

The first well-preserved Early Cretaceous brachiosaurid dinosaur in Asia

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A new genus and species of brachiosaurid sauropods, *Qiaowanlong kangxii* gen. et sp. nov., is reported, representing the first well-preserved Early Cretaceous brachiosaurid in Asia and expanding the distribution of brachiosaurids undoubtedly into the Asian continent. The new taxon was recovered from the late Early Cretaceous Xinminpu Group of Yujingzi Basin in northwestern Gansu Province, China, and is represented by a series of eight mid-cervical vertebrae, a right pelvic girdle and some unidentified bones. The existence of deeply excavated cervical neural spines and a rising transition in the neural spine height among mid-cervical vertebrae clearly show the affinity of *Qiaowanlong* as a member of brachiosaurids. Among brachiosaurids, *Qiaowanlong* shares a derived feature with the North American Early Cretaceous brachiosaurid *Sauroposeidon*: the lack of cranial centrodiapophyseal lamina. However, *Qiaowanlong* is unique in possessing a suite of features, such as a low central length/cotyle height ratio, bifurcated cervical neural spines and a much reduced ischium. The discovery of *Qiaowanlong* and other new material indicates a diverse and abundant sauropod assemblage in China during the Early Cretaceous.

Keywords: brachiosaurid; dinosaur; Early Cretaceous; Xinminpu Group; Yujingzi Basin; Gansu

1. INTRODUCTION

Brachiosauridae is one of the first discovered and best-known groups of sauropod dinosaurs, specialized in having forelimbs that are as long as or even longer than the hind limbs, and is often envisioned as the 'giraffes' of the Mesozoic (Wilson & Curry Rogers 2005). Traditionally well known in the Late Jurassic of North America (Morrison Formation) and Africa (Tendaguru Formation; Riggs 1903; Janensch 1914), the distribution of brachiosaurids has now expanded into the Late Jurassic of Europe (Lapparent & Zbyszewski 1957; Antunes & Mateus 2003; Upchurch & Martin 2003; Upchurch *et al.* 2004), Asia (Ye *et al.* 2005) and South America (Rauhut 2006), as well as the Early Cretaceous of North America (Ratkevitch 1998; Tidwell *et al.* 1999; Wedel *et al.* 2000b; Rose 2007), Africa (Lapparent 1960) and Europe (Naish *et al.* 2004). The existence of Early Cretaceous brachiosaurids in Asia has been postulated based on one tooth from South Korea (Lim *et al.* 2001) and two teeth from Lebanon (Buffetaut *et al.* 2006). Here, we report the first well-preserved Early Cretaceous brachiosaurid in Asia.

The new specimen was excavated from the Lower Cretaceous Xinminpu Group of Yujingzi Basin in northwestern Gansu Province, China (figure 1), in 2007 by the field crew of the Fossil Research and Development Center (FRDC) of the Third Geology and Mineral Resources Exploration Academy of Gansu Provincial Bureau of Geo-exploration and Mineral Development.

The specimen consists of a series of eight articulated cervical vertebrae and the right pelvic girdle, as well as several unidentified bone fragments cranial to the cervical and associated with the pelvic girdle. During excavation, it was jacketed into two blocks (field numbers GJ 07-14-01 and -02) and broken across the fourth articulated cervical.

The Early Cretaceous Xinminpu Group in Yujingzi Basin, although new to dinosaur research, has recently produced a rich and diverse dinosaur assemblage, including a new genus of therizinosauroid (*Suzhousaurus megatherioides*; Li *et al.* 2007, 2008), a new genus of tyrannosauroid (*Xiongguanlong baimoensis*; Li *et al.* in press), a new genus of ornithomimosaur (*Beishanlong grandis*; Makovicky *et al.* in press), a new neoceratopsian (You *et al.* in press), a bonebed of basal neoceratopsians (cf. *Auroraceratops*; You *et al.* 2005), a bonebed of basal hadrosauroids (cf. *Equijubus*; You *et al.* 2003) and numerous other representatives of various vertebrate groups currently under study. The dinosaur-bearing beds in the Yujingzi Basin are generally correlated to those from the Gongpoquan Basin about 100 kilometres to the north (Li *et al.* 2007), the age of which has been proposed as late Early Cretaceous, probably Albian, based on the existence of angiosperm pollens (Tang *et al.* 2001). Dinosaurs from the Gongpoquan Basin are considered to represent a later, more derived stage in the evolution of the Early Cretaceous *Psittacosaurus* fauna in northern China (You & Luo 2008); therefore, dinosaurs from the late Early Cretaceous (Aptian–Albian) of the Mazongshan area (Yujingzi and Gongpoquan basins and surrounding areas) play an important role in understanding the

