

A probable crouching theropod dinosaur trace from the Tuchengzi Formation in Chicheng area, Hebei Province, China

河北赤城地区土城子组中一例极可能的兽脚类恐龙蹲伏迹

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Abstract: A probable theropod dinosaur crouching trace and associated tracks from the Tuchengzi (Houcheng) Formation of Siliang Mountain, Chicheng County, Hebei Province, China are the largest theropod tracks currently known from the formation. Although the crouching trace lacks manus and tail marks, the traces are interpreted as made by a crouching theropod because they include a left metatarsal impression and associated ischial, and possibly pubic, callosity traces. This represents the third known example of an asymmetric crouching position adopted by a theropod.

Key words: crouching theropod trace; *Therangospodus* isp.; cf. *Megalosauripus* isp.; Tuchengzi Formation; Jurassic–Cretaceous boundary

摘要: 描述了河北省赤城县寺梁山土城子(后城)组一例极可能的兽脚类恐龙蹲伏迹及相关的足迹,该蹲伏迹也是该组地层目前发现的最大的兽脚类足迹。虽然缺乏前足迹和尾迹,但因保存了左跖骨印、关联的坐骨及可能的耻骨胫胫印被定为蹲伏迹。该蹲伏迹是世界上第三例非对称的兽脚类恐龙蹲伏迹。

关键词: 兽脚类蹲伏迹; 窄足龙足迹未定种; 似巨齿龙足迹未定种; 土城子组; 侏罗系—白垩系界线

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1 Introduction

Dinosaur crouching (also called sitting or resting) traces are uncommon, but are important sources of information about the anatomies, postures, and behaviors of their track makers. All crouching traces thus far discovered were made by theropod and basal ornithischian dinosaurs. Some specimens made by theropods have even been examined in the contexts of “protofeather” origins and the evolutionary relationships between theropods and birds^[1–4].

Only seven crouching traces made by theropods have been hitherto described^[1–10]. Among these, the best known are specimens originally labeled as *Anomoepus major* (Fig. 1–A) and *Sauropus barratti*^[11–13], which came from the Early Jurassic of the Connecticut Valley^[14]. Subsequently, the ichnotaxonomic statuses of *A. major* and *S. barratti* have changed several times^[13–15]. Gierliński (1994) attributed these specimens to *Grallator*^[5] (*Eubrontes* and *Grallator sensu* Lockley^[16], or *Anchisauripus sensu* Olsen et al.^[17]), and this ichnotaxonomy has since become generally accepted^[7,18]. A large theropod (*Eubrontes*-like) crouching traces was described from Sichuan, China^[7]; another specimen, which includes manus traces, was found in Utah, USA^[4]. The most recently discovered example is an exceptionally well-preserved specimen (Fig. 1–B) from the Early Jurassic of Poland^[10] that pertains to either *Anchisauripus sensu* Olsen et al.^[17] or *Eubrontes sensu* Lockley^[16].

Here we describe an eighth crouching theropod trace (Fig. 1–C), from the Nijiagou track site on the southern slope of Siliang Mountain, Nijiagou Village, Yangtian Township, Chicheng County, Zhangjiakou City, Hebei Province, China. Xing et al. described didactyl *Menglongipus* (Dromaeopodidae) and *Grallator*-type tracks from the same site^[19]. The Nijiagou track site and a second site (the Luofenggou site), which preserves *Therangospodus* isp. and *Megalosauripus* isp. tracks^[20], lie on strata of the Tuchengzi Formation (also known as the Houcheng Formation). Sediments comprising this unit were deposited in the latest Jurassic and earliest Cretaceous: radiometric dating recovered a

minimum age of 136–139 Ma^[21–22] and a maximum age of 147 Ma^[22]. The track-bearing stratum at the Nijiagou locality lies high in the Tuchengzi Formation, but it is not presently possible to determine whether the tracks are latest Jurassic or earliest Cretaceous in age. Theropod tracks, primarily those of the *Grallator* morphotype, are the most common track types in the Tuchengzi Formation^[19,20,23–28].

2 Institutional abbreviations

AC=Hitchcock Ichnology Collection, Pratt Museum of Natural History, Amherst College, Amherst, Massachusetts, U.S.A; J=JuraPark, Solec Kujawski, Poland; LF=Luofenggou Field, Hebei, China; T.B=Track B, Nijiagou Field, Hebei, China; T.C=Track C, Nijiagou Field, Hebei, China.

