First report of deinonychosaurian trackway from the Cretaceous of Guizhou, China

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ABSTRACT

The southern edge of Sichuan Basin has a long-standing folklore about the Tian Ji Stone, which actually tells of the theropod tracks. Here we describe a new Tian Ji track site named Xinglongwan in Chishui, Guizhou Province, China. Two kilometers away from the old site recorded in 2011, the later with cf. Irenesauripus isp. are morphologically different from the Xinglongwan theropod tracks. The tridactyl tracks from Xinglongwan site have been assigned to the cf. Eubrontes. Didactyl tracks in the Xinglongwan site, which are the first discovery of deinonychosaurian tracks in Guizhou Province, are assigned to the Velociraptorichnus. Both tracks were recorded in the report about ichnofauna in Jiaguan Formation, representing the diversity of theropod tracks in Sichuan Basin. The authors also briefly discuss the preservation mode and potential external-morphological changes of cf. Eubrontes and Velociraptorichnus from Xinglongwan site.

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1 Introduction

A large collection of tetrapoda tracks have been found in the Jurassic–Cretaceous strata in Sichuan Basin (Xing et al., 2016a). Residents, whose ancestors originated in BaoYuan town, Chishui, Guizhou Province, have their own explanation to the footprints on the huge rocks laying on the mountains: Tian Ji (Heavenly Chicken) tracks, due to their shapes of chicken footprints. The origin of this legend is unknown, but similar footprints and legends have appeared in Sichuan and Guizhou provinces, providing an example of vertebrate tracks contributing to the formation of myths and legends (Xing et al., 2011a).

Xing et al (2011b) described seven dinosaur trackways in BaoYuan. The tracks were preserved on the red thick feldspar and quartz-sand layer of Jiaguan Formation, and were provisionally assigned to cf. Irenesauripus isp.. Many of the tracks contained extended metatarsal pads. The vast dinosaur tracks discovered in Jiaguan Formation have almost become the only channel for us to learn about the Cretaceous vertebrate fauna in Sichuan Basin. This fauna is dominated by Saurischia tracks, which indicates the rich diversity of theropod (Xing & Lockley, 2016).

In 2006, unidentified marks on the collapsed rocks in Xinglongwan during the construction of a road in Pinghua Village, BaoYuan Township, Chishui City, were thought to be the local legendary Tian Ji tracks (Fig. 1). Later in 2020, The Guizhou Geological Museum transported
these specimens to the museum in Guiyang as a permanent exhibit (catalogued as GP0101-1). Xinglongwan site is a landscape of forests, with no dinosaur tracks being found in the initial stratum. The tracks are all on the surface of the slumped rock, and the levels are generally accompanied by developed desiccation cracks. Xinglongwan site is located about 2 km southwest of Baoyuan site and preserves morphologically inconsistent tracks, which we describe briefly here.

**Figure 1.** Map showing the location of Xinglongwan site (1) and Baoyuan site (2) in the Guizhou Province, China.

### 2 Geological setting

Chishui City is located at the southern margin of the Sichuan Basin, where a 3,000-4,000 m thick red clastic construction and interbedded sandstone and mudstone were deposited during the Jurassic to Cretaceous. The delineation of this set of red clastic rocks is controversial. According to the division scheme of Yibin Subdivision in Sichuan Basin (Long et al., 2011), this set was, from bottom to top, divided into the Lower Cretaceous Wotoushan Formation, the Mid-Cretaceous Da’erdan Formation, the Upper Cretaceous Sanheguan and Gaokanba formations, and the Paleocene Liujia Formation. The lower part of Da’erdan Formation and the Wotoushan Formation can be equated with the Jiaguan Formation of the Chengdu-Ya’an Division in Sichuan Basin.

In the stratigraphic division scheme of Guizhou Province, the Cretaceous-Paleocene strata was referred to the Jiading Group and was divided from bottom to top into the Upper Cretaceous Wotoushan Formation, the Lower Cretaceous Sanhe Formation, and the Paleocene Liujia Formation. The Jiading Group is the main formation in Chishui City, with an outcrop area of 1346.57 km² (Leng et al., 2017), and the lithology is brown-purple and brick-red quartz sandstone interspersed with dark purple-red mudstone, about 942 m thick, which is at the margin of the basin (Hao et al., 2000), mainly distributed in the south of Chishui River in Chishui City. The mainly stratigraphic distribution of the Chishui Danxia landform is the Wutoushan and Sanhe formations.

