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ORIGINAL ARTICLE

Dinosaur tracks from Tang Dynasty Grottoes area in Sichuan Province, China

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ABSTRACT

In recent year the number of tracksites discovered and reported from the Lower Cretaceous Jiaguan Formation, Sichuan Basin has increased steadily. Here we report on the 20th and 21st sites which are situated in unusual locations in a cave and on a steep bedding plane surface in association with Tang Dynasty grottoes. The ichnofauna is represented by two small assemblages which are both theropod-dominated. Due to sub-optimal preservation, the tracks are identified only as grallatorid and small and larger eubrontid, with *Paracorpulentapus* also tentatively recognized.

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1 Introduction

In the Sichuan Basin, the Lower Cretaceous Jiaguan Formation is a typical Type 1 or Type 2 ichnofaunal deposits, with the dinosaur fossil record consisting only of tracks or being dominated by tracks (Xing et al., 2018a). Many dense tracksites record a taxonomic diversity of avian and non-avian theropods, sauropods, ornithopods, possible thyreophorans, and pterosaurs (Xing & Lockley, 2016). This rich track record has permitted detailed study of the Jiaguan Formation's dinosaur fauna (Xing et al., 2016).

Xing and Lockley (2016) and Xing et al. (in review) described 18 track sites from the Jiaguan Formation. The 19th track site, the Changtan site, is geographically close to the 18th and is currently under study. More than 80% of these Jiaguan Formation tracksites are in the southeastern part of the Sichuan Basin, and are concentrated in the Qijiang–Gulin area. In the west of the basin, a few sites have been discovered, such as the Emei (Chuanzhu) and Huibu sites (Xing et al., 2018b). In January 2020, YAN Zongmi, a geological team member from Sichuan, reported to the first author the location of several dinosaur footprints from Qianfoyan, Jiajiang County, Leshan City, in the western Sichuan Basin (Fig 1). These new records became the 20th and 21th track sites of the Jiaguan Formation: Lingyadong site or Lingya cave site (GPS: N 29° 45' 16", E 103° 32' 21") and Qianfoyan site (GPS: N 29° 45' 14", E 103° 32' 58") (Fig 2). The former tracksite lies 1km straight west of the latter.

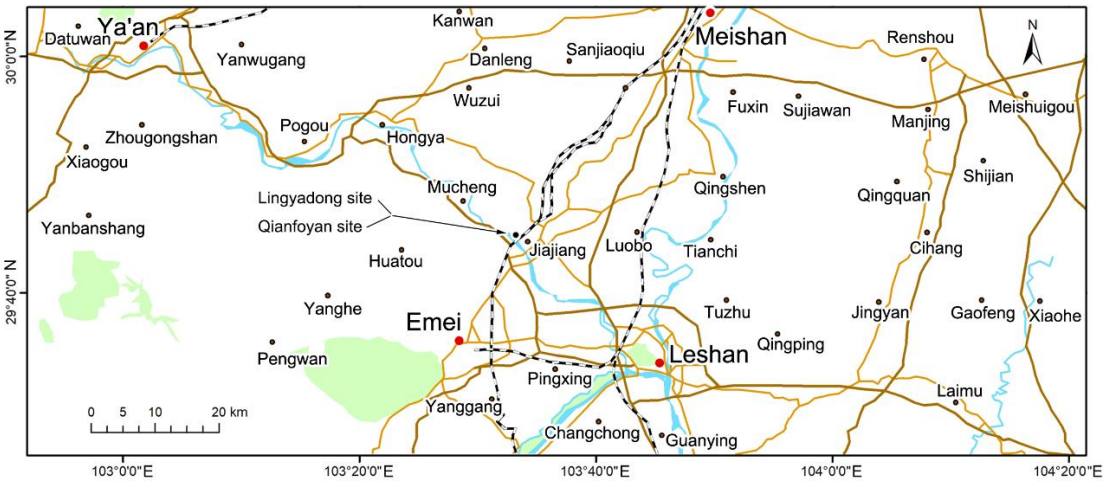

Figure 1. Geographical setting showing the location of the Lingyadong and Qianfoyan sites in Sichuan Province, China.

