EUBRONTES AND *ANOMOEPUS* TRACK ASSEMBLAGES FROM THE MIDDLE JURASSIC XIASHAXIMIAO FORMATION OF ZIZHONG COUNTY, SICHUAN, CHINA: REVIEW, ICHNOTAXONOMY AND NOTES ON PRESERVED TAIL TRACES

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Abstract—The Nianpanshan dinosaur tracksite, first studied in the 1980s, was designated as the type locality of the monospecific ichnogenus *Jinlijingpus*, and the source of another tridactyl track, *Chuanchengpus*, both presumably of theropod affinity. After the site was mapped in 2001, these two ichnotaxa were considered synonyms of *Eubrontes* and *Anomoepus*, respectively, the latter designation being the first identification of this ichnogenus in China. The assemblage indicates a typical Jurassic ichnofauna. The present study reinvestigates the site in the light of the purported new ichnospecies *Chuanchengpus shenglingensis* that was introduced in 2012. After re-evaluation of the morphological and extramorphological features, *C. shenglingensis* is considered here as a *nomen dubium*. The present study also provides details of tail traces associated with two of the *Anomoepus* trackways and adds additional detail to the 2001 tracksite map.

INTRODUCTION

Saurischian-dominated dinosaur assemblages are typical of Jurassic deposits in China (Matsukawa et al., 2006; Xing et al., 2014a), North America (Lockley and Hunt, 1995) and elsewhere. After the skeletal record, this is the case also in the Sichuan Basin, where sauropods dominate the Middle to Late Jurassic records, while ornithischians, including stegosaurs and small-sized ornithopods (Peng et al., 2005), are rare. The composition of Jurassic ichnoassemblages in the Sichuan Basin is partly different. The Nianpanshan site (previously known as the Jinlijing site, GPS: 29°47'39.03"N, 104°38'29.49"E) near Jinlijing Town, Zizhong County (Fig .1), preserves tracks of large theropods and small ornithopods (Lockley and Matsukawa, 2009). The Nianpanshan site also preserves the first reported *Anomoepus* trackways from China (Lockley and Matsukawa, 2009). Here, we offer the first detailed re-description and re-evaluation of the Nianpanshan site, based on the first author's field investigation in April 2015.

HISTORICAL BACKGROUND

In the 1970s, the upper layers of a mountain in Nianpan Village of Jinlijing Town were removed in order to reduce shade and benefit local agriculture. A smooth lower rock layer was left, and this exposure revealed numerous fossil tracks. Local superstition regarded the tracks

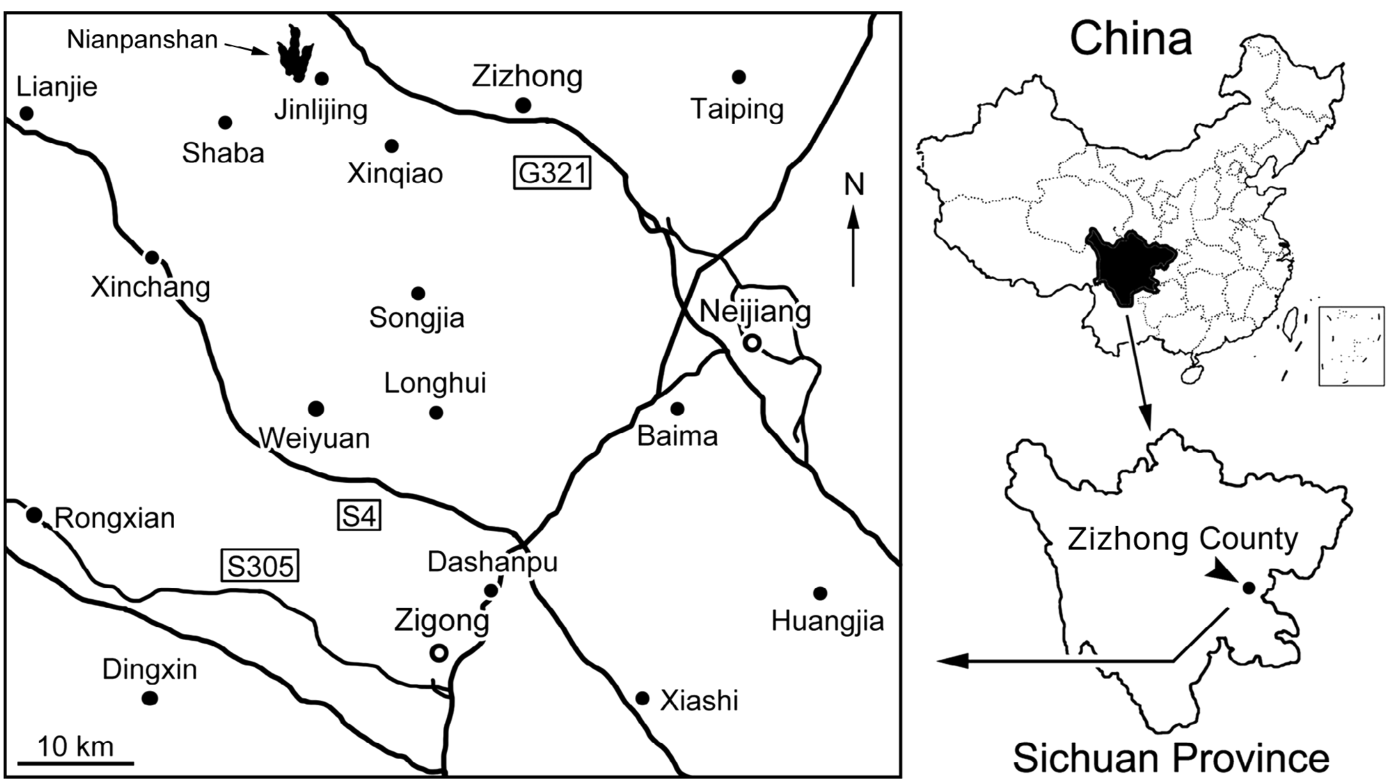

FIGURE 1. Geographic map indicating the location of dinosaur footprint localities in Jinlijing, Sichuan Province, P.R. China.

as those of a "divine crane." Investigations conducted between 1981 and 1982, by researchers from Chongqing Museum of Natural History, identified the tracks as those of dinosaurs. In 1987, Xinglong Yang and Daihuan Yang, from the Chongqing Museum of Natural History, described theropod tracks from the Nianpanshan site. Yang and Yang (1987) suggested that one large track and two medium-sized tracks were left by different individuals of the *Jinlijingpus nianpanshanensis* trackmaker, and that another smaller footprint was similar to the theropod track *Chuanchengpus*.

