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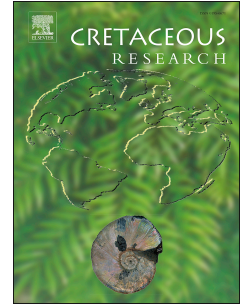
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Feng Li, Shundong Bi, Michael Pittman, Stephen L. Brusatte, Xing Xu



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**A New Tyrannosaurine Specimen (Theropoda: Tyrannosauroidae)
with Insect Borings from the Upper Cretaceous Honglishan
Formation of Northwestern China**

Li Feng^{a, b, *} Bi Shundong^{b, c} Michael Pittman^d Stephen L. Brusatte^e Xu Xing^b

^aUniversity of Chinese Academy of Sciences, No.19A Yuquan Road, Beijing 100049, China

^bKey Laboratory of Vertebrate Evolution and Human Origins of Chinese Academy of Sciences, Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences, 142 Xizhimenwai Street, Beijing 100044, China

^cDepartment of Biology, Indiana University of Pennsylvania, Indiana, Pennsylvania 15705, USA

^dVertebrate Palaeontology Laboratory, Department of Earth Sciences, University of Hong Kong, Pokfulam, Hong Kong, China

^eSchool of GeoSciences, University of Edinburgh, Grant Institute, James Hutton Road, Edinburgh EH9 3FE, UK

* Corresponding author. Present address: Key Laboratory of Vertebrate Evolution and Human Origins of Chinese Academy of Sciences, Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences, 142 Xizhimenwai Street, Beijing 100044, China. E-mail address: cugbdeinosuchus@yahoo.com (Li Feng).

ABSTRACT

A large theropod ilium was recently collected from the Upper Cretaceous Honglishan Formation in the Sangequan area of the northern Junggar Basin, Xinjiang, China, which represents the first officially reported dinosaur fossil from this formation. Several morphological features, including robust supraacetabular ridge, reduced supracetabular crest, concave anterior margin of the pubic peduncle, ventral flange on the pubic peduncle, converging dorsal surface of the iliac blades, laterally visible cuppedicus shelf, and ventral flange on the posterior surface of pubic peduncle, suggest that this specimen can be referred to Tyrannosaurinae, and furthermore, a few differences between this specimen and other

tyrannosaurines in particular the contemporary Asian tyrannosaurine *Tarbosaurus* suggest that IVPP V22757 may represent a new tyrannosaurine species. However, in the absence of extensive data that would make it possible to properly evaluate these differences, we refrain from naming a new taxon based on this specimen. Some insect borings are also identified in this specimen, and are referable to the ichnogenus *Cubiculum*, which is interpreted as the insect pupichnia. This new fossil documents the presence of a gigantic theropod in the Upper Cretaceous of Junggar Basin, adding new information on its poorly studied ecosystems.

Key words Theropod, Tyrannosaurine, Upper Cretaceous, Honglishan Formation, Junggar Basin, Insect Borings

1. Introduction

Tyrannosaurids, known only from the Upper Cretaceous of North America and Asia, are a derived group of coelurosaurian carnivores that includes two subclades: Tyrannosaurinae and Albertosaurinae. The geographical distribution of tyrannosaurines is more widespread, while albertosaurines appear to have been restricted to North America and are unknown in Asia (Brusatte et al., 2010b; Holtz, 2004).

During the Late Cretaceous, China was home to the tyrannosaurines such as *Tarbosaurus*, *Zhuchengtyrannus* and *Qianzhousaurus* (Brusatte et al., 2010a; Carpenter, 1992; Holtz, 2004; Lü et al., 2014). In the mid-1960s, a partial skull and postcranial skeleton of a small tyrannosaurid (IVPP V4878) was recovered from the Subashi Formation of Lianxinmu,

Turpan, Xinjiang Province. In 1977, a new genus and species, *Shanshanosaurus huoyanshanensis*, was named based on this specimen (Dong, 1977). Redescription of the specimen suggested that *Shanshanosaurus huoyanshanensis* is a juvenile *Tarbosaurus* (Currie and Dong, 2001). The unequivocal tyrannosaurine *Zhuchengtyrannus* was discovered from the Campanian Wangshi Group of Shandong Province (Hone et al., 2011). More recently, a longirostrine tyrannosaurine *Qianzhousaurus*, a closely related taxon of *Alioramus*, was discovered from the Upper Cretaceous red bed of the Nanxiong Formation of Jiangxi Province (Brusatte et al., 2009; Kurzanov, 1976; Lü et al., 2014). Additionally, supposed fragmentary tyrannosaurid remains were recorded from multiple Upper Cretaceous deposits across China, which include the equivocal “*Albertosaurus periculosus*” collected from Belye Kruchi on the bank of the Heilongjiang River (Riabinin, 1930); supposed “*Tyrannosaurus rex*” from the red beds of the Sichuan Basin (Louderback, 1935); the so-called “*Tyrannosaurus lanpingensis*” tooth found in the red beds of Yunnan (Ye, 1975); “*Tyrannosaurus turpanensis*” from the Subashi Formation of the Turpan Basin, Xinjiang (Zhai et al., 1978); as well as “*Tyrannosaurus luanchuanensis*” from the Quiba Formation of the Tantou Basin, Henan Province (Dong, 1979; Tong and Wang, 1980). However, most of these referrals were quite asserted instead of based on explicit criteria, and were often lacking detailed character discussions, measurements and photographs of the specimens, which is the reason they were all regarded as synonyms to *Tarbosaurus bataar* by Holtz (2004).

