A primitive ichthyosaur from the Lower Triassic of Zhebao, Guangxi Province, southwestern China (#61178)

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A primitive ichthyosaur from the Lower Triassic of Zhebao, Guangxi Province, southwestern China

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Ichthyosaurs are a group of reptiles that are highly adapted to aquatic life, but the origin and early evolution of ichthyosaurs were still rarely known due to the incompleteness of the fossil record. Here, we describe a newly discovered primitive ichthyosaur collected from the Lower Triassic Luolou Formation, Zhebao region, northwest margin of the Nanpanjiang Basin. This specimen was partially preserved that contains the ribs, gastralia, a femur, 12 centra, and 7 isolated neural arches. It was identified to be a basal ichthyosaur based on the presence of unique combination features of primitive ichthyosaurs, including the strongly amphicoelous vertebrae with a low height to length ratio, an elongated femur, and single-headed ribs. The centra of this specimen are similar to other primitive ichthyosaurs from South China, such as *Chaohusaurus*, but the extremely elongated femur is an unusual feature in the primitive ichthyosaurs. The specimen was a sub-adult individual based on the presence of LAGs, and has a relatively large body size (estimated to be more than 240 cm) compared with other primitive ichthyosaurs. The new specimen is also the first record discovery of ichthyosaur in Guangxi Province, extending the geographic distribution of ichthyosaur in South China.

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Abstract

Ichthyosaurs are a group of reptiles that are highly adapted to aquatic life, but the origin and early evolution of ichthyosaurs were still rarely known due to the incompleteness of the fossil record. Here, we describe a newly discovered primitive ichthyosaur collected from the Lower Triassic Luolou Formation, Zhebao region, northwest margin of the Nanpanjiang Basin. This specimen was partially preserved that contains the ribs, gastralia, a femur, twelve centra, and seven isolated neural arches. It was identified to be a basal ichthyosaur based on the presence of unique combination features of primitive ichthyosaurs, including the strongly amphicoelous vertebrae with a low height to length ratio, an elongated femur, and single-headed ribs. The centra of this specimen are similar to other primitive ichthyosaurs from South China, such as *Chaohusaurus*, but the extremely elongated femur is an unusual feature in the primitive ichthyosaurs. The specimen was a sub-adult individual based on the presence of LAGs, and has a relatively large body size (estimated to be more than 300 cm) compared with other primitive ichthyosaurs. The new specimen is also the first recorded discovery of Early Triassic ichthyosaur in Guangxi Province, extending the geographic distribution of ichthyosaur in South China

Introduction

The Ichthyosauria is a group of Mesozoic marine reptiles with large eyes and fish-shaped bodies that were highly adapted to the aquatic environment (Sander 2000; Motani 2009). They first appeared in the Lower Triassic Spathian (Sander 2000) and had a cosmopolitan distribution until their extinction in early Late Cretaceous Cenomanian (Zammit & Maria 2012). The early evolution of ichthyosaurs is still being studied but new primitive ichthyosaurs from the Early Triassic found in recent years strongly improved their key evolution (Motani et al. 2015a; Jiang et al. 2016).

To date, about 12 genera of ichthyosaurs have been reported in the Early Triassic, but some of them were considered to be *nomen dublium* (Table 1). The fossil records of primitive ichthyosaurs are mainly distributed in South China (Young & Dong 1972; Chen et al. 2013), Spitsbergen (Wiman 1910; Wiman 1929; Callaway & Massare 1989; Maisch & Matzke 2003a) and Canada (Nicholls & Brinkman 1995; Cuthbertson et al. 2013). Ichthyosaur materials are also found in Thailand (Mazin et al. 1991) and Japan (Shikama et al. 1978).

The Vikinghøgda Formation in Spitsbergen preserved a large number of Early Triassic ichthyosaur fossils and has erected five species (Table 1). *Grippia longirostris* (Wiman 1929; Motani 2000b; Hansen et al. 2018) is one of the earliest discovered species among them, and an undeterminate species of *Grippia* was later found in Canada (Brinkman et al. 1992). *Pessopteryx nisseri* (Wiman 1910) was thought to be invalid because of its doubtful jaw fragments (Fern et al. 2003) but was analyzed to be a valid genus by phylogenetic analysis (Maisch 2010), and the giant *Merriamosaurus hulkei* (Maisch & Matzke 2003a), which might be the largest ichthyosaur in Early Triassic (length might reach 6 m), was also considered as a synonym of *P. nisseri* (Maisch 2010). *Quasianosteosaurus vikinghoegdai* (Maisch & Matzke 2003b) is a large ichthyosaur with the cranial length of at least 50 cm. *Omphalosaurus* (Merriam 1908; Ekeheien et al. 2018) has been questioned because of the incompleteness of the fossil record and the presence of several sauropterygian features (Motani 2000a), but most researches have suggested that it is most likely to be an ichthyosaur (Faber 2003; Ekeheien et al. 2018). *Isfjordosaurus minor* (Wiman 1910) is the most questionable species, with only an isolated humerus preserved (Maisch 2010).

In Canada, primitive ichthyosaurs are found in the Lower Triassic members of the Sulphur Mountain Formation in the Wapiti Lake area, British Columbia (Callaway & Brinkman 1989), including *Parvinatator wapitiensis* (Nicholls & Brinkman 1995) and *Gulosaurus helmi* (Cuthbertson et al. 2013). *Grippia* and *Utatsusaurus* were also discovered in the Sulphur Mountain Formation (Brinkman et al. 1992; Nicholls & Brinkman 1993).

