Discovery of a New Middle Jurassic Dinosaur Site in Sichuan, China

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Abstract: The Sichuan Basin, also known as the ‘Red Basin’, is famous for its abundance of Mesozoic dinosaur fossils, especially in the Zigong area during the Jurassic era; the Middle Jurassic Shunosaurus and the Late Jurassic Mamenchisaurus faunal assemblages are the most representative. The Qinglongshan dinosaur fossil site is located in Fuxing, to the northwest of Rong County, Zigong City. This new site is situated within the Middle Jurassic Xiashaximiao Formation, and geologically is roughly equivalent to the well-known Dashanpu dinosaur fossil site. More than 600 dinosaur fossils were found concentrated in the excavation area, including teeth; cervical, dorsal and caudal vertebrae; and various parts of appendicular skeletons. This fossil site is also most significant as it provides new information on non-avian dinosaur life during the poorly understood Middle Jurassic.

Key words: vertebrate paleontology, Dinosauria, Xiashaximiao Formation, Middle Jurassic, Qinglongshan, Sichuan Province

1 Introduction

Sichuan Province is rich in vertebrate fossil resources, especially dinosaur fossils (Young, 1939, 1954, 1959; Dong et al., 1977, 1984; Dong and Tang, 1983; Dong, 1984; He et al., 1988, 1998; Zhen, 1989; Ouyang, 1991; Gao, 1992, 1999; Li and Cai, 1997; Ouyang et al., 1998; Ouyang and Ye, 2002; Li et al., 2010; Hao et al., 2018; Dai et al., 2020). It has been over a century since the first discovery of Sichuan dinosaur fossils in 1915 (Camp, 1935). Subsequently, numerous studies have documented remarkable dinosaur faunal assemblages (Young, 1942; Dong, 1980a; He, 1984), their systematic evolution (Peng et al., 2005), death assemblages and buried environments (Xia and Li, 1988; Wang et al., 2008), paleobiology and behavioral patterns (Xing et al., 2008), bone histology (Ye et al., 2007) and paleopathology (Xing et al., 2009; Hao et al., 2018a, 2020), etc. Approximately 45 species from 34 genera have been identified, which account for approximately one fifth of all non-avian dinosaur species (> 240 species) recovered in China (Fig. 1). In 1980, Dong proposed five representative Chinese dinosaur faunas, including the Shunosaurus fauna from the Middle Jurassic Xiashaximiao Formation and the Mamenchisaurus fauna from the Late Jurassic Shangshaximiao Formation. In recent years, a large number of dinosaur fossils from the lower Middle Jurassic Xintiangou and Xiashaximiao formations have been discovered in Yunyang, Chongqing (Tan et al., 2018, 2021).

The Early/Middle Jurassic comprises a transgressive sequence representing contemporaneous shallow seas in the local area of Sichuan. Because of the transgressions, strata from this time were not frequently preserved and Early/Middle Jurassic terrestrial fossils are fragmentary; however, large-bodied non-avian dinosaurs are frequently found in Sichuan. The discovery of such dinosaur bones in Sichuan Province fills a significant gap in the Early and Middle Jurassic for dinosaur fossils worldwide. This is particularly notable for the Shunosaurus fauna discovered in Dashanpu, Zigong City, of which many evolutionary relationships were obscure, especially for Middle Jurassic dinosaur lineages.

Here we describe a new Jurassic dinosaur fossil site discovered in the northwest of Rong County, Zigong City, near to the Dashanpu dinosaur fauna site. The new locality is near Qinglongshan Mountain in Fuxing Town, Rong County, and so they are referred to as the Qinglongshan dinosaur fossils. This site is dominated by sauropod fossils with theropod fossils and plesiosaur teeth also present. The Qinglongshan dinosaur fossils belong to the ‘Middle Jurassic Shunosaurus fauna’ category. The discovery further supports the studies of the Dashanpu dinosaur fauna and aims to add valuable information about the Middle Jurassic, in which dinosaur fossils are rare. Moreover, as an important feature of the Zigong Global Geopark, the Qinglongshan dinosaur fossils play an important educational role within China.