In 2013, members of an IVPP (Institute of Vertebrate Paleontology and Paleoanthropology, Beijing) expedition collected a partially preserved tyrannosaurid ilium from the Honglishan Formation (Upper Cretaceous) in the Sangequan area of the northern

Junggar Basin, Xinjiang, China. Judging from the broken state, the ilium was transported some distance before it was buried, and there were no shed theropod teeth or skeletal elements found to be associated with it. Further preparation of the specimen led to the discovery of several insect borings attributable to necrophagous insects (Pirrone et al., 2014; Roberts et al., 2007; Xing et al., 2015). Though vertebrate fossils with supposed insect traces have been found across China, formal descriptions of insect traces are scarce (Gong et al., 2009; Xing et al., 2015; Xing et al., 2013). In this paper, we present a formal description of this insect-modified ilium and a tentative reconstruction of its pre-burial taphonomic history.

1.1. Institutional abbreviations

The following abbreviations are used throughout this work: AMNH FARB, Fossil Amphibian, Reptile, and Bird Collections, American Museum of Natural History, New York; BMR, Burpee Museum of Natural History, Rockford, Illinois; CMN, Canadian Museum of Nature, Ottawa, Ontario, Canada; ELDM, Erlianhaote Dinosaur Museum, Inner Mongolia; FDRC, Fossil Research and Development Center, Gansu Bureau of Geology and Mineral Resources Exploration, Lanzhou, People's Republic of China; IGM, Institute of Geology, Ulaan Baatar, Mongolia; IVPP, Institute of Vertebrate Paleontology and Paleoanthropology, Beijing, People's Republic of China; MIWG, Museum of Isle of Wight Geology (Dinosaur Isle, Isle of Wight Museum Services, IWCMS), Sandown, England, United Kingdom; OUMNH, Oxford University Museum of Natural History, Oxford, England, U.K.; PIN, Paleontological Institute, Moscow, Russia; ZPAL, Instytut Paleobiologii PAN, Warsaw, Poland.

2. Geological and Taphonomic Setting

The Honglishan Formation outcrops out in the Sangequan area of the northern Junggar Basin. Rock types and facies relationships suggest a fluviolacustrine origin; brownish-red mudstones, gray-green sandstones, and intercalated conglomerates that were deposited by a river (Chen, 1983, 1987, 1996; Dong, 1992; Shen and Mateer, 1992; Zhao, 1980). Thick red beds, gypsum, and rock salt deposited suggest a seasonally arid tropical-subtropical climate (Dong, 1992; Hendrix et al., 1992; Zhao, 1992). An extensive bone-bearing horizon occurs within the middle lithofacies suite of the Honglishan Formation, approximately 160 m below the contact with the overlying Ulungurhe Formation (Dong, 1992; Zhao, 1980). The fauna of the Honglishan Formation includes: Tyrannosauridae indet., Hadrosauridae indet., Chelonia indet., Pelecypoda, and *Pseudohyria*, suggesting a low biodiversity. All these materials were only briefly mentioned, but have never been described or illustrated ever since (Dong, 1992; Zhao, 1980). The tyrannosaurid-hadrosaurid fossil assemblage was buried in fine-grained sediments deposited on a lacustrine beach-bar during flood season (Dong, 1992; Zhao, 1980). According to stratigraphic and fossil evidence, the Honglishan Formation is of early Late Cretaceous age (Dong, 1992; Gradstein et al., 1995; Li et al., 2009; Zhao, 1980).

3. Systematic Paleontology

Theropoda Marsh, 1881

Tetanurae Gauthier, 1986

Tyrannosauroida Osborn, 1905

Tyrannosauridae Osborn, 1905 (sensu Sereno et al., 2005)

Tyrannosaurinae Osborn, 1905 (sensu Currie et al., 2003)

Tyrannosaurinae gen. et sp. indet.

3.1. Material

IVPP V22757, a left ilium missing most of the preacetabular blade anterior to the supraacetabular crest, the posterior portion of the postacetabular blade, as well as the dorsal margin of the iliac blade.

3.2. Locality and Horizon

Sangequan area, northern Junggar Basin, Xinjiang Autonomous Region, People's Republic of China (Fig. 1). The site outcrops the middle suite of the Honglishan Formation, assigned to the lower Upper Cretaceous (Dong, 1992; Gradstein et al., 1995; Li et al., 2009; Zhao, 1980).

4. Description and Comparison

Although the ilium suffered some degree of weathering and erosion, the preserved bone surfaces are generally of high quality, except for the antitrochanter and the posterior part of the superacetabular crest, which have crumbled beyond recognition. Except for the swollen ventral margin above the cuppedicus fossa, the remainder of the preacetabular blade anterior to the supraacetabular ridge is largely broken off. Additionally, the dorsal margin of the iliac blade and most of the postacetabular blade are also missing. The preserved portion of the ilium is

640 mm long anteroposteriorly and the blade is 250 mm deep dorsoventrally above the acetabulum. The anterior blade is 22 mm thick at the base of the anterior end of the preacetabular process where it is broken, and dorsally it gradually thins to 9 mm at the top of the supraacetabular ridge, whereas the thickness of the blade within the lateral concavity posterior to the supraacetabular ridge is only 6 mm.

