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ORIGINAL RESEARCH

Dinosaur Track from the Jurassic Xiahuayuan Formation of Northern China

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ABSTRACT

An isolated but moderately well-preserved theropod track from the coal-bearing strata of the Zhangjiakou City region of Hebei Province was reported to have originated from the Xiahuayuan Formation, which is considered Middle Jurassic in age. Although the track has a wide divarication angle and length-width ratio reminiscent of Cretaceous tracks like *Magnoavipes,* it would be speculative to apply this Identification based on a single track. Therefore, it is considered most likely to be a preservational variant of *Kayentapus,* in which the heel trace is lacking. *Kayentapus* is widely known from the Lower Jurassic of China. This is the first report of a track or any vertebrate fossil from the Middle Jurassic of this region of Hebei Province, China.

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Introduction

As geological surveying of the Tuchengzi Formation has progressed, numerous dinosaur tracks have been discovered in northern Beijing (Xing et al., 2015a) and northwestern Hebei. Within the Tuchengzi Formation, dinosaur skeletal fossils are comparatively rare, making it a Type 2 or track-dominated deposit (Lockley 1991). Among these newly found sites are Zhangjiakou and Xuanhua (Xing et al., 2021a), which have provided a missing record of Northern China's dinosaur fauna around the Jurassic-Cretaceous boundary.

On November 13, 2020, Zhitao Wang, a master's student from the China University of Geosciences (Beijing), discovered a dinosaur footprint in Jurassic strata at an abandoned coal mine in Cipaoyao Village, Chuaigutuan Town, Yangyuan County, Zhangjiakou City, Hebei Province (Fig. 1). This track is the first documented vertebrate fossil from the Early-Middle Jurassic of northwestern Hebei Province.

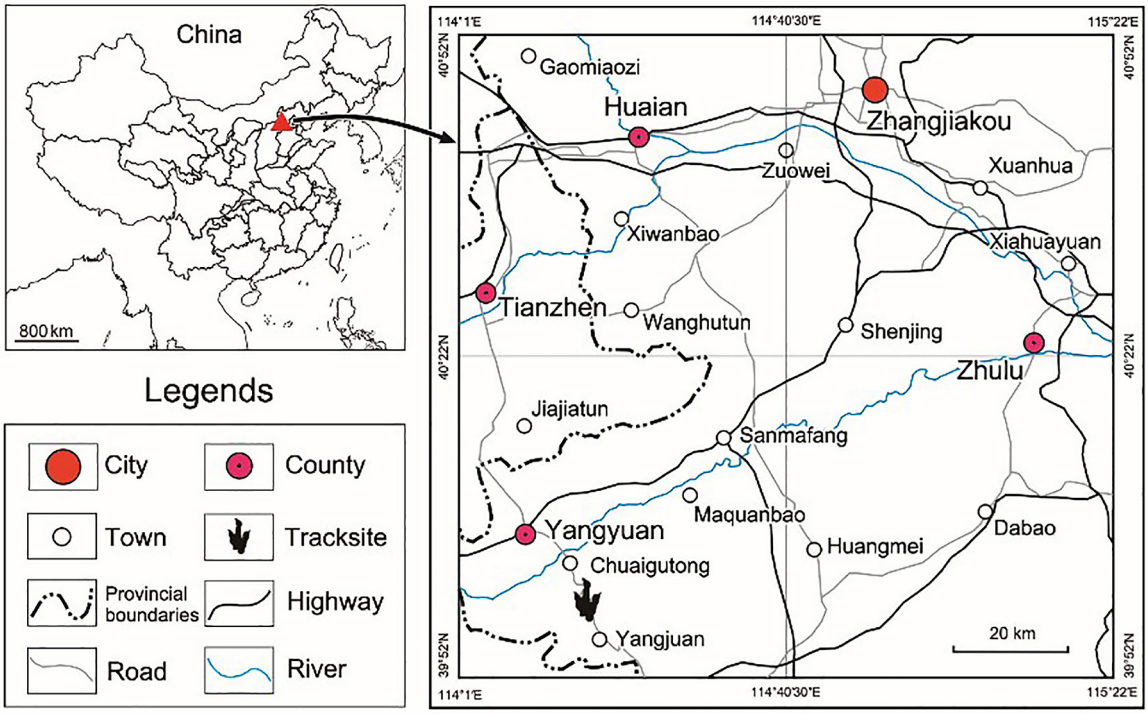

Figure 1. Map showing the location of Cipaoyao track site, Hebei Province, China.

