

Large sauropod and theropod tracks from the Middle Jurassic Chuanjie Formation of Lufeng County, Yunnan Province and palaeobiogeography of the Middle Jurassic sauropod tracks from southwestern China

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Abstract

Tracks of large theropods and a single sauropod footprint are reported from red beds at Beikeshan locality in the Middle Jurassic Chuanjie Formation, of Lufeng County, near the large World Dinosaur Valley Park complex. The Chuanjie theropod tracks are assigned to the ichnogenus *Eubrontes* and the large sauropod track is given the provisional label *Brontopodus*. All occur as isolated tracks, i.e., trackways are not preserved. Saurischian dominated ichnofaunas are relatively common in the Jurassic of China. The producers of the Chuanjie tracks may have been similar to the basal tetanuran theropod *Shidaisaurus* and to mamenchisaurid sauropods, which were widely distributed throughout China, during the Jurassic, and are known from skeletal remains found in the same unit. Other potential sauropod trackmakers include titanosauriforms or as-yet-unknown basal eusauroopods. The ichno- and skeletal records from the Jurassic of the Lufeng Basin are largely consistent, and both document the presence of middle-large sized theropods and sauropods.

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1. Introduction

Abundant skeletal fossils of prosauropod and sauropod dinosaurs have been found in Lower and Middle Jurassic deposits of the Lufeng Basin (Young, 1951; Dong, 1992; Upchurch et al., 2007a). Although less abundant, theropod body fossils have also been discovered from the Lower–Middle Jurassic sediments, including complete specimens of *Sinosaurus triassicus* (Young, 1948) (= *Dilophosaurus sinensis* Hu, 1993)

(Xing, 2012; Xing et al., 2013a) and *Shidaisaurus jinae* (Wu et al., 2009).

Lü et al. (2006a) described the first dinosaur footprints from the Jurassic Lufeng Basin: an isolated large theropod track, which was named *Lufengopus dongi*. Xing et al. (2009a) described two theropod tracks from the Lower Jurassic Lufeng Basin, named *Changpeipus pareschequier*. In a review of Chinese ichnotaxonomy, Lockley et al. (2013) assigned the former to cf. *Eubrontes* and the latter to *Eubrontes pareschequier*. In a review of *Changpeipus*, Xing et al. (2014) considered *Changpeipus* and *Eubrontes* as similar (“sister”) ichnotaxa, on the basis of the large metatarsophalangeal pad positioned nearly in line with digit III, the digit proportions with IV > II, and the relatively large divarication angle between digits II and IV.

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In the summer of 2013, we investigated various dinosaur tracks in the Jurassic and Cretaceous of the Lufeng Basin. More theropod and sauropod tracks were discovered from the Middle Jurassic deposits.

Institutional abbreviations and acronyms. B = Beikeshan tracksite, China; HYMVC = The Collection from Heyuan Museum, Guangdong Province, China; T = Theropod; S = Sauropod; ZLJ = Lufeng Dinosaur Museum of World Dinosaur Valley Park, China.

2. Geological setting

The Red Beds of the Lufeng Series, in the Lufeng Basin, are approximately 750 m thick, and are conventionally divided into upper and lower units (Bien, 1941). Young (1951) determined the age of the Red Beds to be Late Triassic on the basis of the evolutionary ‘grades’ and stratigraphic correlations of its vertebrate fossils. Later, Sheng et al. (1962) proposed an Early Jurassic age for the Lower Lufeng Formation and a Middle Jurassic age for the Upper Lufeng Formation. Zhang and Li (1999) mapped Laochangjing, Chuanjie, and determined the relative stratigraphic positions of dinosaur fossils in the lower part of the Upper Lufeng Formation. Fang et al. (2000) restricted the name ‘Lufeng Formation’ to what was previously called the Lower Lufeng Formation and further divided it into Shawan and Zhangjia’ao members. Fang et al. (2000) also assigned strata that had at various times been included in the Upper Lufeng Formation to the Chuanjie, Laoluocun, Madishan, and Anning formations. This most recent terminology scheme is followed here.