The lateral surface of the ilium is generally well-preserved, especially within the lateral concavity, where fine surface details such as muscle-attachment striations and the accessory ridges or swellings are clearly visible. On the lateral surface, the robust supraacetabular ridge (median ridge) (Fig. 2: mrid), which is often considered as a synapomorphy of tyrannosauroids (Benson, 2008; Brusatte et al., 2014; Brusatte et al., 2010b; Holtz, 2004), is prominent and discrete. Although an anterodorsal orientation of the ridge, like that in this ilium, is also present in some, but not all, specimens of *Daspletosaurus* (CMN 8506), *Gorgosaurus* (CMN 2120), *Alioramus* (IGM 100/1844), and *Tyrannosaurus* (BMR 2002.4.1), the form of the ridge differs from those in most other tyrannosauroid taxa in that it starts curving anterodorsally from the anteroventral corner of the lateral concavity above the acetabulum and then gradually becomes more vertical dorsally. In comparison, the ridge extends nearly straight dorsoventrally (with the iliac blade held horizontal for reference) in most tyrannosauroids (*Tarbosaurus*: ZPAL MgD-I/204; *Tyrannosaurus*: AMNH FARB 5027, Brochu, 2003: fig. 90; *Albertosaurus*: Parks, 1928: fig. 10; *Aviatyrannus*: Rauhut, 2003: fig. 1; *Dilong*: IVPP V14243; *Gorgosaurus*: AMNH FARB 5664, Lambe, 1917: fig. 38; *Guanlong*: IVPP V14531, Xu et al., 2006: fig. 2; *Yutyranus*: ELDM V1001), except those in *Stokesosaurus* (Madsen, 1974: fig. 1), *Juratyran* (Benson, 2008: figs. 8, 9) and *Eotyrannus*

(MIWG 1997.550) where the ridges are oriented posterodorsally.

Curving from the anteroventral corner of the lateral concavity posterior to the midpoint of the acetabulum, the median ridge is 43 mm in anteroposterior length at the place where it starts as a prominent and discrete structure offset from the lateral surface of the ilium, and then becomes less offset and narrower as it trends dorsally. However, given that most of the blade dorsal to the median ridge is missing, it cannot be determined whether the ridge terminates proximally as in other tyrannosaurids (*Daspletosaurus*: CMN 8506; *Gorgosaurus*: AMNH FARB 5664, Lambe, 1917: fig. 38; *Tarbosaurus*: ZPAL MgD-I/204; *Tyrannosaurus*: AMNH FARB 5027, Brochu, 2003; *Alioramus*: IGM 100/1844) as well as in the basal taxon *Dilong* (IVPP V14243), or extends farther dorsally as in most basal tyrannosauroids, such as *Yutyrannus* (ELDM V1001), *Guanlong* (IVPP V14531, Xu et al., 2006: fig.2), *Aviatyrannus* (Rauhut, 2003: fig. 1), and *Stokesosaurus* (Madsen, 1974: fig. 1); not *Juratyran*, which has a ridge that terminates ventrally (Benson, 2008: figs. 8, 9).

Within the lateral concavity posterior to the median ridge, there are two accessory swellings (Fig. 2: antrid, postrid). At their midpoints, the median ridge and anterior swelling are separated by 85 mm, whereas the posterior one is located approximately 42 mm posterior to the latter. Instead of radiating from the dorsal margin of the acetabulum as in some tyrannosauroids, such as *Alioramus* (IGM 100/1844) and *Stokesosaurus* (Madsen, 1974: fig.1), they both originate in a similar position within the lateral concavity to those structures described in *Tyrannosaurus* (Brochu, 2003: fig. 90), where the anterior swelling (Fig. 2: antrid) and posterior swelling (Fig. 2: postrid) do not reach the dorsal margin of the acetabulum. The anterior swelling, being the wider but less offset one, trends roughly parallel

to the median ridge, while the posterior one, which takes the form of a narrow ridge that is much less robust and offset than the median ridge, extends nearly vertically. As a result, the two swellings form an acute angle, but breakage obscures their possible contact. As in other tyrannosaurids, including *Daspletosaurus* (CMN 8506), *Tarbosaurus* (PIN 551-2), and *Tyrannosaurus* (AMNH FARB 5027), the lateral concavity is triangular and rather deep, where the crumbled ventral margin of the postacetabular process forms the ventral border of this concavity which curves dorsally as it continues posteriorly.

Within the lateral concavity, particularly in the vicinity of the accessory swellings, distinct muscle attachment striations are clearly visible. According to the muscle reconstructions for *Tyrannosaurus* by Carrano and Hutchinson (2002), this concavity is the attachment site for two muscles (the *M. iliofibularis* anteriorly and *M. flexor tibialis externus* posteriorly), but it is difficult to assess how the muscles were separated by the two accessory swellings in this case. One possible scenario is that the anterior accessory swelling separated these two muscles, while the posterior swelling may have separated the two heads of *M. flexor tibialis externus*.

The acetabulum is 220 mm in anteroposterior diameter and is generally round in shape. The dorsal half of the acetabulum surface, formed by the ilium, is concave anteriorly, flattened posteriorly, and tilted anterolaterally. As a result, the acetabulum is directed slightly posterolaterally. Although the posterior portion of the supracetabular crest (Fig. 2: sac) has crumbled away, the anterior part is generally well preserved such that the muscle attachment striations are quite distinct. The crest originates on the posterior margin of the lateral surface of the pubic peduncle, where it projects posterolaterally to slightly overhang the acetabulum.

