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Protoconodont fossils for refining the Cambrian bottom and the contribution to shale gas formation along the southwest margin of Yangtze Block

Jun-ping Liu[a, b], Si-cun Song[c, d], Wei Wang[a, b,*], Feng Tang[d,*], Jing Li[b, e], Xiang-dong Duan[b, e], Xiao-hu Wang[a, b], Bai-dong Sun[a, b], Sai-ying Yu[a, b], Shao-bin Hu[a, b], Wen-ting Duan[f]

[a] *Yunnan Institute of Geological Survey*, *Kunming* 650216, *China*
[b] *Key Laboratory of Sanjiang Metallogeny and Resources Exploration and Utilization*, *Ministry of Natural Resources*, *Kunming* 650051, *China*
[c] *Department of Earth Sciences*, *University College London*, *London WC*1E6BT, *United Kingdom*
[d] *Key Laboratory of Stratigraphy and Palaeontology*, *Chinese Academy of Geological Sciences*, *Ministry of Natural Resources*, *Beijing* 100037, *China*
[e] *Yunnan Institute of Land and Resources Planning and Design*, *Kunming* 650216, *China*
[f] *Yunnan Department of Natural Resources*, *Kunming* 65000, *China*

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ABSTRACT

It has been an intense debate on the exact boundary between Ediacaran and Cambrian in the southwest Yangtze Block. The calibration of this critical boundary has a remarkable influence on the further investigation of the break-up of the Rodinia Supercontinent, the early life evolution, and the mechanism of the phosphorite deposit. Ediacaran and Cambrian strata and fossils are widely distributed in Anning, Yunnan Province in China. In recent years, the Xiaowaitoushan Member from the Lower Yuhucun Formation has been studied. Through this interval with continuous collections, the first appearance datums (FADs) of the protoconodont (*Fomitchella* cf. *inchoate* Yang et He, *Protohertzina* cf. *anabarica* Missarzhevsky) and globular embryos fossil (*Olivooides* sp.) earlier than these in the Lower Cambrian strata of the Meishucun Formation were discovered. This discovery indicates that the Xiaowaitoushan Member has included more FADs than the previously discovered single FAD of *Anabarites primitivus* Qian et Jiang, and the Ediacaran–Cambrian boundary in southwest China should be replaced below the Point "A" of the Meishucun Formation in Yunnan Province. The Point "B" of the Meishucun Formation is younger than the suggested age 541 Ma of the Ediacaran–Cambrian boundary and can no longer reference the Global Boundary Stratotype Section and Point (GSSP) correlation in southwest China. It can be suggested based on the previous stratigraphy and palaeontology studies from northern Sichuan and southern Shaanxi and the FAD of the globular embryos fossils that the Ediacaran–Cambrian boundary in the southwest Yangtze Block should be placed at the base of the Xiaowaitoushan Member; other phosphorite strata refer to Xiaowaitoushan Member. The discovery of the FADs of the shelly fossils in the Xiaowaitoushan Member provides new evidence for the global correlation of the Ediacaran–Cambrian boundary in the southwest Yangtze Block. The conodont discoloration index (CAI) of the specimens in Anning is between 2 and 3, which indicates that the organic matter in Xiaowaitoushan Member is matured and has high potential to form a shale gas reservoir.

1. Introduction

The Late Ediacaran and the Early Cambrian experienced a series of biotic and environmental events. After the Nanhuan glaciation, the global historical environment changed fiercely with the break-up of the supercontinents, the oxidation of the ocean, the early evolution of metazoa, the anomalies of the carbon isotope, and the local sulfurous sea. The emergence and the early radiation of the metazoa are encompassed in the complex historical events and are the most significantly unresolved historical phenomenon in the history of life (Qian Y, 1977; Jiang ZW, 1980; Luo HL et al., 1980, 1982, 1984; Xing YS et al., 1984; Yang XH and He TG, 1984; Yue Z and He SC, 1989; Xie YS, 1990; Yue Z and Gao LZ, 1992; An

First author: *E-mail address*: 271090834@qq.com (Jun-ping Liu).
* Corresponding author: *E-mail address*: 1993006148@qq.com (Wei Wang); 523734337@qq.com (Feng Tang).

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TX and Mei SL, 1994; Qian Y and He TG, 1996; Dong ZZ and Wang W, 2003; Qian Y et al., 2008; Zhu RX et al., 2009). The study of paleontology in this critical period is of great significance to the global correlation of stratigraphy and palaeoecology.

