A new juvenile sauropod specimen from the Middle Jurassic Dongdaqiao Formation of East Tibet (#77124)

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A new juvenile sauropod specimen from the Middle Jurassic Dongdaqiao Formation of East Tibet

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Jurassic strata are widely distributed in the eastern part of the Tibet Autonomous Region, and have yielded many dinosaur bones. However, none of these specimens have been studied extensively, and some remain unprepared. Here we give a detailed description of some new sauropod material, including several cervical vertebrae and a nearly complete scapula, recovered from the Middle Jurassic of Chaya County, East Tibet. The new sauropod bones include cervical vertebrae with short centra that bear ventral midline keels, as in other basal eusauropods such as *Shunosaurus*. Moreover, the cervical centra each display deep lateral excavations, separated by a septum. Also present is a large scapula, with proximal and distal ends that are both expanded as in mamenchisaurids and neosauropods. However, relatively small body size and lack of fusion of neurocentral sutures suggest that the available material is from a juvenile, and the length of the cervical centra may have increased relative to the size of the rest of the skeleton in later ontogenetic stages. The new Tibet sauropod specimens provide important information on the morphological transition between *Shunosaurus* and mamenchisaurids, and extend the known biogeographic range of basal sauropods in the Middle Jurassic of East Asia.

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Abstract

Jurassic strata are widely distributed in the eastern part of the Tibet Autonomous Region, and have yielded many dinosaur bones. However, none of these specimens have been studied extensively, and some remain unprepared. Here we give a detailed description of some new sauropod material, including several cervical vertebrae and a nearly complete scapula, recovered from the Middle Jurassic of Chaya County, East Tibet. The new sauropod bones include cervical vertebrae with short centra that bear ventral midline keels, as in other basal eusauropods such as *Shunosaurus*. Moreover, the cervical centra each display deep lateral excavations, separated by a septum. Also present is a large scapula, with proximal and distal ends that are both expanded as in mamenchisaurids and neosauropods. However, relatively small body size and lack of fusion of neurocentral sutures suggest that the available material is from a juvenile, and the length of the cervical centra may have increased relative to the size of the rest of the skeleton in later ontogenetic stages. The new Tibet sauropod specimens provide important information on the morphological transition between *Shunosaurus* and mamenchisaurids, and extend the known biogeographic range of basal sauropods in the Middle Jurassic of East Asia.

Introduction

In Tibet, the highest-altitude region in the world, a series of Jurassic-Cretaceous strata are exposed in the eastern part of Changdu (Qamdo) Prefecture. In the 1970s, the Scientific Expedition Team of the Chinese Academy of Sciences discovered many Early-Middle Jurassic dinosaur bones in this area, representing at least ten species and including sauropodomorph, theropod, stegosaur, and basal ornithischian remains (Zhao 1985; An et al. 2021). Almost all these specimens are still unpublished, the sole exception being the partial, medium-sized stegosaur skeleton, comprising the iliosacral region together with two incomplete vertebrae and three dermal plates, that was made the holotype of *Monkonosaurus lawulacus* (Zhao 1983; Dong 1990). However, this species is probably a *nomen dubium* (Maidment & Wei 2006). Some sauropod dinosaur trackways were also reported in the Jurassic of Changdu and at least 10 track sites have been discovered (Xing et al. 2011; Xing et al. 2021). The wide tracks suggest that large sauropods lived in the Early-Middle Jurassic of this area and may have been closely related to the very abundant sauropods from the Jurassic of the Sichuan Basin, of which about 30 species have been established. Three distinct Jurassic sauropod faunas have been defined within the Sichuan Basin, namely the Early Jurassic *Zizhongosaurus* Fauna, the Middle Jurassic *Shunosaurus*-*Omeisaurus* Fauna and the Late Jurassic *Mamenchisaurus* Fauna (Li 1998).

In 2019, the field team of the Chengdu Center of the China Geological Survey discovered some new dinosaur fossil sites in Chaya County, Changdu District, Tibet, and collected and prepared some sauropod bones (An et al. 2021). Here we give a detailed description of this material, which has significant implications for understanding the evolution and diversity of early sauropods in the Jurassic of East Asia.

Materials & Methods

The sauropod specimens described in this paper are postcranial elements, and are housed at the Chengdu Center of the China Geological Survey (CGS V001). They include four cervical vertebrae and a nearly complete scapula. All these bones were found together within a small area, but none were preserved in articulation. Field experiments were approved by Chengdu Geological Survey Center (project number: DD20190053). Measurements of the bones are given in Table 1.

Institutional abbreviations. CLGPR, Chongqing Laboratory of Geoheritage Protection and Research; **LM**, Lingwu Museum; **ZDM,** Zigong Museum; **MCDUT,** Museum of Chengdu University of Technology.

Geological setting

The specimens described in this paper were discovered in Qamdo District, about 10 km from urban center of Chaya County. Jurassic strata form an extensively exposed succession in the Qamdo Basin, and mainly comprise lacustrine deposits. The Jurassic strata of the Qamdo Basin include the Lower Jurassic Wangbu Formation, the Middle Jurassic Dongdaqiao Formation, and the Upper Jurassic Xiaosuoka Formation. The new specimens are from the Dongdaqiao Formation, which is about 1.2 km thick and mainly consists of purple red feldspar and quartz-bearing sandstones and siltstones. The dinosaur bones were recovered from red argillaceous siltstone in the middle part of the formation, within a thickness of about 5 m (Fig. 1). The Dongdaqiao Formation has generally been considered to date from the Middle Jurassic, based on its bivalve assemblage (Wang & Chen 2005).

Results

Systematic paleontology

Saurischia Seeley, 1887
Sauropodomorpha Huene, 1932
Sauropoda Marsh, 1878
Eusauropoda Upchurch 1995

Description.
Four isolated cervical vertebrae, including an axis, have been prepared. The centra are relatively short, with ratios of length to posterior articular surface height of 1.6-2.0. The equivalent ratio is similar in *Shunosaurus* (1.7-2.3) (Zhang 1988), but larger in the mamenchisaurids *Analong* (2.2-2.6) (Ren et al. 2021) and *Omeisaurus tianfuensis* (2.9-3.9) (He et al. 1988). The lateral surfaces of the three postaxial cervical centra bear pleurocoels that partitioned by anterodorsally-trending ridges, as in mamenchisaurids and neosauropods (Wilson 2002). A ventral midline keel is present on the anterior part of each centrum as in the cervical vertebrae of many basal sauropods, such as *Shunosaurus* (Zhang 1988), *Tazoudasaurus* (Allain & Aquesbi 2008) and *Omeisaurus* (He et al. 1988).

Axis. The axis is nearly complete, and is well preserved (Fig. 2), with a length of 12.6 cm. The anterior surface of the centrum is rugose, and bears deep grooves (Fig. 2C). The odontoid process is not preserved. The ventral part of the anterior part of the centrum contacts, and is fused with, the axial intercentrum (**ic**) (Fig. 2A). The latter is a small, irregular bone with a crescentic outline in anterior view (Fig. 2C). The anterior surface of the axis is rugose with dorsoventral grooves, and is tilted to face somewhat dorsally. The ventral surface is smooth and curved dorsally.

