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Late Silurian radiolarians from a radiolarite pebble within a conglomerate, Kotaki, Itoigawa, Niigata Prefecture, central Japan

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Abstract

This article describes radiolarians from a radiolarite pebble within conglomerate from a float block that was collected along the banks of the Kotaki River in the Kotaki area, Itoigawa, Niigata Prefecture, central Japan. *Futobari morishitai* Furutani, Inaniguttidae gen. et sp. indet., and Palaeoscenidiidae gen. et sp. indet. were recognized on etched surfaces of the pebble. *Pseudospongoprunum* sp., *Zadrappolus* sp., and *Rotasphaera* sp. were discovered in residues obtained by chemically treating the conglomerate. This assemblage may be compared to the assemblage around the boundary between the *Pseudospongoprunum tauversi* to *Futobari solidus–Zadrappolus tenuis* assemblage zones and corresponds to the late Silurian. This report marks the first identification of Silurian radiolarians in Niigata Prefecture, which also makes them the oldest recorded fossils from the prefecture. The clasts are also the oldest recorded radiolarian-bearing clasts within conglomerates of the Japanese Islands and the Korean Peninsula.

Key words: conglomerate, etched surface, Silurian radiolaria, Jurassic, Kuruma Group, Niigata Prefecture, Japanese Islands, Korean Peninsula.

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Introduction

Microfossils from clasts within conglomerates may provide clues about provenance. Radiolarians have been reported from siliceous and argillaceous rock clasts in Cretaceous strata in the Hokuriku district (e.g., Saida, 1987; Ito et al., 2012, 2014, 2015b), as represented by the Itoshiro and Akaiwa subgroups of the Tetori Group. In contrast, few studies have reported radiolarian-bearing clasts from Jurassic strata in the district.

The Lower Jurassic Kuruma Group (Kobayashi et al., 1957) is distributed over Niigata, Nagano, and Toyama Prefectures, central Japan. There has been only one brief report of radiolarian-bearing clasts from the Kuruma Group by Kumazaki and Kojima (1996), but no images were included.

Recently, Devonian corals were discovered in pebbles within conglomerate from a float block collected along the banks of the Kotaki River in the Kotaki area, Itoigawa, Niigata Prefecture (Niko et al., 2014, 2015, 2016). Previous studies reported that the conglomerate was derived from Mesozoic strata, possibly the Kuruma Group.

During sample processing of the conglomerate, we discovered a late Silurian radiolarian assemblage. This article describes the assemblage and is the first report of radiolarians from the Kuruma Group that includes images. This report also marks the first identification of Silurian radiolarians from Niigata Prefecture, which also makes them the oldest fossils recorded in the prefecture. Furthermore, the clasts are the oldest recorded radiolarian-bearing clasts within conglomerates in the Japanese Islands and the Korean Peninsula.

Sample locality and geologic background

Paleozoic basement rocks, overlying Mesozoic sedimentary strata, and Paleozoic through Cenozoic igneous rocks are exposed in the Itoigawa and adjacent regions (e.g., Nagamori et al., 2010) (Fig. 1A). The float block was collected along the banks of the Kotaki River in the Kotaki area, Itoigawa (Fig. 1B) by Kanako Ito. The float block is reposited in the Fossa Magna Museum in Itoigawa.

The float block is about 1 meter (m) in diameter and consists of subrounded to rounded pebbles in a sandy matrix (Niko et al., 2014). The pebbles include abundant volcanic and siliceous rocks, common limestones and mudstones, and relatively rare sandstones (Niko et al., 2014). Devonian corals occurred within the limestone and mudstone pebbles (Niko et al., 2014, 2015, 2016).

The Kuruma Group (Kobayashi et al., 1957) is widely distributed in the upper reaches of the Kotaki River and includes conglomeratic layers in most formations (e.g., Kobayashi et al., 1957; Shiraishi, 1992; Kumazaki and Kojima, 1996; Nagamori et al., 2010). Consequently, Niko

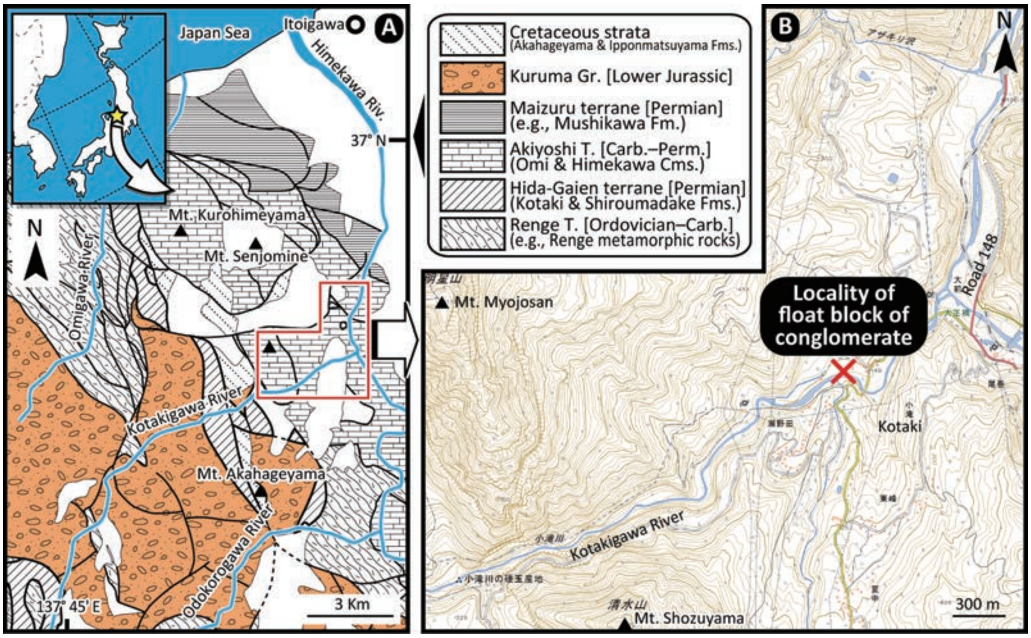

Fig. 1. Index map showing the location of the conglomerate float block in Kotaki, Itoigawa City, Niigata Prefecture, central Japan. (A) Geologic map of the Itoigawa area modified from Nagamori et al. (2010). (B) Map of Kotaki modified from topographic map "Kotaki" scale 1:25000 published by Geospatial Information Authority of Japan.

et al. (2014) concluded that the conglomerate was probably derived from the Kuruma Group. An exposure of the conglomerate layer from which the float block was derived, however, has never been discovered.

Materials and methods

The sample was prepared for an etched surface observation using the method described by Ito et al. (2015b). The sample was sliced into three chips with a rock cutter. The chips were observed using a loupe to assess the presence of radiolarian tests in siliceous and argillaceous rock clasts. Abundant radiolarian tests were recognized in a dark-cyan radiolarite clast (Fig. 2). Two chips, including the radiolarite clast, were soaked in a solution of approximately 5% hydrofluoric acid (HF) for one day at room temperature. After the removal of the HF solution, the etched chips were resoaked in fresh water. After the removal of the water, the etched chips were dried in an oven. A gold coating was applied to the etched chips, which were observed and photographed using a scanning electron microscope (SEM).

Residues from the chips were obtained when the HF solution was removed. The residues were collected through a sieve with a mesh diameter of 0.054 mm. All residues

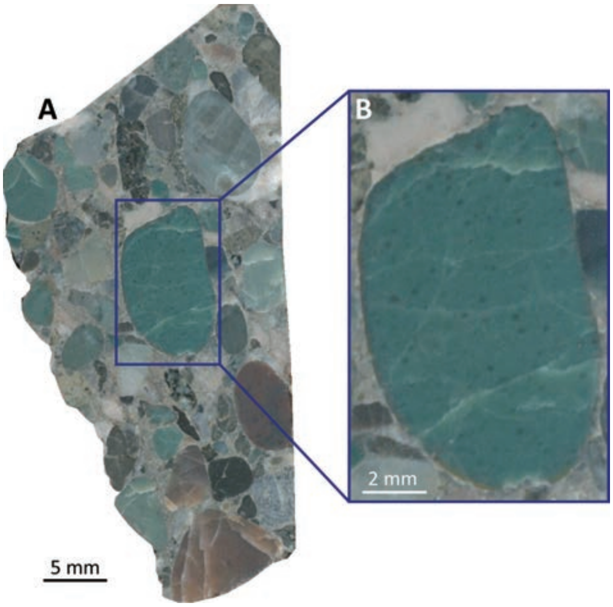

Fig. 2. Polished surface of the conglomerate. (A) Overall view. (B) Enlarged view of the radiolarian-bearing pebble (radiolarite).

were prepared on slides with a mounting medium (Entellan New). The slides were observed and photographed using a transmitted light microscope.

Radiolarian occurrences

The etched surfaces of the radiolarite clast were characterized by a predominance of spherical radiolarians with common spicules (Fig. 3). Terrestrial clastic grains did not appear on the etched surfaces, which implied that the clast is fossil supported. The spherical radiolarians and the spicules did not seem to be sorted and a preferred orientation of the spicules was not observed. Fossil preservation on the etched surfaces and in the residues was generally poor.

A few better-preserved specimens were recognized on the etched surfaces (Fig. 4). *Futobari morishitai* Furutani is characterized by several main spines and rounded pores on the surfaces (Fig. 4.1), which are major characteristics of the species (Furutani, 1990; Kurihara, 2007). Inaniguttidae gen. et sp. indet. display two major spines that are bladed at the base (Fig. 4.2). These characteristics are the same as for some genera of the family, such as *Futobari* and *Zadrappolus* (e.g., Furutani, 1990; Kurihara and Sashida, 2000; Kurihara, 2007). Palaeoscenidiidae gen. et sp. indet. display six thorny spines without rings formed by the basal spines (Fig. 4.3), which is typical of Palaeoscenidiidae genera; an example is *Palaeoscenidium* Deflandre, which is characterized by thorny spines (Deflandre, 1953) and

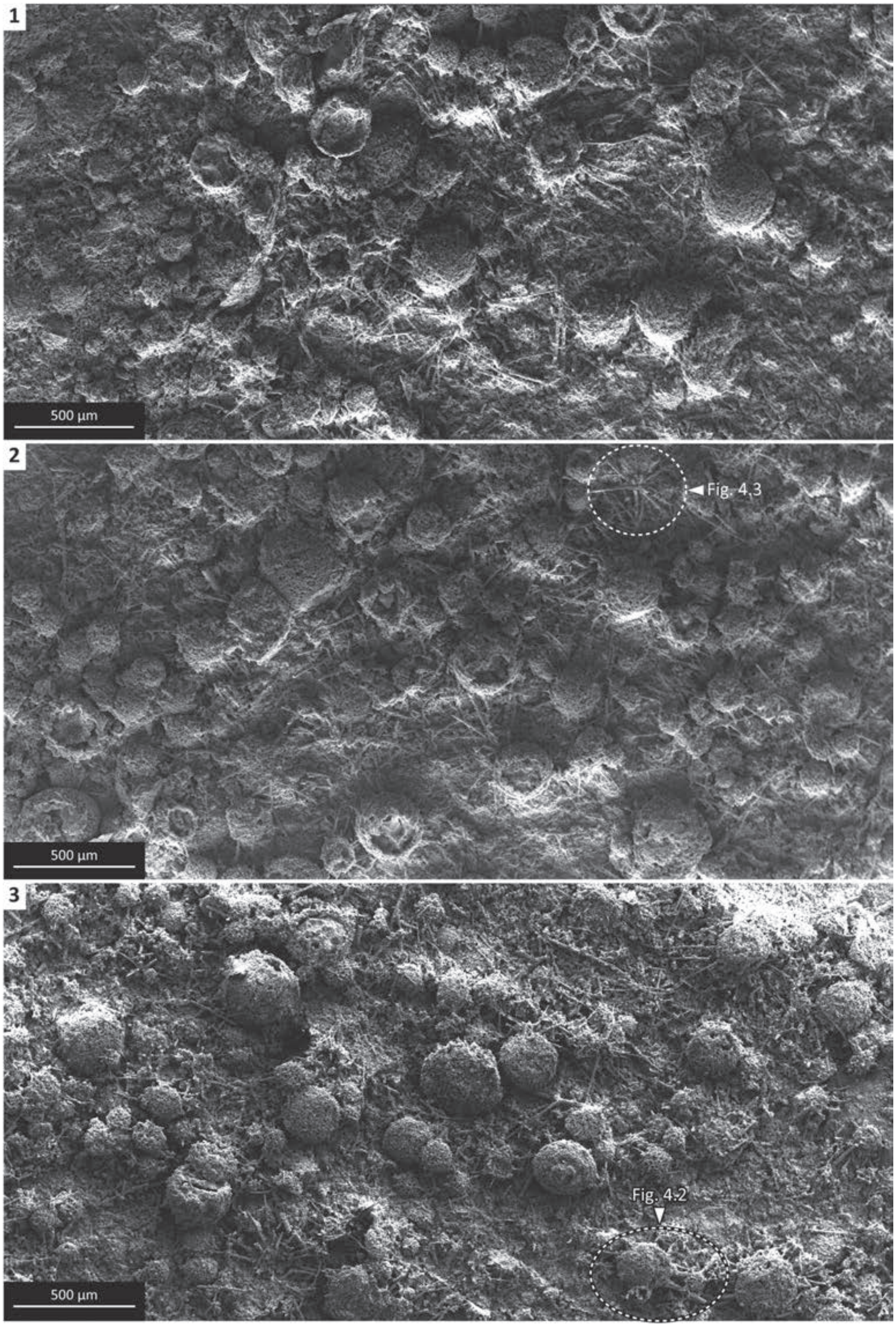

Fig. 3. Scanning electron microscope (SEM) images of the etched surfaces of the radiolarite pebble.

