New Radiolarian Genus Ganjiangmoyea gen. nov. from the Lopingian (Upper Permian) in Guangxi, South China

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Source: Paleontological Research, 23(4) : 281-290

Published By: The Palaeontological Society of Japan

URL: https://doi.org/10.2517/2018PR026

Paleontological Research, vol. 23, no. 4, pp. 281–290, October 1, 2019

doi:10.2517/2018PR026

New radiolarian genus *Ganjiangmoyea* gen. nov. from the Lopingian (upper Permian) in Guangxi, South China

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Received March 23, 2018; Revised manuscript accepted December 29, 2018

Abstract. A new radiolarian genus, *Ganjiangmoyea* gen. nov., was discovered from the Lopingian (upper Permian) of the Yutouling section, Xiaodong area, Guangxi Zhuang Autonomous Region, South China. *Ganjiangmoyea* includes one new species (*G. conica* gen. et sp. nov.) and one possible new species (*G.*? *striata* gen. et sp. nov.). This new genus is characterized by numerous, swordlike radial spines extending from a central test. Single spines, presumably detached from the central test, co-occur with the *Ganjiangmoyea* species. Owing to these characteristics, *Ganjiangmoyea* could be placed under the family Oertlispongidae Kozur and Mostler. *Paroertlispongus* Kozur and Mostler and *Pararchaeospongoprunum* Lahm, belonging to the Oertlispongidae, also occur in the Permian, but their spines are bipolar and are not easily detached from the central test. Some of the Oertlispongidae genera, which occur abundantly in the Middle Triassic, also possess easily detached spines. *Ganjiangmoyea* might belong to a lineage of the Oertlispongidae that differs from that of *Paroertlispongus* and *Pararchaeospongoprunum*.

Key words: *Ganjiangmoyea*, Lopingian, Paleozoic, Permian, Radiolaria, South China

Introduction

The well known Permian–Triassic boundary, between the Paleozoic and Mesozoic eras, is one of the most important boundaries in the Earth's history because most taxa underwent extinction around this boundary. Consequently, discriminating faunal turnovers have been recorded across this boundary for several groups (e.g. Erwin, 1994; Song *et al.*, 2012), including radiolarians (e.g. Yao and Kuwahara, 1997; Feng *et al.*, 2000; De Wever *et al.*, 2003; Yao, 2009): a Permian-type radiolarian fauna changed to a Triassic-type radiolarian fauna (Aitchison *et al.*, 2017).

Alternatively, some studies have reported the presence of Triassic-type radiolarians in the Permian (e.g. Feng, 1992; Noble and Jin, 2010; Maldonado and Noble, 2010) and Permian-type radiolarians in the Triassic (e.g. Sugiyama, 1992, 1997; Feng *et al.*, 2000; Takemura and Aono, 2007). The former and latter are considered to be the progenitor and the survivor, respectively (e.g. Feng *et al.*, 2000; Aitchison *et al.*, 2017). The Triassic-type species are present in some families, such as the Oertlispongidae Kozur and Mostler, Archaeospongoprunidae Pessagno, and Intermediellidae *s.l.* Lahm (Aitchison *et al.*, 2017).

We extracted a new radiolarian genus, *Ganjiangmoyea* gen. nov., from the Lopingian (upper Permian) in the Yutouling section, Xiaodong area, Guangxi Zhuang Autonomous Region, South China. This genus is characterized by having numerous, swordlike radial spines extending from a central test. *Ganjiangmoyea* can, therefore, be placed under the family Oertlispongidae owing to the similarity in spines extending from the test. Furthermore, single spines, which were presumably detached from the test, were extracted. This article describes *Ganjiangmoyea* and then discusses the significance of this new genus in the lineage of the family Oertlispongidae.