The centrum of the axis is relatively elongate (length to posterior height ratio of 1.9), and transversely compressed. In anterior view, the centrum is taller than wide (Fig. 2C). The posterior surface of the centrum is strongly concave, to accommodate the anterior condyle of the third cervical centrum, and has a subcircular outline with equal width and height. The lateral surface of the centrum bears a shallow, elongate fossa with poorly defined margins and no external pneumatic openings, as in the basal sauropod *Shunosaurus* (Zhang 1988), whereas the corresponding fossa is deeper in more derived sauropods such as *Omeisaurus* and *Euhelopus* (He et al. 1988; Wilson & Upchurch 2009). The fossa is deepest at the anterior end, and gradually becomes shallower posteriorly. The fossa is undivided, as in *Shunosaurus* (Zhang 1988), *Mamenchisaurus* (Yang & Dong 1972) and *Xinjiangtitan* (Zhang et al. 2020), whereas the lateral fossa on the axis is partitioned by a ridge in *Omeisaurus* (He et al. 1988) and more derived sauropods. The parapophysis, positioned on the anterior margin of the centrum, is a weakly developed structure that takes the form of a convex ridge (Fig. 2A and 2C).

The posterior half of the ventral surface has a gentle transverse convexity. A prominent midline keel is present on the anterior half of the centrum, separating the ventral surface into two shallow depressions (Fig. 2E). A similar condition is present in *Shunosaurus* (Zhang 1988) and the late Early Jurassic *Tazoudasaurus* from Morocco (Allain & Aquesbi 2008), but the ventral surface of the anterior part of the axial centrum is smooth in *Mamenchisaurus* (Yang & Dong 1972). In the mamenchisaurid *Xinjiangtitan*, the anterior part of the ventral surface of the axial centrum lacks a keel but bears paired fossae whose outer margins are defined by ventrolateral ridges (Zhang et al. 2020).

The neural arch is well developed and is similar in height to the centrum in the mid-region of the vertebra. Two shallow fossae are present on the lateral surface of the neural arch, as in the mamenchisaurids *Mamenchisaurus hochuanensis* (Yang & Dong 1972) and *Xinjiangtitan shanshanensis*. Both diapophyses are largely broken away, but the bases of these structures are anteroposteriorly elongate and located anteroventrally on the neural arch, just above the neurocentral suture (Fig. 2B). No posterior centrodiapophyseal lamina is observable. The anterior opening of the neural canal is large, and taller than wide (Fig. 2C), whereas the posterior opening is relatively small and subcircular, with equal width and height (Fig. 2F).

The prezygapophyses are not preserved. The postzygapophyses are large, and extend posterolaterally beyond the posterior part of the centrum. The postzygodiapophyseal lamina (**podl**) forms a weak ridge extending posterodorsally at an angle of about 30° above the horizontal. A large spinopostzygapophyseal fossa (**spof**) is present between the postzygapophyses (Fig. 2F), as in *Xinjiangtitan* (Zhang et al. 2020). The postzygapophyseal articular facets face ventrally, and elliptical in outline. The long axis of the facet diverges at 45° from that of the centrum. A prominent epipophysis is clearly present on the dorsal surface of the postzygapophysis (Fig. 2A, 2B, and 2F). it is thickened the dorsal region of the postzygapophysis, but seprates the latter by a shallow groove.

The neural spine is weakly developed. The anterior part of the spine is transversely narrow, but a robust ridge runs along the dorsal margin of this portion of the spine and is thick enough to slightly overhang a deep, distinct fossa situated on the spine's lateral surface. The height of the neural spine gradually increases posteriorly, reaching a maximum slightly posterior to the midpoint of the centrum as in *Shunosaurus* (Zhang 1988) and *Mamenchisaurus* (Yang & Dong 1972). In *Tazoudasaurus*, by contrast, the apex of the neural spine is near the posterior margin of the centrum (Allain & Aquesbi 2008). The spinopostzygapophyseal lamina (**spol**) is straight and robust, and trends ventrolaterally.

Postaxial cervical vertebrae. A nearly complete cervical vertebra (CGS V001-2) is well preserved, except that the anterior left half and posterior portion of the neural arch is missing, and the left half of the posterior portion of the centrum were broken away (Fig. 3). The cervical centrum is strongly opisthocoelous, with a prominent hemispherical anterior condyle. The centrum is about 196 mm long, and the ratio of centrum length to posterior centrum height is about 1.9. The posterior articular surface is tilted to face partly ventrally, rather than being perpendicular to the long axis of the centrum. The parapophyses are missing, owing to damage to the anteroventral part of the centrum. The relatively modest height of the preserved neural arch suggests that this vertebra may be from the anterior part of the cervical series.

The lateral surface of the centrum is strongly excavated by a long depression. A thin, sharp, anterodorsally-trending septum (**plr**) divided the depressed area into two deep pleurocoels (Fig. 3A and 3B). The anterior pleurocoel extends into the centrum in all directions, except posteriorly. The external opening of the anterior pleurocoel is elliptical and anteroposteriorly elongate, whereas the posterior fossa is relatively shallow and subrounded. The ventral surface of the centrum is strongly concave anteroposteriorly, and slightly concave transversely. The anterior part of the ventral surface bears two shallow fossae, which are separated by a sharp midline keel.

On the right side of the neural arch, the distal end of the diapophysis is missing, but the basal part of the diapophysis is flattened dorsoventrally, with a thick mid-region and thin anterior and posterior margins. The diapophysis projects laterally and slightly ventrally, and is supported by a well-developed centrodiapophyseal lamina (**cdl**), which is stout and oriented posterodorsally (Fig. 3A). The partially preserved prezygodiapophyseal lamina (**prdl**) extends anterodorsally from the diapophysis to the ventrolateral surface of the prezygapophysis (Fig. 3D). The postzygodiapophyseal lamina (**podl**) is flattened transversely and tapers posterodorsally.

The prezygapophyses are broken away, but a stout centroprezygapophyseal lamina (**cprl**) is preserved on the right side of the neural arch. The lamina runs vertically up (Fig. 3E) a medial centroprezygapophyseal lamina (**mcprl**) extends along the dorsomedial margin of the neural canal. These branches combine dorsally forming a large, deep fossa. The mcprl is widely distributed in non-titanosaur macronarians (Carballido & Sander 2014). A deep elliptical fossa is present between the diapophysis and cdl in lateral view (Fig. 3A). The postzygapophyses are not preserved, and most of the neural spine is likewise missing. The anterior side of the base of the neural spine is incised by a deep, wide vertical groove (Fig. 3E). A robust sprl is preserved on the right side, and extends posteriorly, medially and slightly dorsally from the prezygapophyseal area to the neural spine (Fig. 3D).

A second postaxial cervical vertebra is well preserved, but the anterior part, and much of the right side, of the centrum are missing (CGS V001-3, Fig. 4). The well-developed neural spine suggests that this vertebra may be from the mid-cervical region. The left lateral surface is excavated by a shallow, elliptical, anteroposteriorly elongate pleurocoel (Fig. 4B). A stout, anterodorsally oriented ridge (**plr**) forms the pleurocoel's anterior margin. A second pleurocoel was probably originally present anterior to this ridge, as in other mamenchisaurid and neosauropod cervical vertebrae. Based on the position of the ridge in typical cervicals, in fact, it is likely that the anterior half of the centrum is missing. The ventral part of the right half of the centrum is similarly broken away to expose the centrum's internal structure. A large, anteroposteriorly elongate pleurocoel is present (Fig. 4A) as in other basal sauropods such as *Camarasaurus* (Wedel 2003), but lacks the complexity of the internal cavities that occur in derived titanosaurs. The preserved part of the ventral surface is slightly concave transversely, and strongly concave anteroposteriorly. The preserved part of the centrum lacks a ventral keel, but a ventral keel may have been present more anteriorly, as in the cervical vertebrae of other basal sauropods.