Although numerous tracks were collected from other Sichuan Basin localities throughout the1980s, villagers from Nianpan Village strongly opposed specimen collection, and no footprint material could be obtained from the Nianpan site. Moreover, the Nianpan site was protected in Shenglingshan National Geological Park.

Lockley and Matsukawa (2009) mapped the site in 2001 (Fig. 2) and concluded that the large tridactyl tracks, *Jinlijingpus nianpanshanensis,* were similar to *Eubrontes*, whereas the small tridactyl tracks were similar to *Anomoepus*. Three *Anomoepus* isp. trackways were labelled by these authors as A1-A3, being the first identification of this ichnogenus from China. Two trackways with large tridactyl pes imprints (including *Eubrontes*) were left unlabeled. Li et al. (2011) suggested *Jinlijingpus nianpanshanensis* should be referred to the theropod ichnogenus *Eubrontes*, and Lockley et al. (2013) assigned *J. nianpanshanensis* to the new combination *Eubrontes nianpanshanensis*. Shortly after, Yang et al. (2013) put forth the same taxonomic conclusion.

Without knowing/citing the conclusion from Lockley and Matsukawa (2009), Yang et al. (2011) followed the point from Yang and Yang (1987), named a new ichnospecies *Chuanchengpus shenglingensis* based on a trackway with small pes imprints from the Nianpanshan site, and considered the trackmaker to have been a coelurosaur. In the following year, this trackway was described in more detail (Yang et al., 2012).

It's worth noting that the type ichnospecies of *Chuanchengpus, C. wuhuangensis,* was named by Yang and Yang (1987) based on a trackway from the Middle Jurassic Xintiangou Formation of Wuma Village, Zizhong Township. Lockley et al. (2013) re-assigned the Wuma *Chuanchengpus wuhuangensis* to *Grallator*, whereas, according to Lockley and Matsukawa (2009), the small trackway from the Nianpanshan site is still referred to *Anomoepus*.

GEOLOGICAL SETTING

Strata at the Nianpanshan site were initially thought to be part of the Middle Jurassic Xintiangou Formation (Yang and Yang, 1987). In 2006, a survey of Shenglingshan National Geological Park by the Geochemical Exploration Team of Sichuan Bureau of Geology and Mineral Resources confirmed that the track-bearing unit belongs to the Middle Jurassic Xiashaximiao Formation (Geochemical Exploration Team of Sichuan Bureau of Geology and Mineral Resources, 2006; Yang, 2009; Yang et al., 2013).

The Nianpanshan tracks are preserved on reddish-brown feldspathic quartz sandstone. The lower member of the Xiashaximiao Formation is 650–2500 m thick (Fig. 3), comprising cyclothemic interbedding of yellow-gray and purplish-gray feldspathic quartz sandstone and purplish-red and purplish-gray shale of differing thicknesses. The basal part of the Xiashaximiao Formation consists of medium-grain sandstone with large oblique bedding. At the top of this formation, a layer of grayish-green shale, rich in conchostracans, occurs (Stratigraphic Paleobiology Research Center of China Geological Survey, 2004; Peng et al., 2005; Xing et al., 2014a).

The plant and invertebrate assemblage includes fresh water bivalves, conchostracans, ostracods, and sporopollen. The vertebrate assemblage (i.e., *Shunosaurus* fauna) is typical of Middle Jurassic strata of China (Peng et al., 2005).

MATERIALS AND METHODS

The Nianpanshan site preserves six trackways: T1–T6. T6 and one well-preserved isolated track (TI1) were not previously reported. Trackways originally labeled A1-A3 in Lockley and Matsukawa (2009) are here referred to as T1–T3. Three main trackways (T1, T4 and T5) are oriented toward the northwest. The total track surface is presently surrounded by a protective wall. During the investigation, each track was outlined with chalk, photographed, and measured, after weeds and surface debris were cleared. In 2001, the site was partially covered by harvested crops, which were removed from the trackways so they could be mapped using compass and tape measures. At that time selected tracks were photographed and traced on acetate film (Fig. 2). During the present study the entire tracksite was mapped on

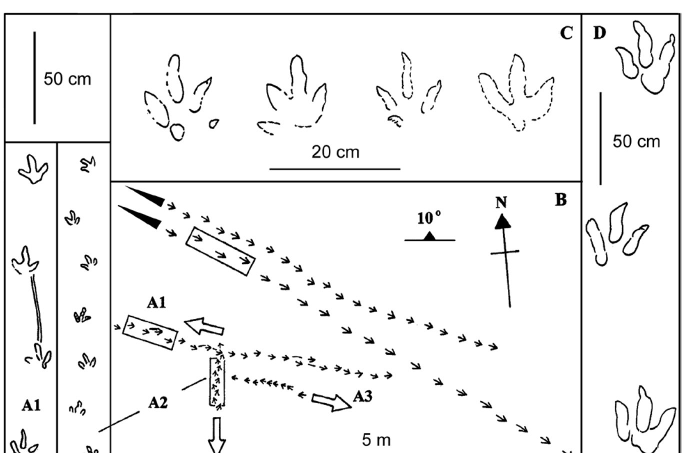

FIGURE 2. Map and detail of tracks from the Nianpanshan dinosaur tracksite near Jilijing village, and other sites near Chongqing, after Lockley and Matsukawa (2009, fig. 6). **A1–A3** were identified as *Anomoepus* trackways (white arrows), corresponding to T1-T3 in the present study. A1 and A2 show detail of trackways with elongate traces. **B,** 2001 map of the site. **C,** *Anomoepus* tracks from the Chongqing Natural History Museum. **D**, detail of *Jinlijingpus nianpanshanensis* (= *Eubrontes nianpanshanensis*) from trackway T4 corresponding to NPS T4 R9, L9 and R10 of the present study.

