Vol. 92 No. 2 pp. 431–441 ACTA GEOLOGICA SINICA (English Edition) Apr. 2018

Redescription of *Gigantspinosaurus sichuanensis* (Dinosauria, Stegosauria) from the Late Jurassic of Sichuan, Southwestern China

HAO Baoqiao[1, *], ZHANG Qiannan[2, 3, 4], PENG Guangzhao[1] , YE Yong[1] and YOU Hailu[2, 3, 4]

1 *Zigong Dinosaur Museum, Zigong 643013, Sichuan, China*
2 *Key Laboratory of Vertebrate Evolution and Human Origins of Chinese Academy of Sciences, Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences, Beijing 100044, China*
3 *CAS Center for Excellence in Life and Paleoenvironment, Beijing 100044, China*
4 *University of Chinese Academy of Sciences, Beijing 100049, China*

Abstract: *Gigantspinosaurus sichuanensis* is one of the six Stegosauria genera discovered from the Sichuan basin, which preserves the first skin impressions of stegosaurs around the world and a huge pair of 'comma' -shaped parascapular spines kept in situ, and being named after the latter feature. The holotype was firstly named and reported in an abstract of a lecture by Ouyang, 1992, since when it has never been detailed studied and the taxonomic position of *Gigantspinosaurus* is also vague. The morphological redescription shows that *G. sichuanensis* is a medium-sized stegosaur, with external mandibular foramen developed. The ratio of femur to humerus is large, and the intersacral fenestrae are big. According to the wear degree of teeth, the holotype of *G. sichuanensis* is regarded as an adult individual. On the basis of the recent data matrix of stegosaurs and the characters revisions of *G. sichuanensis*, its phylogenetic position has been determined again. By our detailed morphological and phylogenetic analysis, *G. sichuanensis* is considered to inherit some primitive traits, but it is more derived than *Huayangosaurus*, and located in a transitional position between *Huayangosaurus* and *Tuojiangosaurus*, as a kind of evolved stegosaurs. The ancestors of Stegosauria are small and quadruped, with primitive ornithopod-like skull, and grow leaf-shaped teeth, a large number of bone plates.

Key words: *Gigantspinosaurus*, Sichuan basin, systematics, transitional type, adult individual

1 Introduction

Stegosauria is a group of specialized herbivorous dinosaurs. There are many basic researches have be done on stegosaurs from China, and already gotten a lot of achievements, such as *Tatisaurus* from the Early Jurassic (Dong Zhiming et al., 1992), *Huayangosaurus* from the Middle Jurassic (Dong Zhiming et al., 1982; Zhou Shiwu et al., 1983), *Jiangjunosaurus* (Jia Chengkai et al., 2007), *Chialingosaurus* (Young Chung Chien et al., 1957), *Tuojiangosaurus* (Dong Zhiming et al., 1977), *Chungkingosaurus* (Dong Zhiming et al., 1983), *Yingshanosaurus* (Zhu Songlin, 1994) and *Gigantspinosaurus* (Ouyang Hui, 1992) from the Late Jurassic, *Wuerhosaurus* (Dong Zhiming et al., 1973) and *Monkonosaurus* (Zhao Xijin, 1983) from the Early Cretaceous.

Sichuan basin is one of the famous basins exposed redbeds in East Asia, and the continental deposits of the Mesozoic are very developed in Sichuan basin, where yielded a great number of dinosaurs and other vertebrate fossils. Except the sauropods like *Mamenchisaurus*, Stegosauria are the second-most groups from Sichuan basin at present, including *Huayangosaurus taibaii* (Dong Zhiming et al., 1982), *Tuojiangosaurus multispinus* (Dong Zhiming et al., 1977), *Gigantspinosaurus sichuanensis* (Ouyang Hui, 1992), *Chungkingosaurus jiangbeiensis* (Dong Zhiming et al., 1983), *Chialingosaurus kauni* (Young Zhongjian, 1959) and *Yingshanosaurus jichuanensis* (Zhu Songlin, 1994), up to 6 genera 6 species in total until now. *Huayangosaurus* is the most primitive and complete material known as the basal stegosaur group (Sereno et al. 1992; Galton et al. 2004). *Chungkingosaurus* was placed into the Huayangosaurinae by phylogenetic analyses (Maidment, 2008; Raven, 2017). *Tuojiangosaurus*, *Chialingosaurus* and *Yingshanosaurus* are more advanced groups.

* Corresponding author. E-mail: haobaoqiao1984@163.com.

Gigantspinosaurus from the Late Jurassic of Sichuan basin is an important stegosaur taxon with some distinguishing features, which preserves the first skin impression fossil of Stegosauria around the world and parascapular spines (shoulder spines) in site. *Gigantspinosaurus* was reported in an abstract of a lecture (Ouyang hui, 1992), without detailed study in skeleton morphology and phylogeny. Peng et al. (2005) made a simple description of *Gigantspinosaurus* and discussed the taxonomic position of it when they summarized the Jurassic dinosaur fauna of Zigong, meanwhile they reported a completely pelvic girdle from Fuquan, Zigong that treated as *Gigantspinosaurus* sp., and placed it in the Huayangosaurinae by some primitive characters, without specific description (Peng Guangzhao et al., 2005). The data matrix from Maidment et al. (2008) and Rave et al. (2017) show that *Gigantspinosaurus* is more primitive than *Huayangosaurus*, and the former becomes the most basal taxa within the Stegosauria. But their studies are not available for the first-hand examination, and only according to the original brief description. However, *Gigantspinosaurus* appeared later than *Huayangosaurus*, and bigger in size than the latter, the relationship between them is still vague and need more works.

2 Geological Setting

The specimen was rather complete and articulated that excavated from Pengtang in Yinhe Village, Zhongquan Town, Zigong City, Sichuan Province in 1985 (Fig. 1). According to the geological time of the Upper Shaximiao Formation (Peng Guangzhao et al., 2005), and the yielding layers of the '*Mamenchisaurus* Fauna', *Mamenchisaurus* the main member of which, is similar to *Diplodocus* and *Camarasaurus* from the Morrison Formation (Late Jurassic) of North America. The isotopic age of the Upper Shaximiao Formation is about 150 million years ago, and the Upper Shaximiao Formation belongs to the early Late Jurassic by the latest International Chronostratigraphic Chart.