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### Discovery and Preservation History

The Qinglongshan fossil was first discovered in April 1987 and brought to the Zigong Dinosaur Museum by two people from Zhujiamiao Village in Rong County (Fig. 2); the piece they donated was identified after preliminarily...
examination as a sauropod humerus. However, because the museum was about to open and was poorly staffed at the time, and the distance to the fossil site was more than 100 km over an unpaved highway, the museum simply recorded and archived the fossil. In February 1995, Mr. Fu Qianming, an engineer at the Zigong Dinosaur Museum, went to Qinglongshan Mountain to investigate the site and found three more fossil outcrops near the original site discovered by the villagers. Then in March that year, the museum conducted a trial excavation at Qinglongshan, digging an area of approximately 10 square meters. During this excavation, more than 60 fossils were found, including eight sauropod humeri, which represented at least four individuals. With further field investigation, another two more outcrops yielding fossils were found at Qinglongshan.

In October 1996, the Qinglongshan dinosaur fossil site was declared as a county-level cultural relics protection unit by the People’s Government of Rong County. In April 1999, the Zigong Dinosaur Museum organized another trial excavation at Qinglongshan, which continued to dig to the inside from the 1995 expedition. This excavation covered more than 60 square meters, and more than 200 fossils were found, which further confirmed the fossil group burial situation. Due to transportation costs at the time, most of the fossils were reburied in situ, with the exception of a few specimens that were added to the museum collection.

At the beginning of 2008, the Qinglongshan dinosaur fossil site became a core protection area of the Zigong Global Geopark. From May to June 2019, the management center of Zigong Global Geopark organized a new project to dig and protect the Qinglongshan fossil site. Within an area that covers about 200 square meters, more than 600 fossils were discovered, mostly dinosaur bones. In May 2020, protective and exhibition facilities, such as a steel protection shed and a wooden walkway, were built at the Qinglongshan dinosaur fossil site, which has subsequently become a unique field research base within Zigong Global Geopark.

4 Results and Fossil Statistics

Of the more than 600 fossils that have been discovered at the Qinglongshan dinosaur fossil site (Fig. 3), the materials include cranial elements, teeth, vertebrae, appendicular skeletons, vertebral chevrons and other miscellaneous bone fragments. Because the fossils are still in situ and have not yet been numbered.

In terms of phylogeny, the dinosaur fossils fall predominantly into two categories: sauropods, accounting for the majority, and theropods. Overall, the site has a relatively low species diversity for dinosaurs, with an estimated three or four total species present. Additionally, scattered plesiosaur teeth are also found, with similar morphology to those of Bishanopliosaurus found in the Dashanpu dinosaur fossil site (Dong, 1980b). Therefore, in terms of fossil species diversity, Qinglongshan is far lower than that of Dashanpu. See Table 1 for details.

4.1 Major fossil records

Based on field investigations and excavations, the dinosaur fossils buried in the Qinglongshan site are very concentrated. The fossil deposits exposed are rich, phylogenetically diverse, and of cascading accumulation. There are a variety of fossils exposed at the site, including a lower jaw, teeth, cervical vertebrae, dorsal vertebrae, caudal vertebrae, appendicular skeletons, and some other parts. Most of the fossils are well preserved, and some are preserved articulated. The main fossils belong to sauropods, along with some theropod skeletons and scattered plesiosaur teeth.

4.2 Suspected Datousaurus lower jaw

A sauropod cranium includes a tall and very thick lower
Acta Geologica Sinica (English Edition), 2022, 96(1): 52–60

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jaw, and some large, typically spoon-shaped teeth. This lower jaw is presumed to be the left mandibular ramus with the posterior part of its lingual side preserved (Fig. 5b), and the depth of the fracture is close to 10 cm. When compared with sauropods found in the Dashanpu dinosaur fauna, it is likely that the cranial fossils belong to Datousaurus, which is probably the most massive among all the Dashanpu sauropods (Dong and Tang, 1984).

