



## Small shelly fossils from the early Cambrian Yanjiahe Formation, Yichang, Hubei, China



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### ABSTRACT

Abundant data have been acquired on the lower Cambrian small shelly fossils (SSFs) of the Yangtze platform during the last three decades, demonstrating that these fossils are an important piece of evidence for the Cambrian radiation and are useful biostratigraphic tools for correlating the lower Cambrian. Here we report SSF associations from the Yanjiahe Formation in the Three Gorges area, South China. The Yanjiahe Formation is well exposed near the Yanjiahe village, and its 40-m-thick sequence can be subdivided on the basis of lithology into five stratigraphic intervals (beds). Small shelly fossils occur mainly in Beds 2 and 5, but abundant SSFs were discovered in thin sections of siliceous–phosphatic nodules from Bed 3 for the first time. No skeletal fossils were discovered in the basal siliceous rock interval (Bed 1), but the negative  $\delta^{13}\text{C}_{\text{carb}}$  excursion and the occurrence of the acritarch *Micrhystridium regulare* indicate that it belongs to the basal Cambrian. The SSF associations are somewhat similar to those of East Yunnan, and can be differentiated into three biozones (in ascending order): the *Anabarites trisulcatus*–*Protohertzina anabarica* assemblage zone (Bed 2), the *Purella antiqua* assemblage zone (Bed 3), and the *Aldanella yanjiaheensis* assemblage zone (Bed 5). The occurrence of *A. yanjiaheensis* in Bed 5 probably indicates that Bed 5 belongs to Cambrian Stage 2, but the Stage 2/Stage 1 boundary is uncertain since Bed 4 lacks fossils. SSF biostratigraphy indicates that the Yanjiahe Formation is pretrilobitic Meishucunian in age (equivalent to the Nemakit–Daldynian to Tommotian of Siberia, Terreneuvian). Five SSF genera occur in Bed 2, more than six genera in Bed 3, and twenty-three genera in Bed 5. The stepwise increase in generic diversity through the Yanjiahe Formation is comparable with the global diversity increase through the Nemakit–Daldynian to early Tommotian interval.

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### 1. Introduction

During Ediacaran to mid-Cambrian times (635–505 Ma), the Earth underwent significant changes in paleogeography that include the rifting of a possible supercontinent and the formation of a second, slightly smaller supercontinent (Meert and Lieberman, 2004; Jiang et al., 2011). The assembly of the Gondwana supercontinent during the waning stages of the Proterozoic seems to have provided a tectonic backdrop for the biological, climatological, tectonic and geochemical changes leading to, and including, the explosive Cambrian radiation (Meert and Lieberman, 2008). Evidence for this radiation event includes the enigmatic (but widespread) Ediacaran fauna, trace fossils, small shelly fossils (SSFs) and soft-bodied fossils found in the Chengjiang, Burgess Shale and Sirius Passett Lagerstätten (Conway Morris et al., 1987; McCall, 2006; Shu, 2008). The abrupt appearance of diversified skeletal fossils during the early Cambrian has also been envisioned as

the biomineralization event, which is an important part of the Cambrian radiation. Many small shelly fossils represent the earliest record of some animal phyla, and some are of enigmatic zoological affinities and may be stem groups of metazoans. Therefore, SSFs are important for investigating the origin and early evolution of metazoans and for analyzing the Cambrian radiation pattern (Li et al., 2007).

Preceded by the soft-bodied Ediacaran fauna and by abundant late Neoproterozoic algae, and succeeded by the oldest trilobites from the base of Cambrian Stage 3, a wealth of skeletal fossils (so-called small shelly fossils) assignable to various animal phyla are distributed worldwide in pre-trilobitic Cambrian sedimentary rocks. These biomineralized or skeletonized animals essentially differ from the older soft-bodied metazoans, and the appearance of these various skeletal fossils represents a fundamental and profound biological innovation. This pre-trilobitic Cambrian interval in geological history was referred to as the Meishucunian age in South China (equivalent to the Terreneuvian epoch in the new Cambrian stratigraphical scheme), since the SSFs are particularly abundant and were well documented in the succession of the Meishucun section, Jinning, Yunnan, South China (Qian, 1977, 1978; Jiang, 1980; Qian et al., 2001; Zhu et al., 2001), which had been taken as one of the candidate sections for