3 Samples and Methods

3.1 Systematics palaeontology

Dinosauria Owen, 1842
Ornithischia Seeley, 1887
Thyreophora Nopcsa, 1915
Stegosauria Marsh, 1877
Stegosauridae Marsh, 1880
Huayangosaurinae Dong et al., 1982
Gigantspinosaurus Ouyang, 1992
Gigantspinosaurus sichuanensis Ouyang, 1992

3.2 Differential diagnosis

A medium primitive stegosaur with a big skull, the external mandibular fenestra preserved, the coronoid process is developed, and the lateral crest of the dentary formed a longitudinal board. 8 cervical vertebrae, 16 dorsal vertebrae and 4 sacral vertebrae, with 3 pairs unclosed intersacral fenestrae, the neural spines of the sacral vertebrae and the last dorsal together form a anteroposteriorly thin plate. Cervicals develop lateral depressions, the diapophysis and neural spine are weak. Dorsal vertebrae also have lateral depression, the neural arches are low, the neural canals are small, and the neural spine is wide plate, the diapophysis are unobviously inclined; the neural spine of the anterior caudals are high,

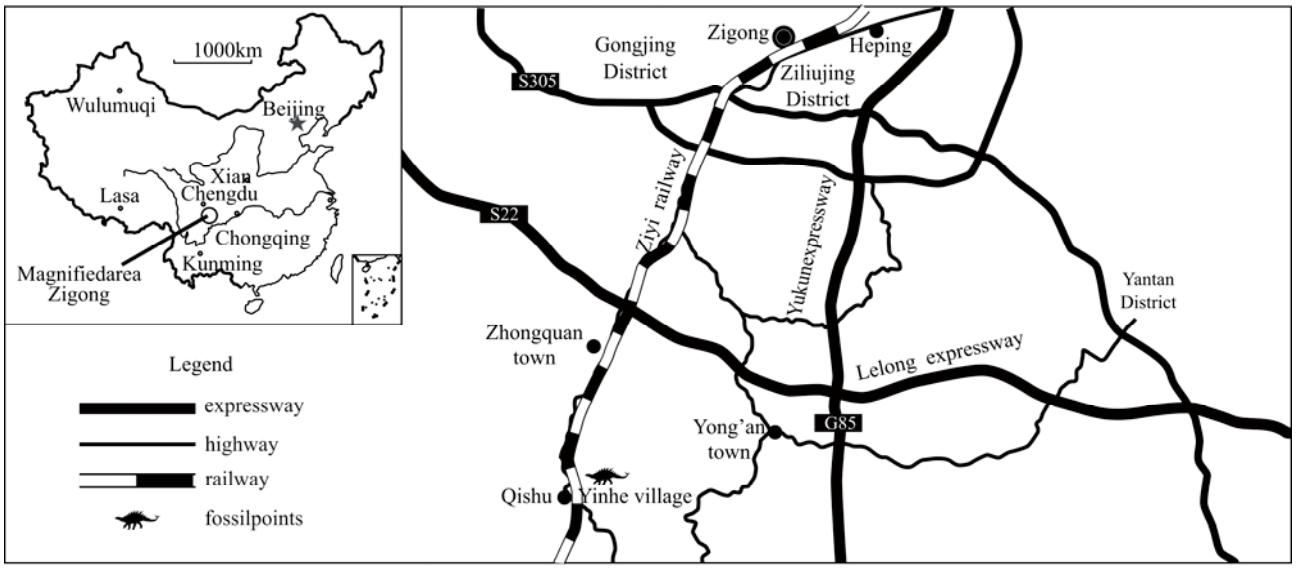

Fig. 1. The geographic location of *Gigantspinosaurus sichuanensis*.

and the distal ends unexpended. The proximal of the humerus are expended, while the deltopectoral crest are slightly developed. Length of the ulna occupies 80% that of the humerus, the olecranon process is highly developed. The femur is flat and straight, the lesser trochanter and fourth trochanter are degenerate. The ratio of the length of femur/humerus is 1.48. The proximal end of the tibia is flat, tibia flange is weak. The fibula is thin and flat. The astragalus is not fused with the tibia and fibula. 2 fused carpi. The metacarpals are short and stout. The phalanges formula is 2-3-3-2-1. The ilium is slightly longer than femur. The ischium and the posterior pubis are slender, and the length of the anterior pubis is about 1/2 the posterior region, both ends of them are not expand. The osteones on the neck are trianglar, small and thin; that on dorsals are thick, low and broad. The parascapular spines are huge, about 2 times longer than the scapula.

3.3 Holotype

ZDM 0019. An almost complete skeleton, includes a pair of complete mandible, 8 cervical vertebrae, 16 dorsal vertebrae and the synsacrum with 4 sacral vertebrae, some anterior caudal vertebrae, parts of appendicular skeleton, parts of osteoderms, a pair of parascapular spines (the right one with a small skin impression fossil).

Institutional abbreviations: ZDM, Zigong Dinosaur Museum, Sichuan, China.

3.4 Locality and horizon

Yinhe Village, Zhongquan Town Zigong City, Sichuan Province; the Upper Shaximiao Formation, the Upper Jurassic (Fig. 2a, Fig.2b).

4 Description

4.1 Skull

ZDM 0019 preserved both mandibular rami without predentary (Fig. 3). The dentary extends anteroposteriorly and upraises in the posterior region, the lateral ridge of the dentary forms the longitudinal drift, and the buccal surface is smooth, several nutrient foramina are visible. The external mandibular fenestra is triangular, and bounded by the dentary, surangular and angular. The teeth are small and lobate, inserting into the dentary and closely arranged with slightly overlap. The teeth of the dentary are up to 30, with low crowns, robust middle carina, and small tuberculiform serrations, the dental rings present on the base of the teeth crown. Level of the teeth tips is staggered arranged as high and low, and this arrangement is helpful for grinding plant. The wear surface of the teeth is obvious, so that ZDM 0019 is speculated to be an adult.

4.2 Axial skeleton

Cervical vertebrae: This specimen preserves an original sequence with 8 cervical vertebrae (Fig. 4), while most stegosaurs have 9 cervicals normally, but *Huayangosaurus* and *Gigantspinosaurus* only have eight. The atlas and axis are poorly preserved, as well the anterior cervical vertebrae are seriously extruded, both neural arch and neural spine are broken before C6. All the centra of the cervicals are amphicoelous, and the posterior surface is more concave than the anterior. The centrum is longer than its width, and wider than its height, with obvious lateral depression and gradually developed to the posterior. The diapophysis is invisible on cervicals, the neural arch and neural spine of C6 to C8 are preserved, the neural arches are high and about two times of the centra. The prezygapophysis and postzygapophysis are connected at their base as a broad plate and present a butterfly-shape in dorsal view. The prezeygapophysis extends to the dorsal of former vertebrae and articulate with its postzygapophysis, and the degree of the protrusion grows to the posterior, the length of the last 3 prezygapophysis even reach to half-length of former vertebrae. The

