

Fossil Association from the Lower Cambrian Yanjiahe Formation in the Yangtze Gorges Area, Hubei, South China

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Abstract: Apart from previously reported Small Shelly Fossils (SSFs), a macroscopic fossil assemblage, comprising abundant algae, cone-shaped tubular fossil forms, and probable impressions of a megascopic metazoan, comes from the Lower Cambrian Yanjiahe Formation in the Yangtze Gorges area of western Hubei Province, south China. The visible fossils are preserved in thin-laminated siltstone or muddy siltstone intercalated between 8–15 mm-thick carbonate deposits, probably representing sedimentary settings of a constrained local depression in the shallow water carbonate platform during the Early Cambrian Meishucunian Stage. The macroscopic fossil association provides significant fossil evidence about the evolution of life from the late Precambrian to the 'Cambrian explosion' interval.

Key words: macrofossil association, Yanjiahe Formation, Lower Cambrian, Yangtze Gorges Area, Hubei Province

1 Introduction

The Precambrian–Cambrian stratigraphic succession is well developed and exposed in the eastern Yangtze Gorges area of southern China, which is replete with complete and continuous sedimentary sections and most significant fossil Lagerstätten, and therefore, may serve as an ideal target for high-resolution biostratigraphic research. Previous work in this area has provided many accomplishments in understanding the Precambrian–Cambrian (Lee and Chao, 1924; Zhao et al., 1985; Qian, 1989, 1999; Bureau of Geology and Mineral Resources of Hubei Province, 1990; Liu, 1991; Ding et al., 1992b, 1996; Wang et al., 1987, 1998; National Committee of Stratigraphy, 2001; Chen et al., 2001; Yuan et al., 2002; Zhu et al., 2003; Yang et al., 2007; Mei et al., 2007).

Previous paleontological studies in the eastern Yangtze Gorges area mainly concentrated on Small Shelly Fossils (SSFs) of the Lower Cambrian Tianzhushan Member of the Dengying Formation, especially before 1982 at the eastern profile of the Huangling anticline, with the result of establishing a mixed zone comprising constituents of

both SSF assemblage zones I and II (*Circotheca-Anabarites-Paragloborilus*) (Qian, 1977, 1978; Qian et al., 1979; Yu, 1979; Chen and Zhang, 1980; Chen et al., 1981a, b). Later, a 50 m-thick succession of strata was found in this region, which was conformably overlain by the black shales of the Lower Cambrian Shuijingtu Formation, and underlain by the fine-crystal dolomite of the uppermost Dengying Formation in conformity in sections at Jijiapo and Yanjiahe villages located on the southern wing of the Huangling anticline, and thus presumably chronostratigraphically equivalent to the Tianzhushan Member (Chen, 1984). Since it is horizontally coherent in occurrence but lithologically distinct from the Tianzhushan Member, this rock unit was originally named the Yanjiahe Formation in the Yanjiahe section near Sandouping Town, Yangchang City (Chen, 1984). Subsequently, restudy of the equivalent strata at Yanjiahe, Miaohe and Hezi'ao localities proposed that the Yanjiahe Formation should be recast as the Yanjiahe Member subordinated to the Dengying Formation, yet chronostratigraphically correlated to the Lower Cambrian (Ding et al., 1992a). Nevertheless, the term Yanjiahe Formation has so far been preferentially and widely

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adopted since then (e.g. Chen et al., 2002; Zhu et al., 2003).

With regard to the boundary between the Yanjiahe Formation and the Bamatuo Member of the terminal Dengying Formation, in this paper we tend to assign the *Micrhystridium regulare*-bearing siliceous rocks to the bottom of the Yanjiahe Formation, and then consider the siliceous dolostone as the top of the Baimatuo Member (Ding et al., 1992a).

2 Geological and Sedimentary Settings

According to the variations of lithofacies, the SSFs-bearing strata of the lowermost Cambrian around the Huangling anticline can be subdivided into two types, i.e., the intraclastic dolostone facies (Tianzhushan Member) and the carbonaceous shale and limestone type (Yanjiahe Formation) intercalated with thin-laminated siltstones (Wang et al., 1987).

