

## Short communication

# New fossil remains of *Fusuisaurus zhaoi* (Sauropoda: Titanosauriformes) from the Lower 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*. With a preserved length of 183.5 cm, the newly collected humerus is tentatively referred to and supports a giant size of *Fusuisaurus zhaoi*, which increases our knowledge of the diversity of giant titanosauriforms from the late Early Cretaceous of Asia.

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## 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*), crocodyliforms (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 Natural Resources of Fusui County (BNRF) re-opened the Longcaoling quarry and uncovered nearly 100 disarticulated dinosaur bones within an area of nearly 600 m<sup>2</sup>. All of these newly discovered bones are preserved in its original site. 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 (Brochu, 1996). A large, nearly complete right humerus (183.5 cm in preserved length, obviously belonging to a giant sauropod) was recovered from the fossil-bearing deposit from which the holotype of *Fusuisaurus zhaoi* was collected and it is positioned close to the latter (25 m), thus we tentatively refer this large humerus (field number LCL 63) to *Fusuisaurus* based on its size.

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## 2. Taphonomy

The Longcaoling site is located near the Liubang Village, about 70 km away from Nanning City, Guangxi Zhuang Autonomous Region (Fig. 1). 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. 2).

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).

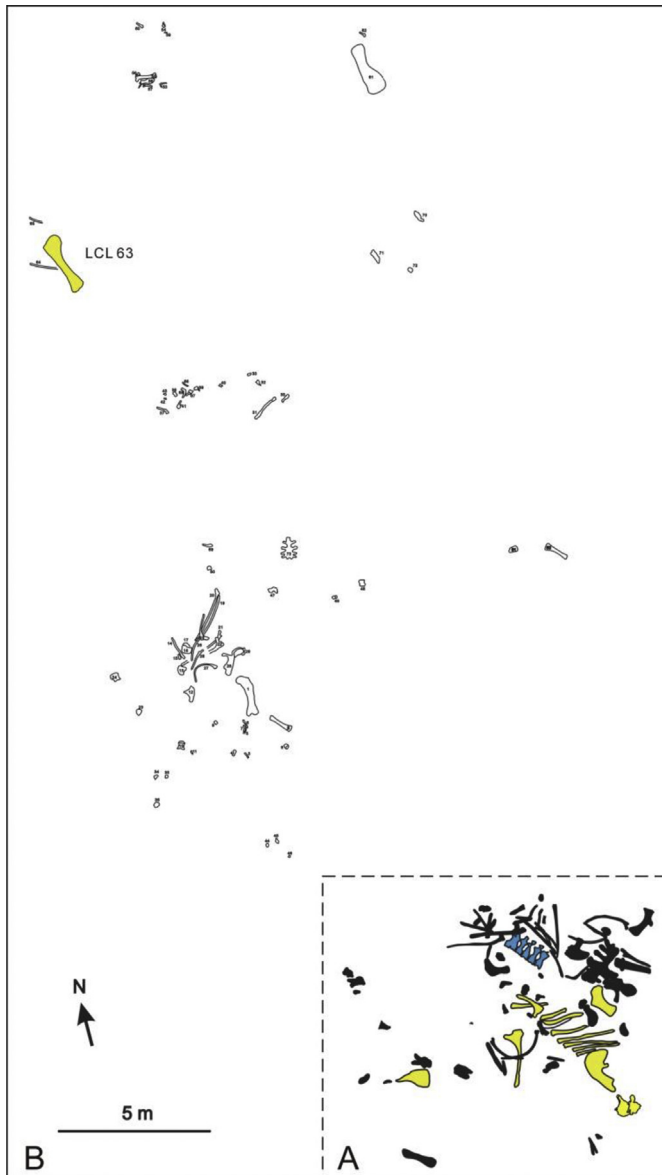
The underlying deposit is a lakeshore subfacies. It may have been submerged in the rainy season, and exposed to the surface in the low water season, so that mud cracks formed when the lake dried up for a long time. The fossil-bearing deposit was probably formed by a sudden flood carrying gravels, sand, 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. Humerus LCL 63 as the referred specimen of *Fusuisaurus zhaoi*

As Mo et al. (2010) noted, there were three individuals of sauropods present at the Quarry A (Fig. 2A), 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 certain that there is one giant sauropod (represented by the large humerus LCL 63), and one small, juvenile sauropod dinosaur present at the



Fig. 1. Map showing the fossil locality at Longcaoling quarry of Liubang Village, Shanxu Town, Fusui County, Guangxi Zhuang Autonomous Region, southern China. Geographic coordinates: 22°21'35.2" N, 107°57'01.3" E.