The two new tracksites are both on Qianfoyan, or Qianfo Cliff, which means "a rock with thousands of Buddha sculptures". Qianfoyan is located at Daguan mountain, along the Qingyi River in Jiajiang County (Yu & Wang, 2012). With a temperate subtropical climate, the area is 380 to 820 meters above sea level and covers an area of about 4.5 km^2. The Qianfoyan Buddha statues were carved in the Tang Dynasty (A.D. 618–907), Ming Dynasty (A.D. 1368–1644), and Qing Dynasty (A.D. 1636–1912) (Liang, 2011; Yu & Wang, 2012). The statues are densely distributed on the steep cliff, facing the river, across a cliff surface roughly 60m tall and 600m long, including 162 caves. More than 2,470 stone statues are present (Yu & Wang, 2012). In 2006, Qianfoyan was included in the sixth batch of historic protected sites (Major Historical and Cultural Site Protected at the National Level, No. VI 85) (National Administration of Cultural Heritage, 2009). No inscriptions or written record were found in the cave at the Lingyadong site, making the exact date of its excavation is uncertain. The Lingyadong site may have served as a warehouse or as a living space for resident Buddhists.

2. Materials and methods

Lingyadong site is inside the Jiajiang Qianfoyan Scenic Spot (Fig 3). The Lingya cave is 3 m in height, 2.5 m in width, and 40 m in deep. The tracks are located on the top siltstone surface at the end of the cave, which is about 2–3m^2. Also present on this surface are well-developed ripple marks. There are eight footprints in total, all of which are natural casts. Three comprise a distinct trackway (cataloged as LYD-T1) and five are isolated tracks (cataloged as LYD-T11–5. The authors outlined the tracks with chalk, and measured and photographed them.

Qianfoyan site is located on a steep rock face in the parking lot at the entrance of the scenic spot and is currently a construction site for an apartment complex (Fig 4). The track bearing rock face is about 25m tall. There are two track areas exposed on the siltstone surfaces. Area 1 is about 7m above the ground, and consists of two footprints (cataloged as QFY-T1-L1 and R1) that form a single step (Fig 5). Area 2 is about 14m above the ground, with well-developed ripple marks and invertebrate traces. The 8 footprints are cataloged as QFY-TI1–8 (Fig 6). Area 1 is approximately 1.5m higher than Area 2 in the sedimentary sequence.

Due to the steepness of the bedding planes (80°) at Qianfoyan tracksite, it was necessary to use safety ropes during the study. Professional mountaineers set up natural anchors at the top of the mountain, descended to Areas 1 and 2 by ropes, cleaned the plants near the tracks, drew the outline of the tracks with chalks, and, following the standard procedures of Leonardi (1987) and Lockley and Hunt (1995), measured the following data: maximum Length (L), maximum width (W), pace length (PL), stride length (SL), and track rotation (R). All footprints were photographed, and some of the well-preserved footprints were traced onto sheets of transparent plastics. No natural casts were collected.

The whole exposed surface was photographically recorded using a remote controlled four axis quadcopter (DJI Phantom 4 Pro: weight: 1388 g; max service ceiling above sea level: 6000 m; max flight time: 30 min; max wind speed resistance: 10 m/s and with DJI GO App, iOS 8.0 or later) with a 20 million effective pixels camera (FC6310, with an 8.8 mm/24 mm lens, f/2.8 – f/11). After taking off from the ground, the DJI Phantom 4 Pro was controlled remotely and it

provide real–time HD video through a mobile APP (DJI GO 4).

3. Geological setting

The local Cretaceous sedimentary sequences are composed of the Jiaguan Formation (Lower Cretaceous) and the Guankou Formation (Upper Cretaceous) (Gu & Liu, 1997). The Jiaguan Formation is characterized by thick, brick red, feldspathic, quartz sandstones (Sichuan Provincial Bureau of Geology aviation regional Geological Survey team 1976) (Fig 2). The main authors of this paper have described in detail the lithostratigraphy and geochronology of the Jiaguan Formation in previous papers (such as Xing et al., 2016).

Qianfoyan is 30 km away from the Leshan Giant Buddha (Leshan Giant Buddha Scenic Area, A.D. 713), which has been listed as a UNESCO World Heritage Site since 1996. They are both located in the Upper Member of the Jiaguan Formation, which is a thick, purplish, sandstone body (He, 2010). From an engineering point of view, this rock very suitable for the excavation of caves and carving of cliff figures.

