A New Basal Titanosaur (Dinosauria: Sauropoda) from the Early Cretaceous of China

YOU Hailu [1,2], TANG Feng [1,2] and LUO Zhexi [3]

1 *Institute of Geology, Chinese Academy of Geological Sciences, 26 Baiwanzhuang Road, Beijing 100037; E-mail: youhailu@sinofossa.org*

2 *Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences, 142 Xiwaidajie, Beijing 100044*

3 *Section of Vertebrate Paleontology, Carnegie Museum of Natural History, Pittsburgh, PA 15213, USA*

Abstract   A new dinosaur of Early Cretaceous age was recently discovered from the Mazongshan area of northwestern Gansu Province, China. The new dinosaur represents a new genus and species of Sauropoda, and is among the most basal members of Titanosauria. Its finding also suggests that titanosaurs might have originated in Asia no later than the Early Cretaceous.

1 Introduction

In 1997, the Sino-American Horse Mane Mountain (Ma-Zong-Shan) Dinosaur Project, consisting of personnel from the Carnegie Museum of Natural History, the University of Pennsylvania, and the Institute of Vertebrate Paleontology and Paleoanthropology (IVPP) of the Chinese Academy of Sciences, explored the late Early Cretaceous vertebrate fossil remains in the Mazongshan area, Gansu Province, northwestern China (Tang et al., 2001b). Here we describe a new sauropod from this region, *Gobititan shenzhouensis* gen. et sp. nov., excavated in the summer of 1999.

Gobititan shares the following derived characters with Titanosauriformes: proximal placement of the neural arch on the centrum, proximally protruding prezygapophyses, and low neural spines on the middle caudal vertebrae; and simple, undivided middle and caudal chevron blades that curve backward and downward. *Gobititan* lacks the diagnostic features of derived titanosaurs, such as a small caudal vertebral count (fewer than 35) and a long haemal canal (approximately half the length of chevron length).

2 Systematic Paleontology

Dinosauria Owen, 1842

   Sauropoda Marsh, 1878

      Titanosauriformes Salgado, Coria, and Calvo, 1997

         Titanosauria Bonaparte and Coria, 1993

            Gobititan shenzhouensis gen. et sp. nov.

Holotype: IVPP 12579, an articulated series of 41 middle and distal caudals and a left hind limb.

Etymology: "Gobi" is the geographical region in Mongolia and Inner Mongolia where diverse Late Mesozoic dinosaurs have been found. "Titan" refers to Greek mythological giants, symbolic of great size. "Shenzhou" is an ancient name of China.

Locality and horizon: Gongpoquan Basin, Mazongshan area, Gansu Province, China. Middle Gray Unit of the Xinminbao Group. Upper Lower Cretaceous (Albian) (Tang et al., 2001b).

Diagnosis: Basal member of Titanosauria distinguished from other titanosaurs in having higher proximal than distal centrum articular faces in middle caudals, distal placement of neural arches on most proximal distal caudals, and relatively short and rod-like distalmost caudals.

Description

Caudal vertebrae: A series of 41 articulated middle and distal caudal vertebrae are preserved, with a combined length of 320 cm. The neural arches and spines on most caudals are intact. Five chevrons are associated with the first six preserved caudals.

In most sauropods for which relatively complete tails are known, the centra of the most proximal caudals have a height greater than the length. Distally, the height of each centrum decreases relative to its length. Usually, the centrum length equals its height in caudals 10 to 15 (Gilmore, 1936; Young and Chao, 1972; He et al., 1988;

Zhang, 1988; McIntosh et al., 1996). The centrum of the first available caudal vertebra in *Gobititan* has about the same height as its length; therefore, the total caudal vertebral number of *Gobititan shenzhouensis* is between 50 and 55. To simplify discussion, the first caudal vertebrae is designated as caudal 13, with the total number of 53 in this series.

The first five preserved caudals, corresponding to caudals 13–17, are similar in shape (Fig. 1A, J). Their centra are slightly amphicoelous proximally and distally, and constricted at midlength. The diameter of the proximal face is slightly larger than that of the distal end. The neural arches are situated in the middle of the centra. The prezygapophyses project proximodorsally, with their extremities protruding slightly beyond the proximal end of the centrum. The postzygapophyses appear to protrude distoventrally and beyond the distal end of the centrum. The neural spines of these first five caudals are tall and oriented distodorsally, with half of their lengths overhanging the distal margin of their respective centra. The height from the tip of each spine to the dorsal margin of its associated centrum is about the same as the height of the centrum.

