

# Skeletal faunas from the Qiongzhusian of southern Shaanxi: biodiversity and lithofacies-biofacies links in the Lower Cambrian carbonate settings\*

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**Abstract** The Xiaoyang section, located in Zhenba County of Shaanxi Province, is important both for documenting the biodiversity of the Qiongzhusian Stage (Lower Cambrian) and for analyzing lithofacies-biofacies links in carbonate depositing environments on the Yangtze Platform. The skeletal fossils from the Xihaoping Member, including lingulid valves, cambroclavid and chancelloriid sclerites, genal and occipital spines of polymerid trilobites, and tubular fossils, are described here as the *Eoobolus-Cambroclavus* fauna, which mainly occurred in peritidal environments. The fossils from the argillaceous limestones of the lower Shuijingtuo Formation, containing lingulate brachiopods, eodiscoid trilobites, bivalved arthropods, microdictyonid sclerites and siliceous sponge spicules, are regarded as the *Palaeobolus-Hupeidiscus-Kunmingella* fauna, which presumably lived in subtidal or deeper water environments. The faunal diversity in the Xihaoping Member is lower than that in the lower Shuijingtuo Formation. The investigations of the skeletal fossil assemblages from carbonate lithofacies in southern Shaanxi will significantly contribute to a detailed documentation of the biodiversity during the Qiongzhusian interval on the Yangtze Platform and add new knowledge on the Cambrian bioradiation.

**Keywords:** skeletal fauna, Xihaoping Member, Shuijingtuo Formation, Lower Cambrian, Shaanxi.

The Yangtze Platform (South China) preserves a particularly significant record of the evolutionary radiation of Early Cambrian skeletal fossils in carbonate sediments, and the co-occurring phosphogenesis episode distinctively enhanced the preservational potentialities of the small skeletal fossils (SSF). During the past decades, the taxonomy of early small skeletal fossils of the Yangtze Platform has been intensively documented<sup>[1-4]</sup>, and four SSF biozones have been recognized for the biostratigraphic subdivision and correlation of the subtrilobitic sequences (Meishucunian)<sup>[3]</sup>. However, most of the previous investigations were particularly focused on the skeletal fossils of the subtrilobitic sequences, whereas the detailed documentations of the skeletal fossils of the Qiongzhusian stage are relatively limited since the Qiongzhusian sequences on the Yangtze Platform (especially in eastern Yunnan) are mainly composed of siliciclastic rocks. Although the famous Chengjiang Lagerstätte exhibits a picture of the Qiongzhusian faunas in siliciclastic depositional environments<sup>[5]</sup>, it provides relatively limited chances for the preservation and recovery of the skeletal microfossils. Fortunately, there

developed a number of the Qiongzhusian carbonate sequences with abundant skeletal microfossils in southern Shaanxi Province, and the detailed investigation of these sequences can provide important data for illustrating the faunal aspects of the Qiongzhusian in marine carbonate environments. Taking the Xiaoyang section in southern Shaanxi as an example, the purpose of this paper is to document the biodiversity of the skeletal faunas in carbonate depositional settings during the Qiongzhusian interval, and to briefly analyze the mutual links between biofacies and lithofacies. All fossils were recovered through acetic acid treatment of carbonate samples.

## 1 Geological setting and stratigraphy

The Xiaoyang section (32°28'N, 107°57'E) (also described as the Xiaoyangba section in the literature<sup>[3]</sup>) is located near the Xiaoyang town, Zhenba County, SE Shaanxi Province (for locality see Fig. 1 of Hao et al.<sup>[6]</sup>), and on the present-day northern margin of the Yangtze Platform. Here a continuous sequence of the upper Neoproterozoic to lower Cam-

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brian stratigraphic successions crops out along the road cut and riverbank. In an ascending order, the Lower Cambrian stratigraphic succession consists of the Xihaoping Member of the Dengying Formation, the Shuijingtuo and Shipai formations. Similar lithostratigraphic units are widely distributed in SE Shaanxi and NW Hubei regions<sup>[7]</sup>. The 8.37-m-thick Xihaoping Member, which unconformably overlies the upper dolomite member (Sinian) of the Dengying Formation (Fig. 1), consists of light dolomites and dolomitic or phosphatic limestones with abundant skeletal fossils, and was deposited in peritidal, high-energy environments. The Shuijingtuo Formation unconformably overlying the Xihaoping Member could be subdivided into two members. The 31-m-thick lower member consists of dark or black, thin-bedded siltstones, mudstones and argillaceous limestones with abundant skeletal fossils, and was deposited in subtidal or deeper low-energy environments. The 85-m-thick upper member consists of fine sandstones and siltstones with a few intercalated thin limestone beds, and only contains scarce skeletal fossils.