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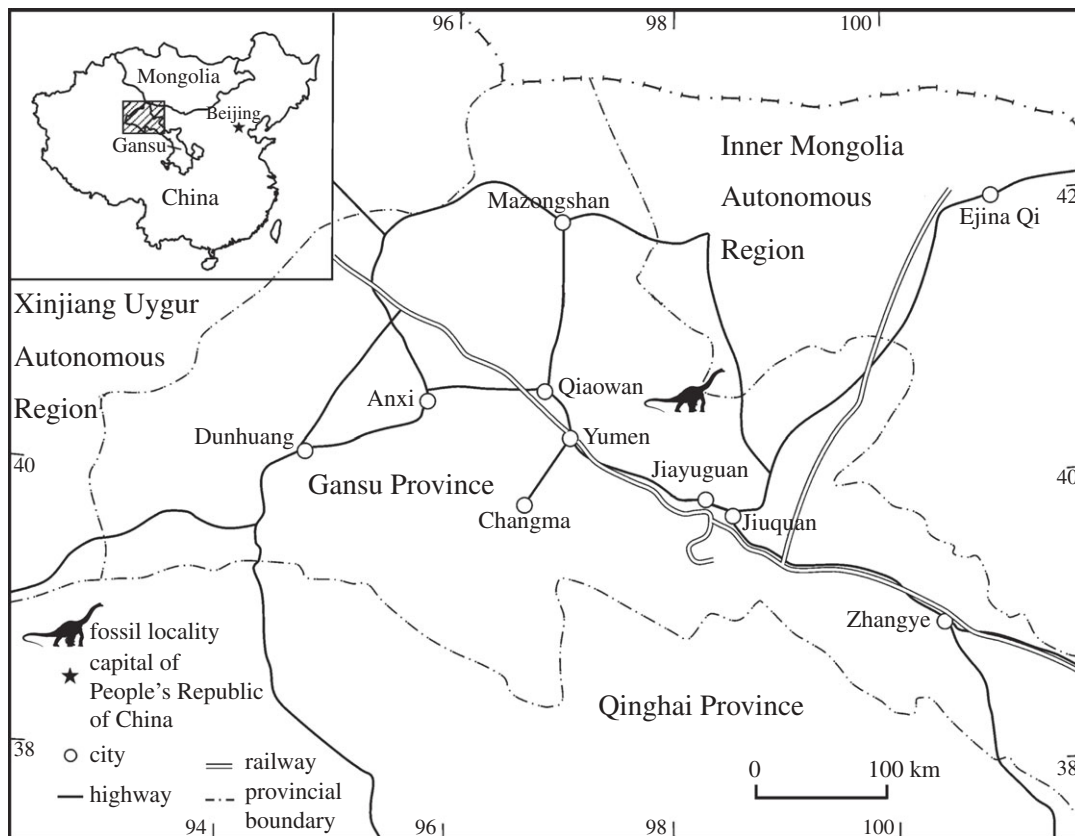


Figure 1. Locality of *Qiaowanlong kangxii* FRDC GJ 07-14.

faunal changes across the Early–Late Cretaceous boundary, especially the origin and early evolution of dinosaur groups that dominated the Late Cretaceous, such as members of the Hadrosauroidea (duck-billed dinosaurs) and Ceratopsidae (horned dinosaurs).

2. DESCRIPTION

Saurischia Seeley, 1887

Sauropodomorpha Huene, 1932

Sauropoda Marsh, 1878

Brachiosauridae Riggs, 1904

Qiaowanlong kangxii gen. et sp. nov.