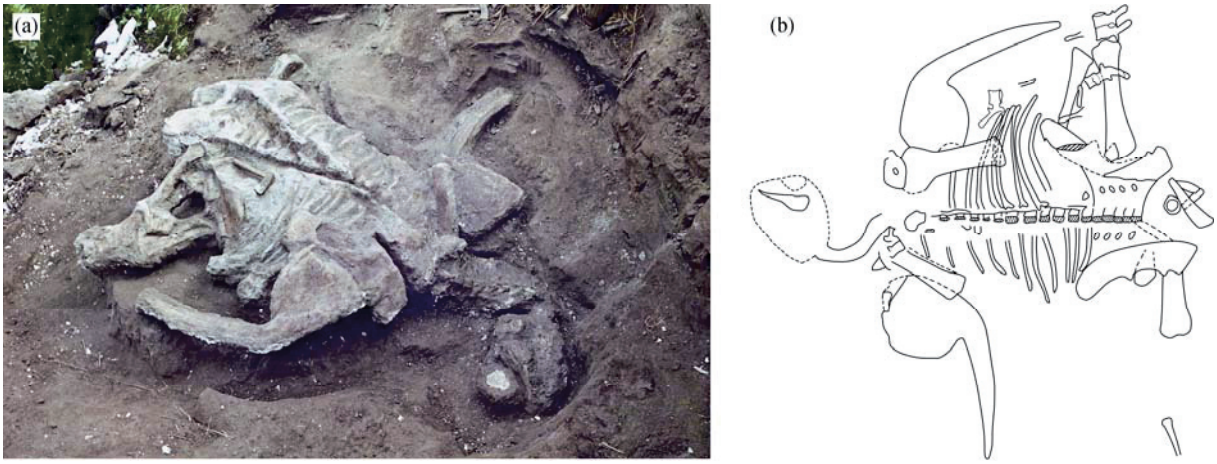

Fig. 2. Photograph and line drawing of *Gigantspinosaurus sichuanensis* during its excavation.

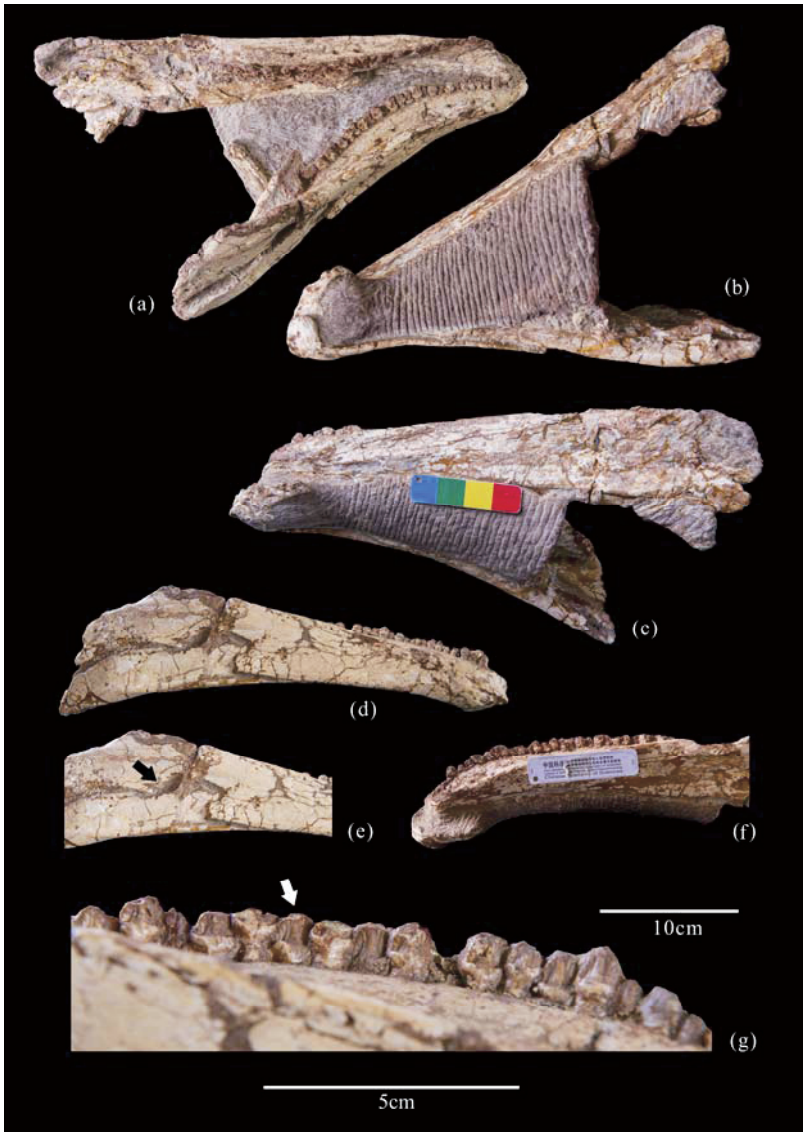

Fig. 3. Mandible.
(a), dorsal view; (b), ventral view; (c), left lateral; (d), right lateral; (e), right mandible details, the black arrow points towards the external mandibular foramen; (f), the left mandibular teeth; (g), the right side of mandibular teeth detail, the white arrow points towards the obvious wear.

articular surfaces of the prezygapophysis and postzygapophysis are both flat and broad. The neural spine is a longitudinal high ridge, much more developed from anterior to posterior.

Dorsal vertebrae: 16 associated dorsal vertebrae exist, and the last one is fused with the sacral vertebrae, the two neural spines are almost entirely fused, so it can be treated as a dorsal-sacral vertebra. The centrum is amphicoelous, while the degree of depression is reduced to the posterior. The center of the centrum is constricted, with slight ventral keel, and obvious lateral depression. The center ridge in the lateral depression are not developed, the cross section is oblate. The parapophysis is located on the dorsal region of centrum, almost the level to the neural arch. The diapophysis is developed like a plate, slightly longer than the neural spine. The diapophyses of anterior dorsals stretch laterodorsally, about 45° with respect to the neural spine, and this angle between them gradually increases to the posterior, almost perpendicular to the neural spine in the last. The neural arch is high, and the neural canal is relatively big, and become bigger backward. The neural spine raises and broadens from anterior to posterior and presents as a table plate in middle-posterior dorsals. The neural spine slight inclines posteriorly, as the caudal end to the level with the posterior end of the centrum.

Sacral vertebrae: There are 4 sacral vertebrae fused with the ilium, the centra are firmly articulated with each other, but the sutures can be seen in ventral view. The centrum is amphicoelous, low in height and broad in width, the articular surfaces are oval, and gradually