The Early Triassic ichthyosaurs are abundant in Southern China, including three genera and six species. Four species of *Chaohusaurus* have been established. *Chaohusaurus geishanensis* (Young & Dong 1972) is the first Early Triassic ichthyosaur described in China, and it is also known as one of the smallest ichthyosaurs with a length of only 70 cm. *Anhuisaurus chaoxianensis* (Chen 1985) is a *nomen dubi*[illegible], because it has been used on a species belongs to Lepidosauria before (Hou 1974), thus it has been renamed as *Chensaurus chaoxianensis* (Mazin et al. 1991; Mazin & Sander 1993). But the allometric growth series test showed that *Chensaurus* is the la[illegible] stage of *Chaohusaurus* (Motani & You 1998a; Motani et al. 2015b) and now ascribe to be *Chaohusaurus chaoxianensis* (Motani & You 1998a; Motani et al. 2015b). The third species is *C. zhangjiawanensis* discovered in the Jialingjiang Formation in Hubei Province (Chen et al. 2013). The fourth species is *C. brevifemoralis*, was described in 2019 based on its difference in forelimb, femora, and neural arch with *C. chaoxianensis* (Huang et al. 2019). The other two taxa, *Sclerocormus breviceps* (Jiang et al. 2016) and *Cartorhynchus lenticarpus* (Motani et al. 2015a) have a short skull and a strong forelimb. Both of them have been considered as the most basal ichthyosauriformes (Jiang et al. 2016), and show the transition form between terrestrial and aquatic life[illegible]

Utatsusaurus hataii discovered in Japan is known as one of the most basal ichthyosaurs (Shikama et al. 1978). In recent phylogenetic analysis (Jiang et al. 2016), *Utatsusaurus* is considered more advance than *Chaohusaurus* and more primitive than all the other species in ichthyopterygia. *Thaisaurus chonglakmanii* (Mazin et al. 1991) might be more primitive with a unique combination feature of its skull and limb, but still need further study (Liu et al. 2018).

In 2017, a Guizhou Geological Survey field crew collected a primitive ichthyosaur from the Lower Triassic Luolou Formation in the northwest margin of the Nanpanjiang Basin, Zhebao region, Guangxi Province (Fig. 1). The Luolou Formation is 98 meters thick and can be divided into 22 beds from bottom to top, and the ichthyosaur described here was found at bed 14, which is light gray medium-thin-beds ammonite limestone intercalated with calcareous mudstone, containing a large number of ammonite and bivalves, and a variety of conodonts at the bottom. The crystal tuff bed LA ICP-MS zircon U-Pb age was 248.6 ± 2.0 Ma, and the ichthyosaur age is determined at the Early Triassic Spathian Substage, Olenekian Stage (Xiang et al. 2020).

Here, we give a detailed description of this ichthyosaur for the first time, which will provide a supplement to the ichthyosaur fossil records in the Early Triassic, and will be significant to the early evolution and paleogeographic distribution of ichthyosaurs.

Materials & Methods

The specimen described here is housed in the School of Earth Sciences, China University of Geosciences (Wuhan) with a collection number of CUGW VH107.
There is only a small part of the ichthyosaur trunk preserved in CUGW VH107, including an isolated femur, some dorsal vertebrae (contains twelve centra and seven neural arches, most of them are separated), gastralia and ribs. Most of these bones have surface striations or spongy internal structures (Fig. 2). The skeletons are very scattered but well preserved in every single element, even the slender gastralia which could be easily broken were completely preserved. This phenomenon suggests that CUGW VH107 is nearly under in-situ preservation, and the underflow has disturbed the original bone after the corruption of muscle, finally forms the dislocation arrangement characteristics seen in the specimen (Xiang et al. 2020). A large isolated element at the corner of the fossil plate (left upper corner of Fig. 2), has a curved triangle outline and a rough surface. It is supposed not a bone due to the lack of any surface striations or spongy internal structures.

Bone histology was also studied to estimate the growth stage of CUGW VH107. The sample is taken from the distal part of the rib, embedded by Araldite-2020 one-component resin, cut with an STX-202A diamond wire automatic microtome, and ground to a thickness of about 100 µm with P400, P800, P1000 and P2000 abrasive paper. The polished thin section was then observed under transmitted and polarized light. The section slide was photographed using a ZEISS Primotech optical microscope.

Results

Systematic Paleontology

Class Reptilia Linnaeus, 1758
Subclass Diapsida Osborn, 1903
Superorder Ichthyopterygia Owen, 1840
Order Ichthyosauria Blainville, 1835
Ichthyosauria indet

Description

Vertebrae. There are twelve isolated centra and seven recognizable neural arches preserved (Fig.3A). The centra are supposed to be the anterior dorsal centra based on their blunt hexagonal shape on their anterior and posterior faces (Roaldset 2017). In the preserved first centrum, the midsagittal section is exposed and showing a strong amphicoelous type (Fig.3C). In the second centrum, the lateral and anterior surfaces are partly missing. The lateral surfaces are exposed in the 3rd, 4th, 6th, 7th, 8th, 9th and 10th centrum, and the anterior surfaces are exposed in the 5th, 11th and 12th centrum. The 10th, 11th and 12th centrum are almost completely preserved. The 1st, 4th, 5th, 6th and 7th neural arches are exposed on their lateral side. The 2nd and 3rd neural arches are compressed on the anteroposterior orientation and show their posterior face. All the neural arches have been preserved from their root to the neural spine, and the 3rd, 6th and 7th neural arches were almost completely preserved, but only centrum 12 articulates the neural arch, indicating that the connection between the centrum and the neural arch is not very [illegible]n.