The Upper Member of the Jiaguan Formation is 345–1000 m thick and is comprised of feldspathic quartz sandstone interbedded with thin layers of lenticular mudstone and siltstone. The sediments of the Jiaguan Formation are those of alluvial fan, river and desert deposits (Geng, 2011). Chen (2009) argued that the Upper Member represents a meandering stream deposit interbedded with deposition from small, braided rivers.

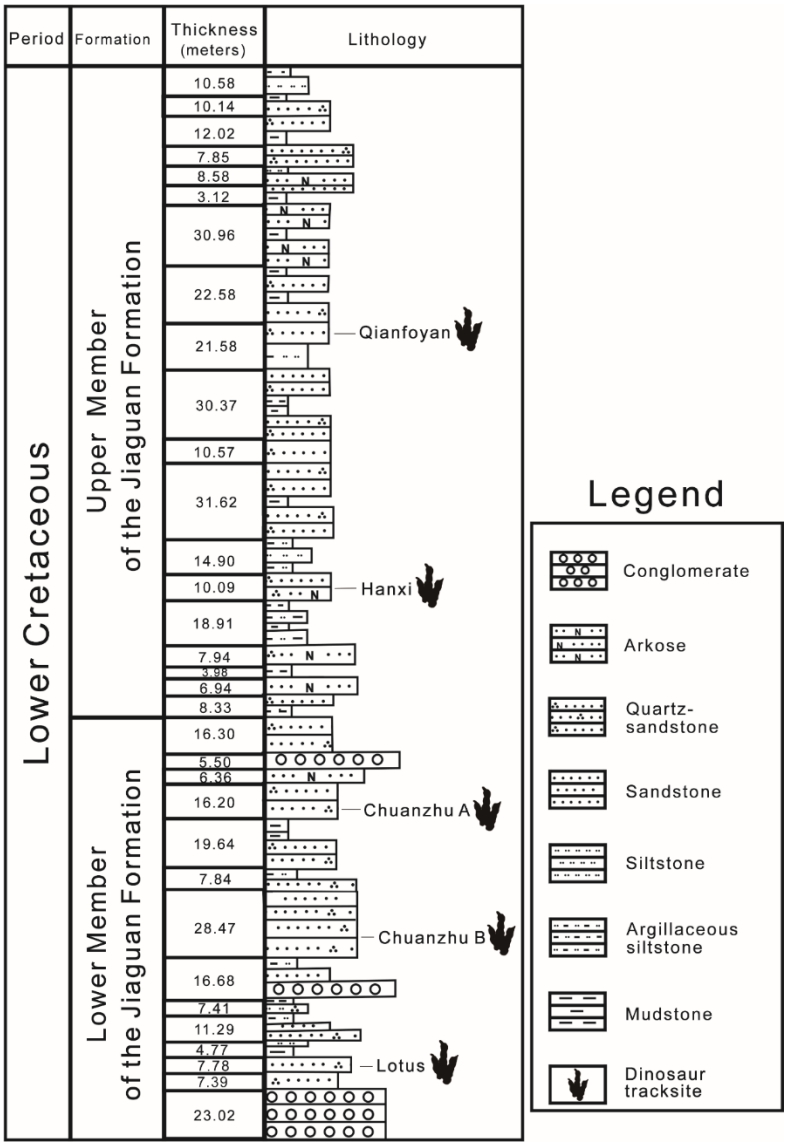

Figure 2. The lithostratigraphic section showing sediment characteristics and position of track-bearing levels at the Qianfoyan Site and other dinosaur track site from Jiaguan Formation.

4 Theropod tracks

4.1 Description

The mean length and width of the LYD-T1-L1–L2 tracks are 15.0 cm and 12.7 cm, respectively, making the mean length/width ratio 1.2 (Table 1). LYD-T1 is the most well-preserved track in the Qianfoyan area (Figs 3, 7) and is a good morphological representative of all the LYD-T1-L1–L2T1-L1 tracks. Digit III projects the farthest anteriorly, followed by digits II and IV. One round metatarophalangeal pad trace is present posterior to digit III. The digit pad impressions are indistinct. Each digit has a sharp claw mark, and digit II has the clearest and longest mark. The divarication angle between digit II and IV is relatively wide (69°). The divarication angle between digits II and III (35°) is almost the same as that between digits III and IV (34°). LYD-T1-L1 has an apparent outward rotation: ~21° from the midline of the trackway. LYD-T1 is characterized by weak mesaxony (average 0.38, range 0.26–0.49, N=3). The step is 2.6 times larger than the footprint length. The pace angulation is 173°, making it a narrow trackway. The features of LYD-T1-R1 and L2 are basically similar to those of the T1-L1.