As it curves dorsally it keeps this overhanging relationship with the anterodorsal region of the acetabulum. Posterior to the midpoint of the acetabulum, the crest is eroded and broken beyond recognition. The reduced morphology of the crest in the anterodorsal region of the acetabulum is similar to that in other tyrannosaurids (e.g., *Tarbosaurus*: PIN 551-2; *Daspletosaurus*: CMN 8506; *Tyrannosaurus*: Brochu, 2003: fig. 90; *Alioramus*: IGM 100/1844; *Qianzhousaurus*: Lü et al., 2014: fig. 3), as well as *Raptorex* (Sereno et al., 2009) and *Xiongguanlong* (FRDC-GS JB16-2-1), and differs from the hood-like morphology of the crest in more basal theropods (e.g., *Guanlong*: IVPP V14531; *Dilong*: IVPP V14243; *Juratyran*: OUMNH J.3311-20, 21; Carrano, 2007: fig. 4; Zhao et al., 2010: fig. 7; *Yutyrannus*: ELDM V1001). Due to the minimal lateral extension, the shape of the crest is slightly concave in dorsal or ventral view, which is neither similar to the straight morphology in most tyrannosauroids nor the semicircular condition in *Guanlong* (IVPP V14531), *Aviatyrannus* (Rauhut, 2003b: fig. 1A), *Stokesosaurus* (Madsen, 1974: fig. 1B) and *Juratyran* (Benson, 2008: fig. 8D). Despite the breakage of the crest mentioned above, the deep notch (Fig. 2: n) that separates the crest from the dorsal base of the ischial peduncle is still clearly visible in lateral view, which is typical of tetanurans (Brusatte et al., 2012; Holtz, 2004; Sereno et al., 2009).

The pubic peduncle is massive and wide, but is not sharply expanded ventrally like those seen in some tyrannosaurids (e.g. *Tarbosaurus*: PIN 551-2; *Daspletosaurus*: CMN 8506; *Tyrannosaurus*: Brochu, 2003: fig. 90). It is 102 mm wide mediolaterally by 160 mm long anteroposteriorly at the base (where it arises from the main body of the ilium). The cranial surface of the pubic peduncle is concave and similar to that in other tyrannosaurids (e.g.,

Tarbosaurus: PIN 551-2; *Daspletosaurus*: CMN 8506; *Tyrannosaurus*: Brochu, 2003: fig. 90), as well as *Qianzhousaurus* (Lü et al., 2014: fig. 3) and *Juratyran* (OUMNH J.3311-20). Furthermore, the ventral flange that extends from it (Fig. 2: antvf) is rather small, which is in sharp contrast to the pronounced ventral flange in some tyrannosaurids (e.g. *Tyrannosaurus*: Brochu, 2003: fig. 90; *Tarbosaurus*: PIN 551-2; *Daspletosaurus*: CMN 8506), as well as *Qianzhousaurus* (Lü et al., 2014: fig. 3). On the posterior surface, there is another ventral flange projecting into the acetabulum (Fig. 2: postvf), but, due to breakage and erosion, the medial half of this flange is missing. This posterior ventral flange is present in some basal tyrannosaurids (e.g., *Guanlong*: IVPP V14531) and the derived tyrannosaurines (*Tyrannosaurus*: Brochu, 2003: fig. 90; *Tarbosaurus*: PIN 551-2; *Daspletosaurus*: CMN 8506), as well as *Qianzhousaurus* (Lü et al., 2014: fig. 3), but is absent in the albertosaurines (*Albertosaurus*: Parks, 1928: fig. 10; *Gorgosaurus*: AMNH FARB 5664, Lambe, 1917: fig. 38). The cuppedicus fossa anterior to the acetabulum is triangular in lateral view (Fig. 2: cupfos), which is the attachment site for the *M. iliofemoralis internus* (Carrano and Hutchinson, 2002). As in other tyrannosaurids, the medial flange (cuppedicus shelf) bounding the fossa internally is strongly developed and clearly visible in lateral view, which is sometimes considered a diagnostic feature of the group (Holtz, 2004).

Although the ischial peduncle suffered some degree of weathering, especially on its lateral surface, it is generally well preserved (Fig. 2: ip). At its base where it arises from the main body of the ilium, the peduncle is 145 mm wide mediolaterally by 122 mm long anteroposteriorly. The antitrochanter has crumbled away, but judging by the base that remains, it can still be seen that the ischial peduncle makes a pronounced contribution to the

antitrochanter as in other large tyrannosaurids such as *Tarbosaurus* (PIN 551-2) and *Tyrannosaurus* (Brochu, 2003: figs. 90–91), in which the iliac contribution to the antitrochanter takes the form of an extensive flange that is deeply inset from the remainder of the ischial peduncle (Holtz, 2004; Sereno et al., 2009). Ventrally the peduncle seems to be truncated, but the real morphology is difficult to assess due to erosion.

The ischial peduncle is relatively smaller relative to the pubic peduncle (Table 1), similar in size and shape to those of other tyrannosaurids (e.g., *Tarbosaurus*: PIN 551-2; *Tyrannosaurus*: Brochu, 2003: fig. 90; *Daspletosaurus*: CMN 8506; *Teratophoneus*: Loewen et al., 2013: fig. 1H; *Alioramus*: IGM 100/1844; *Qianzhousaurus*: Lü et al., 2014: fig. 3). The anteroposterior lengths at the bases of the pubic and ischial peduncles (where they arise from the main body of the ilium) are approximately the same, which is also the case for other tyrannosaurids (Brochu, 2003; Brusatte et al., 2012; Lü et al., 2014; Lambe, 1917; Loewen et al., 2013; Maleev, 1974; Parks, 1928), and is considered a primitive theropod condition (e.g., Holtz, 2004; Benson, 2008; Benson et al., 2010b; Brusatte et al., 2012) in contrast to the condition in many other tetanuran theropods, such as *Yutyrannus* (EDLM V1001), *Guanlong* (IVPP V14531), *Raptorex* (Sereno et al., 2009), and *Juratyran* (Benson, 2008; Brusatte and Benson, 2013), where the ischial peduncle is much smaller than the pubic peduncle.