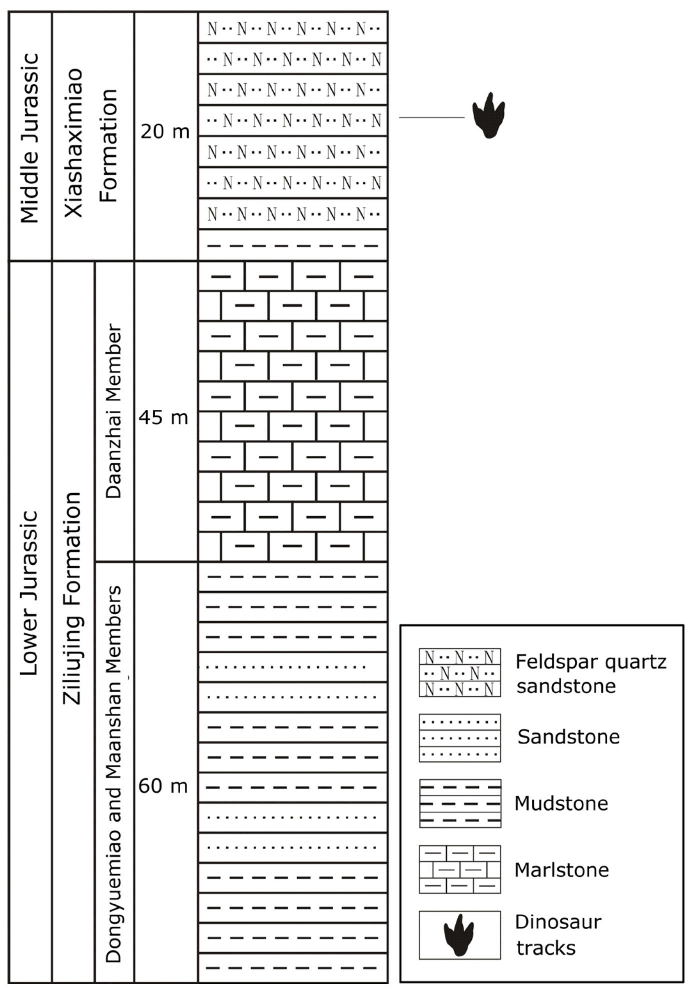

FIGURE 3. Stratigraphic section of Mesozoic sedimentary sequences in the Jinlijing area with the position of the footprint level.

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

Locality abbreviation. NPS = Nianpanshan tracksite, Jinlijing, Zizhong County, Sichuan, Province, China.

Ichnological abbreviations. ML = maximum length of footprint; **MW** = maximum width of footprint; **AT** = anterior triangle formed by tips of digits II, III, IV; L/W = length/width ratio of anterior triangle; **PL** = pace length; **SL** = Stride length; **PA** = pace angulation; **R** = right footprint; **L** = left footprint; **h** = hip height calculated after Thulborn (1990).

SYSTEMATIC ICHNOLOGY

Theropoda Marsh, 1881
Ichnofamily Eubrontidae Lull, 1904
Ichnogenus *Eubrontes* E. Hitchcock, 1845
***Eubrontes nianpanshanensis* (Yang and Yang, 1987)**
Lockley et al., 2013

Holotype: A complete natural mold of a pes track, cataloged as NPS-T4-R8, from the Nianpanshan tracksite (Figs. 4–5; Table 1), and other pes tracks, NPS-T4-R1–L7, L8–L10 in the same trackway, which include the three consecutive tracks illustrated by Lockley and Matsukawa (2009, fig. 2B, D). All the specimens are stored in the Shenglingshan National Geological Park.

Type horizon and locality: Xiashaximiao Formation, Middle Jurassic. Nianpanshan tracksite, Zizhong County, Sichuan Province, China.

Emended diagnosis: A relatively large, functionally tridactyl, tetradactyl footprint, pes L/W ratio of 1.1. Two metatarsophalangeal pad traces from digit II and IV form a burly heel, and the boundary is in extreme proximity to the axis of digit III. Tridactyl portion of footprint nearly symmetrical with a wide divarication angle. Step length is roughly three times footprint length. Mean pace angulation is high, about 170◦.

Description: NPS-T4 trackway (Fig. 2B) is a large tridactyl trackway composed of 19 tracks, the same number as mapped by Lockley and Matsukawa (2009, fig. 6). The average track length is 34.3 cm. The mean length/width ratio is 1.1. The mean L/W ratio of the anterior triangle is 0.37, indicating weak mesaxony (Lockley, 2009). R8 is the best preserved track. Digit III of T4-R8 projects the farthest anteriorly, followed by digits II and IV.

Two metatarsophalangeal pad traces can be seen: a smaller one posterior to digit II (particularly in T4-R8) and a larger one posterior to digit IV. They are amalgamated, with the boundary between both being indistinct. The smaller metatarsophalangeal pad trace is round, positioned near the axis of digit III, and is separated from the first proximal pad of digit II by a larger gap. The larger metatarsophalangeal pad trace is round and positioned near the axis of digit IV. The deep, concave digit impressions retain pad impressions, with a formula (including metatarsophalangeal pads II and IV) of x-3-3-4-x. Each digit has a sharp claw mark, that of digit IV being the longest and most distinctive. The digits have relatively wide divarication angles between digit II and IV (64°). The divarication angle between digits II and III (28°) is smaller than that between digits III and IV (36°).

The morphological characteristics of the other tracks of T4 are generally consistent with those of T4-R8. In the tracks that appear to preserve large or fleshy heel traces, such as L1, L10, R10, the heels are actually formed by metatarsophalangeal pad traces from digit II and IV.

