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Late Jurassic–Early Cretaceous trackways of small-sized sauropods from China: New discoveries, ichnotaxonomy and sauropod manus morphology

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ABSTRACT

The growing database on sauropod tracksites, particularly from China, raises questions about hypotheses that wide-gauge sauropod trackways with low heteropody (*Brontopodus*) dominate the global sauropod track record in the Cretaceous. It also raises questions about the definition of narrow-, medium- and wide-gauge trackways and the quality of preservation needed to use such labels reliably. A number of Lower Cretaceous sauropod tracksites from China have yielded trackways of small-sized sauropods with pronounced heteropody that have been named *Parabrontopodus*. These co-occur with medium-sized to large *Brontopodus* trackways giving rise to at least two possible interpretations regarding sauropod trackmakers at these sites: 1) trackways were left by two different, smaller narrow gauge and larger wide gauge, taxonomic groups, 2) trackmakers belong to the same taxonomic group and were narrow gauge when smaller and wide gauge when larger, therefore not maintaining a constant gauge during ontogeny as inferred from some assemblages. The presence of different taxonomic groups is further evidence that narrow gauge trackmakers, previously considered typical of the Jurassic, persisted into the Early Cretaceous. This could be part of a regional trend in East Asia and some other regions such as the Iberian peninsula in Europe, where similar trackways have been found. Alternatively, this could reflect a previously unrecognized global trend. More track and skeletal data are needed to corroborate these hypotheses, because presently essential parameters are missing.

1. Introduction

In the Late Jurassic–Early Cretaceous, sauropods were widely distributed among several large dinosaur faunas of China, such as the Late Jurassic *Mamenchisaurus* fauna in the Sichuan and Dzungaria basins (Peng et al., 2005), the *Lanzhousaurus-Huanghetitan* fauna in the Lanzhou-Minhe Basin (You et al., 2006), and the Early Cretaceous Jehol biota in northeastern China (Wang et al., 2007). These sauropods, however, are all large-sized, generally ranging between 10 and 20 m, with no small-sized sauropods known.

Abundant sauropod tracks from the Late Jurassic–Early Cretaceous have been discovered in China, mostly from the Early Cretaceous, from sites such as Chabu, Inner Mongolia (Lockley et al.,

Abbreviations: BL, Beilin tracksite, Shandong Province, China; GDM-LT, Litan tracksite, Gansu, China; I, Isolated tracks; L and R, left and right; LG, Provisional Collection (Lin-shi Guancang, LG) of Zhucheng Municipal Museum, Shandong, China; LS, Jishan tracksite, Linshu, Shandong, China; NGZ, Nanguzhai tracksites, Jiangsu, China; P, pes impression; QJD, Qianjiadian tracksite, Beijing, China; S, Sauropod; TDGZ, Tangdigezhuang tracksite, Shandong, China; ZP, Zhongpu tracksite, Gansu, China.

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2002), Linshu, Shandong (Xing et al., 2013), and Zhaojue, Sichuan (Xing et al., 2014a). Among these tracksites, one type of tiny to small sauropod tracks is noteworthy. Commonly their pes prints are approximately 30 cm long, significantly smaller than other medium-sized sauropod tracks from China, such as those from Chabu (60 cm long; Lockley et al., 2002) and Linshu (53 cm long; Xing et al., 2013).

Most tracksites yielding tiny and small sauropod tracks are located within the Lower Cretaceous Dasheng Group of Shandong and neighboring northern Jiangsu Province (Fig. 1, Table 1). In addition, the same track types are also known from the Tuchengzi Formation of Yanqing, Beijing and the Hekou Group of Gansu (Xing et al., 2014b). In 2011, 2012, Wang et al. (2013a) discovered the Beilin tracksite in Tancheng County, Shandong, which is dominated by small sauropod tracks. The first author of this paper investigated the tracksite in 2013. Here, the tracksite is described in detail and tiny to small sauropod tracks from China are systematically reviewed, and discussed in the context of their global record.

There is no scientific reason that the growing track record of sauropods, and related questions of size distribution, morphology (heteropody) and gait (narrow, medium and wide gauge) should not attract as much serious attention as the skeletal record (e.g., Lockley et al., 1995). Indeed tracks may be the only evidence in some areas that lack sauropod body fossils. There is a general consensus that tracks are useful in distinguishing narrow and wide gauge trackmakers as reflected in the sauropodomorph ichnogenera *Parabrontopodus* and *Brontopodus*, respectively. The former have been correlated with diplodocoid sauropods, the latter with titanosauriform sauropods, proving that gait and heteropody patterns help distinguish different sauropod groups (Farlow, 1992; Lockley et al., 1994b. Wilson and Carrano, 1999; Wright, 2005; Henderson, 2006; Romano et al., 2007; Santos et al., 2009; Castanera et al., 2012, 2014; Vila et al., 2013). Ultimately a comprehensive global synthesis of all useful (morphologically diagnostic) sauropod trackway data is just as desirable as an equivalent synthesis of skeletal data. Ideally, the two data sets could be compared and should complement each other synergistically. However, this is a goal for future projects. Here we re-analyze selected sauropodomorph trackways from China and present different working hypotheses that need to be discussed in the future from both ichnological and osteological points of view.

