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New fossil remain of *Fusuisaurus zhaoi* (Sauropoda: Titanosauriformes) from the Early Cretaceous of Guangxi, southern China

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Abstract: We describe a large, nearly completely preserved sauropod humerus from the Lower Cretaceous Xinlong Formation of Napai Basin, Fusui County, Guangxi Zhuang Autonomous Region, southern China. It was excavated from the quarry that produced the holotypic specimen of the titanosauriform *Fusuisaurus zhaoi* and is considered here to belong to the same individual as

the holotype of *Fusuisaurus zhaoi*. With a preserved length of 183.5 cm, the newly collected humerus provides additional evidence suggesting the presence of a giant sauropod (i.e., *Fusuisaurus zhaoi*) during the late Early Cretaceous of Guangxi, China, which increases our knowledge of the diversity of giant titanosauriforms from the late Early Cretaceous of Asia.

Key words: Titanosauriformes; Early Cretaceous; Taphonomy; Asia; *Fusuisaurus zhaoi*

1 Introduction

The Lower Cretaceous Xinlong Formation in Guangxi Zhuang Autonomous region, which was deposited in a non-marine, fluvial environment, has yielded a diverse assemblage of vertebrates including hybodont sharks (*Hybodus*, *Heteroptychodus*, *Khoratodus*, *Acrorhizodus* and *Thaiodus*), actinopterygians (Halecomorphi and Ginglymodi), turtles (the adocid *Shachemys* and the carettochelyid *Kizylkumenys*), crocodilians (cf. *Theriosuchus*) and dinosaurs (the sauropods *Fusuisaurus* and *Liubangosaurus*, carcharodontosaurid and spinosaurid theropods, iguanodontians and a possible psittacosaurid) (Mo et al., 2016).

The holotype of the giant *Fusuisaurus zhaoi*, which comprises about 10% of a complete sauropod skeleton, that of the medium-sized sauropod *Liubangosaurus hei*, and some unidentified sauropod bones were excavated in 2001 by a team from the Natural History Museum of Guangxi (NHMG) at the “Longcaoling” quarry, Liubang Village (Mo et al., 2006, 2010). In 2016-2017, a joint team from the NHMG and the Bureau of Land and Resources of Fusui County (BLRF) re-opened the Longcaoling quarry and uncovered nearly 100 disarticulated dinosaur bones within an area of nearly 600 m² (Fig. 1). Most of these bones are probably derived from juvenile individuals

of hadrosauroid and sauropod dinosaurs, based on the disarticulated conditions of the vertebral centra and neural arches. A large, nearly complete right humerus (183.5 cm in preserved length, obviously belonging to a giant sauropod) was recovered from the fossil-bearing layer from which the holotype of *Fusuisaurus zhaoi* was collected and it is positioned close to the latter (25 m), and from the holotypic *Fusuisaurus* in the same bonebed, we conclude that this large humerus belongs to the same individual of *Fusuisaurus* and consider it as the holotype (field number LCL 63).

2 Taphonomy

The Longcaoling site is located near the Liubang Village, about 70 km away from Nanning City, Guangxi Zhuang Autonomous region. Dinosaur fossils were first excavated by local farmers in 1960s, but all were lost due to a lack of relevant knowledge. In 2001, the Longcaoling site was first excavated by a team organized by NHMG, and yielded the holotype of *Fusuisaurus zhaoi* and of *Liubangosaurus hei*. In 2016-2017, the Longcaoling quarry was re-opened by a joint team from NHMG and BRLF, and yielded nearly 100 dinosaur bones, most of which belong to juvenile hadrosauroid and sauropod dinosaurs (Fig. 1).

Two layers of outcrops at the Longcaoling quarry include the fossil bearing deposit and the underlying deposit (the overlying deposit has been cultivated by local farmers). The fossil bearing deposit is exposed on the surface. It exhibits a succession of purple-red sandy gravels, fine sandstones, muddy sandstones and sandy mudstones. The layer of sandy gravels has a thickness of 15-60 cm in the northern part of the quarry (where LCL 63 was discovered), while it becomes thinner and finally disappears southward. The underlying deposit exhibits a succession of purple-red, light-green mudstones, siltstones and fine-grained sandstones containing some calcareous

concretions. The surface of this layer in the southern area is full of mud cracks. Some mud cracks are nearly 30 cm in depth and 8 cm in width. This indicates that the fossil site had experienced a prolonged dry period before the debris flow occurred and the dinosaurs were buried, compatible with the inferred environment and ecology, characterized by aridity (Amiot et al., 2015).