Comparisons: Two metatarsophalangeal pad traces are common in *Eubrontes* tracks, as in the type specimen AC 151 (Olsen et al., 1998) and *Eubrontes zigongensis* (Xing et al., 2014b). The most striking characters of *Eubrontes nianpanshanensis* are the burly heel traces with a boundary almost reaching the axis of digit III. This is different from other *Eubrontes* tracks.

Eubrontes morphotype tracks (including the coarsely similar *Changpeipus*) are common in the Jurassic of China. However, *Eubrontes nianpanshanensis* has lower mesaxony (mean 0.37, media 0.38). In contrast, the L/W ratio of the anterior triangle in *Eubrontes zigongensis* from the Lower Jurassic Zhenzhuchong Formation (Xing et al., 2014b) is 0.48, in *Changpeipus pareschequier* (*Eubrontes pareschequier*) from the Lower Jurassic Lufeng Formation (Xing et al., 2009a) is 0.53, in *Changpeipus carbonicus* (Xing et al., 2014c) from the Middle Jurassic Sanjianfang Formation is 0.46, and in *Changpeipus carbonicus* (Young, 1960; Xing et al., 2009a) from the Middle or the Lower Jurassic Tuntianying Formation is 0.47.

For theropods, Thulborn (1990) first suggested that hip height $h = 4.9 \times$foot length. The relative stride length (SL/h) may be used to determine whether the trackmaker was 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 ratio of *Eubrontes nianpanshanensis* is 1.17, and this suggests a walking movement. Using the equation to estimate speed from trackways (Alexander, 1976), the mean locomotion speed of the trackmaker is 4.79 km/h. The body length of the trackmaker of *Eubrontes nianpanshanensis* was approximately 4.4 m, calculated using the average hip height to body length ratio of 1:2.63 (Xing et al., 2009b).

cf. *Eubrontes* isp.

NPS-T5 (Figs. 4-5) is a medium-sized tridactyl trackway consisting of 20 tracks, with an average length of 19.8 cm. The mean length/width ratio is 1.0. The mean L/W ratio of the anterior triangle (mean 0.36, media 0.37) is similar to that of *Eubrontes nianpanshanensis,* NPS-T4, also indicating weak mesaxony (Lockley, 2009). NPS-T5 is poorly preserved. None of the NPS-T5 tracks have preserved metatarsophalangeal pads. Each digit has a sharp claw mark, and the digits have relatively wide divarication angles between digit II and IV (89°). It cannot be excluded that NPS-T5 is simply a poorly preserved *E. nianpanshanensis*. However, the preservation of the material does not allow a concrete ichnotaxonomic assignment and therefore is referred here tentatively to cf. *Eubrontes* isp. based on similarities with this ichnogenus.

Ichnogenus *Anomoepus* E. Hitchcock, 1848
***Anomoepus* isp.**

Description: NPS-T1 is a small-sized tridactyl trackway consisting of 26 tracks (Figs. 4, 6), with an average length of 14.4 cm (= trackway A1 of Lockley and Matsukawa 2009). The mean length/width ratio is 1.0. The mean L/W ratio of the anterior triangle is 0.46, indicating weak mesaxony (Lockley, 2009). Trackway NPS-T1 is narrow (pace angulation approximately 167°) and is characterized by short step lengths (51.8 cm on average, 3.6 times longer than footprint length). NPS-T1-R7 is the best preserved, with three digits separated from each other and lacking a metatarsophalangeal pad. The concave digit impressions retain pad impressions with the formula of x-2-3-3-x. Each digit has a claw mark. The claw marks are round and blunt in the middle digit III and relatively sharp in both outer digits. Digit IV reveals the most well-preserved claw trace. The digits have relatively wide divarication angles between digit II and IV (107°).

In non-resting tracks made by bipedal trackmakers, tail marks are rare and sometimes hard to explain. From NPS-T1-L7 to L10, discontinuous linear traces are present and vary from 1–3 cm in width. These are either tail marks or toe “drag” traces, which are sometimes difficult to distinguish. However, a toe “drag” trace would be expected to originate more continuously from distinct digit tips. This cannot be observed in the NPS material. However, they are close to or overlie the inner digit traces (digit II) in most tracks. Single steps in NPS-T1 significantly decrease between L7–L10, in association with the tail marks.

NPS-T2 (Fig. 4B-C) is a small-sized tridactyl trackway consisting of nine tracks, with an average length of 6.8 cm. The mean length/width ratio is 0.9. The tracks show weak mesaxony (0.54). Trackway NPS-T1 (Fig. 4A) is narrow (pace angulation about 140°) and is characterized by comparatively short step lengths (23.7 cm on average, 3.5 times longer than footprint length). NPS-T2-L3 is the best preserved, with three separated digits, and without a metatarsophalangeal pad. The digit impressions are indistinct. Each digit has a relatively blunt claw mark. The digits have relatively wide divarication angles between digit II and IV (114°).

From NPS-T2-R1 to L2, consecutive elongate traces are present and vary from 1–2.5cm in width. This is trackway A2 of Lockley and Matsukawa (2009). The elongate traces are consistently in line with the midline of the trackway. Single steps of NPS-T2 are relatively short in the areas where the elongate traces exist. Yang et al. (2012) proposed naming this trackway *Chuanchengpus shenglingensis*. However, we can see no morphological difference between this trackway (T2) and T1: Figures 2, 4, and 6, show the characteristic inward rotation of the *Anomoepus* trackways. We therefore consider *Chuanchengpus shenglingensis* a *nomen dubium*.