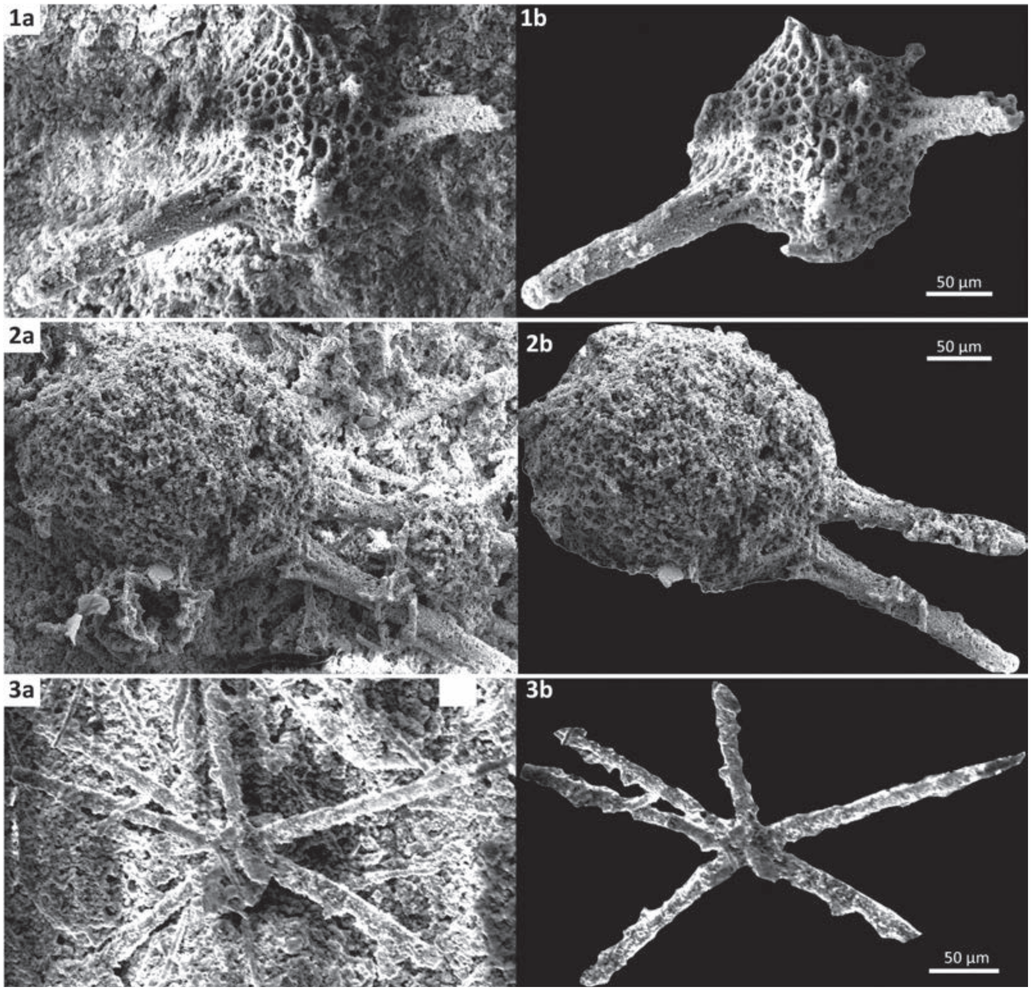

Fig. 4. Scanning electron microscope (SEM) images of radiolarians on etched surfaces (a) and trimmed images (b) from the radiolarite pebble. 1: *Futobari morishitai* Furutani, 1990. 2: Inaniguttidae gen. et sp. indet. 3: Palaeoscenidiidae gen. et sp. indet.

an absence of rings (Furutani, 1983).

In the residues, spinous and spineless spherical radiolarians were observed (Fig. 5); however, no specimen could be identified at the species level. *Pseudospongoprunum* sp. possess an elliptical spongy shell and probably two polar spines (Figs. 5.1, 5.2), which are diagnostic characteristics of the genus (Wakamatsu et al., 1990; Noble, 1994; Umeda, 1998). *Zadrappolus* sp. appear to possess a single cortical shell and double medullary shells (Figs. 5.3–5.5), which are diagnostic characteristics of the genus (Furutani, 1990). *Rotasphaera* sp. appear to have a web-like structure on the shell surface (Fig. 5.6), which is similar to the surface structure consisting of primary and secondary spines of the genus (Noble, 1994).

No radiolarian tests were observed in other clasts within the chips that were treated

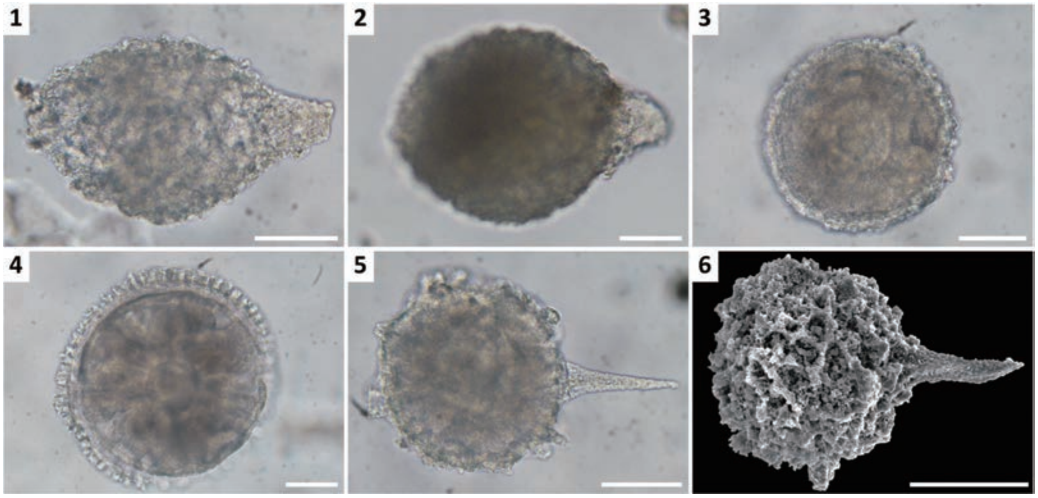

Fig. 5. Photomicrographs of radiolarians obtained from residues of the conglomerate sample. 1, 2: *Pseudospongoprunum* sp. 3–5: *Zadrappolus* sp. 6: *Rotasphaera* sp. All scale bars are 50 micrometers (μm).

with HF solution. Moreover, we determined that the matrices of the chips did not include radiolarians. Therefore, we can say with certainty that the radiolarians obtained from the residues were most likely derived from the radiolarite pebble, not the matrix.

Age assignment of the radiolarite pebble

The radiolarian tests on the etched surfaces, such as *F. morishitai*, are characteristic of the *Futobari solidus–Zadrappolus tenuis* Assemblage Zone of Kurihara (2004, 2007), which corresponds to the uppermost Pridoli (latest Silurian) to Lower Devonian (Pragian) according to Kurihara (2004, 2007).

Pseudospongoprunum, obtained from the residues, occurred in the *Pseudospongoprunum tauversi* Assemblage Zone of Kurihara (2004, 2007). Kurihara (2004, 2007) concluded that the *P. tauversi* Assemblage Zone corresponds to the Pridoli on the basis of the conodont-based age by Noble (1994) and Noble and Aitchison (2000).

Other radiolarians, which were observed on the etched surfaces and were obtained from the residues, are consistent with the components of the *P. tauversi* and *F. solidus–Z. tenuis* assemblage zones (Kurihara, 2004, 2007).

Because we are assuming that the residues were derived from the radiolarite pebble, the assemblage in the pebble can be compared to the assemblage around the boundary between the *P. tauversi and F. solidus–Z. tenuis* assemblage zones. In addition to the conodont-based age (Noble,1994; Noble and Aitchison, 2000), a U–Pb zircon age (Manchuk et al., 2013) indicated that the age around the boundary between the *P. tauversi* and *F. solidus–*

Zadrappolus tenuis assemblage zones is Ludlow to Pridoli (late Silurian). On the basis of these previous studies, we conclude that the age of the radiolarian assemblage of this study is late Silurian. If we assume that the radiolarians in the residues are derived from other clasts, then the pebble includes radiolarians that are at least as old as late Silurian.

Implications

Fossil records in Niigata Prefecture

Paleozoic radiolarian occurrences have been reported from Paleozoic strata in the Itoigawa area. In addition, Paleozoic and Mesozoic radiolarians have occurred in clasts within conglomerates in Mesozoic strata of the area. However, the age of the these previously reported radiolarians is Carboniferous(?), Permian, Triassic, and Jurassic, as documented below. The results of this study indicate that these are the first Silurian radiolarians to be identified in the Itoigawa area (Fig. 6).

Tazawa et al. (1984) found *Pseudoalbaillella* sp. aff. *P. longicornis* Ishiga and Imoto from mudstone of the Kotaki Formation (Nagamori et al., 2010), which is assigned to the Hida-Gaien terrane. The specimen of *Pseudoalbaillella* sp. aff. *P. longicornis* is similar to the short form of *Pseudoalbaillella fusiformis* (Holdsworth and Jones) sensu Ito et al. (2015a). *Pseudoalbaillella fusiformis* occurred generally in the upper Cisuralian (lower Permian) to the Guadalupian (middle Permian) (e.g., Ishiga, 1990; Zhang et al., 2010; Wang and Yang, 2011; Ito et al., 2015a). Ujihara (1985) reported occurrences of *Pseudotormentus* sp. from siliceous mudstone of the Kotaki Formation. *Pseudotormentus* occurred during all of the Permian (Ito et al., 2016), although *Pseudotormentus delawarensis* Schwartzapfel and Holdsworth also occurred in the upper Mississippian (Lower Carboniferous) (Schwartzapfel and Holdsworth, 1996). Kawai and Takeuchi (2001) found *Follicucullus* sp. in chert and siliceous mudstone of the Kotaki Formation. *Follicucullus* occurred generally in the Lopingian (Upper Permian) (e.g., Ishiga, 1990; Zhang et al., 2014).

The Himekawa Complex (Kawai and Takeuchi, 2001; redefined by Nagamori et al., 2010) is assigned to the Akiyoshi terrane. Cherts of this complex yielded *Pseudotormentus* sp. (Kawai and Takeuchi, 2001); siliceous mudstones yielded *Pseudoalbaillella fusiformis, Pseudoalbaillella* sp. cf. *P. globosa* Ishiga and Imoto, *F. porrectus* Rudenko (originally described as *F. scholasticus* Ormiston and Babcock), and *Pseudoalbaillella monacantha* (Ishiga and Imoto) (Tazawa et al., 1984); siliceous mudstones yielded *Pseudoalbaillella fusiformis, F. porrectus,* and *Pseudoalbaillella monacantha* (Kawai and Takeuchi, 2001); siliceous mudstone containing manganese carbonate spherules yielded *Albaillella asymmetrica* Ishiga and Imoto (Kawai and Takeuchi, 2001). According to Zhang et al. (2014), the co-occurrence range of *Pseudoalbaillella fusiformis, Pseudoalbaillella monacantha*, and *F. porrectus* is restricted to the *F. porrectus* Interval Zone of the lower Capitanian,

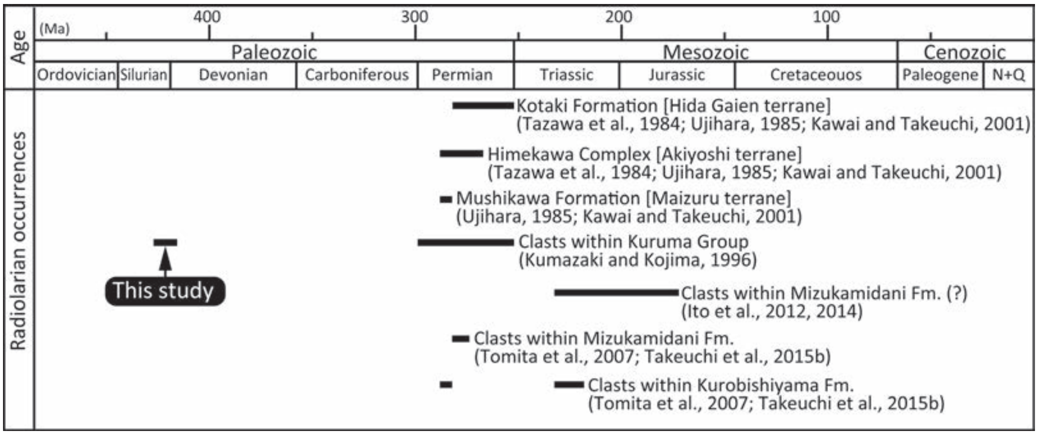

Fig. 6. Radiolarian occurrences from the Itoigawa area, Niigata Prefecture. Geologic ages are after Ogg et al. (2016).

Guadalupian. The range of *A. asymmetrica* is restricted to the Kungurian of the Cisuralian according to Zhang et al. (2010).

Mudstones of the Mushikawa Formation (Ujihara, 1985; redefined by Nagamori et al., 2010), which is assigned to the Maizuru terrane, yielded *A. asymmetrica* Ishiga and Imoto, *Pseudoalbaillella fusiformis*, and *Pseudoalbaillella longtanensis* Sheng and Wang (Ujihara, 1985; Kawai and Takeuchi, 2001). These species co-occurred in the *P. longtanensis* Assemblage Zone of Ishiga (1990), which corresponds to the Kungurian Age of the Cisuralian Epoch.

Kumazaki and Kojima (1996) reported *Pseudoalbaillella* sp. and *Pseudotormentus*? sp. from siliceous mudstone clasts within conglomerates of the lower part of the Gamaharazawa Formation in the Lower Jurassic Kuruma Group exposed along the Kotaki River, although they did not provide images. *Pseudoalbaillella* occurred in the Upper Carboniferous (Pennsylvanian) to the lower Permian (e.g., Holdsworth and Jones, 1980; Nazarov and Ormiston, 1986); *Pseudotormentus* occurred in the Permian (Ito et al., 2016).

Tomita et al. (2007) and Takeuchi et al. (2015b) reported Permian radiolarians (e.g., *Pseudoalbaillella* sp. cf. *P. fusiformis*) and Middle Triassic radiolarians (*Pseudostyloshaera japonica* (Nakaseko and Nishimura) and *Triassocampe* sp.) from chert clasts within the Lower Cretaceous Kurobishiyama Formation (Kobayashi et al., 1957; redefined by Takeuchi et al., 2015a).