Geological setting, material, and methods

The Qinzhou allochthon, located in the Qinzhou Basin,

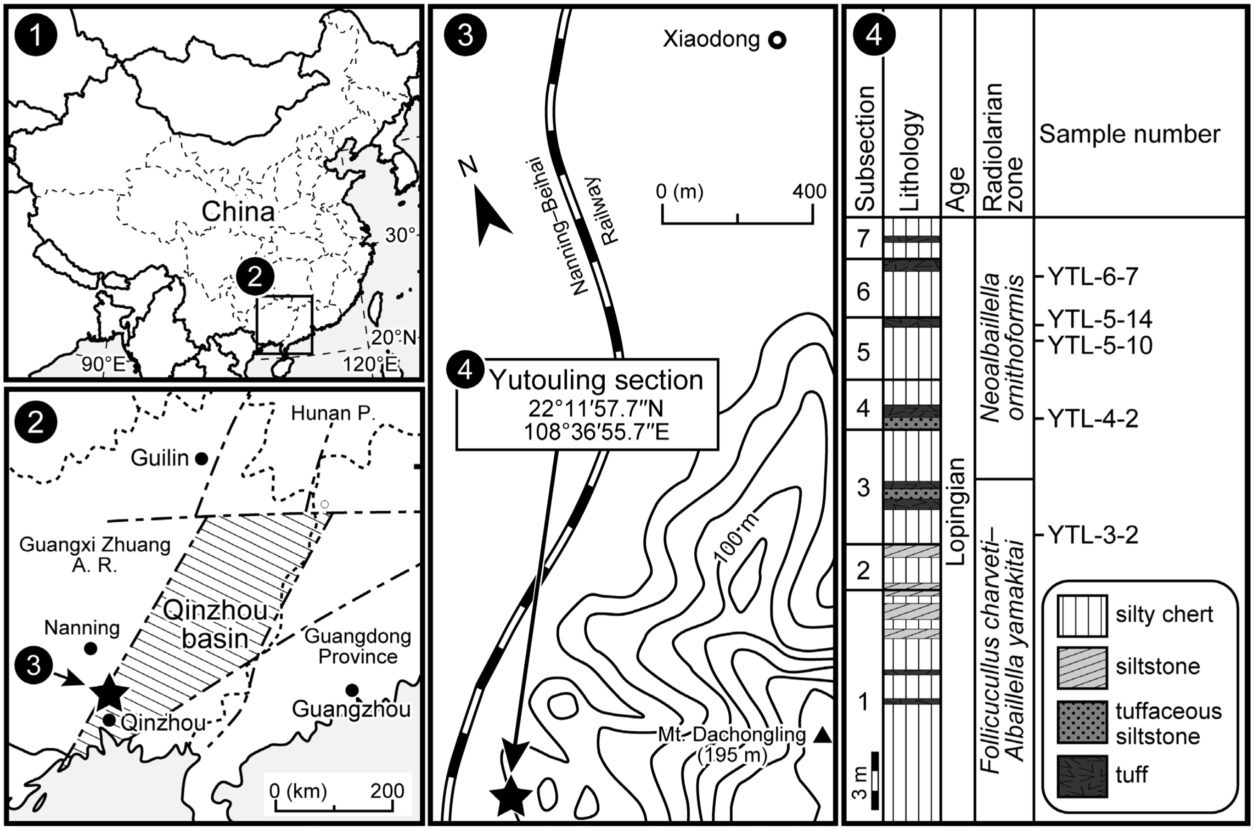

Figure 1. Index map and columnar section of the Yutouling section (modified from Ito *et al.*, 2017b).

South China, has Ordovician–Permian siliceous rock strata (Wang and Jin, 2000) (Figures 1.1, 1.2) and yields Permian radiolarians (e.g. Wang *et al*., 2012; Ito *et al*., 2013, 2015, 2016a, 2017b; Zhang *et al*., 2014). The Yutouling section (22°11′57.7″N, 108°36′55.7″E) is exposed along the southeast side of the Nanning–Beihai railway track, 2 km southwest of Xiaodong, Guangxi Zhuang Autonomous Region (Figure 1.3). The section is composed mainly of red to yellow-red silty chert with minor tuff, tuffaceous siltstone, and siltstone (Figure 1.4).

Radiolarian specimens were obtained by the following method. Crushed samples were soaked in a solution of approximately 3% hydrofluoric acid (HF) for 24 h at 20–30°C. The HF solutions were drained and the containers holding the etched samples were subsequently refilled with fresh HF solution. This process was repeated approximately 10 times. Adequate residues were then collected through a 0.054 mm diameter mesh sieve. Radiolarian specimens collected from the residues were mounted on stubs and photographed using scanning electronic microscopy (SEM) of Quanta 200 (Thermo Fisher Scientific, Inc.) at the State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences in Wuhan. Portions of the residues from each sample were enclosed within slides prepared with a mounting medium (Entellan new).

The *Ganjiangmoyea* species described in this paper were obtained from samples of five horizons of the Yutouling section (Figure 1.4). Furthermore, single spines co-occur with the *Ganjiangmoyea* specimens. These single spines closely resemble the spines of *Ganjiangmoyea* in morphology. No radiolarian having *Ganjiangmoyea*-like spines was obtained from the materials. For these reasons, we regard the single spines as detached spines presumably derived from *Ganjiangmoyea.*

Ito *et al.* (2017b) summarized that the lower part (YTL-3-2) and upper part (YTL-4-2, YTL-5-10, YTL-5-14, and YTL-6-7) of the Yutouling section correspond to the *Follicucullus charveti–Albaillella yamakitai* and *Neoalbaillella ornithoformis* assemblage zones of Kuwahara *et al*. (1998), respectively (Figure 1.4). Both assemblage zones can be ascribed to the Lopingian, upper Permian (Kuwahara *et al*., 1998).

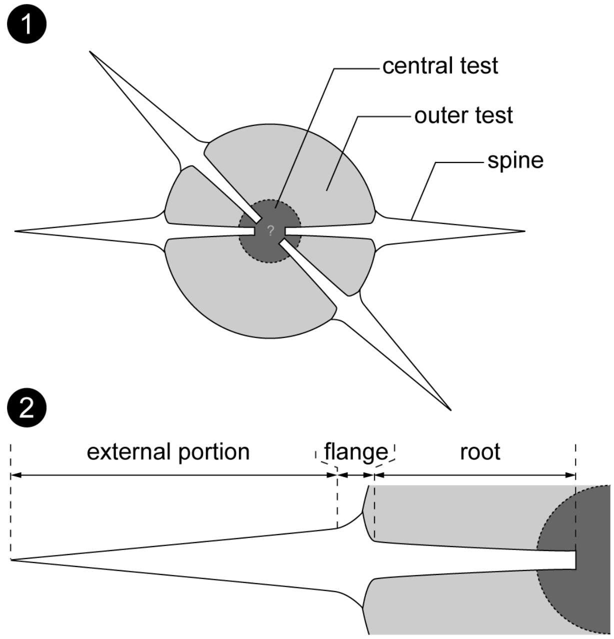

Figure 2. Terminology of *Ganjiangmoyea* gen. nov. **1**, Simplified image of a whole shell consisting of a test and spines; **2**, Simplified image of one swordlike radial spine extending from the central test.