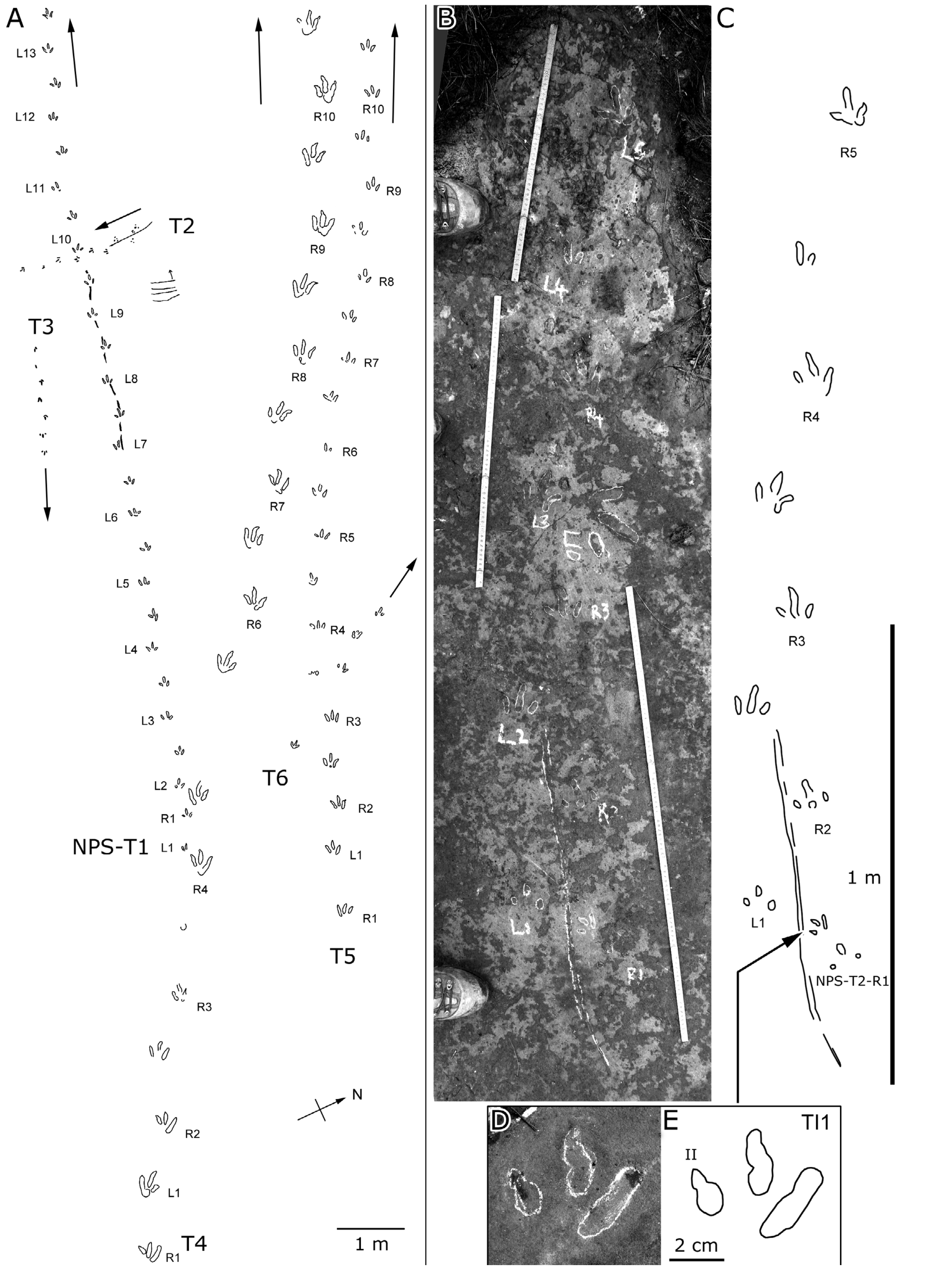

FIGURE 4. Map showing distribution of footprints at Nianpanshan tracksite (**A**); photograph (**B, D**) and outline drawings (**C, E**) of NPS-T2 trackway and TI1 isolated track.