3 *Therangospodus* morphotype in Nijiagou track site

Numerous theropod tracks, in several trackways (each assigned a letter—T.A, T.B, etc.), are preserved at the Nijiagou track site. Several tracks described by Xing et al. fig. 4b^[19], are here re-interpreted based on new observations made during the 2010 field season. Specimens T.B.6, 7, 8, and 10 (Fig. 2), the best preserved in the T.B. trackway, have an average length of 18.8 cm (range 18.2–19.6 cm), an average width of 12.4 cm (range 11.3–13.5 cm), average digit lengths of 8.3, 12.8, and 8.3 cm for digits II, III, and IV, respectively, and average divarication angles between digits II–III and III–IV of 29.5° and 25.3°, respectively. The impressions of digits II and III widen distally. A preservationally and morphologically similar track (specimen LF2) is found at the Luofenggou (LF) track site.

The length:width ratios of the T.B tracks range from 1.4:1–1.7:1, which is slightly larger than the ratio of 1.3:1 of LF 1 and LF 2. Among the T.B tracks, specimen T.B.6 is unique in preserving an ovoid metatarsal region. The T.B. track maker probably sank into the substrate more deeply when making this track, creating a deeper impression in T.B.6. These

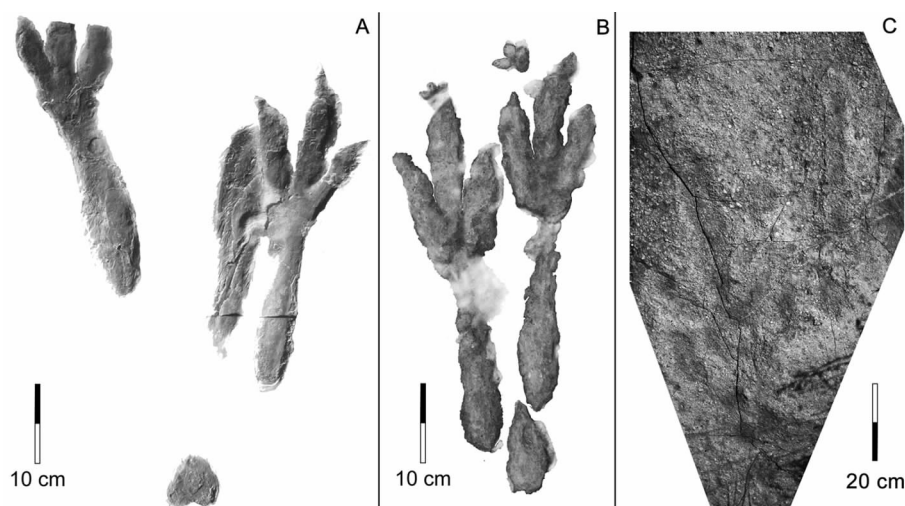


Fig. 1 Comparison of specimen T.C.1 with other asymmetrical crouching theropod impressions
A—specimen AC 1/7 from the Early Jurassic of Massachusetts, USA; B—specimen JuraPark J484 from the Early Jurassic of Poland; C—Resting theropod impression (T.C.1) from the Nijiagou track site, Chicheng County, Hebei Province, China

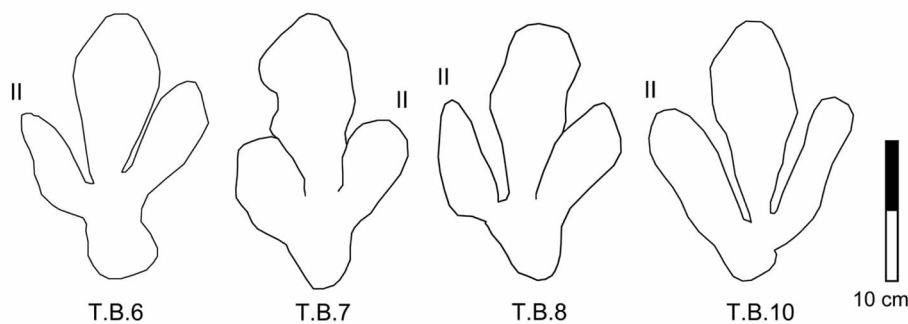


Fig. 2 Outline drawings of *Therangospodus* tracks T.B. 6, 7, 8, and 10 from the Nijiagou track site, Chicheng County, Hebei Province

characteristics are consistent with those of tracks at the Luofenggou site, which pertain to *Therangospodus* isp.^[20], so we revise the ichnotaxonomy of the T.B tracks to *Therangospodus* isp.

