·基础地质·

First large tyrannosauroid theropod from the Early Cretaceous Jehol Biota in northeastern China

中国早白垩世热河生物群中大型霸王龙类化石的发现

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Abstract: An incomplete theropod skeleton including partial skull, mandibles, ilia was collected from the Early Cretaceous Jiufotang Formation of Kazuo County, western Liaoning Province. It can be estimated that this theropod may reach 9~10 meters in total length. It should be classified within Tyrannosauroidea by its tall premaxillary body, median vertical ridge on the external surface of ilium. It differs from the Late Cretaceous tyrannosaurids by much large external naris, slightly concave anterior portion of maxillary dorsal margin, maxillary fenestra reaching past the rostral margin of antorbital fossa but keeping apart from the ventral margin of antorbital fossa. Thus, *Sinotyrannus kazuoensis* gen. et sp. nov. is erected, perhaps representing the earliest member of Tyrannosauridae. This is the largest known pre-Late Cretaceous tyrannosauroid, and also the largest theropod from the Jehol Biota of western Liaoning and the adjacent regions. The discovery of this taxon not only suggests that East Asia should be one of the most important evolutionary centers of tyrannosauroids, but also provides the significant evidences for studying the origin of Tyrannosauridae, and the composition and ecosystem of the Jehol Biota.

Key words: large tyrannosauroid; Jiufotang Formation; Early Cretaceous; Kazuo, western Liaoning

摘要:一件包括部分头骨、下颌、肠骨等的不完整兽脚类恐龙骨架发现于辽宁喀左早白垩世九佛堂组中,估计身体全长可达 9~10m。其前颌骨主体部分高、肠骨外侧面具显著的直立的嵴等特征表明该化石应归霸王龙类。它以外鼻孔大、上颌骨背缘前部略

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内凹、上颌骨孔向前达眶前窝前缘、腹缘与眶前窝腹缘存在较大距离等特征不同于晚白垩世的霸王龙科分子，故被命名为一新属种——喀左中国暴龙(*Sinotyrannus kazuoensis* gen. et sp. nov.)，或许代表了最早的霸王龙科类型。该属种是已知个体最大的前晚白垩世霸王龙类，也是辽西及周边地区热河生物群中个体最大的兽脚类恐龙。它的发现不仅表明东亚是霸王龙类最主要的演化地区之一，而且为探讨霸王龙科的起源、热河生物群的组成与生态系统等提供了重要依据。

关键词：大型霸王龙类；九佛堂组；早白垩世；辽宁喀左

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Recent years, northeastern China has been well-known for numerous feathered non-avian theropods from the Early Cretaceous Jehol Biota[1]. Until now, all the described theropod taxa from this biota in western Liaoning and adjacent regions are small to medium in size. Here we reported a very large theropod whose length may reach 9~10 meters. It was discovered from the lower Jiufotang Formation (Lower Cretaceous) from Kazuo County, western Liaoning Province. The excavated material shows some diagnostic features of tyrannosauroids. It represents the first large-bodied theropod hitherto known in the Jehol Biota, thus is very important for our understanding the ecosystem of the biota.

Tyrannosauroids contain not only the derived, large-bodied Tyrannosauridae from the Upper Cretaceous of northeastern Asia and western North America, but also the small to medium-sized taxa from the Lower Cretaceous or Upper Jurassic of China, England, Portugal and United States[2]. In China, the Late Cretaceous remains of tyrannosaurids were represented mainly by isolated teeth from Shandong[3-4], Guangdong and Henan[5]. *Chingkankousaurus fragilis* from Shandong[6] and *Shanshanosaurus huoyanshanensis* from Xinjiang[7], originally reported as non-tyrannosaurids, were recently regarded to be within Tyrannosauridae, and probable *Tarbosaurus bataar*[8-10]. More recently, some basal tyrannosauroid materials have been described from the Late Jurassic of Xinjiang (*Guanlong wucaii*)[11], the Early Cretaceous of Liaoning (*Dilong paradoxus*)[12] and Gansu (*Xiongguanlong baimoensis*)[13]. These tyrannosauroid taxa are small to medium in size, ranging from 1.6 meters to 4 meters long. The new form described below could reach 9~10 meters long, falling within the size of Late Cretaceous tyrannosaurids. It will shed light on the missing link of tyrannosauroid evolutionary history.