Systematic paleontology

Repository.—All specimens with SEM images in this paper have been deposited in the Geological Museum of the China University of Geosciences, Wuhan, the People's Republic of China, with the prefix ARE.

Terminology.—The terminology of a central test with numerous swordlike radial spines is shown in Figure 2.1. The test is divided into central and outer tests in this study although several terms for spherical radiolarian shells have been proposed (e.g. Suzuki, 1998). The spines extending from a central test consist of three parts: external portion, flange, and root (Figure 2.2). Although the central and outer tests have no morphological difference, we distinguish them by size and relationships to the spines. The central test is a smaller (less than or equal to 50 µm in diameter) spherical part connecting the roots of the spines whereas the outer test is a larger (more than 50 µm in diameter) outer part sheathing the flanges of the spines.

Figure 3 and Figure 4 show thick outer-test-bearing specimens of *Ganjiangmoyea conica* Ito, Zhang, and Feng gen. et sp. nov. and *G.*? *striata* Ito, Zhang, and Feng gen. et sp. nov., respectively. Figure 5 shows specimens of *G. conica* and *G.*? *striata* without the outer test. Figure 6 shows single spines of *G. conica* and *G.*? *striata*.

Subphylum **Radiolaria** Müller, 1858
Class **Polycystina** Ehrenberg, 1839 *emend.* Riedel, 1967
Order **Spumellaria** Ehrenberg, 1876 *emend.* De Wever *et al.*, 2001
Family **Oertlispongidae** Kozur and Mostler, 1980 in Dumitrica *et al.*, 1980

Genus ***Ganjiangmoyea*** Ito, Zhang, and Feng gen. nov.

Type species.—*Ganjiangmoyea conica* Ito, Zhang, and Feng, gen. et sp. nov.

Etymology.—The generic name is based on the morphology of the spines. *Gan Jiang* and *Mo Ye* were a swordsmith couple in the Chinese ancient historical text, "*Spring and Autumn Annals of Wu and Yue*". By extension, *Ganjiangmoyea* means two noted swords forged by the couple. Feminine.

Diagnosis.—Numerous swordlike radial spines extending from a porous central test, which is spherical or ovoidal.

Description.—The initial skeleton is unknown. The shell consists of numerous radial spines and a test. The test seems to possess small pores. The small pores are spherical to ovoidal, disarranged, and almost evenly sized in the same specimen. The outer test sheathes the flange of the spine. The external portion is conical, with or without grooves. The spines generally number 10 to 20. The spines radiate from the center to the outside.

Remarks.—Some Permian radiolarian genera, such as *Paracopicyntra* Feng and *Hegleria* Nazarov and Ormiston, also possess radial spines extending from a spherical shell. However, they differ from *Ganjiangmoyea* with regard to the inner structure of the shell. For example, *Paracopicyntra* possesses a concentric shell; and *Hegleria* possesses internal rays, connecting a central sphere to an outer shell (Nazarov and Ormiston, 1985; Feng *et al.*, 2006; Noble and Jin, 2010; Ito *et al.*, 2017b).

Some specimens have an ovoid shell (e.g. Figures 3.1, 3.5, 3.6). They are seemingly conjoined, i.e., they consist of two individuals joined together. This phenomenon has been reported in both living and fossil specimens (e.g. Anderson and Gupta, 1998; Itaki and Bjørklund, 2007; Dumitrica, 2013; Afanasieva and Amon, 2016; Ito *et al.*, 2017a). However, the estimated intersection point of the spines seems to be single, not double. No remarkable deformation is recognized in specimens having an ovoid shell. Consequently, we tentatively consider that these specimens of *Ganjiangmoyea* are not conjoined.

Occurrences.—The Lopingian (upper Permian) of the Yutouling section in Guangxi (South China) and Gujohachiman section in Gifu (Southwest Japan).