(a) *Etymology*

Generic name is derived from ‘Qiaowan’, a cultural relic near the fossil locality; ‘Qiao’ means ‘bridge’, ‘wan’ means ‘bend in a stream’ and ‘long’ means ‘dragon’, all in Chinese; specific name is after ‘Kangxi’, a famous emperor of the Qing Dynasty, who once had a dream of the scenic beauty of the Qiaowan area.

(b) *Holotype*

FRDC (Fossil Research and Development Center): GJ 07-14.

(c) *Locality and horizon*

Yujingzi Basin, Jiuquan area, Gansu Province, People’s Republic of China. Middle Unit of the Xinminpu Group in this basin, late Early Cretaceous (Aptian–Albian; Li 2008).

(d) *Diagnosis*

A brachiosaurid sauropod having a low elongation index (EI) ratio (central length with condyle divided by cotyle height: 3.6 and 3 in C6 and C9, respectively), deeply bifurcated cervical neural spines, three fossae on the shallowly depressed lateral surface of the centrum, and much reduced ischium with the width and the length of its shaft about 50 and 70 per cent, respectively, of the comparable portions of the pubis, as well as a long pubic process of the ischium, occupying about 60 per cent of the length of its shaft.

(e) *Description*

A series of eight articulated cervical vertebrae are preserved (figure 2). They are assigned as cervicals C4–11 based on central length comparisons with other sauropods (Wedel *et al.* 2000a), especially to *Brachiosaurus brancai* specimen HM SII (Janensch 1950), where the longest cervical central lengths occur around C10 and C11. Except for C4, the cervicals are well preserved, with an average central length (without condyle) of 38 cm (table 1). Compared with other brachiosaurids, the cervical central lengths of GJ 07-14 are short: for example, 43 and 45 cm in C6 and C7, while they are 90 and 93 cm in *B. brancai* specimen HM SII, and 122 and 123 cm in *Sauroposeidon*, respectively (Wedel *et al.* 2000a). Despite the small size of GJ 07-14, the neurocentral sutures are fused, which indicates that the animal was an adult or subadult and probably at least two-thirds of its full size. Here, C9 is described to show the general features of this cervical series.

The centrum of C9 is opisthocelous, with a distinct condyle. Its EI is 3, lower than that in *B. brancai*