The lengths of the centra of caudals 13 to 17 are roughly equal; however, the diameters of these centra and the heights of the neural spines decrease progressively caudally. Caudals 18–20 are fused together; their neural arches and spines are crushed. In the next caudal, 21 (Fig. 1B, K), the height of the neural spine is reduced to approximately 50% of the neural spine of caudal 15. The prezygapophysis extends well beyond the proximal end of its centrum. The postzygapophysis is short, does not reach the distal one-third of the centrum, and does not project distally.

Further distally, caudals 22 to 32 gradually reduce both heights and lengths of the centra, and their neural spine elevations become lower. In caudal 28 and beyond, the neural spine is reduced to almost nothing (Fig. 1C, L). The basal part of the neural arch in caudal 28 occupies the proximal two-thirds of the dorsal surface of the centrum. The prezygapophysis protrudes about 1.5 cm beyond the proximal centrum margin to articulate with the postzygapophysis of the previous caudal. These characteristics are the same through caudal 32, where abrupt morphological changes occur, marking the beginning of the distal portion of the tail.

The distal face of caudal 33 is slightly convex (Fig. 1D, M), unlike the slightly amphicoelous or amphiplatyan centra of the middle caudals (22–32). Although its neural arch is placed entirely on the proximal half of the centrum, the prezygapophysis is flush with the proximal margin of the centrum, therefore losing the zygapophyseal

articulation with the adjacent, more proximal caudal. The dorsal margin of its neural arch bends slightly ventrally, rather than dorsally as in the middle caudals. The following two caudals (34–35) are fused. Caudal 34 is compressed proximodistally (Fig. 1E, N), probably a pathological condition. The centrum of caudal 35 (Fig. 1F, O), shows a strong tapering: the diameter of its distal articular face is only about three-quarters that of its proximal face. The distal face is clearly convex. In ventral view, the centrum tapers to a small ball distally.

The next five caudals (36–40) show progressive reduction in size (Fig. 1G, P). Their distal central faces are convex, while the proximal faces are flat. The neural arches are rudimentary and located on the distal halves of their respective centra, in contrast to the more proximal placement of the neural arches in the more proximal caudals (13–32).

Beginning with caudal 41, the centra become rod-like and display some peculiar features. The centra are neither amphiplatyan, as in those of *Camarasaurus* (McIntosh et al., 1996), nor biconvex, as in those of diplodocoid or titanosaur sauropods (Wilson et al., 1999), but something intermediate between these morphologies. The centers of both proximal and distal faces of the centra have small condyles. The dorsal part of the proximal and distal surface has a pit or concavity (Fig. 1H).

Only the distal half of the last caudal vertebra (53) is preserved (Fig. 1I). The surface texture is rugose. It is not rod-like, but flat (although it is hard to assess whether it is flat vertically or horizontally). In neither the field nor the preparation lab was there evidence of subsequent caudals. Therefore, this may be the terminal element.

Five chevrons that house a relatively short haemal canal are preserved along with the first six caudals. Their proximal ends are not bridged and the distal ends are not forked. In contrast, the chevrons are bridged in *Apatosaurus* and *Mamenchisaurus*, while those of the middle caudals are forked in *Apatosaurus*, *Mamenchisaurus*, and *Shunosaurus*.

Hind limb: A complete left hind limb, lacking only the proximal half of the femur, is preserved (Fig. 2). The distal half of the femur possesses a well-developed medial condyle that is larger than the lateral one. It projects medially and is offset from the shaft of the femur. Well-defined notches separate the condyles on both the cranial and caudal faces.