The Meishucun Formation in Yunnan Province has continuous outcrop from the Late Ediacaran to the Early Cambrian, becoming a decent stratotype for global correlation. In the 1980s, the Meishucun Formation was once a Global Boundary Stratotype Section and Point (GSSP) candidate of the Ediacaran-Cambrian boundary. Besides, in 1992, the GSSP of the Ediacaran–Cambrian boundary was placed on the first appearance datums (FAD) of a complex trace fossil (*Treptichnus pedum*) in the Fortune Head Formation in Newfoundland, Canada. Nonetheless, this complex trace is not ideal as a marker fossil because it is not found in every Cambrian sequence, and whether it is located at the same level in every exposure cannot be assured. Due to the disruption of the complex depositional environment, the correlation of the Ediacaran–Cambrian boundary is roughly placed at the base of "Unit 6" in upper Zhongyicun Member in the Meishucun section and has contradicted the former potential boundary including Point "A" to Point "D". From the research results, there are some controversial views on the boundary between Ediacaran and Cambrian as follows. (1) The base of Cambrian (Point "A") can be defined according to the FADs of small shelly fossil *Anabarites* and protoconodont *Protohertzina* (Qian Y and He TG, 1996; Qian Y, 1999). (2) The range zone for global correlation (Point "B") can be defined using small shelly fossil assemblages (He TG, 1984). (3) The boundary can be placed at the FADs of the oldest trilobites Redlichiids and Ptychopariid bigotinids (Point "D") (Luo HL et al., 1984, 2019). (4) The FAD of the Ediacaran-Cambrian GSSP *Treptichnus pedum* in the Meishucun section is referred to (Li RH (1991).

Apart from the biostratigraphic evidence, the carbon isotope Base of Cambrian isotope Excursion negative anomaly in Otavi carbonate slope in northwest Namibia was used by Hoffman and Knoll to establish an isochronous surface (Hoffman PF, 1998; Knoll AH and Carroll SB, 1999), and a related 541 Ma age from the zircons were extracted as the age of the Ediacaran-Cambrian boundary. In 2009, Ri-xiang Zhu and his team discovered the age of 535.2±1.7 Ma from the zircons in the bentonite layer in the Zhongyicun Member of the Meishucun section with the U-Pb method (Zhu RX et al., 2009). Their results strongly support that the Ediacaran–Cambrian boundary in Meishucun section should be placed on the older Point "A" in the Xiaowaitoushan Member rather than the Point "B" in the upper Zhongyicun Member with age younger than the 541 Ma boundary age.

The Damaidi section in Anning, Yunnan Province is investigated based on the biostratigraphic and geochemistry results. Specifically, the Damaidi section has a clear and continuous outcrop of the Late Ediacaran and Cambrian, and its lithology and biostratigraphy can correlate with the well-known Meishucun section. Then, FADs and the CAI of the protoconodont and globular embryos fossil earlier than these in the Lower Cambrian strata of the Meishucun section were discovered through this interval. The Ediacaran–Cambrian boundary should be placed at the base of the Xiaowaitoushan Member (Point "A") rather than the Upper Zhongyicun Member (Point "B"). The new discovery provides a supportive reference to calibrate the Ediacaran–Cambrian boundary in Yunnan Province and illustrates the potential of shale gas deposit in Yuhucun Formation in the Lower Cambrian strata of Yunnan.

2. Geological background

The research area is in Damaidi, Anning City, Yunnan Province, locating in the coastal Pacific metallogenic domain-Upper Yangtze (continental block) metallogenic Province-the south-central Yunnan metallogenic belt (Liu JP et al., 2020; Sun BD et al., 2019). The outcropped strata in this area are the Upper Sinian Dengying Formation (Z_2dy), Lower Cambrian Yuhucun Formation ($\in_1 y$), Lower Cambrian Qiongzhusi Formation ($\in_1 q$), Lower Cambrian Canglangpu Formation ($\in_1 c$) (Fig. 1); as a near-shore sedimentary sequence from terrestrial clastic rocks to limestone[①].

The examined Damaidi section included continuous strata from the Upper Dengying Formation to the Qiongzhusi Formation (Fig. 2). The Dengying Formation includes the Jiucheng Member and the Baiyanshao Member (previously belongs to the Yuhucun Formation). The Yuhucun Formation is divided into three units from the base to the top as the Xiaowaitoushan Member, the Zhongyicun Member, and the Dahai Member. The Qiongzhusi Formation (correlated to the Heilingpu Formation) is divided into two parts as the Shiyantou Member and the Yuanshan Member. The dolomitic sediments dominate the upper Dengying Formation and the Yuhucun Formation including the Baiyanshao Member, the Xiaowaitoushan Member, and the Dahai Member. The Zhongyicun Member is characterized by phosphorite and dolomitic phosphorite. A zircon age of 535.2±1.7 Ma was discovered from the bentonite in the middle of the Zhongyicun Member (Zhu RX et al., 2009). The lower Qiongzhusi Formation is characterized by organic-rich sandstone, siltstone, and shale. The black shale strata with abundant trace fossils and nodules from the upper Shiyantou Member and the lower Yuanshan Member are called "the lower black layer" and "the upper black layer" and have been recognized as a regional marker.