	L	W	R	PL	SL	PA	L/W	M	II–IV
LYD-T1-L1	16.3	13.6	21	38.0	79.0	173.0	1.2	0.49	69
LYD-T1-R1	15.5	12.5	—	41.0	—	—	1.2	0.26	52
LYD-T1-L2	13.1	11.9	—	—	—	—	1.1	0.38	69
Mean	15.0	12.7	21	39.5	79.0	173.0	1.2	0.38	63
LYD-TI1	13.8	8.7	—	—	—	—	1.6	0.54	50
LYD-TI2	14.0	9.8	—	—	—	—	1.4	0.55	58
LYD-TI3	11.0	8.3	—	—	—	—	1.3	0.55	65
LYD-TI4	11.0	—	—	—	—	—	—	—	—
LYD-TI5	22.4	17.7	—	—	—	—	1.3	—	—
QFY-T1-L1	30.0	16.0	—	114.3	—	—	1.9	0.68	43
QFY-T1-R1	24.0	18.0	—	—	—	—	1.3	0.39	54
Mean	27.0	17.0	—	114.3	—	—	1.6	0.53	49
QFY-TI1	12.7	13.0	—	—	—	—	1.0	0.44	96
QFY-TI2	12.0	7.5	—	—	—	—	1.6	0.47	46
QFY-TI3	9.6	5.6	—	—	—	—	1.7	0.61	48
QFY-TI4	13.4	—	—	—	—	—	—	—	—
QFY-TI5	12.0	5.8	—	—	—	—	2.1	0.78	41
QFY-TI6	10.8	—	—	—	—	—	—	—	—
QFY-TI7	16.7	10.6	—	—	—	—	1.6	0.38	46
QFY-TI8	15.0	11.9	—	—	—	—	1.3	0.54	71

Table 1. Measurements (in centimeter, degree and square centimeter) of the theropod trackways from Lingyadong and Qianfoyan sites, Sichuan Province, China. **Abbreviations**: L: Maximum length; W: Maximum width; R: Rotation; PL: Pace length; SL: Stride length; PA: Pace angulation; L/W is dimensionless; M: Mesaxony; II–IV: the divarication angle of digits II–IV.

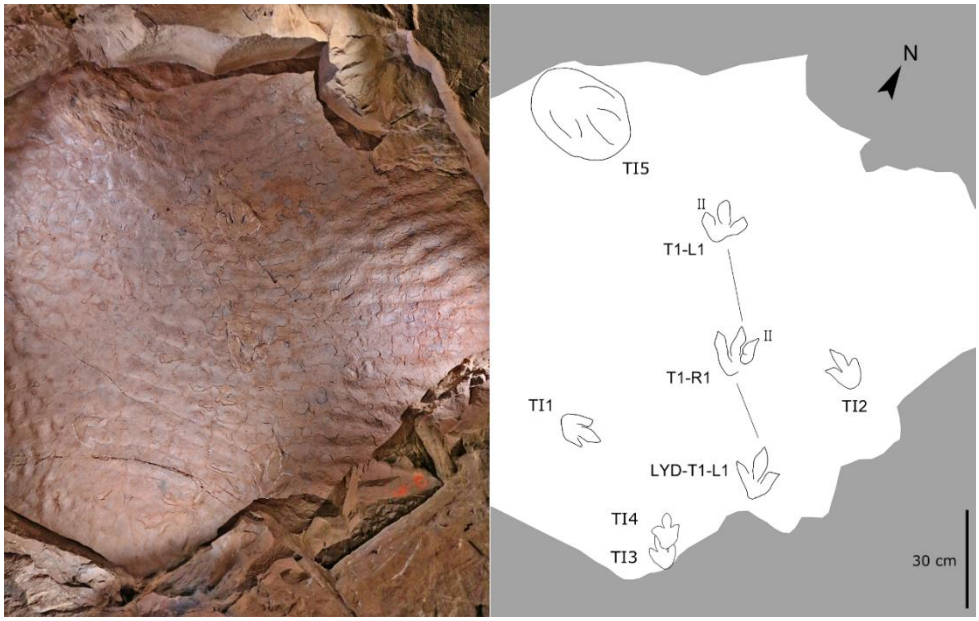

Figure 3. An overview photograph and line drawing of theropod tracks from Lingyadong Site.