**Fig. 2.** 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 referred specimen of *Fusuisaurus zhaoi*.

Quarry B (Fig. 2B), 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 the absence of overlapping materials within these three sauropods. *Fusuisaurus zhaoi* was the only giant sauropod recovered from Longcaoling site. Thus, we tentatively refer the humerus LCL 63 (obviously belongs to a giant sauropod) to *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.

**Referred specimen.** 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, Lower 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, humerus with laterally rather than medially expanded deltopectoral crest near the midshaft, 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 in its original site (Fig. 3A and B), missing only the anterior margins of the distal and proximal parts of the shaft (including the deltopectoral crest), and the distomedial portion. Its preserved length is 183.5 cm, being the longest one for any known sauropod from the Cretaceous (Table 1). The humerus is straight and gracile in anterior view (Fig. 3C), similar to *Ligabuesaurus* (Bonaparte et al., 2006) and *Phuwiangosaurus* (Martin et al., 1994, 1999). The SI (Slenderness Index, i.e., ratio of the proximodistal length to the midshaft width) value is substantially greater than those members of Euhelopodidae, an endemic clade from Asia (Mannion et al., 2019), such as *Huabeisaurus* (Pang and Cheng, 2000), *Borealosaurus* (You et al., 2004), and *Euhelopus* (Wilson and Upchurch, 2009), which are 6.1, about 6.0, 5.2, respectively. The proximomedial process is round and robust, pointing dorsomedially, with its apex lying well medial to the midshaft. The proximal end is robust relatively 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 posterolateral bulge is weakly developed, though this portion was damaged during the excavation. The deltopectoral crest is partly preserved, being double in thickness distally across the anterolateral margin and extends downward to the midshaft, unlike the condition in *Ligabuesaurus* in which the deltopectoral crest only develop in the proximal third of the humerus. The deltopectoral crest expands slightly laterally, rather than medially near the midshaft, unlike the condition seen in *Ligabuesaurus*, *Borealosaurus* and other derived titanosaurian sauropods, such as *Saltasaurus* (Powell, 1992) and *Opisthocoelicaudia* (Borsuk-Bialynicka, 1977). Medial to the deltopectoral crest, the anterior margin of the proximal part of the shaft is greatly excavated. The distomedial part of the shaft was eroded during its fossilization. The posterior margin of the humerus is wrapped in the rock, hindering the observation of the detailed structure of this part.

#### 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. It is previously assigned to Titanosauriformes (Mo et al.,



**Fig. 3.** The referred specimen of *Fusuisaurus zhaoui*, a nearly complete right humerus (LCL 63) in anterodistal (A), anteroproximal (B), and anterior (C) views, scale bar equals 50 cm. dpc, deltopectoral crest; lb, lateral bulge.

2006; D'Emic, 2012; Mannion et al., 2013). The newly recovered humerus shows some characters, such as SI value being greater than 7.5, posterolateral bulge weakly developed, deltopectoral crest laterally rather than medially expanded, also suggest that *Fusuisaurus* is a basal member of Titanosauriformes (D'Emic, 2012).

The left ilium in *Fusuisaurus* 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 referred specimen of *Fusuisaurus*, is the longest one for any giant sauropod from the Cretaceous (Table 1). These available fossils suggest that *Fusuisaurus* was a gigantic titanosauriform.

It is interesting to calculate the body mass of *Fusuisaurus*. Based on the distal part of the left femur and the newly recovered

humerus, the estimated circumferences of the femur and humerus are 795 mm and 605 mm, respectively. Applying the scaling equation for *Fusuisaurus* yields an estimated body mass of 35 tonne (Benson et al., 2014), which is much less than some of titanosaurs, such as *Patagotitan* (69 tonne, Carballido et al., 2017). It can be said that *Fusuisaurus* is very long, but not particularly gigantic (Fig. 4).

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),

**Table 1**

Measurement (in mm) of the humerus (LCL 63), compared to those of giant sauropods recovered from Cretaceous. SI, Slenderness Index; PHR, Proximal Humeral Robusticity.

Species	Specimen	Length	Width, proximal	Width, midshaft	PHR	SI	Age	Sources
<i>Fusuisaurus zhaii</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

*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 Lower 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*.