The complete tibia and fibula are preserved, together with the astragalus. The tibia is much stouter than the fibula, with transversely well-expanded ends. The cnemial crest is prominent, cradling the proximal end of the fibula. The distal end of the tibia is beveled dorsomedially to articulate with the underlying astragalus. The fibula is
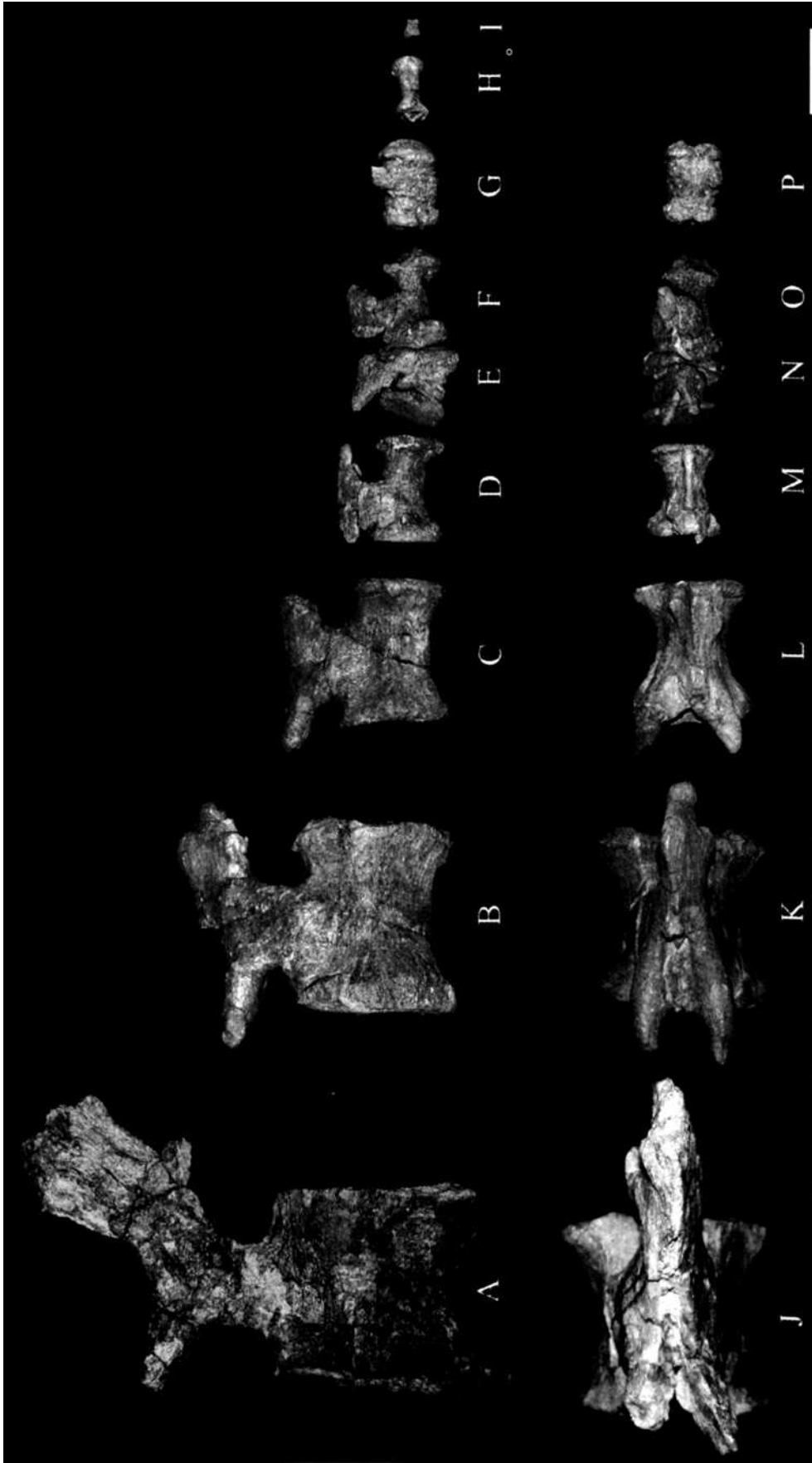