In the Meishucun section, the Point "A" is 0.8 m above the base of the Xiaowaitoushan Member with the emergence of the small shelly fossils. The Point "B" is between the "Unit 6" and "Unit 7" in the upper Zhongyicun Member with the radiation of the small shelly fossils. Both Point "A" and Point

[①]*Notes:* Yunnan Provincial Geological Survey Institute. 2018. Regional geological survey report of Yunnan 1∶50000 Erjie, Yimen, Mingyihe, and Shangpubei blocks.

"B" were recommended as the GSSP candidates of the Ediacaran–Cambrian boundary. Point "C" is the boundary between the Yuhucun Formation and the Qiongzhusi Formation with an abrupt change in the lithology that indicates a deoxidation event in ocean chemistry. Point "D" marked the FAD of the earliest trilobite.

3. Materials and methods

The specimens were collected from the light-grey medium-bedded dolomite at 1.0 m above the base of the Xiaowaitoushan Member at the Damaidi section in 2017. All the specimens were analyzed at the laboratory of the Institution of Yunnan Geological Survey.

The specimens were first crushed into 2.0 –2.5 cm diameter grains. The grains were dissolved in a plastic container with a 9% –10% acetic acid solution bath under room temperature. The specimens were filtered and washed by deionized water and new acid was replaced to dissolve the specimens every 3 –4 days to keep the pH of the solution. After 5–6 times of acid replacements, the phosphoric fossils were recovered in the acetic acid residues. Two sieves were used for the residues. The first sieve is 20 meshes and the second sieve is 100 meshes. The residues bigger than 20 meshes or smaller than 100 meshes were abandoned and washed away by deionized water. The rest of the specimens were gently washed and left to dry naturally. The dried specimens were examined under a binocular microscope, and the fossils were manually picked out by the professionals. The images used in the text were taken at Hubei Geological Research Laboratory. The SEM images were taken by the Quanta400 FEG scanning electron microscope.

4. Fossil description and discussion

The conodonts in the Lower Cambrian in Yunnan were first reported by Zhi-wen Jiang in 1980 (Jiang ZW, 1980). Later, Dong ZZ and Wang W (2003) discovered some cone-shaped conodonts in the logging process in Chenggong, Yunnan Province. These conodonts were named as *Fomitchella inchoate* fauna and include conodonts: *Fomitchella inchoate*, *Hastina bialata*, *Ganloudina* sp., *Kijacus* cf. *kijanicus*, *Hertzina* sp., *Fomitchella* sp.; with hyolithes: *Paragloborilus* cf. *mirus*, *Conotheca* sp. and sclerite: *Allonniaellomenosa*, *Dimidiasimpleca*. From the beddings under the *Fomitchella inchoate* fauna, chancelloriids including *Archiasteasterellapentactina*, *Adversellamountanoides*, and *Chancelloria* sp. were discovered. Even though it is challenging to locate the exact horizon of the fossils with the drill record, the conodont fossil assemblage in Yunnan Province is similar to the assemblage discovered in the Lower Cambrian strata in Nanjiang, Sichuan Province (He TG, 1984). The age of the conodonts was assumed to the early Meishucun stage in Early Cambrian, and the *Fomitchella inchoate* fauna is recorded as the earliest conodonts assemblage in eastern Yunnan.

In 1977, Yi Qian and his team reported some hyolithes, sclerite, and enigmatic fossils from the Early Cambrian in the