2.1 Intraclastic Dolostone type (Tianzhushan Member)

This type of section can be found in the eastern wing of the Huangling anticline and is represented by the Tianzhushan Member of the Dengying Formation at Tianzhushan in Liantuo Village, Yichang City, South China. The lower part of the Tianzhushan Member is dominated by micritic dolostone and overlies the Baimatuo Member, the terminal succession of miarolitic dolostone subordinate to the Dengying Formation in conformity, yet with a distinct boundary. The upper Tianzhushan Member is lithologically composed of siliceous-phosphatic-banded intraclastic dolostone and diagnosed by abundant SSFs, overlain by the Shuijingtuo Formation with a pseudo-conformity. The thickness of this member varies from 0.15 to 6.52 meters with an average of a mere 3 meters. The SSFs assemblage zones I and II tend to be mixed in this section and were thus provisionally outlined as the “*Circotheca-Anabarites-Paragloborilus* Assemblage” (Wang et al., 1987).

2.2 Carbonaceous shale and limestone Type (Yanjiahe Formation)

This type of deposit largely outcrops in the southern and western wings of the Huangling anticline as well as at the core of the Changyang anticline, being well developed in some sections along the riversides of Miaohe village in Zigui County, near Yanjiahe village of Sandouping town of Yichang City, and near Hezi’ao village in Changyang County (Fig. 1).

In terms of lithostratigraphical and paleontological data, the Yanjiahe Formation can be subdivided into five beds in ascending order (exemplified by the Gunzi’ao section of

Yanjiahe in Yichang): (Bed I) medium- to thin-bedded siliceous rocks intercalated with sandy dolostone and shale, containing fossil species *Micrhystridium regulare* (Ding et al., 1992a); (Bed II) grayish-white medium- to thick-bedded siliceous-phosphatic-intraclastic dolostone, containing SSFs assemblage zone of *Circotheca-Anabarites-Protohertzina*; (Bed III) grayish-black medium- to thin-bedded carbonaceous dolostone alternating with grayish-black silty shale, the latter containing abundant macrofossils and diverse SSFs, which are preserved in siliceous-phosphatic nodules in the shale; (Bed IV) grayish-black medium bedded carbonaceous dolostone; (Bed V) grayish-white medium-bedded siliceous-phosphatic-intraclastic dolostone, containing SSFs assemblage zone of *Lophotheca-Aldanella-Maidipingoconus*. The Yanjiahe Formation is up to 40 meters thick conformable with the underlying Baimatuo Member of the Dengying Formation and in parallel unconformity with the overlying Shuijingtuo Formation (Fig. 2).

The thickness and lithology of the Yanjiahe Formation vary from place to place in the region. It is about 20 meters thick and composed merely of Beds I and III along riversides of Miaohe village; the equivalent occurring in Hezi’ao is about 30 meters thick and lithologically similar to that in Gunzi’ao but lacking the terminal siliceous-phosphatic intraclastic dolostone. In terms of the preservation of macrofossils, the deposits from Gunzi’ao are well-preserved and diversified in contrast to those from Miaohe and Changyang.

2.3 Sedimentary environments

The Yanjiahe Formation consists of black thin-bedded siliceous rock interlayered with black carbonaceous shale and thin-bedded micritic dolostone in the lower part that upgrades into black carbonaceous dolostone with interlayered black carbonaceous silty shale rich in planar lamination and organic carbon, which indicates that the western and southern Yangtze Gorges area was situated in a comparatively deep setting of a shallow marine shelf during the deposition of the formation (Wang et al., 1991). Paleogeographically, the Yichang area comprises an Early Cambrian carbonate platform facies (Feng et al., 2001). Considering the limited distribution of the Yanjiahe Formation, we propose that the sedimentary facies of the research area might be a locally depressed shelf-sea carbonate platform during the Early Cambrian Meishucunian Stage.