1 Systematic Paleontology

Theropoda Marsh, 1881

Coelurosauria von Huene, 1914

Tyrannosauroidea Walker, 1964

?Tyrannosauridae Osborn, 1905

***Sinotyrannus kazuoensis* gen. et sp. nov.**

Etymology: The generic name is composed of the Latin "Sino-" (an ancient name of China), and Greek "tyrannus" (tyrant). The specific name is after "Kazuo", the county in which the type specimen was discovered.

Holotype: KZV-001, the disarticulated skeleton including the anterior portions of skull and mandibles, three articulated dorsal vertebrae, several dorsal ribs, incomplete ilia, partial manual phalanges, and some other fragmentary bones. This specimen is housed in the Bureau of Land and Resources of Kazuo County, Liaoning Province.

Locality and horizon: Dachengzi town, Kazuo County, western Liaoning Province, China; lower part of Jiufotang Formation, Early Cretaceous[14].

Diagnosis: Large tyrannosauroid roughly 9~10 meters long, much longer than other Late Jurassic or Early Cretaceous tyrannosauroids. This new genus falling into the size of Late Cretaceous tyrannosaurids, but differing from those in the following combined characters: proportionally large external naris; anterior portion of the dorsal margin of maxilla slightly concave; maxillary fenestra reaching past the rostral margin of the antorbital fossa, but keeping apart from the ventral margin of the antorbital fossa; the preacetabular blade of ilium comparatively short, and lacking the

ventrally expanded anterior hook.

2 Description

2.1 Skull, mandible and dentition

The skull and mandibles are represented by premaxillae, partial maxillae, anterior portions of nasals, and dentaries of both sides (Fig. 1). The preserved cranial and dentary bones are extremely compressed laterally. The preserved portion of skull measures 458 mm in length, and the total skull length may be estimated to reach around 1 meter.

The premaxilla bears a short and tall body, as in other tyrannosaurids. The supranarial process is narrow, but the suture between it and the premaxillary process of nasal is hardly observed. The slender subnarial process contacts the subnarial process of nasal, and both separate maxilla from external naris. The premaxillary process of nasal is much stouter than the subnarial process. The external naris is only enclosed by premaxilla and nasal. In lateral view, the external naris is large and long oval in shape, with its long axis 212 mm, proportionally much larger than those in other tyrannosaurids[2,15-17].

Either maxilla is preserved by most of the portion before antorbital fenestra. Although incomplete, the alveolar edge is somewhat straight or slightly convex. The anterior apex of maxilla is blunt. The anterior portion of dorsal margin is slightly concave, unlike the convex condition seen in other tyrannosaurids[2,15-17]. There are some pits on the outer side of the bone except the antorbital fossa. The antorbital fossa is clearly outlined with its ventral margin roughly straight and horizontally oriented. The oval maxillary fenestra is slightly large. Anteriorly, its rostral margin reaches past the rostral margin of the antorbital fossa; while there exists a wide space between the ventral margins of maxillary fenestra and antorbital fossa. Within the antorbital fossa, a row of oval and shallow depressions lie along this space rostrocaudally.

Each dentary is exposed by its external surface, only with the posterior portion missing. The preserved length of right dentary measures 409 mm. Anteriorly, the anterior portion of the ventral margin curves gradually upwards to the rostral margin of dentary. No visible angle forms between the rostral and ventral margins. There exist some visible pits at the anterior portion on the outer side of dentary. Meanwhile, there is a visible groove on the outer side of the posterior dentary half, about parallel to its ventral margin.

Only three broken right premaxillary teeth are distinguishable, among which the first preserved one is large.

Ten right maxillary teeth remain at their original positions in spite of incompleteness. Unfortunately, we can not give the complete count of maxillary teeth. Each tooth crown seems labio-lingually compressed in cross-section, partly owing to their preserved condition. Denticles are present on both anterior and posterior carinae, as well shown by the 1st, 3rd, 7th right teeth. There are 15 or 16 anterior denticles per 5 mm compared with 14 posterior denticles per 5 mm, making the denticle size difference index (DSDI) 1.07~1.14, which resembles those in tyrannosaurids.

Some of the left dentary teeth are preserved, which resemble the maxillary teeth in shape and in size. But the complete number of dentary teeth also remains undetermined.

2.2 Postcranial bones

Three articulated dorsal vertebrae are preserved in their left lateral view (Fig. 2-A). The neural spine is massive and very tall, and is primarily vertical or extends slightly posteriorly. In lateral view, the centrum is roughly rectangular in outline, with its middle portion of ventral margin remarkably embayed. There seems to be a shallow pleurocoel close to the parapophysis.