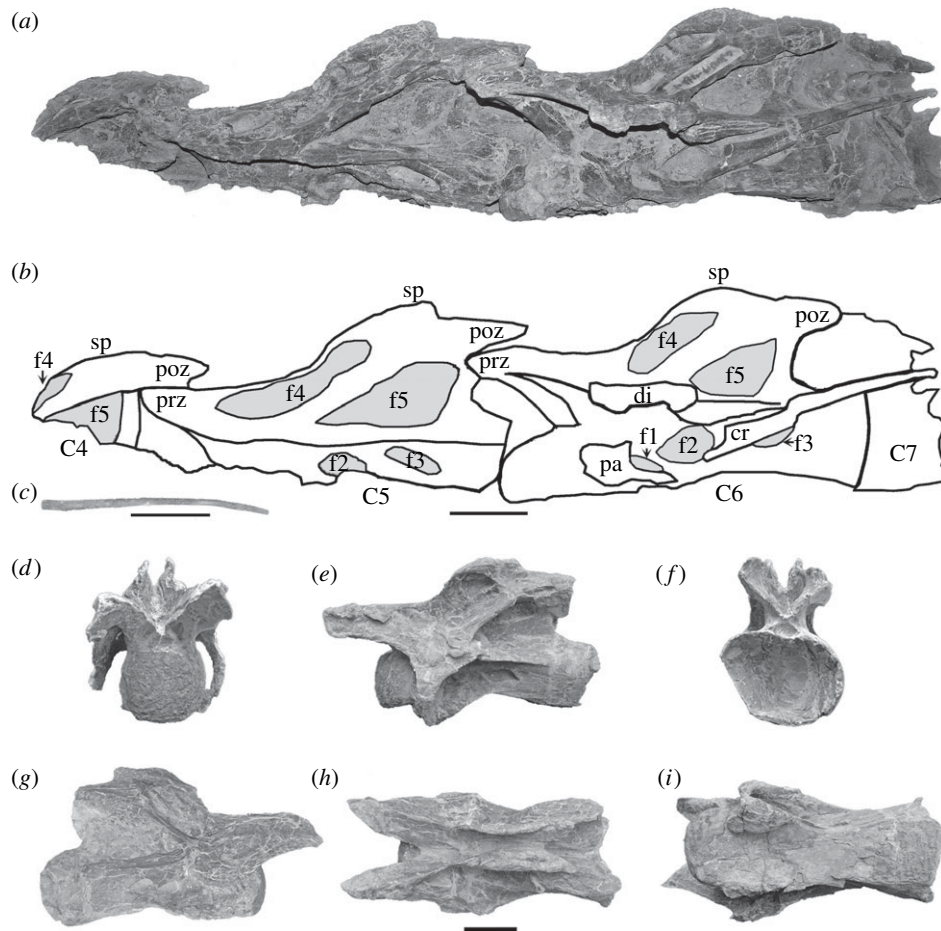


Figure 2. Cervical vertebrae of *Q. kangxii* FRDC GJ 07-14. (a) Photograph and (b) interpretative line drawing of C4–C7 in left lateral view; (c) a distal portion of a cervical rib; C9 in (d) cranial, (e) left lateral, (f) caudal, (g) right lateral, (h) dorsal and (i) ventral views. di, diapophysis; f1–f5, fossa 1–fossa 5; pa, parapophysis; poz, postzygapophysis; prz, prezygapophysis; sp, neural spine. Scale bars, 10 cm.

Table 1. Measurements of cervical vertebrae of *Q. kangxii* FRDC GJ 07-14. —, not applicable; +, close and more than; *, estimated. Measurements are in cm.

	C4	C5	C6	C7	C8	C9	C10	C11
length of condyle (left side)	—	—	4.5	8.5	—	8	7	—
length of centrum without condyle (left side)	—	35	38.5	36.5	39	38	41	39
total length including prezygapophyses	23+	44	47	47	49	52.5	54	53
height of condyle	—	—	6+	9+	—	12.5	13	—
height of cotyle	—	8+	12	—	14	15.5	—	—
height of neural arch and neural spine (left side)	12+	13.5	14	15	16	20	20.5	20.5
height of centrum, neural arch and neural spine (left side)	—	20+	21.5	24.5	25	28	30	30
width of condyle	—	—	9	12	—	14	19	—
width of cotyle	—	10	13	—	18.5	18+	—	18+
minimum width between tops of divided neural spine	1	3	4.5	6	6	5	6	7
maximum width between diapophyses	—	20*	22	22*	31*	27	33	33.5
maximum width between postzygapophyses	13.5	14	15.5	17.5	17.5	19.5	21	24.5

specimen HM SII (3.8 in C9) and *Sauroposeidon* (4.6 in C8; Wedel *et al.* 2000a). The ventral surface of the centrum is concave at its cranial half, especially in its caudal half, while the caudal half of the ventral surface is roughly flat. In lateral view, the middle portion of the centrum is concave and occupied by three fossae. The parapophysis is situated on the cranioventral corner of the centrum, and bears a short centroparapophyseal lamina along the cranial half of the central lateroventral edge.

The prezygapophysis is robust and protrudes beyond the cranial end of the central condyle as in *B. brancai* and *Sauroposeidon* (Janensch 1950; Wedel *et al.* 2000a). Its articular surface faces dorsomedially. The centro-prezygapophyseal and the prezygodiapophyseal laminae are merged with each other and robust. They direct horizontally at its cranial portion, and craniodorsal-caudoventrally for its caudal portion, and terminate on the cranial end of the laterodorsal edge of the centrum.