The lengths of LYD-TI1 and TI2 are 13.8 cm and 14.0 cm and their length/width ratios are 1.6 and 1.4, respectively. Both tracks have stronger mesaxony than LYD-T1, (0.54 and 0.55, respectively). The divarication angles between digit II and IV are a bit narrower, 50° and 58°, respectively. The digit pad impressions are faint. LYD-TI3 and TI4 are poorly preserved and are the smallest footprints in this track site. They are both 11cm long, their length/width ratio is 1.3 (slightly lower than that of LYD-TI2), and their mesaxony is in accord with that of LYD-TI2. LYD-TI3 and TI4 have the same length and morphology, and may have been left by the same foot.

LYD-TI5 is located in an oval cast that measures 33.5cm in length and 24.3cm in width. Three faint digit impressions are discernable. The length of the footprint is 22.4cm, the width is 17.7cm, and the length/width ratio is 1.3. This makes LYD-TI5 the largest footprint at this site.

Figure 4. An overview photograph of Qianfoyan site.

QFY-T1-L1 and R1 are located at Qianfoyan Site Area 1(Fig 5). The mean length and width are 27.0 cm and 17.0 cm, respectively. The mean length/width ratio is 1.6. Digit III projects the farthest anteriorly, followed by digits II and IV. One round metatarophalangeal pad trace is present posterior to digit III. The digit pad impressions are indistinct. Each digit has a sharp claw mark, and digit III has the clearest and longest mark. The divarication angles between digit II and IV are relatively narrow (49°). QFY-T1 is characterized by weak mesaxony (average 0.53). The step is more than 4.2 times longer than footprint length.

QFY-T1-L1 and R1 are located in Qianfoyan Site Area 1. The mean length and width are 27.0 cm and 17.0 cm, respectively. The mean length/width ratio is 1.6. Digit III projects the farthest anteriorly, followed by digits II and IV. One round metatarophalangeal pad trace is present posterior to digit III.

The digit pad impressions are indistinct. Each digit has a sharp claw mark, and digit III has the clearest and longest mark. The divarication angles between digit II and IV are relatively narrow (49°). QFY-T1 is characterized by weak mesaxony (average 0.53). The step is more than 4.2 times the footprint length.

QFY-TI1–8 are located in Qianfoyan Site Area 2 (Figs 6, 8). QFY-TI1–6 are orientated from south to north, and QFY-TI7 and TI8 from east to west. None of the footprints clearly belong to trackways, but TI3 and TI6 may form a single step. QFY-TI1–8 are variable in overall size and proportions,

ranging from 9.6 to 16.7cm in length, with a length/width ratio ranging from 1.3 to 2.1cm, and mesaxony ranging from 0.38 to 0.78. The best preserved of these is QFY-TI8. QFY-TI8 has a length of 15.0 cm, a width of 11.9 cm, and a length/width ratio of 1.3. It has a single round metatarophalangeal pad trace posterior to digit III. No digital pad traces are visible across much of the track, because they are covered by overlaying sediments. Digit III has a sharp claw mark. The divarication angle between digit II and IV is relatively wide (71°) and digits II and IV show weak mesaxony (0.54).