Geological setting

The coal-bearing strata set in Zhangjiakou, Xuanhua, Xiahuayuan, Yangyuan, and Weixian in northwestern Hebei Province are Jurassic fluvial-lacustrine-swamp facies (Pang et al., 1995). However, researchers have differed in interpreting the exact age of this set of strata, especially the Xiahuayuan Formation. The Xiahuayuan Formation, named by Benyu Tian and Zhijia Yang in a 1950 geological survey report, is a coal-bearing stratum initially considered Early Jurassic (Pang et al., 1995). Pang et al. (1995) argued that the age of the Xiahuayuan Formation is no older than the Middle Jurassic, based on an analysis of the invertebrate fossil record, which included ostracods, conchostracans, insects, and plants. Zhang et al. (2009, 2016) combined plant fossil and lithostratigraphic evidence to suggest that the Xiahuayuan Formation was deposited in the Middle Jurassic, making it equivalent to the Xishangyao Formation in northern China. The Jiulongshan Formation overlies it.

Based on lithology, the Xiahuayuan Formation can be divided into three members (Pang et al. 1995). The lower member is composed of light yellow and yellow-green medium-coarse-grained feldspathic quartz sandstone interspersed with light yellow sandy mudstone and coal seam. The second member is composed of grayish-black carbonaceous mudstone and siltstone interspersed with grayish-grayish-white muddy siltstone and calcareous mudstone. The third and upper-most member is composed of light yellow and gray medium-coarse-grained feldspath-

ic quartz sandstone interspersed with light gray and gray siltstone and miscellaneous sandstone and mudstone, containing thin coal horizons and lenticular coal seams. The footprint is preserved in a ripple marked sandstone that caps a medium-coarse-grained light-yellow sandstone slab (Fig. 2), consistent with the third member. Because the rock slabs bearing the tracks were individually stacked among miscellaneous rocks from the area, it is difficult to compare with the surrounding strata precisely. The tracks are tentatively classified as originating in the upper member of the Xiahuayuan Formation.

Figure 2. Photograph and interpretative outline drawings of track and ripple marks in Cipaoyao site. Note that the upper layer with the track is thin, friable darker and finer-grained than the more massive, lighter colored underlayer.

Lithological details visible on the slab's surface include a distinction between a coarser-grained, thicker (decimeter scale) light-colored basal unit and a thin (~1.0-2.0 cm) upper ripple marked fine sand unit with grey coloration pronounced in the ripple troughs, indicating a fine organic mud component to this thinly bedded unit, which is also friable, and breaks up easily (Fig. 2). The track is a natural impression (concave epirelief) registered at the top of the ripple marked unit, inferred to represent the end of a depositional cycle. This impression is filled with a slightly coarser sand that weathers to rusty color (Figs. 2 and 3).

Figure 3. Photograph and interpretative outline drawings of tridactyl track in Cipaoyao site. Note the track, and a natural impression is filled with a rusty colored sandstone filling. The coarser gained texture of the main sand unit is clearly seen in the upper right of the photo.

In the northern Hebei Province, the depositional environments of the Xiahuayuan Formation have been interpreted as lacustrine-swamp facies. The presumed warm and humid climate supported a variety of fossil taxa, including bivalves: *Lamprotula (Eolamprotula), Ferganoconcha, Psilunio, Tutuella, Yananoconcha;* ostracods: *Darwinula sarytirmenesis, D. impudic;* and plants: *Coniopteris hymenophylloides, Cladophlrbis* sp., etc. (Pang et al. 1995).

Ichnotaxonomy
Description

The specimen from Cipaoyao Village was catalogued as CPY-1 (CPY=Cipaoyao) and has a quality of preservation ranking of ~2.0 on the scale of Belvedere and Farlow (2016), showing clear outlines of all three digits. The track offers a typical tridactyl theropod track morphology. A short lateral digit with an indentation on the proximal side is inferred to represent digit II (right side in Fig. 2). CPY-1 has relatively unambiguous phalangeal pads on digits II and III, with two and three pads, respectively. Digit II is the shortest, and digit III is the longest and shows strong tapering distally: i.e., the proximal pad, close to its connections with digits II and IV is extensive. The track is 23 cm long and 25cm wide, with a length/width ratio of 0.92. Distinctive triangular claw traces are clearly visible. An undeveloped metatarsophalangeal pad is aligned with the track axis. The divarication angle is 91° between digits II and IV. The divarication angle between digit III and digit IV (53°) is less than that between digit II and digit III (38°). The average anterior triangle length/width ratio is 0.44.

Discussion

Historically, Chinese Jurassic dinosaur ichnospecies have been over-interpreted and clearly 'over split' (Lockley et al. 2003, 2013; Lockley and Matsukawa 2009; Xing et al., 2021b). In early manuscripts, all theropod tracks from one site were routinely split into many ichnotaxa. See, for instance, Zhen et al. (1986), which established four new genera with five new species based on the tracks from the Xiyang Village, Yunnan Province.

As an isolated track, CPY-1 is morphologically close to the *Kayentapus* type (Welles, 1971; Lockley et al., 2011), although the divarication angle is greater, and the posterior heel (metapodial) trace is absent. This may be due to a more digitigrade stance during the registration of the track. Because of the low L/W ratio (less than 1.0) the overall shape is more like *Magnoavipes* known from North America (Lee, 1997; Lockley et al., 2001) and also from China Matsukawa et al., 2014). However, this is well known as a Cretaceous track, and it would be speculative to apply this Identification to a single Jurassic track.

