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

3

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22

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

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

31

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

33

34 **1 Introduction**

35

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

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

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

56

57 **2 Taphonomy**

58

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

66 Two layers of outcrops at the Longcaoling quarry include the fossil bearing deposit and the
67 underlying deposit (the overlying deposit has been cultivated by local farmers). The fossil bearing
68 deposit is exposed on the surface. It exhibits a succession of purple-red sandy gravels, fine
69 sandstones, muddy sandstones and sandy mudstones. The layer of sandy gravels has a thickness of
70 15-60 cm in the northern part of the quarry (where LCL 63 was discovered), while it becomes
71 thinner and finally disappears southward. The underlying deposit exhibits a succession of purple-
72 red, light-green mudstones, siltstones and fine-grained sandstones containing some calcareous

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

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

86

87 **3 LCL 63 as the holotypic material of *Fusuisaurus zhai***

88

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

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

101

102 **4 Systematic Palaeontology**

103

104 Saurischia Seeley, 1888

105 Sauropoda Marsh, 1878

106 Titanosauriformes Salgado, Coria & Calvo, 1997

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

108

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

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

114 **Type horizon.** Napai Basin, Xinlong Formation, Early Cretaceous (possibly Aptian) (Mo et al.,
115 2016)

116 **Emended Diagnosis.** A gigantic basal titanosauriform (Mo et al., 2006) or Somphospondyli
117 (Mannion et al., 2013) diagnosed by the following characters: humerus with Slenderness Index
118 8.55 and Proximal Humeral Robusticity 2.63, anterior dorsal ribs lacking pneumatic foramina,

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

122

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

142

143 **5 Discussion**

144

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

153 Titanosauriformes represent a diverse and globally distributed clade of neosauropod dinosaurs
154 (D’Emic, 2012; Mannion et al., 2013). Although the number of named Asian Titanosauriformes
155 has dramatically increased in the last decade, most of them are represented by medium or large-
156 sized animals (Azuma and Shibata, 2010; Ksepka and Norell, 2006; Li et al., 2014; Lü et al., 2008,
157 2009a, 2013a; Mo et al., 2008, 2010, 2017; Saegusa and Ikeda, 2014; Wang et al., 2007; Wu et al.,
158 2006; Xu et al., 2006; You et al., 2006; You and Li, 2009; Zhang et al., 2009), only *Huanghetitan*
159 *ruyangensis* (Lü et al., 2007), *Daxiatitan* (You et al., 2008), *Yunmenglong* (Lü et al., 2013b),
160 *Ruyangosaurus* (Lü et al., 2009b, 2014) are comparable with *Fusuisaurus* in terms of gigantism.

161 *Huanghetitan ruyangensis* is based on a partial skeleton, including a nearly complete sacrum,
162 10 proximal caudals, haemal arches, dorsal ribs, and incomplete ischium, from the Early
163 Cretaceous Haoling Formation (Aptian-Albian, Xu et al., 2012), Ruyang Basin, Henan Province,
164 central China. The anteriormost caudal centrum is 26.9 cm and 32 cm in posterior height and

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

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

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

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

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

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

197 During the Early Cretaceous, the global temperature was generally warm (Tremolada et al.,
198 2006), with some short periods of cold temperature in some areas (Amiot et al., 2011). Seasonal
199 climatic changes were probably present in the Early Cretaceous (Steuber et al., 2005). On the
200 other hand, warm or seasonal climate may have resulted in the expansion of the angiosperms in
201 continental environments (Sun et al., 2002; Leng et al., 2003). These environmental conditions
202 may have influenced the distribution and evolution of titanosauriforms, the dominant sauropod
203 clade in Asia during the Cretaceous (Barrett et al., 2002; Barrett and Wang, 2007), especially those
204 gigantic forms from the late Early Cretaceous of Asia.

