

A Titanosaurian Sauropod Dinosaur with Opisthocoelous Caudal Vertebrae from the Early Late Cretaceous of Liaoning Province, China

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Abstract We describe a new titanosaurian sauropod dinosaur, *Borealosaurus wimani* gen. et sp. nov., based on a distinctive mid-distal caudal vertebra from the early Late Cretaceous Sunjiawan Formation exposed in the Shuangmiao village of Beipiao in Liaoning, China. We provisionally refer an isolated tooth crown, a middle caudal vertebra, and a right humerus from the same locality and horizon to this taxon. *Borealosaurus* is distinguished from other sauropods in its possession of opisthocoelous mid-distal caudal vertebrae. The occurrence of opisthocoelous caudals in *Borealosaurus* and the Mongolian sauropod *Opisthocoelicaudia* raises the possibility that these taxa pertain to an as-yet unrecognized titanosaurian subclade endemic to the Cretaceous Asia.

Key words: Dinosauria, Sauropoda, Titanosauria, Opisthocoelicaudiinae, Sunjiawan Formation, early Late Cretaceous, Liaoning, China

1 Introduction

Dinosaur material from fossiliferous beds of the Sunjiawan Formation exposed near the Shuangmiao village of Beipiao in Liaoning Province, China (Fig. 1) was excavated from 1999–2002 and repositied in the Liaoning Paleontological Museum (LPM) in Beipiao. Remains of theropod, sauropod, ankylosaurian (Dong, 2002), and hadrosauroid (You et al., 2003) dinosaurs have been recognized in this collection, and the age of the Sunjiawan Formation is considered to be early Late Cretaceous (Dong, 2002; You et al., 2003). Here, we describe a new titanosaurian sauropod based on an unusual mid-distal caudal vertebra and tentatively referred material including a tooth crown, another caudal vertebra, and a right humerus from the same locality and horizon.

2 Systematic Paleontology

Dinosauria Owen, 1842

Sauropoda Marsh, 1878

Titanosauriformes Salgado, Coria, and Calvo, 1997

Titanosauria Bonaparte and Coria, 1993

?Opisthocoelicaudiinae McIntosh, 1990

Borealosaurus gen. nov.

Type species: *Borealosaurus wimani* sp. nov.

Etymology: “Borealis” (Greek), northern, referring to the location of the fossil site in northern China, and the Northern Hemisphere. “Sauros” (Greek), lizard.

Diagnosis: As for the type and only known species.

Borealosaurus wimani sp. nov.

Holotype: LPM0167: a mid-distal caudal vertebra.

Referred specimens LPM0169: an isolated tooth crown; LPM0168: a middle caudal vertebra; LPM0170: a right humerus. The possible association of these specimens to each other or to the holotype cannot be determined.

Etymology: In honor of Swedish paleontologist Carl Wiman, who named the first Chinese dinosaur (*Euhelopus*) in 1929.

Type locality and horizon: Shuangmiao village of Beipiao in Liaoning, China (Fig. 1). Sunjiawan Formation, early Late Cretaceous (Dong, 2002; You et al., 2003).

Diagnosis: *Borealosaurus wimani* is distinguished from all other sauropods in its possession of opisthocoelous mid-distal caudal vertebrae.

Description

(1) Holotype: The holotype of *Borealosaurus wimani*, LPM 0167, is an isolated caudal vertebra from the mid-distal region of the tail (Fig. 2). The centrum has a length larger than height, transversely compressed, and strongly opisthocoelous, with a convex proximal articular condyle approximately 2.5 cm in proximodistal length. The diameter of the proximal face is slightly smaller than that of the distal. There is no longitudinal sulcus on the ventral surface of the centrum. The neural arch is situated on the proximal half of the centrum. The prezygapophyses project proximally, with their extremities extending just beyond the proximal end of the articular condyle. The right