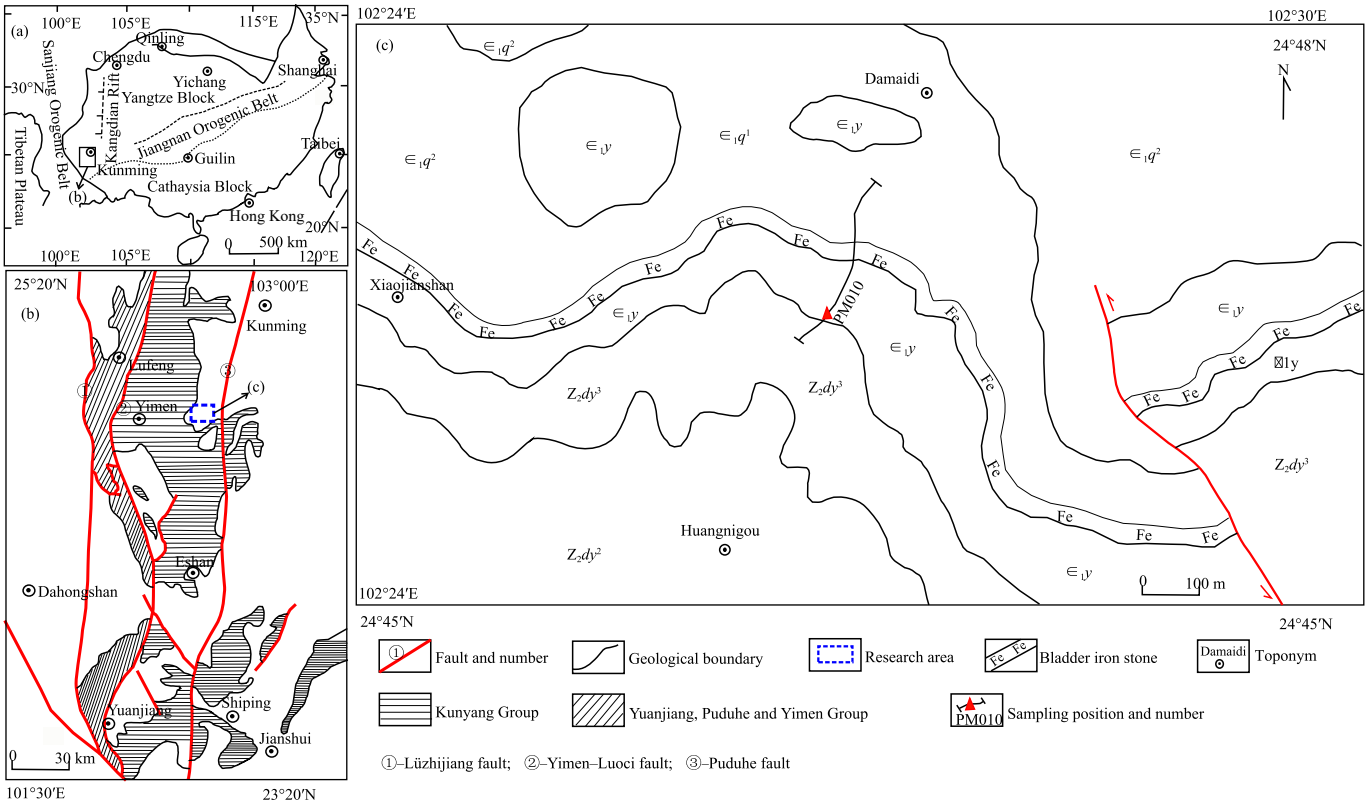

Fig. 1. Tectonic division sketch of the south China continent (a), geological sketch map of central Yunnan area (b) and geological sketch map and sampling locations (c) of the Anning area, central Yunnan.

southwest of central China (Qian Y, 1977). *Protohertzina* was first described in the Kuanchuanpu Formation in Ningqiang, Shaanxi Province, and the Huangshandong Formation in Yichang, Hubei Province (Qian Y, 1977). In 2008, Yi Qian systematically described and classified 13 genera of the protoconodonta and suggested these fossils had evolved in multi directions and might relate to the tooth-like organs of some extinct Bilateria (Qian Y et al., 2008). The protoconodonta was reclassified. The fractural surfaces of the protoconodonts have lamellated microstructures and the teeth growth proceeds by adding from the base or the outside of the basal cavity to the end of the cusp which is similar to the jaw spines growth of the modern Polychaeta. The results of this paper support Qian's view that the protoconodonta are related to the Polychaeta and the occurrence of the protoconodonta is the evidence of predators with jaw spines in Cambrian.

During the 1∶50000 mapping in Anning, Yunnan Province, the authors discovered new materials of protoconodonts in Yunnan Province (Fig. 3). These specimens are similar to the *Fomitchella inchoate* from Sichuan, Shaanxi, and Hubei provinces and the *Protohertzina anabarica* from Meishucun, Yunnan Province.

Phylum, Class, Family Uncertain

Genus *Fomitchella* Missarzhevsky 1969

Species *Fomitchella inchoate* Yang et He 1981

(Plate.1, Fig. 3, A1–A4)

