

Latest Permian Entactinaria (Radiolaria) from southern Guangxi, China

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ABSTRACT – A highly diverse and well-preserved latest Permian radiolarian fauna was obtained from muddy siliceous rocks and siliceous mudstones of the Dalong Formation, southern Guangxi, China. Specimens of the Order Entactinaria were selected for taxonomic study. Thirty-four species, among which were nine new species and twelve unidentified species, are included in this investigation. The nine new species are *Entactinia wangi*, *Entactinia minuta*, *Entactinia sashidai*, *Trilonche textiles*, *Triaenosphaera variabilis*, *Triaenosphaera megacantha*, *Provisocyntra densa*, *Provisocyntra ormistoni* and *Wuyia dongpanica*. Permian species of the Family Spongactiniidae Nazarov are reported first and the extinction pattern of the Order Entactinaria is discussed. *J. Micropalaeontol.* 26(1): 19–37, April 2007.

KEYWORDS: *radiolaria, latest Permian, taxonomy, evolution, South China*

INTRODUCTION

The radiolarian Order Entactinaria was proposed originally by Kozur & Möstler (1982) and is characterized by an initial spicule located inside a spherical shell or the innermost concentric shell (Dumitrica in De Wever *et al.*, 2001). Members of the order were common in the Palaeozoic and Triassic, and became less common in the Jurassic, Cretaceous and Cenozoic. Systematic palaeontological study of Palaeozoic Entactinaria began with the classical works of Foreman (1963), Deflandre (1973), Nazarov (1975), Holdsworth (1977) and Kozur & Möstler (1982). During the 1980s, systematic taxonomy investigations on the order were conducted in Europe, Asia, North America and Australia. Won (1983) and Gourmelon (1987) investigated many well-preserved Early Carboniferous Entactinaria from Germany and France, respectively. Nazarov & Ormiston (1983, 1985) described Late Palaeozoic Entactinaria from West Australia, Southern Urals and West Texas. Sashida & Tonishi (1985, 1988) contributed to the detailed taxonomic studies on Late Permian Entactinaria from central Japan. Kozur & Möstler (1989) reported well-preserved Permian Entactinaria from the Cis-Ural. Since the 1990s, many taxonomic papers covering the order have been published, including Germany (Braun, 1990), Italy (Kozur, 1993), USA (Blome & Reed, 1992), Russia (Afanasyeva, 2000), China (Wang *et al.*, 1994; Wu *et al.*, 1994; Feng *et al.*, 1998; Yao & Kuwahara, 1999, 2000), Thailand and Malaysia (Sashida *et al.*, 1995; 2000b) and Australia (Aitchison, 1993). However, the taxonomy of Late Permian Entactinaria is still poorly understood, partly because of the rarity of these radiolarians and partly due to the lack of well-preserved radiolarians revealing inner structures necessary for taxonomic study.

Recently, a well-preserved latest Permian radiolarian fauna was recovered from muddy siliceous rocks and siliceous mudstones of the Dalong Formation, southern Guangxi, China (Fig. 1). Primarily 138 species, belonging to Albaillellaria, Entactinaria, Spumellaria and Latentifistularia, were identified. Among them, 34 species of the Order Entactinaria are illustrated and described in this paper (Fig. 2).

STRATIGRAPHY AND RADIOLARIAN LOCALITY

The studied area is located between Dongmen and Liuqiao Towns, Fusui County, Guangxi Zhuang Autonomous Region in southern China (Fig. 1) and the strata distributed in this region mainly consist of Late Permian and Early Triassic sections (BGMRG, 2001). The Late Permian is divided into three formations in ascending order: the Heshan, Changxing and Dalong (Fig. 1). All specimens described in the present paper were collected from the Dalong Formation from the Dongpan Section (which equates to the Liuqiao Section of Shang *et al.*, 2001) near Dongpan Village (22° 16.196' N, 107° 41.505' E). In this section, the Dalong Formation overlies the limestones of the Changxing Formation of Early Changhsingian age and is overlain by the mudstones of the Early Triassic Luolou Formation containing *Ophiceras tingi* Tien and *Claraia dieneri* Nakazawa. Therefore, stratigraphically the Dalong Formation is Late Changhsingian in age. The lower part of the Dalong Formation is mainly composed of mudstones and siliceous rocks; the middle part, of bedded siliceous rocks with shales; and the upper part, of siliceous mudstones and bentonite with Permian brachiopods and bivalves. Abundant well-preserved radiolarians were obtained from the bedded siliceous rocks and siliceous mudstone of the middle and upper parts, including *Neobaillella optima* Ishiga *et al.*, *Albaillella triangularis* Ishiga *et al.*, and *Albaillella yaoui* Kuwahara. These and other radiolarians described in this paper therefore belong to the Late Changhsingian *Neobaillella optima* Zone (Yao *et al.*, 2001).

SYSTEMATIC PALAEOONTOLOGY

All specimens described in this paper are deposited in the Geological Museum of China University of Geosciences, Wuhan, the People's Republic of China.

Order **Entactinaria** Kozur & Möstler, 1982
Family **Entactiniidae** Riedel, 1967
Genus *Entactinia* Foreman, 1963

Type species. *Entactinia herculea* Foreman, 1963.

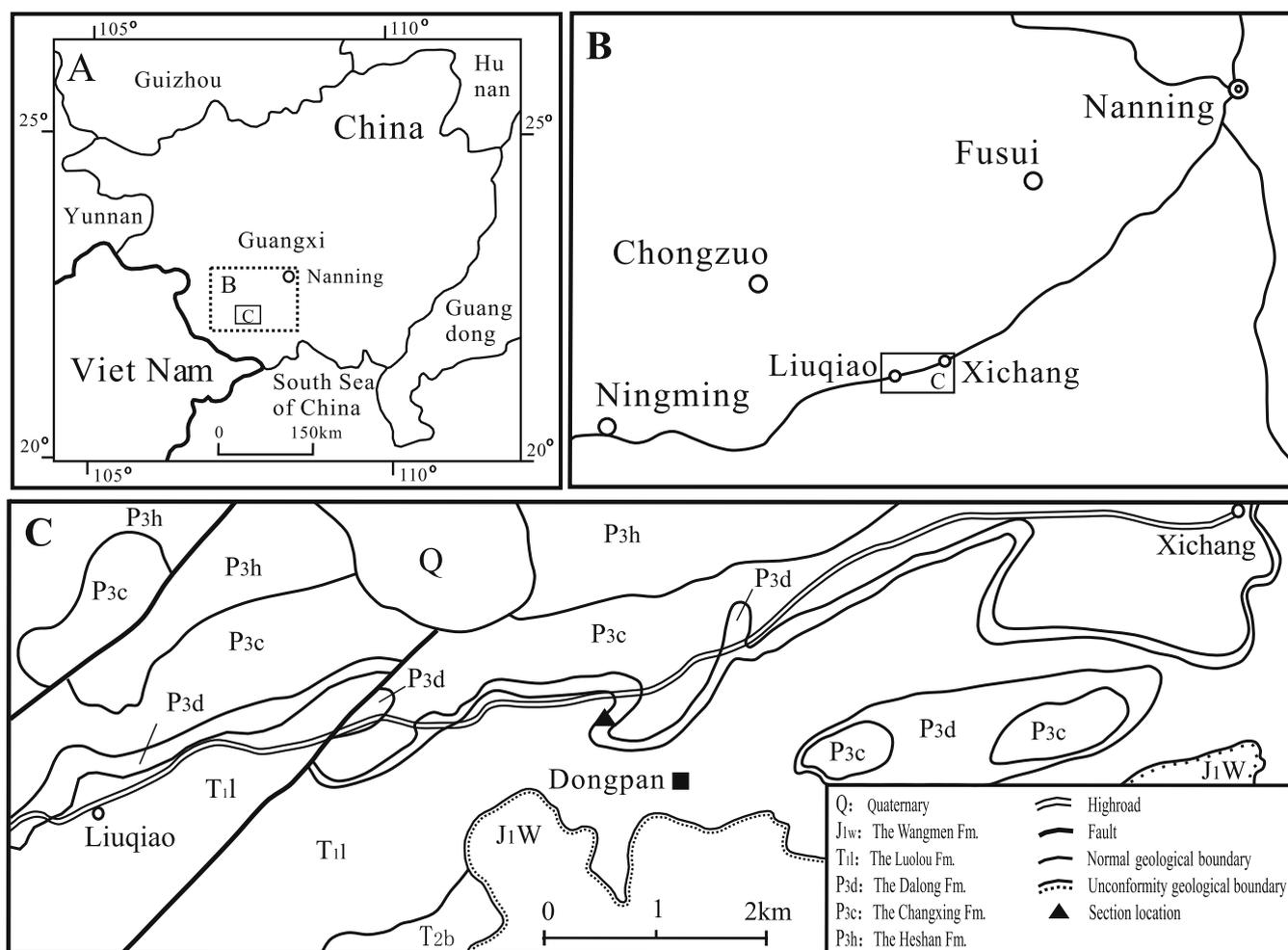


Fig. 1. Geological map and location of the studied area (after BGMARGAR, 2001).

Entactinia itsukaichiensis Sashida & Tonishi
(Pl. 1, figs 1–2)

1985 *Entactinia itsukaichiensis* Sashida & Tonishi: 9–10, pl. 1, figs 1–10.

1990 *Entactinia itsukaichiensis* Sashida & Tonishi; Ishiga: pl. 1, fig. 1.

1992 *Entactinia itsukaichiensis* Sashida & Tonishi; Blome & Reed: 369, figs 11.2–11.5.

1993 *Stigmosphaerostylus itsukaichiensis* (Sashida & Tonishi); Kozur: 120, pl. 3, fig. 13.

1998 *Entactinia itsukaichiensis* Sashida & Tonishi; Kuwahara & Yao: pl. 2, fig. 59.