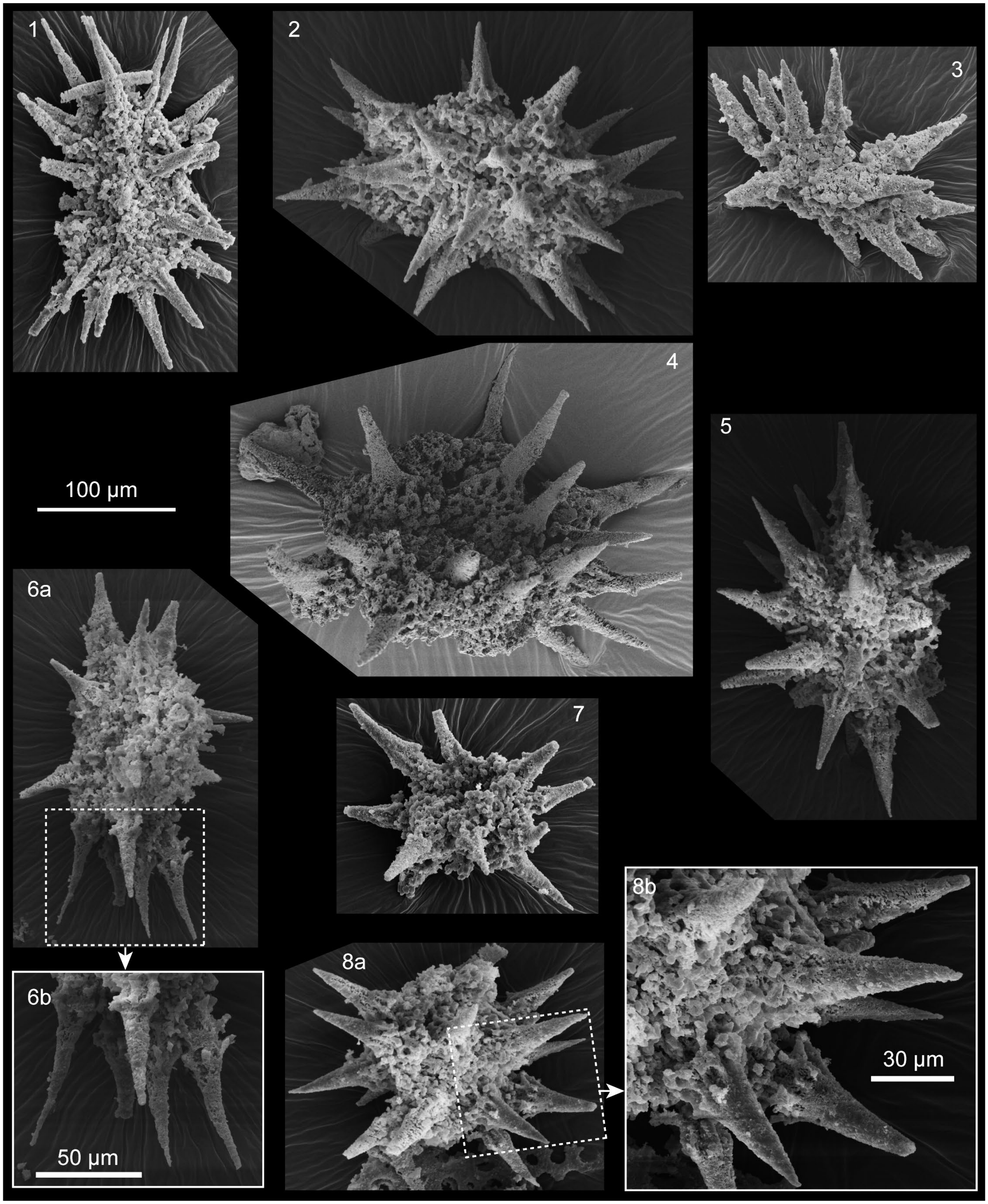

Figure 3. SEM images of thick outer-test-bearing *Ganjiangmoyea conica* gen. et sp. nov. **1,** X0308-12 (paratype); **2,** X0308-11 (holotype); **3,** X0308-12 (paratype); **4,** X0308-13 (paratype); **5,** X0308-14 (paratype); **6,** X0308-15 (paratype); **7,** X0308-16 (paratype); **8,** X0308-17 (paratype). Sample number: 1–6, YTL-3-2; 7, YTL-4-2. 6b and 8b are enlarged view showing the conical spines.