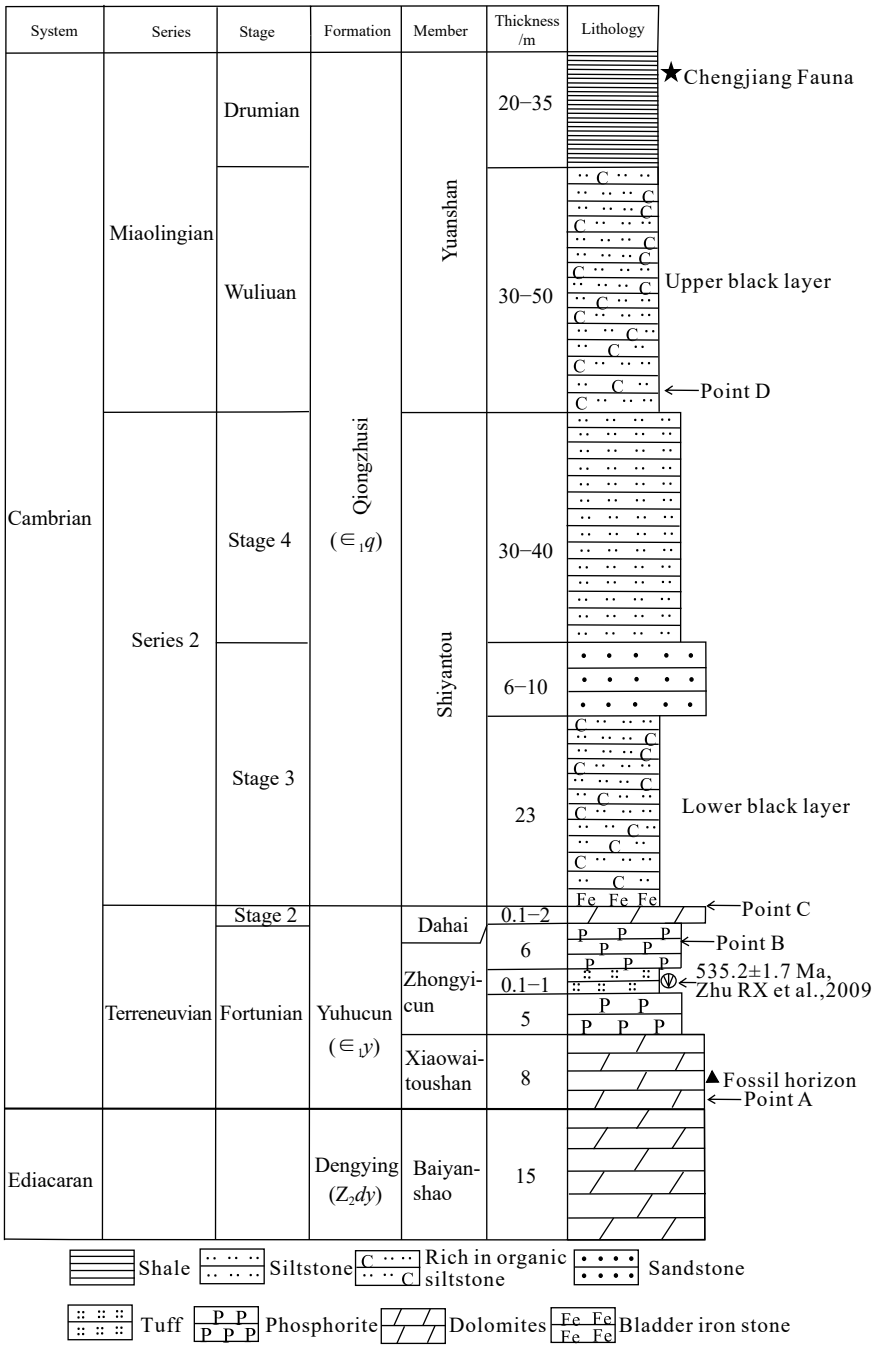

Fig. 2. Stratigraphic division of the Damaidi section in Anning area, central Yunnan (modified from Luo HL et al., 1984).

1984 *Fomitchella inchoate*, Yang et He, P40, Plate Ⅱ, Figs. 8–9.

Description: The fossils are hollow cones; the tooth is bilateral symmetry, usually slightly flattened laterally, with widely flaring bases and narrow, drawn-out tips; the cusp is sharp, pointing at an angle of 25°–30° away from the basal spine; the cross-section is circular; the edge of the basal cavity is smooth; the cavity does not extend into the narrow tip; the cavity is large, covered by white infill; the teeth length are from 0.68–1.20 mm; the basal section is 0.3–0.4 mm wide and 0.2–0.7 mm high.

Remarks: The specimens A1–A4 from Anning are similar to the *Protohertzina robusta* reported from the Kuanchuanpu Formation in Ningqiang, Shaanxi Province as hollow cones (Qian Y, 1997; Plate. II, Figs. 13, 14). The dorsal and ventral margin of *P. robusta* is obviously ridged, with shallow heart-shaped grooves on both sides of the longitudinal ridge, and a pair of lateral ridges. The specimens A1–A4 from Anning are