The lateral surface of the centra are sub-rectangular in outline (with an average height to length ratio of about 1.15). The ventral surface is smooth and arched dorsally with the highest point at the middle part (Fig. 3A, Centrum NO. 6, NO. 10). The anterior surface of the centrum is a blunt rounded hexagonal, and the posterior surface is circular (Fig. 3A, Centrum NO. 5 and NO. 11) in outline. A large parapophysis is present on the lateral surface of the anterior dorsal centrum (Fig. 3B). It is sub-triangular in outline and extends to the mid-region of the centra. It tapers ventrally along the anterior margin of the centra. The dorsal region combines with the neural arch facet. The neural arch articular facets are prominent and rugose, and the floor of the neural canal is deeply and narrowly excavated, extends symmetrically from anterior to posterior (Fig. 3C).

The prezygapophyses and postzyga[illegible]yses are well developed (Fig. 3B), extending anteriorly and posteriorly to the nearly same length of the anterior and posterior edge of the centrum. The diapophyses of the neural arches are well developed and robust, extending laterally. The anterior and dorsal surfaces are convex whereas the posterior margin is concave. In lateral view, the dorsal region is narrower and extends posterodorsally. The ventral part is damaged but may be articulated with the paraphophysis based on the articular facet of centrum NO. 10 and neural arch NO. 6 are generally anastomosis, and they form a large synapophysis together (Romer 1956), where the single-headed rib connected with both the centrum and the neural arch. This type of articulation can be seen in *Hupehsuchians* (Young 1972; Robert et al. 1991; Zhao et al. 2016) and *Chaohusaurus brevifemoralis* (Huang et al. 2019). The prezygaphysis is well persevered in neural arch NO. 7, and there is a smooth concave surface between it and the diapophysis (Fig.

3B). A deep fossa is present between the diapophysis and the postzygapophyses (Fig. 3B and D), and this fossa is not seen in the other primitive ichthyosaurs and may represent an autapomorphies.

The neural spine is relatively vertical, tall and narrow (Fig. 3D), and it becomes anteroposteriorly width towards the distal end. The anterior margin is thin and slightly concave, the posterior margin is straight in the distal part and is concave in the proximal part. The neural spine is relatively thin in the anterior and posterior margin, and is thickest in the middle part (Fig. 3D). Furthermore, a pair of small triangular processes are present at the mid-region of the posterior margin. It has an oval concave surface facing posteroventrally (Fig. 3D). This small process is also not seen in other primitive ichthyosaurs. In general, the neural spine in the anterior dorsal region of CUGW VH107 is similar to that of *Utatsusaurus hataii* (Shikama et al. 1978), as their neural spine both located above the middle part of the centrum and have a broad, tall and straight outline (nearly vertical, maybe slightly inclined backward). It is different from *C. brevifemoralis*, which is located above the anterior part of the centrum in anterior dorsal and is significantly smaller in height (Huang et al. 2019).

The preserved anterior dorsal centra have a height to length ratio (H/L ratio) between 1.03 to 1.27, with an average of 1.15 (Table 2). This is similar to that of *Utatsusaurus* (1.1-1.2) (Shikama et al. 1978), a bit larger than *Chaohusaurus* (0.9-1.1) (Sander 2000), and smaller than *Grippia* (1.27) (Roaldset 2017), *Omphalosaurus* (about 1.3) (Faber 2003) and all the other species living in the Late Triassic and after. The H/L ratio indicates CUGW VH107 might be a very basal species closely related to *Chaohusaurus* and *Utatsusaurus*.

Ribs. There are about thirty recognizable ribs preserved in CUGW VH107. Some of them are almost completely preserved and some are broken. The ribs are generally long and thin, and have a length between 100 mm to 200 mm (Fig. 4A). The proximal part of the rib is thick and curved dorsally, while the distal part becomes thin and straight. All the ribs are single-headed, with only one rib head connected directly to the centrum. The dorsal surface of the rib proximal part raised up and expanded into the rib head, which has the shape of a trapezoid from the proximal view (Fig. 4A and B).

In most cases, the ribs of ichthyosaurs commonly show an anterior and posterior groove, producing a biconcave cross-section (Sander 2000). In CUGW VH107, the groove only exists in the proximal and the middle part of the rib, became shallow and finally disappeared toward the distal end, thus the biconcave cross-section can only be seen in the proximal and the middle part of the rib, as it gradually changes to a circular section in the distal part (Fig. 4B, red and black arrow).

Gastralia. Due to later flow disturbance, the gastralia of CUGW VH107 were separated and the original contact relationship could not be identified clearly. There are two types of gastralia: The

Y-shaped median element and the long lateral element, one median element is flanked by a pair of slender lateral elements. The Y-shaped median element consists of two long lateral splints and a short middle process, the angle between two lateral splints is about 150°, and the angle between the lateral splint and the middle process is about 100°. The shape of the lateral element is a single bar which is thin in the edge and thick in the middle part (Fig. 4C). In this specimen about seven complete median elements and more than seven pairs of lateral elements can be confirmed, they are rather slender and considerably thinner than the ribs. The gastralia are all small elongated elements with rounded cross-sections, and their thickness is less than a quarter of that of the ribs. The width of a single median element is about 68.5 mm.

Femur. The isolated limb element is considered as the femur based on its slender shaft and the presence of two articular facets at the distal end (Huang et al. 2019). The femur is elongate with a maximum length and width of 69.8 mm and 32.1 mm, respectively. It is subrectangular in outline with both of the proximal and distal ends expanded. The dorsal/ventral surface exposed a number of radial bone striations. The anterior edge of its shaft is straight whereas the posterior edge is concave. The outline of its proximal extremity is a smooth concave surface, and the outline of its distal extremity is a broken line with two articular facets for tibia and fibula, the tibial facet is larger than the fibular facet (Fig. 4D). The angle between the two facets is about 120°.