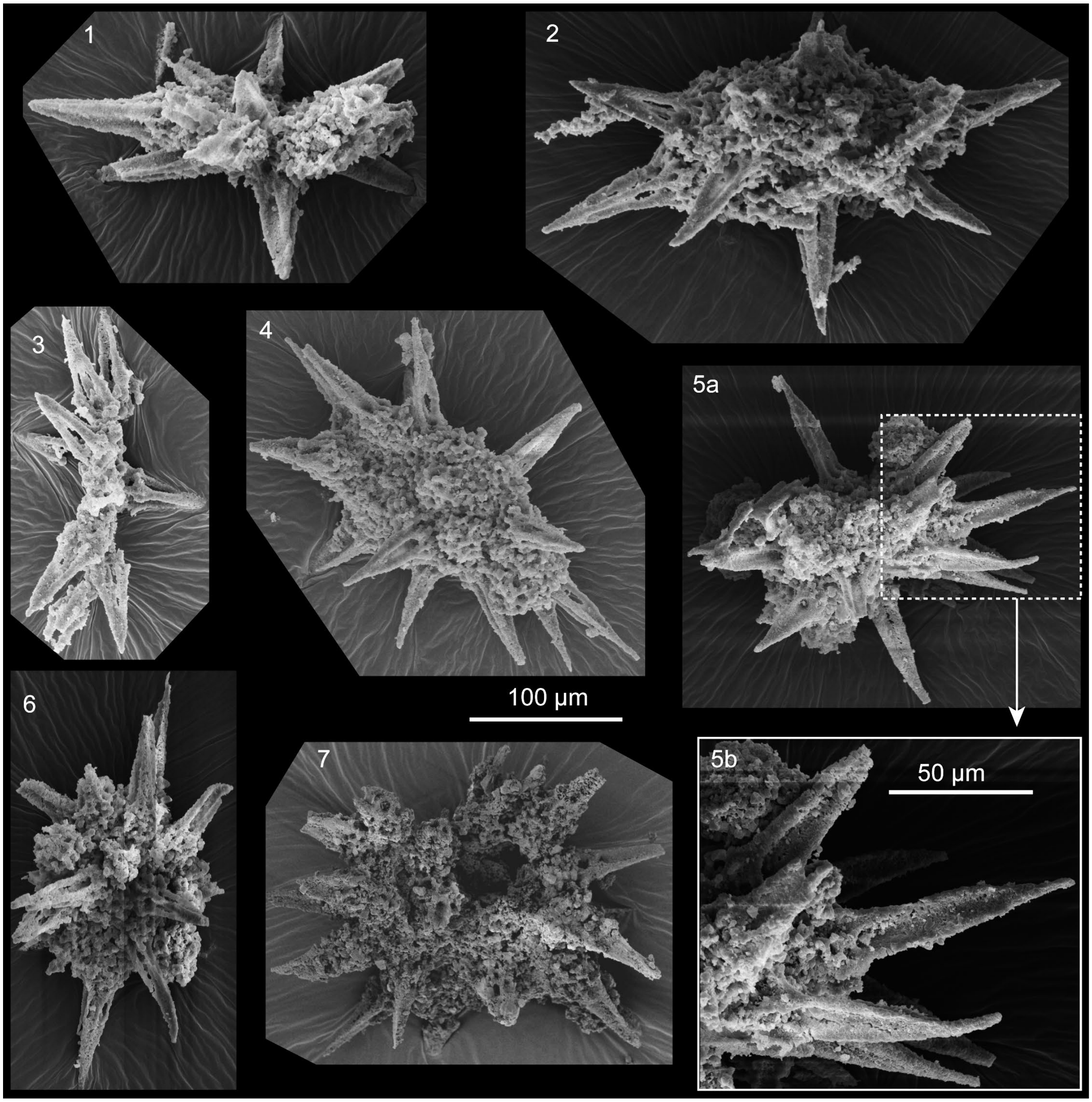

Figure 4. SEM images of thick outer-test-bearing *Ganjiangmoyea*? *striata* gen. et sp. nov. **1,** X0308-21 (paratype); **2,** X0308-22 (paratype); **3,** X0308-23 (paratype); **4,** X0308-24 (paratype); **5,** X0308-20 (holotype); **6,** X0308-25 (paratype); **7,** X0308-26 (paratype). Sample number: 1–3, 5–7, YTL-3-2; 4, YTL-4-2. 5b is enlarged view showing the three-bladed spines.

Ganjiangmoyea conica Ito, Zhang, and Feng sp. nov.

Figures 3.1–3.8, 5.1, 5.2, 6.1–6.7

Spumellaria *incertae sedis* BK. Kuwahara and Yao, 2001, pl. 1, fig. 25.

Type.—Holotype: X0308-11 (Figure 3.2). Paratype: X0308-12 (Figure 3.1); X0308-12 (Figure 3.3); X0308-13 (Figure 3.4); X0308-14 (Figure 3.5); X0308-15 (Figure 3.6); X0308-16 (Figure 3.7); X0308-17 (Figure 3.8); X0308-18 (Figure 5.1); X0308-19 (Figure 5.2).

Etymology.—Based on the spine morphology: *conic-us -a -um* (Latin, adj.) = conical.

Diagnosis.—*Ganjiangmoyea* having conical spines.

Description.—Conical radial spines extend from a central test. An outer test sheathes, either partially or entirely, the root of the spines. The test is spherical or ovoidal.