3 Fossil Association of the Yanjiahe Biota

Dedicated collecting campaigns since 2005 have led to

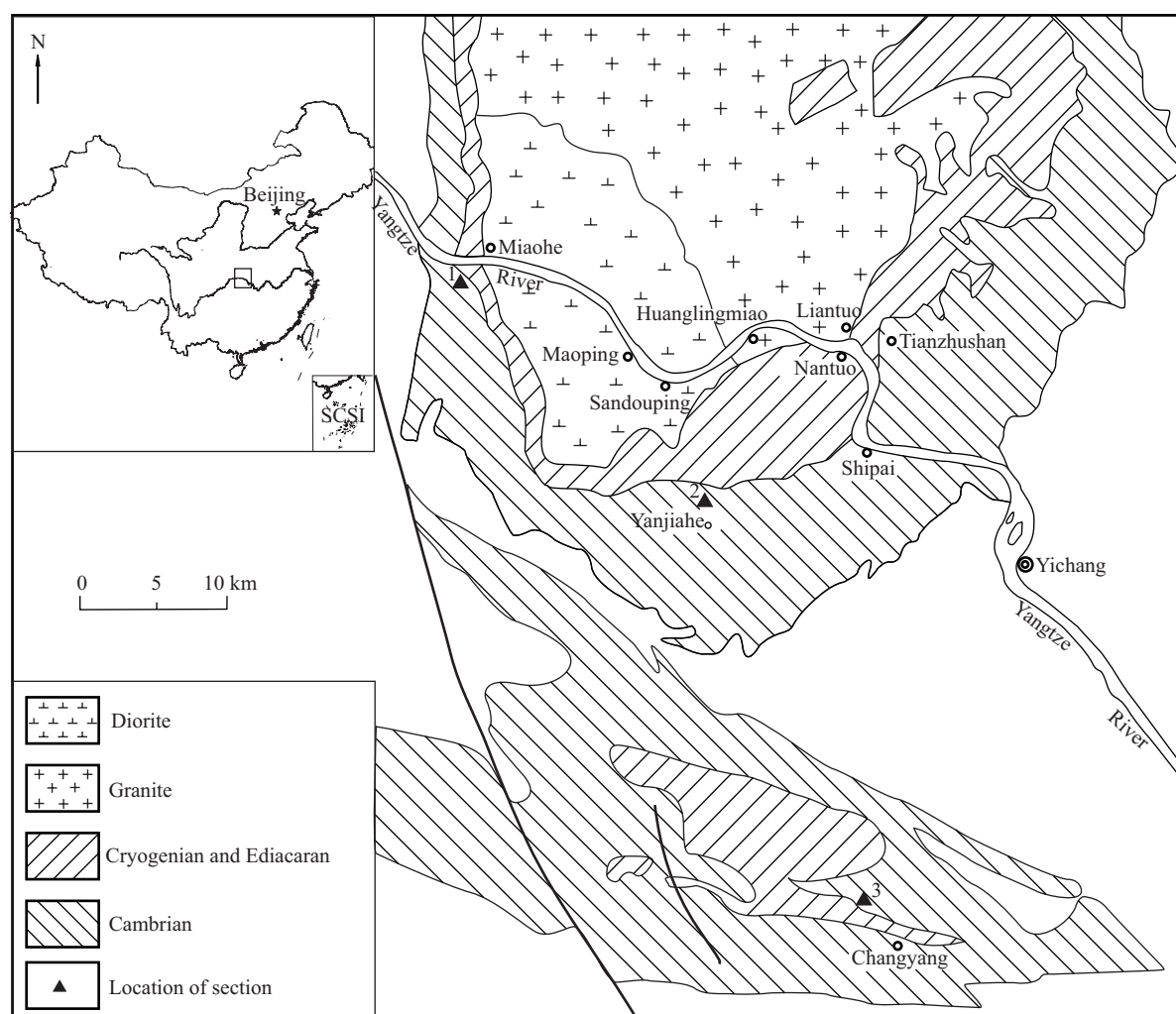


Fig. 1. Simplified geological sketch map of the Three Gorge area, Hubei province, southern China, showing the outcrops of Cambrian strata and the fossil locality.

