

Theropod footprints from the Lower Cretaceous Cangxi Formation in the Northern Margin of the Sichuan Basin, China

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ABSTRACT

A single well-preserved theropod trackway identified as *Eubrontes* was discovered in the Lower Cretaceous (Berriasian-Valanginian) Cangxi Formation on the northern margin of the Sichuan Basin. This is the first report of tracks from this formation. The occurrence is consistent with reports of theropod dominated ichnofaunas from broadly coeval deposits such as the Feitianshan Formation in southern parts of the basin. There is growing evidence that *Eubrontes* and *Eubrontes*-like tracks are common in the Lower Cretaceous of Sichuan Province.

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Introduction

The northern margin of the Sichuan Basin extends through Cangxi County in Guangyuan City, Nanjiang and Tongjiang Counties in Bazhong City, and Xuanhan County in Dazhou City. Vertebrate fossils are rare in northern Sichuan. Currently, Jurassic tetrapod tracks are

only known from Guangyuan and Xuanhan. Young (1943) named the ichno taxa *Kuangyuanpus szechuanensis* from the mid-Jurassic Xiashaximiao Formation, and considered it the tracks of a saurischian dinosaur. Zhen et al. (1989) instead attributed *K. szechuanensis* to the archosaurian tracks of

Batrachopus szechuanensis. Lockley *et al.* (2010) considered *K. szechuanensis* likely to represent crocodylian swim tracks. Xing *et al.* (2017) described two relatively small tridactyl cf. *Anomoepus* tracks from Middle Jurassic Xintiangou Formation of Xuanhan.

During regional geological surveys of northern Sichuan, atoposaurid crocodyliforms from the Cangxi Formation and theropod teeth from the Bailong Formation have been documented (Gu & Liu, 1997). However, neither descriptions nor figures are available from these records. Peng (1995, 1996) described *Sichuanosuchus huidongensis* from the Lower Jurassic Shangshaximiao Formation of Zigong. Wu *et al.* (1997) described another species of *Sichuanosuchus* (*S. shuhanensis*), which was reported to be from the Early Cretaceous strata of Sichuan, but not necessarily from North Sichuan.

Local residents of Goujiayuanzi Natural village (Fig. 1), Chaoyang Village, Tongjiang County, Bazhong City have long considered a huge sandstone slab in the village courtyard to contain “chicken footprints”. On October 1st, 2020, five-year-old Zherui YANG and his family reported to the first author that these “chicken footprints” might be non-avian theropod tracks. On October 9th, the main authors visited the tracksite (GPS: 31°57'0.46"N, 107°19'45.07"E). The slab does contain multiple non-avian dinosaur tracks, making them the first Cretaceous dinosaur tracks to be found on the northern margin of the Sichuan Basin. Zhang *et al.* (in press) briefly described these tracks, and classified in *Eubrontes*. This article will describe Tongjiang tracks in detail, and discusses the behavior and potential trackmakers.

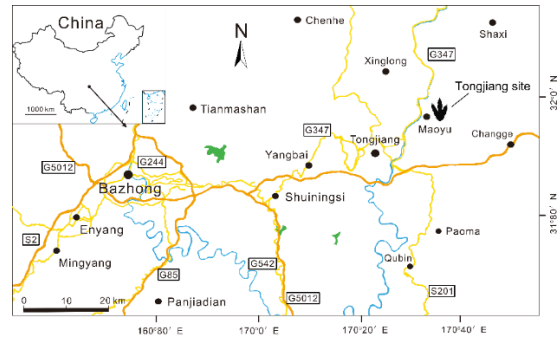


Figure 1. Map showing the location of Tongjiang site in the Lower Cretaceous Cangxi Formation of Sichuan Province, China (Note: Institutional abbreviations: TJ = Tongjiang site, Bazhong City, Sichuan Province, China)

Materials and methods

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). The mesaxony of tridactyl tracks (the degree to which digit III protrudes anteriorly beyond the digits II and IV) was calculated according to the methods of Olsen (1980), Weems (1992), and Lockley (2009). Speed (v) estimates were derived using Alexander's (1976) formula: $v = 0.25g^{0.5} \times SL^{1.67} \times h^{-1.17}$, where g = gravitational acceleration in m/sec; SL = stride length; and h = hip height. In small theropods, hip height was estimated as 4.5 times foot length, using the ratio for small theropods proposed by Thulborn (1990). In large theropods, hip height was estimated as 4.9 times the track length (Thulborn, 1990) and body length was estimated to be 2.63 times the hip height (Xing *et al.* 2009)