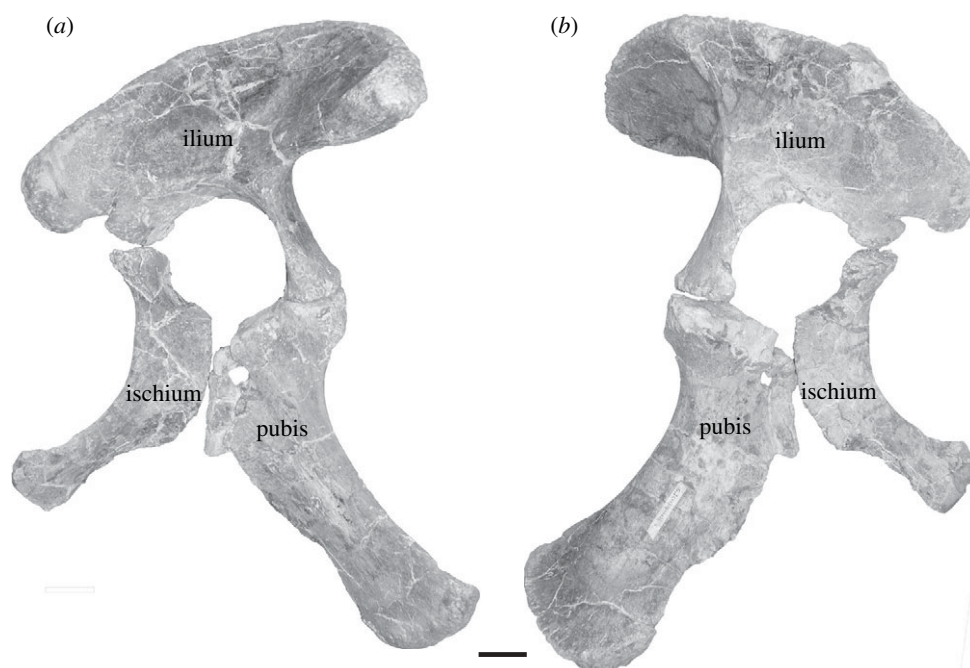


Figure 3. Right pelvic girdle of *Q. kangxii* FRDC GJ 07-14 in (a) lateral and (b) medial views. Scale bar, 10 cm.

The spinoprezygapophyseal lamina is delicate and very long, extending to the tip of the neural spine. The caudal half of the spinoprezygapophyseal lamina and the cranial half of the postzygodiapophyseal lamina border a large and elongate fossa (f4 in figure 2) on the lateral surface of the neural spine, which is a key feature of Brachiosauridae (Upchurch *et al.* 2004). The distinct caudal centrodiapophyseal lamina runs almost horizontally, ending at the position below the almost vertical and robust centropostzygapophyseal lamina. A large fossa (f5 in figure 2) is formed by the previously mentioned three laminae. The neural spine is deeply V-shaped in both cranial and caudal views.

A proximal portion of a rib is associated with C6, which is broken off near the caudal end of the centrum, with an equilateral triangular cross section of 1.5 cm for each side. Another partial 32-cm-long distal portion of a cervical rib is preserved. Its oval cross sections are 1.4 cm long and 0.4 cm wide at the proximal end, and 0.7 cm long and 0.2 cm wide at the distal end. Judging from the slenderness and lengths of these two portions of ribs, as well as the lengths of the cervical centra, a complete rib would probably cover at least two cervical centra as in other brachiosaurids (Janensch 1950; Wedel *et al.* 2000a).

The complete right pelvic girdle is preserved (figure 3). The ilium is similar to that of *B. brancai* (Janensch 1950). The preacetabular process of the ilium has a more subtriangular than lobe-shaped outline and deflects laterally. The postacetabular process is very short and terminates in a blunt end. The pubic peduncle of the ilium is long and terminates in a transversely expanded articular surface, while the ischial peduncle is very short and much reduced. The pubis is robust and directs more ventrally than cranially, with a concave cranial margin. The ischium is much slenderer and shorter than the pubis, with the width of its shaft about half and the length of its shaft about 70 per cent of the comparable portions

of the pubis. The ischium also has a long pubic process, occupying about 60 per cent of the total length of its shaft. The distal end of the ischial shaft expands slightly.