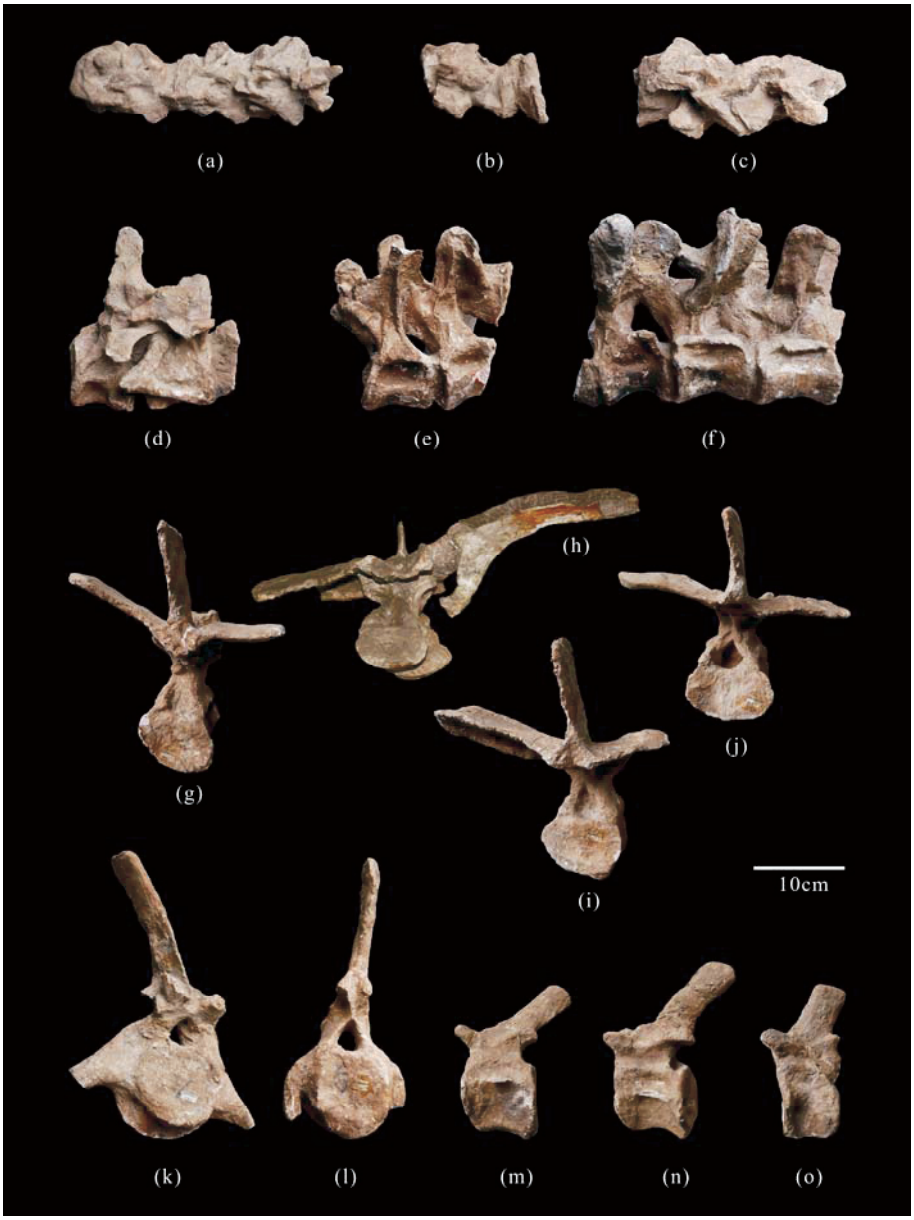

Fig. 4. Vertebrae.
(a), cervical 1-4 in dorsal view; (b), cervical 5 in dorsal view; (c), cervical 6-8 in dorsal view; (d), dorsal 1-2 in right view; (e), dorsal 3-4 in right view; (f), dorsal 5-7 in right view; (g), dorsal 11 in posterior view; (h), dorsal 12 in anterior view; (i), dorsal 13 in posterior view; (j), dorsal 14 in posterior view; (k) , caudal 1 in anterior view; (l), caudal 4 in posterior view; (m), caudal 11 in left view; (n), caudal 12 in left view; (o), caudal 18 in left view.

heighten and widen from anterior to posterior. The neural arch of the sacral extremely inclines forward, so the posterodosal margin of the neural canal reaches the same level with the anterior surface of the centrum. The sacral rib is closely fused with the diapophysis, expands anteroposteriorly in the base, and connects the lateral surface of the relative centrum. The sacral ribs articulated with each other in the dorsal, forming 3 pair of sacral foramina. The development of the sacral foramina between left and right are different. The first one on left is closed completely, only three small pits remain; the middle one on left is closed at a certain degree, and two small foramina and one small medial pit left; the third one on left is large and oval. While, the first one on right is small, “comma”-shaped, and closed in ventral; the following two are large and oval. This phenomenon indicates that the sacral foramen of stegosaurs has a trend from open to close. The distal end of the sacral rib reaches the pubic process of the ilium and medial surface of the ischium respectively. The neural spine is high and expands anteroposteriorly to fuse with the dorsal-sacral vertebrae to form an anteroposteriorly elongate plate.

Caudal vertebrae: ZDM 0019 preserves 10 anterior caudal vertebrae, all of them are are amphicoelous but unobvious. The centrum of the anterior caudal is very short, disk shape, and increases the length gradually to the

posterior. The articular surfaces change from sub-rounded to oval, the ventral surface of the centrum is flat, without any keel, but some have shallow grooves. The following centra have unobvious lateral depressions on the lateral surface. The ribs of anterior caudals are very developed, some are sharp cone and ventrolaterally stretch as 45°, some are plate-like and extend laterally, the proximal ends that connect with the centra are vertically extend, and the anterior and posterior of them develop depressions. The caudal ribs of the rear caudals present crest on dorsal region of both sides of their centrum, which indicating that some caudals are missing between them and other front vertebrae. The neural arch of anterior caudal is high, gradually lowers to the posterior the prezygapophysis and postzygapophysis of the caudal vertebrae are very developed, the latter is obviously higher than the former, the postzygapophysis gradually lowers to the level of the prezygapophysis. There is a vertical crest between the prezygapophysis and postgapophysis of the rear caudals, the neural spine is plate-like in lateral view, without thick table and divergence on the top, the angle of the neural spine gradually decreases from anterior to posterior.

4.3 Appendicular Skeleton

The proximal end of the right scapula expands as a thin plate, and the margin are straight and slightly thick. The shaft is long, slight concave in medial and convex in lateral. The posterior margin is thick and smooth as arc-shaped. The anterior margin is thin, the dorsal half is straight, while the ventral half posteriorly bends, forming a distinct contractive neck between the shaft and the distal end, and the dorsal part of the contractive neck is remarkably concave. The distal end expands to fuse with the coracoid, the suture is still clear, and the glenoid is semilunar, thick and solid. The coracoid is sub-parallelogram, the coracoid foramen exists, and the medial and lateral openings are in the same level, but the lateral opening is front in the medial one.

Some of the elements of the left forelimb are associated, including the humerus, ulna, radius, and part of the metacarpi and phalanx. The shaft of the humerus is straight and no twist with oblate transverse section, which is about 44 cm long, and the middle-ventral regions obviously shrink. Both ends are expanded and in one parallel surface, the proximal surface is bigger than the distal, the ratio of the maximum width of the proximal surface to the distal surface is bigger than that of *Huayangosaurus*. The glenoid articular process is on the mediolateral region of the distal end, as a thick semi-spherical protrusion. The deltopectoral crest is reduced, the medial and lateral condyles of the distal end are almost equal, the anterior intercondyle groove is obvious, but the posterior one is much deeper.