Table 1

Measurements (in mm) of IVPP V22757

Total length	640*
Length across peduncles	430
Length at top of peduncles	410
Height, anterior blade at pubic peduncle	260*

Height above acetabulum	250*
Dorsoventral height of pubic peduncle	165
Dorsoventral height of ischial peduncle	130
Anteroposterior width of pubic peduncle at base	160
Anteroposterior width of pubic peduncle at neck	120
Anteroposterior width of ischial peduncle at base	145
Anteroposterior width of pubic peduncle at distal facet	170
Anteroposterior width of ischial peduncle at distal facet	60
Lateral width of pubic peduncle at base	102
Lateral width of ischial peduncle at base	122
Lateral width of pubic peduncle at distal facet	97
Lateral width of ischial peduncle at distal facet	70
Thickness of anterior blade at the base of the anterior end of the preacetabular process	22
Thickness of blade at the top of the midline supraacetabular ridge	9
Minimum thickness of blade	6
Width of brevis fossa at the anterior margin	30*
Width of cuppedicus fossa at the posterior margin	35*
Anteroposterior length of acetabulum	220

* Indicates the value is estimated.

Given that most of the lateral flange of the postacetabular process is broken, it is impossible to assess most aspects of its morphology. The medial flange is much narrower dorsoventrally than those in other derived tyrannosaurids (e.g., *Tarbosaurus*: PIN 551-2; *Tyrannosaurus*: Brochu, 2003: fig. 90; *Daspletosaurus*: CMN 8506), which makes the brevis fossa rather shallow and thus could be considered as an autapomorphy of this specimen. Due to erosion, the exact position and morphology of the anterior margin of the brevis fossa cannot be assessed, but it seems that the anterior margin did not extend to the base of the ischial peduncle. A peculiar round foramen (5 mm in diameter) excavates the lateral surface of the medial flange at the anterior end and it may excavate the anterior margin of the brevis

fossa as in *Alioramus* (IGM 100/1844). But unlike *Alioramus*, this foramen largely faces lateroventrally. Despite the breakage described above, it can still be seen that the fossa is broad mediolaterally and gradually expands in width posteriorly. The brevis fossa is 30 mm in width measured at the foramen, and posteriorly the fossa gradually expands to 85 mm at its broken end. As in other tyrannosaurids (*Daspletosaurus*: CMN 8506; *Tarbosaurus*: PIN 551-2; *Tyrannosaurus*: AMNH FARB 5037), the fossa reaches the posterior end of the fifth sacral vertebra. Due to the breakage of the lateral flange, it is impossible to assess whether the anterior portion of the brevis fossa is visible laterally as in other tyrannosaurids. Additionally, as in *Qianzhousaurus* (Lü et al., 2014: fig. 3), *Alioramus* (IGM 100/1844), *Dilong* (IVPP V14243), *Gorgosaurus* (Lambe, 1917), *Teratophoneus* (Loewen et al., 2013) *Guanlong* (IVPP V14531), and *Raptorex* (Serenó et al., 2009), the ventral margin of the medial flange is straight, and does not form a discrete convex lobe-like flange as seen in some derived tyrannosaurids (e.g., *Tarbosaurus*: Maleev, 1974: fig. 38; *Tyrannosaurus*: AMNH FARB 5027; *Albertosaurus*: Parks, 1928: fig. 10; *Daspletosaurus*: CMN 8506; *Teratophoneus*: Loewen et al., 2013: fig. 1H), as well as the basal taxon *Yutyranus* (EDLM V1001).

The sacral rib attachment scars are clearly visible on the medial surface. The facet for the first rib lies on the medial surface of the cuppedicus shelf as in other tyrannosaurids (e.g., *Tyrannosaurus*: Brochu, 2003: fig. 92), but its exact shape and size is difficult to assess (Fig. 2: s1). The second and third sacral rib facets make contact to form a large oval scar extending onto the medial surface of the pubic peduncle (Fig. 2: s2/3). A broad ridge radiates anterodorsally from the acetabulum and borders the scar posteriorly, whereas the posterior margin of the ridge is excavated by a large round fossa. The medial edge of the acetabulum is

flared as in other tyrannosaurids (e.g., *Tarbosaurus*: PIN 551-2; *Tyrannosaurus*: Brochu, 2003: fig. 92; *Daspletosaurus*: CMN 8506). Although the distal facet suffered some degree of weathering, it can still be seen that two deep fossae excavate the facet anteriorly and posteriorly and are connected by a sulcus. The fourth sacral rib facet is posterodorsal to the acetabulum and only slightly overlies the anterior end of the brevis shelf on the medial surface (Fig. 2: s4). The facet for the fifth sacral rib is widely separated from the fourth facet and also extends onto the brevis shelf (Fig. 2: s5). This differs from the condition seen in *Tyrannosaurus* (Brochu, 2003: fig. 92), where the two facets are in contact. The buttressing fossa bounded by the fourth and fifth facets ventrally is much larger but shallower than that in *Tyrannosaurus* (Brochu, 2003: fig. 92), and such a fossa has only been described for tyrannosaurids thus far (Brochu, 2003). Given that a small portion of the sacral neural spine (Fig. 2: sns) is still attached to the ilium, the dorsal blade must have lain against the neural spines; iliac blades that converge dorsally are often considered as a synapomorphy of tyrannosaurids (Brusatte et al., 2010b; Holtz, 2004). However, due to the breakage of the dorsal margin, it is impossible to assess if the opposing blades make contact above the neural spine.