1998 *Entactinia itsukaichiensis* Sashida & Tonishi; Feng *et al.*: 239, figs 3c, 3d.

2000a *Entactinia itsukaichiensis* Sashida & Tonishi; Sashida *et al.*: 797–799, fig. 7.24.

2000b *Entactinia itsukaichiensis* Sashida & Tonishi; Sashida *et al.*: 251, pl. 1, figs 24–26.

Material. Ten specimens examined by SEM, of which two are illustrated.

Distribution. Abundant in the Late Permian, central Japan, USA, Italy, South China and Thailand.

Remarks. Our specimens compare well to *Entactinia itsukaichiensis* Sashida & Tonishi in having a small latticed shell with six three-bladed main spines and numerous thorn-like accessory spines.

Entactinia reticulata Sashida & Tonishi
(Pl. 1, figs 3–4)

1985 *Entactinia reticulata* Sashida & Tonishi: 10–11, pl. 2, figs 7–12.

Material. Nine specimens examined by SEM.

Distribution. Common in the Upper Permian, central Japan and South China.

Remarks. Specimens illustrated compared well with *Entactinia reticulata* Sashida & Tonishi from the Late Permian of central

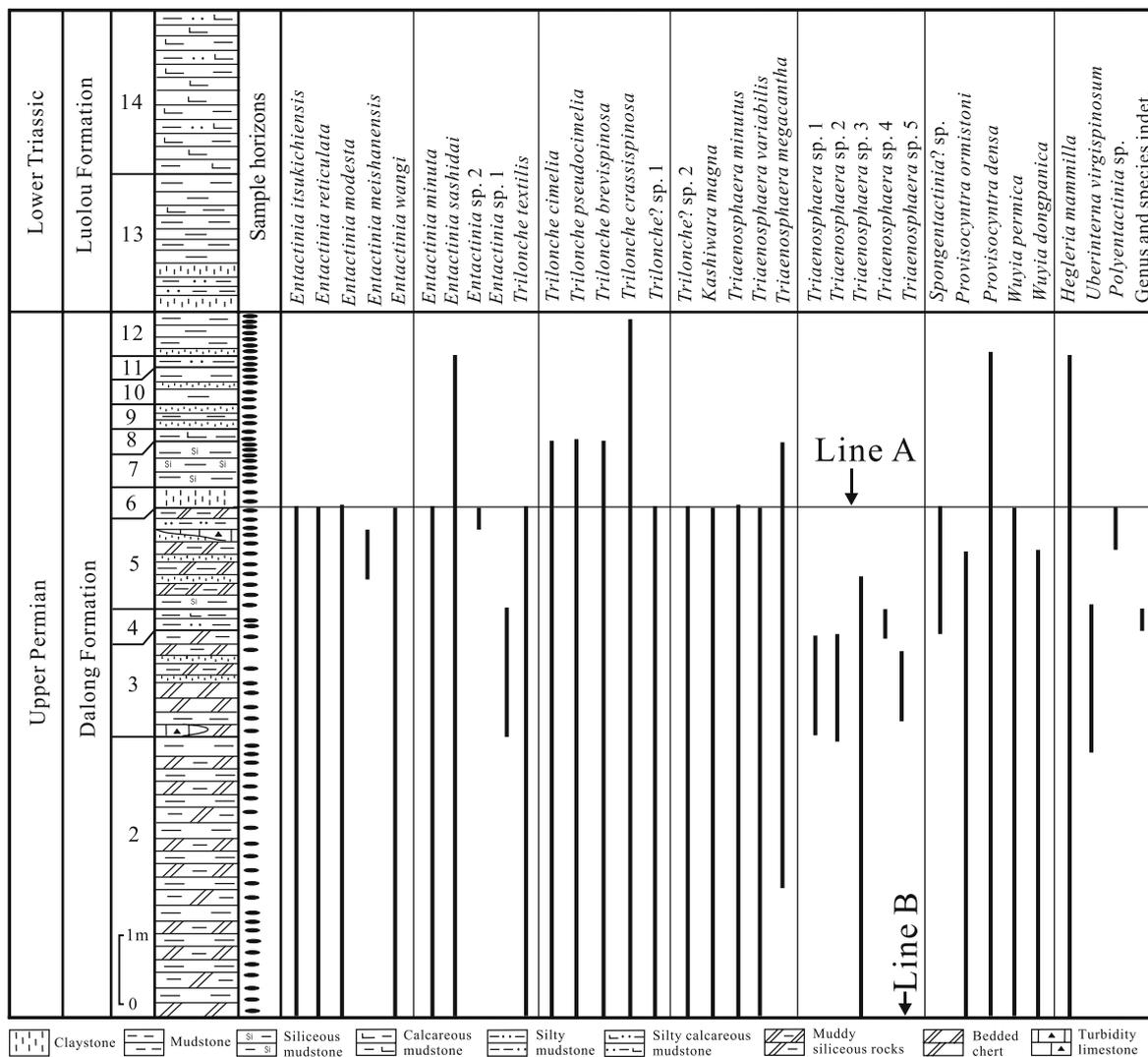


Fig. 2. Distribution of the radiolarians reported in this paper.

Japan in having a very thin shell with large pores and short three-bladed main spines.

Entactinia modesta Sashida & Tonishi
(Pl. 1, figs 5–6)

1985 *Entactinia modesta* Sashida & Tonishi: 10, pl. 1, figs 11–12; pl. 2, figs 1–6.

Material. Five specimens examined by SEM.

Distribution. Common in the Late Permian, central Japan and South China.

Remarks. Specimens illustrated here compare well with *Entactinia modesta* Sashida & Tonishi from the Late Permian of central Japan in having a medium-sized spherical lattice shell with six three-bladed main spines and some small accessory spines.

Entactinia meishanensis He, Feng & Gu
(Pl. 2, fig. 10)

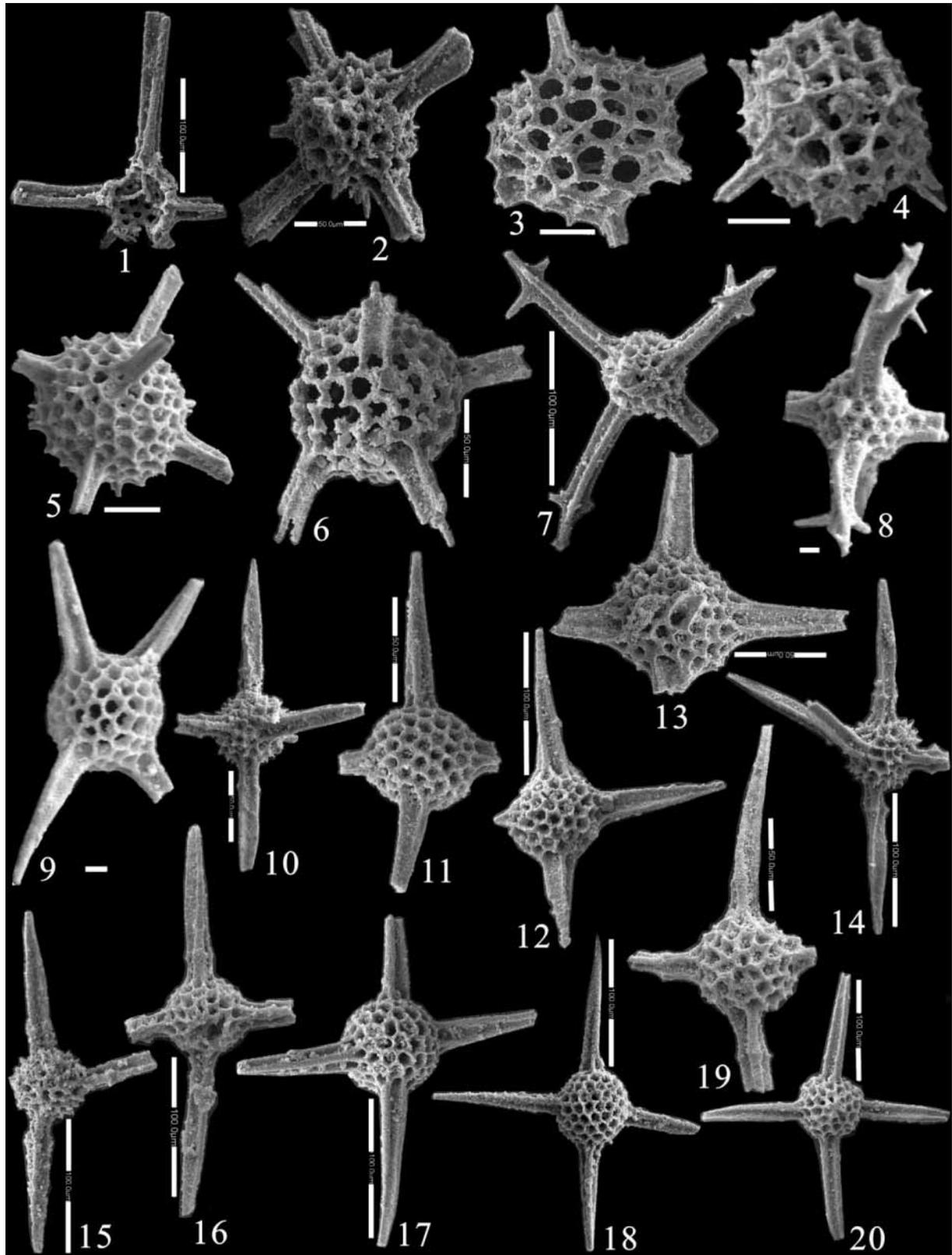
2005 *Entactinia meishanensis* He, Feng & Gu: 210, figs 4.9–4.11.

Material. Two specimens.

Distribution. Rare in the Changhsingian, South China.