The proximal end of the ulna is transversely expended, and the articular surface is triangular, high in lateral, and low in medial. The cubital process is developed and projecting to exceed the articular surface of the humerus, which is subtriangular and on the anterolateral region of the proximal end of the ulna. The shaft is prolate, with laterally convex and medial concave, gradually shrinking from the proximal to the distal, then become to a flat column. The ulna is much bigger than the radius, but the distal end of the ulna is smaller than that of the radius. The anterolateral surface of the proximal end presents a subtriangular concave surface, which is the articular surface to connect with the radius.

The radius is small and expanded in the proximal end, the articular surface for humerus is slightly concave, articulating with the radial condyle of the humerus. The shaft is flat and constricted in the middle part. The distal end is remarkably expanded and much bigger than the proximal. There is a big space between the shafts of the ulna and radius when they are touched.

The carpus is composite, which comprised by two elements: the radiale and the ulnare, the radiale is bigger. There are 5 metacarpals, and the metacarpus II is the longest one. All of them are similar, with end expanded and shaft flat. 5 phalanxes are preserved: I-1, II-2, III-1, IV-1 and V-1, in different morphology, from big to small and robust to thin by I-V. The left manus preserves claw I and II, and claw I is big with broad proximal end, the articular surface is oval concave, and the shaft arches up

Table 1 List of the stegosaur fossils currently known from China

Name	Locality	Age	Horizon	Material
Tatisaurus oehleri	Lufeng, Yunnan	Early Jurassic	Lower Lufeng Formation	a left mandible
Huayangosaurus taibaii	Zigong, Sichuan	Middle Jurassic	Lower Shaximiao Formation	at least three skeletons and some individual bone
Jiangjunosaurus junggarensis	Qitai, Xinjiang	Late Jurassic	Shishugou Formation	some individual bone
Chialingosaurus kuani	Quxian, Sichuan	Late Jurassic	Upper Shaximiao Formation	some individual bone
Tuojiangosaurus multispinus	Zigong, Sichuan	Late Jurassic	Upper Shaximiao Formation	two incomplete skeletons
Chungkingosaurus jiangbeiensis	Jiangbei, Chongqing	Late Jurassic	Upper Shaximiao Formation	an incomplete skeleton and some individual bone
Yingshanosaurus jichuanensis	Yingshan, Sichuan	Late Jurassic	Upper Shaximiao Formation	some individual bone
Gigantspinosaurus sichuanensis	Zigong, Sichuan	Late Jurassic	Upper Shaximiao Formation	a complete skeleton and some individual bone
Wuerhosaurus homheni	Karamay, Xinjiang	Early Cretaceous	Tugulu Group	an incomplete skeleton
Wuerhosaurus ordosensis	Ordos, Nei Mongol	Early Cretaceous	Ejinhoro Formation	an incomplete skeleton
Monkonosaurus lawulacus	Changdu, Xizang	Late Jurassic-Early Cretaceous	Laoran Formation	a sacral and some plates

like a bow, with the distal tip reduced. The proximal end of the claw II is broader than the claw I, the distal tip is sharp, but the camber is less than the claw I.

The ilium is low and connected with the sacral vertebrae firmly, the dorsal part of the acetabulum and the postacetabular process transversely expand and stretch laterally, present to be oval, and the end of the postacetabular process shrinks like the condition in *Tuojiangosaurus*. The preacetabular process is narrow and prolate as a vertical plate, lateral convex and medial concave, slightly raises up and just contrary to that of *Huayangosaurus*. The transverse constriction between the pre- and postacetabular process forms an obvious neck. The acetabulum is rather shallow, both pubic peduncle and the ischial peduncle are not developed. The pubis is slender, the iliac articular surface is half round. The prepubis is short and like a flat bar, with anterior end expanded, while the postpubis is tall and thin, slightly curved and stretches posterolaterally along the ventral part of the ischium, the distal end expands transversely, and attaches with the distal end of the ischium. The proximal end of the ischium expands and flips in lateral, the iliac surface transversely expands, and the shaft shrinks narrow, turn to medial as a lath, with distal end expanded.

Both femurs are preserved, the left femur is distorted by extrusion or injury when alive. The shaft is straight, 67 cm long with oval cross section. The ratio to humerus is 1.52, to tibia (50 cm) is 1.3, relative big femur. The proximal end expands, the femur head and the greater trochanter are developed, while the less trochanter is not, and the forth trochanter is like a low ridge, in the half of posterolaterally region of the femur. The distal end obviously expands, and the medial condyle slightly bigger than lateral one, the lateral condyle has a distinct groove for attaching tendons, and the posterior intercondylar groove is obvious.

The proximal end of the tibia is remarkably expanded, and the cnemal crest is developed. The shaft is straight and gets thinner in ventral, the narrowest part is close to the distal end. The cross section of the midlength shaft is triangular. The distal end expands with a transverse crest in anterolateral. The fibula is very thin, both ends expand slightly, and the shaft curved in lateral. The astragalus is wide in posterior and anterior narrow like a wowhead. The calcaneus is small, fused with the astragalus. Either end of the metatarsals is big, constricted shaft, the proximal surface is triangular, and the distal surface is pulley-shaped. Only the left phalanx III-1 is preserved, the proximal surface is slightly concave, and the distal surface is pulley-shaped.

4.4 Osteoderms

ZDM 0019 preserves 10 osteoderms (Fig. 5), but which was buried quite scattered, so that the arrangement of the osteoderms is unclear.

The osteoderms are varied in forms. The cervical osteoderms are triangular and thin, the articular surface is crude and oval. The dorsal osteoderns are relatively thick and peach-shaped, the articular surface is oval, and a crest exists in the anterior-middle region of the articular surface. The caudal osteoderns are small and solid, medial concave and lateral convex, there are two pits in the medioanterior of the osteodern.

This specimen preserves a pair of symmetrical parascapular spine on the shoulder. The parascapular spine consists of a very broad basal plate and a long also strong sharp spine, whose shape is very like a comma. Comparing with the parascapular spine of *Huayangosaurus* (ZDM 7010), which is yielded in the same dinosaur location in Dashanpu, Zigong. The basal plate of the parascapular spine in *Gigantspinosaurus* is sub-quadrangular, three sides of which are straight, with some small pit. The medial center of the proximal end of spine develops a big pit, and the lateral center has a deep and long longitudinal groove. The spine is curved, gradually tapers to the distal end. The spine and the basal plate are not in a same plane, the former projectes out of the latter one. Angle between spine and basal plate is big, degree of angle between the spine and the long axis of basal plate is 24. The parascapular spines of *Huayangosaurus* are not regular, about oval, hava big tubercles around it. The spine is slightly curved, and the angle between it and the long axis of the basal plate is obviously small than that of *Gigantspinosaurus*.