On the left side of the neural arch, the diapophysis is well preserved, has a subtriangular outline in dorsal view, and tapers ventrolaterally (Fig. 4B). The dorsal surface of the diapophysis is flattened. The prezygodiapophyseal lamina (**prdl**) is partially preserved as a sheet of bone arising from the base of the anterior edge of the diapophysis, the thin edge of the prdl extending anterodorsally (Fig. 4B). The postzygodiapophyseal lamina (**podl**) runs from the base of the diapophysis to the lateral margin of the postzygapophysis, forming an angle of about 50° with respect to the long axis of the centrum. No epipophysis is present. A prominent, tapering process protrudes posteriorly from the base of the diapophysis (Fig. 4B: **ppr**), resembling the costal spur present in the neosauropod *Euhelopus zdanskyi*. However, the costal spurs of *Euhelopus* are less prominent and more distally located (Wilson & Upchurch 2009).

The prezygapophyses are missing. The spinoprezygapophyseal lamina (**sprl**) is sharp, its margin curving posterodorsally from the prezygapophyseal area to merges with the anterior edge of the neural spine (Fig. 4B). The neural spine is well preserved, subrectangular in outline in lateral view, and transversely compressed. The anterior neural spine groove is present and transversely narrow. In posterior view, a deep and wide concavity surrounded by spols extends dorsoventrally (Fig. 4C).

A third postaxial cervical vertebra can be recognized as a posterior member of the cervical series, based on the relative shortness of the centrum (ratio of centrum length to posterior centrum height of only about 1.6) (CGS V001-4, Fig. 5). The centrum is strongly opisthocoelous, with a prominent hemispherical anterior condyle. The lateral surface of the centrum is strongly excavated by a deep, elliptical, anteroposteriorly elongate pleurocoel (Fig. 5A). The right parapophysis is broken away, and the left parapophysis is pyramidal, located in the anteroventral region of the centrum, and tapers laterally, having a triangular outline in lateral and anterior views (Fig. 5B).

The ventral surface is strongly concave anteroposteriorly, the apex of the concavity being located in the anterior half of the centrum. A strong ventral midline keel is present, and extends from the anterior margin to the posterior end. The midline keel is sharp and deep anteriorly, and progressively becomes wider and less prominent towards the centrum's posterior end (Fig. 5D). The centroprezygapophyseal lamina (**cprl**) is a simple stout ridge, extending anterodorsally from the diapophysis to support the prezygapophysis (Fig. 5C).

The left prezygapophysis is well preserved, with a subtriangular facet that is wider than long as in posterior cervicals in sauropods. The articular surface is flattened. A large shallow fossa is present on the underside of the prezygapophysis (Fig. 5C). The spinoprezygapophyseal lamina (**sprl**) forms a prominent ridge extending posterodorsally from the prezygapophysis (Fig. 5A). The anterior part of the prezygodiapophyseal lamina (**prdl**) is preserved as a stout ridge, whereas the postzygodiapophyseal lamina (**podl**) is thinner, and more sheet-like (Fig. 5B). The podl, pcdl (posterior centrodiapophyseal lamina) and lcpol (lateral centropostzygapophyseal lamina) define a deep fossa posterior and dorsal to the diapophysis in lateral view (Fig. 5B). The centrodiapophyseal laminae on both sides are not exposed. The left diapophysis is partially preserved, and tapers ventrolaterally. The diapophysis is robust, dorsoventrally compressed, and anteroposteriorly broad (Fig. 5B). The dorsal surface of the diapophysis is convex whereas the ventral surface is flat, giving this structure a "D" shaped outline in lateral view. Both postzygapophyses are missing, as is the neural spine.

Scapula. The left scapula is nearly complete, lacking only small portions of the proximal plate and distal expansion (CGS V001-5, Fig. 6), and is generally flat and elongate. The lateral and medial surfaces of the proximal plate are both shallowly excavated, but the acromial ridge that is present in most neosauropods (Upchurch et al. 2004) is lacking. The dorsoventral height of the strongly expanded proximal plate is estimated to be more than 50% of the total length of the scapula, as in mamenchisaurids and more advanced sauropods (Upchurch et al. 2004). The dorsal margin of the acromial process is transversely thin, whereas the long, anteroventrally protruding glenoid region is transversely thick. The glenoid region is rectangular in lateral view, and bears a slightly concave articular surface. The lateral and medial surfaces of the scapular blade are both convex, creating a lenticular cross section, although the convexity of the lateral surface is more pronounced. The blade is slightly deflected medially, relative to the proximal plate. The distal end of the blade is strongly expanded dorsoventrally, though the dorsal part of the expanded area is slightly damaged. The distal end of the scapular blade is also strongly expanded in *Omeisaurus*, *Mameichisaurus* and *Yuanmousaurus* (Lu et al. 2006), but only slightly expanded in the basal sauropod *Shunosaurus* (Zhang 1988) (Fig. 7).

Discussion

The recovered bones of the new Tibetan sauropod dinosaur are generally similar to those of other Early and Middle Jurassic sauropods, and also preserve some derived features previously known in mamenchisaurids. The cervicals are opisthocoelous and short, as in the Early Jurassic sauropods *Kotasaurus* from India (Yadagiri 2001), *Tazodosaurus* from Morocco (Allain & Aquesbi 2008), and *Zizhongosaurus* and *Gongxiansaurus* from the Sichuan Basin (He et al. 1998). The lateral surfaces of the centra are excavated, as most sauropods, such as *Tonganosaurus* from the Lower Jurassic Yimen Formation of the Sichuan Basin (Li et al. 2010), but the cervicals of *Tonganosaurus* are more elongated and have no septa in their lateral excavations. The shallow concavity of the lateral surface of the axial centrum, together with the lateral excavations and ventral midline keels on the postaxial cervical centra, represent strong similarities to Middle Jurassic sauropods from the Sichuan Basin, such as *Shunosaurus* and *Dashanpusaurus* (Zhang 1988; Peng et al. 2005). In addition, the Tibetan sauropod bones also display some features seen in mamenchisaurids and neosauropods, such as a relatively robust scapula with a strongly dorsoventrally expanded proximal plate. However, the Tibetan sauropod also lacks many derived features of mamenchisaurids, including a deep lateral excavation on the axis, elongated cervical vertebrae, cervical centra with three or more lateral excavations and no ventral midline keel, and bifurcate cervical neural spines (Young & Zhao 1972; He et al. 1988; Ouyang & Ye 2002; Ren et al. 2021). In summary, the Tibet sauropod specimen can be identified as a eusauropod more derived than *Shunosaurus* but basal to mamenchisaurids.