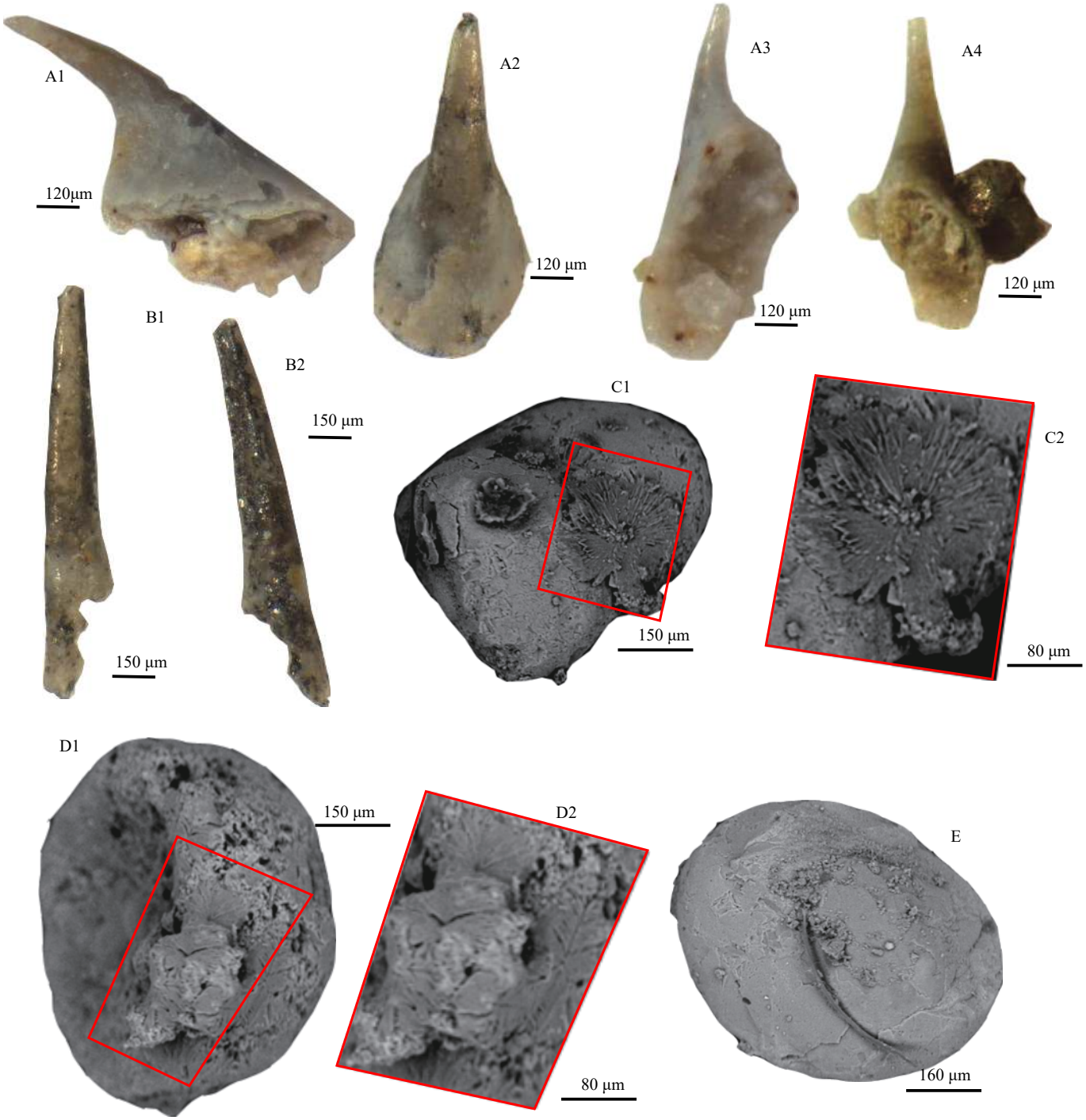

Fig. 3. Protoconodonts and globular embryo fossils from Anning area, Yunnan Province. A1–A4–*Fomitchella inchoate* Yang et He, 1984. A1 –lateral view; A2 –front view; A3 –posterior view; A4 –posterior view. B1 –B2 – *Protohertzina cf. anabarica* Missarzhevsky, 1973. B1–B2–side view. C1–C2, D1–D2, the radial structure on the surface of *Olivooides*. E, *Olivooides* individuals with tubular bodies. All specimens are collected from the Xiaowaitoushan Member of the Yuhucun Formation in Anning area, Yunnan Province.

not *P. robusta* for the margin is smooth without heart-shaped grooves and longitudinal ridge. The specimens from Anning have small, smooth, and semi funnel-shaped spines. The basal cavity is large and deep. The base margin is semicircular. The overall shape of the tip is slender. The tooth cone is short and the cross-section is nearly circular. These features are basically the same as the *F. inchoate* fossils reported by Xin-he Yang and Ting-gui He in Sichuan Province in 1984 (Plate. 2, Figs. 8, 9) (Yang XH and He TG, 1984), and Zhi-zhong Dong and Wei Wang in Yunnan Province in 2003 (Plate.1 Figs. 10, 15) (Dong ZZ and Wang W, 2003).

Distribution: Early Cambrian.

Occurrence: The Xiaowaitoushan Member is in Yuhucun Formation, Lower Cambrian, Damaidi, Anning, Yunnan Province. The Mofangyan Member is in Dengying Formation, Lower Cambrian, Nanjiang, Sichuan Province.