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the GSSP of the Precambrian–Cambrian boundary (Luo et al., 1982, 1984). Stratigraphic successions of the Meishucunian stage are well developed and widely exposed on the Yangtze platform, and contain abundant SSFs (Qian et al., 1999). Previous studies of the Meishucunian fossils in the eastern Yangtze Gorges area focused mainly on the SSFs of the early Cambrian Tianzhushan member of the uppermost Dengying Formation in the eastern profile of the Huangling anticline before 1982 (Qian, 1977, 1978; Qian et al., 1979; Yu, 1979; Chen and Zhang, 1980; Chen et al., 1981a,b). But the Tianzhushan member ranges from several cm to 8 m in thickness, and represents a very incomplete record of the Meishucunian. Also, there is a distinct unconformity between the Tianzhushan member and the overlying Shuijingtuo Formation. Later, a continuous succession of the Meishucunian was found in the southern profile of the Huangling anticline (Chen, 1984), and the 40-m-thick sequence was called the Yanjiahe Formation since it is well exposed near the Yanjiahe village (Fig. 1). The Yanjiahe Formation is overlaid by black shale of the early Cambrian Shuijingtuo Formation, and is conformably underlain by finely crystalline dolomite of the uppermost Dengying Formation.

Previous work on the Yanjiahe Formation in the Three Gorges area focused on the SSFs, microscopic algae (Chen, 1984; Ding et al., 1992a,b) and C and Sr isotopes (Ishikawa et al., 2008; Sawaki et al., 2008; Jiang et al., 2012). Since 2005, a number of macroscopic fossils have been discovered from intercalated silty shales in the middle of the Yanjiahe Formation. Besides SSFs and spheroidal fossils (possibly embryos), fossils recovered from the Yanjiahe Formation near the Yanjiahe village include cyanobacteria, acritarchs, macroalgae and macroscopic metazoans (Guo et al., 2008, 2009, 2010a,b, 2012). The fossil assemblage of the Yanjiahe Formation is quite different from the Meishucun fauna, and hence was called the Yanjiahe biota (Guo et al., 2008).