Mudstone clasts within the Lower Cretaceous Mizukamidani Formation (Kobayashi et al., 1957; redefined by Takeuchi et al., 2015a) yielded *F. porrectus* and *Pseudoalbaillella* sp. cf. *P. fusiformis* (Tomita et al., 2007; Takeuchi et al., 2015b). These species occurred in the Guadalupian to Lopingian of the Permian (Zhang et al., 2014; Ito et al., 2015a).

Chert clasts within conglomerates of sections exposed in the right bank of the Sakaigawa

River yielded Middle to Late Triassic and Jurassic radiolarians (Ito et al., 2012); siliceous mudstone clasts within the conglomerate yielded Bajocian to early Bathonian (Middle Jurassic) radiolarians (Ito et al., 2014). Ito et al. (2012, 2014) assigned the conglomerate to the Mizukamidani Formation. However, Takeuchi et al. (2015a) designated the conglomerate section as the type locality of the middle Cretaceous Shiritakayama Formation (Yoshimura and Adachi, 1976) and redefined the formation.

Paleozoic radiolarian fossils have also occurred in several areas of the Niigata Prefecture other than the Itoigawa area (e.g., Matsumoto et al., 2001; Suzuki and Kuwahara, 2003; Uchino et al., 2010); however, all are Permian. Consequently, the radiolarians from the Itoigawa area are the first Silurian radiolarians to be identified in the Niigata Prefecture.

The radiolarians are the oldest fossils recorded in Niigata Prefecture. Previously reported Paleozoic fossil taxa from Niigata Prefecture, such as brachiopods (e.g., Hayasaka, 1918; Tazawa et al., 1983; Tazawa, 2004), foraminifers (e.g., Ueno and Nakazawa, 1993; Ichida et al., 2010), corals (e.g., Niikawa, 2001; Ibaraki et al., 2009; Ibaraki and Niko, 2012), bryozoans (e.g., Kobayashi et al., 1982; Nakazawa, 2001), and conodonts (e.g., Sato et al., 1975; Watanabe, 1975) range in age from Devonian to Permian. Although Nakamizu (1981) described occurrences of middle Paleozoic corals and trilobites from a lenticular limestone block within mélanges of the Renge terrane, detailed information and images were not provided.

Silurian fossils have been reported in some geologic units in limited areas of Japan, such as in the Kurosegawa terrane in Kochi Prefecture (e.g., Furutani, 1983; Wakamatsu et al., 1990; Umeda, 1997, 1998), the Hida-Gaien terrane in Gifu and Fukui prefectures (e.g., Furutani, 1990; Tazawa and Kaneko, 1991; Kurihara and Sashida, 2000; Kurihara, 2004, 2007), and the South Kitakami terrane in Iwate Prefecture (e.g., Kawamura et al., 1984; Ehiro et al., 1986). This study provides a new location in Japan for Silurian fossils.

Radiolarian-bearing clasts within upper Paleozoic and Mesozoic strata of the Japanese Islands and the Korean Peninsula

Radiolarian-bearing clasts have been identified in the upper Paleozoic to Mesozoic terrigenous strata of the Japanese Islands and the Korean Peninsula, such as in the Maizuru Group (Takemura et al., 1996), the Nariwa Group (Kametaka, 1997), the Choshi Group (Kashiwagi and Isaji, 2015), the Sasayama Group (Umeda et al., 1995), the Tetori Group (Saida, 1987; Ito et al., 2015b), and the Hayang Group (Chang et al., 1990; Kamata et al., 2000). The age of these clasts ranges from Permian through Cretaceous but may be as old as Carboniferous (e.g., Ishida et al., 2003; Ito et al., 2017). This study identified Silurian radiolarian-bearing clasts within conglomerate, making them the oldest radiolarian-bearing clasts within upper Paleozoic through Mesozoic strata in the Japanese Islands and the Korean Peninsula.

Concluding remarks

Limestone and mudstone pebbles and Devonian corals are present in the conglomerate examined during this study (Niko et al., 2014, 2015, 2016). Microscopic observations identified the presence of a Silurian radiolarian-bearing pebble (radiolarite) in the conglomerate. The conglomerate was probably derived from the Lower Jurassic Kuruma Group. The age of the radiolarians in the pebble implies that a geologic unit (or units) that included Silurian radiolarites, as well as younger Devonian limestones and mudstones, was exposed and eroded in the provenance of the Kuruma Group in the Kotaki area by the time the conglomerate was deposited.

Meanwhile, the source exposure for the conglomerate is unknown, which allows for the possibility that the conglomerate was derived from other geologic units. The discovery of the original bed will provide the further knowledge, such as the origin of the conglomerate and a more precise date for the time of deposition.

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SEM morphological study of clam shrimp *Diestheria* (spinicaudatan) of the Jehol Biota of China

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Abstract

Morphological re-examination under a scanning electron microscope (SEM) of the type specimens of *Diestheria longinqua* Chen, in Zhang et al., 1976 from the Lower Cretaceous Yixian Formation of the Jehol Group at Dakangpu of Yixian County, western Liaoning Province, northeastern China revealed morphological features on the carapace that had not been recognized previously: 1) growth lines with fine ridges; 2) radial lirae intercalated with small irregular reticulation on the growth bands in the postero-middle part of the carapace.

Key words: fossil clam shrimps, taxonomy, Lower Cretaceous, Yixian Formation, western Liaoning, northeastern China.

Introduction

The Upper Mesozoic in China are mainly of continental origin and contain an abundance of fossil clam shrimps, whose rapid evolution and radiation make them biostratigraphically useful in subdividing and classifying non-marine strata (Li et al., 2004, 2010, 2015, 2016a, b; Li and Matsuoka, 2012, 2013, 2015; Boukhalfa et al., 2015; Teng et al., 2016). Muroi (1940) established the Yixian Formation in the western part of Yixan County, which is extensively

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developed in northern Hebei and western Liaoning provinces of China. It is 620–3,695 m thick in western Liaoning (Wang et al., 1989), and consists mainly of volcanic rocks with lacustrine sedimentary intercalations yielding an exceptionally well-preserved Early Cretaceous Jehol Biota (Batten, 1998; Chen and Jin, 1999; Chang et al., 2003; Zhou et al., 2003). The Jehol Biota has become well-known in recent years because its beautifully preserved fossils are of evolutionary importance, such as early angiosperms (Sun et al., 1998, 2002), feathered theropod dinosaurs (Chen et al., 1998; Ji et al., 1998), early birds (Hou et al., 1995; Hou and Chen, 1999) and primitive mammals (Hu et al., 1997; Ji et al., 2002, 2009; Luo et al., 2003, 2007; Li and Luo, 2006).

The spinicaudatan *Diestheria* Chen is an important component of the diverse *Eosestheria* fauna of the Early Cretaceous Jehol Biota in northern China (Chen et al., 2007; Li et al., 2007a). In this paper a re-examination under a scanning electron microscope (SEM) of the type specimens of *Diestheria longinqua* Chen, in Zhang et al., 1976 revealed important morphological features not previously seen, as recorded below.

Material and methods

The studied two specimens are deposited in the collection of the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences (NIGPCAS). The holotype (NIGPCAS 15462) is an external mould of a left valve and the paratype (NIGPCAS 15463) is a right valve. They were originally collected from the Lower Cretaceous Yixian Formation at Dakangpu of Yixian County, western Liaoning Province, northeastern China.

Most of the previous studies on the palaeontology of fossil clam shrimps have used a light microscope (Zhang et al., 1976). This means that some morphological characters of potential taxonomic value were difficult to see clearly (Li, 2004; Li and Batten, 2004a, b, 2005; Li et al., 2006, 2007a, b, 2009, 2014, 2017). Here the authors have relied on examination of the paratype specimen using a LEO 1530 VP SEM and a Zeiss V20 stereomicroscope.

Systematic palaeontology

The classification of recent spinicaudatans of Martin and Davis (2001) is followed here. Because the genus *Cyclestheria* Sars, 1887 has been removed from the suborder Spinicaudata Linder, 1945 and is now placed in the suborder Cyclestherida Sars, 1899, which is on an equal footing with the remaining Spinicaudata and Cladocera Latreille, 1829, the order Conchostraca Sars, 1867 as a taxonomic unit has been abandoned. Thus, we follow Martin and Davis (2001) to use the order Diplostraca Gerstaecker, 1866 as a taxonomic unit.

Class: Branchiopoda Latreille, 1817
Subclass: Phyllopoda Preuss, 1951
Order: Diplostraca Gerstaecker, 1866
Suborder: Spinicaudata Linder, 1945
Superfamily: Eosestherioidea Zhang and Chen, in Zhang et al., 1976
Family: Diestheriidae Zhang and Chen, in Zhang et al., 1976
Genus: *Diestheria* Chen, in Zhang et al., 1976

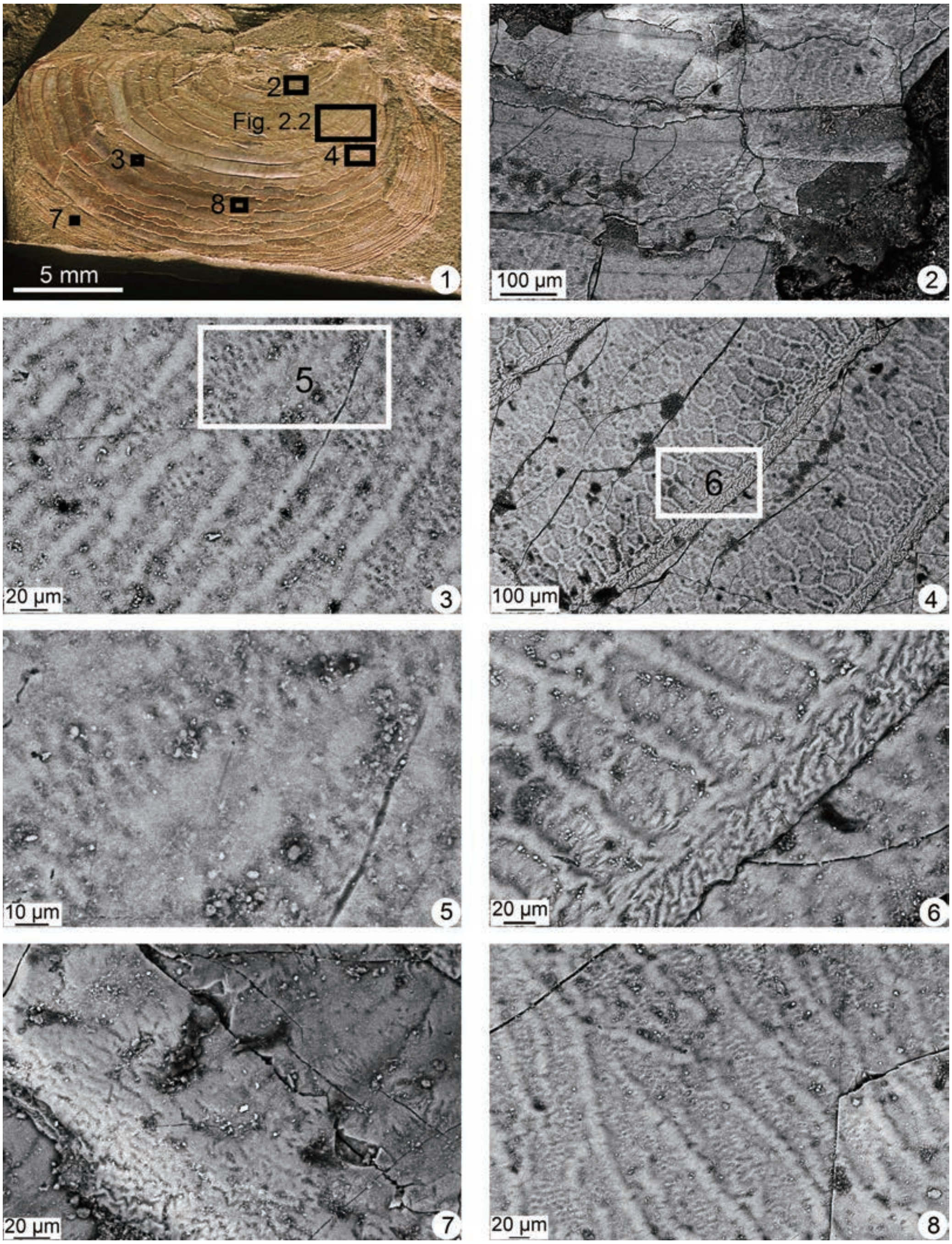
1976 *Diestheria* Chen gen. nov., in Zhang et al., p. 175.
1982 *Diestheria* Chen. Shen et al., p. 64.
1985 *Diestheria* Chen. Chen and Shen, p. 118.

Type species. Diestheria yixianensis Chen, in Zhang et al., 1976

Occurrence. Lower Cretaceous Yixian and Shahai formations, western Liaoning, northeastern China. Lower Cretaceous Chijinpu Formation, Yumen, Gansu Province; Lower Cretaceous Bayingobi Formation, Inner Mongolia, northwestern China.

Diagnosis. Carapace very large, rounded, elliptical or oval in outline, growth bands in the dorsal or in the antero-ventral parts of the carapace ornamented with medium- or large-sized irregular polygonal reticulations, which change gradually to radial lirae on the ventral or postero-ventral parts, the transition from reticulation to radial lirae could be seen on the growth bands in ventral part of the carapace, on which the upper part is ornamented with reticulation, and the lower part with radial lirae; radial lirae less than 40 within a width of 1 mm, thick and usually curved or forked; growth bands in the posterior or ventral parts of the carapace also ornamented with transversely enlarged reticulation superimposed on the radial lirae.

Discussion. Diestheria was erected by Chen (in Zhang et al., 1976) on the basis of a light microscope examination of specimens mostly collected from the Yixian Formation. This genus is widely distributed in the Lower Cretaceous in northern China (Shen et al., 1982; Chen and Shen, 1985; Fu et al., 2007). *Diestheria* is closely related to *Eosestheria*, but differs by having superimposed (overlapping) transversely elongated reticulation on radial lirae in ventral and postero-verntral parts of the carapace. Recent SEM morphological studies on the type specimens of *Eosestheria sihetunensis* Chen, 1999 and *Neodiestheria dalaziensis* Chen, in Zhang et al., 1976 have revealed new features that have not been recognized previously. *Eosestheria sihetunensis* has fine ridges and puncta within the reticulation on the dorsal and middle parts of the carapace (Li et al., 2015). *Neodiestheria dalaziensis* yields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8

puncta in the carapace, which is either evenly distributed on the growth bands of the dorsal part, or within fine reticulation and between radial lirae in the lower part of the carapace (Li et al., 2016a). The SEM re-examination of the type specimens of *Diestheria longinqua* has also found fine reticulation not recognized previously.