It is difficult to ascribe the Tibet sauropod specimen to any known sauropod species or genus. The shortness of the cervical vertebrae *Shunosaurus*, but the cervicals bear more complicated excavations than occur in that taxon. However, the complexity of the cervical excavations may be subject to ontogenetic variation in sauropods. While documented examples of ontogenetically-driven morphological changes in sauropods are scant, such changes have been reported in a few genera, including *Shunosaurus* (Ma et al. 2022), *Brachiosaurus* (Carballido et al. 2012), *Europasaurus* (Carballido & Sander 2014) and *Barosaurus* (Melstrom et al. 2016). Information from these taxa implies that the pleurocoels of the cervical and dorsal vertebrae became more complicated, and the cervical centra more elongate in older individuals. Carballido & Sander (2014) divided the ontogeny of *Europasaurus* into five stages, based on the degree to which pleurocoels and laminae were developed.

The new Tibetan sauropod specimen may be a juvenile, based on its relatively small size and the presence of visible neurocentral sutures (Fig. 5C). The axial centrum is about as long as that of a complete *Shunosaurus* (125 mm, ZDM T5042) specimen (Zhang 1988), which was estimated to have a total body length of 11 m. The maximum length of the preserved scapula is estimated to be less than 70 cm (referred to the scapula of mamenchisaurids), making it much shorter than the scapulae of adult individuals of such basal sauropod taxa as *Shunosaurus* (90 cm, ZDM T5042) (Zhang 1988) and *M. youngi* (119 cm, ZDM0083) (Ouyang & Ye 2002). However, the scapula of the Tibetan sauropod specimen is slightly larger than that of a recently described partial juvenile *Shunosaurus* skeleton (scapula length equals 57.4 cm) from the Middle Jurassic of Chongqing Municipality, China (CLGPR V00007) (Ma et al. 2022). The latter has a slender shaft and low acromial process as in adults of *Shunosaurus*, and in contrast to the condition in the Tibetan sauropod. Unfortunately, no cervical vertebrae are preserved in the juvenile *Shunosaurus*, and most of the ontogenetic variations that could be inferred based on this specimen pertained to limb bones which are not represented in the Tibetan material (Ma et al. 2022).

The lack of fusion of the neurocentral sutures in the preserved cervical vertebrae, suggest the new Tibetan sauropod material represents a juvenile individual. Using the criteria defined by Carballido & Sander (2014) (assuming that the ontogeny of Europasaurus similar to that of the presumably much more basal taxon represented by the Tibetan material), the new Tibetan sauropod specimen is recognized as a late immature individual, as well-developed laminae and fossae are apparent in the cervical series but the cervical vertebrae are still short. Similarly, the juvenile holotype of *Daanosaurus* from the Upper Jurassic of the Sichuan Basin has a very short axis (Ye et al. 2005), and juvenile specimens of *Bellusaurus* from the Middle Jurassic of Xinjiang Autonomous Region, have relatively short cervicals that bear deep excavations divided by septa, although in the *Bellusaurus* material the cervicals lack ventral midline keels and the scapulae are relatively slender (Dong 1990). These comparisons indicate that the cervical vertebrae of the Tibetan sauropod would likely have developed more complex excavations and increased in size relative to other parts of the skeleton if ontogeny had continued, suggesting that an adult of the same species would have been more similar to mamenchisaurids (Carballido & Sander 2014).

In summary, the new Tibetan sauropod specimen bears a unique combination of features not seen in other basal sauropods. However, more material is needed before a new taxon can be established, due to the incompleteness of the preserved bones and their juvenile status. The similarities between the Tibetan specimen and mamenchisaurids, which are already known to have a wide distribution in the Middle Jurassic of Asia (Ren et al. 2021), suggest that the Tibetan specimen maybe at least closely related to Mamenchisauridae, particularly when possible ontogenetic effects are taken into account. A detailed study of ontogenetic variation in mamenchisaurids would be helpful in more confidently establishing the taxonomic position of the Tibetan specimen.

Conclusions

The Tibetan sauropod bones reveal the presence of a short-necked basal sauropod in the Middle Jurassic Dongdaqiao Formation of Chaya County, Changdu District. Among previously described taxa, the specimen is most closely similar to basal eusauropods from the Middle Jurassic, the resemblances including the shortness of the cervical centra and the fact that they bear lateral excavations and prominent ventral midline keels. The specimen also possesses some derived features seen in the Late Jurassic sauropod *Mamenchisaurus*, such as a robust scapula with a strongly dorsoventrally expanded proximal end, and the presence of epipophyses on the axis. The smallness of the available bones and the visible neurocentral sutures on the preserved cervicals all suggest that the specimen represents a juvenile, which might have increased in relative neck length and complexity of pleurocoel and laminar development in the cervical region if growth had continued. Therefore, an adult individual of the same species might show clearer similarities to mamenchisaurids. The new material provides significant information on the morphological transition from basal eusauropods to mamenchisaurids, and expands the known diversity and biogeographic range of sauropods in the Middle Jurassic of East Asia.

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Figure 1

Geologic map and stratigraphyic layer of sauropod remains in this study.

(A) Simple geologic map of the Chaya County, Changdu District, where the material described in this paper was collected; (B) Lithostratigraphic column of the Dongdaqiao Formation in the study area