Remarks. The specimen illustrated here resembles *Entactinia itsukaichiensis* Sashida & Tonishi in the size of test and in the shape of main spines, but differs from it in having more massive, three-bladed accessory spines. It compares well with *Entactinia meishanensis* He, Feng & Gu from the Changxing Formation in the Meishan D Section, Changxing, China (He *et al.*, 2005).

Entactinia wangi Feng n. sp.
(Pl. 1, figs 9–20)



Derivation of name. This species is named in honour of Prof. Wang Yujing, for his studies on Palaeozoic Radiolaria.

Diagnosis. A small spherical latticed shell with four to six long three-bladed main spines.

Holotype. Plate 1 (fig. 9), sample DP4/3404 from the Dalong Formation of the Dongpan section, Fusui County, southern Guangxi, depositional number X0301-37.

Material. Over 40 specimens were found and 23 examined by SEM.

Description. Test is a small, spherical, latticed shell with hexagonal pore frame. Thirty-one to 45 pores visible on the outer surface of hemisphere. Four to six main spines; four co-planar main spines long (1.5–2.5 times of the diameter of the shell), massive, three-bladed, slowly decreasing distally in width; other two main spines similar to the four main spines in length, or shorter, even lacking; the two main spines also three-bladed, and perpendicular with the four co-planar main spines. Accessory spine very short, rod-like.

Dimensions (µm). Based on 15 specimens: diameter of shell 56–78; maximum length of long main spines 83–184; maximum width of long main spines 16–22; length of short main spine 0–24.

Distribution. Abundant in the Late Changhsingian, South China.

Remarks. This new species is similar in outline to *Entactinia itsukaichiensis* Sashida & Tonishi, but differs from it in having a smaller shell, shorter main spine, and less accessory spines. It also resembles Lower Carboniferous forms *Entactinia parva* Won and *Entactinia tortispina* (Ormiston & Lane, 1976) in outline, but these two species have longer main spines and accessory spines, and a larger shell.

Entactinia minuta Feng n. sp.
(Pl. 1, figs 7–8)

Derivation of name. *minutus*-*a*-*um* (Latin, adj.)=small.

Diagnosis. A small spherical latticed test with four to six three-bladed main spines; each main spine has three distal branches.

Holotype. Plate 1 (fig. 8), sample DP4/3408 from the Dalong Formation of the Dongpan section, Fusui County, southern Guangxi, depositional number X0301-38.

Material. Six specimens were found and five specimens examined by SEM.

Description. Test is a small, latticed, spherical shell. Pore frame is small, uniform, pentagonal or hexagonal. Thirty to 35 pores are present on the hemisphere outer surface. Four to six massive, three-bladed main spines similar in size and form; each main spine has three short distal branches. When four main spines are developed on the surface they are co-planar, or tetrahedrally arranged.

Dimensions (µm). Based on five specimens: diameter of shell 50–52; length of longest main spine 70–95; maximum width of long main spine 15–17.

Distribution. Rare in the Late Changhsingian, South China.

Remarks. This new species is similar in outline to *Entactinia wangi* n. sp., but differs from it in having three distal branches on the end of each main spine. Its spines resemble those of *Entactinia pycnoclada* Nazarov & Ormiston, but the latter has a smaller cortical shell. *Stigmosphaerostylus sakmaraensis* Kozur & Möstler differs also from this new species in having a larger shell with developed accessory spines and circular to oval pore frames.

Entactinia sashidai Feng n. sp.
(Pl. 2, figs 1–6)

Derivation of name. This species is named for Dr K. Sashida, in honour of his studies on Palaeozoic Radiolaria.

Diagnosis. *Entactinia* with a short, conical three-bladed main spine.

Holotype. Plate 2 (fig. 2), sample DP5/2095 from the Dalong Formation of the Dongpan section, Fusui County, southern Guangxi, depositional number X0301-39.

Material. Eleven specimens were examined by SEM.

Description. Test is spherical, latticed, with three to four main spines and numerous accessory spines. Main spines are three-bladed, and quickly decrease in width distally; accessory spines are very short, needle-like. Pore frames are hexagonal. Forty-two to 54 pores present on outer surface of the hemisphere.

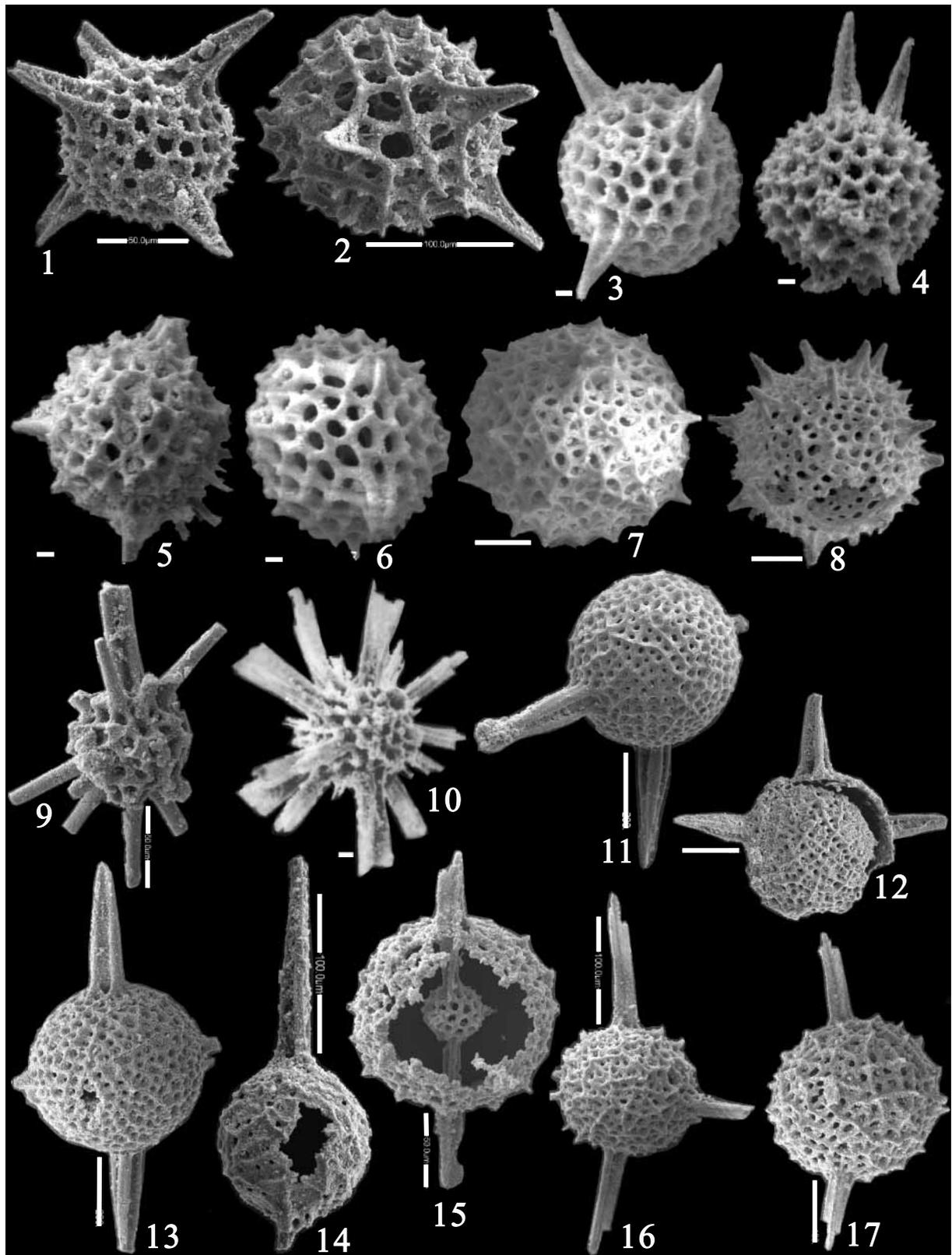
Dimensions (µm). Based on nine specimens: diameter of outer sphere 91–160; maximum width of external spine 18–35; maximum length of external spine 49–68.

Distribution. Common in the Late Changhsingian, South China.

Remarks. This species is similar to *Entactinia modesta* Sashida & Tonishi in outline and size, but differs from it in having shorter, conical three-bladed main spines. It also resembles *Entactinia tyrrelli* Nazarov & Ormiston in outline, but the pore frames of the latter are smaller and oval.

Explanation of Plate 1.

figs 1–2. *Entactinia itsukichiensis* Sashida & Tonishi: 1, DP2/B024; 2, DP4/P016. figs 3–4. *Entactinia reticulata* Sashida & Tonishi: 3, DP5/2369; 4, DP3/4548. figs 5–6. *Entactinia modesta* Sashida & Tonishi: 5, DP4/3223; 6, DP3/J095. figs 7–8. *Entactinia minuta* Feng n. sp.: 7, DP2/B016; 8, DP4/3408, holotype. figs 9–20. *Entactinia wangi* Feng n. sp.: 9, DP4/3404, holotype; 10, DP5/2073; 11, DP3/J098. 12, DP5/2071. 13, DP5/2341. 14, DP3/K052; 15, DP3/J067; 16, DP3/J079; 17, DP4/O057; 18, DP5/1240; 19, DP5/2337; 20, DP5/1167. Scale bar is 10 µm in figs 8, 9; 50 µm in figs 2–6, 10, 11, 13, 19; 100 µm in figs 1, 7, 12, 14–18, 20).



Latest Permian radiolaria, China

Entactinia sp. 1
(Pl. 2, figs 7–8)

Material. Six specimens found and four examined by SEM.

Description. Single spherical test with short conical spines. Pore frame oval. The cross-section of the spines are three- or four-bladed in its proximal part and circular in its distal part.

Distribution. Rare in the Late Changhsingian, South China.

Remarks. This indeterminate species is similar in outline to *Astroentactinia multispinosa* (Won, 1983) from the Early Carboniferous, but differs from it in having a single-layered shell with oval pores. It differs from the known species of the genus *Entactinia* in having numerous, short conical spines.