Diestheria longinqua Chen, in Zhang et al., 1976, emend.

Figs. 1–2

1976 *Diestheria longinqua* Chen sp. nov., in Zhang et al., p. 177.

Material. Holotype NIGPCAS 15462, an external mould of a left valve, and paratype NIGPCAS 15463, a right valve, from the Lower Cretaceous Yixian Formation of Yixian County, western Liaoning Province, northeastern China.

Dimensions of the type specimens. In order: specimen no.: number of growth lines, length of carapace (mm), height of carapace (mm): NIGPCAS 15462: >26, 23.0, 12.1; NIGPCA 15463: >20, 20.7, 10.9.

Description. Carapace is very large, which is long elliptical or oblong in outline; umbo small, located between the anterior end and the median point of the long and straight dorsal margin; growth lines more than 20 in number, ornamented with very fine ridges (Fig. 1.4, 1.6, 1.7). Growth bands in the umbonal area ornamented with small-sized irregular polygonal reticulation (Fig. 1.2), which become larger in antero-middle part of the carapace (Figs. 1.4, 2.2); reticulation gradually changes to radial lirae in the ventral part of the carapace (Figs. 1.5, 1.8, 2.4). The transition from reticulation to radial lirae could be seen on the growth bands in the middle part of the carapace, on which the upper part of each band is ornamented with reticulation, and the lower part with radial lirae (Figs. 1.4, 1.6, 2.2). The upper half of each lirae-bearing growth band in the ventral and postero-ventral parts of the carapace is ornamented with overlapping reticulations, which are manifested as large

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←**Fig. 1. 1–8**, *Diestheria longinqua* Chen, in Zhang et al., 1976, emend. All figures, except Fig. 1.1 (a light microscopy image), are SEM images of a right valve from the Lower Cretaceous Yixian Formation at Dakangpu of Yixian County, western Liaoning Province, northeastern China. **1,** paratype, NIGPCAS 15463, a right valve. **2,** irregular polygonal small-sized reticulation on growth bands near the umbo of the carapace. **3,** radial lirae intercalated with irregular small-sized reticulation on growth bands in the postero-middle part of the carapace. **4,** transition from irregular reticulation to radial lirae on growth bands in the antero-middle part of the carapace. **5,** small-sized irregular reticulation between radial lirae on a growth band in the postero-middle part of the carapace. **6,** fine ridges on the growth line, fine ridges intercalated between radial lirae. **7,** fine ridges on growth line in the postero-ventral part of the carapace. **8,** thick, forked radial lirae intercalated with fine ridges on growth bands in the ventral part of the carapace.

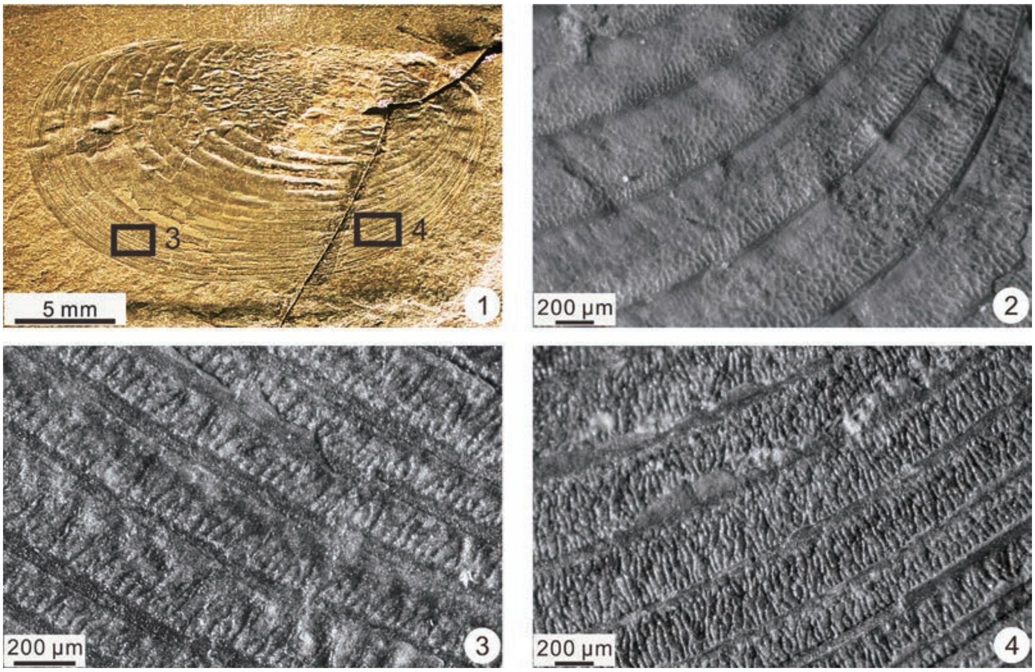

Fig. 2. 1–4, *Diestheria longinqua* Chen, in Zhang et al., 1976, emend. All are light microscopy images of the holotype and paratype specimens from the Lower Cretaceous Yixian Formation at Dakangpu of Yixian County, western Liaoning. **1,** holotype, NIGPCAS 15462, external mould of a left valve. **2,** irregular reticulation and radial lirae on the growth bands in antero-middle part of the carapace of the paratype specimen, NIGPCAS 15463. **3,** large tubercules on the upper half of each lirae-bearing growth band in the postero-ventral part of the carapace of the holotype specimen. **4,** irregular radial lirae on the external mould, the holotype NIGPCAS 15462, on the growth bands in the antero-ventral part of the carapace.

tubercles on external mould (Fig. 2.3). Radial lirae are well developed on the growth bands in the ventral part of the carapace (Figs. 1.5, 1.8, 2.4), which become fine, dense, forked, and intercalated with irregular small-sized reticulation and short ridges in the postero-ventral part of the carapace (Fig. 1.3, 1.5).

Discussion. SEM morphological re-examination of the paratype specimen (NIGPCAS 15463) of *Diestheria longinqua* revealed new features not previously seen: 1) growth lines ornamented with fine ridges; 2) radial lirae intercalated with irregular small reticulation on the growth bands in the postero-middle part of the carapace. The here discovered delicate reticulation between radial lirae is different from the evenly distributed puncta found in *Neodiestheria* (Li et al., 2016a). The specimen of the holotype (NIGPCAS 15462) is too big to be examined under an SEM. The other species of *Diestheria* is needed to be examined under an SEM in the future to recognize if this kind of irregular small reticulation is a common feature within *Diestheria*.

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Sci. Rep., Niigata Univ. (Geology), No. 32, 25–31, 2017

Middle Devonian tabulate corals from the Kotaki area, Niigata Prefecture, central Japan

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Abstract

Three species of tabulate corals were recovered from a float block of limestone collected in the Kotaki area, Itoigawa, Niigata Prefecture, central Japan. They are a pachyporid favositid *Thamnopora itoae* Niko, Ibaraki and Tazawa, 2014, an alveolitid favositid *Scoliopora hosakai* Niko, Ibaraki and Tazawa sp. nov., and a multithecoporid auloporid *Syringoporella* sp. Previously *T. itoae* was known from pebbles in Mesozoic conglomerate collected in the same area. *Scoliopora hosakai* differs from two similar species from the Qinling Mountains, China in its characters of branches and tabulae. Specific compositions of these corals suggest Middle Devonian in age for this block.

Key words: Middle Devonian, tabulate corals, *Thamnopora*, *Scoliopora*, *Syringoporella*, Kotaki area.

Introduction

This paper presents the systematic paleontology and chronological discussions of tabulate corals preserved in a float block of light gray limestone (bioclastic wackestone). This block was collected by Mr. Ryuji Hosaka at riverbed of the Kotaki River in the Kotaki area, Itoigawa, Niigata Prefecture, central Japan. Detailed collecting site is the downstream side of the Kotakigawa Hydraulic Power Plant (Denka Company Limited) near a small

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community named Senoda (see fig. 1 of Ibaraki et al., 2009, for its position on map). All specimens examined herein are kept in the Fossa Magna Museum (abbreviation: FMM).

Age

Specific compositions of tabulate corals occur within the present limestone block are *Thamnopora itoae* Niko, Ibaraki and Tazawa, 2014, *Scoliopora hosakai* Niko, Ibaraki and Tazawa sp. nov., and *Syringoporella* sp. *Thamnopora* is a cosmopolitan genus, but its undoubted stratigraphic distributions are restricted in Devonian (Hill, 1981). Furthermore, Niko et al. (2014) in the erection of *T. itoae* suggested that this species most closely resembles a Givetian (late Middle Devonian) species. *Scoliopora* ranges from the Upper Silurian to Upper Devonian in Europe and Asia (Lin et al., 1988). Two species similar with *S. hosakai* occur in the Middle Devonian of the Qinling Mountains in China. *Syringoporella* is not effective for precise age determination; the genus is widely known in the Lower to Middle Palaeozoic rocks (Lin et al., 1988). From the evidence it is concluded that the age of the block is best constrained as Middle Devonian.

Systematic Paleontology

Subclass Tabulata Milne-Edwards and Haime, 1850
Order Favositida Wedekind, 1937
Suborder Favositina Wedekind, 1937
Superfamily Pachyporoidea Gerth, 1921
Family Pachyporidae Gerth, 1921
Genus *Thamnopora* Steininger, 1831

Type species.—*Thamnopora madreporacea* Steininger, 1831.

Thamnopora itoae Niko, Ibaraki and Tazawa, 2014
Figs. 1-1, 2

Thamnopora itoae Niko, Ibaraki and Tazawa, 2014, p. 61, 63, figs. 2-1–3, 4-1–6.

Material.—FMM6223–6233.

Discussion.—A full description of *Thamnopora itoae* is referable in Niko et al. (2014). The types of this species were recovered from limestone pebbles in a float block of conglomerate derived probably from the Lower Jurassic Kuruma Group. Collecting site of this block is riverbed of the Kotaki River in the Kotaki area.

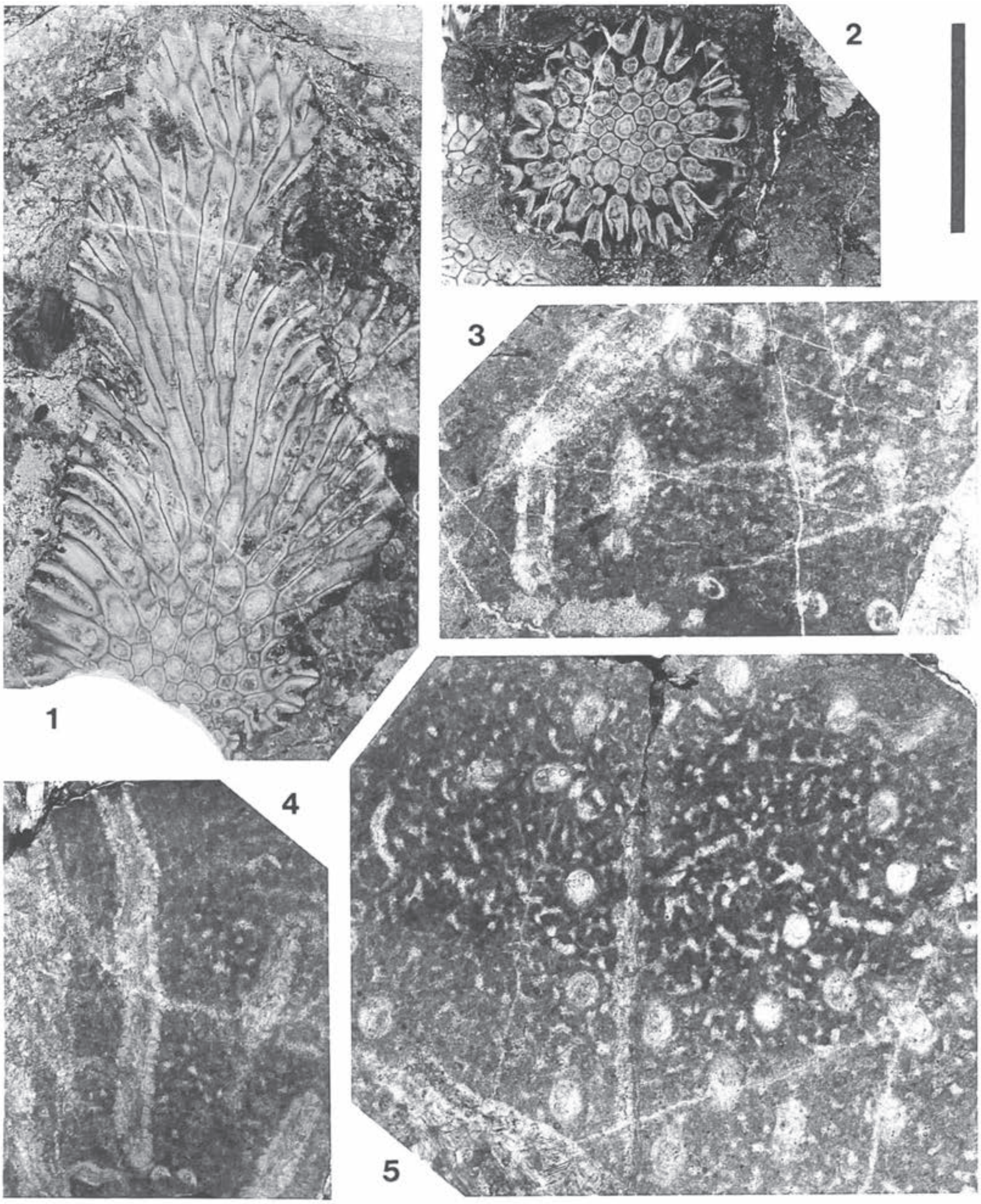

Fig. 1. **1, 2**: *Thamnopora itoae* Niko, Ibaraki and Tazawa, 2014, thin sections. 1, FMM6231, longitudinal section of branch; 2, FMM6232, transverse section of branch. **3–5**: *Syringoporella* sp., thin sections. 3, FMM6219, longitudinal to transverse sections of corallites; 4, FMM6221, longitudinal sections of corallites; 5, FMM6216, transverse sections of corallites. Scale bar = 6 mm for Figs. 1-1, 2; 3 mm for Figs. 1-3–5.