has been collected, the senior author recovered a great number of librigenal and occipital spines of trilobites (Fig. 2, B, C, D) through etching of the carbonate samples with acetic acid. The occurrence of trilobite spines further suggests an early or middle Qiongzhusian age for the Xihaoping Member, and indicates the existence of a protracted hiatus at least spanning the Meishucunian. The lower Shuijingtuo Formation contains *Hupeidiscus*, *Zhenbaspis*, *Eoredlichia* (trilobites) and *Kunmingella* (bradoriids), all of which indicates the lower Shuijingtuo Formation is of the late Qiongzhusian age<sup>[9, 10]</sup>. The occurrence of the cosmopolitan index fossil *Rhombocorniculum cancellatum* here can provide important information for the global correlation of the Qiongzhusian<sup>[11]</sup>. The absolute time spanning the hiatus between the Xihaoping Member and the lower Shuijingtuo Formation is unclear. Although the upper Shuijingtuo Formation is routinely interpreted as the lower Canglangpuian Stage, it is difficult to draw the boundary horizon between the Qiongzhusian and Canglangpuian at the Xiayang section since the upper member contains only scarce fossils.

## 2 Xihaoping skeletal fossil assemblage

Skeletal fossil assemblages of the Xihaoping Member are dominated by linguloid valves, cambroclavid and chancelloriid sclerites, genal and occipital spines of polymerid trilobites, and tubular fossils. In addition to the originally phosphatic skeletal fossils (such as lingulates and *Torellella*), most of the initial calcareous skeletal fossils were also preserved as phosphatic steinkerns, coatings or replacements.

Although linguloid brachiopod shells are the most abundant fossils in the Xihaoping Member, nearly all of them are preserved as fragmented valves. The majority of the specimens can be assigned to *Eoobolus* sp. (Fig. 2, I and J<sub>1</sub>), which is characterized by a larval shell with pitted microornamentation and by a postlarval shell with finely pustulose ornamentation (Fig. 2, J<sub>2</sub>). This record represents the first known occurrence of *Eoobolus* in the Lower Cambrian of China. Other fragmented valves belong to an indeterminate taxon, which is characterized by a thick shell ornamented with concentric growth lines and radial lines (Fig. 2, G).

Calcareous cambroclavid sclerites (Fig. 2, E) are the second abundant skeletal fossils in this lithologic unit, and are preserved as phosphatic steinkerns or

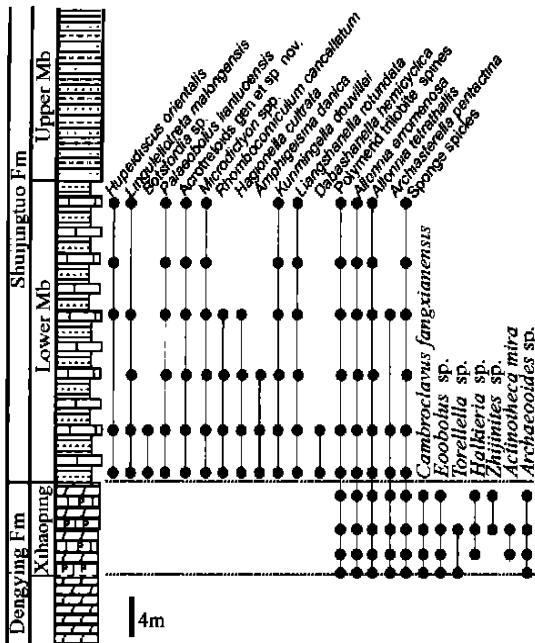


Fig. 1. Range chart for skeletal fossils of the Xiayang section, Zhenba, southern Shaanxi.