Fig. 1. Caudals 15(A, J), 21(B, K), 28(C, L), 33(D, M), 34(E, N), 35(F, O), 37(G, P), 42(H), and 53(I) of *Gobititan shenzhouensis* gen. et sp. nov in left lateral (A-I) and dorsal (J-P) views (numbers refer to the most likely positions in the caudal series as discussed in text). Scale bar: 5 cm.
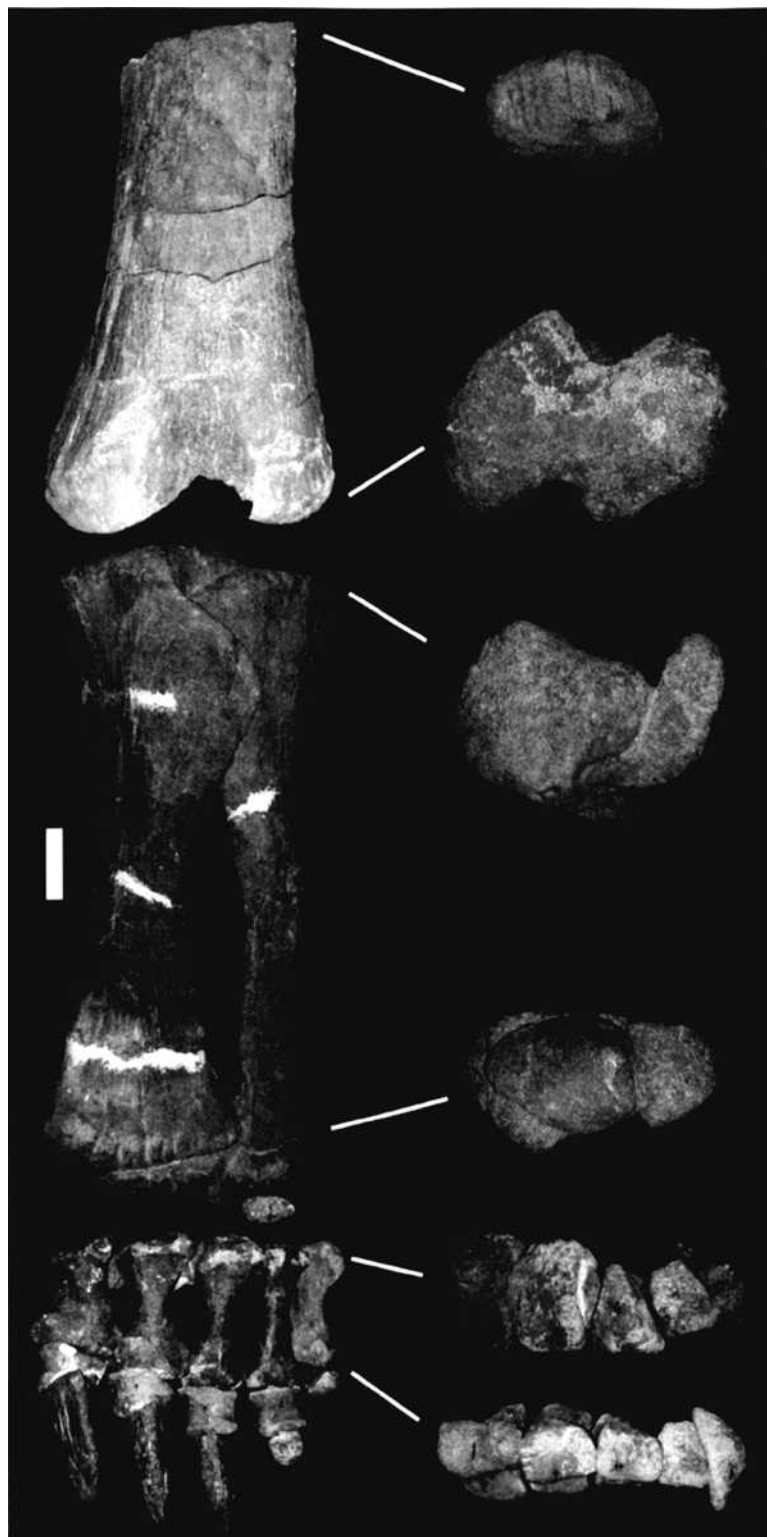
Fig. 2. Left hind limb of *Gobititan shenzhouensis* gen. et sp. nov in anterior and terminal views.