Suborder Alveolitina Sokolov, 1950

Family Alveolitidae Duncan, 1872

Subfamily Natalophyllinae Sokolov, 1950

Genus *Scoliopora* Lang, Smith and Thomas, 1940

Type species.—*Alveolites denticulatus* Milne-Edwards and Haime, 1851.

Scoliopora hosakai sp. nov.

Figs. 2-1–6

Etymology.—The specific name honors Mr. Ryuji Hosaka, who collected the examined limestone block containing this new species.

Material.—Holotype, FMM6222, from which six thin sections were prepared.

Diagnosis.—Species of *Scoliopora* having branch diameters of 5–12 mm; corallites up to 0.84 mm in diameter; intercorallite wall thickness 0.15–0.31 mm in peripheral zone; septal spines short conical; tabulae very rare.

Description.—Corallum ramose with subcylindrical branches, cerioid-like in axial zone and alveolitoid in peripheral zone of branches; branching probably bifurcate; diameters of branches are 5–12 mm; total corallum diameter and growth form unknown. Corallites subcylindrical, slender, and consist of longitudinally directed proximal portion with indistinct polygonal to fan-shaped transverse sections and outwardly curved distal portion with hemicircular to elliptical transverse sections; diameters of proximal corallites are 0.21–0.50, 0.25 × 0.38, 0.42 × 0.52 mm, then they gradually increase to 0.63 × 0.36, 0.67 × 0.33, 0.84 × 0.61 mm in distal ones; proximal and distal portions of corallites respectively form axial and peripheral zones of branch; tabularia (lumina) have subcircular transverse sections, and shift to very deep calices that open obliquely upwards to nearly perpendicular for branch surface; increases of new corallites are lateral, and frequently occur at axial zone. Intercorallite walls differentiated into median dark line and stereoplasm; thickness of walls is relatively thin for the genus, 0.07–0.17 mm in axial and 0.15–0.31 mm in peripheral zones; mural pores well developed, situate on narrow sides of corallite faces near angles, having longitudinally elongated to circular profiles; diameters of pores are 0.14 × 0.20, 0.21 × 0.29, 0.15–0.25 mm; septal spines well developed, short conical with 0.08–0.15 mm in length; tabulae very rarely developed at peripheral zone, complete.

Discussion.—The Kotaki specimen places within *Scoliopora* rather than *Natalophyllum* Radugin (1938; type species, *N. giveticum* Radugin, 1938) because of its ramose corallum, slender corallites and well developed septal spines. This discovery represents the first record of the genus in Japan.

Scoliopora hosakai sp. nov. is similar to *S. gansuensis* Zhang (1981, p. 142, pl. 75, figs. 1a, b) and *S. obliqueformis* Zhang (1981, p. 143, pl. 74, figs. 4a, b) both from the Middle Devonian of

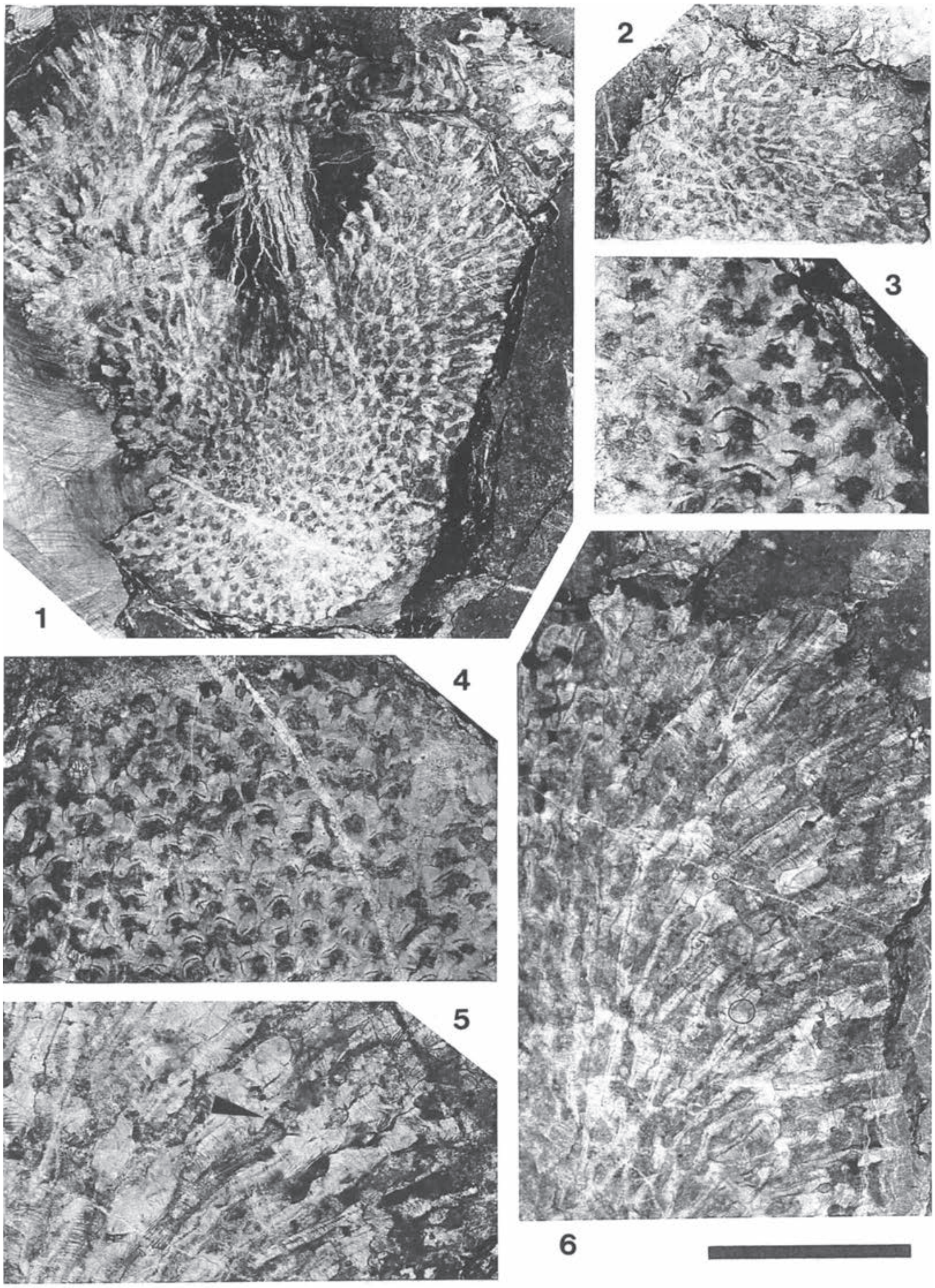

Fig. 2. 1–6: *Scoliopora hosakai* Niko, Ibaraki and Tazawa sp. nov., holotype, FMM6222, thin sections. 1, oblique section of corallum; 2, transverse (slightly oblique) section of branch; 3, transverse sections of distal corallites; 4, transverse sections of proximal to distal corallites; 5, longitudinal sections of distal corallites, arrow indicates tabula; 6, longitudinal sections of proximal to distal corallites. Scale bar = 6 mm for Figs. 2-1, 2; 2.1 mm for Figs. 2-3, 5; 3 mm for Figs. 2-4, 6.

the Qinling Mountains, Gansu Province, China. However, the new species differs from these Chinese species in having slightly larger diameters of the branches and fewer tabulae.

Order Auloporida Sokolov, 1947
Superfamily Syringoporoidea Fromentel, 1861
Family Multithecoporidae Sokolov, 1950
Genus *Syringoporella* Kettner, 1934

Type species.—*Syringopora moravica* Roemer, 1883.

Syringoporella sp.
Figs. 1-3–5

Material.—FMM6216–6221.

Description.—Coralla phaceloid, occur inside stromatoporoids. Corallites cylindrical and very narrow, 0.44–0.56 mm in diameter; connecting tubuli are relatively rare. Thickness of corallite walls is variable, ranging from 0.07 to 0.25 mm; septal element and tabula are not observed.

Discussion.—Three (or four) species of *Syringoporella* were previously known from the Silurian to Devonian rocks in Japan, namely *S. fujiwarai* Niko and Senzai, 2006, *S. yamakoshii* Niko, 2001a, *S.* sp. (Niko, 2001b), and *S.*? sp. (Niko and Adachi, 2004). The present fragmentary specimens cannot be compared with these species, owing to their poor state of preservation.

Acknowledgments

We would like to express our sincere gratitude to Mr. Ryuji Hosaka, who donated examined tabulate coral specimens herein to the Fossa Magna Museum. We also thank Drs. Atsushi Matsuoka and Isao Niikawa for their incisive reviews of an earlier version in this paper.

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Spinomarginifera and *Waagenoconcha* (Productida, Brachiopoda) from the middle Permian (Wordian–Capitanian) of the South Kitakami Belt, Japan

Jun-ichi TAZAWA*

Abstract

This paper describes five species of two productoid brachiopod genera, *Spinomarginifera* and *Waagenoconcha*, from the middle Permian (Wordian–Capitanian) of the Kamiyasse–Imo area, South Kitakami Belt, northeastern Japan. Cooccurrence of a tropical genus *Spinomarginifera* and an antitropical genus *Waagenoconcha* from the middle Permian of the South Kitakami Belt suggests that the South Kitakami region was located in the transitional zone between the Boreal and Tethyan realms, immediately east of North China (Sino-Korea) in the middle Permian.

Key words: Brachiopoda, middle Permian, South Kitakami Belt, *Spinomarginifera, Waagenoconcha.*

Introduction

This paper describes five productoid brachiopod species belonging two genera (*Spinomarginifera* and *Waagnoconcha*) from the Kamiyasse Formation (Wordian–Capitanian) of the Kamiyasse–Imo area, South Kitakami Belt, northeastern Japan. The species are as follows: *Spinomarginifera lopingensis* (Kayser, 1883), *Spinomarginifera kueichowensis* Huang, 1932, *Spinomarginifera alpha* Huang, 1932, *Waagenoconcha humboldti* (d'Orbigny, 1842) and *Waagenoconcha irginae* (Stuckenberg, 1898). Cooccurrence of *Spinomarginifera* and *Waaagenoconcha* from the middle Permian of the South Kitakami Belt is strong additional

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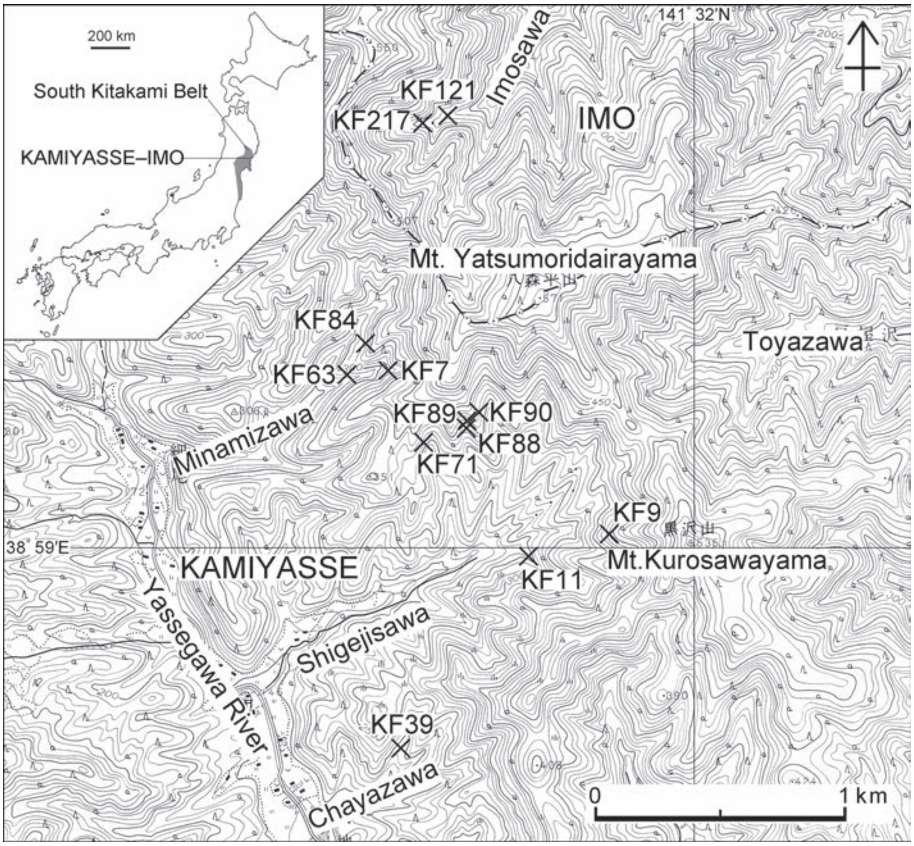

Fig. 1. Map showing the fossil localities KF7, KF9, KF11, KF39, KF63, KF71, KF84, KF88, KF89, KF90, KF121 and KF217 in the Kamiyasse–Imo area, South Kitakami Belt (using the topographic map "Shishiori" scale 1:25,000, published by the Geospatial Information Authority of Japan).

evidence for that the middle Permian brachiopod fauna of the South Kitakami Belt is a mixture of both Boreal and Tethyan elements, and for that the South Kitakami region was placed in the transitional zone between the Boreal and Tethyan realms, immediately east of North China (Sino-Korea) in the middle Permian.