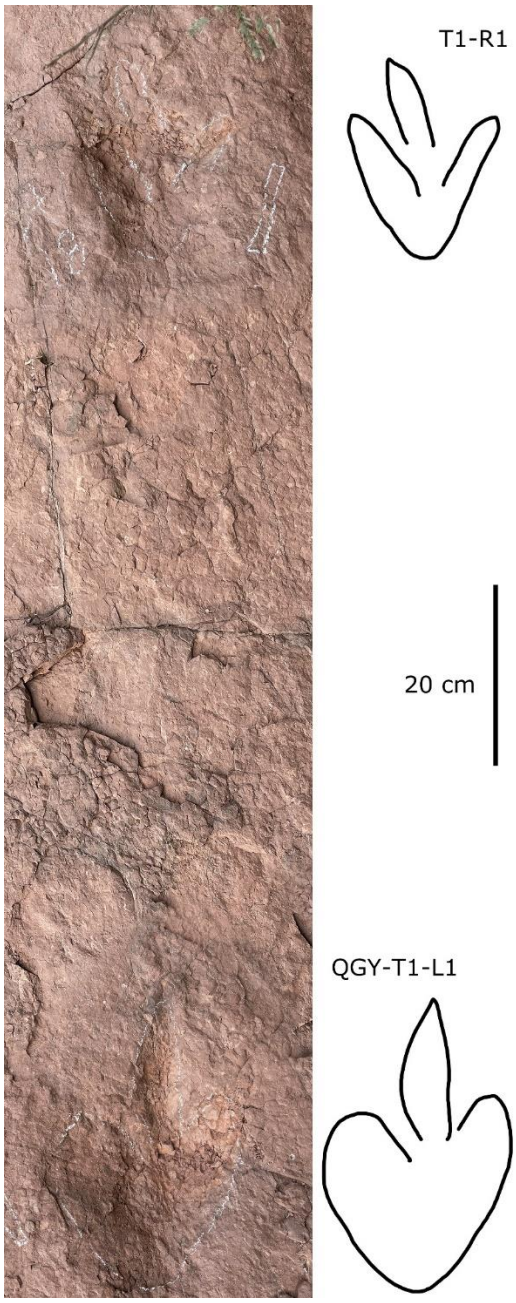

Figure 5. Photograph and line drawing of theropod track step from Qianfoyan Site.

QFY-TI5 shows a distinct morphology. It is 12.0 cm long and 5.8 cm wide, with a length/width ratio of 2.1. There is one round metatarophalangeal pad trace posterior to digit III, but there are no distinct digital pad traces. Digit III has a sharp claw mark. The digits have strong mesaxony (0.78) and the divarication angle between digit II and IV is narrow (41°).

4.2 Comparison and discussion

Paracorpulentapus

LYD-T1 from the Lower Cretaceous Jiaguan Formation is superficially similar to the theropod ichnogenus *Paracorpulentapus* from the Upper Cretaceous Xiaoyan Formation. However, the sub-optimal quality of preservation does not permit confident identification of the tracks at the ichnogenus level. Xing et al. (2014) named *Paracorpulentapus zhangsanfengi* recognizing it to be larger than *Corpulentapus* (Li et al., 2011) in absolute size (16 cm vs. 11.8 cm), having slightly stronger mesaxony (0.37 > 0.32), and wider divarication (74° > 65°). *Paracorpulentapus* has the following characteristics: it is a robust tridactyl theropod tracks, almost as wide as it is long, it is medium-size (~16.0 cm long and ~15.4 cm wide); it has a mean divarication between digits II and IV of 74°; it has weak mesaxony; the digit traces are relatively short and "fleshy" with blunt claws and only indistinct creases between pads; the digits traces are separated by a hypex for most of their proximal length; digit IV is always the narrowest; digit traces II and III proximally with thin interspace area; the metatarsophalangeal pad of digit IV is close to the axis of digit III and forms a short rounded "heel"; the trackways are narrow with short steps; step lengths are 2.7 times that of the track length. The LYD-T1 trackway conforms to or closely resembles most of these features: the tracks are medium-sized (15 cm) robust tridactyl theropod tracks, with and average length/width ratio of 1.2, the average divarication between digits II and IV is 63° (52° –69°), the average mesaxony is weak (0.38), the average step length is 2.6 times that of the average footprint length. Thus, we tentatively label trackway LYD-T1 as *P. zhangsanfengi*. Among the isolated tracks, the morphology of QFY-TI8 is similar to *P. zhangsanfengi*, but QFY-TI8 has a much higher mesaxony (0.54).