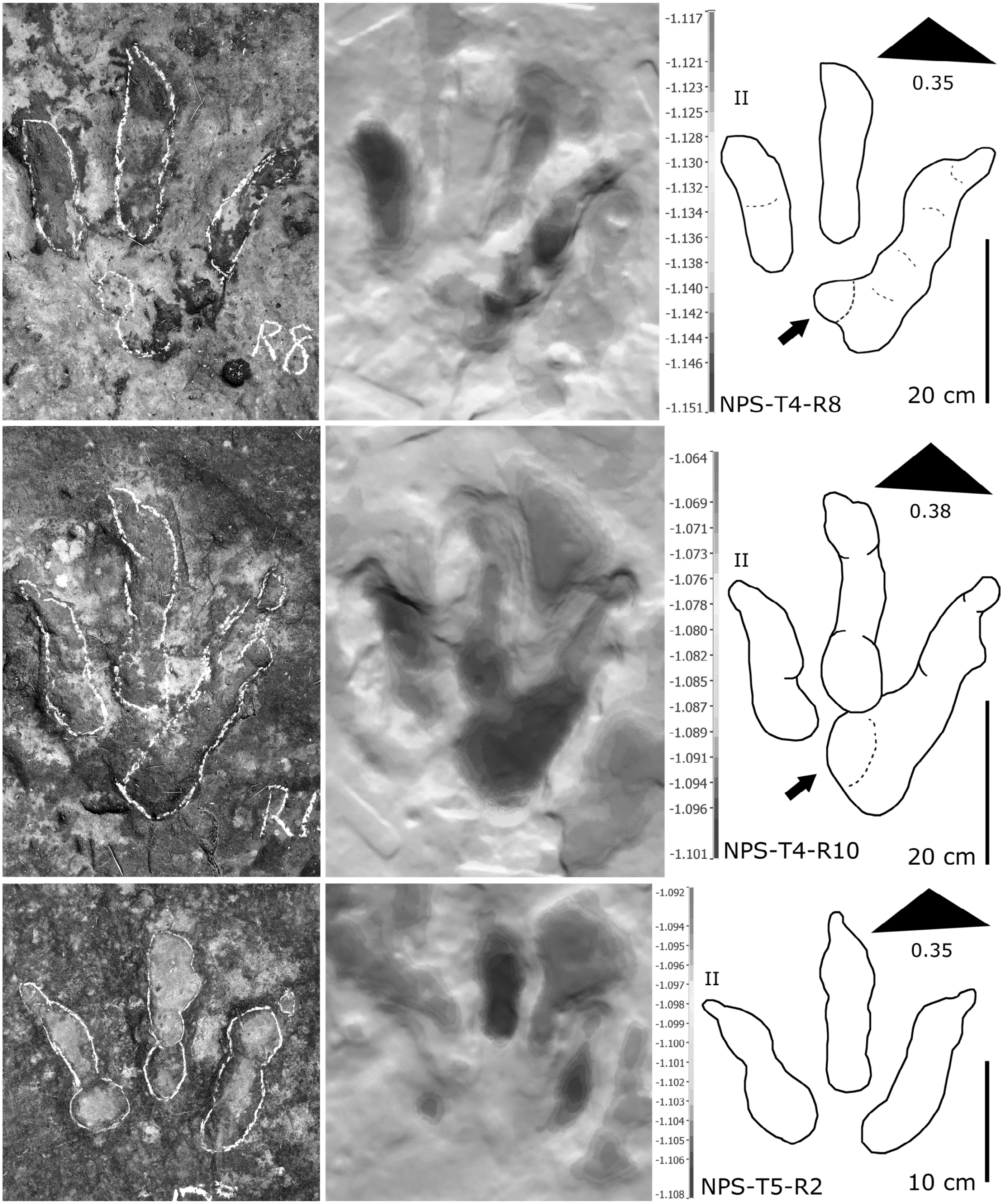

FIGURE 5. Photographs, 3D models, and outline drawings of *Eubrontes nianpanshanensis*. Arrows indicate metatarsophalangeal pad impression of digit II.

Table. 1 Measurements (in cm and degrees) of dinosaur tracks from Nianpanshan tracksite, Sichuan Province, China.

Number NPS-	ML	MW	ML/MW	II-IV	M	PL	SL	PA
T1-L1	13.5	—	—	—	—	53.0	99.0	180
T1-R1	16.0	15.5	1.0	103	0.57	46.0	95.0	163
T1-L2	16.0	12.0	1.3	95	—	50.0	105.0	158
T1-R2	14.5	13.5	1.1	87	0.45	57.0	109.0	165
T1-L3	14.5	16.5	0.9	108	0.34	53.0	109.0	180
T1-R3	15.0	14.5	1.0	96	0.52	56.0	105.0	161
T1-L4	15.5	16.5	0.9	115	0.46	50.5	99.0	169
T1-R4	19.0	13.5	1.4	67	0.69	49.0	99.0	154
T1-L5	13.5	15.5	0.9	96	0.36	52.5	106.0	180
T1-R5	13.0	16.0	0.8	110	0.43	53.5	109.0	161
T1-L6	12.0	19.0	0.6	102	0.25	57.0	108.0	158
T1-R6	13.5	15.5	0.9	99	0.39	53.0	101.0	145
T1-L7	12.0	19.5	0.6	—	—	53.0	103.0	164
T1-R7	14.0	16.0	0.9	107	0.52	51.0	104.0	180
T1-L8	13.0	14.5	0.9	96	0.40	53.0	102.0	157
T1-R8	14.5	16.0	0.9	112	0.61	51.0	100.0	180
T1-L9	14.5	13.5	1.1	108	0.53	49.0	97.5	168
T1-R9	15.5	15.0	1.0	90	0.56	49.0	99.0	180
T1-L10	13.5	16.0	0.8	103	0.44	50.0	97.0	168
T1-R10	15.0	15.0	1.0	94	0.49	47.5	97.5	146
T1-L11	14.5	—	—	—	—	54.5	104.0	169
T1-R11	14.0	16.5	0.8	108	0.35	50.0	101.0	169
T1-L12	12.5	13.0	1.0	87	0.41	52.0	103.5	180
T1-R12	15.0	15.0	1.0	89	0.52	51.5	106.0	180
T1-L13	14.5	15.0	1.0	88	0.40	53.0	—	—
T1-R13	16.0	15.5	1.0	87	0.51	—	—	—
Mean	14.4	15.4	1.0	98	0.46	51.8	102.4	167
T2-R1	5.5	7.0	0.8	160	0.56	21.5	36.0	104
T2-L1	5.0	7.0	0.7	125	0.48	24.0	44.0	139
T2-R2	6.0	7.5	0.8	98	0.58	23.0	41.5	132
T2-L2	7.0	7.0	1.0	93	0.46	22.5	45.5	151
T2-R3	7.0	8.0	0.9	113	0.57	24.5	50.5	157
T2-L3	8.0	8.0	1.0	82	0.53	27.0	47.5	140
T2-R4	8.0	8.5	0.9	66	0.49	23.5	56.0	158
T2-L4	5.5	—	—	—	—	23.5	—	—
T2-L5	9.0	8.0	1.1	83	0.61	—	—	—
Mean	6.8	7.6	0.9	103	0.54	23.7	45.9	140
T3-L1	7.5	—	—	—	—	25.0	50.5	164
T3-R1	—	—	—	—	—	26.0	51.0	180
T3-L2	9.0	7.0	1.3	88	—	25.0	51.5	164
T3-R2	7.5	—	—	—	—	27.0	53.5	164
T3-L3	7.0	—	—	—	—	27.0	53.0	158
T3-R3	7.0	9.0	0.8	135	0.50	27.0	—	—
T3-L4	7.5	8.5	0.9	114	0.52	—	—	—
Mean	7.6	8.2	1.0	112	0.51	26.2	51.9	166
T4-R1	29.0	30.0	1.0	72	0.19	109.0	201.0	180
T4-L1	42.5	29.0	1.5	62	0.56	92.0	199.0	180
T4-R2	28.0	30.5	0.9	66	0.22	107.0	196.0	164
T4-L2	28.0	28.0	1.0	75	0.32	91.0	—	—
T4-R3	27.0	21.5	1.3	60	—	—	206.0	—
T4-L3	—	—	—	—	—	—	—	—
T4-R4	39.0	29.5	1.3	58	0.27	105.0	—	—
T4-L4	34.5	28.0	1.2	64	0.44	—	201.0	—
T4-R5	—	—	—	—	—	—	—	—
T4-L5	36.0	27.5	1.3	66	0.48	103.5	194.5	180
T4-R6	32.0	33.5	1.0	82	0.35	91.0	184.0	168
T4-L6	31.5	26.0	1.2	58	0.33	94.0	193.0	164
T4-R7	37.0	29.5	1.3	59	0.38	101.0	199.0	180
T4-L7	35.0	32.5	1.1	71	0.37	98.0	195.0	168
T4-R8	38.0	34.0	1.1	64	0.35	98.0	196.0	180
T4-L8	36.0	35.0	1.0	64	0.38	98.0	201.0	164
T4-R9	34.5	27.5	1.3	63	0.40	105.0	203.5	172
T4-L9	35.5	36.6	1.0	70	0.48	99.0	194.0	154
T4-R10	37.0	33.0	1.1	58	0.38	100.0	—	—
T4-L10	37.5	33.0	1.1	69	0.38	—	—	—
Mean	34.3	30.3	1.1	66	0.37	99.4	197.4	171
T5-R1	20.5	22.0	0.9	69	0.17	95.0	165.0	180
T5-L1	23.0	20.0	1.2	74	0.37	70.0	132.0	156
T5-R2	22.5	23.0	1.0	82	0.35	65.5	131.5	180
T5-L2	23.0	22.0	1.0	82	0.37	66.5	142.5	180
T5-R3	21.0	20.0	1.1	77	0.27	76.0	140.0	138
T5-L3	—	—	—	—	—	74.0	139.5	142
T5-R4	14.5	21.0	0.7	104	0.24	73.5	138.5	154
T5-L4	18.5	—	—	—	—	68.5	138.5	166
T5-R5	17.0	21.0	0.8	107	0.30	71.0	132.5	180
T5-L5	20.0	22.0	0.9	85	0.40	61.5	141.5	180
T5-R6	19.5	16.0	1.2	—	—	80.0	142.5	161
T5-L6	17.0	20.0	0.9	90	0.30	64.5	126.5	170
T5-R7	22.0	20.0	1.1	105	0.47	62.5	128.0	180
T5-L7	19.5	21.0	0.9	90	0.38	65.5	134.0	156
T5-R8	21.5	18.5	1.2	94	0.59	71.5	139.5	155
T5-L8	21.0	21.0	1.0	86	—	71.5	138.5	150
T5-R9	22.5	18.5	1.2	83	0.49	72.0	138.5	158
T5-L9	16.5	19.5	0.8	99	0.41	69.0	138.5	170
T5-R10	18.5	21.5	0.9	85	0.29	70.0	—	—
T5-L10	18.0	21.5	0.8	95	0.38	—	—	—
Mean	19.8	20.5	1.0	89	0.36	70.9	138.2	164
T6-R1	14.5	12.0	1.2	79	0.44	—	138.0	—
T6-L1	—	—	—	—	—	—	—	—
T6-R2	14.5	16.0	0.9	82	0.35	54.0	101.0	155
T6-L2	13.5	14.5	0.9	58	—	49.5	—	—
T6-R3	14.0	12.5	1.1	84	—	—	—	—
Mean	14.1	13.8	1.0	76	0.40	51.8	119.5	155
TI1	4.0	4.7	0.9	93	0.32	—	—	—