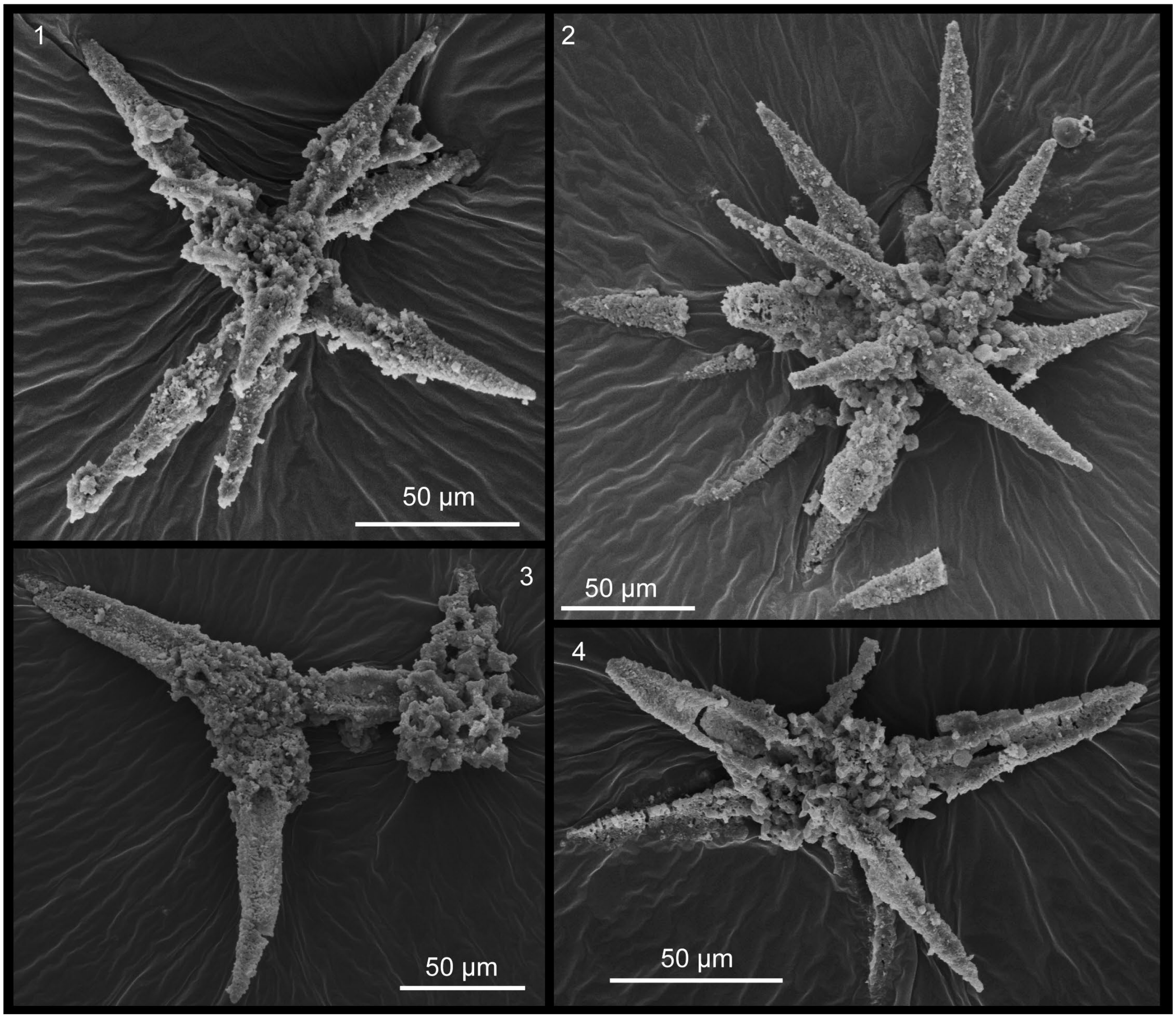

Figure 5. SEM images of specimens without outer test of *Ganjiangmoyea conica* and *G.*? *striata*. **1, 2,** *G. conica*; 1, X0308-18 (paratype); 2, X0308-19 (paratype), **3, 4,** *G.*? *striata*; 3, X0308-27 (paratype); 4, X0308-28 (paratype). Sample number: 1–4, YTL-3-2.

An external portion of the spine is imperforate without an ornament or groove (Figures 3.6b, 3.8b). The external portion is either straight or bends slightly (Figures 3.6b, 3.8b). A flange of the spine flares (skirtlike) with 6–10 grooves, which are parallel to the axial direction of the spine (Figure 3.8b). The root of the spine is conical (Figures 6.2, 6.5) or rodlike (Figures 6.3, 6.7). The root possesses very short lateral spines in some specimens (Figures 6.2, 6.5). The spines are fused at the base of the roots with the central test (Figures 5.1, 5.2, 6.1). Normally 10–20 radial spines are identified in one specimen. The spines radiate from the center to the outside. The diameter of the test, excluding the spines, ranges from 28 to 91 μm. The lengths of the single spines range from 92 to 133 μm.

Remarks.—Some specimens are flattened (e.g. Figure 3.3). These specimens are possibly deformed.

Noble and Jin (2010) reported isolated spines of *Hegleria agnusiforma* Noble and Jin. The spines of *H. agnusiforma* are similar in being imperforately surfaced to those of *G. conica*, but differ in lacking the flange.

Materials examined.—Over 20 specimens were examined by SEM, of which 10 are illustrated here. One specimen and six single spines within the prepared slides are also illustrated here.

Occurrences.—The Lopingian (upper Permian) of the Yutouling section in Guangxi (South China) and Gujohachiman section in Gifu (Southwest Japan).