5. Borings

During the preparation, we found several borings on the ilium (Fig. 3). These borings have overhung edges - where the width of the borings deep in the bone is greater than the width of the boring on the surface - that would have been impossible for a tooth to make.

The individual borings are discrete, with slightly overhanging edges and concave walls bored into inner spongy and outer cortical bone surfaces. On either side of the median ridge, at least one explicit boring is located on the lateral surface, and there might be a broken third one right next to the boring on the posterior side (Figs. 2A: 1, 2; 2B). Although the iliac blade is thin at the places where these borings are located, none of the borings penetrates the medial surface of the blade. The margins of these borings are somewhat rounded, which indicates they suffered some degree of weathering. The first boring (the one anterior to the median ridge) is 16×9 mm and 6 mm deep (Fig. 2B), and located more dorsally than the other ones (the ones posterior to the median ridge) (Fig. 2A: 1, 2). The long axis of the first boring forms an angle of 45° to the median ridge, while the other ones are almost parallel to it. The second and third borings are closely spaced; the second boring measures 17×8 mm and 8 mm in depth, while the third boring is a little narrower (6 mm) and much shallower (5 mm). The third boring is in a broken condition where the ventral border is missing and forms a wide, deep excavated groove connecting the crumbled surface posteriorly.

There is a subtriangular divot of bone right below the deep excavated groove, which is clearly partially expelled from the surrounding surfaces. Additionally, the surface of the divot appears to be polished and has a darker coloration than the surrounding bone surface. The large irregular patch of crumbled surface posterior to the third boring is 50 mm in maximum length and 30 mm at its widest point (Fig. 2A: 3). The formation of this surface was probably due to a densely bored surface modified by weathering. However, matrix preserved on the ventral edge of the crumbled surface supports the interpretation that this modification was made before deposition of the specimen. The crumbled surface seems to bear randomly

oriented grooves, which are so faint that are only visible under horizontal, raking light. But since weathering may well alter surface projections without modifications by insects, it is impossible to determine if these faint grooves were made on the weathered or unweathered surface.

6. Discussions

IVPP V22757 can be confidently referred to Tyrannosauridae based on the following combination of character states: robust supraacetabular ridge (median ridge); reduced supraacetabular crest not forming a hood; anterior margin of the pubic peduncle concave; a ventral flange on the pubic peduncle; dorsal surface of the iliac blades converging closely on the midline; and strong and laterally visible medial flange (cuppedicus shelf) bounding the cuppedicus fossa internally (Benson, 2008; Brusatte et al., 2010b; Holtz, 2004). The posterior ventral flange on the posterior surface of the pubic peduncle projecting into the acetabulum supports its referral to derived Tyrannosaurinae, including *Tarbosaurus*, *Tyrannosaurus*, and *Daspletosaurus*. Although the ilium can be referred to Tyrannosaurinae and all the tyrannosaurid materials previously found in the Upper Cretaceous deposits across Xinjiang are thought to pertain to *Tarbosaurus* (Currie and Dong, 2001; Dong, 1992), some differences from previously described taxa suggest that IVPP V22757 may represent a new tyrannosaurine species (e.g., the medial flange is much narrower dorsoventrally than those in other derived tyrannosaurids and a peculiar round foramen excavates the lateral surface of the medial flange at the anterior end of brevis fossa). However, some of these variations may reflect ontogeny, sexual dimorphism or individual variation. In the absence of extensive data

that would make it possible to properly evaluate these variations, we refrain from naming a new taxon based on this specimen.

Vertebrate paleontology has a long history in the northern Junggar Basin, and the dinosaur fossil record in this area has been explored for more than 60 years (Zhao, 1980). So far, the fauna of the Honglishan Formation includes: Tyrannosauridae indet., Hadrosauridae indet., Chelonia indet., Pelecypoda, and *Pseudohyria* (Dong, 1992; Zhao, 1980). Much of the previous work on the dinosaur fossils discovered in this formation was conducted by X.J. Zhao, who suggested that these fossils represent the primitive form of Tyrannosauridae and Hadrosauridae, and the Honglishan Formation is assigned to the lower Upper Cretaceous (Zhao, 1980). These fossils were only briefly mentioned in an institute's internal publication by Zhao (1980) and a stratigraphic review of Chinese dinosaur by Dong (1980, and expanded 1992), but have never been described or illustrated ever since (Dong, 1992; Zhao, 1980). For this reason, our study on IVPP V22757 represents the first officially reported dinosaur fossil from this formation. In addition, from its phylogenetic affinity, the derived position of IVPP V22757 as a tyrannosaurine suggests that the specimen may be of late Late Cretaceous age and the Honglishan Formation in the Sangequan area may be much younger than previous works suggested (Dong, 1992; Gradstein et al., 1995; Li et al., 2009; Zhao, 1980).