1. Riverside section, Miaohé, Zigui; 2. Gunzi'ao section, Yanjiahe, Zigui; 3. Hezi'ao section, Changyang.

discovery of an abundant variety of fossils from the Lower Cambrian Yanjiahe Formation. Besides a number of SSFs, abundant macroscopic fossils including algae, cone-shaped tubular fossil forms and problematic metazoans have been discovered. To differentiate it from contemporary Early Cambrian Meishucunian biotas, this fossil association comprising distinctive macroscopic animals and algae as well as abundant SSFs is tentatively termed herein the “Yanjiahe biota”, with detailed description provided below.

3.1 SSFs

The SSFs are found in the lower portion (Bed II) and top (Bed V) of the Yanjiahe Formation, preserved in siliceous-phosphatic-intraclastic dolostone (Fig. 3). In between, abundant SSFs occur sporadically inside siliceous-phosphatic nodules and are in horizontal beds in dolostone-shale of Bed III (Fig. 4).

3.1.1 SSFs in siliceous-phosphatic-intraclastic dolostone

Chen (1984) revealed myriad SSFs in siliceous-phosphatic-intraclastic dolostone from both lower and terminal portions of the Yanjiahe Formation, accordingly and respectively defining the SSFs Lower Assemblage (Zone I) of “*Circotheca-Anabarites-Protohertzina*” and the Upper Assemblage (Zone II) of “*Lophotheca-Aldanella-Maidipingoconus*”. The upper and lower SSFs Assemblages from the Yanjiahe Formation can be significantly comparable to the Assemblage of “*Circotheca-Anabarites-Paragloborilus*” from the Tianzhushan Member. Equivalent SSFs-bearing sections are also widespread at other localities of the Yangtze platform, South China, i.e., the eastern Yunnan province (Jiang, 1980; Luo et al., 1982, 1984), western Sichuan province (Yin et al., 1980), and western Guizhou province (Qian and Yin, 1984).