Phylum, Class, Family Uncertain

Genus *Protohertzina cf.* Missarzhevsky 1973

Species *Protohertzina cf. anabarica* Missarzhevsky 1973

(Plate.1, Fig. 3, B1–B2)

1973 *Protohertzina anabarica* Missarzhevsky, M. ИЗД—ВО. 《Hayka》, СТР. 54, ТабЛ. Ix, φИг. 1, 2, 4, 6, РИС. 1—3.

1977 *Protohertzina anabarica* Missarzhevsky, Yi Qian, P267, Plate Ⅱ, Figs. 7–12.

Description: The fossils are typically simple cones with less flaring bases. The tooth is slender, symmetrical on both sides, gentle bending, gradually thinning near the top of the tooth, and the cusp is broken. The dorsal margin is smooth, with longitudinal ridges on both sides of the abdominal margin, and a shallow heart-shaped groove in the middle. The length of the tooth is 1.2 mm, the height and width of the base section are 0.2 mm.

Remarks: The specimens B1–B2 from Anning are similar to the *P. anabarica* reported from the Kuanchuanpu Formation in Ningqiang, Shaanxi Province (Qian Y, 1977, 2008; Plate. II, Figs. 7–12) and the *P. anabarica* from the Zhongyicun Formation in Meishucun, Yunnan Province (Fig. 1, E1 –E2). The base of the specimens from Zhongyicun Formation is wide, and the teeth of the specimens from the Kuanchuanpu Formation have shallow and thin longitudinal grooves in the center of the dorsal margin, and the ridges and troughs do not reach the cusp. In the former, the dorsal and ventral margin is smooth and the tooth cusp is broken. The overall characteristics of the two are similar, but the features are slightly different.

Distribution: Early Cambrian.

Occurrence: The Xiaowaitoushan Member is in Yuhucun Formation, Lower Cambrian, Damaidi, Anning, Yunnan Province. The Zhongyicun Member is in Yuhucun Formation, Lower Cambrian, Jinning, Yunnan Province. The Mofangyan Member is in Dengying Formation, Lower Cambrian, Nanjiang, Sichuan Province. The Kuanchuanpu Formation is in Lower Cambrian, Ningqiang, Shaanxi Province. The Huangshandong Formation is in Lower Cambrian, Shipai, Yichang, Hubei Province.

At the same location where the authors discovered the *F. inchoate* and *P. anabarica,* globular embryo fossils (*Olivooides* sp.) were found in the same period (Fig. 3, C1–E). *Olivooides* are common in Lower Cambrian and were first reported in the muddy phosphorous limestone in Ningqiang, Shaanxi Province by Yi Qian in 1977 (Qian Y, 1977). Little is known about which organisms *Olivooides* is related to. In recent studies, *Olivooides* has been compared to echinoderms based on its pentaradial symmetry (Stefan B and Yue Z, 1997; Yue Z and Stefan B, 1999; Chen JY, 2004; Dong XP et al., 2004, 2016; Dong XP, 2009).

In this study, the specimens from Anning (Fig. 3, C1–E) are similar to the *Olivooides* in the Bitiao Formation in Yongshun, Hunan Province (Dong XP, 2007, 2009) and the Kuanchuanpu Formation in Ningqiang, Shaanxi Province (Hou XJ, 2010) in the Early Cambrian. The sphere-shaped embryos have thin and smooth eggshells and develop lobar radial respiratory tract. Some individuals develop tubular bodies.

The discovery of the fossil assemblage of *F. inchoate, P. anabarica* and *Olivooides* indicates that the protoconodont assemblage has occurred and evolved into a thick-tooth form before the digenesis of the Xiaowaitoushan dolomite. Feng-xian Xian in 2019 reported earlier FADs of the globular embryo fossils at the base of the Kuanchuanpu Formation (Xian FX et al., 2019). The deviation of the FADs supports Point "A" in the Meishucun Formation as the boundary between Ediacaran and Cambrian (Xian FX et al., 2019). Combined with the age of 535.2±1.7 Ma obtained by Ri-xiang Zhu (Zhu RX et al., 2009) in the middle of the Zhongyicun Member and the Cambrian base boundary age of 541 Ma inferred from the Oman Formation, the Ediacaran–Cambrian boundary should be placed no higher than the Point "A" in the Xiaowaitoushan Member (Fig. 2). The Xiaowaitoushan Member is a transitional unit. The previous stratigraphic division established by Hui-lin Luo in 1982 seems too broad (Luo HL et al., 1982). The authors suggest that the Yuhucun Formation only includes the phosphorous beddings of the Xiaowaitoushan, Zhongyicun, and Dahai Members. The underlying Baiyanshao Member along with the Jiucheng Member should be divided into the Dengying Formation in the Upper Ediacaran. Point "B" (Unit ±535 Ma) in the Meishucun section should no longer be suggested as a potential GSSP since its age is far from the recommended 541 Ma by the International Commission on Stratigraphy in 2014.