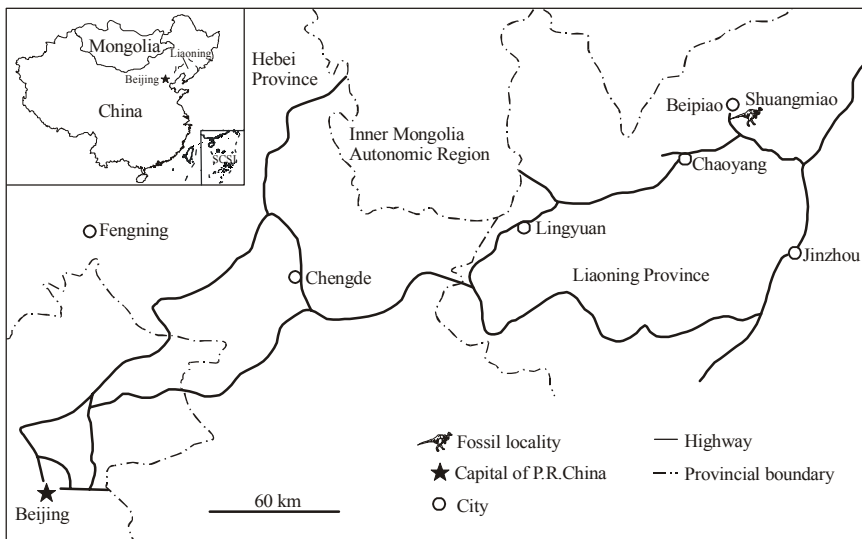


Fig. 1. Type locality of *Borealosaurus wimani*, gen. et sp. nov., in the Shuangmiao village of Beipiao in Liaoning Province, China.

postzygapophysis is well preserved, and protrudes distoventrally without surpassing the distal end of the centrum. The neural spine is oriented more distally than dorsally, and positioned above the distal half of the centrum. The height of the neural arch, from the apex of the neural spine to the dorsal margin of the centrum, is approximately two fifths the height of the centrum.

(2) Referred material

a. Tooth: An isolated apical portion of a tooth crown is preserved (LPM0169; Fig. 3). It is 24 mm long apicobasally. Its basal cross section is cylindrical and measures 9 mm mesiodistally by 7 mm labiolingually. It is unknown whether this tooth is from the upper or lower jaw. The crown is enamelled, except for on the worn lingual surface of its apex. On both the labial and lingual surfaces, the enamel is wrinkled by three or four weak ridges. The labial surface is slightly more convex mesiodistally than the lingual. In lingual view, two shallow grooves run apicobasally. No denticles are present. The tooth narrows apically and is worn. The worn surface is more extensive on the lingual side than on the labial side.

b. Caudal vertebra: Another caudal vertebra (LPM0168; Fig. 4) is preserved. Its neural spine is more elevated than in LPM 0167. Accordingly, LPM 0168 probably represents a more proximally positioned middle caudal. The centrum has a length large than height, possessing a flat proximal and a concave distal surface that is approximately 1.5 cm deep at its center. The diameter of the proximal face is slightly greater than that of the distal. The neural arch is situated on the proximal two-thirds of the centrum. The prezygapophyses project proximally, with their extremities protruding 3 cm beyond the proximal end of the centrum. The postzygapophyses are poorly preserved,

but appear to protrude distoventrally, not beyond the distal end of the centrum. The neural spine is oriented distodorsally and positioned above the distal half of the centrum. The height from the summit of the spine to the dorsal margin of the centrum is nearly equal to the height of the centrum.

c. Humerus: A right humerus is preserved, missing its proximomedial, proximolateral, and extreme distal portions (LPM0170; Fig. 5). It is robust, with a straight shaft and mediolaterally expanded extremities. The element is 62 cm in preserved length, and 27, 11, and 22 cm wide across the proximal end, mid-shaft, and the distal end,

respectively. Approximately 12 cm distal to the proximalmost portion preserved, the relatively long (19 cm) and moderately developed deltopectoral crest runs along the cranioventral margin, becoming increasingly medially positioned and mediolaterally expanded distally. It projects 3 cm cranially. Medial to the deltopectoral crest, the cranial surface of the humerus is shallowly concave and terminates in a ridge delimiting the proximomedial border. The caudal surface of the proximal end is convex. The shaft is elliptical in section, with the long axis of the ellipse oriented mediolaterally. The humeral distal end is less expanded than the proximal. The craniodistal surface is flat, while the caudodistal is deeply concave, bounded by prominent subvertical ridges.

3 Discussion

Recent cladistic analyses of sauropod phylogeny (Salgado et al., 1997; Upchurch, 1998; Wilson and Sereno, 1998; Curry Rogers and Forster, 2001; Wilson, 2002) all support a monophyletic Titanosauriformes, defined as the most recent common ancestor of *Brachiosaurus* and *Saltasaurus* and all of its descendants (Sereno, 1998). Within this clade, Titanosauria is defined as *Andesaurus delgadoi*, *Saltasaurus loricatus*, their most recent common ancestor and all descendants (Wilson and Upchurch, 2003). The titanosaurian subclade Saltosauridae includes *Opisthocoelicaudia skarzynskii*, *Saltasaurus loricatus*, their most recent common ancestor and all of its descendants, while Opisthocoelicaudiinae is defined as all saltosaurids more closely related to *O. skarzynskii* than to *S. loricatus* (Wilson and Upchurch, 2003).