4.3 Theropod teeth

We find scattered theropod teeth that are laterally flat, distally curved along the crown, have a distal edge thinner than the mesial edge, and are serrated along both edges (Fig. 5c). These characteristics suggest that the teeth are those of an indeterminate carnivore theropod, and similar in size to those of Szechuanosaurus (Gao, 1993).

4.4 Associated cervical vertebrae

There are three associated cervical vertebrae preserved (Fig. 4b). The general form of the centrum can be described as being relatively longer than wide, ventrally concave, with the anterior articular surface protruding forward in a hemispherical shape, and the posterior articular surface deeply concave. The middle of the vertebra is constricted, laterally concave, and prism-shaped in lateral view, with several visible pits inside. The neural spine is relatively high, laterally oblate, fore and aft elongated, the upper margin straight, and the terminal not expanded.

4.5 Associated caudal vertebrae

There are 10 associated caudal vertebrae, one of which is partially preserved, along with four chevrons (Fig. 5a).
Fig. 4. Fossils with obvious burial characteristics 1.
(a) Metatarsals; (b) associated cervical vertebrae; (c) femur; (d) scattered sacral vertebrae.
Fig. 5. Fossils with obvious burial characteristics 2.
(a) Associated caudal vertebrae; (b) suspected *Datousaurus* skull; (c) theropod tooth; (d) plesiosaur tooth.
Although the structure of the caudal vertebra is simple, the centra are more complicated, with marked lateral concavity, the anterior articular surface larger than the posterior, and slightly concave with a large and subcircular surface. The diaphysis of the caudal vertebra is short and thick. The neural spine of the caudal is tall, roughly square, and slightly anteriorly angled. The anterior portion of the neural spine is slightly convex, with the posterior edge being slightly concave. The prezygapophysis and postzygapophysis are not well-developed. The chevron is “Y”-shaped in anterior view, similar to that of other sauropods (Dong and Tang, 1983). The tuberculum dorsal area is well-developed.

4.6 Femurs

Eight femurs are present, all belonging to sauropods that are indeterminate. The femurs vary significantly in thickness, with a straight shaft, are relatively crushed, and are oval in cross-section. The femoral head is large and rounded. The fourth trochanter is well-developed. The distal end of the femur is expanded, with the interior and exterior condyles being well-developed and the intercondylar groove deep (Fig. 4c).

4.7 Metatarsals

Five robust metatarsals are preserved (Fig. 4a). The central shaft of the metatarsal is contracted. The first metatarsal is thick and short, proximally convex, and with severe twisting; it is inclined from the medial side of the proximal metatarsal to the lateral side. The second metatarsal is longer than the first one and slightly flattened, with the proximal articular surface coarsely inclined ventrally. The third metatarsal is thinner and longer, with the lateral and proximal edges being dilated. The proximal end of the third metatarsal is enlarged. The diaphysis gradually contracts in size/merges to the distal end, and the anterior articular surface is small.

4.8 Plesiosaur teeth

Two teeth are generally well-preserved, slender, and weakly curved, with a length of 18.4 mm. The crown is intact, with only slight wear apically; the enamel of the crown is smooth with enamel striations that extend from the tip to the base (Fig. 5d). All of the teeth are circular in cross-section. The root is slightly curved, the crown surface is smooth, and the enamel ridges are prominent, those on the lingual side of the crown extend to the apex, while most enamel ridges on the buccal side do not. Tooth crown curvature is less than that of Bishanopliosaurus youngi Dong, 1980 (Dong, 1980b).

5 Fossil Burial Characteristics

5.1 Multi-layer distribution of fossils

The Qinglongshan dinosaur fossils clearly derive from three distinct layers, hereafter numbered in ascending order as L1, L2, and L3. The thicknesses of the first and second layers are about one meter, and there is no clear stratification between the two layers. Fossils are most abundant in L1 and L2, where more than 90% of all fossils are recovered. L3 is not thick, at only about 10 cm, with a clear separation from the second layer. This third layer contained relatively few fossils with mainly cranial fragments, scattered teeth, a few caudal vertebrae, and an appendicular skeleton being recovered.