5 Disscusion

In order to determine the phylogenetic position of *Gigantspinosaurus* within Stegosauria, we perform the phylogenetic analysis based on the data matrix by Maidment 2010, which is comprised of 20 taxa and 89 characters, and a branch and bound search in using PAUP 4.0. Although Raven (2017) published a new matrix of stegosaurs, the fitness of some characters and the single MPTs should be reconsidered, so we still use that from Maridment (2010) which is more suitable for *Gigantspinosaurus*. Previous works made by Maidment 2008 and 2010 contain most valid stegosaurs except *Yingshanosaurus* and exclude *Jiangjunosaurus* due to the reliability. Although these works all cover *Gigantspinosaurus*, but are unavailable for the first-hand examination, so that the characters coding is inaccurate relative to our observation and description in this paper. After detailed study of this specimen, we update characters 18, 33, 51, 53, 72, 74, 75 and 88 in Maidment

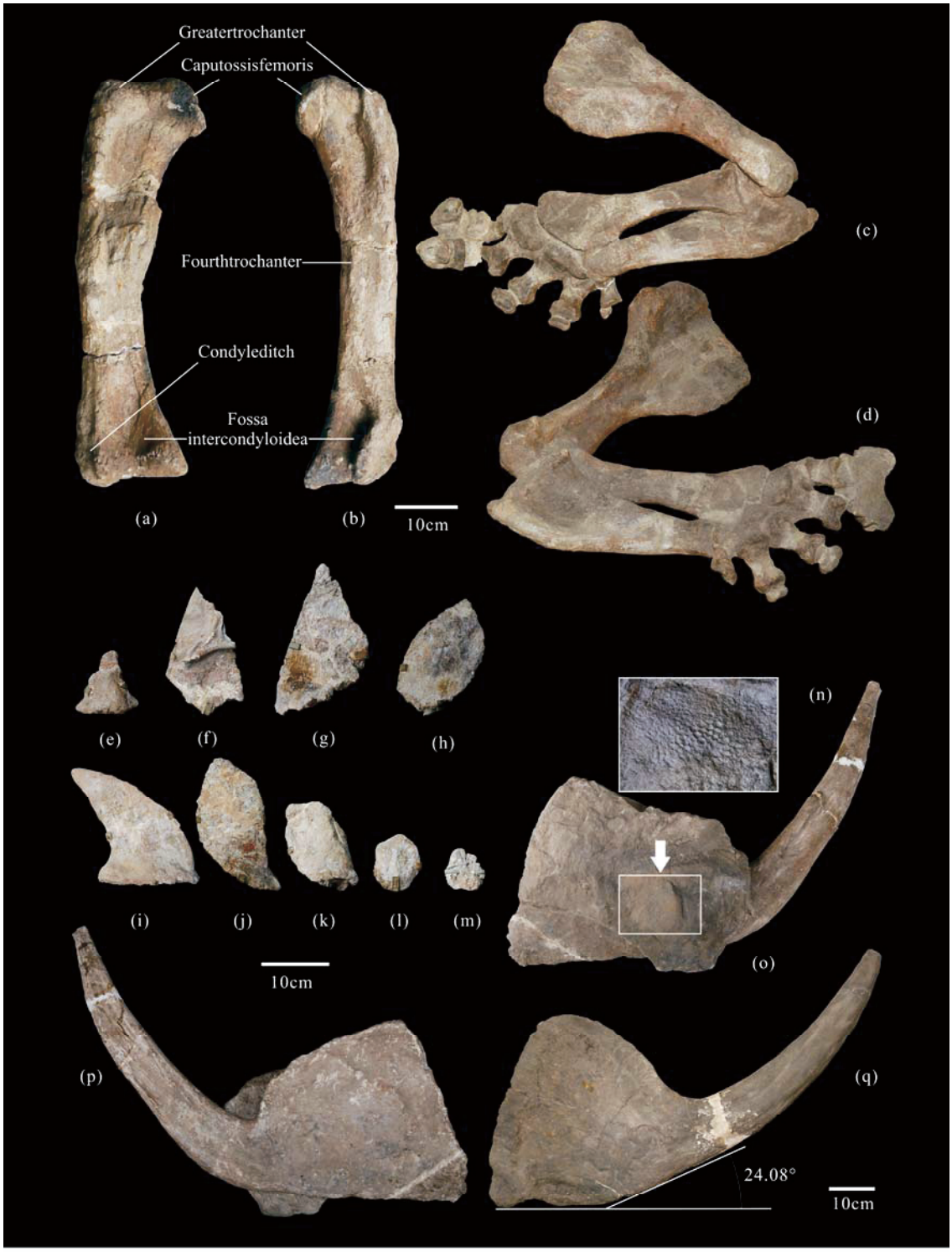

Fig. 5. Limb and Plate.
(a), left femur in posterior view; (b), right femur in posterior view; (c), left forelimb in dorsal view; (d), left forelimb in ventral view; (e),, left plate 1; (f), right plate 2; (g), left plate 3; (h), right plate 6; (i), right plate 9; (j), left plate 10; (k), right plate 13; (l), left plate 14; (m), right plate 15; (n), skin impression; (o), right parascapular spine in ventral view; (p), right parascapular spine in dorsal view; (q), left parascapular spine in dorsal view.

work. 18: The cingulum of the maxillary teeth exists or not: because the skull of *Gigantspinosaurus* is not preserved very well, and the maxilla is missing, so this character state is changed to ? ; 33: The anterior caudal vertebrae: could see process of dorsal region on the diapophysis; 51: Phalanx, if sharp of fingers and toes, because the elements of the left forelimb of *Gigantspinosaurus* are articulated and sharp like claw

rather than hoof, as 0; 53: Ilium, the reacetabular process of the ilium is narrow and prolate, as a vertical plate, the lateral convex and the medial concave, slightly dorsally bent and the strongly incline to the anterior, as 1; 72: Pubis, the posterior pubis is slender, slightly curved and expands to posteroventral along the ventral of the ischium, and the distal end slightly expands in transverse, as 1; 74: Pubis, the anterior pubis is short, like a flat plate, and the anterior end slightly expands, as 1; 75: Femur, the fourth trochanter presents as weakly ridges, on the half of the posteromedial femur, as 1; 88: The array of the osteoderms: combine the site map and repair, it is undefined as symmetrical or interlaced, as ?.

After these revisions of *Gigantspinosaurus*, the cladistic analysis is conducted and achieves 216 MPTs, and obtains the strict consensus tree and 50% majority consensus tree (Fig. 6), of which the length of the tree is 235 steps, with a CI of 0.783, a RI of 0.710 and a RC is 0.556. Obviously, after changing some morphological coding on *Gigantspinosaurus*, which is recovered as the sister group with *Huayangosaurus*, but the latter is still the most primitive stegosaurs, and *Gigantspinosaurus* exhibits some primitive characters, but still derived than *Huayangosaurus*. *Gigantspinosaurus* shows a big difference among Stegosauria, and reveals the diversity of the dinosaurs, expecially stegosaurs in whole China.