Although the borings in the ilium are not well preserved, they can be identified based on the available information. None of these borings resemble the bite marks produced by the teeth of theropods, crocodylians, or any other vertebrates because the tooth marks left by them would have a U to V-shaped section (D'Amore and Blumenschine, 2009; Erickson and Olson, 1996; Erickson et al., 1996; Gignac et al., 2010; Hone et al., 2010; Hone and Rauhut,

2009; Hone and Watabe, 2010; Jacobsen, 1998, 2001; Longrich et al., 2010; Longrich and Ryan, 2010; Njau and Blumenschine, 2005; Peterson et al., 2009; Rogers et al., 2003). They would also be unable to produce the overhang in the markings. Despite the lack of bioglyphs, such as scratches or grooves, observed on the walls of the borings, the continental origin, size range and morphology of the better preserved borings found on this ilium are consistent with the original diagnostic features of the ichnogenus *Cubiculum* proposed by Roberts et al. (2007) as well as the emended ones suggested by Pirrone et al. (2014) and Xing et al. (2015). Since the naming of the ichnotaxon *Cubiculum ornatus* by Roberts et al. (2007), the ichnogenus *Cubiculum* has seen some expansions in the last few years. Pirrone et al. (2014) proposed an emended diagnosis for original ichnotaxon *Cubiculum ornatus* and named a new ichnotaxon *Cubiculum levis*. More recently, Xing et al. (2015) named another new ichnotaxon *Cubiculum inornatus*, which is similar to the original *Cubiculum ornatus*, but it does not have bioglyph associated with it. Except for those broken beyond recognition, we suggest that the better preserved borings found on IVPP V22757 may well fit into either *Cubiculum levis* or the new taxon *Cubiculum inornatus* (Pirrone et al., 2014; Xing et al., 2015).

As to the question of the possible producer, although previous workers (Pirrone et al., 2014; Roberts et al., 2007; Xing et al., 2015) confidently attributed the *Cubiculum* borings to the activity of necrophagous or osteophagous insect fauna and interpreted them as insect pupal chambers (pupichnia), they avoided definitively linking these borings to the behavior of any specific taxon due to the lack of experimental and actualistic experiments that could offer well documented information as concrete evidence (Pirrone et al., 2014; Roberts et al., 2007;

Xing et al., 2015). In this study, we also follow the reasoning of these previous works and do not assign *Cubiculum* to a specific insect taxon.

We suggest the following as the possible pre-burial taphonomy of the ilium: The tyrannosaurine most likely died during the dry season (early summer), and its skeletal elements were disarticulated and scattered by geological and biological processes (Coe, 1978; Hasiotis et al., 1999; Pickering and Bachman, 1997; Smith, 1986). After being carried to its resting place in a lacustrine beach-bar, the ilium (or at least the lateral concavity) had to stay above the water or sediment to facilitate the infestation of necrophagous insects. This condition would have persisted for an extended period of time until the pupation of the larvae. Since the sensitivity of insects to habitat conditions, such as temperature, humidity, and food source availability, there could not have been rains large enough to flood the beach-bar or spells of cold weather to interrupt their life cycle during this period (Coe, 1978; Hasiotis et al., 1999; Martin and West, 1995; Timm, 1982; West and Martin, 2002). However, the low number of pupation chambers suggests that there may not have been adequate food source (dried tissues) remaining on the ilium to support a large number of larvae to maturity. According to Behrensmeyer's (1978) weathering values, the ilium shows an overall weathering stage of 4 to 5, which is characterized by moderate to extensive cracking and flaking. Matrix preserved in these cracks suggests that this modification was in place before burial of the bone, and it may have taken several years to bury the entire ilium (Behrensmeyer, 1978).

7. Conclusions

A detailed comparative description of a large theropod ilium, collected from the Upper Cretaceous Honglishan Formation in the Sangequan area of the northern Junggar Basin, Xinjiang, represents the first officially reported dinosaur fossil from this formation. This specimen is diagnostic to the level of Tyrannosaurinae and may turn out to belong to a new species. Insect borings found on the specimen are referable to the ichnogenus *Cubiculum*, adding new information on the poorly studied ecosystems in the Upper Cretaceous of Junggar Basin. The phylogenetic identity of the specimen as a derived tyrannosaurine may also have potential stratigraphic significance, as it indicates that the Honglishan Formation in the Sangequan area is much younger than previously thought.