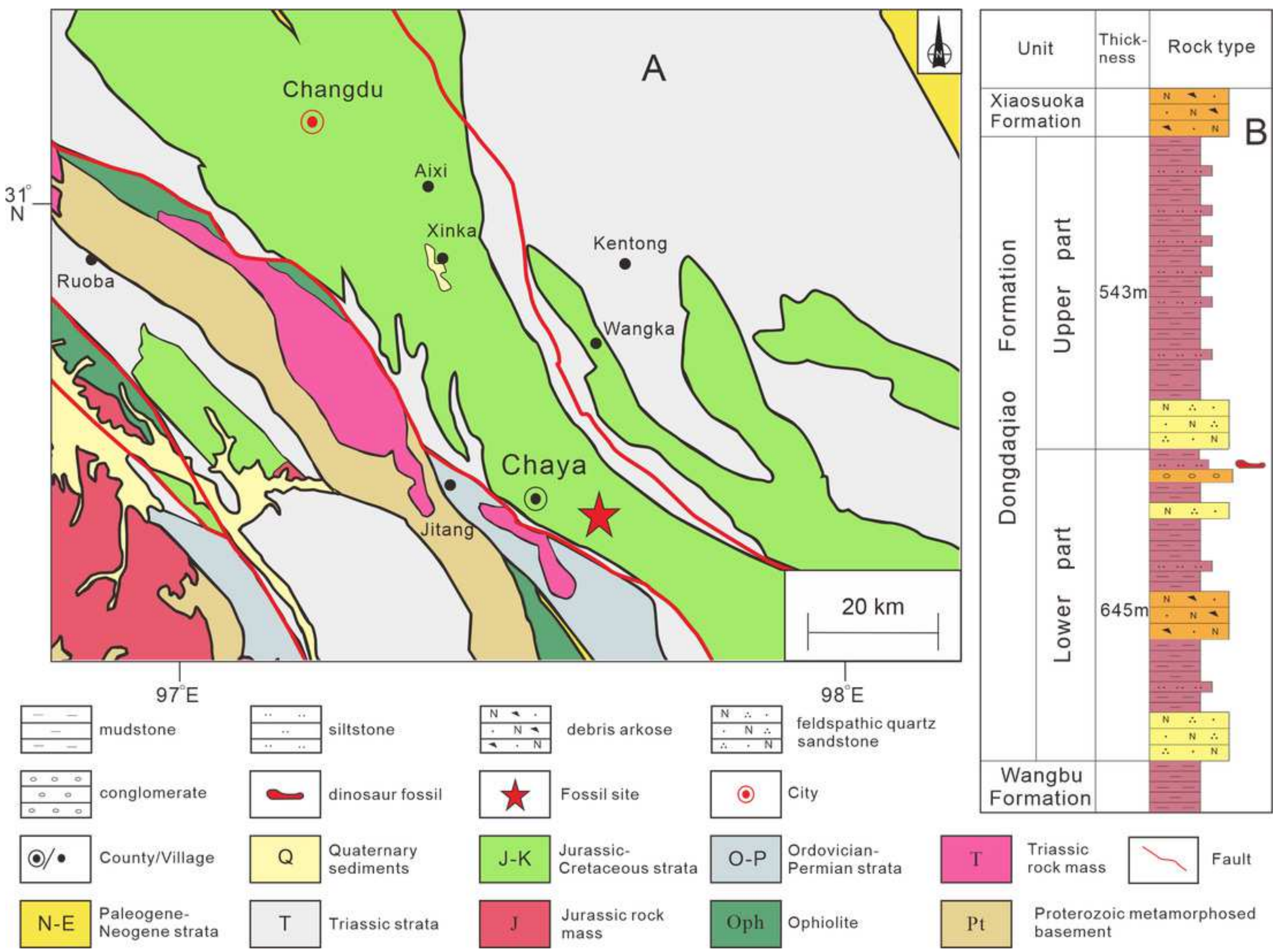


Figure 2

Axis of the Tibetan sauropod.

(A) Left lateral view; (B) Right lateral view; (C) Anterior view; (D) Dorsal view; (E) Ventral view; (F) Posteroventral view. **Abbreviations**: **di**, diapophysis; **fo**, fossa; **ic**, intercentrum; **ns**, neural spine; **podl**, postzygodiapophyseal lamina; **poz**, postzygapophysis; **pp**, parapophysis; **spof**, spinopostzygapophyseal fossa; **spol**, spinopostzygapophyseal lamina; **vk**, ventral keel

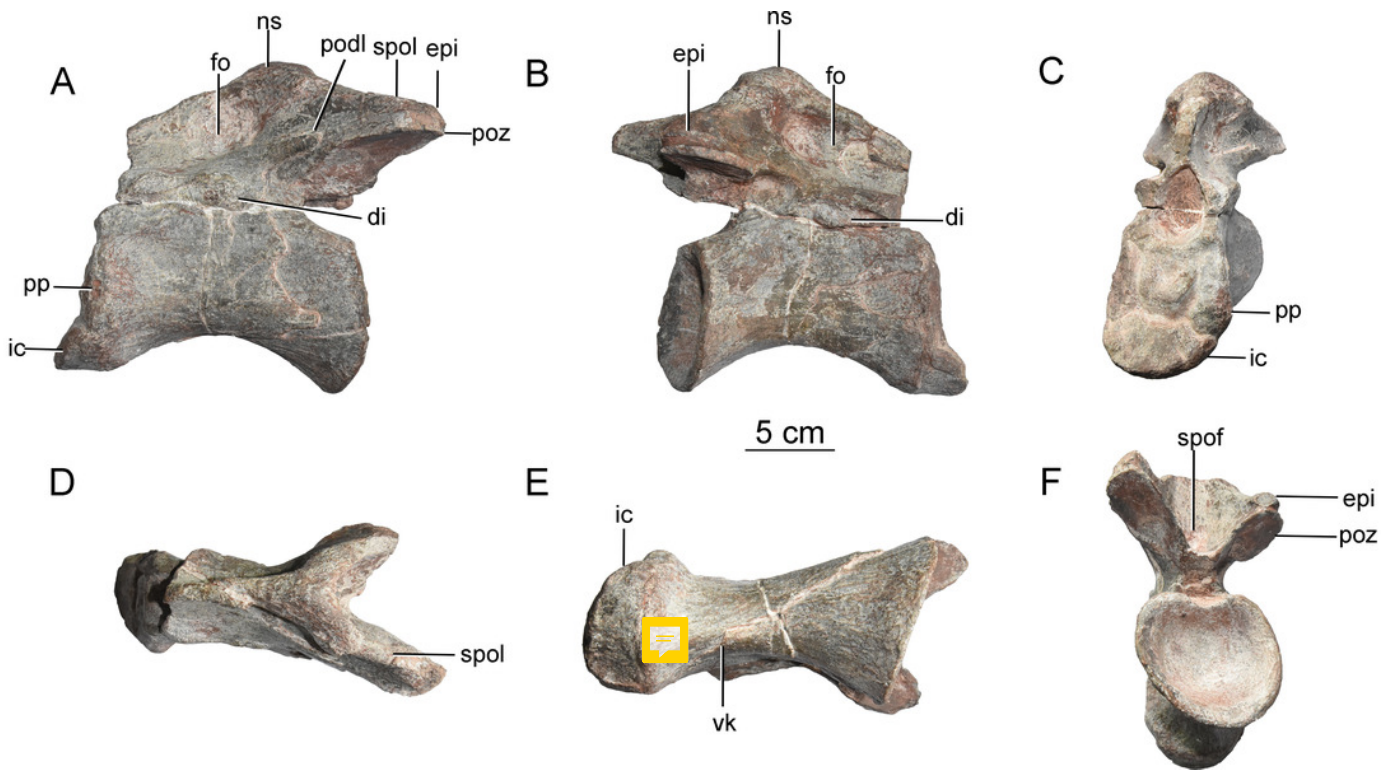
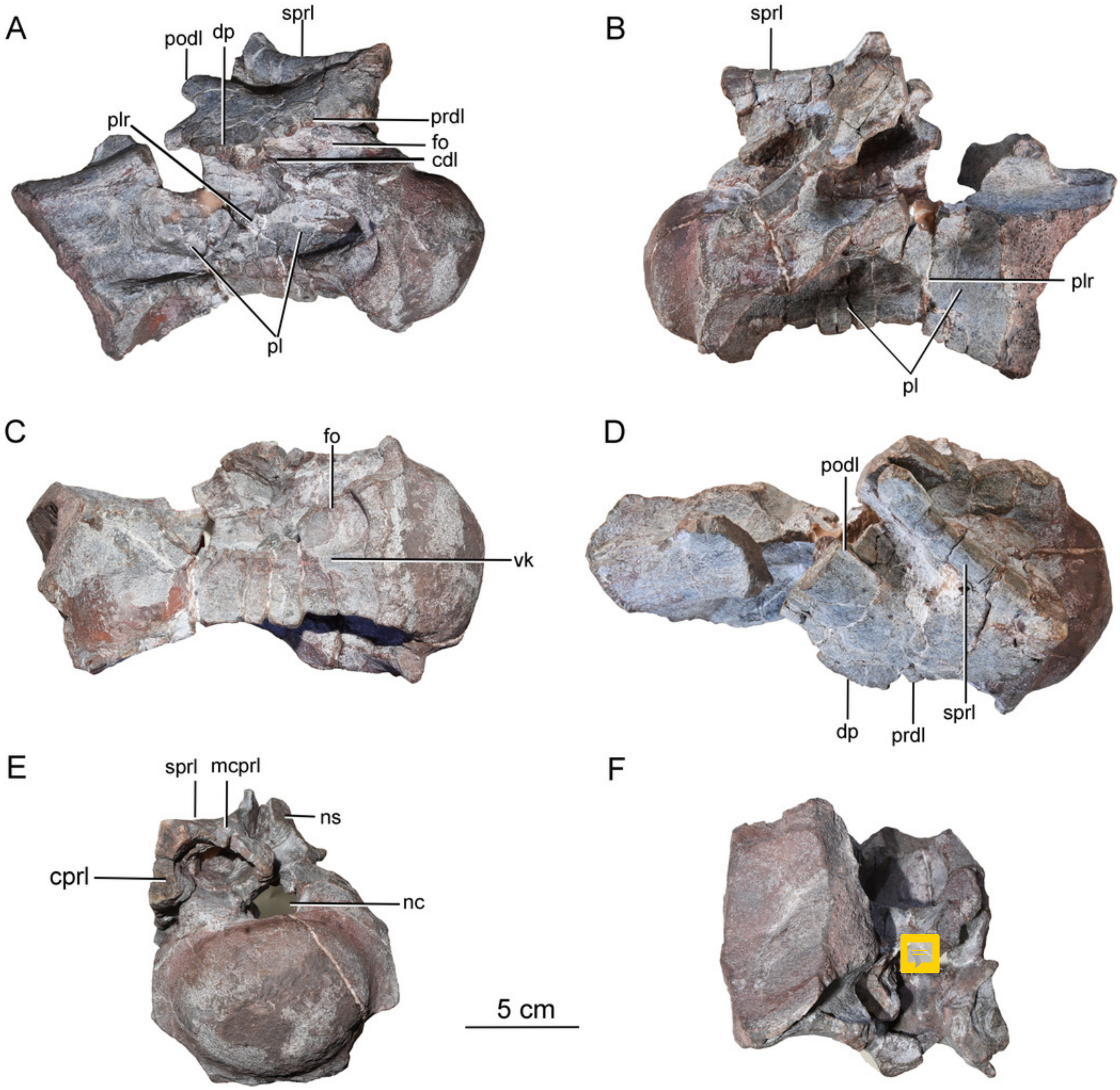