Spinomarginifera was established by Huang (1932) with *Spinomarginifera kueichowensis* Huang, 1932, from the upper Permian (Wuchiapingian) of Guizhou, southwestern China, as type species. The genus is small- to medium-sized productoid, with numerous spine bases on both ventral and dorsal valves and a prominent marginal ridge in dorsal valve, and distributed in the middle to upper Permian (Roadian–Changhsingian) of the Tethyan region, mostly of South China. In Japan four species of the genus have been described from the middle and upper Permian of the South Kitakami Belt, northeastern Japan (Nakamura, 1959; Tazawa, 2012), from the upper Permian of the Maizuru Belt, southwestern Japan (Shimizu, 1961), from the upper Permian of the Kurosegawa Belt, southwestern Japan (Yanagida, 1973), and from the middle Permian of Hitachi (southern extension of the South Kitakami

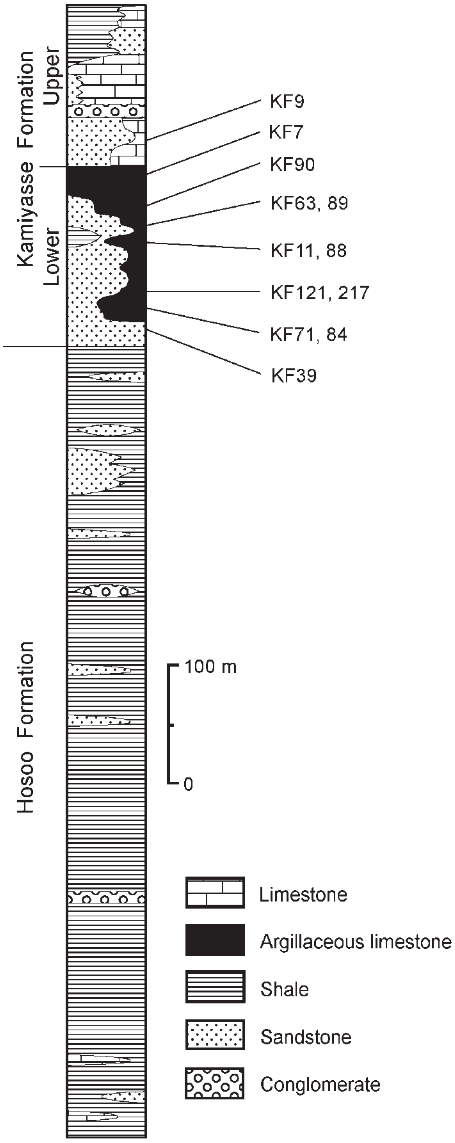

Fig. 2. Generalized columnar section of the middle Permian in the Kamiyasse–Imo area, South Kitakami Belt, showing the fossil horizons KF7, KF9, KF11, KF39, KF63, KF71, KF84, KF88, KF89, KF90, KF121 and KF217 (adapted from Tazawa, 2016).

Belt), central Japan (Tazawa et al., 2014; Tazawa, 2015).

Waagenoconcha was established by Chao (1927) with *Productus humboldti* d'Orbigny, 1842, from the lower Permian of Yarbichambi, Bolivia, as type species. The genus is medium- to large-sized productoid, with numerous quincunxially arranged spine bases on both valves, and distributed in the lower Carboniferous (Visean) to upper Permian (Changhsingian), mostly in the lower to middle Permian, of both Boreal and Gondwanan regions. In Japan five species of the genus have been described from the lower Carboniferous of the Akiyoshi Belt, southwestern Japan (Minato and Kato, 1963), from the lower and middle Permian of the South Kitakami Belt, northeastern Japan (Tazawa, 1974;

Tazawa and Ibaraki, 2001; Tazawa and Shintani, 2010, 2014, 2015; Tazawa and Araki, 2016), from the middle Permian of the Hida Gaien Belt, central Japan (Tazawa, 2001), and from the upper Permian of Mizukoshi (southwestern extension of the Hida Gaien Belt), central Kyushu, southwestern Japan (Tazawa, 2008).

The brachiopod specimens described herein were collected by Koji Nakamura and by the present author. The materials are now registered and housed in the Hokkaido University Museum, Sapporo, Japan (with the prefix UHR) and the Department of Geology, Niigata University, Niigata, Japan (with the prefix NU-B).

Stratigraphy

Stratigraphy of the Permian rocks of the Kamiyasse–Imo area has been studied by Shiida (1940), Kambe and Shimazu (1961), Tazawa (1973, 1976), Misaki and Ehiro (2004) and Shiino et al. (2011). The middle Permian rocks in the Kamiyasse–Imo area is subdivided into the lower, Hosoo Formation (400–500 m thick) and the upper, Kamiyasse Formation (150–250 m thick). The lower part of the Kamiyasse Formation consists of sandstone and argillaceous limestone with subordinate shale and conglomerate, and the upper part of the Kamiyasse Formation is composed of sandstone and limestone with subordinate shale and conglomerate. The age of the lower Kamiyasse Formation is assigned to a Wordian based on ammonoids (Ehiro and Misakai, 2005) and brachiopods (Tazawa, 2014), and the upper Kamiyasse Formation is assigned to a Capitanian by fusulinids (Tazawa, 1976; Kobayashi et al., 2009). The brachiopods treated in this study were collected from sandstone and argillaceous limestone of the lower Kamiyasse Formation at eleven sampling localities (KF7, KF11, KF39, KF63, KF71, KF84, KF88, KF89, KF90, KF121 and KF217), and from sandstone of the upper Kamiyasse Formation at one locality (KF9). The fossil localities and horizons are summarized below and indicated in Figs. 1, 2.

KF7: Upper Minamizawa Valley (38°59′23″N, 141°31′08″E), float of dark grey argillaceous limestone of the lower Kamiyasse Formation, with *Spinomarginifera lopingensis*.

KF9: Upper Shigejisawa Valley (38° 59′ 02″ N, 141° 31′ 44″ E), outcrop of greenish grey fine-grained sandstone of the upper Kamiyasse Formation, with *Waagenoconcha irginae*.

KF11: Upper Shigejisawa Valley (38° 58′ 59″ N, 141° 30′ 31″ E), outcrop of dark grey argillaceous limestone of the lower Kamiyasse Formation, with *Waagenoconcha irginae*.

KF39: Upper Chayazawa Valley (38°58′35″N, 141°31′10″E), outcrop of greenish grey fine-grained sandstone of the lower Kamiyasse Formation, with *Waagenoconcha irginae*.

KF63: Upper Minamizawa Valley (38° 59′ 22″ N, 141° 31′ 02″ E), float of greenish grey fine-grained sandstone of the lower Kamiyasse Formation, with *Spinomarginifera kueichowensis*.

Stage / Species	Gzhelian (Carboniferous)	Permian								
		Asselian	Sakmarian	Artinskian	Kungurian	Roadian	Wordian	Capitanian	Wuchiapingian	Changhsingian
Spinomarginifera lopingensis							━	━	━	━
Spinomarginifera kueichowensis							━	━	━	━
Spinomarginifera alpha							━	━	━	━
Waagenoconcha humboldti	━	━	━	━	━	━	━	━		
Waagenoconcha irginae		━	━	━	━	━	━	━		

Fig. 3. Stratigraphic distribution of *Spinomarginifera lopingensis, S. kueichowensis, S. alpha, Waagenoconcha humboldti* and *W. irginae*.

KF71: Upper Shigejisawa Valley (38° 59′ 13″ N, 141° 31′ 10″ E), float of greenish grey fine-grained sandstone of the lower Kamiyasse Formation, with *Spinomarginifera kueichowensis*.

KF84: Upper Minamizawa Valley (38° 59′ 26″ N, 141° 31′ 04″ E), float of dark grey argillaceous limestone of the lower Kamiyasse Formation, with *Spinomarginifera kueichowensis*.

KF88: Upper Shigejisawa Valley (38° 59′ 15″ N, 141° 31′ 22″ E), float of dark grey argillaceous limestone of the lower Kamiyasse Formation, with *Spinomarginifera kueichowensis*.

KF89: Upper Shigejisawa Valley (38° 59′ 16″ N, 141° 31′ 22″ E), float of greenish grey fine-grained sandstone of the lower Kamiyasse Formation, with *Spinomarginifera alpha*.

KF90: Upper Shigejisawa Valley (38° 59′ 14″ N, 141° 31′ 23″ E), outcrop of greenish grey fine-grained sandstone of the lower Kamiyasse Formation, with *Spinomarginifera lopingensis, Spinomarginifera kueichowensis* and *Spinomarginifera alpha*.

KF121: Upper Imosawa Valley (38° 59′ 55″ N, 141° 31′ 18″ E), float of greenish grey fine-grained sandstone of the lower Kamiyasse Formation, with *Waagenoconcha humboldti*.

KF217: Upper Imosawa Valley (38° 59′ 55 ″ N, 141° 31′ 14″ E), outcrop of greenish grey fine-grained sandstone of the lower Kamiyasse Formation, with *Spinomarginifera lopingensis, Spinomarginifera kueichowensis, Spinomarginifera alpha* and *Waagenoconcha humboldti*.

Palaeobiogeograpical importance of *Spinomarginifera* and *Waagenoconcha*

Stratigraphic and geographic distributions of the five species of *Spinomarginifera* and *Waagenoconcha* are summarized as follows and shown in Fig. 3 and Figs. 4, 5, respectively.

Spinomarginifera lopingensis is known from the Wordian to Changhsingian of

Region / Species	Japan					N. Russia					W. Russia	C. Russia		NW. China		N. China	NE. China	E. Russia	E. China				CS. China				SW. China				
	1. South Kitakami Belt	2. Hitachi (S. Kitakami B.)	3. Hida Gaien Belt	4. Maizuru Belt	5. Spitsbergen	6. Kanin Peninsula	7. Timan	8. Pechora Basin	9. Northern Urals	10. Kolyma	11. Moscow Basin	12. Southern Urals	13. Southern Mongolia	14. Qinghai	15. Gansu	16. Inner Mongolia	17. Jilin	18. South Primorye	19. Jiangsu	20. Anhui	21. Zhejiang	22. Jiangxi	23. Hubei	24. Hunan	25. Guangdong	26. Guangxi	27. Guizhou	28. Sichuan	29. Yunnan	30. Tibet	31. Bolivia
Spinomarginifera lopingensis	+													+		+		+	+	+	+	+	+	+	+	+	+	+	+	+	
Spinomarginifera kueichowensis	+	+		+													+				+		+	+	+	+	+	+			
Spinomarginifera alpha	+																				+			+	+	+	+	+		+	
Waagenoconcha humboldti	+						+	+			+				+	+		+													+
Waagenoconcha irginae	+		+		+	+	+	+	+	+		+	+			+		+													

Fig. 4. Geographic distribution of *Spinomarginifera lopingensis, S. kueichowensis, S. alpha, Waagenoconcha humboldti* and *W. irginae*.

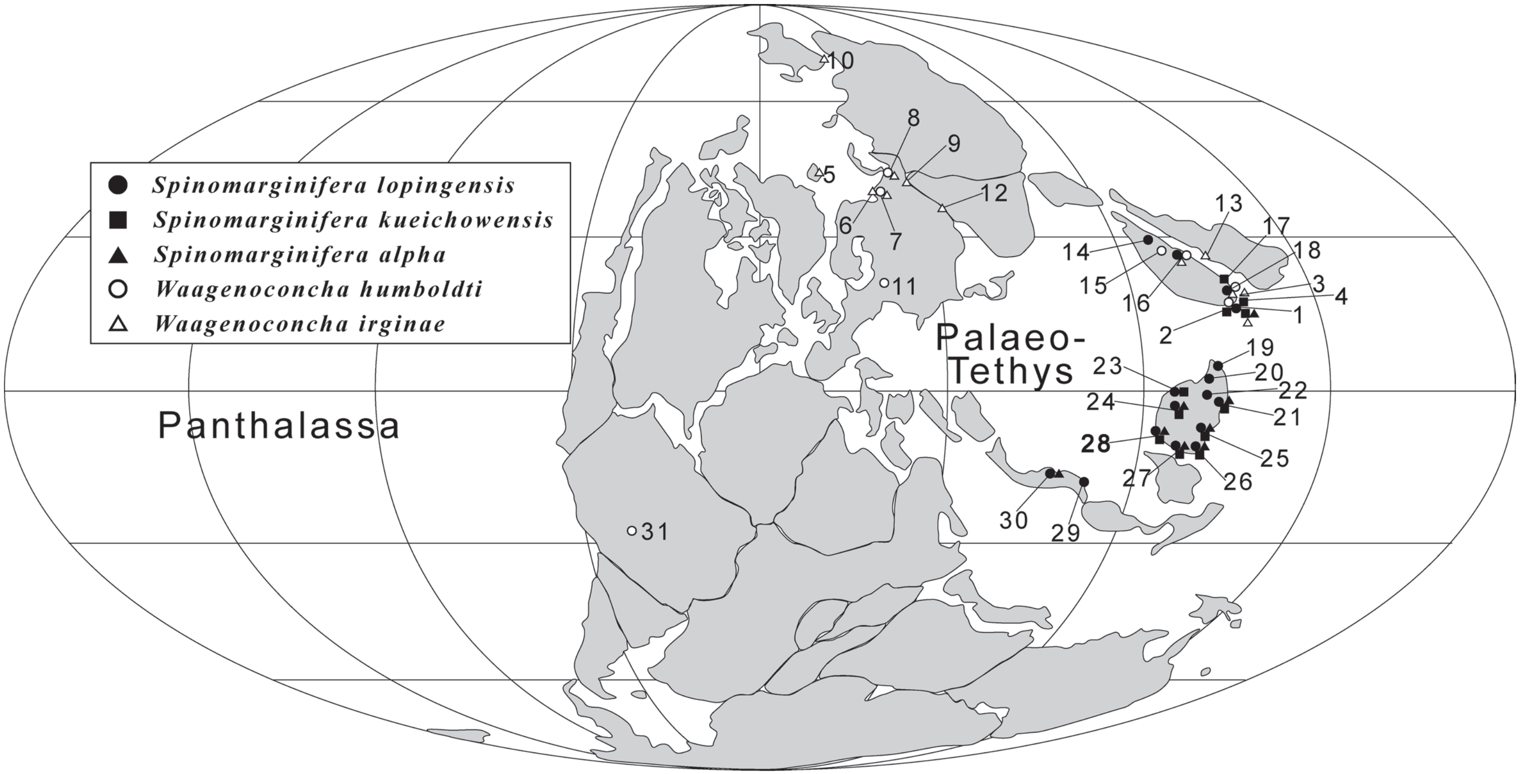

Fig. 5. Middle Permian (Wordian–Capitanian) reconstruction map of the world showing geographic distribution of *Spinomarginifera lopingensis, S. kueichowensis, S. alpha, Waagenoconcha humboldti* and *W. irginae* (adapted from Scotese, 2004). Location numbers are same in Fig. 4.

northwestern China (Qinghai), northern China (Inner Mongolia), eastern Russia (South Primorye), northeasteran Japan (South Kitakami Belt), eastern China (Jiangsu, Zhejiang, Anhui and Jiangxi), central-southern China (Hubei, Hunan, Guangdong and Guangxi) and southwestern China (Guizhou, Sichuan, Yunnan and Tibet); *Spinomarginifera kueichowensis* is known from the Wordian to Changhsingian of northeastern China (Jilin), northeastern Japan (South Kitakami Belt), central Japan (Hitachi, southern extension of the South Kitakami Belt), southwestern Japan (Maizuru Belt), eastern China (Zhejiang), central-southern China (Hubei, Hunan, Guangdong and Guangxi) and southwestern China (Guizhou and Sichuan); and *Spinomarginifera alpha* is known from the Wordian to Changhsingian of northeastern Japan (South Kitakami Belt), eastern China (Zhejiang), central-southern China (Hunan, Guangdong and Guangxi) and southwestern China (Guizhou, Sichuan and Tibet).