The proximal placement of the neural arch in the

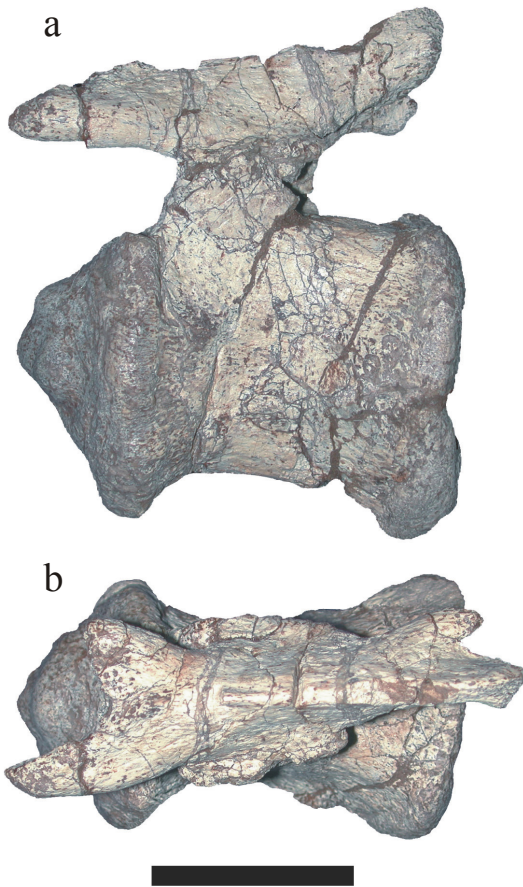


Fig. 2. *Borealosaurus wimani*, gen. et sp. nov.: holotype mid-distal caudal vertebra (LPM 0167) in left lateral (a) and dorsal (b) views. Scale bar equals 5 cm.

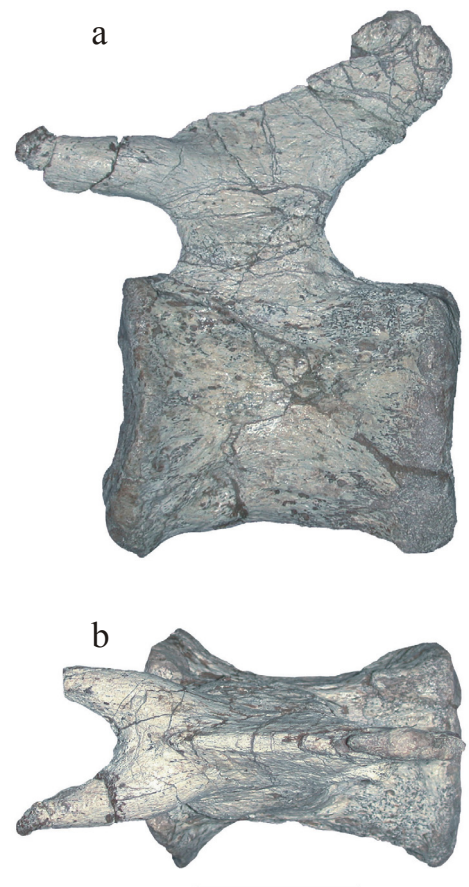


Fig. 4. *Borealosaurus wimani*, gen. et sp. nov.: provisionally referred middle caudal vertebra (LPM 0168) in left lateral (a) and dorsal (b) views. Scale bar equals 5 cm.



Fig. 3. *Borealosaurus wimani*, gen. et sp. nov.: provisionally referred tooth crown (LPM 0169) in labial (a) and lingual (b) views. Scale bar equals 0.5 cm.



Fig. 5. *Borealosaurus wimani*, gen. et sp. nov.: provisionally referred right humerus (LPM 0170) in cranial (a) and caudal (b) views. Scale bar equals 10 cm.