Figure 3

Possible anterior cervical vertebra of the Tibetan sauropod.

(A) Right lateral view; (B) Right lateral view; (C) Ventral view ; (D) Dorsal view; (E) Anterior view; (F) Posterior view. **Abbreviations**: **cdl**, centrodiapophyseal lamina; **cprl**, centroprezygapophyseal lamina; **dp**, diapophysis; **fo**, fossa; **mcprl**, medial centroprezygapophyseal lamina; **nc**, neural canal; **ns**, neural spine; **pl**, pleurocoel; **plr**, pleurocoel ridge; **prdl**, prezygodiapophyseal lamina; **sprl**, spinoprezygapophyseal lamina; **vk**, ventral keel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sprl
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mcprl
ns
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nc
F
5 cm

Figure 4

Possible mid-cervical vertebra of the Tibetan sauropod.

(A) Right lateral view; (B) Left lateral view; (C) Posterior view; (D) Ventral view; (E) Anterior view. **Abbreviations**: **agr**, anterior neural spine groove; **cdl**, centrodiapophyseal lamina; **dp**, diapophysis; **nc**, neural canal; **ns**, neural spine; **pl**, pleurocoel; **plr**, pleurocoel ridge; **podl**, postzygodiapophyseal lamina; **posp**, postzygapophysis; **ppr**, posterior process; **prdl**, prezygodiapophyseal lamina; **spol**, spinopostzygapophyseal lamina; **sprl**, spinoprezygapophyseal lamina

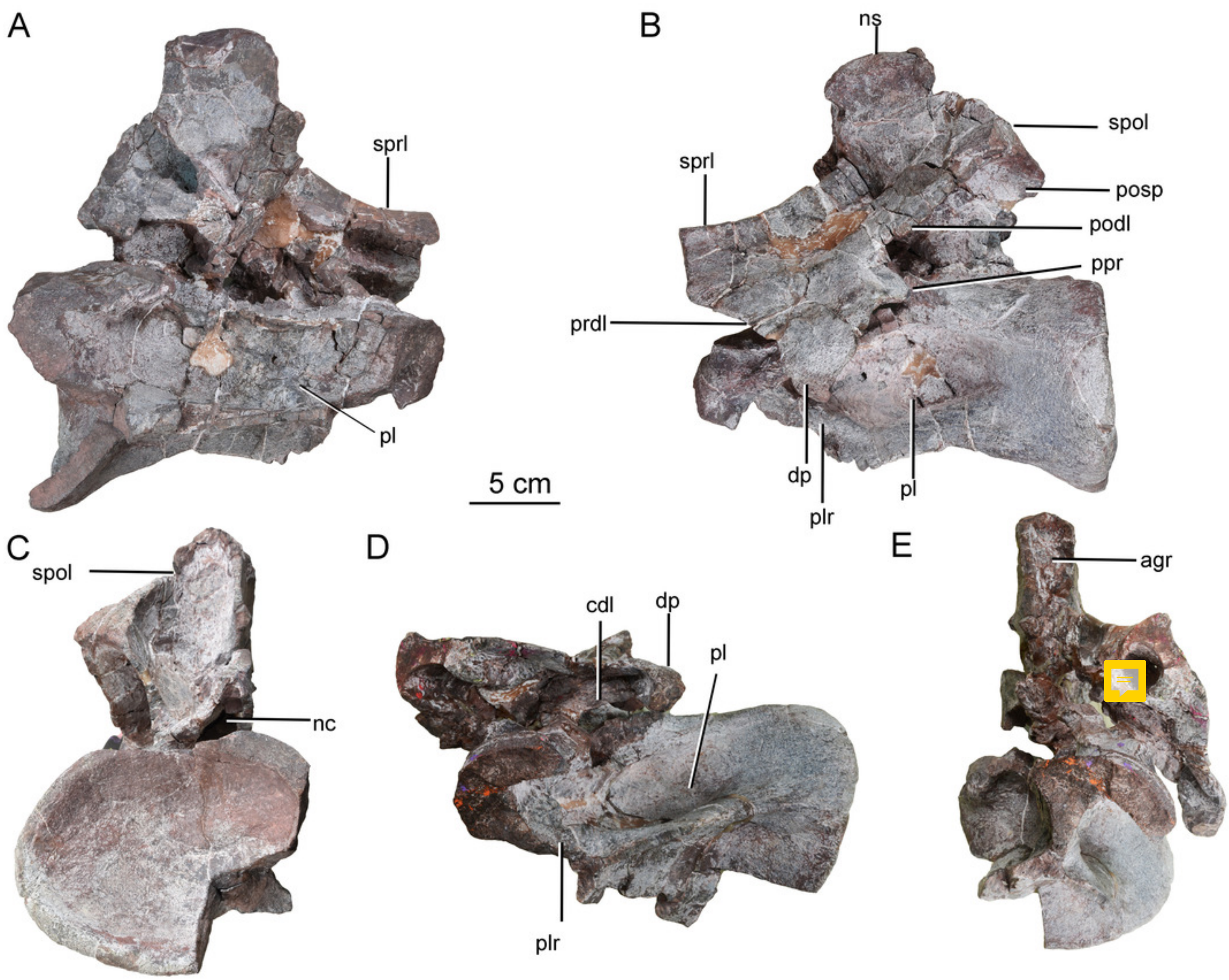

Figure 5

Possible posterior cervical vertebra of the Tibetan sauropod

(A) Right lateral view; (B) Left lateral view; (C) Anterior view; (D) Ventral view; (E) Dorsal view; (F) Posterior view. **Abbreviations**: **cprl**, centroprezygapophyseal lamina; **dp**, diapophysis; **fo**, fossa; **lcpol**, lateral centropostzygapophyseal lamina; **ncs**, neurocentral suture; **pcdl**, posterior centrodiapophyseal lamina; **pl**, pleurocoel; **podl**, postzygodiapophyseal lamina; **pp**, parapophysis; **prdl**, prezygodiapophyseal lamina; **sprl**, spinoprezygapophyseal lamina; **vk**, ventral keel