6 Conclusions

(1) The classic position of *Gigantspinosaurus* makes it the transitional forms between *Huayangosaurus* and *Tuojiangosaurus*, and much close to *Tuojiangosaurus*, indicating that it is a stegosaur during evolution. *Gigantspinosaurus* possesses some primitive characteristics as a relatively basal stegosaur, is located between the sister taxa of *Huangyangosaurus* + *Chungkingosaurus* and other Stegosauria, together with which constitutes the Huayangosaurinae.

(2) All of them have unclosed sacral foramen, the neural arch of the dorsal vertebrae is low, and the femur is slightly longer than the humerus, and the forth trochanter is small. However, we need to put forward that the ratio of femur/humerus of *Chungkingosaurus* is 1.62, which is greater than that 1.13 of *Huayangosaurus*. The ratio of

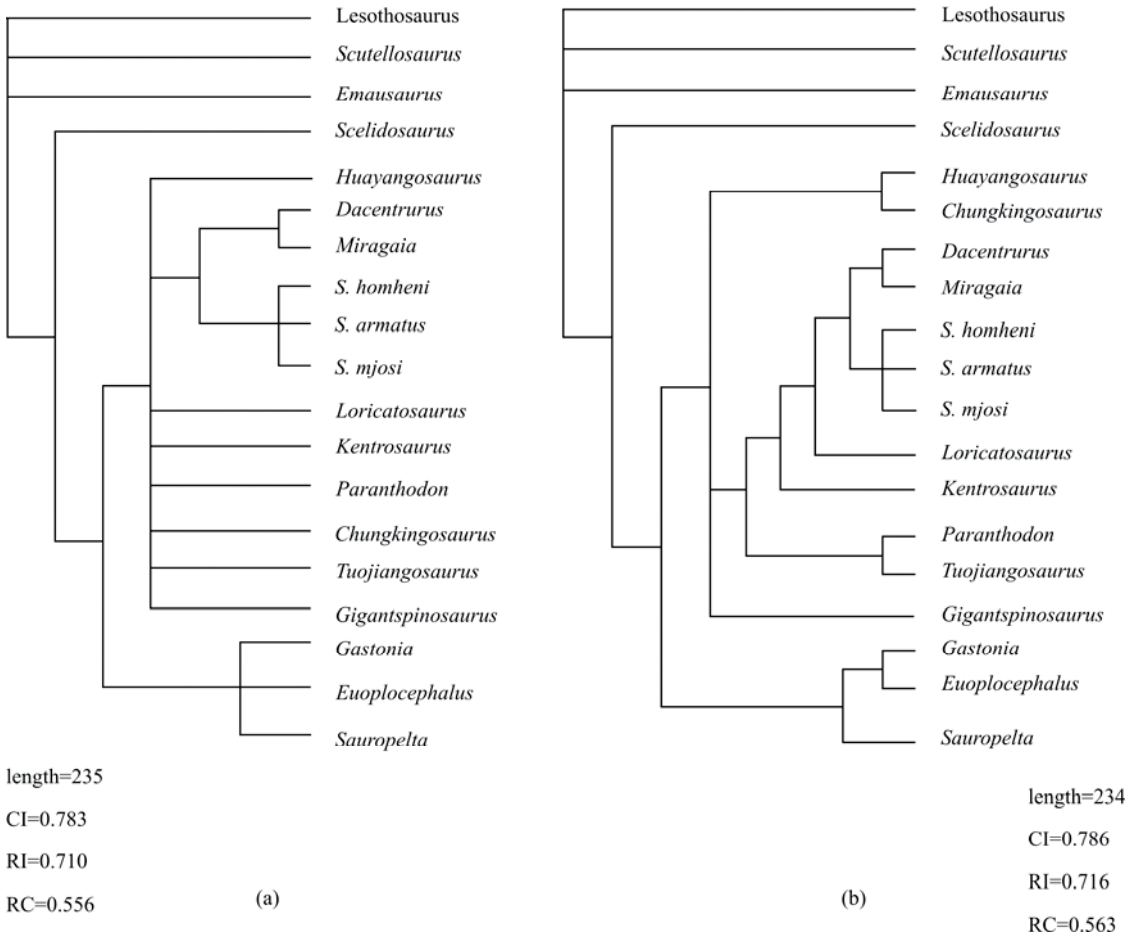

Fig. 6. The phylogenetic tree of stegosaurs.
(a), the strict consensus tree; (b), 50% majority consensus tree.

limbs is an important indicator to determine the evolution degree of Stegosauria, so the classification of *Chungkingosaurus* has not been discussed, also the relationship between the mentioned two taxa will be illustrated in another study.

(3) In addition, although the systematic tree describes the analysis of the *Jiangjunosaurus*, the taxonomic relationship of *Jiangjunosaurus* is not stable due to the morphological description or other vague problems. Therefore, the character coding for the *Jiangjunosaurus* should be re-examined, and the data matrix contains the Chinese specimens has a lot of work to do in the future.

Acknowledgements

We show our great appreciates to Mr. Huang Daxi, Mr. Ouyang Hui, and Mr. Jiang Shan for supporting the field work and geological materials, we also feel grateful to Mrs. Ling Man and Ms. Luo Shu for drawing figures in this paper. The current study was supported by Zigong Dinosaur Museum curator foundation.

Manuscript received Sept. 14, 2017
accepted Dec. 12, 2017
edited by Liu Lian

References

Barrett, P.M., and Upchurch, P., 1995. Regnosaurus northamptoni, a stegosaurian dinosaur from the Lower Cretaceous of southern England. *Geological Magazine*, 132: 213–222.

Berman, D.S., and McIntosh, J.S., 1986. Description of the lower jaw of Stegosaurus (Reptilia, Ornithischia). *Annals of Carnegie Museum*, 55: 29–40.

Bininda-Emonds, O.R.P., Bryant, H.N., and Russell, N.P., 1998. Supraspecific taxa as terminals in cladistic analysis: implicit assumptions of monophyly and a comparison of methods. *Biological Journal of the Linnean Society*, 64: 101–133.

Carpenter K., 2010. Species concept in North American stegosaurs. *Swiss Journal of Geosciences*, 103: 155–162.

Chappill, J.A., 1989. Quantitative characters in phylogenetic analysis. *Cladistics*, 5: 217–234.

Dong Zhiming, 1973. Dinosaurs from Wuerho. *Institute of Paleontology and Paleoanthropology Memoir*, 11: 45–52 (in Chinese with English abstract)

Dong Zhiming, Li Xuemin and Zhou Shiwu, 1977. On the Stegosaurian remin from Zigong (Tzekung), Zsechuan Province. *Vertebrata Palasiatica*, 15(4): 307–312 (in Chinese with English abstract)

Dong Zhiming, Tang Zhilu and Zhou Shiwu, 1982. Note on the new Mid-Jurassic Stegosaurian from Sichuan Basin, China. *Vertebrata Palasiatica*, 20(1): 83–86 (in Chinese with English abstract)

Dong Zhiming, Zhou Shiwu and Zhang Yihong, 1983. *The dinosaurian remaims from Sichuan Basin, China*. Ancient China, No. 23. 147 (in Chinese with English abstract)

Dong Zhiming, 1990. Stegosaurs of Asia, in: Carpenter, K. and Currie J. (eds.). *Dinosaur Systematics*. Cambridge: Cambridge University Press, 255–268.