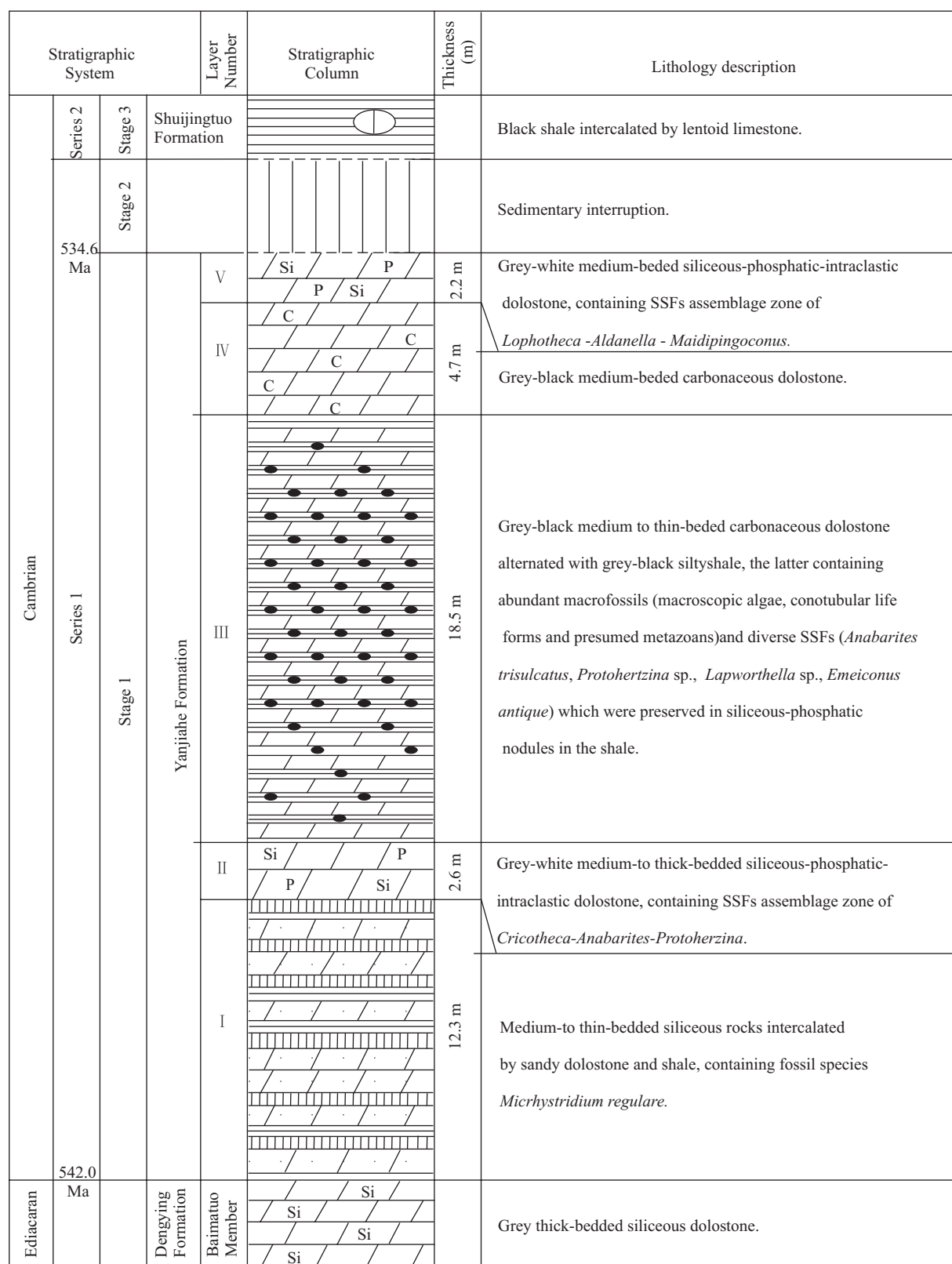


Fig. 2. Stratigraphic histogram of the Lower Cambrian Yanjiahe Formation, Yanjiahe, Yichang.

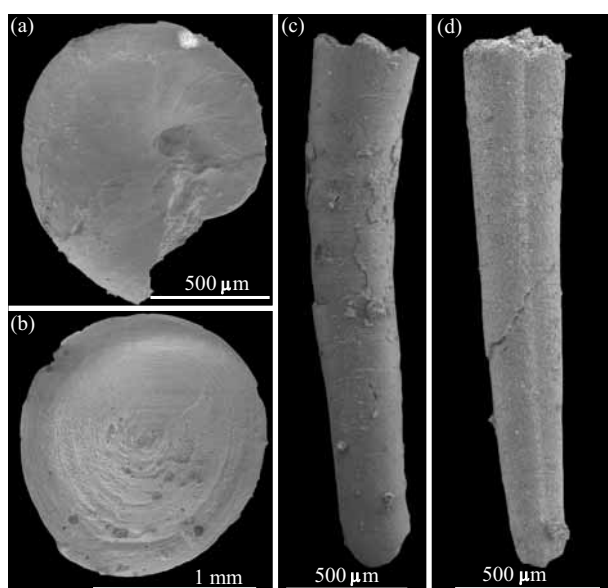


Fig. 3. Small shelly fossils in siliceous-phosphatic intraclastic dolostone from the Lower Cambrian Yanjiahe Formation, Gunzi'ao, Yanjiahe, Yichang.

(a) *Aldanella yanjiaheensis*, bottom view, Yjh-003; (b) *Scenella yanjiaheensis*, top view, Yjh-003; (c) *Circotheca longiconica*, side view, Yjh-003; (d) *Anabarites trisulcatus*, side view, Yjh-003. Horizon and locality: Lower Cambrian Yanjiahe Formation; Gunzi'ao, Yanjiahe, Yichang. specimens preserved in School of Earth Sciences and Resources Management, Chang'an University.