Entactinia sp. 2
(Pl. 2, fig. 9)

1998 *Entactinia* sp. Feng *et al.*: 240, fig. 3e.

Material. One specimen found and examined by SEM.

Description. Test is small, spherical, and latticed. Pores subcircular, oval. Main spines are three-bladed, massive; accessory spines long, circular in cross-section.

Distribution. Rare in the Late Changhsingian, South and Southwest China.

Remarks. This indeterminate species is similar to *Astroentactinia? mirousi* Gourmelon, 1986 reported from the Early Carboniferous in outline and size, but differs from it by having more massive three-bladed main spines. It is similar to *Entactinia* sp. of Feng *et al.* (1998) from the latest Permian in southwestern Yunnan, Southwest China.

Genus *Trilonche* Hinde, 1899

Type species. *Trilonche vetusta* Hinde, 1899.

Trilonche cimelia (Nazarov & Ormiston)
(Pl. 2, figs 15–17)

1985 *Entactinosphaera cimelia* Nazarov & Ormiston: 22, pl. 1, figs. 9, 11.

1991 *Entactinosphaera cimelia* Nazarov & Ormiston; Wang: pl. 3, fig. 16.

2001 *Entactinosphaera cimelia* Nazarov & Ormiston; Kuwahara & Yao: pl. 2, fig. 9.

Material. Six specimens examined by SEM, of which three illustrated.

Distribution. Common in the Middle and Late Permian; USA (Texas), Japan, South China.

Remarks. Specimens illustrated here compare well to *Trilonche cimelia* (Nazarov & Ormiston) from the Middle Permian of America in having a large outer shell with arcuate ridges and two to three long three-bladed main spines.

Trilonche pseudocimelia (Sashida & Tonishi)
(Pl. 2, fig. 14)

1988 *Entactinosphaera pseudocimelia* Sashida & Tonishi: 528–529, figs 7.1–3, 6–8.

Material. Six specimens examined by SEM, of which one is illustrated.

Distribution. Common in the Changhsingian, central Japan and South China.

Remarks. This species is similar to *Trilonche cimelia* (Nazarov & Ormiston) in the character of the outer shell, but differs from the latter in having two shorter main spines.

Trilonche brevispinosa (Sashida & Tonishi)
(Pl. 2, figs 11–13)

1988 *Entactinosphaera brevispinosa* Sashida & Tonishi: 529, figs 7.9–13.

Material. Six specimens examined by SEM, of which three are illustrated.

Distribution. Common in the Changhsingian, central Japan and South China.

Remarks. Our specimens differ slightly from *Trilonche brevispinosa* (Sashida & Tonishi) from the Late Permian of Japan as some main spines are longer.

Trilonche crassispinosa (Sashida & Tonishi)
(Pl. 3, figs 1–5)

1985 *Entactinosphaera? crassispinosa* Sashida & Tonishi: 12, pl. 3, figs 6–12.

Material. This species is common in our material. Ten specimens were examined by SEM, of which five are illustrated.

Distribution. Changhsingian, central Japan and South China.

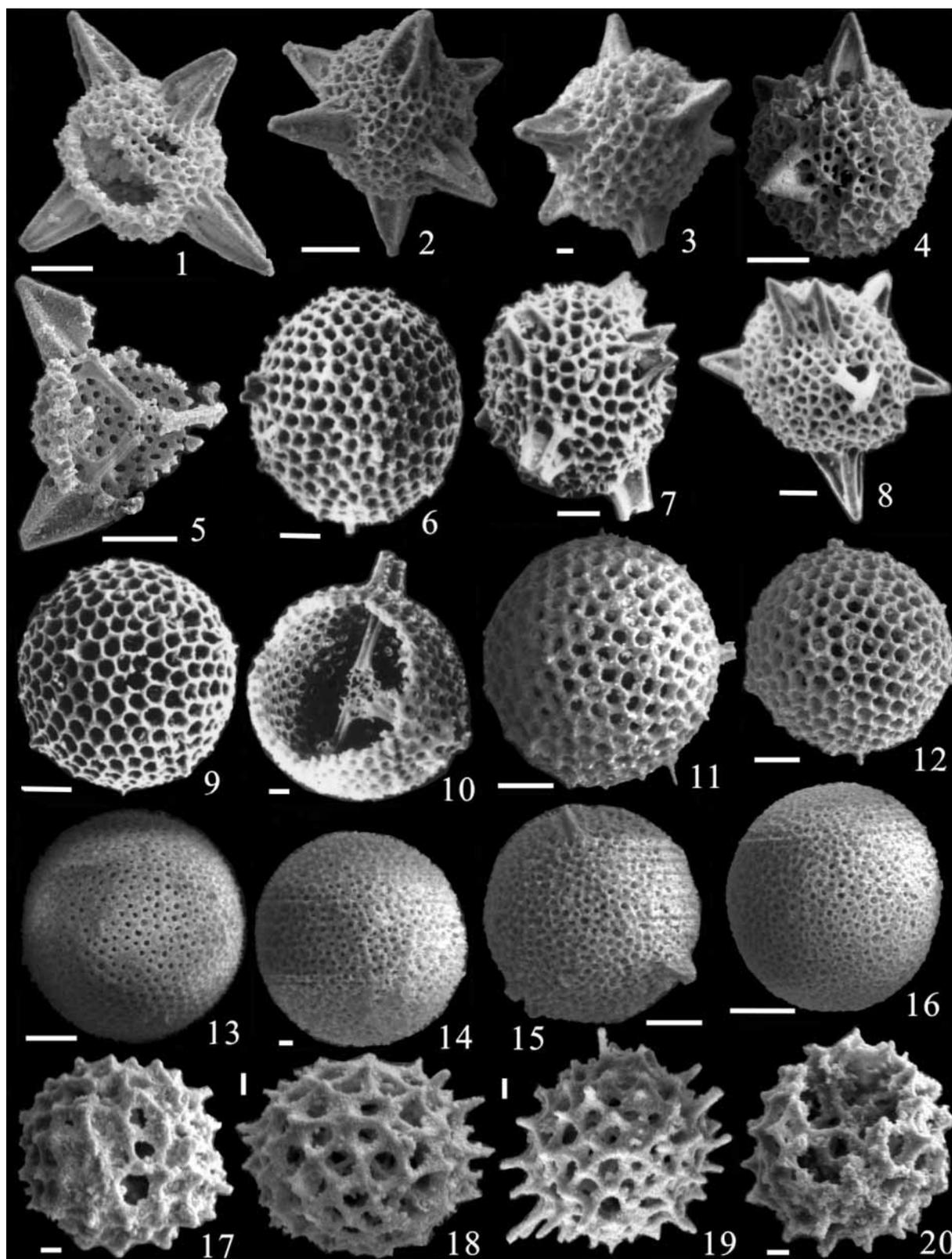
Remarks. Most specimens in our material compare well with *Trilonche crassispinosa* (Sashida & Tonishi) from the Late Permian of Japan, but some specimens differ slightly from the latter in having shorter, wider main spines.

Trilonche textilis Feng n. sp.
(Pl. 3, figs 17–20)

Derivation of name. *textilis-is-e* (Latin, adj.)=woven.

Explanation of Plate 2.

figs 1–6. *Entactinia sashidai* Feng n. sp.: 1, DP2/5767; 2, DP5/2095, holotype; 3, DP3/4579; 4, DP3/4117; 5, DP3/4587; 6, DP3/4532. figs 7–8. *Entactinia* sp. 1: 7, DP4/3351; 8, DP3/4207. fig. 9. *Entactinia* sp. 2, DP5/2100. fig. 10. *Entactinia meishanensis* He, Feng & Gu, DP5/2591. figs 11–13. *Trilonche brevispinosa* (Sashida & Tonishi): 11, DP5/1098; 12, DP2/D040; 13, DP5/2489. fig. 14. *Trilonche pseudocimelia* (Sashida & Tonishi), DP2/D023. figs 15–17. *Trilonche cimelia* (Nazarov & Ormiston): 15, DP2/5744; 16, DP5/2247; 17, DP5/2353. Scale bar is 10 μ m in figs 3–8, 10; 50 μ m in figs 1, 9, 15, 17; 100 μ m in figs 2, 11–14, 16).



Explanation of Plate 3.

figs 1–5. *Trilonche crassispinosa* (Sashida & Tonishi): 1, DP4/3341; 2, DP3/4578; 3, DP3/4431; 4, DP3/4126; 5, DP2/5749. figs 6, 9–12. *Kashiwara magna* Sashida & Tonishi: 6, DP5/1592; 9, DP5/1790; 10, DP5/1110; 11, DP3/4220; 12, DP3/4244. figs 7–8. *Trilonche?* sp. 1: 7, DP5/2297; 8, DP5/2145. figs 13–16. *Trilonche?* sp. 2: 13, DP3/4238; 14, DP4/3616; 15, DP4/3224; 16, DP4/3248. figs 17–20. *Trilonche textilis* Feng n. sp.: 17, DP3/4720; 18, DP3/4541, holotype; 19, DP3/4219; 20, DP3/4703. Scale bar 10 μ m in figs 3, 10, 14, 17–20; 50 μ m in figs 1, 2, 4–9, 11–13, 15, 16.

Latest Permian radiolaria, China

Diagnosis. Small *Trilonche* with large pores and numerous thorn-like spines at the vertices of the pore frames. Without main spines.

Holotype. Plate 3 (fig. 18), sample DP3/4541 from the Dalong Formation of the Dongpan section, Fusui County, southern Guangxi, depositional number X0301-40.

Material. Sixteen specimens from the Dongpan section examined by SEM, of which four are illustrated.