Waagenoconcha humboldti is known from the Gzhelian to Capitanian of northern Russia (Timan and Pechora Basin), western Russia (Moscow Basin), northwestern China (Gansu), northern China (Inner Mongolia), eastern Russia (South Primorye), northeastern Japan (South Kitakami Belt) and Bolivia; and *Waagenoconcha irginae* is known from the Asselian to Capitanian of Spitsbergen, northern Russia (Pechora Basin, northern Urals and Kolyma), central Russia (southern Urals), southern Mongolia, northern China (Inner Mongolia), eastern Russia (South Primorye), northeastern Japan (South Kitakami Belt) and central Japan (Hida Gaien Belt).

In palaeobiogeographical terms, *Spinomarginifera* is a tropical genus, whereas *Waagenoconcha* is an antitropical genus. Therefore, the middle Permian (Wordian–Capitanian) brachiopod fauna of the Kamiyasse–Imo area is a mixed Boreal–Tethyan fauna. In addition, coocurrence of both *Spinomarginifera* and *Waagenoconcha* is restricted to the area including northern China (Inner Mongolia), eastern Russia (South Primorye), central Japan (Hida Gaien Belt) and northeastern Japan (South Kitakami Belt), i.e., the northern and eastern margin of North China (Sino-Korea). This conclusion supports the previous opinion of Tazawa (1993, 1998, 2002, 2007) that the South Kitakami region was located in the transitional zone between the Boreal and Tethyan realms, i.e., Inner Mongolian–Japanese Transition Zone of Tazawa (1991) [=Sino-Mongolian–Japanese Province of Shi and Tazawa (2001)].

Systematic descriptions

Order Productida Sarytcheva and Sokolskaya, 1959
Suborder Productidina Waagen, 1883
Superfamily Productoidea Gray, 1840
Superfamily Marginiferoidea Stehli, 1954
Family Costispiniferidae Muir-Wood and Cooper, 1960

Subfamily Spinomarginiferinae Waterhouse, 2002
Genus *Spinomarginifera* Huang, 1932

Type species.—*Spinomarginifera kueichowensis* Huang, 1932.

Spinomarginifera lopingensis (Kayser, 1883)
Fig. 6

Productus nystianus var. *lopingensis* Kayser, 1883, p. 187, pl. 28, figs. 1–5.

Productus (Marginifera) helicus var. Frech, 1911, p. 130, pl. 19, figs. 1–3.

Marginifera lopingensis (Kayser): Chao, 1927, p. 153, pl. 16, figs. 8–12.

Spinomarginifera kueichowensis Huang: Nakamura, 1959, p. 143, pl. 15, fig. 1 only; Minato et al., 1979, pl. 63, fig. 1 only.

Spinomarginifera lopingensis (Kayser): Zhang and Ching, 1961, p. 412, pl. 4, figs. 26–33; Wang et al., 1964, p. 312, pl. 49, figs. 21–23; Yang et al., 1977, p. 349, pl. 139, fig. 5; Tong, 1978, p. 222, pl. 79, fig. 6; Licharew and Kotlyar, 1978, pl. 15, figs. 9, 10; Zhan, 1979, p. 80, pl. 5, figs. 17, 18; Liao, 1980, pl. 5, figs. 35–39; Wang et al., 1982, p. 219, pl. 92, figs. 1, 2; Wang, 1984, p. 187, pl. 80, fig. 16; Yang, 1984, p. 217, pl. 33, fig. 4; Liao, 1987, pl. 5, figs. 5, 7–18; Zeng et al., 1995, pl. 9, fig. 1; Shen et al., 2002, p. 677, figs. 4.32, 4.33, 5.1–5.4; He et al., 2008, p. 812, figs. 4.1–4.10; Li and Shen, 2008, p. 315, figs. 4.17–4.19, 6.1–6.7; Shen and Zhang, 2008, figs. 4.13–4.19; Shen and Shi, 2009, p. 157, figs. 3P–3X; Tazawa, 2012, p. 20, figs. 4.1–4.3.

Spinomarginifera lopingensis (Chao): Jin et al., 1985, p. 194, pl. 9, figs. 3–9; Jin, 1985, pl. 7, figs. 5, 16, 18, 20.

Spinomarginifera lopingensis Huang: Liao and Xu, 2002, pl. 1, figs. 28–33.

Spinomarginifera huangi Wang and Zhang, 2003, p. 73, pl. 21, fig. 12 only.

Material.—Six specimens from localities KF7, KF90 and KF217: (1) external and internal moulds of two conjoined shells, UHR12642, 30077; (2) internal moulds of two conjoined shells, with external moulds of the ventral valves, NU-B2021, 2022; and (3) external moulds of two dorsal valves, NU-B2023, 2024.

Description.—Shell medium in size for genus, transversely subquadrate in outline, with greatest width at hinge; length about 19 mm, width about 32 mm in the best preserved specimen (UHR12642). Ventral valve strongly and unevenly convex in lateral profile, most convex at umbonal region, gently convex on visceral disc, strongly geniculated at anterior margin of visceral disc, and followed by long trail; umbo rounded, incurved beyond hinge; ears moderately large; sulcus broad and shallow; lateral slopes steep. Dorsal valve almost flat on visceral disc, strongly geniculated at anterolateral margins, and followed by short trail. External surface of ventral valve ornamented with numerous fine spine bases and fine

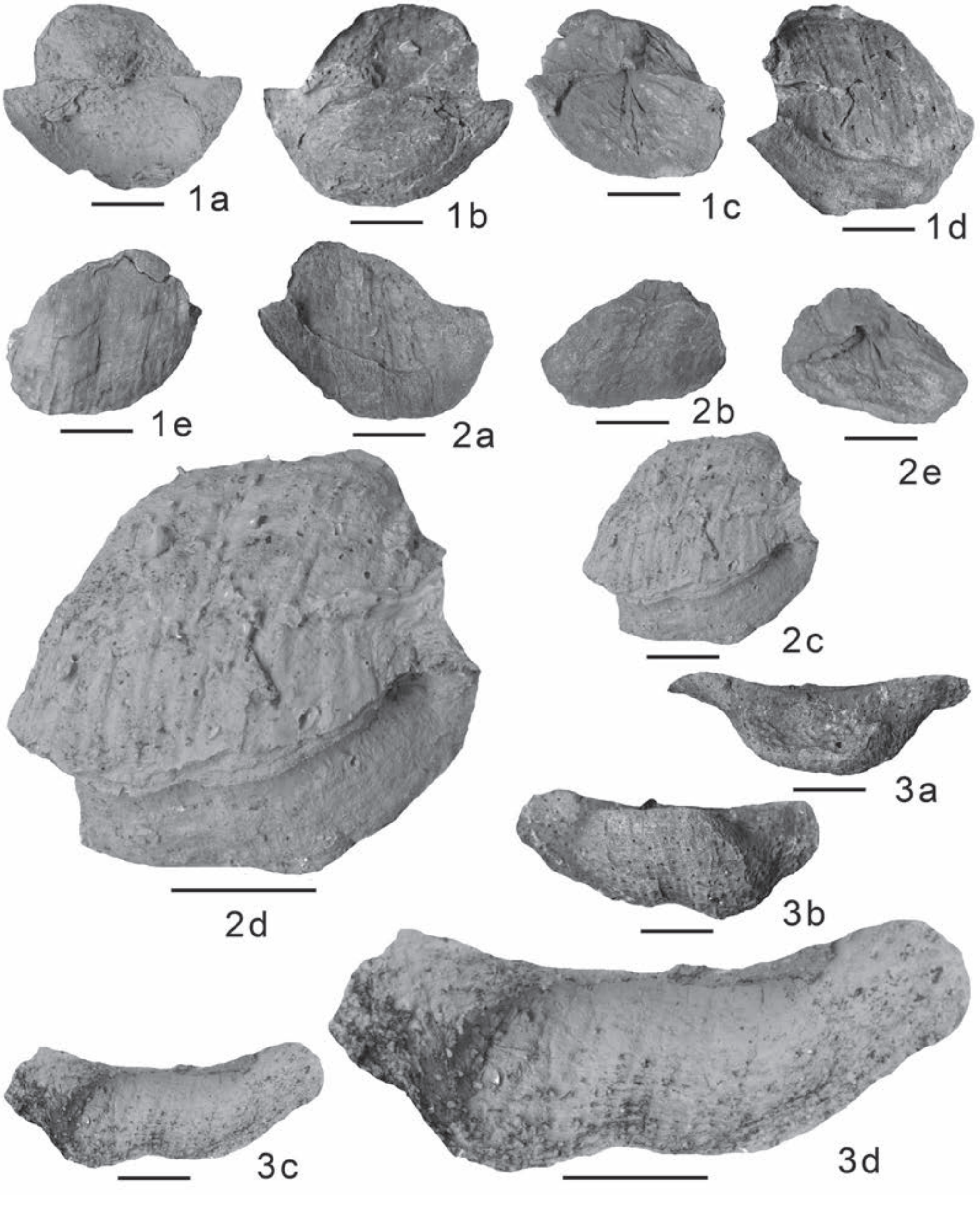

Fig. 6. 1–3, *Spinomarginifera lopingensis* (Kayser): 1, dorsal views of external latex cast (1a), external mould (1b) and internal mould (1c), and ventral views of external mould (1d) and internal mould (1e) of conjoined shell, UHR12642; 2, ventral views of external mould (2a), internal mould (2b) and external latex cast (2c, 2d), and dorsal view of internal mould (2e) of conjoined shell, NU-B2021; 3, dorsal view (3a) and anterior view (3b) of external mould, and external latex cast (3c, 3d) of dorsal valve, NU-B2023. Scale bars represent 1 cm.

concentric rugae on visceral disc, and numerous prominent costae on trail. External ornament of dorsal valve same as opposite valve. Dorsal interior with a small bilobate cardinal process, a long median septum extending to half shell length, and pear-shaped adductor scars on both sides of median septum; lateral ridges slightly diverging towards anterior; marginal ridge strongly developed around visceral disc; brachial ridges occurring anteriorly.

Remarks.—These specimens are referred to *Spinomarginifera lopingensis* (Kayser, 1883), originally described from the upper Permian of Loping, Jiangxi Province, southwestern China, by their medium size and in having prominent costae on the trails of both valves. *Spinomarginifera kueichowensis* Huang (1932, p. 56, pl. 5, figs. 1–11), from the upper Permian (Wuchiapingian) of Guizhou, southwestern China, differs from *S. lopingensis* in lacking radial costae on both ventral and dorsal valves.

Distribution.—Wordian–Changhsingian: northeastern Japan (Kamiyasse–Imo and Nabekoshiyama in the South Kitakami Belt), northwestern China (Qinghai), northern China (Inner Mongolia), eastern Russia (South Primorye), eastern China (Jiangsu, Anhui, Zhejiang and Jiangxi), central-southern China (Hubei, Hunan, Guangdong and Guangxi) and southwestern China (Guizhou, Sichuan and Yunnan) and Tibet.

Spinomarginifera kueichowensis Huang, 1932

Fig. 7

Spinomarginifera kueichowensis Huang, 1932, p. 56, pl. 5, figs. 1–11; Nakamura, 1959, p. 143, pl. 15, figs. 2–4 only; Muir-Wood and Cooper, 1960, p. 65, figs. 15–22, 24; Wang et al., 1964, p. 316, pl. 51, figs. 9–11; Jin et al., 1974, p. 312, pl. 164, fig. 13; Tazawa, 1976, pl. 2, fig. 1; Feng and Jiang, 1978, p. 252, pl. 89, figs. 5, 6; Minato et al., 1979, pl. 63, fig. 2 only; Zhan, 1979, p. 80, pl. 11, figs. 14–17, 20; Liao, 1980, pl. 4, fig. 29; Liu et al., 1982, p. 184, pl. 131, figs. 8–10; Wang, 1984, p. 187, pl. 74, fig. 16; pl. 76, fig. 3; Zeng et al., 1995, pl. 5, fig. 10; Tazawa, 2002, fig. 10.11; Chen in Chen et al., 2006, p. 314, fig. 8, table 2; Shen and Shi, 2009, p. 158, figs. 3DD, 3EE, 4I; Tazawa et al., 2014, p. 381, fig. 2.10; Tazawa, 2015, p. 67, fig. 6.10.

Spinomarginifera nipponica Shimizu, 1961, p. 244, pl. 8, figs. 1–20; pl. 9, figs. 14–16.

Spinomarginifera cf. *kueichowensis* Huang: Lee et al., 1980, p. 357, pl. 165, fig. 11; pl. 166, fig. 25; Gu, 1992, p. 224, pl. 69, fig. 6.