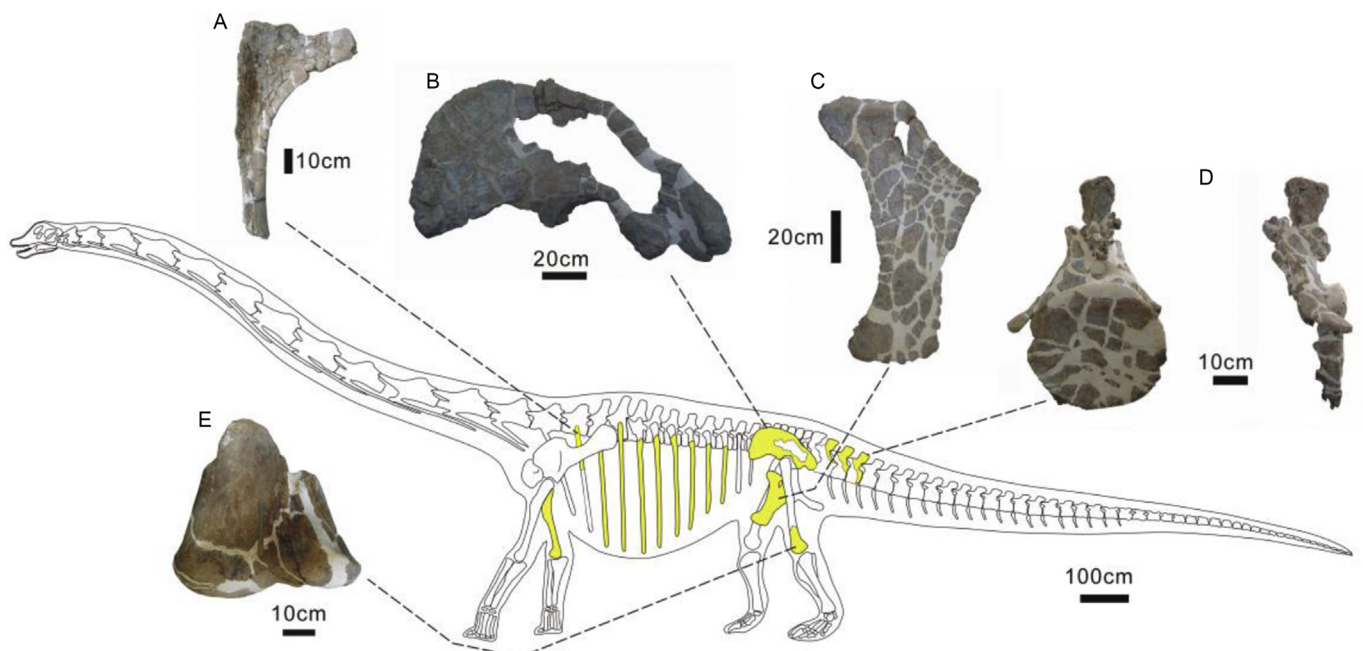
*Daxiatitan* is based on a postcranial skeleton, including the caudalmost 10 cervicals, 10 dorsals, 2 proximal caudals, partial cervical and dorsal ribs, one haemal arch, right scapulocoracoid, and right femur, from the Lower Cretaceous Haoling Formation of the Hekou Group, Gansu Province, northwestern 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 Lower Cretaceous Haoling Formation, Ruyang Basin. The anterior caudal centrum measures 38 cm and 42 cm in its posterior centrum height and width, respectively, comparable to that of *Fusuisaurus*. The complete right femur in *Yunmenglong* measures 192 cm 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 Lower 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 127 cm, 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 titanosaurs are all from the late Early Cretaceous (Aptian–Albian), implying a high diversity of giant Asian titanosaurs from this period. This raises the possibility that the late Early Cretaceous was a key period for the evolution and diversity of giant titanosaurs, corresponding to the simultaneous evolution event of giant



**Fig. 4.** Reconstructed skeleton and body silhouette of *Fusuisaurus zhaii* showing the preserved holotype and referred specimen (yellow). a, anterior dorsal rib in posterior view; b, left ilium in lateral view; c, left pubis in lateral view; d, anterior caudal in posterior and lateral views; and e, distal part of left femur in anterior view.

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 only sauropod clade in the Cretaceous of Asia (Barrett et al., 2002; Barrett and Wang, 2007), especially those gigantic forms from the late Early Cretaceous of Asia.

## 6. Conclusions

The newly discovered longest Cretaceous humerus from the Xinlong Formation in Napai Basin, Guangxi Province, southern China, is referred to *Fusuisaurus*. The anatomical features in this new specimen, such as SI value being greater than 7.5, posterolateral bulge weakly developed, deltopectoral crest laterally rather than medially expanded near the midshaft, also suggest that *Fusuisaurus* is a basal member of titanosauriform. Combined with other approximately contemporaneous gigantic Asian titanosauriformes, the recovery of the late Early Cretaceous *Fusuisaurus* increases our knowledge of the diversity of giant titanosauriforms by the Early Cretaceous of Asia.

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