The underlying deposit is a lakeshore subfacies. It may have been submerged in the rainy season, and exposed to the surface in the low water season, so that mud cracks formed when the lake dried up for a long time. The fossil-bearing deposit was probably formed by a sudden flood carrying gravels, sand, mud, and scattered dinosaur bones. Some dinosaur bones, such as an ulna, pubis, and metacarpal were preserved in a steeply inclined position. The articulated condition of the holotypic *Liubangosaurus* and the semidisarticulated condition of the holotypic *Fusuisaurus* can be attributed to a rapid deposition before they were scattered. Many of the lost dinosaur bones were either displaced before burial or destroyed by the local farmers prior to discovery.

3 LCL 63 as the holotypic material of *Fusuisaurus zhaoi*

As Mo et al. (2010) noted, there were three individuals of sauropods present at the Quarry A (Fig. 1A), a very large one (which pertains to *Fusuisaurus*), and two smaller ones (one of which pertains to *Liubangosaurus hei*, an adult, medium-sized sauropod, and the other is an unnamed, small-sized sauropod), based on the three left ilia present at the Quarry A, measuring 145 cm, 119 cm, and at least 67 cm in length, respectively. In addition, it is certainty that there are one giant sauropod (represented by the large humerus LCL 63), and one small, juvenile sauropod dinosaur present at the Quarry B (Fig. 1B), based on some disarticulated conditions of the vertebral centra

and neural arches. Therefore, there are at least three individuals of sauropod dinosaurs present at the Quarry A and B, including a giant one, a medium-sized one, and a small, juvenile one, based on the absence of overlapping materials within these three sauropods. *Fusuisaurus zhaoi* was the only giant sauropod recovered from Longcaoling site. Thus, we consider the humerus LCL 63 (obviously belongs to a giant sauropod) as the same individual of *F. zhaoi*.

4 Systematic Palaeontology

Saurischia Seeley, 1888

Sauropoda Marsh, 1878

Titanosauriformes Salgado, Coria & Calvo, 1997

Fusuisaurus zhaoi Mo, Wang, Huang, Huang & Xu 2006

Holotype. NHMG 6729, a relatively complete left ilium, a complete left pubis, 3 incomplete articulated anterior caudals, most of dorsal ribs, and distal end of the left femur. LCL 63 (field number at “Longcaoling” quarry of Liubang Village), a nearly complete right humerus.

Type locality. Longcaoling quarry, Liubang Village, Shanxu Town, Fusui County, Guangxi Zhuang Autonomous Region, southern China.

Type horizon. Napai Basin, Xinlong Formation, Early Cretaceous (possibly Aptian) (Mo et al., 2016)

Emended Diagnosis. A gigantic basal titanosauriform (Mo et al., 2006) or Somphospondyli (Mannion et al., 2013) diagnosed by the following characters: humerus with Slenderness Index 8.55 and Proximal Humeral Robusticity 2.63, anterior dorsal ribs lacking pneumatic foramina,

ilium with a prominent, pointed anteroventral process, ilium with a strongly dorsoventrally expanded preacetabular blade, anterior caudal vertebrae with dorsoventrally flattened transverse processes.

Description. The humerus is nearly completely preserved, missing only the anterior margins of the distal and proximal parts of the shaft (including the deltopectoral crest), and the distomedial portion (Fig. 2). Its preserved length is 183.5 cm, being the longest one for any known sauropod from the Cretaceous (Table 1). The proximal, midshaft, and distal widths are 56.5 cm, 21.5 cm, and about 54.0 cm, respectively. The humerus is gracile in anterior view, with the SI (Slenderness Index, i.e., ratio of the proximodistal length to the midshaft width) value being about 8.55, which is substantially greater than those of all other giant Cretaceous sauropods. The proximomedial process is round and robust, pointing dorsomedially, with its apex lying well medial to the midshaft. The proximal end is robust relative to the midshaft, with its PHR (Proximal Humeral Robusticity, i.e., ratio of proximal to midshaft width) value being about 2.63, only smaller than those of *Ruyangosaurus* and *Notocolossus*, and larger than those of other giant Cretaceous sauropods. It is unknown whether the proximolateral corner was round or square due to the erosion of this part. The deltopectoral crest is not preserved, but appears to have continued to about midshaft and does not appear to exhibit a significant transverse expansion. Medial to the deltopectoral crest, the anterior margin of the proximal part of the shaft is greatly excavated. The posterolateral bulge on the lateral margin of the proximal part of the shaft is not present. The proximal and distal transverse widths are significantly greater than the midshaft width. The shaft is elliptical in cross-section, with its long axis oriented mediolaterally. The anterior surface and the distal end of the distal part of the shaft were eroded during its fossilization.