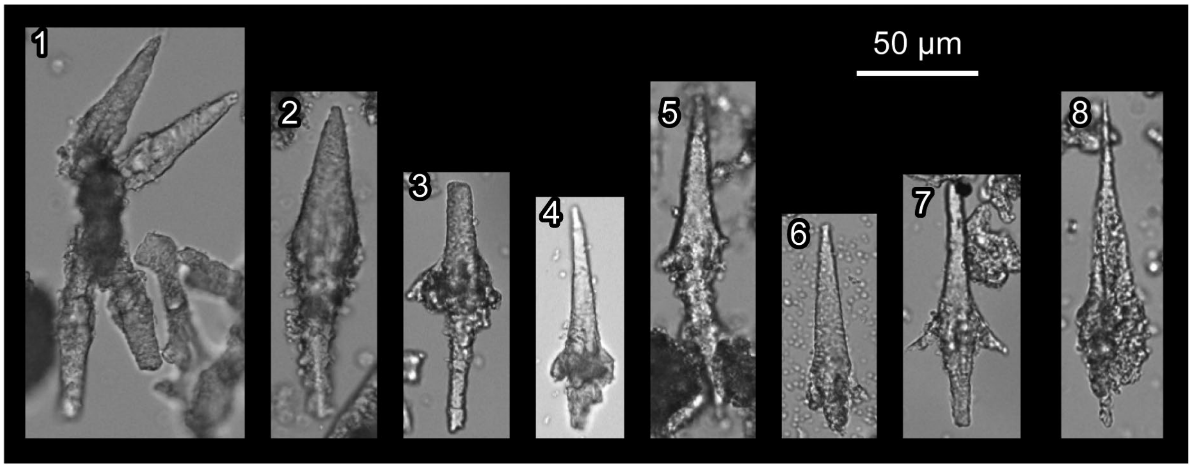

Figure 6. Transmitted-light photomicrographs of single spines of *Ganjiangmoyea conica* and *G.*? *striata*. **1–7,** *G. conica*; **8,** *G.*? *striata*. Sample number: 1, 4, 8, YTL-5-10; 2, YTL-3-2; 3, 5–7, YTL-4-2.

Ganjiangmoyea*? *striata Ito, Zhang, and Feng sp. nov.

Figures 4.1–4.7, 5.3, 5.4, 6.8

Types.—Holotype: X0308-20 (Figure 4.5). Paratype: X0308-21 (Figure 4.1); X0308-22 (Figure 4.2); X0308-23 (Figure 4.3); X0308-24 (Figure 4.4); X0308-25 (Figure 4.6); X0308-26 (Figure 4.7); X0308-27 (Figure 5.3); X0308-28 (Figure 5.4).

Etymology.—Based on the morphology of a spine: *striat-us -a -um* (Latin, adj.) = grooved.

Diagnosis.—*Ganjiangmoyea* having three-bladed spines.

Description.—Three-bladed radial spines extend from a central test (Figure 4.5b). An outer test sheathes, either partially or entirely, the roots of the spines. The test is spherical or ovoidal. The external portion of the spine is either straight or slightly bent (Figure 4.5b). The grooves of the external portion are deep; therefore, a slit aperture is recognized at the base of the external portion in some specimens (Figures 4.2–4.4). The flange of the spines weakly flares with three grooves; the grooves in the external portion connect with those in the flange (Figure 4.5b). Although the roots of the spines were not well observed in our materials (Figure 6.8), the spines seem to be fused at the roots with the central test (Figures 4.3, 5.3, 5.4). Normally 10 to 20 radial spines were identified in one specimen. The spines radiate from the center to the outside. The diameter of the test, excluding the spines, ranges from 29 to 87 µm.

Remarks.—Although the single spines having well preserved roots were not observed compared to *G. conica*, the spines of *G.*? *striata* seem to be fused at the roots with the central test (e.g. Figures 4.3, 5.3, 5.4) like those of *G. conica*. We therefore place *G.*? *striata* under the genus *Ganjiangmoyea* with a question mark in this study.

This species differs from *G. conica* in having grooved spines. Furthermore, as far as we observed, no *G.*? *striata* with a spherical test was found. Some specimens have a flattened test (e.g. Figure 4.1, 4.7) which might be due to deformation.

Materials examined.—Over 20 specimens were examined by SEM and nine specimens are illustrated. One single spine within the prepared slide is illustrated here.

Occurrence.—The Lopingian (upper Permian) of the Yutouling section in Guangxi (South China).

Implications

Higher classification of *Ganjinagmoyea*

In this study, we placed *Ganjiangmoyea* under the family Oertlispongidae because of the similarity in spines extending from the test. The Oertlispongidae is characterized by a spherical test with a primary spine (De Wever *et al.*, 2001). The spines of Triassic genera of the Oertlispongidae were thick, recurved, twisted, or bladelike and easily detached (De Wever *et al.*, 2001). Detached spines often occur (e.g. Sugiyama, 1997). Likewise, the *Ganjiangmoyea* species dealt with in this study are characterized by their spines extending from the central test. Further, single spines, presumably detached from *Ganjiangmoyea*, were obtained (Figure 6).

The family Spongotortilispinidae Kozur and Mostler (defined by Moix *et al.*, 2007; emended by Kozur *et al.*, 2009; further emended by Xiao *et al.*, 2017) possesses polar spines extending from a spherical test. However, *Ganjiangmoyea* has no clear polar spines. Further, the spines of the Spongotortilispinidae are not easily detached. We therefore do not consider that *Ganjiangmo-*