4 Probable crouching theropod trace

Material: A pair of incomplete natural molds found at the Nijiagou track site is cataloged as T.C.1 (Fig.1 –C, Fig.3; Table 1). The original tracks were not collected and are still in the field.

Holotype locality and horizon: Tuchengzi Formation, Upper Jurassic–Lower Cretaceous (Tithonian–Valanginian). Nijiagou track site, Chicheng, Hebei

Province, China.

Description: A theropod resting impression comprising large, tridactyl, semiplantigrade footprints, an ischial callosity print, and a possible pubic callosity print, but lacking traces of the manus, belly, and tail. T.C.1 (Fig.3–A) is preserved as a dark stain of extremely shallow depth on a conglomeratic substrate. The left footprint (T.C.1L) is the most complete and serves as the representative of pedal morphology; only the impression of the mesaxononic toe (digit III) is well preserved in the right print (T.C.1R) (Fig. 3–B). Its length:width ratio is 1.49:1. Digit III is directed cranially, and digit IV is longer than digit II. The length of digit III

Table 1 Measurements of crouching theropod trace T.C.1
from the Nijiagou track site, Chicheng County, Hebei Province

	ML	MW	II	III	IV	LM	WM	II—III	III—IV
T.C.1L	58.7	33.6	19.1	42.8	24.4	23.3	18.7	31°	32°
T.C.1R	63.6	—	—	43.4	—	13.7	10	—	—

notes: L: left; R: right; LM: length of metatarsal impression (cm); ML: maximum length (not including the metatarsal impression)(cm); MW: maximum width, distance between the tips of digits II and IV (cm); WM: width of metatarsal impression(cm); II: length of digit II (cm); III: length of digit III (cm); IV: length of digit IV (cm); II—III: angle between digits II and III (°); III—IV: angle between digits III and IV (°)

comprises about 73% of footprint length, differing markedly from the outer digits, which span only 33%–42% of the total footprint length. Digit II has two digital pads; both digits III and IV have at least three faint digital pads. The divarication angle between digits II and IV is 63°. A metatarsal impression lies in line with the axis of digit III; its caudal margin is slightly convex caudally. The metatarsal impression lies closer to the lateral side of the axis of footprint than the medial side; its terminal margin enlarges to exceed the width of the metatarsophalangeal region.

A sub-ovoid impression (12cm×7.4cm) located close to the caudomedial end of T.C.1L is an ischial callosity impression. A second sub-ovoid impression (10cm×9.2cm) between the left and right footprints might be the impression of a pubic callosity.

5 Discussion

The Siliang T.C.1 specimens are large, elongate, tridactyl theropod tracks readily compared with several well-known theropod ichnotaxa (e.g., *Grallator*, *Anchisauripus*, *Eubrontes*, *Kayentapus*, and *Gigandipus*). The T.C.1 tracks have less acute angles of divarication (63°) than those of the *Grallator*–*Anchisauripus*–*Eubrontes* plexus, but they are close to the angles described for *Kayentapus* (60–72°^[29]), *Megalosauripus* (52°; Lockley et al. fig. 8^[30]) and *Therangospodus* (56°; Lockley et al. Fig. 7^[31]). The length of digit III as a function of overall track length in the Siliang tracks (73%) is greater than the values for *Megalosauripus* (60%) and *Kayentapus* (69%), but close to the value for *Therangospodus* (74%). The T.C.1 tracks (58.7–63.6