Scale bar: 10 cm.

distal end of the tibia and has only a small contact with the dorsolateral corner of the astragalus.

The astragalus is firmly articulated with the tibia and fibula. It is triangular in cranial view, with a horizontal edge covered by the distal end of the tibia. The upper half of the short lateral margin is covered by the medial surface of the portion of the fibula that projects distal to the tibia. Caudally, only the lateral portion of the astragalus is visible, which is well inserted into the tibia and the fibula. The calcaneum is a small element and situated underneath the fibula, but it does not contact the surrounding bones. It is round in dorsal view, and relatively flat dorsoventrally. Its surface is rugose.

A complete left pes is preserved. The five metatarsals are arranged relatively straight transversely, with a slight backward curvature. Among the five metatarsals, metatarsal I is the shortest, slightly shorter than metatarsal V, while metatarsal III is the longest, slightly longer than II and IV. Metatarsal I is the stoutest, and the maximum transverse widths of subsequent metatarsals reduce gradually from II to V. In dorsal view, the proximal end of metatarsal I is narrow mediolaterally than the distal end, and the medial edge is shorter than the lateral edge proximodistally. The distal condyle of metatarsal II projects both medially and laterally. As in metatarsal I, the proximal surface of metatarsal II is much larger than its distal surface. In metatarsals III and IV, the proximal surface is only slightly wider than the distal surface, and the shaft is slender. Metatarsal V possesses an extremely craniocaudally broadened, fan-shaped proximal end, and a much reduced distal end. Its transverse width is the smallest among all five metatarsals.

The phalangeal formula is 2-2-2-2-2, with claws on digits I to III. The first phalanges of digits I and II are subrectangular in the dorsal view, with the lateral shorter than the medial edges, inducing the slight outward orientation of the claws. The size of the claws decreases from digit I to III. In all three claws, the surface is rugose, and a small notch on the caudal edge extends two-thirds the distance to the proximal end. The first phalanx of digit IV is similar in shape to that of the first three digits, but looks

slender and slightly longer than the tibia. Its proximal end is transversely broadened. Its shaft is relatively straight, with a muscle scar on the craniomedial surface at the midshaft. The distal end is slightly enlarged and extends beyond the

more square-shaped in dorsal view. The second and last phalanx of digit IV is small with a relatively straight proximal edge and round distal margin. The first phalanx of digit V is tiny and irregular in shape; it does not project beyond the level of distal end of metatarsal IV. The second and last phalanx of digit V is the smallest among all phalanges, and tightly covers the distal surface of the first phalanx, with a round and smooth distal surface.

3 Discussion

Recent cladistic analyses of sauropod phylogeny (Salgado et al., 1997; Upchurch, 1998; Wilson and Sereno, 1998; Wilson, 1999; Curry Rogers and Foster, 2001) all support a well-defined Titanosauriformes, defined as the most recent common ancestor of *Brachiosaurus* and *Saltasaurus*, and all of its descendents. Comparable derived features in the middle and distal caudals and hind limb include: 1) proximally positioned neural arches in the middle caudals (Salgado et al., 1997; Upchurch, 1998); 2) simple and undivided chevron blades (Wilson, 1999; Rogers and Foster, 2001); 3) backward and downward curved middle and distal chevron blades (Curry Rogers and Foster, 2001). The existence of all these characters in *Gobititan* confirms that it is nested within the Titanosauriformes.

Among the Titanosauriformes, derived titanosaurs (Saltasauridae, Wilson, 1999) are characterized by procoelous middle and distal caudal centra, biconvex distal caudal centra, and a deep haemal canal. *Gobititan* lacks all these features, and is therefore precluded from membership in a derived titanosaur clade. This leads to four possible positions for *Gobititan*: a taxon on the *Brachiosaurus* branch, a sister taxon to Somphospondyli, a sister taxon to *Euhelopus*, or a basal member of Titanosauria (a stem-based definition of titanosauriforms more closely related to *Saltasaurus* than to either *Brachiosaurus* or *Euhelopus*, Wilson and Sereno, 1998). However, few diagnostic features in the limited comparable anatomical parts (middle and distal caudals and hind limb) make it difficult to explore the specific phylogenetic position of *Gobititan*.

Euhelopus (Wiman, 1929) was found to have a closer relationship to Titanosauria than to Brachiosauridae by Wilson and Sereno (1998), forming the phylogenetic basis of Somphospondyli. No tail is known for *Euhelopus*, and the comparable hind limb elements of *Euhelopus* and *Gobititan* display several obvious differences. The hind limb of *Euhelopus* is relatively more slender than that of *Gobititan*. This is clearly shown by the relatively transversely expanded proximal and distal ends of the tibia in *Gobititan*. Metatarsal I of *Euhelopus* lacks the distolateral process that exists in *Gobititan*. Digit 1 of *Euhelopus* has only one phalanx, the claw, which is smaller

than that of digit 2, and has a round rather than pointed shape. In contrast, digit 1 of *Gobititan* has two phalanges, including the large and pointed claw. Therefore, a close relationship between *Gobititan* and *Euhelopus* is precluded. Also, no synapomorphies are currently diagnosed in either the caudal vertebrae or the hind limb of Somphospondyli (Wilson and Sereno, 1998; Wilson, 1999), and it is therefore impossible to assess the relationship between *Gobititan* and this group.