Three articulated manual phalanges could be the second finger based on their proportional lengths (Fig. 2-B). The terminal phalanx (claw) is obviously longer than the penultimate phalanx. There is a large flexor tubercle on the ventral surface near the proximal end, and the quite deep groove on each side of the claw.

Both ilia are primarily shown by their moulds of

external sides in lateral view (Fig. 3). The most mould of the left ilium is preserved, it is quite long, measuring 770 mm from its cranial margin to caudal margin. The preacetabular blade seems short but wide. The postacetabular blade is much longer than but slightly narrower than the preacetabular blade. Its caudal margin is smoothly convex in lateral view. The pubic peduncle is more massive than the ischial peduncle. The

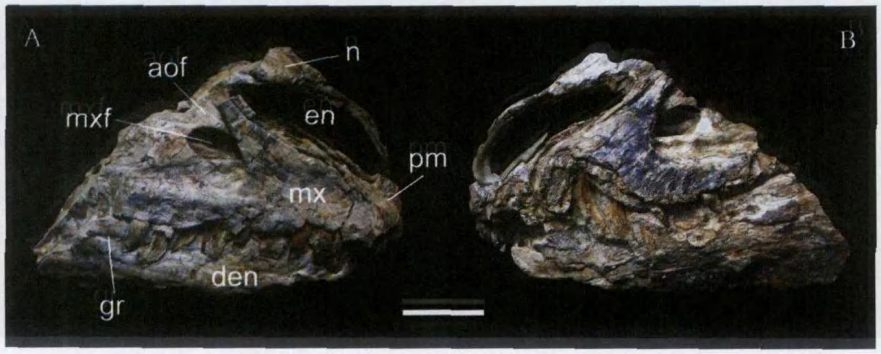

Fig. 1 Anterior portions of skull and mandibles in right (A) and left (B) lateral views(scale bar=100mm)

aof–antorbital fossa; den–dentary; en–external naris; gr– groove; mx–maxilla; mxf–maxillary fenestra; pm–premaxilla; n–nasal

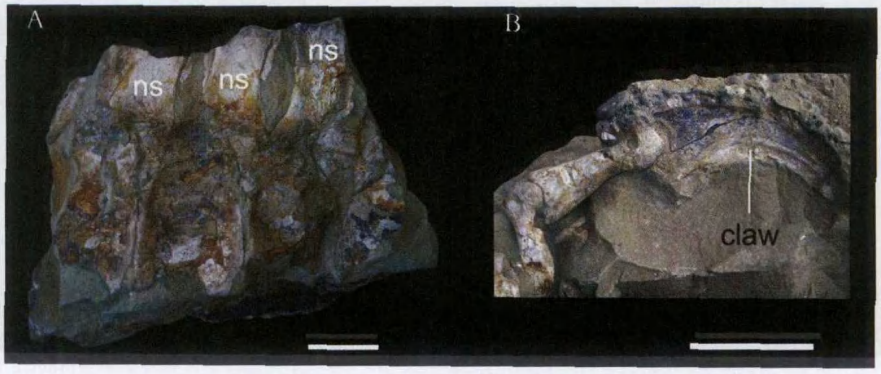

Fig. 2 Some postcranial bones showing the articulated dorsal vertebrae in left lateral view (A) and an incomplete manual finger (B)(scale bars=100mm)

ns–neural spine

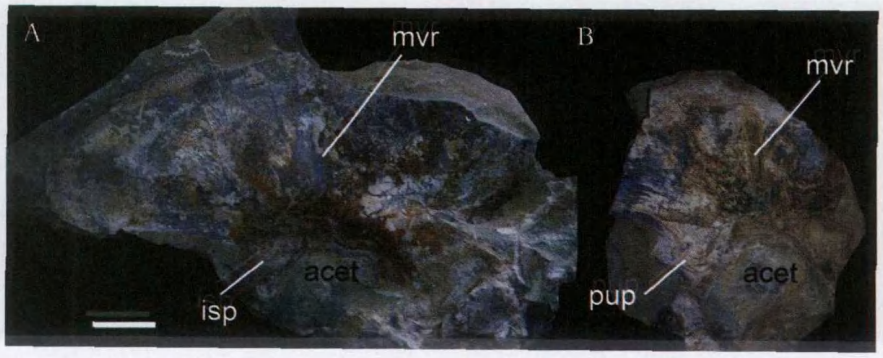

Fig. 3 Moulds of external sides of incomplete left (A) and right (B) ilia (scale bar=100mm)

acet–acetabulum; isp–ischial peduncle; mvr–median vertical ridge; pup–pubic peduncle

former is roughly rectangular in shape and extends anteroventrally, while the latter is triangular and downwards. The anterior margin of the pubic peduncle is concave in lateral view. A well-marked, prominent median vertical ridge (about 25 mm in width) exists on the external side of the ilium, from the dorsal margin of ilium to the dorsal border of acetabulum, showing the typical feature in tyrannosaurids[2,18].