The fossil assemblage discovered in Anning has the same characters as the *Anabarites trisulcatus– Protohertzina anabarica* Assemblage Zone defined by Yi Qian in 2008 (Qian Y et al., 2008). And the FADs of the *F. inchoate* and *P. anabarica* are earlier than the ones reported. The protoconodonts and the globular embryo fossil assemblage from Anning reveals an ancient origin of the conodont-bearing metazoans and has the potential as a regional indicator in the southwest Yangtze. However, due to the limited conditions, the authors haven't conveyed histological and comparative histological study on the discovered protoconodonta. The lamination microstructure and the aggradation growth mode of the medial and basal margins of the protoconodonta also remain for further research.

5. The CAI of protoconodont and shale gas

In recent years, many shale gas deposits have been found in the Lower Cambrian strata in the Yangtze Block and have proved that early sediments can preserve the petroleum reservoir (Zhai GY et al., 2018a, 2018b). The shale gas deposits have been discovered within the Lower Cambrian sediments of Hetang Section in southwest Zhejiang Province and northeast Fujian Province (Shao W et al., 2020), the Lower Cambrian strata near Huangling (Bao SJ et al., 2018; Chen XH et al., 2018; Chen K et al., 2020; Zhang JF et al., 2020), the Early Cambrian marine facies sediments in Huangping in northern Guizhou Province (Ge MN et al., 2018; Zhao L et al., 2015; Chen R et al., 2019), the Shuijintuo Section in Yichang, Hubei Province (Chen XH et al., 2018), the marine facies sediments on the margin of Hannan palaeouplift (Chen XL et al., 2018), the Upper Ediacaran sediments in western Hubei Province (Li HH et al., 2017), the Lower Cambrian Qingxudong Section, the Niutitang Section, and the Upper Ediacaran Dengying Section and Doushantuo Section in Sichuan Province (Zhao MS et al., 2013; Zhai GY et al., 2018b; Wang YF et al., 2019; Zhang JF et al., 2020; Yang YR et al., 2020; Wang SJ et al. 2020). The latest drilling data, the geologic survey of surrounding outcrops, and the laboratory test results of rock samples in these recent studies reveal the shale gas generation and potential of the Lower Cambrian strata in the Yangtze region.

The Conodont Alteration Index (CAI) is used to estimate the maximum temperature reached by a sedimentary rock using the thermal alteration of conodont fossils (Marshall CP et al., 2001; Trotter JA et al., 2007). The CAI is commonly used by paleontologists due to its ease of measurement and the abundance of Conodonta throughout marine carbonates of the Paleozoic. The CAI of the protoconodonts in the researched area is less than 2–3, which indicates that the strata are not metamorphosed, and a reservoir of petroleum may be in this area. The CAI data can be used on conodont analysis and establish a GIS database, to determine the new prospecting direction for oil, shale gas, and other fossil-fuel in the future prospection.

The Yuhucun Section in Yunnan Province has similar stratigraphy, lithology, and paleogeography features as the Upper layer of Dengying Section in Sichuan Province, which suggests that the Yuchucun Section holds the potential to preserve petroleum reservoirs. Considering the CAI of the protoconodonts in the Damaidi Formation, the Yuhucun Section is recommended as a latent shale gas source in Southwest China. With a further sampling of the conodont fossils in Yunnan Province, workers can establish an isocaloric contour line map and locate the potential petroleum reservoirs in the area.

6. Conclusions

(i) The discovery of the earlier FADs of the protoconodonts (*Fomitchella inchoate* Yang et He, *Protohertzina* cf. *anabarica* Missarzhevsky) and the globular embryo fossil (*Olivooides* sp.) can be considered that the first appearance and origin of conodonts maybe earlier than previously recognized, and this fossil assemblage have the potential to become the index fossils for the Ediacaran –Cambrian boundary and the fossil assemblage zones.

(ii) Considering the age of 535.2±1.7 Ma obtained by Zhu RX et al. (2009) in the middle bentonite of the Zhongyicun Member, the Ediacaran–Cambrian boundary in the southwest Yangtze should be no higher than the Point "A" at the base of the Xiaowaitoushan Member. The discovery of the protoconodont assemblage provides an important reference for redefining the boundary between Ediacaran and Cambrian and replenishes the geochronology and geographical distribution of protoconodonts and globular embryo fossils. The discovery from Anning provides important materials for the biostratigraphic correlation of the Ediacaran –Cambrian transitional layer in the southwestern margin of the Yangtze Block. At the same time, it can be a reliable basis for the exploration of oil and shale gas in the Lower Cambrian Yuhucun Formation.

CRediT authorship contribution statement

Jun-ping Liu, Wei Wang, and Feng Tang conceived of the presented idea. Jun-ping Liu and Si-cun Song wrote the manuscript in consultation. Wei Wang and Feng Tang supervised the findings of this work. All authors discussed the results and contributed to the final manuscript.

Declaration of competing interest

The authors declare no conflict of interest.

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