Brachiosauridae is a poorly defined clade, with few synapomorphies, especially in the caudal vertebrae (Tidwell et al., 1999; Wedel et al., 2000). The recently discovered, North American, late Early Cretaceous *Cedarosaurus* (Tidwell et al., 1999) provides valuable information for comparison. The distal caudals in *Cedarosaurus* have higher neural spines than those of *Gobititan*, and they possess an elongate ridge along the sides of each neural arch that does not exist in *Gobititan*. The tibia of *Cedarosaurus* does not expand transversely as in *Gobititan*. The phalanges of *Cedarosaurus* are relatively more slender than those of *Gobititan*.

There are several basal, Early Cretaceous titanosaurs, including the African *Malawisaurus* (Jacobs et al., 1993; Gomani, 1999), South American *Andesaurus* (Calvo and Bonaparte, 1991), and Asian *Phuwiangosaurus* (Martin et al., 1994, 1999), *Tangvayosaurus* (Allain et al., 1999), and *Jiangshanosaurus* (Tang et al., 2001a). In *Malawisaurus*, the middle caudals are slightly procoelous with strongly proximally extended prezygapophyses; these derived titanosaur characters do not occur in *Gobititan*. The haemal canal of *Andesaurus* is very deep, again a derived titanosaur feature not found in *Gobititan*. The femur of *Phuwiangosaurus* is more slender (robust in titanosaurs) than that of *Gobititan*, with a less pronounced distomedial process. The proximal ends of both the tibia and fibula in *Phuwiangosaurus* do not expand transversely as in *Gobititan*. The general shape of the femur and tibia of *Tangvayosaurus* is more similar to that of *Gobititan* than to *Phuwiangosaurus*. However, the proximal end of the fibula in *Tangvayosaurus* is not as expanded transversely as in *Gobititan*, and the middle caudal centrum has a distal higher than proximal articular face, which is opposite to the state in *Gobititan*. Only two possible middle caudals of *Jiangshanosaurus* are comparable to *Gobititan*, and the characteristic higher proximal than the distal centrum articular faces in middle caudals of *Gobititan* does not exist in *Jiangshanosaurus*. Therefore, *Gobititan* is probably a basal titanosaur less derived than *Malawisaurus* and *Andesaurus*, more derived than *Phuwiangosaurus*, and closely related to *Tangvayosaurus*.

Because the three very basal titanosaurs are currently known from the Early Cretaceous of Asia, an Asian origin

for the Titanosauria is possible. This is further enhanced when the Early Cretaceous *Euhelopus* is perceived as its sister group (Wilson and Sereno, 1998).

4 Conclusions

A new sauropod dinosaur, *Gobititan shenzhouensis* gen. et sp. nov., was discovered from the Early Cretaceous of the Mazongshan area, northwestern Gansu Province, China. It is represented by an articulated series of 41 middle and distal caudals and a left hind limb. Comparison with other related dinosaurs shows that *Gobititan* is a basal titanosaur, and indicates an Asian origination for Titanosauria.

Acknowledgements

References

Allain, R., Taquet, P., Battail, B., Dejax, J., Richir, P., Véran, M., Linon-Duparcmeur, F., Vacant, R., Mateus, O., Sayarath, P., Khenthavong, B., and Phouyavong, S., 1999. Un nouveau genre de dinosaure sauropode de la formation des Grès supérieurs (Aptien-Albien) du Laos. *Comptes Rendus de l'Académie des Sciences de Paris, Sciences de la Terres et des Planètes*, 329: 609–616.

Calvo, J. O., and Bonaparte, J. F., 1991. *Andesaurus delgadoi* gen. et sp. nov. (Saurischia-Sauropoda), dinosaurio Titanosauridae de la Formación Río Limay (Albiano-Cenomaniano), Neuquén, Argentina. *Ameghiniana*, 28(3–4): 303–310.

Curry Rogers, K., and Forster, C. A., 2001. The last of the dinosaur titans: a new sauropod from Madagascar. *Nature*, 412: 530–534.

Gilmore, C. W., 1936. Osteology of *Apatosaurus*, with special reference to specimens in the Carnegie Museum. *Memoirs of the Carnegie Museum of Natural History*, 11: 175–300.