3 Comparison and Discussion

Sinotyrannus kazuoensis gen. et sp. nov. possesses some tyrannosauroid apomorphies, such as tall premaxillary body; a prominent median vertical ridge on the lateral side of the ilium; and a concave anterior margin of the pubic peduncle of ilium[2,18-19]. Thus it is reasonable to put the new taxon within Tyrannosauroidea.

Among the pre-Late Cretaceous tyrannosauroid taxa, *Sinotyrannus* represents the largest one. According to the measurements of the preserved skull and ilia, it is estimated that this theropod should reach 9~10 meters long, much longer than other tyrannosauroids whose total length ranging from 1.6 meters to 5 meters. Furthermore, *Sinotyrannus* is also distinguishable from *Guanlong wucaii*[11] (Late Jurassic, China), *Dilong paradoxus*[12] (Early Cretaceous, China) by the maxillary fenestra reaching past the rostral margin of the antorbital fossa, from *Eotyrannus lengi*[20] (Early Cretaceous, England) by the concave anterior portion of dorsal margin of maxilla, and from *Xiongguanlong baimoensis*[13] (Early Cretaceous, China) by the relatively short region before the antorbital fossa. Based on the characters of ilium, *Sinotyrannus* is different from *Aviatyrannis jurassica*[19] (Late Jurassic, Portugal) by the very short preacetabular blade, and from *Stokesosaurus clevelandi* and *S. langhami*[21] (Late Jurassic, United States and United Kingdom) by the absence of ventrally expanded anterior hook.

Appalachiosaurus montgomeriensis is a 6.5-meter-long tyrannosauroid from the Late Cretaceous of Alabama, United States[22]. Its external naris is short oval in shape, and its roughly round maxillary fenestra is central between the anterior margins of the antorbital fossa and antorbital fenestra. So the differences between *Sinotyrannus* and *Appalachiosaurus* are distinct.

As to the total length, *Sinotyrannus* falls within the range of Late Cretaceous tyrannosaurids (9~13 meters). But *Sinotyrannus* differs from those by the relatively much large external naris, anterior portion of the dorsal margin of maxilla slightly concave, and the short ilic preacetabular blade lacking the hooklike ventral projection[2,15-17]. The position and size of maxillary fenestra show some variations in different tyrannosaurid taxa. In *Sinotyrannus*, the slightly large fenestra reaches anteriorly past the rostral margin of the antorbital fossa, resembling those in Tyrannosaurinae (such as *Daspletosaurus*, *Tyrannosaurus*, *Tarbosaurus*)[2,16,22]. This feature, together with its huge body, suggests that *Sinotyrannus* may be a member of the family Tyrannosauridae. If so, it represents the earliest known, large-sized tyrannosaurid taxon. It should be pointed out that the Early Cretaceous *Siamotyrannus isanensis* from Thailand, originally thought to be a tyrannosaurid [23], is later considered to be outside Tyrannosauridae[10].

The discovery of *Sinotyrannus* is of great scientific significance. Firstly, this new element enriches our knowledge about the pre-Late Cretaceous tyrannosauroids in China. It seems that East Asia is one of the most important early evolutionary centers of tyrannosauroids. Moreover, *Sinotyrannus* may be the earliest member of the family Tyrannosauridae. This gives the evidence that tyrannosaurids may originated in East Asia during the Early Cretaceous, and later spread to North America. Secondly, *Sinotyrannus* is the longest tyrannosaur (9~10 meters) among all the Late Jurassic and Early Cretaceous tyrannosauroids, falling within the size of Late Cretaceous tyrannosaurids. This suggests that the trend towards increasing body size of the tyrannosauroid lineage had taken place during the Early Cretaceous, thus further fills the gap between Early Cretaceous tyrannosauroids and Late Cretaceous tyrannosaurids in body size.

Thirdly, *Sinotyrannus* is the known largest theropod of the Jehol Biota in western Liaoning and the neighboring regions. This discovery further improves our understanding of the composition and ecosystem of this biota.

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