Well-known medium to large Jurassic theropod tracks includes *Eubrontes* and *Kayentapus,* which are ubiquitous worldwide (Lockley et al. 2013). In the arbitrary size classification of theropod tracks, a length of 25 cm is regarded as the cut off between large and small footprints. However, the size of CPY-1 is not outside the range of *Eubrontes* or *Kayentapus* (Piubelli et al., 2005; Lockley and Xing, 2021). In the holotype of *K. hopii* (Fig. 4A), the length/width ratio is 1.3, the digit divarication between digits II and IV is 60-75°, and the anterior triangle length/width ratio is 0.52 (Lockley et al., 2011). With larger angles between digits and a lower anterior triangle, CPY-1 is wider. The lack of other tracks excludes comparison of other essential features, such as separated digits and step length. *Kayentapus* is a typical Lower Jurassic track (Lockley et al. 2011) and has never been reported confidently from the Upper Jurassic (Wagensommer et al. 2012) or Cretaceous. Well-preserved typical *Kayentapus* are known from the Early Jurassic of China, including *K. hopii* from the Lower Jurassic Geleshan site in Chongqing (Xing et al., 2021c) and *K. xiaohebaensis* from the Lower Jurassic Yunnan Province (Zhen et al., 1986; Lockley et

al., 2013). At least three occurrences of *Kayentapus* are known from the Middle Jurassic. Previous discoveries also included Shansong *Kayentapus* from Panxi region (Xing et al. 2013) and Nianpan *Kayentapus* from Zizhou, Shaanxi Province (Xing et al. 2015b). The former track example suffers from deformation (Xing et al. 2013), and the Nianpan *Kayentapus* are limited to a small number of specimens, such that they could not be diagnosed with the ichnospecies level (Xing et al. 2015b, 2021c). Xing et al. (2021d) re-described the *Kayentapus*-type tracks from the Middle Jurassic Hailiutu site, which are 16-40.5 cm long and have an unclear phalangeal pad formula. The length/width ratio of HLT-T4 and T6 are both 1.0. The divarication angles II-IV are relatively wide (89° and 78°), and the anterior triangle length/width ratios are 0. 49 and 0.47. CPY-1 is closer to the Middle Jurassic Kayentapus-type tracks than the Early Jurassic specimens.

Generally speaking, CPY-1 shows aff inity with *Kayentapus* type and would be consistent with typical ichnofaunas assuming our age inference (Early-Middle Jurassic) for the Xiahuayuan Formation is correct. Technically this expands the range of Chinese *Kayentapus* into the Middle Jurassic. As the most eastern record, CPY-1 is consistent with the global distribution (Lucas 2007) of *Kayentapus*-type theropod tracks.

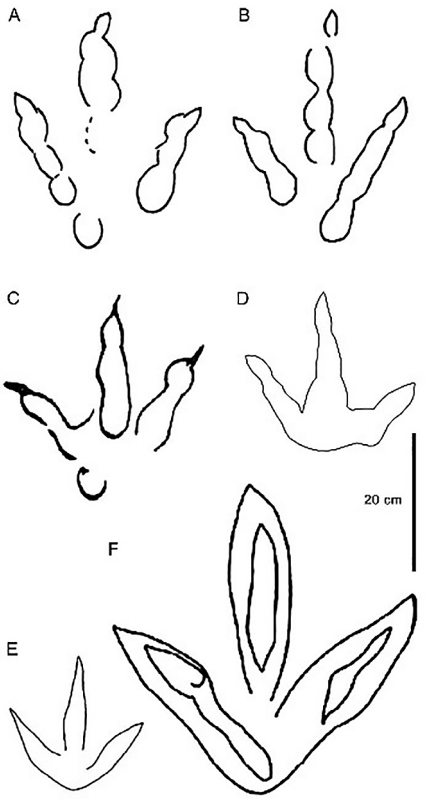

Figure 4. A, the type specimen of *Kayentapus hopii* (Lockley et al., 2011); B, *Kayentapus hopii* from Lower Jurassic Geleshan site in Chongqing, China (Xing et al., 2021c); C, *Kayentapus xiaohebaensis* from Lower Jurassic Yunnan Province, China (Zhen et al. 1986; Lockley et al., 2013); D, *Kayentapus*-type track CPY-1 from this study; E and F, *Kayentapus*-type tracks from Middle Jurassic Hailiutu site (Xing et al., 2021d).

Conclusion

The first Jurassic track reported from the study area (eastern Hebei Province) is identified as a medium-sized theropod track with likely affinities to the slender toed ichnogenus *Kayentapus,* which is common in the Lower Jurassic of China and globally. The track is extensive, indicating a digitigrade stance while the footprint was registered. As a result, the track bears a resemblance to *Magnoavipes.* However, this ichnogenus is only known from the Cretaceous, and we cannot confidently support such an identification based on a single footprint.

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