5 Discussion

Fusuisaurus is based on a partial skeleton, including a relatively complete left ilium, a complete left pubis, 3 incomplete articulated anterior caudals, most of the dorsal ribs, and the distal part of the left femur. The left ilium is 145 cm in length, obviously longer than any other known sauropod ilia. The incomplete left femur is 60 cm in distal width, with a probable restored length of 200 cm. One anterior caudal centrum is about 40 cm in diameter. In addition, one complete posterior dorsal rib measures 230 cm in length. The recently recovered right humerus, the holotype of *Fusuisaurus*, is the longest one for any giant sauropod from the Cretaceous (Table 1). These available fossils suggest that *Fusuisaurus* was a typical gigantic titanosauriform (Fig. 3).

Titanosauriformes represent a diverse and globally distributed clade of neosauropod dinosaurs (D’Emic, 2012; Mannion et al., 2013). Although the number of named Asian Titanosauriformes has dramatically increased in the last decade, most of them are represented by medium or large-sized animals (Azuma and Shibata, 2010; Ksepka and Norell, 2006; Li et al., 2014; Lü et al., 2008, 2009a, 2013a; Mo et al., 2008, 2010, 2017; Saegusa and Ikeda, 2014; Wang et al., 2007; Wu et al., 2006; Xu et al., 2006; You et al., 2006; You and Li, 2009; Zhang et al., 2009), only *Huanghetitan ruyangensis* (Lü et al., 2007), *Daxiatitan* (You et al., 2008), *Yunmenglong* (Lü et al., 2013b), *Ruyangosaurus* (Lü et al., 2009b, 2014) are comparable with *Fusuisaurus* in terms of gigantism.

Huanghetitan ruyangensis is based on a partial skeleton, including a nearly complete sacrum, 10 proximal caudals, haemal arches, dorsal ribs, and incomplete ischium, from the Early Cretaceous Haoling Formation (Aptian-Albian, Xu et al., 2012), Ruyang Basin, Henan Province, central China. The anteriormost caudal centrum is 26.9 cm and 32 cm in posterior height and

width, respectively, significantly smaller than that of *Fusuisaurus*. However, the longest preserved dorsal rib in *Huanghetitan ruyangensis* is 293 cm in length, substantially larger than any known dorsal rib of *Fusuisaurus*.

Daxiatitan is based on a postcranial skeleton, including the caudalmost 10 cervicals, 10 dorsals, 2 proximal caudals, partial cervical and dorsal ribs, one haemal arch, right scapulocoracoid, and right femur, from the Early Cretaceous of the Hekou Group, Gansu Province, northwestern China. The complete right femur measured 57 cm at its distal width, comparable to that of *Fusuisaurus*.

Yunmenglong is based on a partial skeleton, including 7 articulated anterior cervicals, 2 isolated posterior cervicals, one dorsal, 4 anterior caudals, and one complete right femur, from the Early Cretaceous Haoling Formation, Ruyang Basin. The anterior caudal centrum measures 38cm and 42cm in its posterior centrum height and width, respectively, comparable to that of *Fusuisaurus*. The complete right femur in *Yunmenglong* measures 192cm and 65 cm in its total length and distal width, respectively, also comparable to that of *Fusuisaurus*.

Ruyangosaurus is known from two skeletons, including 9 cervicals, 13 dorsals, a dorsosacral, articulated sacrum and ilia, 5 mid-posterior caudals, 7 incomplete cervical and dorsal ribs, a complete right humerus, a complete right femur, the proximal half of the right femur, and a complete right tibia, from the Early Cretaceous Haoling Formation, Ruyang Basin. The estimated body length of *Ruyangosaurus* may have exceeded 35 m, with the maximum width of the dorsosacral centrum, the length of the longest cervical centrum, and the length of the right tibia reaching 68 cm, 124 cm, and 127cm, respectively, being among the largest ones reported for any known sauropods. Its ilium is 130 cm in length, smaller than that of *Fusuisaurus*. Its incomplete right femur is 60 cm in proximal width, with its estimated length being 207 cm, comparable to that

of *Fusuisaurus*. The complete right humerus of the smaller individual is 145 cm in its preserved length, and the incomplete humerus of the bigger individual is 135 cm and 26 cm in its preserved length and midshaft width, respectively, reaching nearly 190 cm in its reconstructed length, also comparable to that of *Fusuisaurus*.

