J.P., Milner, A.R.C., Klein, H., Li, D.Q., Persons IV, W.S., Ebi, J.F., 2013b. A new Early Cretaceous dinosaur track assemblage and the first definite non-avian theropod swim trackway from China. Chinese Science Bulletin (English version) 58, 2370–2378.
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., 2013c. 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., Klein, H., Lockley, M.G., Kan, Z.Z., Zhang, J.P., Peng, G.Z., Ye, Y., 2014a. First chirothere and possible grallatorid footprint assemblage from the Upper Triassic Baoding Formation of Sichuan Province, southwestern China. Palaeogeography, Palaeoclimatology. Palaeoecology 412, 169–176.
Xing, L.D., Peng, G.Z., Marty, D., Ye, Y., Klein, H., Li, J.J., Gierliński, G.D., Shu, C.K., 2014b. An unusual trackway of a possibly bipedal archosaur from the Late Triassic of the Sichuan Basin, China. Acta Palaeontologica Polonica 59 (4), 863–871.
Xing, L.D., Peng, G.Z., Ye, Y., Lockley, M.G., Klein, H., Persons IV, W.S., Zhang, J.P., Shu, C.K., Hao, B.Q., 2014c. Sauropod and small theropod tracks from the Lower Jurassic Ziliujing Formation of Zigong City, Sichuan, China with an overview of Triassic-Jurassic dinosaur fossils and footprints of the Sichuan Basin. Ichnos 21, 119–130.
Xing, L.D., Lockley, M.G., Zhang, J.P., Klein, H., Persons, W.S.I.V., Dai, H., 2014d. 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.
Xing, L.D., Lockley, M.G., Klein, H., Gierliński, G.D., Divay, J.D., Hu, S.M., Zhang, J.P., Ye, Y., He, Y.P., 2014e. The non-avian theropod track *Jialingpus* from the Cretaceous of the Ordos Basin, China, with a revision of the type material: implications for ichnotaxonomy and trackmaker morphology. Palaeoworld 23, 187–199.
Xing, L.D., Klein, H., Lockley, M.G., Wetzel, A., Li, Z.D., Li, J.J., Gierliński, G.D., Zhang, J.P., Matsukawa, M., Divay, J.D., Zhou, L., 2014f. *Changpeipus* (theropod) tracks from the Middle Jurassic of the Turpan Basin, Xinjiang, Northwest China: review, new discoveries, ichnotaxonomy, preservation and paleoecology. Vertebrata PalasiAtica 52 (2), 233–259.
Xing, L.D., Lockley, M.G., Zhang, J.P., Klein, H., Kim, J.Y., Persons IV, W.S., Matsukawa, M., Yu, X.Q., Li, J.J., Chen, G.B., Hu, Y., 2014g. Upper Cretaceous dinosaur track assemblages and a new theropod ichnotaxon from Anhui Province, eastern China. Cretaceous Research 49, 190–204.
Xing, L.D., Lockley, M.G., Marty, D., Piñuela, L., Klein, H., Zhang, J.P., Persons IV, W.S., 2015a. Re-description of the partially collapsed Early Cretaceous Zhaojue dinosaur tracksite (Sichuan Province, China) by using previously registered video coverage. Cretaceous Research 52, 138–152.
Xing, L.D., Peng, G.Z., Lockley, M.G., Ye, Y., Klein, H., Zhang, J.P., Persons IV, W.S., 2015b. Early Cretaceous sauropod and ornithopod trackways from a stream course in Sichuan Basin, Southwest China. New Mexico Museum of Natural History and Science Bulletin 68, 319–325.
Xing, L.D., Lockley, M.G., Yang, G., Mayor, A., Klein, H., Persons IV, W.S., Chen, Y., Peng, G.Z., Ye, Y., Ebi, J.F., 2015c. Tracking a legend: An Early Cretaceous sauropod trackway from Zhaojue County, Sichuan Province, southwestern China. Ichnos 22 (1), 22–28.
Xu, X.S., Liu, B.J., Xu, Q., 1997. Analysis of the largescale basins in western China and geodynamics Beijing. Geological Publishing House, p. 168.
Yang, S., Zhang, J., Yang, M., 2004. Trace Fossils of China. Science Press, Beijing, p. 353.
Zhang, J., Li, D., Li, M., Lockley, M., 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.
Zhen, S., Li, J., Zhang, B., 1994. Dinosaur and bird footprints from the Lower Cretaceous of Emei County, Sichuan, China. Memoirs of the Beijing Natural History Museum 54, 105–120.

## Appendix A. Supplementary data

Supplementary data related to this article can be found online at http://dx.doi.org/10.1016/j.cretres.2015.05.008.