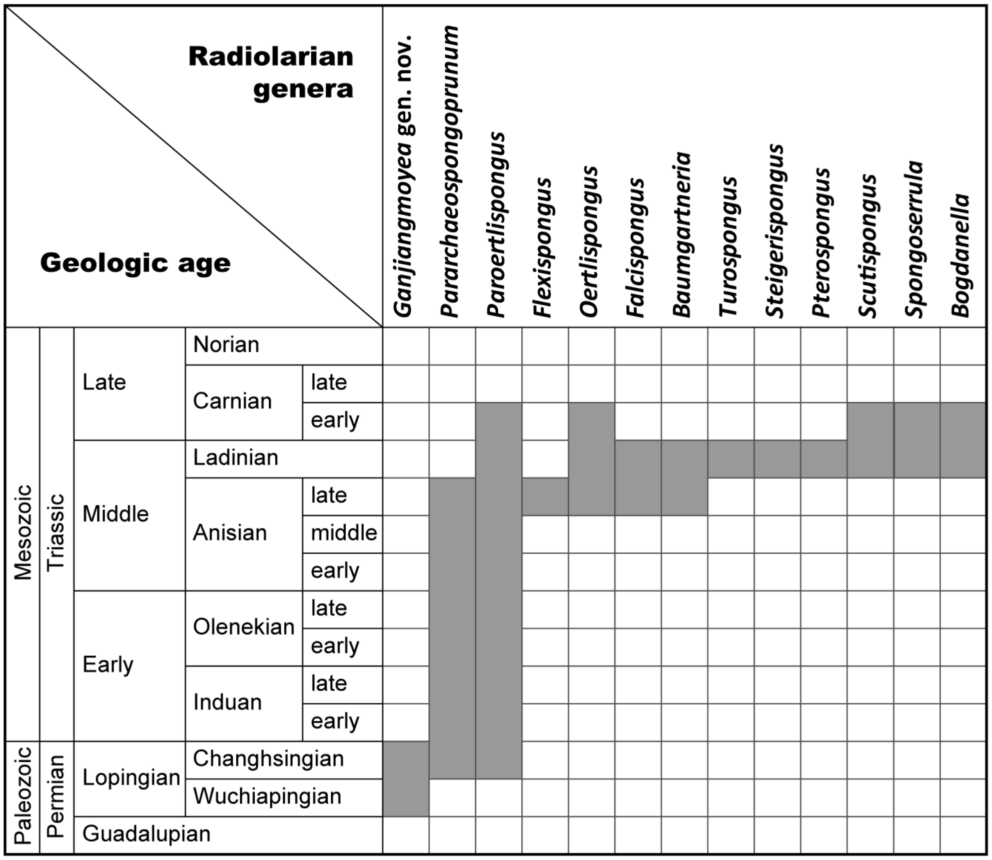

Figure 7. Geological age range of *Ganjiangmoyea* gen. nov. and occurrence of other genera in the family Oertlispongidae (based on O'Dogherty *et al.*, 2009).

yea is to be placed under this family.

Pegoxystris Sugiyama occurring in the Olenekian (Lower Triassic) possesses two major spines and numerous minor spines extending from a spherical test (Sugiyama, 1992). Sugiyama (1992) placed *Pegoxystris* under the Oertlispongidae; however, O'Dogherty *et al.* (2009) placed it under the family Archaeospongoprunidae with a question mark. Morphology of the major spines of *Pegoxystris* is conical and is closely similar to that of *G. conica*; however, *Pegoxystris* has concentric layered shells (Sugiyama, 1992).

Lineage of the Oertlispongidae and *Ganjiangmoyea*

Most genera of the Oertlispongidae originated in the Triassic (e.g. Dumitrica, 1982, 1999; Kozur and Mostler, 1983, 1994, 1996; Ito *et al.*, 2016b); however, only two genera, *Paroertlispongus* Kozur and Mostler and *Pararchaeospongoprunum* Lahm, are known to occur in the Lopingian, upper Permian (e.g. Feng, 1992; Feng and Liu, 1993; Sashida *et al.*, 2000a, 2000b; Kuwahara and Yao, 2001; Sashida and Salyapongse, 2001; Shang *et al.*, 2001; Wang and Shang, 2001; Feng and Gu, 2002; Feng *et al.*, 2006, 2007). Consequently, *Ganjiangmoyea* is one of the oldest known genera in the Oertlispongidae (Figure 7).

The spines of the Oertlispongidae genera in the Triassic were easily detached, unlike *Paroertlispongus* and *Pararchaeospongoprunum* in the Permian. As mentioned previously, the single spines were presumably detached from *Ganjiangmoyea*. Consequently, *Ganjiangmoyea*, occurring in the Permian, bears a greater similarity in having easily detached spines with the Triassic Oertlispongidae genera than with the Permian *Paroertlispongus*. In short, although the morphofunctional meaning of the character is still unclear, oertlispongids having easily detached spines appeared in the Permian. *Ganjiangmoyea* described in this article might belong to a different Oertlispongidae lineage that differs from that of *Paroertlispongus* and *Pararchaeospongoprunum*.

Acknowledgments

We thank Toshiyuki Kurihara (Niigata University) for the careful review that improved greatly this manuscript, likewise Noritoshi Suzuki (Tohoku University) for his comments on the taxonomy. We are grateful to the Associate Editor, Atsushi Matsuoka (Niigata University), for valuable comments on the manuscript. This study was supported financially by the NSFC (40839903, 40921062, and 41402001) and "111" project (B08030) of China University of Geosciences, Wuhan.

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Author contributions

T. I. initiated the study and described most part of the manuscript. L. Z. picked up and photographed radiolarian specimens. T. I., L. Z. and Q. F. carried out the taxonomic work on the radiolarians. W. H. supported through the study and describing the manuscript. All authors contributed to the writing of the paper.