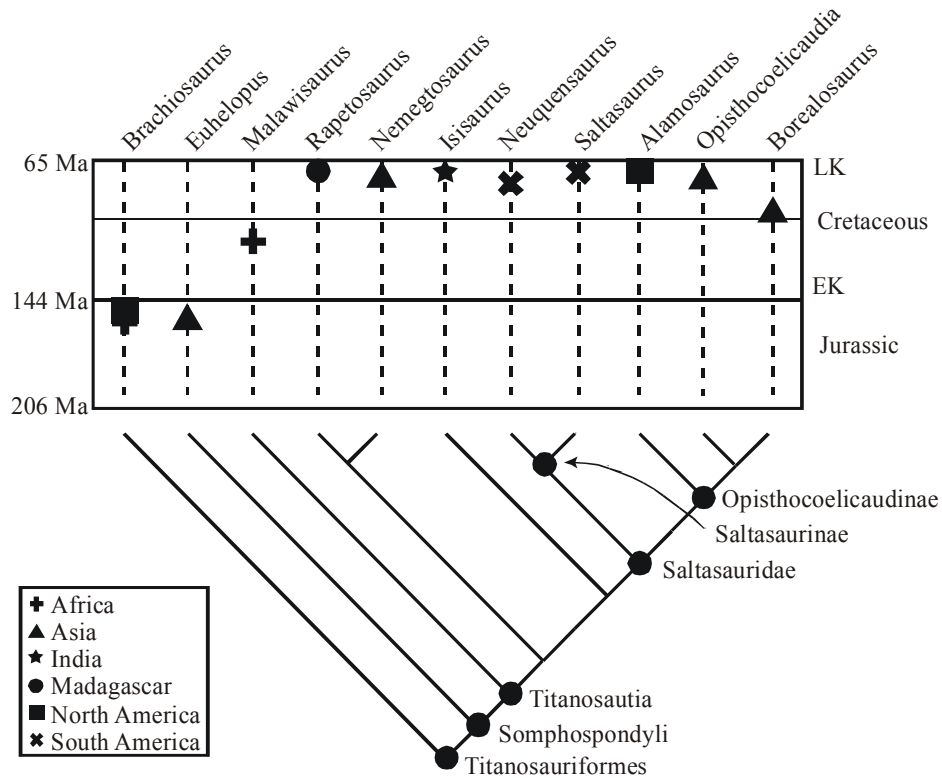


Fig. 6. Hypothesized phylogenetic relationships of *Borealosaurus wimani*, gen. et sp. nov. with geographic and stratigraphic distribution of *Borealosaurus* and selected titanosauriforms. Tree topology modified from Wilson (2002).

holotype mid-distal caudal vertebra indicates that *Borealosaurus* pertains to Titanosauriformes (Salgado et al., 1997; Upchurch, 1998). Moreover, within Sauropoda, opisthocoelous caudals are only known in *Borealosaurus* and the opisthocoelicaudiine titanosaurian *Opisthocoelicaudia* (Borsuk-Bialynicka, 1977). Consequently, we refer *Borealosaurus* to Titanosauria, and within that clade, tentatively to Opisthocoelicaudiinae (Fig. 6).

Material provisionally referred to *Borealosaurus* exhibits characters consistent with titanosaurian relationships. The enamel of the tooth crown is wrinkled, a synapomorphy of Eusauropoda (Wilson, 2002). Because it lacks marginal denticles, this crown is referable to Neosauropoda (Wilson, 2002). Its cylindrical cross section indicates affinities with titanosaurians more derived than *Malawisaurus*, or alternatively with Diplodocoidea (Wilson, 2002). As in the holotype, the proximally placed neural arch of the referred middle caudal permits its referral to Titanosauriformes (Salgado et al., 1997; Upchurch, 1998). The Shuangmiao humerus likely pertains to Titanosauria, and within that clade, possibly to Saltosauridae, as its deltopectoral crest is mediolaterally expanded distally (Wilson, 2002).

Borealosaurus is distinguished from all known

sauropods by its possession of opisthocoelous mid-distal caudals. In the latest Cretaceous Mongolian titanosaurian *Opisthocoelicaudia*, the proximalmost 15 caudals are opisthocoelous, but the middle and mid-distal caudals (numbers 16–27) are amphiplatyan and the distalmost caudals (28–34) are biconvex (Borsuk-Bialynicka, 1977). Opisthocoely in caudal vertebrae is clearly a derived condition within Sauropoda. The distribution of this character, so far identified only in *Borealosaurus* and *Opisthocoelicaudia*, suggests that these two taxa may pertain to an as-yet unrecognized titanosaurian subclade that may have been endemic to the Cretaceous Asian. This intriguing possibility remains to be confirmed by additional evidence.

Interestingly, the middle caudal vertebrae of the newly described Late Cretaceous Chinese sauropod *Huabeisaurus* are amphicoelous, but with the distal cotyle deeper than the proximal (Pang and Cheng, 2000). This character could represent an anatomical precursor to the opisthocoelous condition. Consequently, *Huabeisaurus* may prove to be more closely related to *Borealosaurus* and *Opisthocoelicaudia* than to other sauropods. Further study of *Huabeisaurus* is needed to elucidate its phylogenetic position.

4 Conclusions

A new titanosaurian sauropod dinosaur, *Borealosaurus wimani* gen. et sp. nov., is described from the early Late Cretaceous Sunjiawan Formation of Liaoning, China. It is based on a distinctive, opisthocoelous mid-distal caudal vertebra, and a tentatively referred tooth crown, caudal vertebra, and a right humerus. *Borealosaurus* is distinguished from other sauropods in its possession of opisthocoelous mid-distal caudal vertebrae. The presence of opisthocoelous caudals in *Borealosaurus* and *Opisthocoelicaudia* may indicate that both genera pertain to an as-yet unrecognized titanosaurian subclade endemic to the Cretaceous Asian.

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