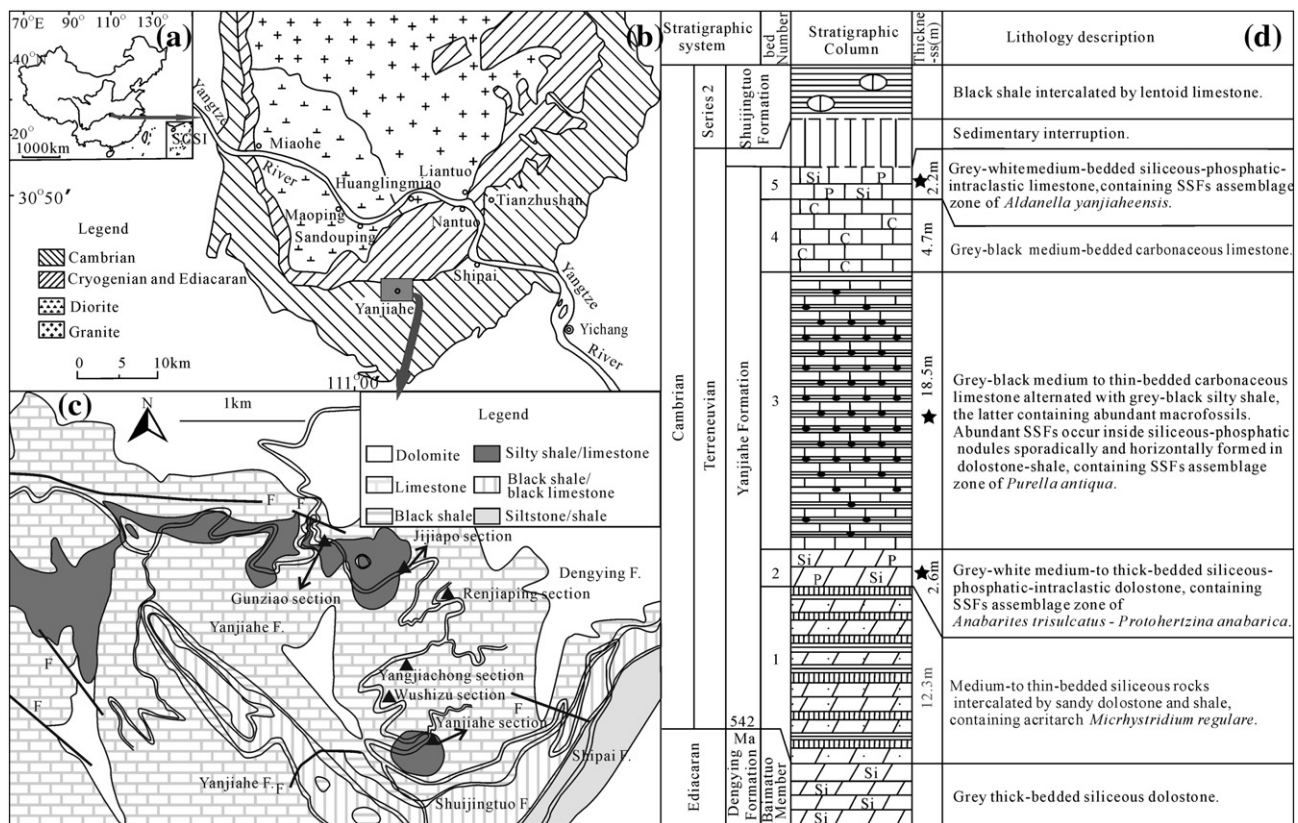
The purpose of the present paper is mainly to provide an overview of SSFs from the early Cambrian Yanjiahe biota, and to study the SSF biozonation of the Yanjiahe Formation.

**2. Material and methods**

For phosphatic carbonate rock samples, the traditional method of acid maceration was used. The fossils were extracted from the carbonate matrix with 3–5% acetic acid, and several thousand SSFs were handpicked from the undissolved rock residues. All specimens examined with a scanning electron microscope (SEM) were placed on metal stubs using double-sided carbon tape, and were gold coated. For the siliceous–phosphatic nodules, petrographic thin sections were made to examine skeletal fossils under a polarized microscope, and fossils were photographed with a digital camera. All specimens are registered and deposited in the School of Earth Science and Resources, Chang’an University, Xi’an, China.

**3. Fossil locality and stratigraphy**

All small shelly fossils under this paper were collected from the Yanjiahe Formation at seven sections (Yanjiahe, Gunziao, Jijiapo, Renjiaping, Yangjiachong, Wushizu and Heziao (Fig. 6)) in the Three Gorges area (Fig. 1). The Yanjiahe Formation outcrops mainly around the southern and western flanks of the Huangling anticline, as well as the core of the Changyang anticline, in the Yichang area. The Yanjiahe Formation can be subdivided on the basis of lithology into five beds, and the SSFs studied herein were recovered from Beds 2, 3 and 5 of the seven sections. But the exposure of the strata in different sections are different, the successions are particularly well developed and exposed around the Yanjiahe village (Sandouping town) and the Heziao



**Fig. 1.** Locality and stratigraphy of the early Cambrian Yanjiahe Formation, Yichang, Hubei, China. (a) Sketch map of the People's Republic of China, showing the position of the collecting locality in Hubei province; (b) simplified geological sketch map of the Three Gorges area, Hubei province, South China, showing the outcrops of Cambrian strata; (c) detailed geological sketch map of the Yanjiahe area, showing the outcrops of the Yanjiahe Formation; and (d) stratigraphic sequence of lower Cambrian strata in the Gunziao section, Three Gorges area, indicating the horizons where SSFs were collected.

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