Geological setting

The Sichuan Basin of Southwest China is filled with thick Lower Paleozoic–Cenozoic deposits. During the Early Cretaceous, the depocenter of the basin

was mainly distributed at the front edge of Longmenshan Fault Zone, with the thickest areas primarily located in Guangyuan and Bazhong, in northern Sichuan. The strata of this region are characterized by a set of rhythmic red thick-bedded fine sandstones and have been termed the Chengqiangyan Group by Zhao and Huang (1931). Wang *et al.* (1982) divided the strata into four formations: the Cangxi, Bailong, Qiqusi and Gudian from bottom to top.

The Cangxi Formation is 452 m thick (Fig. 2). It is composed of purple-gray, brick red and other chromatic debris, feldspathic quartz sandstone, siltstone, and mudstone. It is interbedded with rhythmic layerings of unequal thickness and rarely with conglomerate bands and lenses. It is rich in bivalve and ostracod fossils. The bottom of the Cangxi Formation forms a non-angular unconformity with the mixed purple-red mudstone and gray-purple fine sandstone and siltstone at the top of the underlying Penglaizhen Formation. The top of the Cangxi Formation is conformable with the gray-white massive sandstone and conglomerate at the base of the overlying Bailong Formation (Gu & Liu, 1997). Ostracods (such as *Djungarica*, *Darwinula*, and *Jingguella*), bivalves (such as *Nakamuraia* and *Nipponoia*), Estherians (such as *Yanjiestheria*), and isolated crocodyliform elements are abundant throughout (Gu & Liu, 1997).

Paleomagnetic and biostratigraphic data has identified the Cangxi Formation as Berriasian (Bureau of Geology and Mineral Resources of Sichuan Province, 1991; Compiling Group of Continental Mesozoic Stratigraphy and Palaeontology in Sichuan Basin of China, 1982; Zhuang *et al.*, 1988). Hou *et al.* (2020) reported the pollen assemblages of the Cangxi–Bailong formations to be dominated by *Classopollis* and to also include *Dicheiropollis*, *Cycadopites*,

Cyathidites, *Deltoidospora* and *Cicatricosisporites*. This pollen data constrains the age to Valanginian–Hauterivian. The age of the Cangxi Formation is constrained to Berriasian–Valanginian herein. Pollen assemblages show that the phytocenosis during this period was dominated by Cheirolepidiaceae, reflecting the very dry climate (Hou *et al.*, 2020). In the sedimentary sequence, the pollen assemblages show insignificant changes, which may indicate a highly stable and dry climate (Hou *et al.*, 2020).

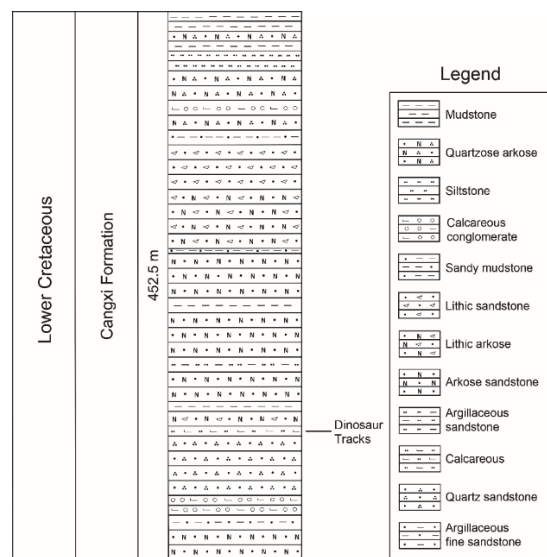


Figure 2. Stratigraphic section showing position of track-bearing level of Tongjiang site in the Lower Cretaceous Cangxi Formation of Sichuan Province, China.

The dinosaur tracks here described are located on Cangxi Formation siltstone, which is exposed in a large rock fall. There are relatively small ripple marks developed on the bedding plane, and the dinosaurs' direction of travel was cut to the paleocurrent direction.