Description. Test small, spherical, without main spines. Cortical shell with orbicular, elliptical, rounded, polygonal pores that are irregular in size and arrangement. Pore frames tetragonal to hexagonal, and with numerous thorn-like spines at vertices. Thirty-two to 40 pores visible on a hemisphere. Medullary shell large compared with outer shell, subspherical, with large hexagonal pores, and linked with the cortical shell by three-bladed radial bars.

Dimensions (µm). Based on eight specimens: diameter of outer sphere 93–105.

Distribution. This species is only known from the latest Changhsingian in southern Guangxi, South China.

Remarks. This new species is distinguished from other species of the genus as it lacks a main spine, and has large pores and numerous thorn-like spines at the vertices of the pore frames.

Trilonche? sp. 1
(Pl. 3, figs 7–8)

Material. Seven specimens all examined by SEM.

Description. Cortical shell large, subspherical, and latticed. Pores are hexagonal, oval. Main spines are short, massive, three- or four-bladed in cross-section, variable in size, more than seven in number, irregularly distributed on the shell. Small accessory spines and nodes arise from junctions of pore frames.

Dimensions (µm). Based on seven specimens: diameter of outer shell 171–258; length of main spine 62–82; maximum width of main spine 48–71.

Distribution. Common in the Late Permian of South China.

Remarks. The indeterminate species is assigned tentatively to *Trilonche* Hinde because the inner structure is unknown. Number and irregular arrangement of main spines distinguish this species from other known species of *Trilonche*.

Trilonche? sp. 2
(Pl. 3, figs 13–16)

Material. Nine specimens examined by SEM.

Description. Test is large, spherical, latticed. Pores are very small, oval. Most specimens lack a main spine; but some have

short, three-bladed main spines. The number of the spines varies: from one to six.

Distribution. Common in the Late Permian of South China.

Remarks. This indeterminate species is assigned tentatively to the genus *Trilonche* Hinde because its inner structure is unknown.

Genus *Kashiwara* Sashida & Tonishi, 1985

Type species. *Kashiwara magna* Sashida & Tonishi, 1985.

Distribution. Late Permian, Japan and South China.

Remarks. The genus *Kashiwara* was proposed by Sashida & Tonishi (1985) for *Kashiwara magna*. They thought that this genus was characterized by two spherical lattice shells with four tetrahedrally arranged main spines. On the basis of investigations, this genus consists of a latticed cortical shell and two latticed inner shells. The cortical shell connected with first inner shell by three to four three-bladed beams, and the first inner shell connected with second inner shell by three to four strong three-bladed beams and numerous thin rays. It resembles the genus *Uberinterna* Sashida & Tonishi, 1988 in inner structure, but *Uberinterna* differs from *Kashiwara* in having six three-bladed beams between the cortical shell and the first medullary shell and in having more than two inner shells.

Kashiwara magna Sashida & Tonishi
(Pl. 3, figs 6, 9–12; Pl. 6, figs 12–20)
1985 *Kashiwara magna* Sashida & Tonishi: 15, pl. 5, figs 4–12.

Material. This species is abundant in our material. Twenty-nine specimens were examined by SEM, of which eleven are illustrated.

Distribution. Changhsingian, central Japan and South China.

Remarks. Our specimens differ slightly from *Kashiwara magna* illustrated by Sashida & Tonishi (1985) in having thinner main spines and developed secondary spines.

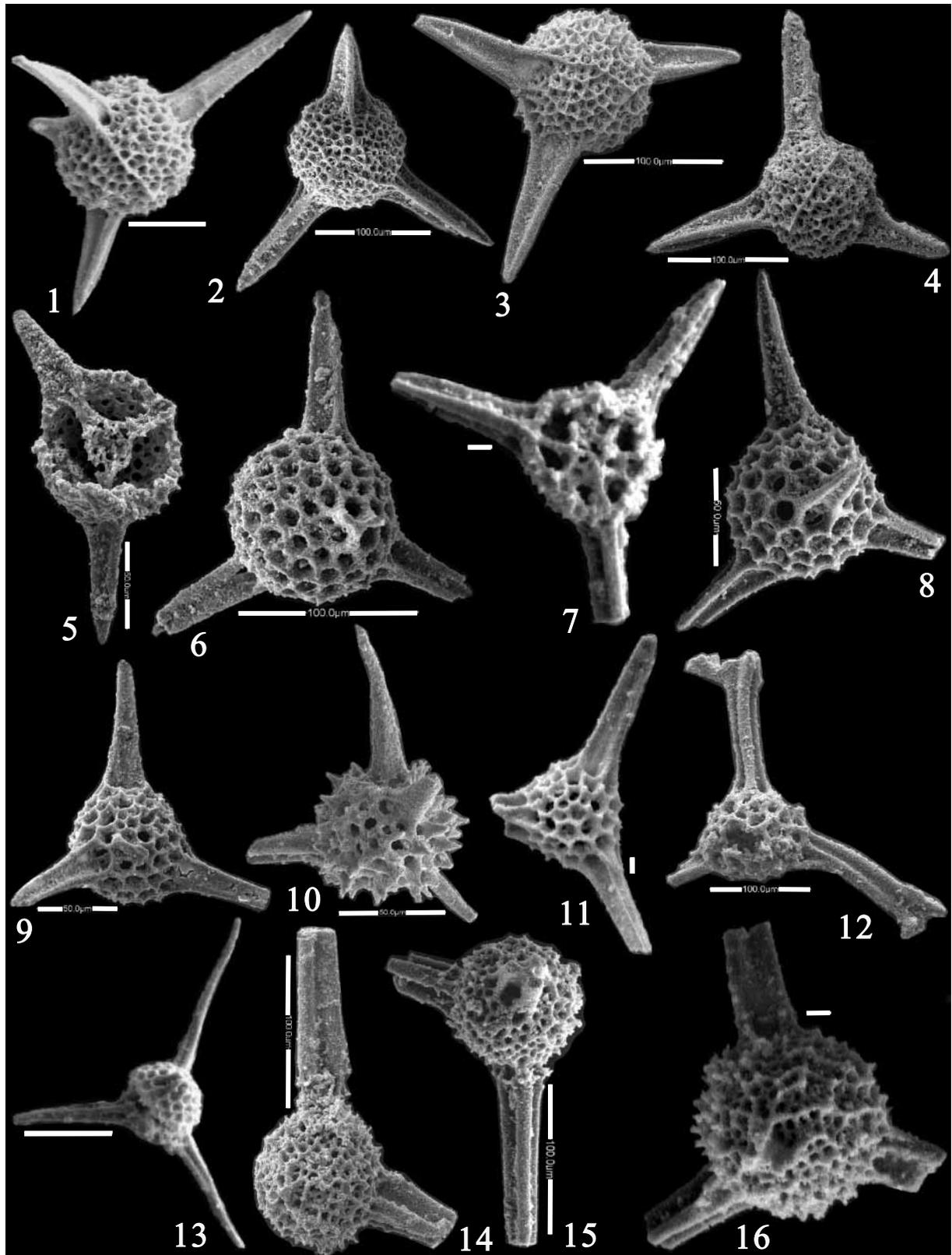
Genus *Triaenosphaera* Deflandre, 1973 emend. Gourmelon,
1987

Type species. *Triaenosphaera sicarius* Deflandre, 1973

Triaenosphaera minutus Sashida & Tonishi
(Pl. 4, figs 6–9)
1988 *Triaenosphaera minutus* Sashida & Tonishi: 530, figs 8.1–8.6.

Material. This species is common in our material and four specimens are illustrated.

Distribution. Late Permian; Japan and South China.



Latest Permian radiolaria, China

Triaiosphaera variabilis Feng n. sp.
(Pl. 4, figs 1–5)

Derivation of name. *variabilis*–*is*–*e* (Latin, adj.)=alterable.

Diagnosis. *Triaiosphaera* with three co-planar massive main spines and a poorly developed main spine.

Holotype. Plate 4 (fig. 1), sample DP4/3436 from the Dalong Formation of the Dongpan section, Fusui County, southern Guangxi, depositional number X0301-41.

Material. Twenty-one specimens from the Dongpan section were examined by SEM, of which five are illustrated.

Description. Test small, spherical with three to four main spines. Cortical shell comprises small pore frames with poorly developed nodes at vertices and has some narrow ridges. Pore frames usually hexagonal. Sixty-five to 130 pores present on a hemisphere. Medullary shell is small, subspherical, with small pores, and linked with the cortical shell by three-bladed radial bars. These bars extend beyond cortical shell into main spines. Main spines are three-bladed; three massive, usually co-planar, the fourth mostly very short, nearly perpendicular to the three spines.

Dimensions (µm). Based on nine specimens: diameter of cortical shell 91–100; maximum width of spines 30–35; maximum length of spines 100–125; diameter of medullary shell 31.

Distribution. This species is known only from the latest Changhsingian in southern Guangxi, South China.

Remarks. This new species is distinguished from other known species of the genus by the characteristic arrangement of main spines.

Triaiosphaera megacantha Feng n. sp.
(Pl. 4, figs 14–16)

Derivation of name. *megacanthus* (Greek)=large spine.

Diagnosis. *Triaiosphaera* with four elongate, strong, three-bladed spines.

Holotype. Plate 4 (fig. 16), sample DP3/4246 from the Dalong Formation of the Dongpan section, Fusui County, southern Guangxi, depositional number X0301-42.

Material. Six specimens from the Dongpan section examined by SEM, of which three illustrated.

Distribution. This species is known only from the uppermost Changhsingian in southern Guangxi, South China.

Description. Test very small, spherical with four main spines. Cortical shell comprises small pore frames with poorly developed nodes at vertices. Pores small, oval, and dense. The four main spines tetrahedrally disposed, and similar in outline and size. They are three-bladed, massive, long (about two times the diameter of test), and gradually tapering distally.

Dimensions (µm). Based on five specimens: diameter of cortical shell 82–100; maximum width of main spine 30–35; maximum length of main spine 155.