In the Early Triassic, the hindlimb bones of most ichthyosaurs are short and not very developed (Chen et al. 2013; Huang et al. 2019). But in the femur of CUGW VH107, its maximum length/width ratio reaches 2.33, which is larger than that of many other Early Triassic ichthyosaurs which have shortened and robust femurs, such as *Chaohusaurus* (1.33) (Motani & You 1998b) and *Grippia* (about 1.4) (Mazin 1981; Mazin & Sander 1993; Roaldset 2017). A similar elongated femur can be seen in *Thaisaurus chonglakmanii* (Mazin et al. 1991; Mazin & Sander 1993) with a L/W ratio of 2.27 and in *Utatsusaurus hataii* (Shikama et al. 1978) with a L/W ratio of about 1.6. Both of their femora have a relatively straight anterior margin and a curved posterior margin. However, in *T. chonglakmanii* and *U. hataii* the femur only expanded at the distal end, whereas in CUGW VH107 both of the proximal and distal ends are expanded. The elongated femur may suggest that CUGW VH107 has a hindlimb much longer and stronger than most other primitive ichthyosaurs.

Bone histology. The section was taken from the distal part of the rib. The microstructure of the distal rib sections has a large medullary cavity with some trabeculae (Fig. 5). The cortex is very thin with a few longitudinal vascular canals. Large erosional cavities are shown in the inner region. A growth line can be seen in the outer cortex (Fig. 5D), suggesting that CUGW VH107 grew slowly when it died and may have reached an early-subadult stage (Kolb et al. 2011; Houssaye et al. 2014; Nakajima et al. 2014).

Discussion

CUGW VH107 shows the combination of many typical ichthyosaur characters, including shortened flat disc-shaped centrum strongly amphicoelous, the presence of synapophysis as in primitive ichthyosaurs, the single-headed rib connected with both the centrum and the neural arch, and an elongated femur that is comparable with some ichthyosaurs but shorter than most of sauropterygians (Sander 2000; Cheng 2015). CUGW VH107 preserved many characters that are comparable with other Asian ichthyosaurs such as *Chaohusaurus*, but also have some unique features (e.g., the deep fossa between the diapophysis and the postzygapophysis, the small subround process on the posterior margin of the neural spine) that are not seen in other primitive ichthyosaurs.

CUGW VH107 shares some characters with *Chaohusaurus*. The anterior dorsal vertebrae have a large synapophysis formed by a ventral half (parapophysis) and a dorsal half (diapophysis), and the single-headed rib connected with both the centrum and the neural arch (Huang et al. 2019). However, their synapophyses differ from each other. In CUGW VH107, the synapophysis ventral half is an elongated sub-rectangle with a smooth outline, and the dorsal half is more developed with a convex anterior and dorsal surface, whereas in *Chaohusaurus* it has a triangular ventral half and a sub-rectangle dorsal half slightly curved backward (personal observation).

On the neural arches of the anterior dorsal region, both CUGW VH107 and *Chaohusaurus* have well-developed zygapophyses, which mainly existed in Early Triassic ichthyosaurs but are strongly reduced in more advanced species (Sander 2000). However, the neural spines of anterior dorsal vertebrae are located on the middle part of the centrum and have broad, tall, and straight outlines, whereas in *Chaohusaurus*, they are located on the anterior parts of the centra in anterior dorsals, and are much shallower (Huang et al. 2019).

In CUGW VH107, the femur is elongated (has a maximum length/width ratio of 2.33) with broadened proximal and distal ends. This is completely different from *Chaohusaurus* (Motani & You 1998b; Huang et al. 2019), as the femur of *Chaohusaurus* is a shortened robust bone with a L/W ratio of 1.33.

Utatsusaurus is another well-known primitive ichthyosaur in Asia. In *Utatsusaurus*, the proximal end of the ribs in anterior dorsal region are jointed with the anteroventral corner of the centra, and the parapophysis has an obscure outline (Shikama et al. 1978). These features are different from the pattern of single-headed ribs connected with both the centra anterodorsal corner and neural arch in CUGW VH107. A broad and vertical neural spine similar to CUGW VH107 is present in *Utatsusaurus* (Shikama et al. 1978). *Utatsusaurus* also have an elongated femur similar to CUGW VH107, but there are detailed differences between them: in CUGW VH107 the femur expanded at both the proximal and distal extremities, and in *Utatsusaurus* the femur only expanded at the distal extremity (Shikama et al. 1978). A similar elongated femur is also seen in *Thaisaurus* (Mazin et al. 1991; Mazin & Sander 1993), but the specimen of *Thaisaurus* is incomplete and still needs a further study (Liu et al. 2018), it is hard to draw more comparisons between them.

Comparing with other primitive ichthyosaurs discovered in Europe, such as *Grippia* and *Omphalosaurus*, both of their anterior dorsal parapophyses have a similar shape of elongated sub-rectangle, but the rib articulation pattern is different (Wiman 1929; Sander & Faber 1998; Roaldset 2017). In *Omphalosaurus*, it is supposed that the single-headed rib connected only with the centrum but not with the neural arch, and the parapophysis & diapophysis are not as developed as that of CUGW VH107 (Faber 2003; Ekeheien et al. 2018). The centrum H/L ratio of *Omphalosaurus* is more than 1.3, much larger than CUGW VH107 (Ekeheien et al. 2018). The morphology of the neural arch of *Grippia* is rarely known, but on the centrum, the parapophysis of *Grippia* is not as developed as CUGW VH107 (Roaldset 2017). Furthermore, *Grippia* does not have an elongated femur, as its femur L/W ratio is about 1.4.