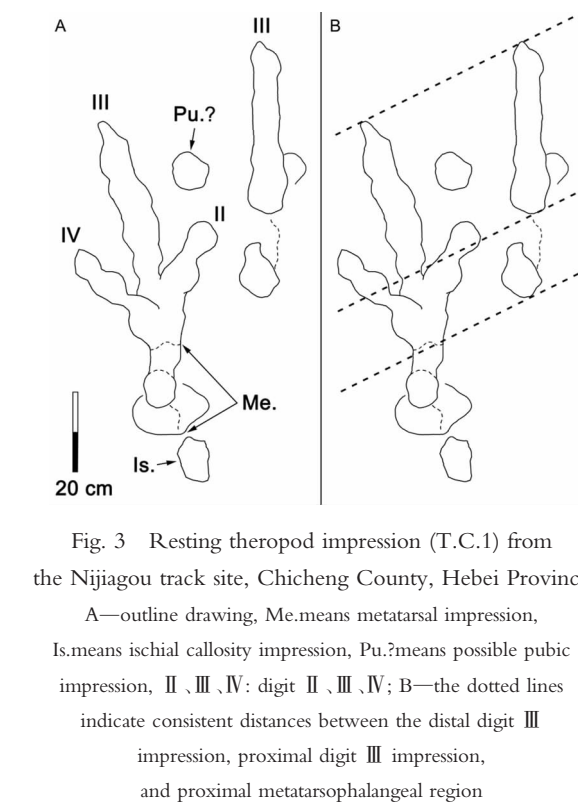


Fig. 3 Resting theropod impression (T.C.1) from the Nijiagou track site, Chicheng County, Hebei Province
A—outline drawing, Me. means metatarsal impression, Is. means ischial callosity impression, Pu.? means possible pubic impression, II、III、IV: digit II、III、IV; B—the dotted lines indicate consistent distances between the distal digit III impression, proximal digit III impression, and proximal metatarsophalangeal region

cm in length) are longer than medium-sized *Therangospodus* tracks (averaging 28 cm long^[31]) and *Kayentapus* (pes length ~35 cm^[32]). Furthermore, the T.C.1 tracks lack cigar-shaped digits, unlike the *Therangospodus* morphotype described by Lockley et al.^[31], but they are more robust than more gracile *Kayentapus* tracks^[32]. Because the sample size of the Silian tracks is so small, coupled with the inability to discern systematic features, the T.C.1 tracks are impossible to attribute to a particular ichnotaxon.

As yet, no theropod body fossils have been recovered from the Tuchengzi Formation. The T.C.1

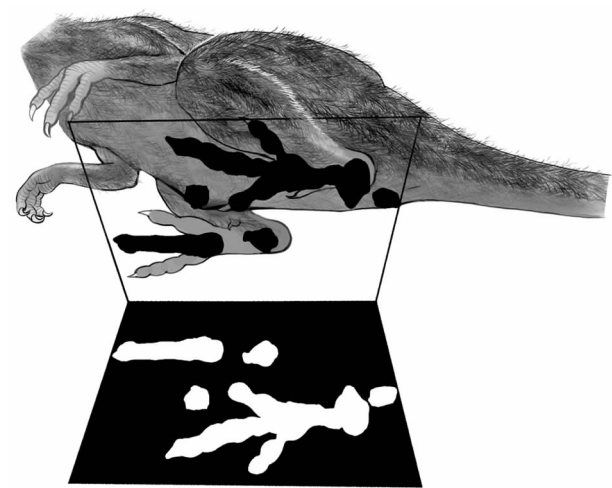


Fig. 4 Restoration of the resting theropod impression (T.C.1), made when the dinosaur placed its metatarsal impression and associated ischial, and pubic area in contact with the ground (by Xing Lida and Liu Yi (art assistant))

tracks, with total lengths of up to 82 cm including the metatarsal impression in T.C.6, are the largest theropod tracks from the Tuchengzi Formation and indicate that at least one large theropod taxon existed in the area during Tuchengzi time.

The classic Connecticut Valley crouching theropod traces (AC 1/7 and AC 1/1) include sub-crescentic or heart-shaped ischial callosity impressions and subparallel metatarsus impressions^[1,2,7,18]. The *Eubrontes*-like Wumacun crouching track specimen also exhibits subparallel metatarsus impressions, a sub-triangular ischial impression, and a cranially situated pelvic (presumably pubic) impression^[7]. The Coyote Buttes, Arizona specimen, which is more poorly preserved than other specimens, includes subparallel metatarsus impressions and a subcircular ischial impression^[9]. The crouching *Eubrontes* specimen from St. George, Utah possesses nearly symmetrical, elongate metatarsus impressions and circular ischial impressions^[4]. It is unclear whether symmetrical vs. asymmetrical crouching traces reflect taxonomic or morphofunctional differences in the track makers, different behaviors in different conditions at the moments of track making on the parts of the track makers, or simply an ability of theropods

to comfortably alternate between symmetrical and asymmetrical resting poses with no internal or external etiological origin.

The areas immediately cranial and caudal to the T.C.1 tracks were, at the time the tracks were discovered and studied, buried by overlying mudstone strata, so the presence of manus or associated tail prints is impossible to assess at present, which limits comparison of T.C.1 to other theropod crouching traces that preserve these features^[4,9]. Specimen T.C.1 resembles AC 1/7 and JuraPark J484 in possessing an ischial callosity impression located asymmetrically, closer to the caudomedial end of the left footprint. This indicates that the track maker rested in an asymmetric crouched or semi-crouched position (Fig. 4).

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