5.2 Poorly articulated fossils

In several field investigations, the Qinglongshan fossils have been found to have a large distribution range that is concentrated as relatively well-preserved specimens; however, the paleobiodiversity is relatively low. Generally, fossils of this site are poorly articulated, with most of them being scattered and few specimens being associated. However, nine anterior caudal vertebrae and four chevrons of a large sauropod individual are assumed to be associated. Additionally, three large sauropod sacral vertebrae are scattered separately at the site. Dinosaur sacral vertebrae are usually very closely associated (Dong Z M, 1980b; Gao, 1992), so these dispersed, isolated sacral vertebrae are rarely preserved. However, the Plesiosaurs had been found in Bishan, Dashanpu and Qinglongshan, Zigong, indicating that Plesiosaurs had been widely distributed in Sichuan Basin in the Middle Jurassic (Thulborn, 1980; Peng et al., 2005). Conglomerates are found in the fossil-rich formation in several field investigations. The burial characteristics of fossils at Qinglongshan indicate that the dinosaur fossils were deposited and buried after the animals died in variable hydrodynamic conditions and after being transported for a long way. The site is a typical heterochthonous burial, with the sedimentary facies belonging to a fluviual depositional environment. These burial characteristics are clearly different from those at Dashanpu.

6 Conclusions

(1) Six fossil outcrops are found at the Qinglongshan dinosaur fossil locality, one of which shows that fossils are concentrated and abundant, with an unusual association of sauropod and theropod dinosaurs with plesiosaurs. The six fossil outcrops also show that the Qinglongshan dinosaur fossils are widely distributed and cover a larger area than the other two Jurassic dinosaur sites in Zigong, the Wujiaba and Dashanpu dinosaur fossil sites. Because of the abovementioned reasons, the Qinglongshan fossils sites represent an excellent resource for studying the evolution of Jurassic dinosaurs in the Sichuan Basin.

(2) According to geological maps and stratigraphic sections, the Qinglongshan dinosaur fossil site belongs to the lower part of the Middle Jurassic Xiaxianximiao Formation. Based on the fossils found at the site, this stratigraphic level is slightly younger than the Dashanpu dinosaur fossil site. Temporally, there appears to be an evolutionary relationship among the Dashanpu, Qinglongshan, and Wujiaba dinosaur fossils in Zigong. Further dating methods are needed to determine a more constrained age for the Qinglongshan dinosaur fossil site.

(3) At the Qinglongshan dinosaur fossil site, all dinosaur fossils are poorly articulated. Sauropod dinosaurs account for more than 95% of all fossils, a finding that is quite distinct from the Dashanpu dinosaur fossil site.
Therefore, we speculate that at Qinglongshan, the dinosaurs living near this area at the time of burial were predominantly sauropods, which were transported after they died and buried in high-energy rivers or in a lakeside environment where plesiosaurs also swam and died.

Acknowledgements

We thank the editor and anonymous reviewers for professional and critical comments. We show our great appreciation to Mr. Liu Yu, Mr. Huang Daixi, Mr. Ouyang Hui, and Mr. Jiang Shan for supporting the field work. We are also grateful to Mrs. Ling Man for drawing figures and Dr. James L. King and Dr. Susan Turner for improving the language of this paper. This research was supported by the Fund from the Key Laboratory of Stratigraphy and Palaeontology, Ministry of Natural Resources (Grant No. KLSP2104), the Beijing Green Shoots Project of the Beijing Academy of Science and Technology (Grant No. BGS202001), the Sichuan Province cultural and museological research project (Grant No. SCWW2021A01), the Zigong Talent Project and Sichuan Province Land and Resources Department Project “Dinosaur fossil resources protection and development and utilization model in Sichuan Basin” (Grant No. KJ-2017-11).

Manuscript received Aug. 25, 2020 accepted Sep. 9, 2021 associate EIC: XU Xing edited by FEI Hongcai

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