The body size of CUGW VH107 is much larger than *Chaohusaurus*, as the preserved 10 measurable dorsal centra in CUGW VH107 has an average length of 27.83 mm and in *Chaohusaurus* the centrum length is always less than 10 mm (Young & Dong 1972; Chen et al. 2013; Huang et al. 2019). We have made a primary estimation of its body length comparing with *Chaohusaurus* and *Utatsusaurus*, as they have shown most similarities with CUGW VH107. In the holotype (AGB7401) of *C. brevifemoralis* (Huang et al. 2019), the average length of anterior dorsal vertebrae is about 7 mm and its total length is about 80 cm. If the amount and proportion between their vertebrae are similar, the total length of CUGW VH107 would reach 318 cm. In the holotype (NO. K_1) of *U. hataii* (Shikama et al. 1978), the average length of anterior dorsal vertebrae is about 13.8 mm, and its total length is about 140 cm. If using *U. hataii* as the sample, the estimated length of CUGW VH107 would be 282 cm. Thus, CUGW VH107 may have a total length of about 300 cm. Considering the fact of CUGW VH107 is still an early-subadult individual, it might be even longer after it reaches adulthood. This is a large size among Early Triassic ichthyosaurs (e.g., *Chaohusaurus*, 70-140 cm; *Utatsusaurus*, 140-200 cm; *Gulosaurus* and *Grippia*, less than 120 cm; *Parvinatator*, 80-100 cm) (Young & Dong 1972; Shikama et al. 1978; Nicholls & Brinkman 1995; Cuthbertson et al. 2013; Roaldset 2017; Huang et al. 2019).

Conclusions

As a newly reported primitive ichthyosaur from Early Triassic, the main identification characters of CUGW VH107 are the single-headed rib connected with the synapophysis, the developed zygapophysis and an elongated femur. The type of articulation between the synapophysis and singled-headed ribs suggests that CUGW VH107 has a relatively high morphological similarity with *Chaohusaurus* in general, but they are clearly distinguished through the size of their centrum and the extremely elongated femur. The centrum H/L ratio, the straight neural spine and the elongated femur is similar to *Utatsusaurus*, but the femur proximal extremity in CUGW VH107 is expanded and in *Utatsusaurus* is not. These unique feature combinations are shown in CUGW VH107, and the differences between it and *Chaohusaurus* & *Utatsusaurus* may suggest that CUGW VH107 represents a new ichthyopterygian species with a large body size living in the eastern Paleo-Tethys. It is also the first record of the ichthyosaur in Guangxi Province in the Early Triassic, and together with two new species of *Chaohusaurus* (Chen et al. 2013; Huang et al. 2019), *Cartorhynchus* (Motani et al. 2015a) and *Sclerocormus* (Jiang et al. 2016), these recent discoveries have expanded the geographical distribution of ichthyosaur in China, and call for further studies of the paleoecology and paleogeography of Early Triassic ichthyosaurs to understand the rise of the new ecosystem at the eastern margin of Paleo-Tethys. In general, the discovery of CUGW VH107 has an important paleogeographic significance and suggests a higher taxonomic diversity of South China ichthyopterygian fauna in Spathian, Early Triassic.

Acknowledgements

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Figure 1

Fossil location.

The specimen was found in Zhebao region, northwest of Baise City, Guangxi Province.

Figure 2

Photograph and outline drawing of CUGW VH107.

It shows semi-articulated incomplete vertebrae, forelimb, ribs and gastralia. **Abbreviations**: **Dv**, dorsal vertebrae; **F**, femur; **G**, gastralia; **R**, ribs.