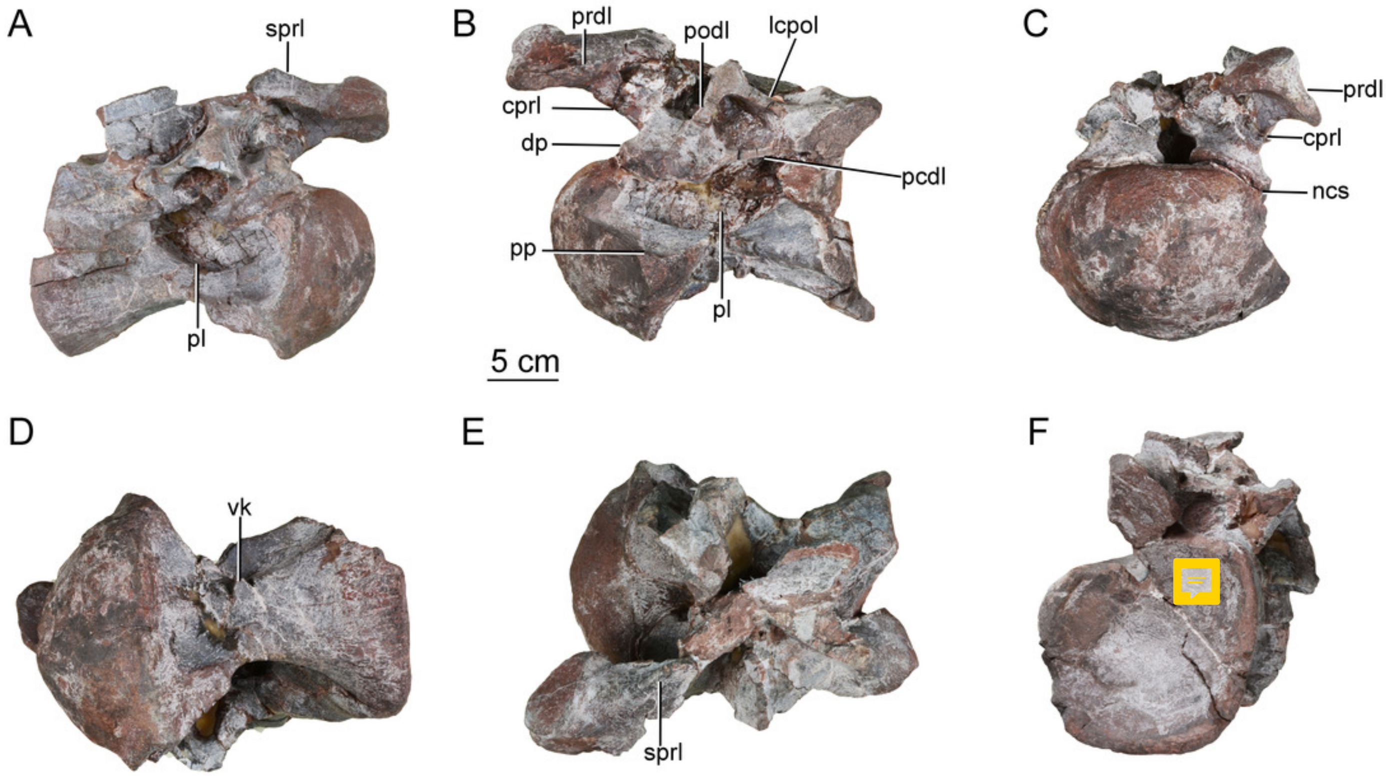

Figure 6

Left scapula of the Tibetan sauropod.

(A) Lateral view; (B) Medial view; (C) Ventral view; (D) Dorsal view; (E) Posterior view; (F) Anterior view. **Abbreviations**: **ac**, acromial process; **gl**, glenoid