Interestingly, the above mentioned five gigantic Asian titanosauriforms are all from the late Early Cretaceous (Abtian-Abian), implying a high diversity of giant Asian titanosauriforms from this period. This raises the possibility that the late Early Cretaceous was a key period for the evolution and diversity of giant titanosauriforms, corresponding to the simultaneous evolution event of giant Patagonian titanosaurs in the Southern Hemisphere (Carballido et al., 2017).

During the Early Cretaceous, the global temperature was generally warm (Tremolada et al., 2006), with some short periods of cold temperature in some areas (Amiot et al., 2011). Seasonal climatic changes were probably present in the Early Cretaceous (Steuber et al., 2005). On the other hand, warm or seasonal climate may have resulted in the expansion of the angiosperms in continental environments (Sun et al., 2002; Leng et al., 2003). These environmental conditions may have influenced the distribution and evolution of titanosauriforms, the dominant sauropod clade in Asia during the Cretaceous (Barrett et al., 2002; Barrett and Wang, 2007), especially those gigantic forms from the late Early Cretaceous of Asia.

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Figure captions

Fig. 1. Taphonomic map of the Longcaoling quarry showing the specimens. A, The Longcaoling quarry excavated in 2001, yielding the holotypes of *Fusuisaurus* (Yellow) and *Liubangosaurus* (Blue), and some unidentified sauropod bones (Black); B, The Longcaoling quarry was re-opened in 2016-2017, yielding nearly 100 dinosaur bones of juvenile hadrosauroids and sauropods, and some bones of adult sauropods, including a large humerus (LCL63), the holotype of *Fusuisaurus zhaoi*.

Fig. 2. The holotype of *Fusuisaurus zhaoi*, a nearly complete right humerus (LCL 63) in situ (A) and anterior view (B), scale bar equals 50 cm. dpc, deltopectoral crest

Fig. 3. Reconstructed skeleton and body silhouette of *Fusuisaurus zhaoi* showing preserved elements from the holotype specimen.

Table 1

Species	Specimen	Length	Width, proximal	Width, midshaft	PHR	SI	Age	Sources
<i>Fusuisaurus zhaoi</i>	LCL 63	1835	565	215	2.63	8.55	Aptian	This paper
<i>Notocolossus gonzalezparejasi</i>	UNCUYO-LD 301	1760	720	250	2.88	7.04	Coniacian–Santonian	González Riga et al., 2016
<i>Paralititan stromeri</i>	CGM 81119	1690	562	234	2.4	7.25	Cenomanian	Smith et al., 2001
<i>Patagotitan mayorum</i>	MPEF-PV 3397	1675	625	245	2.55	6.85	latest Albian	Carballido et al., 2017
<i>Dreadnoughtus schrani</i>	MPM-PV 1156	1600	740	320	2.31	5.00	Campanian–Maastrichtian	Lacovara et al., 2014
<i>Futalognkosaurus dukei</i>	MUCPv-323	1560	600	250	2.4	6.25	Coniacian	Calvo, 2014
<i>Ruyangosaurus giganteus</i>	KLR15-08-2	1450	540	200	2.7	7.25	Aptian-Albian	Lü et al., 2014

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377 Table caption

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379 Table 1: Measurement (in mm) of the humerus (LCL 63), compared to those of giant sauropods

380 recovered from Cretaceous. SI, Slenderness Index; PHR, Proximal Humeral Robusticity