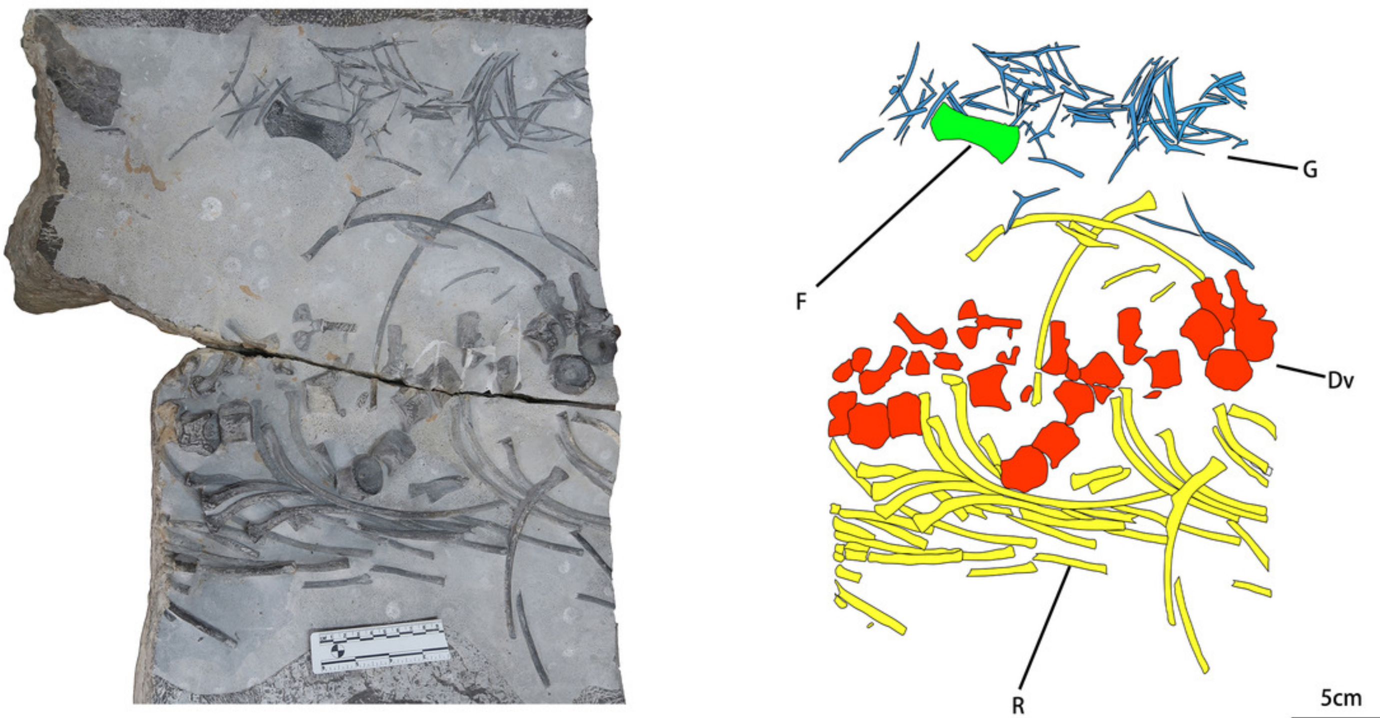
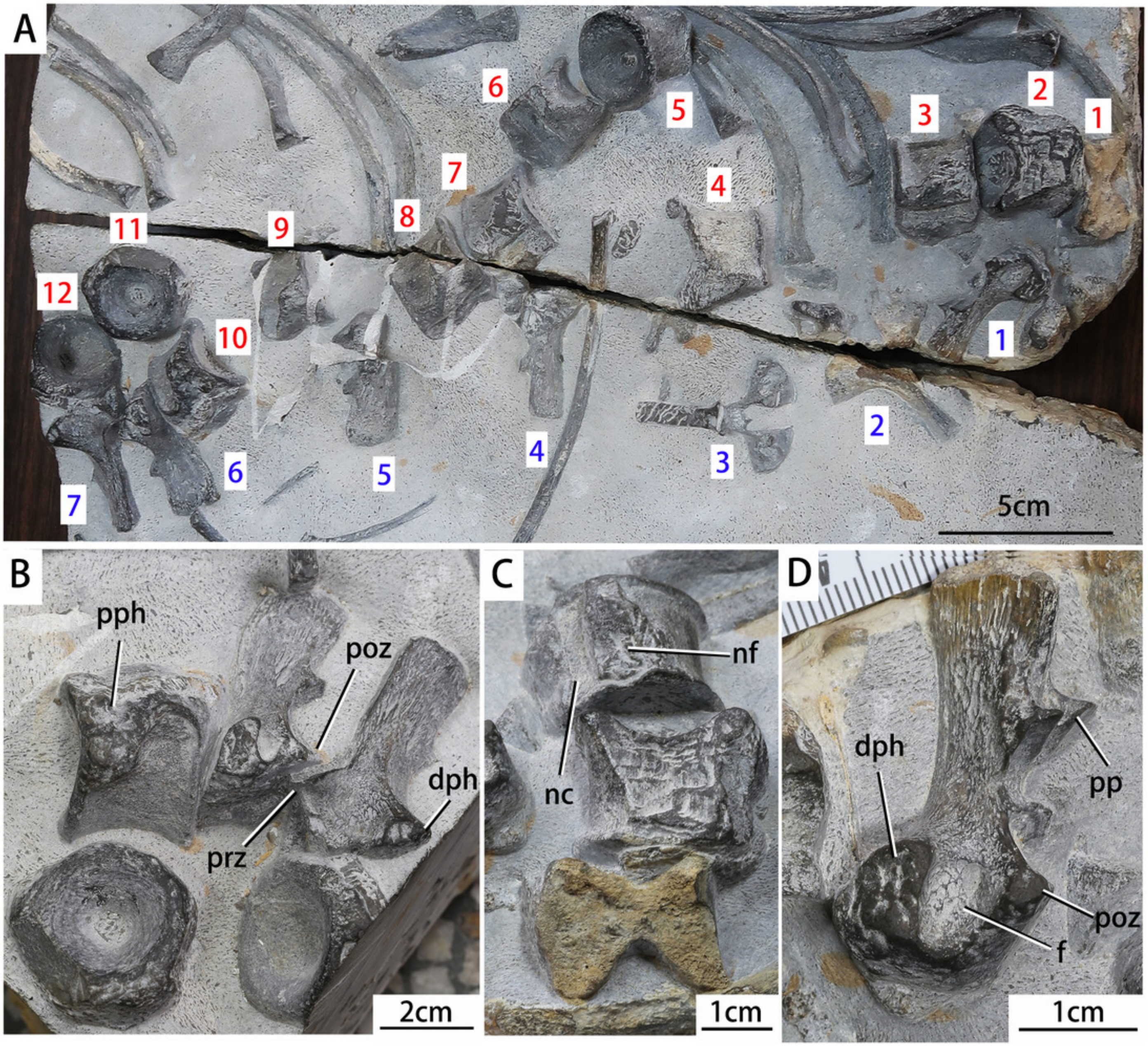


Figure 3

Photographs of the vertebrae in CUGW VH107.