Remarks. This new species is distinguished from the other species of the genus by having a smaller shell and four long, massive main spines.

Triaiosphaera sp. 1
(Pl. 4, fig. 11)

Material. Only one specimen was recovered in the present study.

Description. Test small, subtriangular with three main spines. Cortical shell comprises small pore frames with poorly developed nodes at vertices. Pore frames usually hexagonal. Thirty-five pores visible on a hemisphere. Medullary shell small, subspherical. Main spines three-bladed, massive, co-planar, gradually decreasing in width distally.

Distribution. This indeterminate species is known only from the latest Changhsingian in southern Guangxi, South China.

Remarks. The indeterminate species is similar to *Triaiosphaera minutus* Sashida & Tonishi in pore character, but is distinguished from it by having three co-planar, more elongate main spines and smaller cortical shell.

Triaiosphaera sp. 2
(Pl. 4, fig. 13)

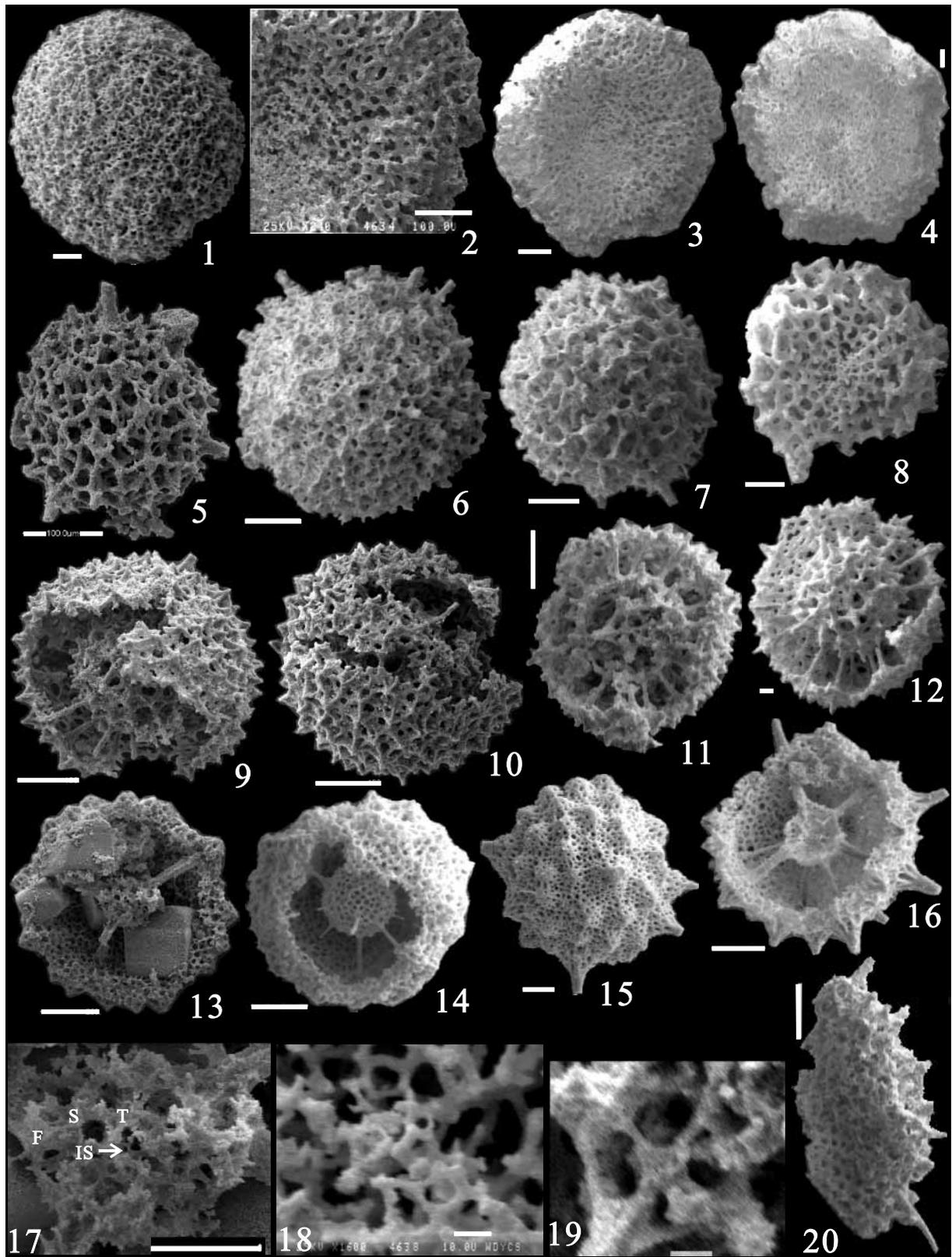
Material. Only one specimen was recovered in the present study.

Description. Test small, spherical with four main spines. Cortical shell comprises small, usually hexagonal pore frames. Thirty-seven pores are visible on a hemisphere. The four main spines tetrahedrally arranged. They are similar in outline and size, namely three-bladed, thin, long (about twice the diameter of the test) and gradually decreasing in width distally.

Distribution. This indeterminate species is known only from the latest Changhsingian in southern Guangxi, South China.

Explanation of Plate 4.

figs 1–5. *Triaiosphaera variabilis* Feng n. sp.: 1, DP4/3436, holotype; 2, DP2/A013; 3, DP3/F022; 4, DP4/Q054; 5, DP5/1063. figs 6–9. *Triaiosphaera minutus* Sashida & Tonishi: 6, DP2/B033; 7, DP3/4791; 8, DP2/C024; 9, DP2/D024. fig. 10. *Triaiosphaera* sp. 4, DP4/O004. fig. 11. *Triaiosphaera* sp. 1, DP3/4218. fig. 12. *Triaiosphaera* sp. 5, DP3/4218. fig. 13. *Triaiosphaera* sp. 2, DP3/4218. figs 14–16. *Triaiosphaera megacantha* Feng n. sp.: 14, DP5/1113; 15, DP5/2312; 16, DP3/4246, holotype. Scale bar is 10 µm in figs 7, 11, 16; 50 µm in figs 1, 5, 8–10; 100 µm in figs 2–4, 6, 12–15.



Latest Permian radiolaria, China

Remarks. The indeterminate species differs from *Triaenosphaera megacantha* n. sp. in having larger pores and thinner main spines. It resembles *Triaenosphaera longispina* Sashida (Sashida *et al.*, 2000b) in outline, but the latter has well-developed accessory spines.

Triaenosphaera sp. 3
(Pl. 6, figs 2–4)

Material. Four specimens were recovered in the present study.

Description. Test small, spherical with four main spines. Cortical shell with large pore frames. Pore frames hexagonal, triangular, or reniform. The four main spines tetrahedrally arranged. They are similar in outline, being three-bladed, but differ in size; usually three are robust and one thin.

Distribution. This species is known only from the latest Changhsingian in southern Guangxi, South China.

Remarks. This species is similar in outline to *Triaenosphaera minuta* Sashida & Tonishi, but differs from it in having larger, irregular pores. It differs also from *Triaenosphaera variabilis* n. sp. in having fewer and larger pores.

Triaenosphaera sp. 4
(Pl. 4, fig. 10)

Material. Only one specimen was recovered in the present study.

Description. Test small, spherical with four main spines. Cortical shell comprises hexagonal pore frames with conical secondary spines at vertices. Thirty-one pores are visible on a hemisphere. The four main spines tetrahedrally disposed. They are circular or three-bladed in cross-section, gradually decreasing in width distally.

Distribution. This indeterminate species is known only from the latest Changhsingian in southern Guangxi, South China.

Remarks. The indeterminate species is similar to *Triaenosphaera minuta* Sashida & Tonishi in outline, but differs from it in having developed secondary spines and rod-like main spines.

Triaenosphaera sp. 5
(Pl. 4, fig. 12)

Material. Only one specimen was recovered in the present study.

Description. Test small, spherical with four strong main spines. Cortical shell comprises subcircular pore frames. Twenty-eight pores are visible on hemisphere. The main spines three-bladed and have short distal branches.

Distribution. This indeterminate species is known only from the latest Changhsingian in southern Guangxi, South China.

Remarks. Strong main spines with distal branches distinguish this indeterminate species from other known species of this genus.

Wuyia Feng n. gen.

Type species. *Wuyia dongpanica* Feng n. gen. & sp.

Derivation of name. This genus is named in honour of Prof. Wu Yi, for his studies on the stratigraphy of the Guangxi Zhuang Autonomous Region.

Diagnosis. Spherical test composed of three concentric shells and a small microsphere.

Description. Test spherical in outline, composed of three concentric shells and a small microsphere. Cortical and first inner shells are connected by numerous beams, while other inner shells and microsphere are linked by four to six three-bladed beams. Cortical shell is with, or without main spines, but has numerous short spines.

Distribution. Middle and Late Permian. Japan, West Texas and South China.

Remarks. This new genus is similar in its characteristics of the cortical shell to *Meschedea* Won, 1983, but the innermost shell of *Meschedea* is quite large. *Trilonche* Hinde differs from this new genus in having only one inner shell. Late Permian *Meschedea permica* Sashida & Tonishi from Japan and Middle Permian *Meschedea? endocarpa* Nazarov & Ormiston, 1993 from USA are assigned to this new genus.

Wuyia permica (Sashida & Tonishi, 1985)
(Pl. 6, figs 9–11)

1985 *Meschedea permica* Sashida & Tonishi: 15–16, pl. 4, figs 10–12; pl. 5, figs 1–3.