205

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207

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215

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217

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351 Figure captions

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

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

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

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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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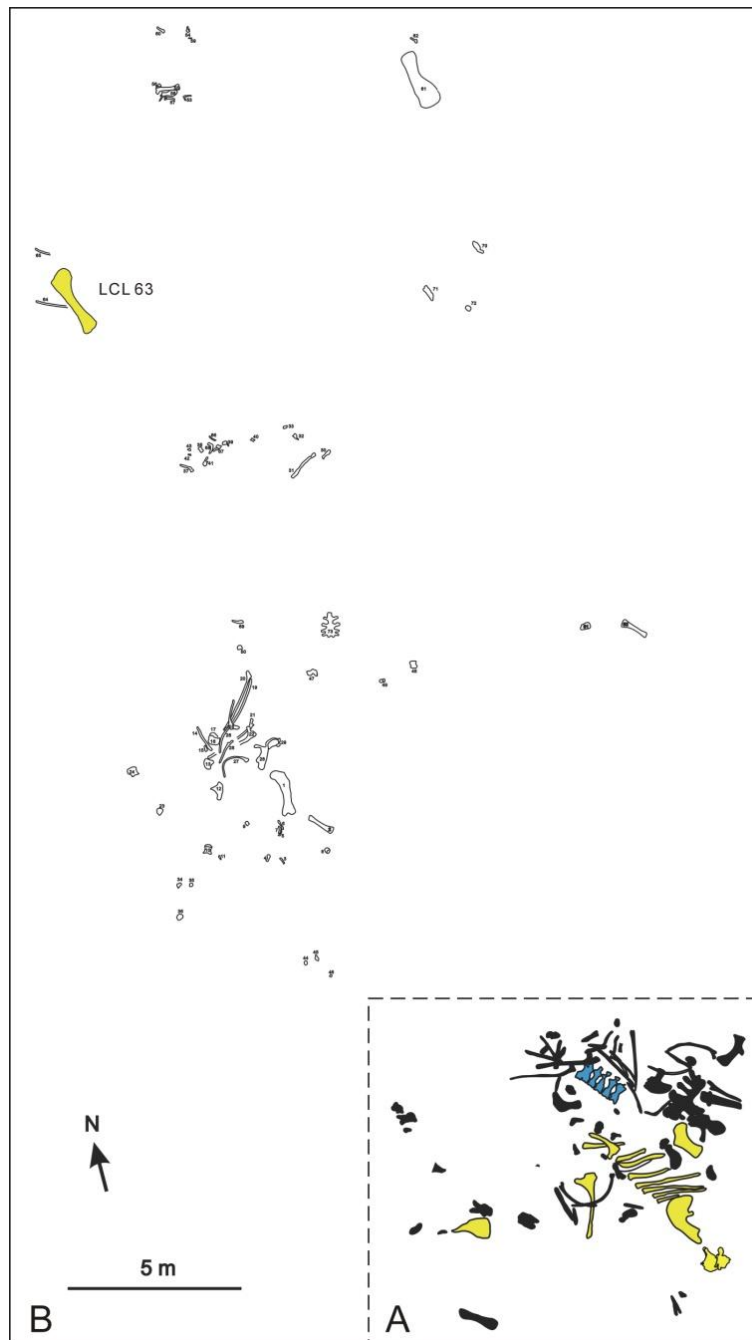
377 Table caption

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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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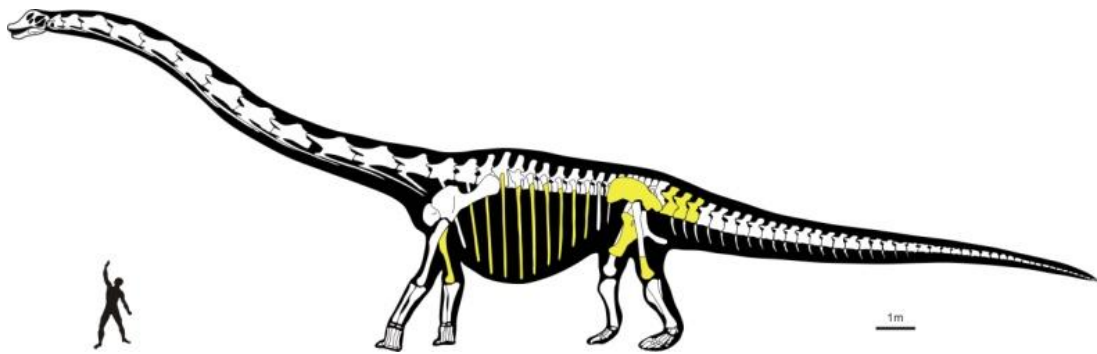
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