(A) the preserved vertebrae, the centra are numbered in red 1-12, and the neural arches are numbered in blue 1-7; (B) isolated centrum (NO. 10, 11, 12) and neural arches (NO. 6, 7); (C) articulated centrum (NO. 1, 2, 3), showing the amphicoelous type; (D) an isolated neural arch (NO. 1) in posterolateral view. **Abbreviations**: **dph**, diapophysis; **f**, fossa; **nc**, neural canal; **nf**, neural arch articular facet; **poz**, postzygapophysis; **pp**, posterior process (on neural spine); **pph**, parapophysis; **prz**, prezygapophysis.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B
pph
poz
dph
prz
2cm
C
nf
nc
1cm
D
dph
pp
poz
f
1cm

Figure 4

Photographs of the dorsal ribs, gastralia and femur.

(A) dorsal ribs; (B) rib heads in anterior view, red arrow shows the rib head facet, black arrow shows the distal cross section; (C) the gastralia; (D) the femur. **Abbreviations**: **fi**, fibular articular facet; **l**, gastralia lateral element; **m**, gastralia median element; **ti**, tibial articular facet.

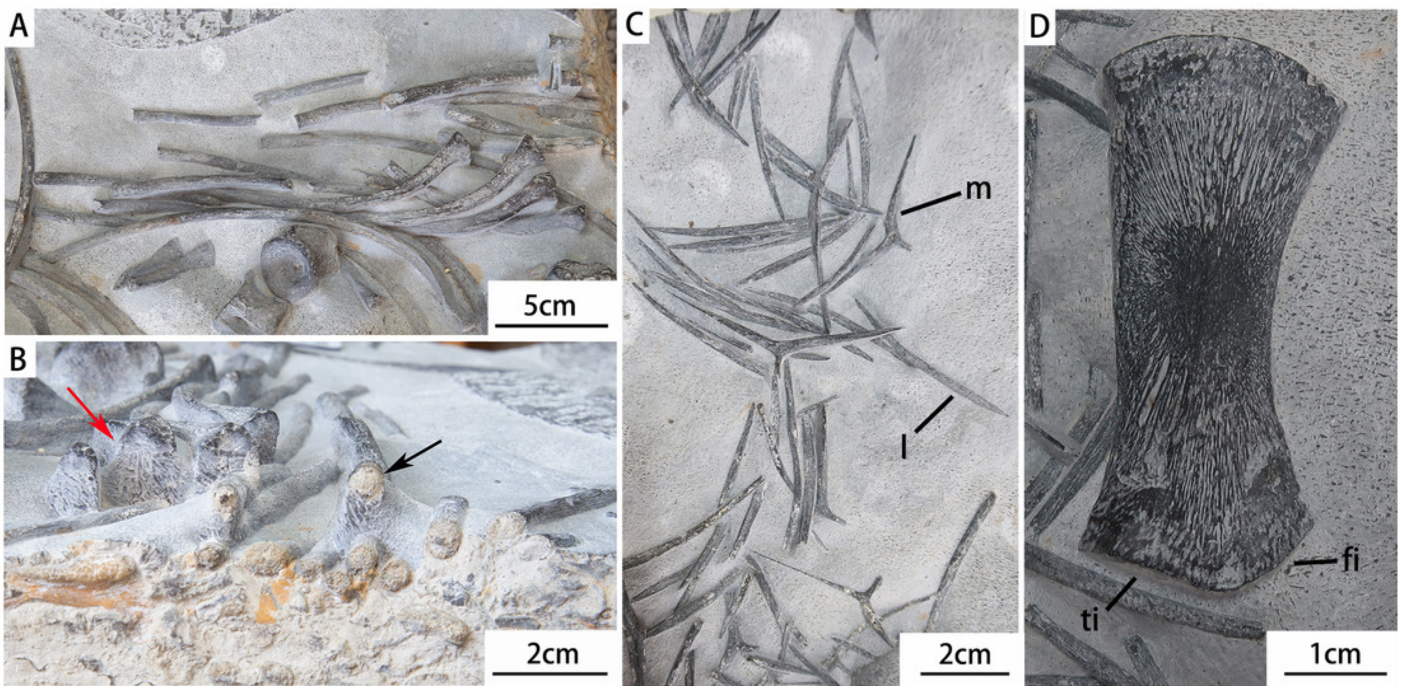

Figure 5

Bone microstructure of the distal rib.

(A) partial cross section showing the large medullary cavity and the trabeculae; (B) white arrow shows the vascular canal near the periphery; (C) white arrow shows the erosional cavity in the inner cortex; (D) a LAG near the periphery.