Ichnotaxonomy

Description

Trackway TJ-T1 is a large tridactyl trackway composed of 5 tracks, cataloged as TJ-T1-R1 to R3 (Figs. 3, 4; Table 1). It extends for 5.5 m in total length. The average track length is 36.7 cm. The mean length/width ratio is 1.2. The mean length/width ratio of the anterior triangle is 0.42, indicating weak mesaxony (Lockley, 2009). The weak projection of digit III and the increased digital width are interpreted as adaptations for graviportality (Lallensack *et al.*, 2020).

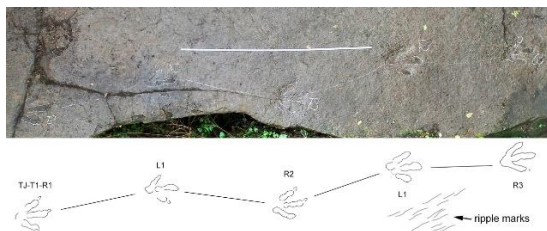


Figure 3. Photograph and interpretative outline drawing of the theropod trackway from the Tongjiang site, Sichuan Province, China.

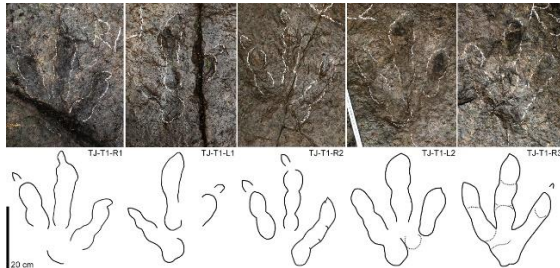


Figure 4. Photograph and interpretative outline drawing of the theropod tracks from the Tongjiang site, Sichuan Province, China.

TJ-T1-R3 is the best-preserved single track. Digit III of TJ-T1-R3 projects the farthest anteriorly, followed by digits IV and II. There are relatively large metatarsophalangeal pad traces of digit IV, near the axis of digit III, and these pads are separated from those of digit II by a larger gap. The deep, concave digit impressions retain pad impressions, with a formula of x-2-3-4-x. Each digit has a sharp claw mark, with that of digit IV being the longest and most distinctive. The digits have

relatively wide divarication angles (averaging 63°) between digit II and IV. The divarication angle between digits II and III is almost equal to that between digits III and IV. The morphological characteristics of the other tracks of TJ-T1 are generally consistent with those of TJ-T1. The average pace angulation is 166°, and the footprint length to pace length ratio is 1:3.51.

TJ-T1-	ML	MW	L/W	II-IV	PL	SL	PA	M
R1	37.0	35.0	1.1	67	134.5	267.0	168	0.38
L1	36.0	32.5	1.1	74	134.0	255.0	159	0.55
R2	38.0	31.0	1.2	58	125.5	245.5	170	0.38
L2	37.5	30.5	1.2	59	121.0	—	—	0.42
R3	35.0	29.0	1.2	58	—	—	—	0.39
Mean	36.7	31.6	1.2	63	128.8	255.8	166	0.42

Table 1. Measurements (in cm and degree) of theropod tracks from the Lower Cretaceous Cangxi Formation in the northern margin of the Sichuan Basin (**Note:** Abbreviations: ML: maximum length; MW: maximum width; R: rotation; PL: pace length; SL: stride length; PA: pace angulation; L/W, is dimensionless; M, mesaxony).

For theropods, Thulborn (1990) first suggested that hip height $h = 4.9 \times \text{foot length}$. 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 TJ-T1 is 1.42, and this suggests walking. Using the equation to estimate speed from trackways (Alexander, 1976), the mean locomotion speed of the trackmaker is 6.8 km/h. The body length of the TJ-T1 trackmaker was approximately 4.73 m, calculated using the average hip height to body length ratio of 1:2.63 (Xing *et al.*, 2009).