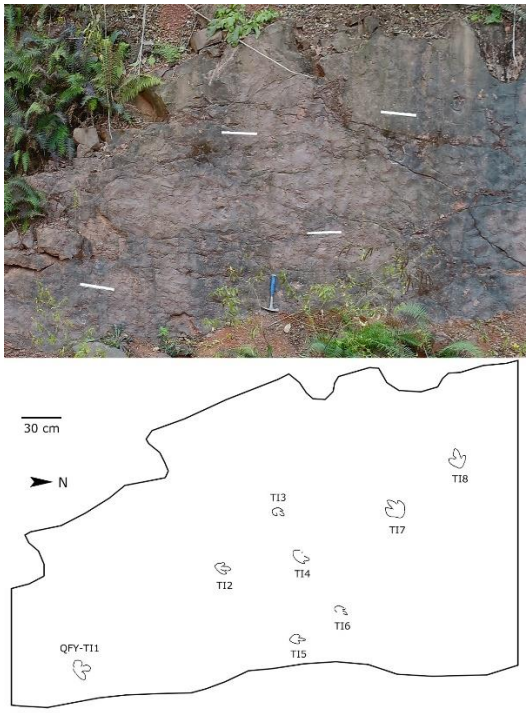

Figure 6. Photograph and line drawing of the distribution of theropod tracks from Qianfoyan Site.

Trackmaker speed (v) was calculated using Alexander's (1976) formula: $v = 0.25g^{0.5}. SL^{1.67}. h^{-1.17}$, where g = gravitational acceleration in m/sec; SL = stride length; and h = hip height, estimated as 4.9 times foot length, using the ratio for small theropods proposed by Thulborn (1990). Based on the length of the stride of LYD-T1, we estimate a speed of ~ 0.84 m/s or ~ 3.02 km/h. The relative stride length (SL/h) is 1.17, implying that the animal was walking, not trotting or running. This state is also similar to the SL/h value (1.2) of *P. hangsanfengi.*

Small Eubrontid track

The length of LYD-TI–TI4 is only 11.0–14.0 cm, the length/width ratio is 1.3–1.6, and characterized by weak to moderate mesaxony (range 0.54–0.55), which is typical for footprints of the ichno- or morphofamily Eubrontidae (Lockley, 2009). However, LYD-TI–TI4 commonly have a wider divarication of digits II–IV (50°–65°) compared with the North American *Eubrontes* from the Late Triassic–Early Jurassic (10°–40°; Olsen et al., 1998).

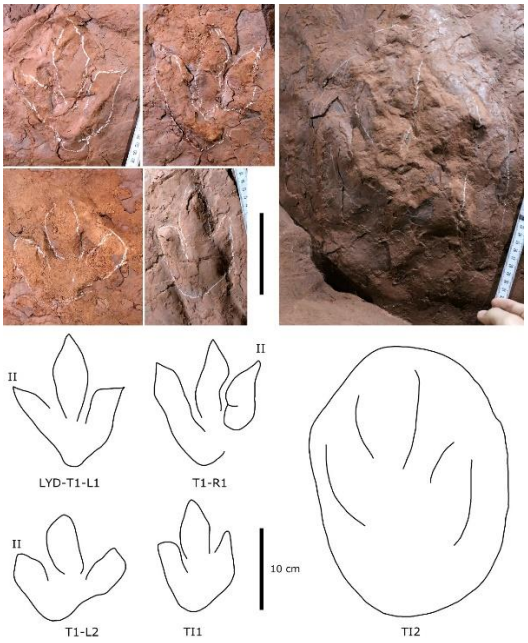

Figure 7. Photograph and line drawing of theropod tracks from Lingyadong Site.

Eubrontid tracks

QFY-T1-L1 and R1 have a mean length of 27 cm and a length/width ratio of 1.6. Both are characterized by weak to moderate mesaxony (average0.53). These proportions are typical for footprints of the ichno- or morphofamily Eubrontidae (Lockley, 2009). Similar tracks abound in the Chinese Jurassic and Cretaceous track record (Lockley et al., 2013; Xing et al., 2016). Although the small sample size and limited preservation state makes the identification of specific systematic features difficult, these tracks are here classified as eubrontid tracks. QFY-T1-L1 and R1 constitute a single step. Assuming that the length of a stride equals that of two steps, speed was calculated using Alexander's (1976) formula, estimated as 4.9 times foot length, using the ratio for large theropods proposed by Thulborn (1990). We estimate a speed of ~ 2.24 m/s or ~ 8.06 km/h. The relative stride length (SL/h) is 1.73, implying that the animal was walking, not trotting or running.