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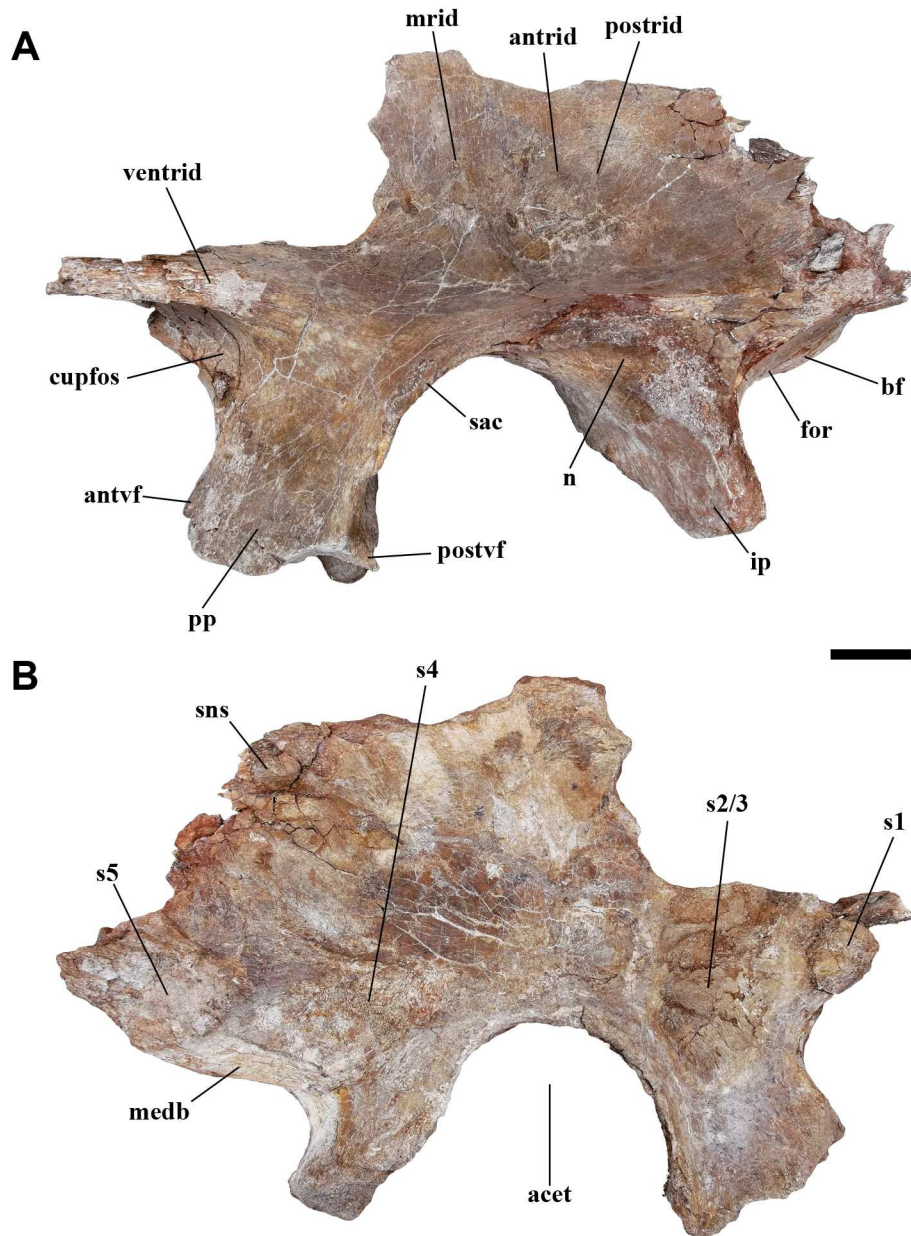
Fig. 1. Map showing the location of the fossil locality near the Sangequan area, northern Junggar Basin, Xinjiang Autonomous Region, China.

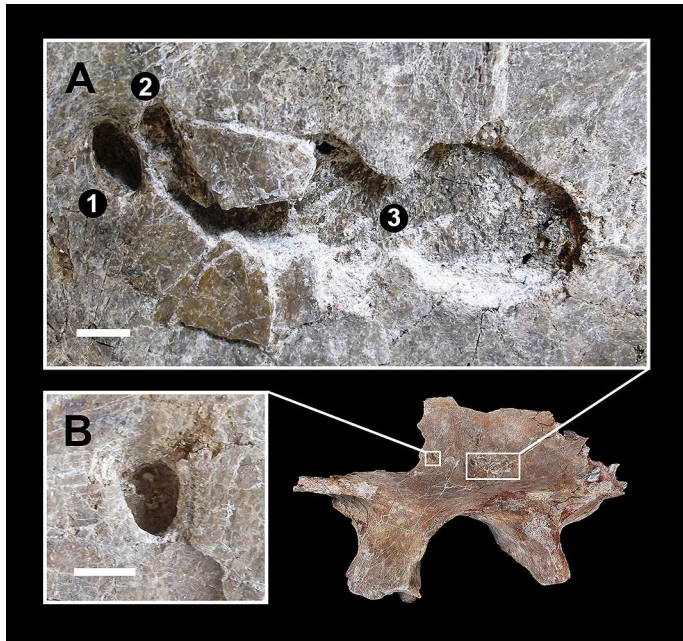
Fig. 2. IVPP V22757, partial left ilium in lateral view (A) and medial view (B). Scale bar = 5 cm. Abbreviations: antrid, anterior accessory ridge on lateral surface; antvf, anterior ventral flange on the cranial surface of the pubic peduncle; bf, brevis fossa; cupfos, cuppedicus fossa; for, foramen; ip, ischial peduncle; medb, median blade of iliac brevis shelf; mrid, median ridge on lateral surface; n, notch; postrid, posterior accessory ridge on lateral surface; postvf, posterior ventral flange on the cranial surface of the pubic peduncle; pp, pubic peduncle; s1-s5, sacral rib facets; sac, supracetabular crest; sns, sacral neural spine; ventrid, ventral ridge of the preacetabular process on lateral surface of ilium.

Fig. 3. Borings present on IVPP V22757. A. The second (1) and third (2) borings posterior to the median ridge and the large irregular patch of crumbled excavated bone posterior to the third boring (3); B. The first boring anterior to the median ridge. Scale bars in A and B = 1 cm.



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Highlights

- The first officially reported dinosaur fossil from the Honglishan Formation, China.
- The specimen can be referred to Tyrannosaurinae and may represent a new species.
- Insect borings found on the specimen are referable to the ichnogenus *Cubiculum*.

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