Abbreviations: **ML**: Maximum length; **MW**: Maximum width (measured as the distance between the tips of digits II and IV); **II-IV**: angle between digits II and IV; **PL**: Pace length; **SL**: Stride length; **PA**: Pace angulation. ; **ML/MW** is dimensionless.

NPS-T3 (Fig. 4A) is a trackway of a small tridactyl biped consisting of seven tracks and overall morphological characteristics that resemble NPS-T2. The average length of the tracks is 7.6 cm. The mean length/width ratio is 1.0. The tracks show weak mesaxony (0.51). NPS-T6 is a small-medium-sized tridactyl trackway with four tracks and resembles NPS-T1 in overall morphology. The average length of the tracks is 14.1 cm. The mean length/width ratio is 1.0. The tracks show weak mesaxony (0.40). NPS-TI1 is the smallest track (4.0 cm long) at the Nianpanshan site and morphologically resembles NPS-T2 tracks. The length/width ratio of NPS-TI1 is 0.9, and it shows weak mesaxony (0.32).

Comparisons: The tridactyl tracks NPST1-NPS T3 from Nianpanshan resemble the ichnogenus *Anomoepus*, as noted by Lockley and Matsukawa (2009). They are similar in size, having wide divarication angles, weak mesaxony, and round and blunt claw marks. In general, the Nianpanshan *Anomoepus* tracks have smaller L/W ratios but larger L/W ratios of the anterior triangle (Fig. 7) compared with other tridactyl tracks from the same site.

In China, most *Anomoepus* are found in Lower–Middle Jurassic formations, and are known from Inner Mongolia (Li et al., 2010), Shaanxi Province (Li et al., 2012; Xing et al., 2015), Sichuan Province (Lockley and Matsukawa, 2009), Chongqing municipality (Xing et al., 2013), and Yunnan Province (unpublished data). The Nianpanshan *Anomoepus* tracks from Sichuan Province represent the first historical record of the ichnogenus from China (Lockley and Matsukawa, 2009).

The Nianpanshan *Anomoepus* tracks can be assigned to at least three size classes: 4 cm, 6.8–7.6 cm, and 14.1–14.4 cm, indicating that local trackmakers were relatively diverse. Based on the hip height of small ornithopods = 4.8 (hip height conversion factors) the maximum length of the pes trace (Thulborn, 1990), and the average ratio of hip height to body length of these bipedal dinosaur of 1:2.63 (Xing et al., 2009b), the NPS *Anomoepus* trackmakers are thereby estimated to have been 0.5 m, 0.9–1.0 m, and 1.8 m long, similar to those of skeletal specimens of ornithischians from the Sichuan Basin. The Sichuan Basin was inhabited by diversified small Neornithischia during the Middle Jurassic, including *Xiaosaurus* Dong and Tang, 1983, *Agilisaurus* Peng, 1990, and *Hexinlusaurus* Barrett et al., 2005. All of these taxa are 1.4–2 m long (Peng et al., 2005), similar to the larger NPS *Anomoepus* trackmakers.

