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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.

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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

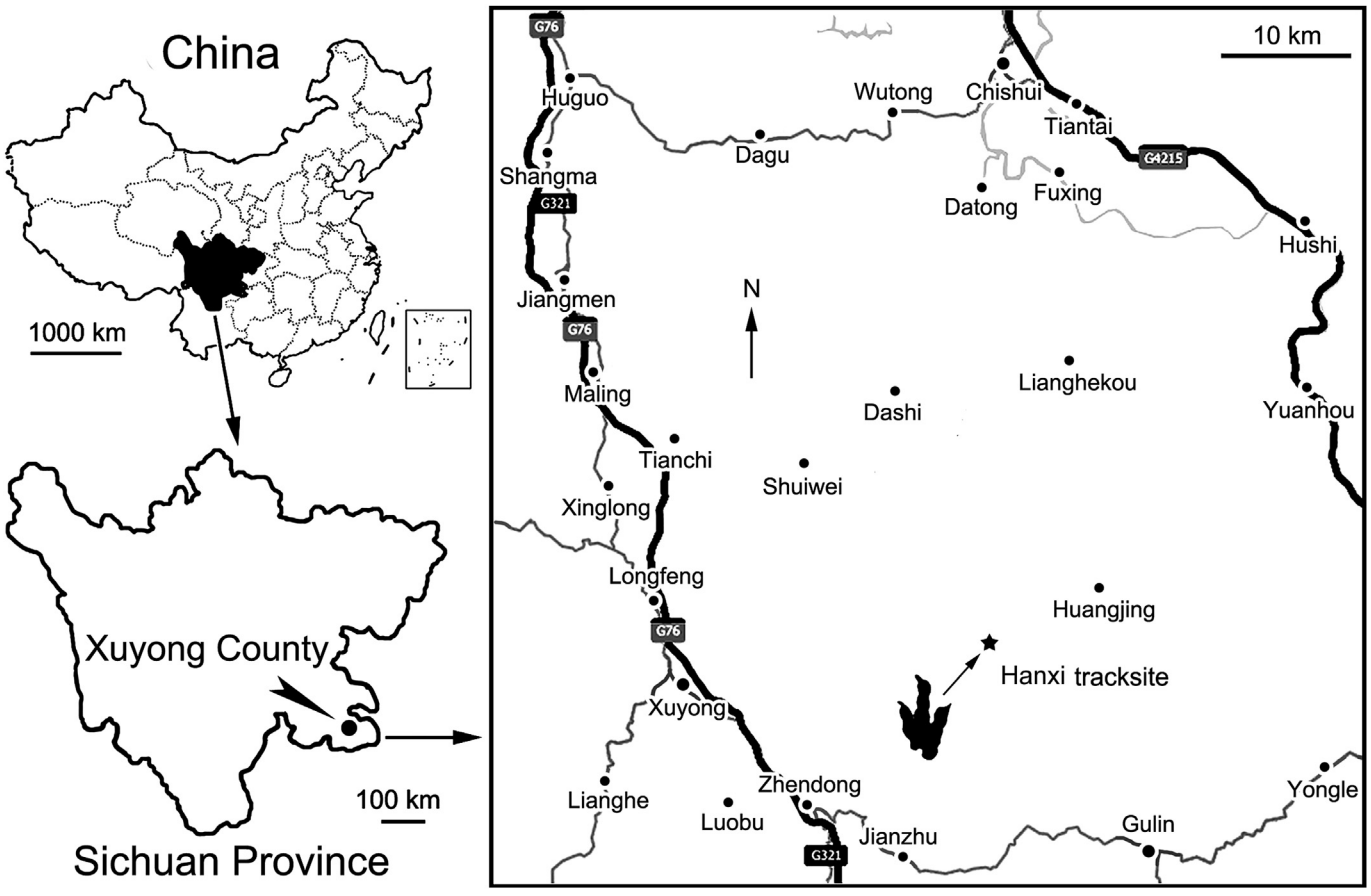

Fig. 1. Map showing the position of the footprint locality (footprint icon), the Hanxi tracksite, Xuyong County, Sichuan Province, China.

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