Previously, the Xihaoping Member was inappropriately correlated with the Shiyantou Formation (upper Meishucunian) of eastern Yunnan<sup>[8]</sup>. But recently, based on the occurrence of *Microcornus*, *Cambroclavus*, etc., the Xihaoping Member has been considered as the middle Qiongzhusian in age<sup>[3]</sup>. Although no complete trilobite cranium or pygidium

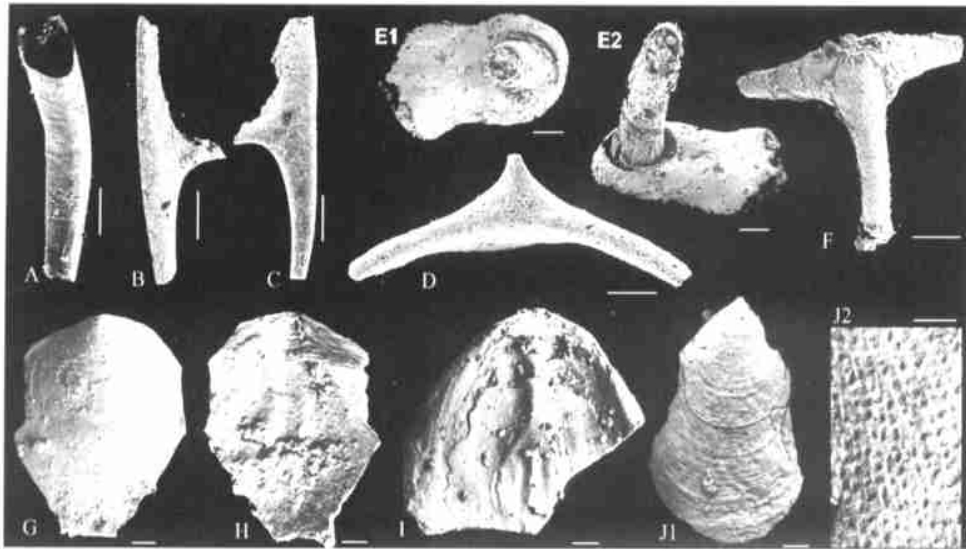


Fig. 2. SEM photographs of skeletal fossils from the Xihaoping Member. Scale bar is  $200\mu\text{m}$  for A ~ J<sub>1</sub>;  $50\mu\text{m}$  for J<sub>2</sub>. A, *Torellella* sp.; B and C, librigenal spines of polymerids; D, occipital spine of polymerids; E<sub>1</sub> and E<sub>2</sub>, *Cambroclavus fangxianensis*; F, *Allonnia errromenosa*; G and H, exterior and interior view of a ventral valve of an unnamed lingulid; I and J<sub>1</sub>, dorsal and ventral valves of *Eoobolus* sp.; J<sub>2</sub> detail of J<sub>1</sub> showing pustulose ornamentation.

replacements. Each sclerite bears an elongate spine and an irregular basal shield. Although they have been assumed as dorsal sclerites of a slug-like animal, their biological affinities are still unknown due to the lack of soft-body preservation<sup>[12, 13]</sup>. The sclerites are variable in morphology, and have been described as different form-taxa, but most of them can be regarded as junior synonyms of *Cambroclavus fangxianensis* Qian et Zhang<sup>[1]</sup>.

Nearly all of the chancelloriid sclerites are preserved as phosphatic steinkerns with short and thick rays. The form-taxa include *Allonnia errromenosa* (Fig. 2, F), *A. tetrathallis*, and *Archiasterella pentactina*. The librigenal and occipital spines of polymerids are often recovered, though no cranium or pygidium has been discovered.

Tubular fossils are also quite common, but most of them belong to the phosphatic *Torellella* sp. (Fig. 2, A), which is characterized by lenticular cross-sections and bearing a narrow and shallow sulcus on each narrow side. Additionally, also some *Hyalithellus*-like fragmented tubes could be examined. The calcareous hyolithid *Microcornus parvulus*, and *Actinotheca mira* (affinity unknown) are occasionally recovered.

Most of siliceous sponge spicules are stout hex-

actins with distinct axial cavities. Occasionally, there also occur some globular fossils resembling *Archaeoides granulatus* (with unknown affinities). We did not examine the occurrence of the univalved mollusc fossils in the Xihaoping Member. Although there occur some univalved mollusc taxa in this lithologic unit at other sections, the diversity of univalved mollusks is much lower than that of the Meishucunian in eastern Yunnan. Qian and Zhang<sup>[7]</sup> recovered *Rhombocorniculum cancellatum* from the Xihaoping Member at the Tanbao section of Fangxian County, Hubei Province. Although Xie<sup>[14]</sup> mentioned the occurrence of *Rhombocorniculum insolutum* (a junior synonym of *Rh. cancellatum*<sup>[13]</sup>) from the Xihaoping Member at the Xiaoyang section, we could not confirm the occurrence of this morphotype.