The Sanhe Formation is equated to the Upper Member of the Jiaguan Formation. It is an interbedded brick-red thin layer to medium-thick layered muddy feldspar sandstone and brick-red-purple mudstone. The Wotoushan Formation is equated to the Lower Member of the Jiaguan Formation, which is a brick red thick layer to massive feldspar quartz sandstone with a very
small amount of brick red mudstone and pisolitic limestone (Wang, 2020). Sandstone has cross bedding, and sometimes huge oblique bedding can be seen to several meters. Mud cracks, ripple marks or raindrop impressions are also seen on mudstone and siltstone layers. The bottom sandstone contains 2–3.5m thick conglomerate, which is pseudo-integrated on the purple-red mudstone and sandstone of the Late Jurassic Penglaizhen Formation.

The Jiading Group is mainly composed of sandstone interbedded with mudstone, with strong resistance to weathering. Tall ridges, mostly covered by vegetation, are mainly formed in this terrain. Vertical joints and fissures are developed in the sandstone layer. Under the influence of temperature difference and weathering, the cliff area is prone to collapse (Leng et al., 2017). Exposed strata within the Xinglongwan area belong to the upper section of Cretaceous Jiaguan/Sanhe Formation, and is primarily formed by medium-thick to hugely-thick feldspar-clastic sandstone interbedded with thin mudstone. The area from Xishui (Guizhou Province) to Hejiang of Luzhou City was a braided river deposit in the Cretaceous (Geng, 2011).

3 Morphology

The length and width of GP0101-1 are 2.56 m and 1.8 m respectively, and it is divided into two layers with developed mud cracks (Fig. 2). At least 14 footprints are distributed on the layer of Lay 1, including 12 tridactyl tracks and 2 didactyl tracks. All tracks are preserved as natural casts (convex hyporeliefs). Most of the tracks are covered by mud cracks, indicating that the tracks are left before the desiccation.

Figure 2. Photograph of the GP0101-1 specimen from Xinglongwan site, Guizhou Province, China.

3.1 Didactyl tracks

Material: Two natural casts of didactyl pes impressions, cataloged as GP0101-1-T2-R1 and L1 (Figs. 2, 3, Table. 1) from the Xinglongwan site.

<table>
<thead>
<tr>
<th>GP0101-1</th>
<th>L</th>
<th>W</th>
<th>PL</th>
<th>SL</th>
<th>PA</th>
<th>II-III</th>
<th>III-IV</th>
<th>II-IV</th>
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<td>33</td>
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<td>31</td>
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<td>1.4</td>
<td>0.49</td>
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<td>14.8</td>
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<td>1.5</td>
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Table 1. Measurements (in cm and °) of the dinosaur tracks from Xinglongwan tracksite, Guizhou Province, China. Notes: Abbreviations: L: Maximum length; W: Maximum (measured as the distance between the tips of digits II and IV); PL: Pace length; SL: Stride length; PA: Pace angulation; II-III, III-IV, II-IV: angle between digits II-III, III-IV, II-IV; L/W is ML/MW’s dimensionless; M: Mesaxony.
**Figure 3.** The photograph and interpretative outline drawings of GP0101-1 theropod tracks.

**Description:** GP0101-1-T2-R1 and L1 are the single pace with a mean length/width ratio of 1.5. The pes tracks are elongate (average length 9.5 cm) with two-digit impressions (digits III and IV) and rounded heel. The impressions of digits III are longer than digit IV, and roughly equal in width. The average divarication angle between digits III and IV of GP0101-1-T2 is 42°. Claw impressions are relatively sharp. The large metatarsal region is semicircular and not separated from the digit traces by a distinct border. No trace of a digit II impression is visible in either track. GP0101-1-T2-R1 and L1 are interpreted as a right-left step of 40 cm.

**Comparisons and discussion:** The didactyl pes imprints with the absence of digit II traces in all specimens indicate their affinity to deinonychosaurs. Deinonychosaur ichnotaxa currently consists of five ichnogenera (*Dromaeopodus*, *Dromaeosauripus*, *Menglongipus*, *Sarmientichnus* and *Velociraptorichnus*) (Kim et al., 2008, 2012; Xing et al., 2013a, b, 2018a, b). *Velociraptorichnus* is characterized by relatively robust digits, and by the absence of well-defined digital pads, or digit curvature, all features shared by the Xinglongwan tracks. The Xinglongwan didactyl tracks and *Velociraptorichnus sichuanensis* are similar in size and morphology. But there is minor difference between them. For instance, the divarication angle between digits III and IV in Xinglongwan specimens is slightly larger than the *Velociraptorichnus* holotype, but almost as same as the Mujiaowu *Velociraptorichnus* isp. Therefore, we refer the didactyl tracks from the Xinglongwan tracksites tentatively to *Velociraptorichnus* isp.