Gomani, E. M., 1999. Sauropod caudal vertebrae from Malawi, Africa. In: Tomida, Y., Rich, T. H., and Vickers-Rich, P. (eds), *Proceedings of the Second Gondwanan Dinosaur Symposium, National Science Museum Monographs*. National Science Museum of Tokyo, Tokyo, 235–248.

He Xinlu, Li Kui and Cai Kaiji, 1988. *The Middle Jurassic dinosaur fauna from Dashanpu, Zigong, Sichuan: sauropod dinosaurs (2) Omeisaurus tianfuensis*. Chengdu: Sichuan Publishing House of Science and Technology, 143 (in Chinese with English abstract).

Jacobs, L. L., Winkler, D. A., Downs, W. R., and Gomani, E. M., 1993. New material of an Early Cretaceous sauropod dinosaur from Africa. *Palaeontology*, 36(3): 523–534.

Martin, V., Buffetaut, E., and Suteethorn, V., 1994. A new genus of sauropod dinosaur from the Sao Khua Formation (Late Jurassic or Early Cretaceous) of northeastern Thailand. *Comptes Rendus de l'Academie des Sciences de Paris*, Série II, 319: 1085–1092.

Martin, V., Suteethorn, V., and Buffetaut, E., 1999. Description of the type and referred material of *Phuwiangosaurus sirindhornae* Martin, Buffetaut and Suteethorn, 1994, a sauropod from the Lower Cretaceous of Thailand. *Oryctos*, 2: 39–91.

McIntosh, J., Miles, C. A., Cloward, K. C., and Parker, J., 1996. A new nearly complete skeleton of *Camarasaurus*. *Bulletin of Gunma Museum of Natural History*, 1: 1–87.

Salgado, L., Coria, R. A., and Calvo, J. O. 1997. Evolution of titanosaurid sauropods: I: phylogenetic analysis based on the postcranial evidence. *Armeghiniana*, 34(1): 3–32.

Tang Feng, Kang Ximin, Jin Xingsheng, Wei Feng and Wu Weitang, 2001a. A new sauropod dinosaur of Cretaceous from Jiangshan, Zhejiang Privince. *Vertebrata PalAsiatica*, 39(4): 272–281.

Tang, F., Z-X. Luo, Z-H. Zhou, H-L. You, J. A. Georgi, Z-L. Tang and X-Z. Wang, 2001b. Biostratigraphy and paleoenvironment of the dinosaur-bearing sediments in Lower Cretaceous of Mazongshan area, Gansu Province, China. *Cretaceous Research*, 22: 115–129.

Tidwell, V., Carpenter, K., and Brooks, W., 1999. New sauropod from the Lower Cretaceous of Utah, USA. *Oryctos*, 2: 21–37.

Upchurch, P., 1998. The phylogenetic relationships of sauropod dinosaurs. *Zoological Journal of the Linnaean Society*, 124: 43–103.

Wedel, M. J., Cifelli, R. L., and Sanders, R. K., 2000. Osteology, paleobiology, and relationships of the sauropod dinosaur *Sauroposeidon*. *Acta Palaeontologica Polonica*, 45(4): 343–388.

Wilson, J. A., 1999. *The evolution and phylogeny of sauropod dinosaurs*. Ph. D. dissertation, University of Chicago, 384.

Wilson, J. A., and Sereno, P. C., 1998. Early evolution and higher-level phylogeny of sauropod dinosaurs. *Society of Vertebrate Paleontology Memoir*, 5: 1–68.

Wilson, J. A., Martinez, R. N., and Alcober, O., 1999. Distal tail segment of a titanosaur (Dinosauria: Sauropoda) from the Upper Cretaceous of Mendoza, Argentina. *Journal of Vertebrate Paleontology*, 19(3): 591–594.

Wiman, C., 1929. Die Kreide-Dinosaurier aus Shantung. *Paleontologia Sinica*, Series C, 6: 1–67.

Young, C. C., and Chao Xijin, 1972. *Mamenchisaurus hochuanensis*. *Institute of Vertebrate Paleontology and Paleoanthropology Monograph*, Series A, (8): 1–30 (in Chinese).

Zhang Yihong, 1988. *The Middle Jurassic dinosaur fauna from Dashanpu, Zigong, Sichuan: sauropod dinosaurs (1) Shunosaurus*. Chengdu: Sichuan Publishing House of Science and Technology, 89 (in Chinese with English abstract).