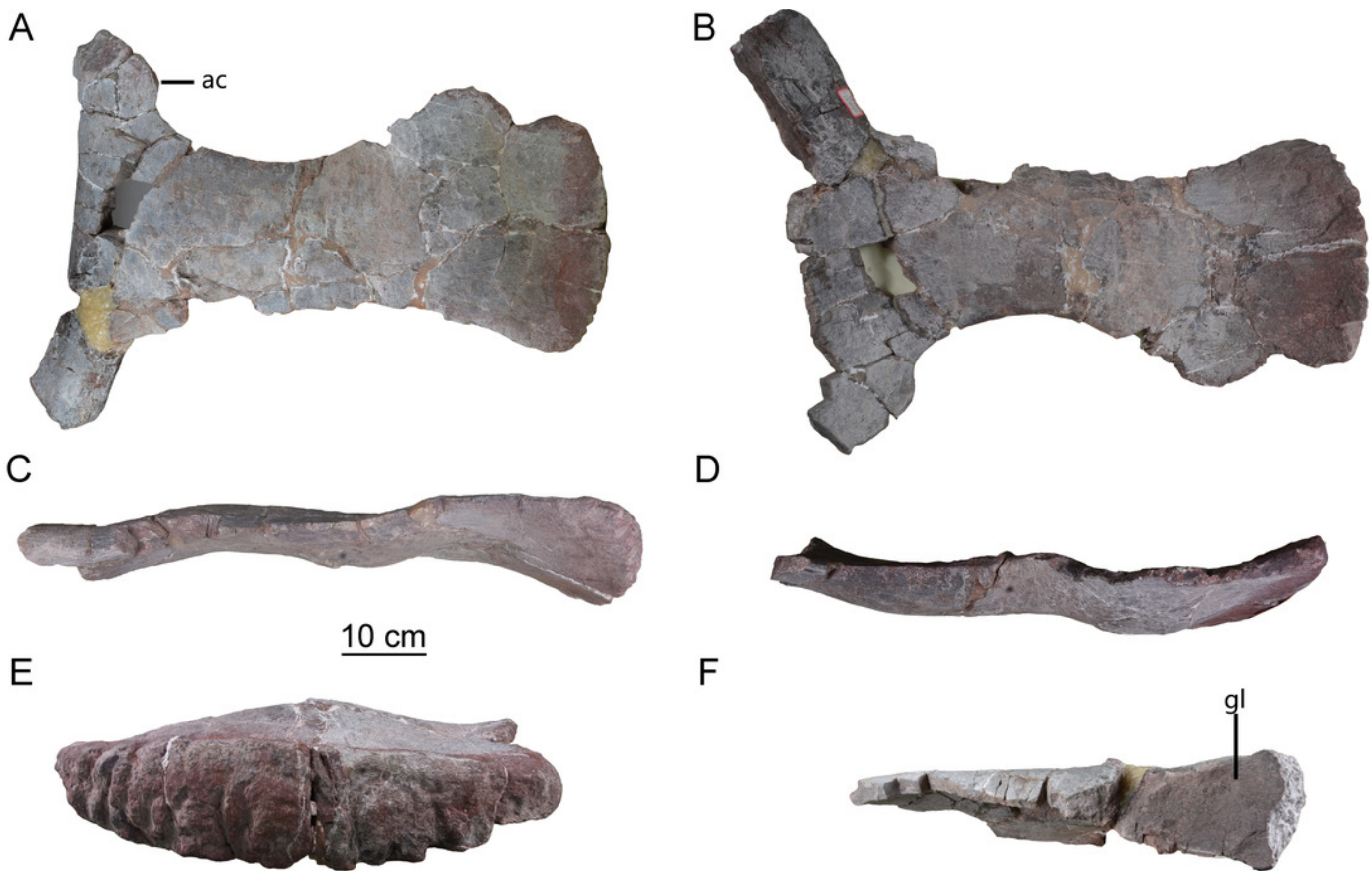

Figure 7

Comparison of left scapulae in lateral view

(A) *Tonganosaurus hei* (MCDUT 14454, reversed); (B) *Shunosaurus lii* (ZDM T 5402); (C) Tibetan sauropod (CGS V001); (D) *Lingwulong shenqi* (LM V001b, reversed); (E) *Omeisaurus tianfuensis* (ZDM T5704); (F) *Mamenchisaurus youngi* (ZDM0083). **Abbreviations**: **ac**, acromial process; **gl**, glenoid

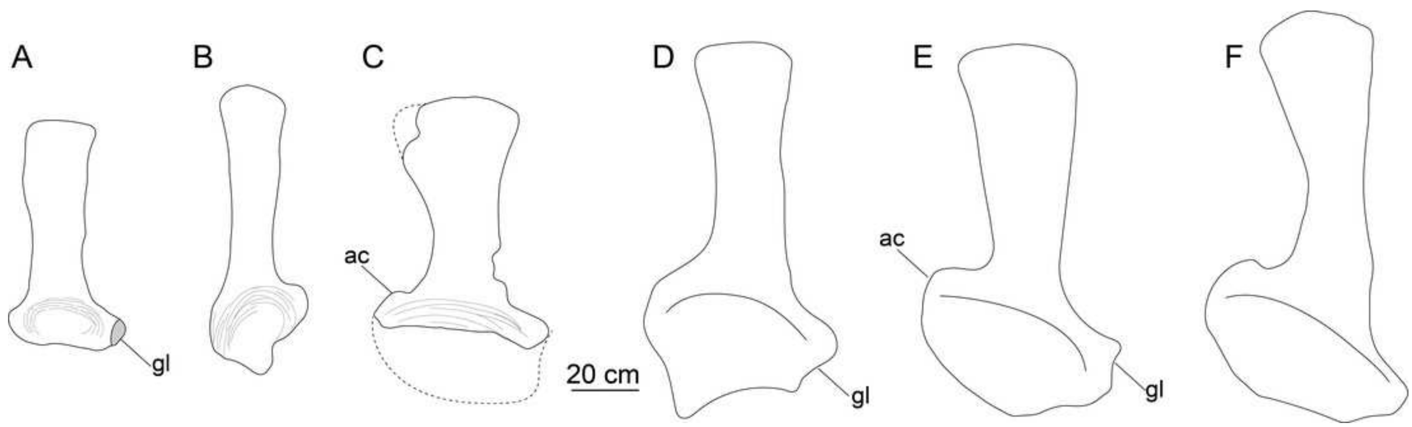

Table 1(on next page)

Measurements of Tibetan sauropod bones.

Table 1. Measurements of Tibet sauropod bones.

Elements	Dimension	Measurements (mm)
Axis(CGS V001-1)	1 centrum length (including ball)	126.09
	2 Anterior centrum height	92.89
	3 Anterior centrum width	67.66
	4 Centrum height at the mid region	65.37
	5 Centrum width at the mid region	/
	6 posterior centrum height	78.29
	7 Preserved posterior centrum width	85.10
	8 Neural arch length (shortest)	98.03
	9 Neural arch height	84.26
	10 Neural arch width (proximal end)	48.12
	11 Neural canal width (proximal end)	29.82
	12 Neural canal height (proximal end)	45.25
	13 Neural canal width (distal end)	24.52
	14 Neural canal height (distal end)	24.66
	15 Neural arch width (distal end)	45.17
	Ratio of length to posterior centrum height	126/78=1.62
Cervical (CGS V001-2)	1 centrum length (including ball)	196.07
	2 centrum length (excluding ball)	153.55
	3 anterior condyle height	71.60
	4 anterior condyle width	86.85
	5 Anterior centrum height	78.07
	6 Anterior centrum width	110.67
	7 Centrum height at the mid region	61.85
	8 Centrum width at the mid region	/
	9 posterior centrum height	103.15
	10 Preserved posterior centrum width	68.35(incomplete)
	11Anterior pneumatopore length	71.44
	12Anterior pneumatopore height	30.38
	13 Posterior pneumatopore length	40.65
	14 Posterior pneumatopore height	40.57
	15 Neural arch length (shortest)	141.73
	16 Neural arch height	79.97
	17 Neural arch width (mid region)	83.98
	18 Neural canal width (proximal end)	27.40
	19 Neural canal height	18.35
	Ratio of length to posterior centrum height	196/103=1.9
Cervical (CGS V001-3)	1 preserved centrum length	252.06
	2 Centrum height at the mid region	125.79

	3 posterior centrum height	123.06
	4 Preserved posterior centrum width	159.67(incomplete)
	5 Posterior pneumatopore length	131.17
	6 Posterior pneumatopore height	55.66
	7 Neural arch length (shortest)	144.26
	8 Neural arch height (including neural spine)	186.55
	9 Neural spine height	51.64
	10 Neural spine width (anteroposteriorly)	66.15
	11 Neural spine thickness	37.46
	12 Neural canal width (distal end)	30.09
	13 Neural canal height(distal end	30.55
	Ratio of length to posterior centrum height	252/123=2
Cervical (CGS V001-4)	1 centrum length (including ball)	263.65
	2 centrum length (excluding ball)	175.57
	3 anterior condyle height	141.64
	4 anterior condyle width	176.65
	5 Anterior centrum height	143.00
	6Anterior centrum width	176.93
	7 Centrum height at the mid region	107.73
	8 Centrum width at the mid region	/
	9 posterior centrum height	135.34
	10 posterior centrum width	155.21
	11right pneumatopore length	102.02
	12 right pneumatopore height	56.68
	13 left pneumatopore length	117.55
	14 left pneumatopore height	51.94
	15 Neural arch length (shortest)	150.17
	16 Neural arch height	141.48
	17 Neural arch width (mid region)	158.91
	18 Anterior neural canal width (distal end)	30.88
	19 Anterior neural canal height	42.26
	20 Posterior neural canal width (distal end)	31.46
	21 Posterior neural canal height	33.12
	Ratio of length to posterior centrum height	264/135=1.96
Scapula (CGS V001-5)	1dorsoventral length of the proximal end	518.44
	2 dorsoventral length of the mid-region	186.55
	3 Preserved dorsoventral length of the distal end	283.83(incomplete)
	4 Anteroposterior length	685.97
	5 transversal width of the proximal end	51.50
	6 transversal width of the mid-region	36.04
	7 transversal width of the distal end	61.55

8 transversal width of the glenoid	119.60
9 anteroposterior length of the glenoid	103.58

3