3.1.2 SSFs in siliceous-phosphatic nodules

A variety of well-preserved SSFs were found in siliceous-phosphatic nodules (3–15 cm in diameter) from the intercalations of silty shale (Bed III) of the middle Yanjiahe Formation. These nodules have been sampled and sliced into a great number of thin sections. The nodules invariably occur concordantly to bedding planes, which indicates their syngeneic origin. The predominant elements of the SSFs are *Anabarites trisulcatus*, *Protohertzina* sp., *Lapworthella* sp., *Emeiconus antique*, and some questionable species (Fig. 4). The SSFs contained in the nodules embrace not only typical elements of the SSFs Assemblage Zone I, such as *Anabarites trisulcatus*, *Protohertzina* sp., but also representatives of Zone II, i.e., *Emeiconus antique* and *Lapworthella* sp. However, compared with those from Bed V, the SSFs preserved in the nodules are less abundant and diversified, which may indicate their evolutionary interim from SSFs Zone I to Zone II.

3.2 Macrofossils

The novel macrofossils consisting of macroscopic algae, cone-shaped tubular life forms and presumed metazoans are usually preserved as carbonaceous compressions or body fossils in intercalations of the silty shale of the middle Yanjiahe Formation (Fig. 5).

3.2.1 Macroscopic algae in shales

The preponderant algal genus from the Yanjiahe Formation is *Vendotaenia* (Chen et al., 2002), which usually occurs as ribbon-like carbonaceous compressions or body fossils, showing longitudinal striae and lateral expansion. The preservation and morphology is similar to *Vendotaenia* from both the Shibantan Member (Mid Dengying Fm.) and the Miaohu biota (terminal Doushantuo Formation) (Fig. 5d-e). Some specimens are cluster-like, with root-like structure as carbonaceous compressions at the base (Fig. 5f), generally analogous to *Yuknessia* derived from the Chengjiang biota (Yunnan) and the Niutitang Formation (Guizhou) (Yang et al., 2003). Others reported here show biramous features (Fig. 5g) but lack organs like roots or holdfasts, morphologically resembling *Konglingphyton* from the Miaohu biota.

3.2.2 Cone-shaped tubular fossils

The 10–20 mm long cone-shaped tubular fossils from the Yanjiahe biota possess an opening at the top and taper towards the bottom with a slight curve (Fig. 5a–c), comparatively resembling a metazoan described as *Protoconites minor* by Chen et al., 1994 (Ding et al., 1996; Xiao et al., 2002; Zhao et al., 2004) from the Miaohu biota in morphology and preservation. They are also morphologically similar to *Archotuba conoidalis*, a presumed fossil coelenterate from the Chengjiang biota (Hou et al., 1999) yet lack the diagnostic transverse septum-like structures preserved in the latter, thus more morphological and anatomical evidence is required to support their phylogenetic connection.

3.2.3 Probable metazoan fossils

The probable metazoans are generally preserved as carbonaceous compressions parallel to bedding planes and in general they exhibit a bipartite bodyplan. The discal anterior unit consists mostly of a carbonaceous mass and shows after careful preparation interior structures as filaments or wrinkles (Fig. 5h). The worm-like posterior section is generally curved into U-shaped or L-shaped and tends to taper slightly towards the end. The posterior unit is distinct with transverse wrinkles and has a longitudinal mid-ridge along the entire body, which presumably represents the alimentary canal (Fig. 5i). The characters of the posterior unit are similar to *Sabellidites* from the Cambrian (Sokolov, 1965; Chen et al., 1975; Yang et al., 2006), but most of the *Sabellidites* are incomplete vermicular fossils, and the discal anterior unit of the probable metazoan fossils is different from that of *Sabellidites*. Compared with the posterior, the anterior shows more closely-spaced and distinct wrinkle-like