The table 2 shows all records of *Velociraptorichnus* so far, demonstrating some interesting phenomena. In terms of morphological consistency, tracks with a length of 7–11 cm have a stable ratio (4.2–5) between pes length and track length. The divarication angle between digit III and IV has a larger range, which is from 27° to 42°. In all of the 7 records, three sites were found in Jiaguan Formation (Barremian–Albian), two sites were from Xiaoba Formation (the First Member of the Xiaoba Formation is equivalent to the Jiaguan Formation from the Sichuan Basin, CGCMS, 1982), with two sites respectively located in Tianjialou Formation (Barremian–Albian, Kuang et al., 2013) and the Third Member of the Tuchengzi Formation (Late Jurassic Oxfordian–Tithonian or Early Cretaceous Neocomian, or Berriasian–Barremian). These records widespread in Barremian, corresponding to the paleoecological pattern proposed by Lockley et al. (2013); *Dromaeopodus*, *Velociraptorichnus*, *Minisauripus* and *Eubrontes* tracks, also bird tracks (*Koreanornis*) with distinct East Asian features.
3.2 Tridactyl tracks

**Material:** 12 natural casts of tridactyl pes impressions, cataloged as GP0101-1-T1, T3, and 6 separated tracks (Figs. 2, 3, Table. 1). The two trackways are each composed of three tracks, while T3 is missing a right footprint.

**Description:** The theropod trackway GP0101-1-T1 is consists of three tridactyl footprints preserved as natural casts (convex hyporeliefs), labelled GP0101-1-T1-R1–R2 (Figures 2-3) (Table 1). The footprints have an average length and width of 18.6 cm and 14.8 cm, respectively. The average length: width ratio of the imprints is 1.3, the pace angulation 152° and the average divarication angle between digits II and IV 62°.

The relative stride length (SL/h) is 1.11, implying that the animal was walking. All separated tracks are poorly preserved. The possibility of undertracks should not be excluded. Its overall dimensions, length/width ratio and mesaxony are basically the same as those of T1 and T3.

**Comparisons and discussion:** By their size (< 25 cm pes length) and by the degree of mesaxony, the tridactyl tracks from Xinglongwan can be assigned to the ichnogenus *Eubrontes* (Olsen et al. 1998). They are characterized by weak to moderate mesaxony, which is close to that of typical footprints of the ichno- or morpho-family Eubrontidae, Lull 1904 (0.37–0.58 in *Eubrontes* type; Lockley 2009). Xinglongwan specimens lack the key feature of *Eubrontes*, such as a distinct metatarsophalangeal pad trace posterior to digit II, such as the type specimens of *Eubrontes AC 151* (Olsen et al. 1998). On the other hand, the size and interdigital divarication of digits II–IV of the Xinglongwan specimens are different from those conventional. And the Jurassic *Eubrontes*. Xinglongwan specimens are apparently discrepant form *Irenesauripus* isp. in the same area (Xing et al., 2011), which show hallux impressions. Thus, we classify the specimens as *Eubrontes* because of the limited and moderately preserved sample.

### 4. Preservation

Notably, all of these tridactyl theropod tracks showed flattening (widening), especially manifested by lateral extension at the end of digit III, which is consistent with the external-morphological changes discussed in detail by Lockley and Xing (2015), which are associated
with differential effects of overburden pressures on different lithologies. Since all tridactyl tracks on GP0101-1 show a similar phenomenon, it is likely that the two Velociraptorichnus tracks also have the same changes. This leads us to realize that both Xinglongwan Velociraptorichnus and V. sichuanensis from E’mei are flatter/wider or significantly flatter than Shandong Velociraptorichnus (Li et al, 2007) or Mujiaowu Velociraptorichnus (Xing et al., 2015) which are likely to be external-morphological variations. Another supporting evidence is the similar flattening of grallatorid tracks from E’mei, which were initially mistaken for iguanodonts tracks (Zhen et al., 1994). However, Koreanaornis and Minisauripus, also from the E’mei site, do not appear to have significant flattening, which may be related to their tiny size and requires more comparison and discussion in the future.

5 Conclusions

1. Although northeastern Guizhou Province is part of the Sichuan Basin, this is the first record of deinonychosaurian tracks in Guizhou Province.
2. The didactyl (Velociraptorichnus) and tridactyl tracks (cf. Eubrontes) described here both occur in the Jiaguan Formation ichnofauna, again demonstrating the diversity of theropod tracks in the Sichuan Basin.
3. Velociraptorichnus records from Hebei Province in northern China, Shandong Province in eastern China, and the Sichuan Basin (Sichuan and Guizhou Provinces) in southwest China are reviewed, and their commonality is described, as well as their universality in the Barremian, which may suggest that some specific tracks morphology may provide better geological age information in the future.
4. The "flattening" Velociraptorichnus type specimen is probably an external-morphological variation.
5. The cf. Eubrontes from Xinglongwan contribute to the known diversity of theropod tracks from the Jiaguan Formation and suggest a high prevalence of cf. Eubrontes and Eubrontes type in small and medium size.

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Xing, L.D., Lockley, M.G., Tang, Y.Z., Romilio,


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