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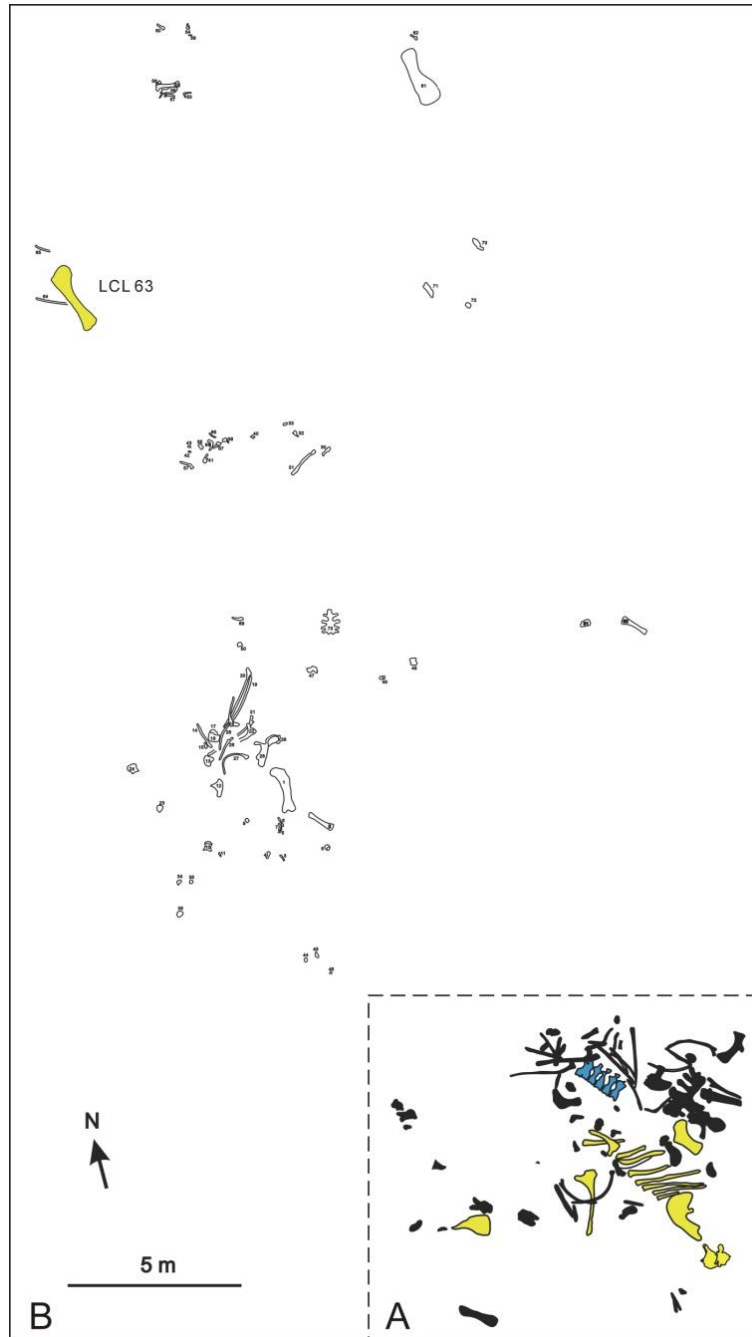


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392 Fig. 2. The holotype of *Fusuisaurus zhaoi*, a nearly complete right humerus (LCL 63) in situ (A)

393 and anterior view (B), scale bar equals 50 cm. dpc, deltopectoral crest

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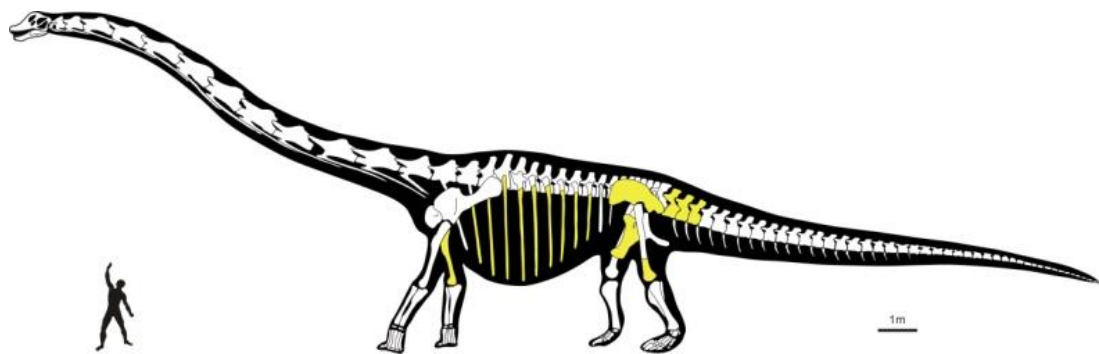


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