Grallatorid tracks

QFY-TI5 has a high length/width ratio (2.1), strong mesaxony (0.78), and resemble grallatorid tracks (Lockley, 2009). Similar footprints are found in abundance in the Jurassic-Cretaceous boundary and Early Cretaceous records of China. For example, Morphotype B grallatorid tracks from Yanqing, Beijing have a length/width ratio and mesaxony of 0.89 and 2.0, respectively (Xing et al., 2015). Although, the mesaxony is weaker than that reported for North American *Grallator*

(Olsen et al., 1998; Lockley, 2009). The small sample size makes it difficult to identify systematic features, but QFY-TI5 herein tentatively referred to grallatorid tracks.

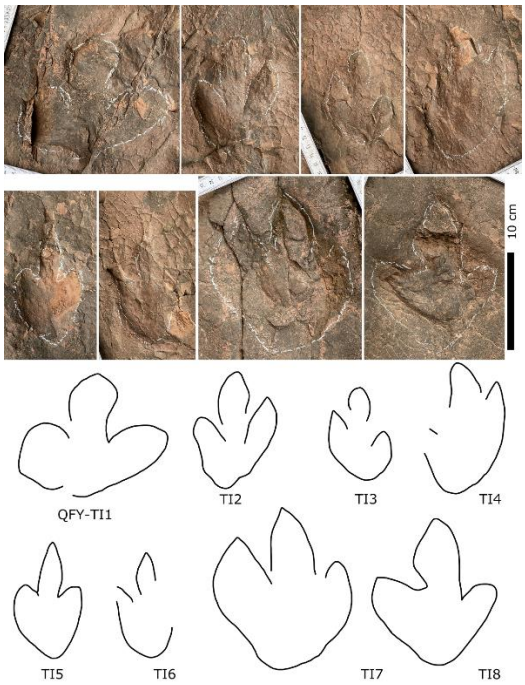

Figure 8. Photograph and line drawing of theropod tracks from Qianfoyan Site.

5 Discussion

The Upper Cretaceous Xiaoyan Formation Xiaohutian site of Huangshan City, Anhui Province, has a theropod tracks assemblage that includes *Paracorpulentapus*, *Therangospodus*, and small eubrontid tracks (Xing et al., 2014). That theropod ichnotaxa fauna is very similar to that of the Qianfoyan sites. Sullivan (2006) tentatively assigned the Xiaoyan Formation to the early Maastrichtian, based on the pachycephalosaurid record. *Paracorpulentapus* from the Qianfoyan sites is the first record of the genus in the Early Cretaceous (Jiaguan Formation, Barremian–Albian). Xing et al. (2014) mentioned that the theropod trackmaker of the *Paracorpulentapus* may have been a short toed and long legged theropod. Qianfoyan sites in the southwestern China is separated from the Xiaohutian site by a relatively large time span and geographical distance (it is roughly1400 km east). However, both sites are at a similar latitude: 29°48' N (Xiaohutian tracksite) and 29° 45' N (Qianfoyan area). The Jiaguan deposition was located at 25.5° ancient north latitude (Jiang et al., 2000). The sedimentary environments of both are also similar. The Xiaohutian tracks are also preserved in the red sandstone of fluvial-lacustrine facies (Xing et al., 2014).

The theropod track assemblages from the Jiaguan Formation not only consisted of the classic *Grallator* and *Eubrontes* assemblages but also *Dromaeopodus*, *Velociraptorichnus*, and *Minisauripus* (Xing & Lockley, 2016). Lockley et al. (2014) suggested that the composition of China's Early Cretaceous ichnofaunas implies a distinctive regional signature. The record of *Paracorpulentapus* also fits in this situation. Like other track sites in the Lower Cretaceous Jiaguan Formation, the theropod track assemblages in Qianfoyan area, *Paracorpulentapus*, small and larger eubrontid, grallatorid tracks together suggest a relatively high diversity.

6 Conclusion

The dinosaur tracks from the upper part of the Jiaguan Formation in the Tang Dynasty Grottoes area are preserved in unusual situations, in the Lingya cave and on a steep rock face at the Qianfoyan site. The assemblages together yield 18 footprints and represent the 20th and 21st reported from the Jiaguan Formation, and are completely theropod-dominated like several others from this formation.

Acknowledgments

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