### 3 Skeletal fossil assemblage from the lower Shuijingtuo Formation

Faunal assemblages from the argillaceous limestones of the lower Shuijingtuo Formation are dominated by lingulate brachiopods, eodiscoid trilobites, bivalved arthropods and siliceous sponge spicules. The preservation of the skeletal fossils is various. The lingulate brachiopods, microdictyonid sclerites, protoconodonts, *Rhombocorniculum* elements, and bradoriid carapaces mainly represent primary phosphatic preservation, although the organic contents in

the skeletons can also be replaced by secondary phosphatization. The exuviae or carapaces of eodiscoids are well preserved as phosphatic replacements, while the chancelloriid sclerites and the univalved mollusc are preserved as phosphatic steinkerns. Most of the sponge spicules are still preserved as siliceous skeletal elements, but some of the spicules are preserved as phosphatic steinkerns, which were formed through phosphate infillings into the axial canals and secondary dissolution of the siliceous spicules.

The phosphatic micro-brachiopods are the most abundant fossils in the lower Shuijingtuo Formation, and most of their valves are completely preserved. Some of the juvenile linguloid shells are even preserved with both ventral and dorsal valves conjoined. The thickness of the shell (especially linguloids) is relatively thin compared with those from the Xihaoping Member. The co-occurring taxa include *Palaeobolus liantuensis* (Fig. 3, K and L), *Lingulellotreta malongensis* (Linguloidea) (Fig. 3, J),

*Botsfordia* sp. (Acrotheloidea), and an unnamed primordial species of the acrotretoids (Fig. 3, C and D). *Palaeobolus liantuensis* is the most abundant taxon, and it is rounded subtriangular and subacuminate in outline. Its ventral pseudointerarea is orthocline with a U-shaped pedicle groove, while the dorsal valve is elliptical with the pseudointerarea apsacline. *Lingulellotreta malongensis* is one of the unique Cambrian linguloids, and characterized by its elongate foramen, internal pedicle tube and smooth larval shell. *Botsfordia* sp. is quite small (less than 1 mm), and is characterized by the larval shell with pitted microornamentation but with indistinct apical tubercles and postlarval shell ornamented with pustules. The acrotretoid fossils are somewhat similar to *Hadrotreta*, but the interiors of their ventral valves bear indistinct apical processes and apical pits, and the dorsal valve lacks a median sulcus. The columnar microstructures of the secondary layer of acrotretoids are well preserved.