Ford, Tracy, L., 2006. Stegosaurs: plates, splates, and spikes, part 1. *Prehistoric Times*, 76: 20–21.

Galton, P.M., and Upchurch, P., 2004. Stegosauria. Pp. 343–362 in: Weishampel, D.B., and Dodson, P. (eds) *The Dinosauria* (2nd edition). University of California Press: Berkeley, 232–258.

Gao Renyan, Zhu Shida and Huang Daxi, 1986. The stegosaurus shoulder spine materials found in Zigong, *Vertebrata Palasiatica*, 24(1): 78–79 (in Chinese with English abstract)

Guo Xiangqi, Xu Li and Jia Songhai, 2018. Morphological and Phylogenetic study based on new materials of anchiornis huxleyi (dinosauria, theropoda) from Jianchang, Western Liaoning, China. *Acta Geologica Sinica* (English Edition), 92 (1): 1–15.

Jia Chengkai, Catherine A. Forster, Xu Xing, James M. Clark, 2007. The first stegosaur (Dinosauria, Ornithischia) from the Upper Jurassic Shishugou Formation of Xinjiang, China. *Acta Geologica Sinica* (English Edition), 81(3): 351–356.

Jiang Shan, Peng Guangzhao and Ye Yong, 2015. The stegosaur fossils in China. *Journal of Geology*, 39(4): 530–534 (in Chinese with English abstract)

Lull, R.S., 1910. Stegosaurus ungulatus Marsh, recently mounted at the Peabody Museum of Yale University. *American Journal of Science*, 30(180): 361–377.

Lv Junchang, Xu Li, Chang Huali and Zhang Xingliao, 2011. A New Darwinopterid Pterosaur from the Middle Jurassic of Western Liaoning, Northeastern China and its Ecological Implications. *Acta Geologica Sinica* (English Edition), 85(3): 507–514.

Maidment, S.C.R., and Norman, D.B., 2006. Re-description of the postcranial skeleton of the middle Jurassic stegosaur *Huayangosaurus taibaii*. *Journal of Vertebrate Paleontology*, 26: 944–956.

Maidment, S.C.R., and Wei Guangbaio, 2006. A review of the Late Jurassic stegosaurs (Dinosauria, Stegosauria) from the People's Republic of China. *Geological Magazine*, 143: 621–634.

Maidment, S.C.R., Norman, D.B., 2008. Syshaftatics and phylogeny of Stegosauria (Dinosauria: Ornithischia). *Journal of Syshaftatic Palaeontology*, 6(4): 367–407.

Maidment, S.C.R., 2010. Stegosauria: A historical review of the body fossil record and phylogenetic relationships. *Swiss Journal of Geosciences*, 103: 199–210.

Maidment, S.C.R., Brassey, C., and Barrett P.M., 2015. The postcranial skeleton of an exceptionally complete individual of the plated dinosaur stegosaurus stenops (Dinosauria: Thyreophora) from the Upper Jurassic Morrison Formation of Wyoming, U.S.A. *Plos One*, 10: 10.

Marsh, O.C., 1877. A new Order of extinct Reptilia (Stegosauria) from the Jurassic of the Rocky Mountains. *American Journal of Science*, 3rd series 14: 34–35.

Olshevsky, G., 1993. The origin and evolution of the stegosaurs. *Dinosaur Frontline*, 4: 64–103.

Ouyang Hui, 1991. New discovery of upper Jurassic stegosaurian skin from Zigong, Sichuan. *Journal of Chengdu College of Geology*, 18（3）: 38–39 (in Chinese with English abstract)

Ouyang Hui, Pi Xiaozhong and Ye Yong, 1998. A new discovery of sauropod skin fossil from Zigong, *Sichuan. Jmineral Petrol*, 18(1): 146–149 (in Chinese with English abstract).

Paul, G.S., 2010. *The princeton field guide to dinosaurs*. Princeton University Press, 222.

Peng Guangzhao, Ye Yong, Gao Yuhui, Shu Chunkang and Jiang Shan, 2005. *Jurassic dinosaur faunas in Zigong*. Chengdu: sichuan people's publishing house, 236 (in Chinese with English abstract)

Raven, T.J., and Maidment, S.C.R., 2017. A new phylogeny of Stegosauria (Dinosauria, Ornithischia). *Palaeontology*, 60(3): 401–408.

Sereno, P.C., 1986. Phylogeny of the bird-hipped dinosaurs (order Ornithischia). *National Geographic Research*, 2: 234–256.

Thorley, J.L., and Page, R.D.M., 2000. RadCon: phylogenetic tree comparison and consensus. *Bioinformatics*, 16: 486–487.

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

Wiens, J.J., 2001. Character analysis in morphological phylogenetics: problems and solutions. *Syshaftatic Biology*, 50: 689–699.

Xing Lida, Peng Guangzhao and Shu Chunkang, 2008. Stegosaurian skin impressions from the Upper Jurassic Shangshaximiao Formation, Zigong, Sichuan, China: a new observation. *Geological Bulletin of China*, 27: 1049–1053.

Yadagiri, P., and Ayyasami, K., 1979. A new stegosaurian dinosaur from the Upper Cretaceous sediments of south India. *Journal of the Geological Society of India*, 20: 521–530.

Yang Zhongjian, 1959. A new stegosaurus from Qu county, Sichuan province. *Vertebrata Palasiatica*, 3(1): 1–8 (in Chinese).

Yang Jingtao, You Hailu, Xie Li, and Zhou Hongrui, 2017. A New Specimen of Crichtonpelta benxiensis (Dinosauria: Ankylosaurinae) from the Mid-Cretaceous of Liaoning Province, China. *Acta Geologica Sinica* (English Edition), 91 (3): 781–790.

Zhao Xijin, 1983. Phylogeny and evolutionary stages of Dinosauria. *Acta Palaeontologia Polonica*, 28(1/2):295–306 (in Chinese with English abstract).

Zhu Songlin, 1994. A stegosaurus fossil from YingShan county, Sichuan province. *Sichuan Cultural Relics*, 1: 8–14 (in Chinese with English abstract).

Zhou Shiwu, 1984. *The Middle Jurassic dinosaurian fauna from Dashanpu, Zigong, Sichuan (Stegosaurs)*. Sichuan science and technology publishing house, 52 (in Chinese with English abstract).

About the first author

HAO Baoqiao, male; born in 1984, Hebei Province, China; master; graduated from Yunnan Key Laboratory for Paleobiology, Yunnan University in 2011.He is working at Zigong Dinosaur Museum and interested in researching vertebrate palaeontology. Email: haobaoqiao1984@163.com; phone: 18081663044.