Tail and Toe Traces

It may be difficult to distinguish between tail and toe traces made by tridactyl bipedal dinosaurs. There have been relatively few papers

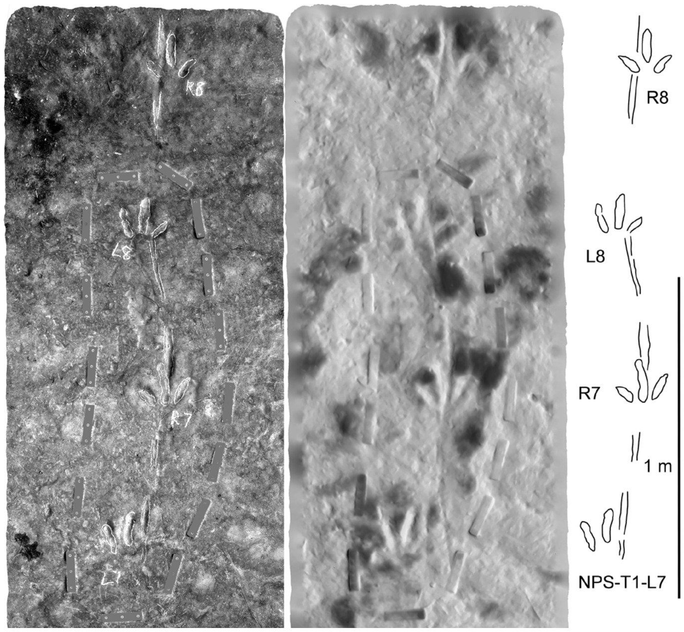

FIGURE 6. Photographs, 3D models, and outline drawing of Nianpanshan *Anomoepus* trackway NPS-T1.

dealing specifically with tail traces of dinosaurs (Platt and Hasiotis, 2008; Kim and Lockley, 2013). The more recent of these reviews notes that believable tail traces occur at only 33 sites, and, of these, 31 reports represent bipedal dinosaurs (17 ornithopods and 14 theropods). These 31 reports do not include the two Nianpanshan trackways attributed to *Anomoepus*. Both these studies recognize that tail traces vary in width, continuity and sinuosity, and Kim and Lockley (2013, p. 139) recognized that " it is necessary to consider that some presumed tail traces may have been made by dinosaurs dragging their toes… [and that]… it may be difficult to differentiate tail traces and toe drag marks." Despite these uncertainties the elongate traces associated with trackway segment NPS-T1-L7-R8 (Figs. 4A, 6) shows an almost continuous sinuous trace with a wave length roughly corresponding to stride length: i.e., about 1 meter. This observation strongly suggests that the elongated traces were made by the tail and not by toe dragging.

CONCLUSIONS

The Nianpanshan tracksite was reinvestigated and remapped to show some previously undescribed detail: i.e., six trackways (NPS T1–T6) rather than the five previously reported.

Tail traces associated with two *Anomoepus* trackways were

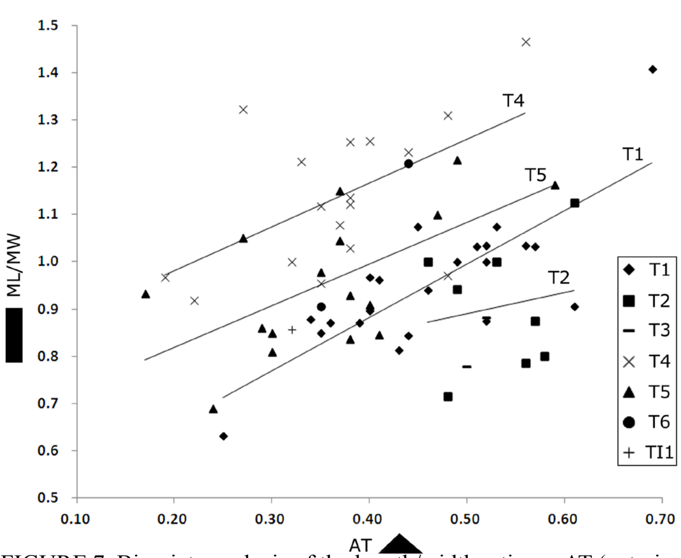

FIGURE 7. Bivariate analysis of the length/width ratio vs. AT (anterior triangle length-width ratio) of Nianpanshan dinosaur tracks and other tridactyl theropod ichnotaxa (Lockley, 2009).

TABLE 2. Estimated data of the speed of Nianpanshan dinosaur trackmakers

No.	SL/h	S (km/h)
NPS-T1	1.48	4.50
NPS-T2	1.41	2.84
NPS-T3	1.42	3.06
NPS-T4	1.17	4.79
NPS-T5	1.55	5.54
NPS-T6	1.77	5.98

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

illustrated but not described. These are illustrated here and described in more detail and shown to have a sinuous morphology that demonstrates they are tail rather than toe drag traces. These reports can be added to the 33 convincing tail trace reports by Kim and Lockley (2013), of which 17 are associated with ornithischian trackways.

The identification of two track morphotypes, *Eubrontes* and *Anomoepus,* by Lockley and Matsukawa (2009) is confirmed as the appropriate ichnotaxonomy to replace *Jilijingpus* and *Chuanchenpus,* respectively, of Yang and Yang (1987).

Attempts to introduce the new ichnospecies *Chuanchengpus shenglingensis* for trackway T2 by Yang et al., (2011, 2012) are rejected because Trackway T2 is a typical example of *Anomoepus*, *C. shenglingensis* as therefore considered a *nomen dubium*.

The small Jurassic Neornithischia found in Sichuan Basin are considered the potential trackmakers of Nianpanshan *Anomoepus* isp.

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