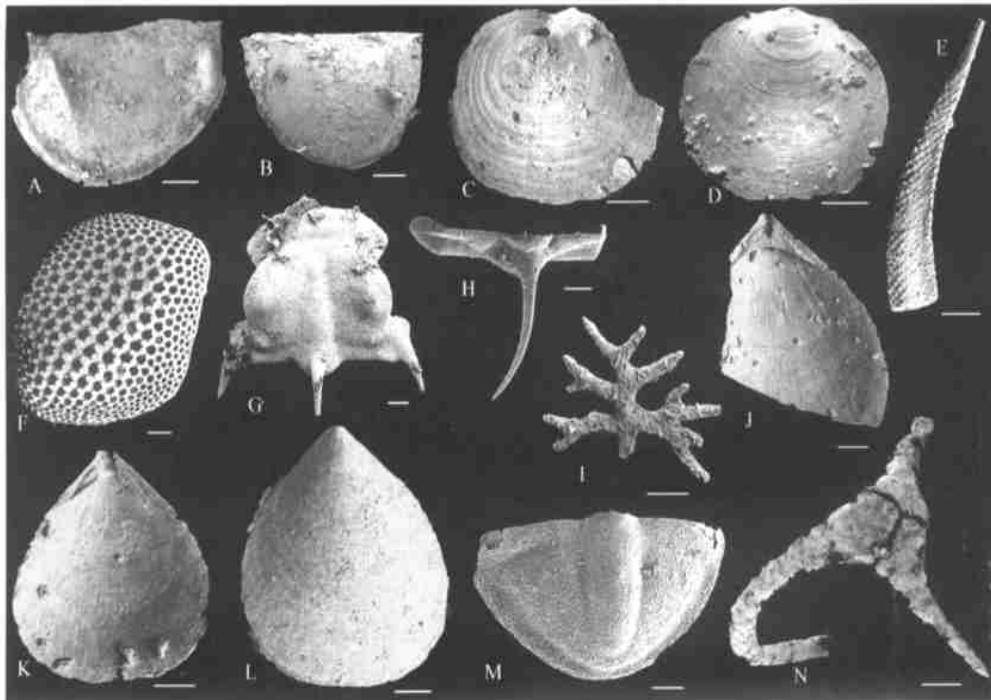


Fig. 3. SEM photographs of skeletal fossils from the Shuijingtuo Formation. Scale bar is 200 $\mu$ m for A, C, D, F, H, J, K, L; 100 $\mu$ m for B, E, G, I, M, N. A, *Kunmingella douvillei*; B, *Dabashanella hemicyclica*; C and D, ventral and dorsal valves of an unnamed acrotretoid; E, *Rhombocorniculum cancellatum*; F, *Microdictyon chinense*; G, H and M, cranium, thoracic segment and pygidium of *Hupeidiscus orientalis*; I, dichostauract; J, ventral valve of *Lingulellotreta malongensis*; K and L, ventral valves of *Palaeobolus liantuensis*; N, *Allonnia erromenosa*.

Arthropod fossils are also quite abundant in this lithologic unit, and include the eodiscoid *Hupeidiscus orientalis*, the bivalved bradoriid *Kunmingella douvillei* and *Liangshanella rotundata*, and the phosphatocopid *Dabashanella hemicyclica*, among them.

*H. orientalis* and *K. douvillei* are the most abundant taxa. The phosphatized specimens of *Hupeidiscus orientalis* (Fig. 3, G, H and M) preserve delicate structures, such as granules or tubercles on the cuticular surface, the axial, fixigenal and occipital spines,

and doublures. The material includes different growth-stage specimens, which can offer a significant insight into elucidating the ontogeny of *H. orientalis*. *Kunmingella douvillei* (Fig. 3, A) is characterized by each valve bearing a broad anterodorsal node and an elongate, straight posterodorsal lobe<sup>[9, 16]</sup>. An indistinct anterodorsal node on each valve characterizes *Liangshanella rotundata*, while *Dabashanella hemicyclica* (Fig. 3, B) is characterized by a very small univalve carapace (less than 1 mm) with a straight dorsal and semicircular lateral outline.

The slender protoconodont elements which show a striking similarity with grasping hooks of chaetognaths are usually taken as evidence for the existence of predators in the earliest Cambrian ecosystems<sup>[12]</sup>. The taxa related to this fossil group from the lower Shuijingtuo Formation include *Amphigeisina danica* and *Hagionella cultrata*. The element of *A. danica* is a bilaterally symmetrical cusp with a distinct concave posterior bound by a carina on both sides. *H. cultrata* is characterized by the cusp having a distinct anterior keel<sup>[14]</sup>. The enigmatic fossil *Rhombocorniculum cancellatum* (Fig. 3, E) is one of the characteristic conodont-like fossils in the Lower Cambrian with a wide geographic distribution<sup>[17]</sup>. The material from the lower Shuijingtuo Formation consists of both dextral and sinistral tooth-like sclerites with rhomboid ornamentations. All elements are cultrate in appearance and curved towards the posterior, therefore, the basal cross-sections are asymmetrically tear-shaped but circular near the apex.

The lower Shuijingtuo Formation is well known for the occurrence of diverse microdictyonid sclerites (plates) of *Lobopodia*<sup>[6, 15]</sup>. Based on the characteristics of the plate framework and the node types, three species, including *Microdictyon chinense* (Fig. 3, F), *M. spiniferum* and *M. typicum*<sup>[6]</sup>, are discerned. The plates of *M. chinense* are characterized by bearing mushroom-like nodes with curved spines, whereas the nodes of *M. spiniferum* are spinose with one to several tips. The plates of *M. typicum* are characterized by the irregular distribution of spines on the upper plate surfaces.

All cancelloriid sclerites are preserved as phosphatic steinkerns with slender rays, and the form-taxa include *Allonnia erromenosa* (Fig. 3, N), *A. tetrathallis*, *Archiasterella pentactina* and *Chancelloria* sp. The sponge spicules are quite abundant and diverse, although no body fossils have been found.