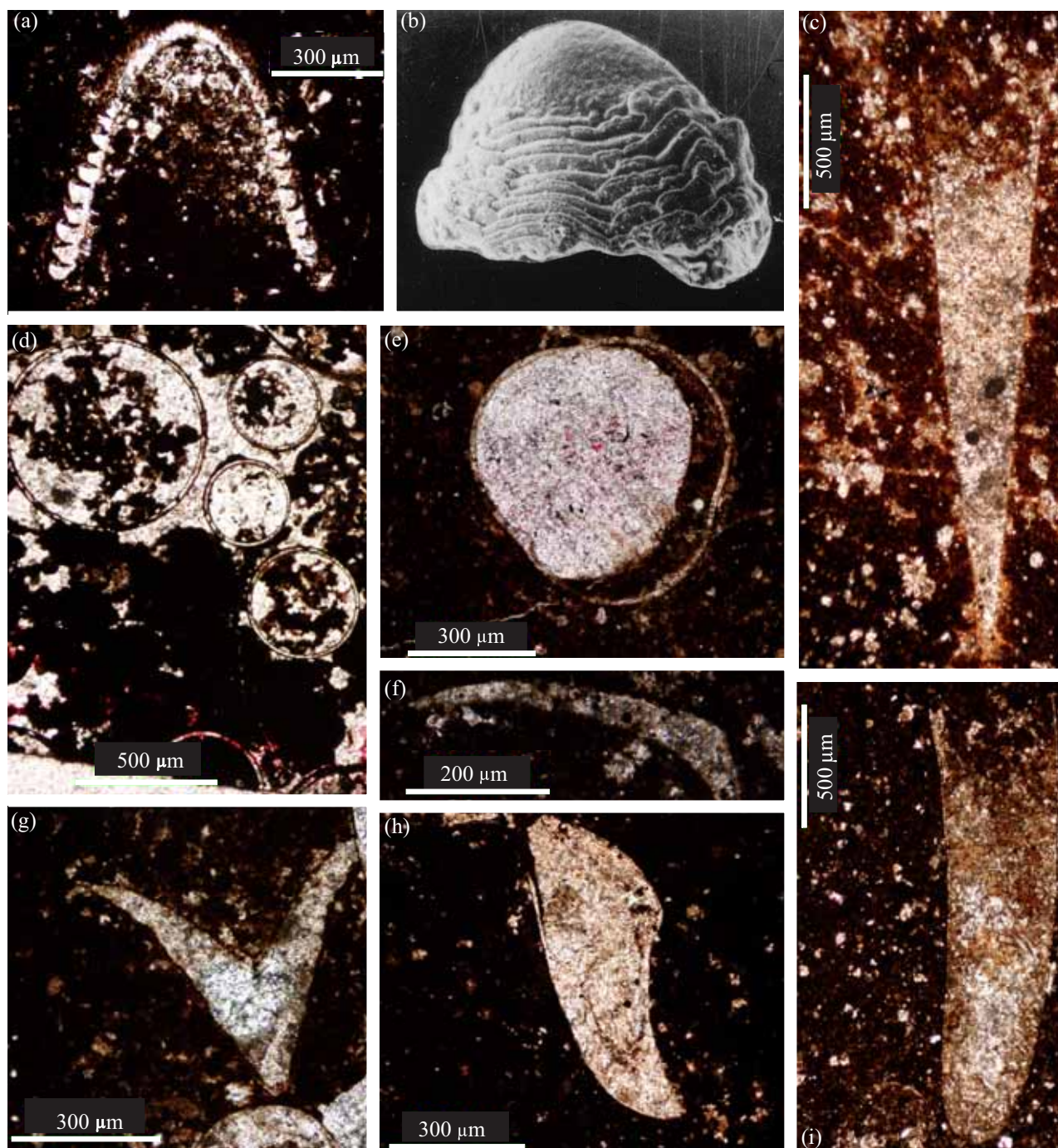


Fig. 4. Small shelly fossils in siliceous-phosphatic nodules from the Lower Cambrian Yanjiahe Formation, Gunzi'ao, Yanjiahe, Yichang.