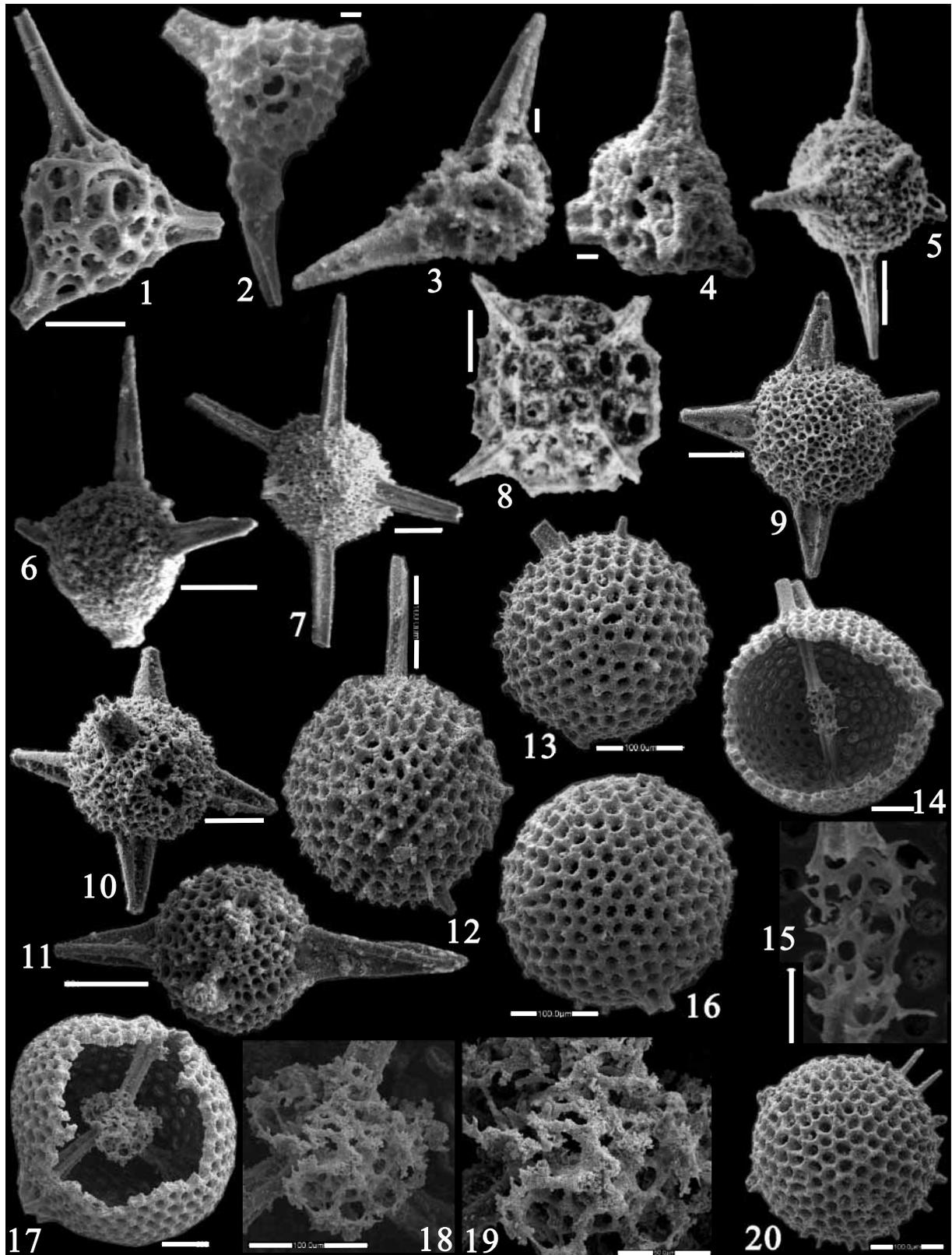
Material. Five specimens examined by SEM.

Distribution. Late Permian, central Japan and South China.

Remarks. Our specimens compare well to *Meschedea permica* from the Late Permian of central Japan (Sashida & Tonishi, 1985) in the outline of the shell and spine, and in the structure of the cortical shell. This species is assigned to the new genus *Wuyia* according to its inner structure.

Explanation of Plate 5.

figs 1–4. *Provisocyntra densa* Feng n. sp.: 1, DP3/4630, holotype; 2, DP3/4634, magnification of fig. 3; 3, DP3/4623; 4, DP7/3602. figs 5–8, 18, 20. *Provisocyntra ormistoni* Feng n. sp.: 5, DP3/J007; 6, DP3/4631; 7, DP3/4636, holotype; 8, DP3/4540; 18, DP3/4638, magnification of fig. 8; 20, DP3/4635. figs 9–12, 19. *Wuyia dongpanica* Feng n. gen. & sp.: 9, DP5/X011, holotype; 10, DP2/C008; 11, DP3/4609; 12, DP3/4412; 19, DP3/46091, magnification of fig. 11. figs 13, 17. *Uberinterna virgispinosum* Sashida & Tonishi: 13, DP3/4252; 17, DP3/4253, magnification of fig. 13 (F, first medullary shell; S, second medullary shell; T, third medullary shell; IS, inner spicule). figs 14–16. *Hegleria mammilla* (Sheng & Wang): 14, DP3/4819; 15, DP4/3429; 16, DP3/4744. Scale bar is 10 µm in figs 12, 18, 19; 20 µm in fig. 17; 50 µm in figs 1, 3, 4, 6–11, 13–16, 20; 100 µm in figs 2, 5.



Wuyia dongpanica Feng n. gen. & sp.
(Pl. 5, figs 9–12, 19)

Derivation of name. According to the occurrence in the Dongpan section.

Diagnosis. A representative of *Wuyia* lacking a main spine.

Holotype. Plate 5 (fig. 9), sample DP3/4630 from the Dalong Formation of the Dongpan section, Fusui County, southern Guangxi, depositional number X0301-45.

Material. Eight specimens were recovered, of which six were examined by SEM.

Description. Test spherical in outline, composed of three concentric shells and a small microsphere. Cortical shell is thin, with numerous very short three- to four-bladed spines; pores oval, small. The cortical and first inner shells are connected by numerous beams; and the distance between both shells is about half the radius of the test. The beam varies in thickness, the middle part is thin and circular in cross-section, and the parts near both shells are wider, three- to four-bladed. At least four three-bladed beams link other inner shells and microsphere.

Dimensions (µm). Based on six specimens: diameter of cortical shell 167–189; diameter of first inner shell 91–99; diameter of second inner shell 32; diameter of microsphere 8.

Distribution. Late Changhsingian, South China.

Remarks. This new species differs from Middle Permian *Wuyia endocarpa* (Nazarov & Ormiston, 1993) in lacking a main spine.

Genus *Hegleria* Nazarov & Ormiston, 1985

Type species. *Hegleria mammifera* Nazarov & Ormiston, 1985.

Hegleria mammilla (Sheng & Wang, 1985)
(Pl. 5, figs 14–16)

1985 *Phaenicosphaera mammilla* Sheng & Wang: 179–180, pl. 3, figs 1–8.

1985 *Hegleria mammifera* Nazarov & Ormiston: 22, pl. 6, figs 3–5.

1987 *Phaenicosphaera mammilla* Sheng & Wang; Kozur & Krahl: 365–366, fig. 7a.

1990 *Hegleria mammifera* Nazarov & Ormiston; Noble & Renne: 387, pl. 1, figs 9, 10.

1992 *Hegleria mammilla* (Sheng & Wang); Blome & Reed: 369, pl. 11, figs 10, 12, 13.

1993a *Phaenicosphaera mammilla* Sheng & Wang; Wang: 449, pl. 2, figs 1–6.

1993b *Phaenicosphaera mammilla* Sheng & Wang; Wang: 466, pl. 2, figs 13–16.

1994 *Hegleria mammilla* (Sheng & Wang); Wang & Li: 209–210, pl. 1, figs 22, 23.

1997 *Hegleria mammilla* (Sheng & Wang); Wang & Fan: 66, pl. 1, figs 1–3.

1998 *Hegleria mammilla* (Sheng & Wang); Feng *et al.*: 240, figs 3f–3h, 3k.

2000b *Hegleria mammilla* (Sheng & Wang); Sashida *et al.*: 252, pl. 3, figs 1–4, 6.

2002 *Hegleria mammilla* (Sheng & Wang); Feng & Gu: 801, figs 4.1–4.3.

Material. The species is abundant in our material. Twenty specimens were examined by SEM.

Distribution. Middle and Late Permian; South and Southwest China, North America, Thailand and Sicily.

Remarks. Sheng & Wang (1985) and Nazarov & Ormiston (1985) described this species as *Phaenicosphaera mammilla* and *Hegleria mammifera*, respectively. Kozur & Krahl (1987) considered that *Hegleria mammifera* should be a junior synonym of *Phaenicosphaera mammilla*. Blome & Reed (1992) suggested *Hegleria mammilla* (Sheng & Wang) was used instead of *Hegleria mammifera* and *Phaenicosphaera mammilla* according to the law of priority in the nomenclature and because the genus *Phaenicosphaera* is a modern radiolarian form. Sheng & Wang (1985) did not illustrate the interior structure of this species. The holotype of *Hegleria mammifera* (Nazarov & Ormiston, 1985, pl. 6, fig. 3) is different from the specimen the authors illustrated for the inner structure (pl. 6, fig. 5, possibly belonging to *Grandetortura* Sashida & Tonishi, 1991). De Wever *et al.* (2001) suggested that *Hegleria* possibly belongs to the Family Pseudolitheliidae Kozur & Möstler, 1989. Therefore, the higher taxonomy of the genus remains a puzzle.

On the basis of many investigations, this genus is characterized by having a thick spherical cortical shell with numerous conical mammae on the surface and two to three medullary shells; each mamma has numerous small pores framed by thick bars; first medullary shell connected to the cortical shell by multiple rays. Therefore, it is believed that it should belong to the Family Entactiniidae Riedel, 1967.

Genus *Uberinterna* Sashida & Tonishi, 1988

Type species. *Uberinterna virgispinosum* Sashida & Tonishi, 1988.