Most of the spicules belong to hexactinellids, and are well preserved. The spicules include dichopentactins, dichostauracts (Fig. 3, I), stauracts, hexactins, paraclavules, tylostyles, acanthopentactins, and acanthohexactins. No calcareous sponge spicules and fewer demosponge spicules have been recovered. There occur some globular fossils with unknown affinities resembling *Archaeooides granulatus*. Only one specimen of univalved mollusk, *Mackinnonia plicata*, has been recovered.

#### 4 Biofacies-lithofacies links

The skeletal faunal assemblages from the above two lithologic units are evidently different (Fig. 1). This difference is interpreted here as a result of variations of lithofacies rather than of bio-evolution. The grey limestones and dolomites of the Xihaoping Member represent high-energy, peritidal deposits, whereas the dark or black, thin-bedded siltstones, mudstones and argillaceous limestones of the lower Shuijingtuo Formation represent low-energy, subtidal (or deeper) deposits. This distinct lithofacies-biofacies shift around the boundary between the above two units is associated with the major transgression event which is widely recorded in SE Shaanxi and the NW Hubei region. The faunal diversities of the two lithologic units are also different. There are about 12 species of skeletal fossils occurring in the Xihaoping Member, while there are more than 20 species from the lower Shuijingtuo Formation. This observation is quite consistent with the previous conclusion that faunal diversity is lower in the peritidal carbonate than that in the subtidal limestone<sup>[18]</sup>.

The skeletal faunal assemblages of the Xihaoping Member are characterized by abundant occurrence of the thick-shelled eobolids, cambroclavid sclerites and polymerid trilobites, but rare sponge spicules. Some of the taxa only occur in the Xihaoping Member and are more lithofacies-dependent, such as *Cambroclavus fangxianensis* and *Eoobolus*. Some taxa occur not only in this lithologic unit but also in the lower Shuijingtuo Formation and are less lithofacies-dependent, but they show some special features characteristic of the lithofacies, for example, the cancelloriid rays and sponge spicules from the Xihaoping Member being quite short and thick. We tentatively call them the *Cambroclavus-Eoobolus* fauna, which typically occurred in dolomites or limestones of peritidal, high-energy environments. It may be correlated with the *Ninella tarimensis* — *Cambroclavus fangxianensis*

Zone as suggested for the southeastern Shaanxi Region<sup>1)</sup>. Most of the skeletal fossils are preserved as fragments because of the high-energy settings and secondary transportation in shallow environments. Meanwhile, the ratio of brachiopod valves with microborings is relatively high (more than 5%).

The faunal assemblages of the lower Shuijingtuo Formation are characterized by abundant thin-shelled brachiopods, eodiscoid trilobites, bradoriids and diverse sponge spicules. There are many lithofacies-dependent taxa, such as eodiscoid *Hupeidiscus orientalis*, the bivalved bradoriid *Kunmingella douvillei* and *Liangshanella rotundata*, the phosphatocopid *Dabashanella hemicyclica*, the lingulate *Palaebolus liantuensis*, *Lingulellotreta malongensis*, *Botsfordia* sp., and abundant microdictyonid sclerites. The cancelloriid rays and sponge spicules are quite slender. Here we tentatively describe them as the *Palaebolus-Hupeidiscus-Kunmingella* fauna, which usually occurs in the subtidal, low-energy environments. Most of the skeletal fossils are well preserved with less secondary fragmentation. The ratio of brachiopod valves with microborings is relatively low (less than 2%).

It needs to be noted that there is no archaeocyathid record from the Qiongzhusian strata in the SE Shaanxi Region since the distribution of archaeocyathids is quite dependent on sedimentary facies. In contrast, archaeocyathid bioherms were well developed in the corresponding strata in the SW Shaanxi region<sup>[19]</sup>. The study on the faunal assemblages of the archaeocyathid bioherms will provide important data for documenting the unique aspect of the Qiongzhusian fauna in reef environments. The investigations of the faunal assemblages in various carbonate lithofacies in southern Shaanxi will significantly contribute to the detailed documentation of the biodiversity and bioradiation event during the Qiongzhusian interval on the Yangtze Platform, though the Chengjiang Biota has received the greatest attention in this context.

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1) See notefoot on page 93.