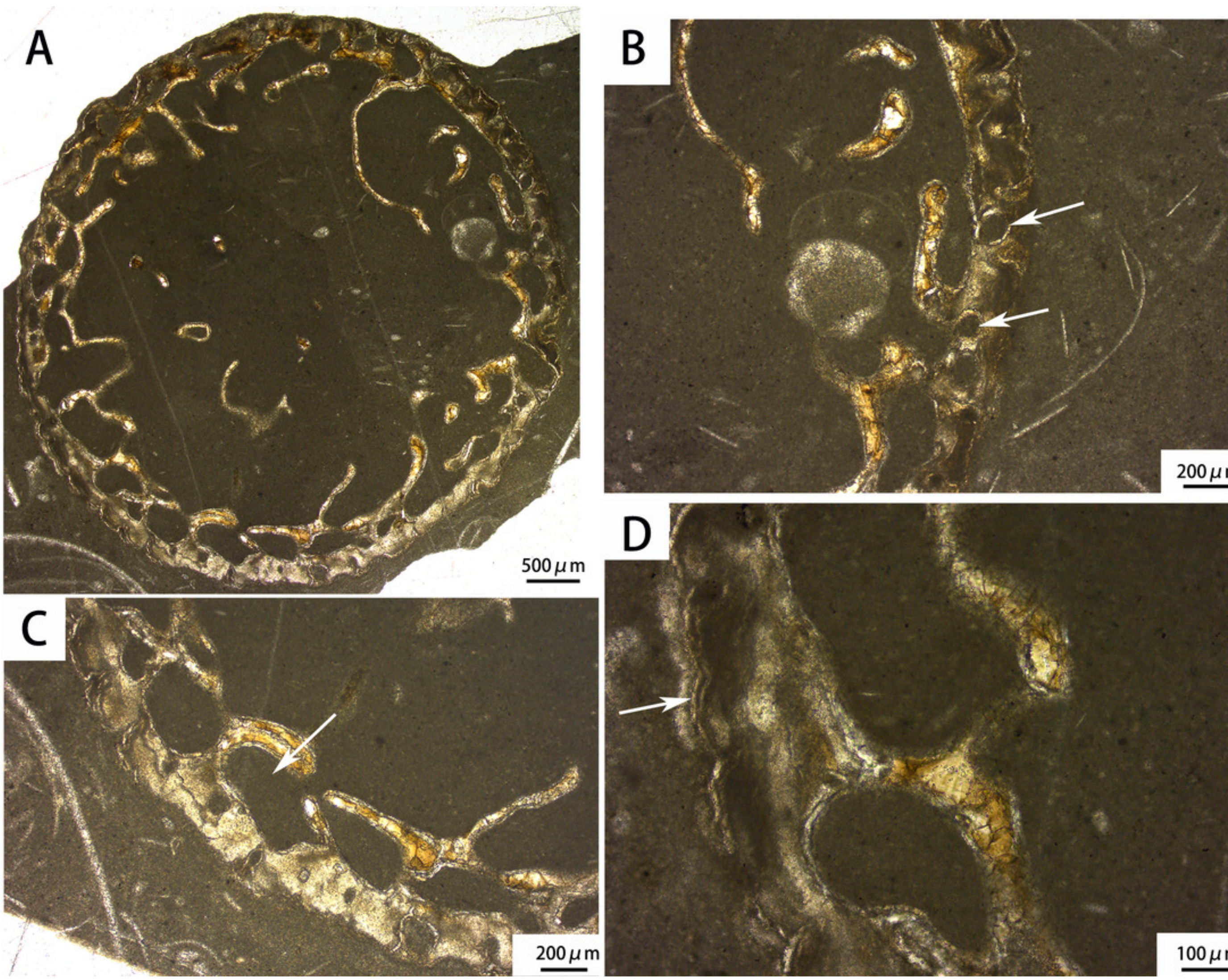

Table 1 (on next page)

Lists of known Early Triassic Spathian ichthyosaurs

1

Table 1. Lists of known Early Triassic Spathian ichthyosaurs

Locality	Stratigraphic horizon	Taxon	References	Remarks
Southern Peninsula, Thailand	Unrecorded horizon	*Thaisaurus chonglakmanii*	Mazin et al. 1991	Need further study
Anhui, China	Nanlinghu Formation	*Chaohusaurus geishanensis*	Young & Dong, 1972	-
		Chaohusaurus chaoxianensis	Chen,1985; Motani et al. 2015	=*Chensaurus chaoxianensis* (Mazin, 1991) =*Anhuisaurus chaoxianensis* (Chen, 1985)
		Chaohusaurus brevifemoralis	Huang et al. 2019	-
		Cartorhynchus lenticarpus	Motani et al. 2015	-
		Sclerocormus breviceps	Jiang et al. 2016	-
Hubei, China	Jialingjiang Formation	*Chaohusaurus zhangjiawanensis*	Chen et al. 2013	-
British Columbia, Canada	Sulphur Mountain Formation	*Parvinatator wapitiensis*	Nicholls & Brinkman, 1995	-
		Gulosaurus helmi	Cuthbertson et al. 2013	-
		Grippia sp.	Brinkman et al. 1992	-
		Utatsusaurus sp.	Nicholls & Brinkman, 1993	-
Spitzbergen, Norway	Vikinghøgda Formation	*Grippia longirostris*	Wiman, 1929	-
		Quasianosteosaurus vikinghoegdai	Maisch & Matzke, 2003	-
		Pessopteryx nisseri	Wiman, 1910	=*Merriamosaurus hulkei*

				(Maisch & Matzke, 2000)
		Isfjordosaurus minor	Wiman, 1910	Doubtful because of incompleteness
		Omphalosaurus merriami	Wiman, 1910	Doubtful because of incompleteness
Miyagi, Japan	Osawa Formation	*Utatsusaurus hataii*	Shikama et al. 1978	-

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Table 2(on next page)

Measurements of the centra and the neural arches (in mm) of CUGW VH107.

Table 2. Measurements of the centra and the neural arches (in mm) of CUGW VH107

Centrum

Centrum NO.	Max Length	Max Height	H/L Ratio
1	25.7	32.7	1.27
2	31.7	-	-
3	25.4	30.1	1.19
4	29.6	35.9	1.21
5	30.1	31.1	1.03
6	26.5	-	-
7	25.6	29.1	1.14
8	29.1	32.7	1.12
9	24.7	30.2	1.22
10	29.9	31.5	1.05
11	-	31.7	-
12	-	30.2	-

Neural Arch

Neural Arch NO.	Max Length	Max Height
1	14.8	46.9
2	-	47.9
3	-	49.1
4	-	47.3
5	17.3	47.5
6	17.5	49.6
7	18.1	48.8