The new tracksite reported herein was discovered in Beikeshan (Shelled Hill) near Yaozhan, 1 km southeast of the World Dinosaur Valley Park, Lufeng County (GPS: 24°57′49.96″ N, 102°4′41.14″ E) (Fig. 1). The dinosaur footprint-bearing layer is 221.2 m thick and consists of thick-bedded purple mudstone and argillaceous siltstone mixed with thin purple deposits of fine-sandstone (Fig. 2). Although only a few isolated tracks occur at this site, the three theropod tracks illustrated here (Fig. 3) have been protected by the construction of concrete and brick shelters. Lü et al. (2006a) regarded the Beikeshan tracksite layer as positioned within the second member of the Upper Lufeng Formation (= Laoluocun Formation). However, later geological studies indicate that the Beikeshan tracksite layer is located at the top of the first member of the Upper Lufeng Formation (= Chuanjie Formation) (Fang and Li, 2008).

3. Ichnology

3.1. Theropod tracks

Material: Three natural molds (ZLJ BT1–3) from the Beikeshan tracksite (Fig. 3; Table 1). Protective coverings were built for each individual track. ZLJ BT1 was previously cataloged as No. L028; a cast of the specimen is stored in the Heyuan Museum, Guangdong Province, cataloged as HYMVC-1.

Locality and horizon: Chuanjie Formation, Middle Jurassic. Beikeshan tracksite, Lufeng County, Yunnan Province, China.

Description and Comparison:

The three specimens (ZLJ BT1–3) are imperfectly preserved. The heel impression of ZLJ BT2 (Fig. 3C, D) is incomplete. ZLJ BT1 (Fig. 3A, B) is a tridactyl left pes, with a length/width ratio of 1.1. Digit II is the shortest and the most robust. The digit III impression constitutes approximately 61% of the footprint length. Each digit has a sharp claw mark. The claw marks of digit II and III point strongly inward. The borders of the digital pads of digit II and III are indistinct, with two or three pads observed. The phalangeal pads of digit IV are discernible; there are three digit pads and a relatively large metatarsophalangeal pad. The divarication between digit II and III is less than that between digit III and IV. The morphological characteristics of ZLJ BT2 and BT3 generally correspond with those of ZLJ BT1. However, the metatarsophalangeal pad of ZLJ BT3 is more developed, with a strong indentation behind digit II.

Lü et al. (2006a) previously described ZLJ BT1. However, our measurements indicate that the specimen is smaller than measured by these authors. ZLJ BT2 and BT3 are newly reported here.

ZLJ BT1 is similar to the *Eubrontes* morphotype in the following respects: ZLJ BT1 is a large (>25 cm long) functionally tridactyl footprint with a broad general shape; digit III is relatively short; there is no hallux trace; and the divarication of digits II and IV is on average 25°–40° (Olsen et al., 1998). Although the small sample size makes it difficult to identify systematic features, ZLJ BT1–3 are here referred to *Eubrontes* isp.

The *Eubrontes* morphotype is widely distributed in the Lower Jurassic deposits of China (Lockley et al., 2013). The earliest record of *Eubrontes* from China is *E. platypus* (Lull, 1904) from the Lower Jurassic Fengjiahe Formation of Jinning, Yunnan (Zhen et al., 1986). Subsequently, *Eubrontes monax* and *Eubrontes xiyangensis* (Lockley et al., 2013) were described from the Lower Jurassic of Jinning, Yunnan. *Eubrontes nianpanshanensis* has been reported from the Middle Jurassic strata of the Sichuan Basin (Yang and Yang, 1987; Lockley et al., 2013), which is situated close to the Lufeng Basin. Among these footprints only *E. platypus* and *E. xiyangensis* are represented by well-preserved specimens. All these tracks are attributable to *Eubrontes* based on the divarication of digits II–IV (37° and 21°) and the presence of a metatarsophalangeal pad that is positioned nearly in line with digit IV. More recently, a number of middle–large theropod tracks, from various other Jurassic sites have been assigned to *Eubrontes* (Lockley et al., 2013). In particular, the Xintiangou Formation of the Sichuan Basin has yielded a diverse assemblage of Middle Jurassic theropod footprints, which include *Eubrontes* and the ichnogenera *Grallator* and *Kayentapus* (Lockley and Matsukawa, 2009; Lockley et al., 2013; Xing et al., in press a). Although several other ichnogenera described based on this Xintiangou material (Yang and Yang, 1987) appear to be junior synonyms. The Xincun Formation in the Panxi region of the Sichuan Basin has yielded theropod tracks similar to *Kayentapus* (Xing et al., 2013b). The Middle Jurassic Shanshan tracksite, in the Turpan Basin (Xinjiang Uyghur Autonomous Region, northwestern China), Sanjianfang Formation, contains numerous theropod footprints that have been assigned to the ichnogenus *Changpeipus*, which is

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