2. Geological setting

The Lower Cretaceous Dasheng Group in Shandong represents a set of alluvial fan–fluvial–lacustrine facies of detrital rocks mixed with muddy limestone (Fig. 1). Liu et al. (2003) divided the Dasheng Group from base to top into the Malanggou, Tianjialou, Siqiancun and Mengtuan formations. However, Kuang et al. (2013) considered these units to have a different facies only, but to be contemporaneous. The Tianjialou and Mengtuan formations form the majority of the Jiaolai Basin deposits, which are a set of lacustrine facies deposits dominated by dark gray, yellow green, purple detrital rocks, occasionally mixed with dolomitic mudstones and micrite dolomite (dolomicrite), the thickness exceeding 500 m.

The sediments suggest a shallow lake environment with calcareous concretions horizons developed in the Tianjialou/Mengtuan formations (Kuang et al., 2013). Gymnosperms and ferns flourished indicating that the climate changed in the late Early Cretaceous from humid to arid and warm (Si, 2002). Based on regional geological surveys and biostratigraphy, Kuang et al. (2013)

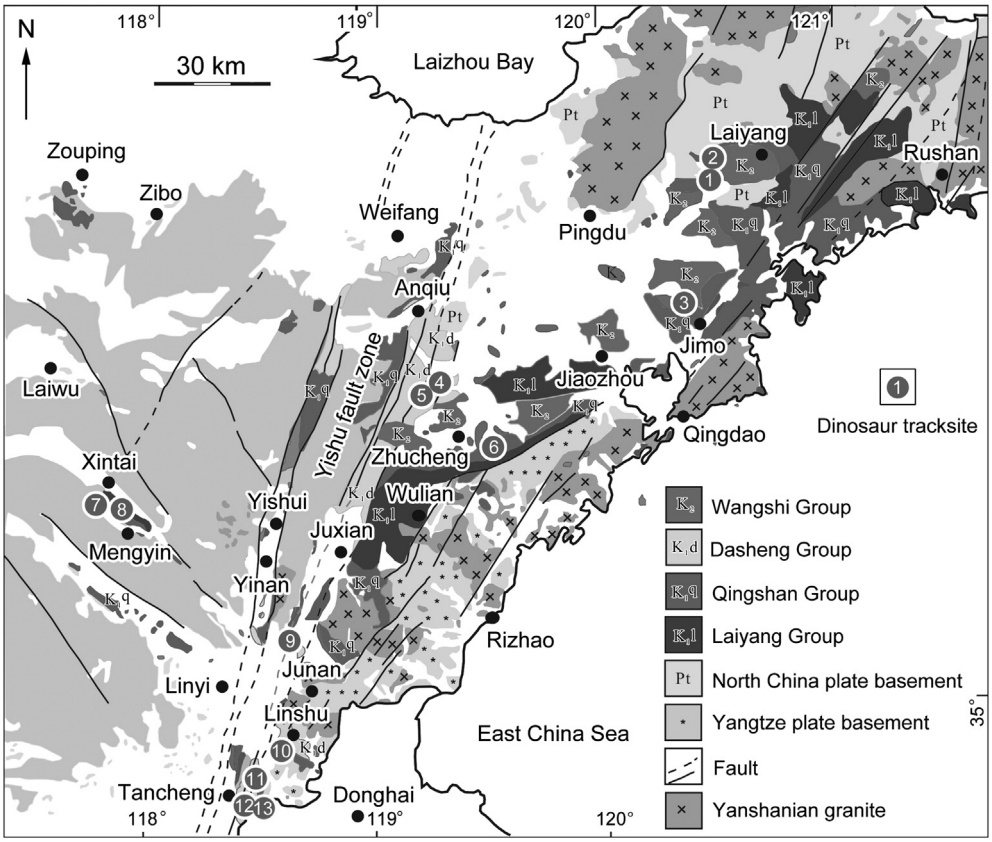

Fig. 1. Geographical and geological setting with the position of dinosaur tracksites in Shandong and northern Jiangsu provinces. 1, Shuinan, Laiyang; 2, Huangyandi, Laiyang; 3, Wenxiyuan, Jimo; 4, Zhangzhuhewang, Zhucheng; 5, Tangdigezhuang, Zhucheng; 6, Huanglonggou, Zhucheng; 7, Ningjiagou, Mengyin; 8, Yangzhuang, Mengyin; 9, Houzuoshan, Junan; 10, Jishan, Linshu; 11, Qingquansi, Tancheng; 12, Beilin, Tancheng (this study); 13, Nanguzhai, Donghai.