Discussion

TJ-T1 is typical of theropod tracks, and it is characterized by weak mesaxony, which is typical

for footprints of the ichno- or morphofamily Eubrontidae (0.37–0.58, Lockley, 2009). *Eubrontes* morphotype tracks (>25 cm, Olsen *et al.*, 1998) are common in the Jurassic and Cretaceous of China (Xing *et al.*, 2016a). The mesaxony and length/width ratios is 0.58 and 1.7, respectively, for Lower Jurassic *Eubrontes giganteus* from the Hitchcock collection (Lockley, 2009), which differ from those of TJ-T1 (0.42 and 1.2). However, other Lower Jurassic Hitchcock specimens assigned to *Eubrontes* have wider interdigital divarication angles and lower length/width ratios (some measure 0.44 and 1.3) (Ishigaki & Fujisaki, 1989), which is quite close to TJ-T1. In addition, the ratio of digit III to footprint length is 0.68, which is very close to ~0.7 of *E. giganteus*, and the mean value (0.64) derived from a large sample of *Eubrontes* from Utah (Lockley *et al.*, 2021).

Two metatarsophalangeal pad traces are reported in the type specimen of *Eubrontes* (AC 151: Olsen *et al.*, 1998) and *Eubrontes zigongensis* (Xing *et al.*, 2014), but is not a universal feature. TJ-T1 lacks distinct metatarsophalangeal pad traces from digit II, throughout the trackway, with the exception of a faint trace in TJ-T1-L2, probably due to the preservation and a less developed digit II metatarsophalangeal pad.

The Early Cretaceous theropod tracks in southwest Sichuan Basin, as well as the Mishi–Jiangzhou Basin (Xichang Basin), are fairly abundant. Theropod tracks from southwest Sichuan Basin have mainly been discovered in the Jiaguan Formation (Barremian–Albian), and include *Grallator*, *Eubrontes*, *Minisauripus*, cf. *Irenesauripus*, *Velociraptorichnus*, cf. *Dromaeopodus*, and coelurosaur tracks. Theropod tracks from Mishi–Jiangzhou Basin were discovered in the underlying Feitianshan Formation (Berriasian–Barremian) and the overlying Xiaoba Formation (Aptian–Albian/Cenomanian). The

former yielded *Grallator*-type, *Eubrontes*-type, *Minisauripus*, cf. *Dromaeopodus* and *Siamopodus*. The latter has yielded *Grallator*-type, *Eubrontes*-type and *Velociraptorichnus* (Xing & Lockley, 2016).

The TJ-T1 tracks are similar to the *Eubrontes* track HX-T3 (30 cm in length), from the Jiaguan Formation, and the *Eubrontes* track BJA-T4 (23.9 cm in length) from the Feitianshan Formation. The mesaxony and length/width ratios of HX-T3 is 0.37 and 1.4 (Xing *et al.*, 2015), and the mesaxony and length/width ratios of BJA-T4 is 0.46 and 1.4 (Xing *et al.*, 2016b). This demonstrates consistency across Early Cretaceous theropods in the north and south of Sichuan Basin (Zhang *et al.*, in press).

Eubrontes is reported from the Late Triassic to the Late Cretaceous and corresponding to medium–large sized theropods of various species, such as the Early Jurassic *Dilophosaurus* (Morales & Bulkeley, 1996) and the Early Cretaceous allosaur *Acrocanthosaurus* (Farlow, 2001; Farlow *et al.*, 2006; Adams *et al.*, 2010). However, it is generally more common in the Early Jurassic, where is one of the dominant members of the Lower Jurassic Biochron (*sensu* Lucas, 2007). The distribution of *Eubrontes* in the Cretaceous in China and globally is less well known and still under investigation (Xing *et al.*, in review). Except for Tyrannosauroids (such as *Yutyranus* Xu *et al.*, 2012), Early Cretaceous medium–large sized theropods are rare and poorly preserved in China (Dong, 1973; Brusatte *et al.*, 2012). Thus, potential trackmakers of the Early Cretaceous *Eubrontes* of China can only be very generally inferred, they may include all medium–large sized non- deinonychosaurian theropods.

Conclusions

Although the number is limited, the track records

are consistent with other Early Cretaceous theropod tracks from the Sichuan Basin in morphology. The tetrapod ichnofauna described here is the only credible evidence of dinosaurian faunas in this region. Thus, it is a type 1 deposit (correspondence between bones and tracks) where only contains tracks (Lockley, 1991). The report is consistent entirely with the widespread evidence that the ichnofaunas of the Sichuan Basin region are consistently theropod dominated.

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