3. DISCUSSION

Brachiosauridae is a small group of sauropods, well represented only by *B. brancai*, with multiple skeletons (Janensch 1914). Their Early Cretaceous representatives have been reported mainly from North America: *Sonorasaurus* (Ratkevitch 1998), *Cedarosaurus* (Tidwell *et al.* 1999), *Sauroposeidon* (Wedel *et al.* 2000b) and *Paluxysaurus* (Rose 2007), with two other unnamed taxa from Africa (Lapparent 1960) and Europe (Naish *et al.* 2004). Although all these taxa are based on partial skeletons, comparisons of cervical vertebral morphology, especially that between the new specimen and *Sauroposeidon*, provide strong evidence to support a brachiosaurid affinity of *Qiaowanlong*.

A key feature shared by *Qiaowanlong*, *Brachiosaurus* and *Sauroposeidon* is the existence of deeply excavated cervical neural spines. The status of this feature in other brachiosaurids is unknown owing to lack of preservation, but it seems to be an autapomorphy of brachiosaurids. Another feature shared by *Qiaowanlong* and *Sauroposeidon* is the lack of cranial centrodiapophyseal lamina. This lamina is short in *B. brancai* and well developed in *Paluxysaurus* (Rose 2007). *Brachiosaurus* and *Sauroposeidon* possess a marked rising in mid-cervical neural spine height, where those of C7 are about twice as tall as those of C6 (Wedel & Cifelli 2005, fig. 10). In *Qiaowanlong*, this transition is much less pronounced than in other brachiosaurids in which it is known, and occurs between C8 and C9, with an increase in the height of neural arch and spine from 16 to 20 cm (an increase of 25%). These features and other general similarities suggest a close relationship between *Qiaowanlong* and *Sauroposeidon*, and therefore confirm the brachiosaurid affinity of

Qiaowanlong, assuming that *Sauroposeidon* is correctly identified as a brachiosaurid. However, *Qiaowanlong* lacks the autapomorphies of *Sauroposeidon*, such as greatly expanded centroparapophyseal laminae and caudally extended pneumatic fossae reaching to the cotyles, and perforated pneumatic fossae in neural spines.

As a member of Brachiosauridae, *Qiaowanlong* possesses several unique features, such as the low EI ratio, bifurcated cervical neural spines, three fossae on the middle half of the shallowly depressed lateral surface of the centrum, as well as a unique pelvis with much reduced ischium. Therefore, it is clear that *Qiaowanlong* is distinct from all other known brachiosaurids and requires assignment to a new genus. The bifurcated cervical neural spine of *Qiaowanlong* is of particular interest because it represents the first occurrence of this feature in brachiosaurids. Bifid spines are already known in various subgroups of sauropods (Upchurch *et al.* 2004), and their discovery in brachiosaurids suggests strongly that this was an independent evolutionary event and bears important functional significance to explain sauropod neck posture (Wedel *et al.* 2000a).

The discovery of *Qiaowanlong* adds one more member to the rapidly growing record of Early Cretaceous sauropods in China (You *et al.* 2008) and raises this question again: did sauropods really decline in the Early Cretaceous (Upchurch & Barrett 2005; Wedel & Taylor 2008)? Sauropods appear to have been diverse and abundant in China during the Early Cretaceous, and hypotheses of sauropod evolution and biogeography will need to take this diversity and abundance into account.

We are grateful to the crew of the Fossil Research and Development Center of Third Geology and Mineral Resources Exploration Academy of Gansu Provincial Bureau of Geo-exploration and Mineral Development for discovering, excavating and preparing the specimen. Ling-Qi Zhou helped with photography. Kristian Remes provided valuable discussions and improved the manuscript with great patience. Funding was provided by the National Natural Science Foundation of China (40672007), the 973 project and the basic outlay of scientific research work from Ministry of Science and Technology and the Hundred Talents Project of Ministry of Land and Resources of China to H.-L.Y., and Gansu Provincial Bureau of Geo-exploration and Mineral Development to D.-Q.L.

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