Uberinterna virgispinosum Sashida & Tonishi, 1988
(Pl. 5, figs 13, 17)

1988 *Uberinterna virgispinosum* Sashida & Tonishi: 531–532, figs 8.7–12.

Explanation of Plate 6.

fig. 1. Genus & species indet., DP4/3389. figs 2–4. *Triaenosphaera* sp. 3: 2, DP3/4210; 3, DP3/4315; 4, DP3/4620. figs 5–7. *Spongontactinia?* sp.: 5, DP5/2205; 6, DP3/4627; 7, DP4/3235. fig. 8. *Polyentactinia* sp., DP5/2594. figs 9–11. *Wuyia permica* (Sashida & Tonishi): 9, DP5/1605; 10, DP2A029; 11, DP5/2327. figs 12–20. *Kashiwara magna* Sashida & Tonishii: 12, DP4/O038; 13, DP5/X014; 14, DP2/C020; 15, DP2/C021, magnification of fig. 14; 16, DP2/A079; 17, DP4/R009; 18, DP4/R010, magnification of fig. 17; 19, DP4/R011, magnification of fig. 17; 20, DP5/Y017. Scale bar is 10 µm in figs 2–4; 20 µm in fig. 15; 50 µm in figs 1, 5–11, 14, 17, 19; 100 µm in figs 12, 13, 16, 18, 20).

Material. The species is rare in our material. Five specimens were examined by SEM.

Distribution. Late Permian, Japan and South China.

Remarks. This species is similar to *Hegleria mammilla* (Sheng & Wang) in outline and structure of cortical shell, but differs from it in having six three-bladed beams between the cortical shell and the external medullary shell and in having more than three medullary shells.

Family Spongentactiniidae Nazarov, 1975

Type genus. *Spongentactinia* Nazarov, 1975.

Diagnosis. Spongy Entactinaria with an initial spicule of six or more spines, usually with a medullary and a cortical shell (De Wever *et al.*, 2001).

Range. Formerly, the family was recovered only from the Devonian and Carboniferous (De Wever *et al.*, 2001). This is the first report from the Permian.

Genus *Provisocyntra* Nazarov & Ormiston, 1987

Type species. *Provisocyntra cassicula* Nazarov & Ormiston, 1987.

Provisocyntra densa Feng n. sp.
(Pl. 5, figs 1–4)

Derivation of name. *densus*–*um*–*a* (Latin, adj.)=dense.

Diagnosis. A very large *Provisocyntra* composed of dense concentric shells and lacking long radial spines.

Holotype. Plate 5 (fig. 1), sample DP3/4630 from the Dalong Formation of the Dongpan section, Fusui County, southern Guangxi, depositional number X0301-43.

Material. Nine specimens were recovered, of which six were examined by SEM.

Description. Test is very large, spherical, composed of about 20 concentric shells. Distance between two adjacent shells is very short. The shell is meshed by rod-like bar and connected by beams. Pores are small and irregular. Spines are few and very short. The inner structure of the medullary shell is unknown.

Dimensions (µm). Based on five specimens: diameter of test 980–1320.

Distribution. Late Changhsingian, South China.

Remarks. This new species differs from the other species of *Provisocyntra* by its large test, dense concentric layers and a poorly developed spine.

Provisocyntra ormistoni Feng n. sp.
(Pl. 5, figs 5–8, 18, 20)

Derivation of name. This species is named for Dr Allen R. Ormiston, in honour of his studies on Palaeozoic Radiolaria.

Diagnosis. Medium-sized *Provisocyntra* with few, short, rod-like spines and composed of dense concentric shells.

Holotype. Plate 5 (fig. 7), sample DP3/4636 from the Dalong Formation of the Dongpan section, Fusui County, southern Guangxi, depositional number X0301-44.

Material. Eleven specimens were recovered, of which five were examined by SEM.

Description. Test medium, spherical. Outer shell with few, short, rod-like spines. Pores small, variable and irregular in form. Inner shells are covered by thin rods and connected by straight beams. Each beam is slightly wider rods.

Dimensions (µm). Based on five specimens: diameter of shell 480-940.

Distribution. Late Changhsingian Permian, South China.

Remarks. This new species is similar in outline and structure to *Provisocyntra cassicula* Nazarov & Ormiston from the Early Carboniferous, but differs from the latter in having few, short outer spines.

Genus *Spongentactinia* Nazarov, 1975

Type species. *Spongentactinia fungosa* Nazarov, 1975.

Spongentactinia? sp.
(Pl. 6, figs 5–7)

Material. Four specimens were recovered, of which three were examined by SEM.

Description. Test is small, spherical, with six main spines. Outer shell is spongy, with very small, oval pores. The main spines are uniform; they are three-bladed and gradually decrease in width distally.

Distribution. Late Changhsingian; South China.

Remarks. The specimens reported herein are assigned tentatively to the genus *Spongentactinia* Nazarov because their inner structure is unknown.

Family Polyentactiniidae Nazarov, 1975

Type genus. *Polyentactinia* Foreman, 1963.

Diagnosis. Entactinaria having a spicule with eight bar-centred spines and usually a single cortical shell with polygonal surface. With or without pylome (De Wever *et al.*, 2001).

Distribution. Devonian or older to Late Cretaceous.

Latest Permian radiolaria, China

Genus *Polyentactinia* Foreman, 1963

Type species. *Polyentactinia craticulata* Foreman, 1963.

Polyentactinia sp.
(Pl. 6, fig. 8)

Material. Only a single specimen was found in this study.

Description. Test is a single cortical shell. The shell is subdivided into eight trapeziform and two square areas. Each area has four oval pores. Four main spines are three-bladed, short and medium in thickness.

Distribution. Late Changhsingian; South China.

Remarks. According to its characters, the specimen illustrated herein can be placed in the genus *Polyentactinia* Foreman, 1963.

Genus and species indeterminate
(Pl. 6, fig. 1)

Material. Only one specimen, illustrated.

Description. Test subspherical, with three co-planar spines. Cortical shell with thin, smooth bars forming subcircular to oval pores which are unequal in size. Spines are thin, three-bladed and gradually decrease in width distally. Inner shell is similar to the cortical shell in structure and composed of some thin bars.

Distribution. Late Changhsingian, South China.

Remarks. This indeterminate species resembles genus *Cryptostephanidium* Dumitrica (1978) in its shape of the cortical shell and number of spines but differs from it in having a latticed medullary shell.

DISCUSSION

Many studies on the mass extinction of Permian radiolarians indicated that the Changhsingian was a main extinction interval of the Permian radiolarian fauna and that this event was a gradual process (Kakuwa, 1996; Vishnevskaya, 1997; Kuwahara & Yao, 1998). Our detailed investigation in the Dongpan Section, South China, however, shows that three orders of Radiolaria – Entactinaria, Spumellaria and Latentifistularia – diversified rapidly during the Late Changhsingian, followed by rapid extinction at the end of the Changhsingian. Similar conclusions were reached by Kozur (1998) and Feng *et al.* (2000).

In the Dongpan Section, the highest diversity occurred in an interval between 267 cm (line A) and 979 cm (line B) below the Permian–Triassic Boundary (PTB) (Fig. 2), with 138 species belonging to the Orders Albaillellaria, Entactinaria, Spumellaria and Latentifistularia. Thirty-four species of the Order Entactinaria, as reported in this paper, were also found in the interval between lines A and B and 26 disappeared at line A (Fig. 2). From line A to the PTB, the radiolarian fauna decreased quickly in both diversity and abundance. Only eight of the 34 species extend through line A. The lithology of the section changes from

bedded siliceous rocks to siliceous mudstones across line A, which indicates that productivity of the radiolarian fauna decreased quickly. Additionally, important changes in test structure took place in proximity to line A: most of the species with developed external spines disappeared, whereas most of the species that survived lack an external spine, or have undeveloped external spines. The external spines of some other species, such as *Trilonche crassispinosa* and *Hegleria mammilla*, became thinner and shorter across the line. Therefore, line A demarks an important event for the radiolarian fauna in this area.

Kozur (1993) erected four radiolarian ecological zones: (1) 0–50 m water depth, consisting almost exclusively of Copicytrinae; (2) 50–200 m water depth, dominated by Entactinaria, accompanied by Copicytrinae; (3) 200–500 m water depth, dominated by Entactinaria, accompanied by Copicytrinae and Albaillellacea; (4) below 500 m depth, characterized by Albaillellacea, accompanied by Entactinaria, Ruzhencevispongacea and Phaenicosphaera. At the line A, the rapid decrease of the radiolarian fauna was not as a consequence of palaeoecological factors. Albaillellidae, Latentifistularia, Entactinaria and copicytrids had similar extinction rates near line A. No new taxa occurred in the interval between lines A and the PTB. Globally, the rapid extinction of the radiolarian fauna at the end of the Changhsingian has been recorded in other sections in South China and Japan (Feng *et al.*, 1998; Shang *et al.*, 2001; Gu & Feng, 2002; Xia *et al.*, 2004).

In the Dongpan Section, line A also represents the upper limits of the *Neobaillella optima* Assemblage Zone and *Albaillella triangularis* Abundance Zone. Investigations on conodonts and radiolarians in the Guji-hachiman section indicates that the upper limit of these two zones corresponds to the upper limit of the *Clarkina meishanensis zhangi* Interval Zone (Yao *et al.*, 2001). Taxa from the *Clarkina meishanensis zhangi* Interval Zone were recovered from Bed 24e in the Meishan Section D, Changxing, China (Mei *et al.*, 1998). Therefore, the upper limit of the Permian bedded chert and line A, as indicated by rapid disappearance of the Changhsingian radiolarians in the Dongpan Section, corresponds to the upper limit of the limestone of Bed 24e and the extinction event as marked by the disappearance of benthics in the Meishan Section D, such as fusulinid and coral reef. The reasons for these changes are still not well understood.

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