(a)-(b) *Emeiconus antique*, (a) longitudinal section, Byjh-106; (b) side view, $\times 72$, TzsFB; (c) longitudinal section of hyoliths or Hyolithelminthes, Byjh-125; (d) transverse section of hyoliths or Hyolithelminthes, Yjh-059A; (e) *Anabarites trisulcatus*, transverse section, Yjh-030; (f) *Protohertzina* sp., longitudinal section, Byjh-034; (g) *Lapworthella* sp., longitudinal section, Yjh-030; (h) longitudinal section of hyoliths or Hyolithelminthes, Byjh-107; (i) longitudinal section of hyoliths or Hyolithelminthes, Yjh-21. Horizons and localities: specimen numbers with "TzsFB" mark the collecting horizon of the Tianzhushan Member, Dengying Formation, while "Yjh" or "Byjh" the Yanjiahe Formation of Gunzi'ao, Yanjiahe, Yichang. Specimens preserved in School of Earth Sciences and Resources Management, Chang'an University.

structures, while the posterior is distinct in the mid-ridge and some terminal filaments (Fig. 5j). However, the phylogenetic position of these probable metazoans remains has yet to be resolved.

4 Discussion and Conclusions

Macroscopic fossil algae in the interval from the late Neoproterozoic to the early Cambrian in South China were reported from the Miaohu biota (Zigui, Hubei; Jiangkou,



Fig. 5. Macrofossils from the Lower Cambrian Yanjiahe Formation, Gunzi'ao, Yanjiahe, Yichang. (a)-(c) *Protoconites minor* Chen et al. 1994, Yjh-HS36, Yjh-HS32, Yjh-HS31; (d)-(e) *Vendotaenia* sp., Yjh-HS51, Yjh-HS16; (f) *Yuknessia* sp., Yjh-HS81; (g) *Konglingiphyton* sp., showing birameous features, Yjh-HS24; (h)-(j): a probable metazoan, Yjh-HS18; (i) a close-up of (h), diagnostic of closely-spaced transverse wrinkles and a longitudinal mid-ridge along the entire body; (j) a close-up of (h), showing the longitudinal mid-ridge. Horizon and locality: Yanjiahe Formation of Gunzi'ao, Yanjiahe, Yichang. Specimens preserved in Department of Geology, Northwest University.

Guizhou), the Lantian biota (Anhui), and the Shibantan Member (mid Dengying Formation) (Ding et al., 1996; Yuan et al., 2002; Xiao et al., 2002; Zhao et al., 2004). Morphologically similar algae were also found in the early Cambrian Niutitang biota (Yang et al., 1999) and the Chengjiang biota, which indicates the survival of a stable botanic ecosystem during the interval from late Cryogenian to Cambrian in the neritic marine of the Yangtze platform. Thus, more analogical fossil sites should be uncovered in southern China.

For a long time, our previous understanding of the paleobiology of the early Cambrian Meishucun Age were confined to a combination of SSFs and acritarchs. The Yanjiahe fossil association, i.e. macroscopic metazoans, algae and SSFs, first systematically outlines the palaeobiological community of the shelf-sea carbonate platform facies or a local depression in the platform during the Meishucun Age. Macroscopic algae and cone-shaped tubular fossils from the Yanjiahe biota, in terms of both preservation and morphology, possess considerable earmarks of the Miaohu biota. In addition, this biota also has potential affiliations with the Niutitang and Chengjiang biotas. Clearly, the Yanjiahe biota will provide fossil evidence for the evolution and taphonomy of early life.

The probable metazoans in the Yanjiahe biota might represent the earliest known soft-bodied macroscopic metazoans associated with the SSFs of the Meishucun Age. They might play a critical role in decoding the "Cambrian Explosion" of animal radiation. Accordingly, these potential metazoans in the Yanjiahe biota are of paramount significance in evolutionary paleobiology, although their detailed anatomical characteristics and definite phylogenetic lineages await further research.

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