Material.—Twelve specimens from localities KF63, KF71, KF84, KF88, KF90 and KF217: (1) external and internal moulds of a conjoined shell, NU-B2017; (2) internal moulds of two conjoined shells, with external mould of the ventral valves, UHR12584, 30074; (3) external and internal moulds of four dorsal valves, NU-B2018, 2019, 2020, UHR30071; and (4) external moulds of five dorsal valves, UHR11554, 12368, 30068, 30080, 30082.

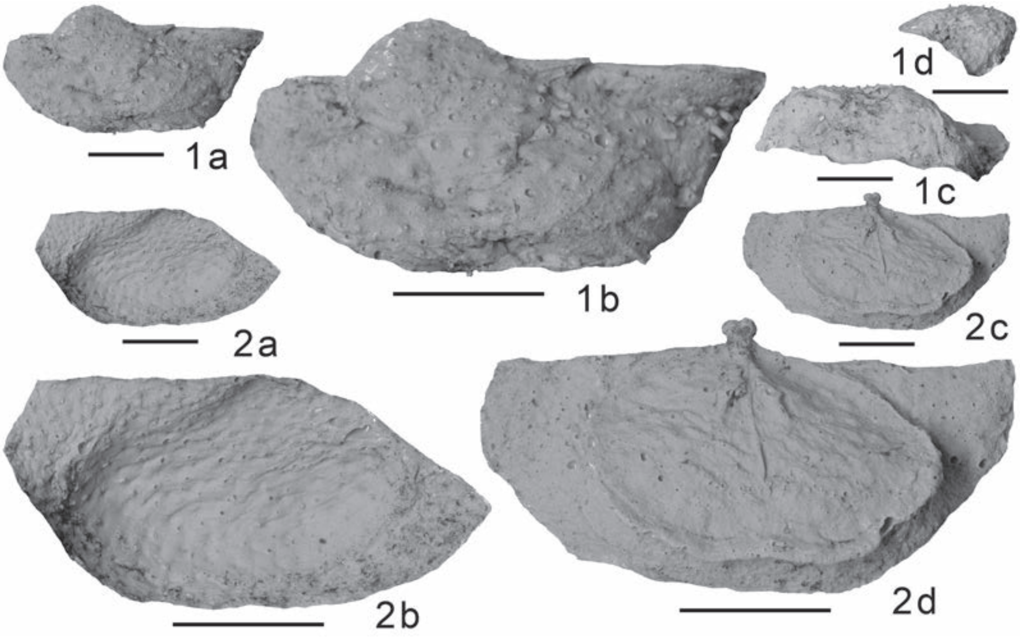

Fig. 7. 1, 2, *Spinomarginifera kueichowensis* Huang: 1, ventral view (1a, 1b), anterior view (1c) and lateral view (1d) of ventral valve, UHR30074; 2, external latex cast (2a, 2b) and internal latex cast (2c, 2d) of dorsal valve, UHR30071. Scale bars represent 1 cm.

Description.—Shell medium in size for genus, transversely subquadrate in outline, with greatest width at hinge; length 18 mm, width about 38 mm in the largest specimen (UHR30074). Ventral valve strongly and unevenly convex in lateral profile, most convex at umbonal region, gently geniculated, and followed by long trail; umbo slightly incurved beyond hingeline; ears large, triangular, slightly convex; sulcus wide and shallow; lateral slopes steep. Dorsal valve flattened on visceral disc, strongly geniculated, and followed by long trail; no fold. External surface of ventral valve ornamented with weak, irregular concentric rugae and numerous spines; spine bases quincunxially arranged on visceral region, and crowded on ears. External ornament of dorsal valve same as ventral valve, but spine bases smaller and not crowded on ears. Dorsal interior with a short bilobate cardinal process, a long median septum extending to two-thirds length of visceral disc, a pair of lateral ridges diverging from hinge, curving inside ears and connected to marginal ridges developed around anterolateral margins of visceral disc; brachial ridges well preserved in some specimens; anterior adductor scars smooth, pear-shaped, diverging and elevated, but posterior adductor scars smaller and not elevated.

Remarks.—These specimens are referred to *Spinomarginifera kueichowensis* Huang, 1932, from the upper Permian (Wuchiapingian) of Guizhou, southwestern China, in their medium size, transverse outline, numerous spine bases on the ventral valve and strongly developed marginal ridge in the dorsal valve. *Spinomarginifera nipponica* Shimizu, 1961, from the Gujo Formation of Kawahigashi in the Maizuru Belt, southwestern Japan, is regarded as a junior synonym of the present species. The preceding species, *Spinomarginifera lopingensis* (Kayser, 1883), is distinguished from *S. kueichowensis* in having costae on the trails of both valves. *Spinomarginifera alpha* Huang, 1932, originally described by Huang (1932, p. 60, pl. 5, figs. 12, 13) as *Spinomarginifera kueichowensis* mut. *a* from the upper Permian of Guizhou, southwestern China, differs from the present species in its larger size and in having coarser and sparser spine bases on the ventral valve.

Distribution.—Wordian–Changhsingian: northeastern Japan (Kamiyasse–Imo in the South Kitakami Belt), central Japan (Hitachi), southwestern Japan (Kawahigashi in the Maizuru Belt), northeastern China (Jilin), eastern China (Zhejiang), central-southern China (Hubei, Hunan, Guangdong and Guangxi) and south-western China (Guizhou and Sichuan).

Spinomarginifera alpha Huang, 1932

Fig. 8

Spinomarginifera kueichowensis mut. *a* Huang, 1932, p. 60, pl. 5, figs. 12, 13; Wang et al., 1964, p. 316, pl. 49, figs. 31–33; Jin et al., 1974, p. 313, pl. 164, figs. 11, 12; Yang et al., 1977, p. 349, pl. 139, fig. 9.

Spinomarginifera huangi Nakamura, 1959, p. 145, pl. 15, figs. 5–7; Minato et al., 1979, pl. 63, figs. 3–5.

Spinomarginifera alpha Huang: Liao, 1980, p. 259, pl. 5, figs. 44–47; Zhao et al., 1981, pl. 8, figs. 28, 29; Wang et al., 1982, p. 219, pl. 96, fig. 26; Shen et al., 2003, p. 231, pl. 1, figs. 6–9; Chen et al., 2005, p. 355, figs. 10C, 10D.

Material.—Six specimens from localities KF89, KF90 and KF217: (1) internal mould of a conjoined shell, with external mould of the ventral valve, NU-B2025; (2) internal moulds of two conjoined shells, with external moulds of the dorsal valves, NU-B2026, UHR12370; (3) external moulds of a conjoined shell, UHR30086; (4) external and internal moulds of a dorsal valve, UHR12371; and (5) external mould of a dorsal valve, UHR12369.

Description.—Shell large in size for genus, transversely trapezoidal in outline, with greatest width at hinge; length 29 mm, width 35 mm in the best preserved ventral valve specimen (UHR30086); length 30 mm, width 36 mm in the best preserved dorsal valve specimen (UHR12371). Ventral valve strongly and unevenly convex in lateral profile, with strongly incurved umbo and wide and flattened visceral disc, geniculated and followed by long trail; ears large, triangular and slightly convex; sulcus narrow, deep, originating just anterior to umbo and extending to anterior margin of valve; lateral slopes steep. Dorsal valve with wide, flat visceral disc, strongly geniculated at anterior margin, and followed by

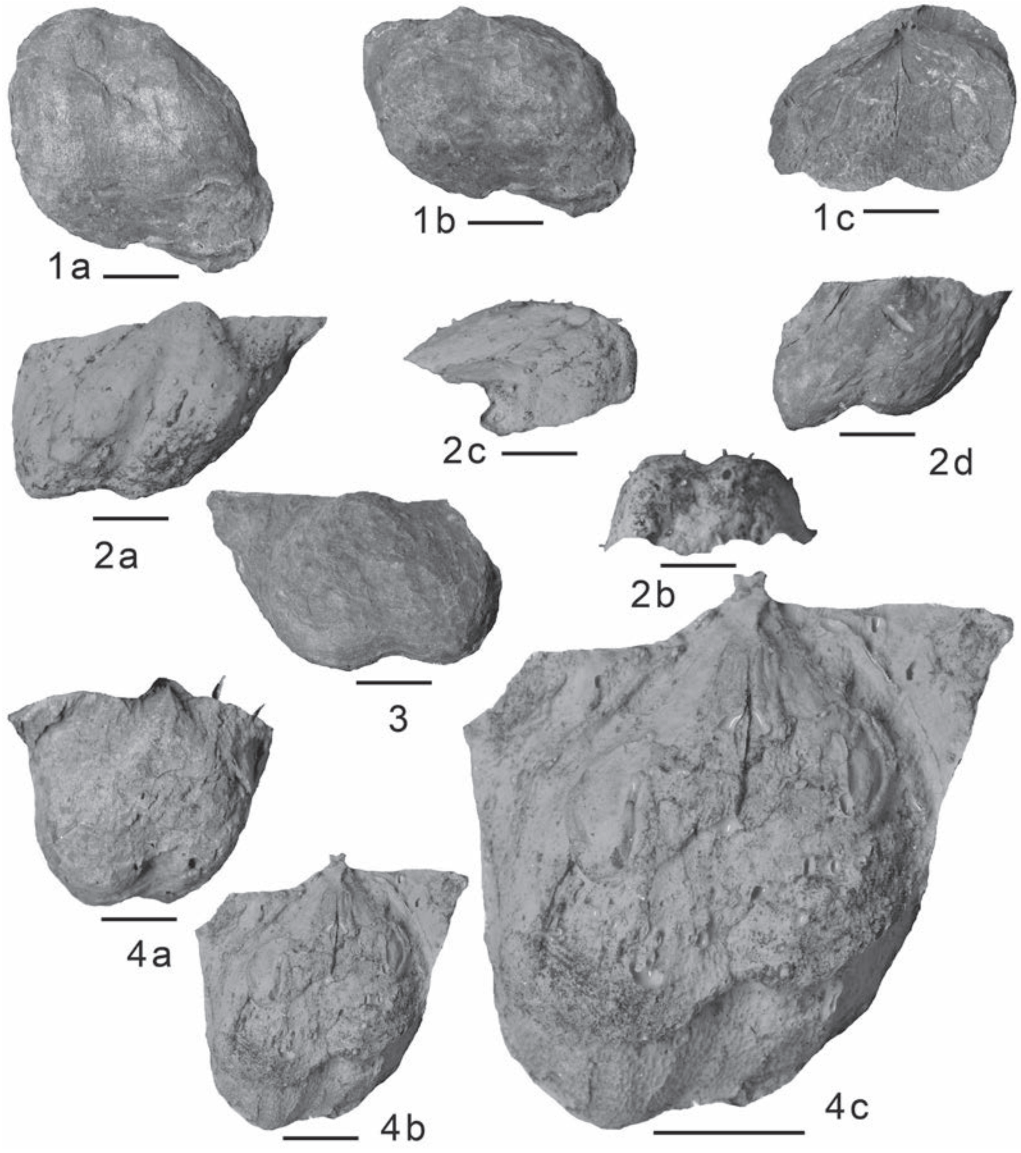

Fig. 8. 1–4, *Spinomarginifera alpha* Huang: 1, ventral view of internal mould (1a), and ventral view (1b) and dorsal view (1c) of internal mould of conjoined shell, NU-B2026; 2, ventral view (2a), anterior view (2b) and lateral view (2c) of external latex cast, and ventral view of external mould (2d) of conjoined shell, UHR30086; 3, external mould of dorsal valve, UHR12369; 4, external mould (4a) and internal latex cast (4b, 4c) of dorsal valve, UHR12371. Scale bars represent 1 cm.

long trail; fold narrow and low on trail. External surface of ventral valve ornamented with numerous coarse spine bases and some irregular rugae. Dorsal valve ornament same as the opposite valve. Dorsal interior with a short bilobate cardinal process, a thin, short median septum and prominent marginal ridge; a pair of brachial ridges developed on both sides of median septum anteriorly.

Remarks.—The specimens from the Kamiyasse–Imo area are referred to *Spinomarginifera alpha* Huang, 1932, originally described by Huang (1932, p. 60, pl. 5, figs. 12, 13) as *Spinomarginifera kueichowensis* mut. *a* from the upper Permian (Lopingian) of Guizhou, southwestern China, in their large size, coarse, widely-spaced spine bases on the both ventral and dorsal valves. *Spinomarginifera huangi* Nakamura (1959, p. 145, pl. 15, figs. 5–7), from the lower Kanokura Series (=lower Kamiyasse Formation) of the South Kitakami Belt, is regarded as a junior synonym of the present species. The preceding species, *Spinomarginifera kueichowensis* Huang, 1932, is distinguished from the present species by its smaller size, much transverse outline and more numerous and finer spine bases on the both ventral and dorsal valves.

Distribution.—Wordian–Changhsingian: northeastern Japan (Kamiyasse–Imo in the South Kitakami Belt), eastern China (Zhejiang), central-southern China (Hunan, Guangdong and Guangxi) and southwestern China (Guizhou, Sichuan and Tibet).

Superfamily Echinoconchoidea Stehli, 1954
Family Waagenoconchidae Muir-Wood and Cooper, 1960
Subfamily Waagenoconchinae Muir-Wood and Cooper, 1960
Genus *Waagenoconcha* Chao, 1927

Type species.—*Productus humboldti* d'Orbigny, 1842.

Waagenoconcha humboldti (d'Orbigny, 1842)
Fig. 9

Productus humboldti d'Orbigny, 1842, p. 54, pl. 5, figs. 4–7; Tschernyschew, 1902, p. 275, 620, pl. 53, figs. 1–3; Kozlowski, 1914, p. 40, pl. 7, figs. 7–9; Fredericks, 1925, p. 19, pl. 2, fig. 84.

Waagenoconcha humboldti (d'Orbigny): Chao, 1927, p. 86, pl. 15, figs. 2, 3; Sarytcheva and Sokolskaya, 1952, p. 98, pl. 15, fig. 109; Chronic, 1953, p. 86, pl. 15, figs. 4–7; Muir-Wood and Cooper, 1960, pl. 89, figs. 6–10; Samtleben, 1971, p. 60, pl. 2, figs. 17–19; Ifanova, 1972, p. 102, pl. 3, figs. 11–13; Tazawa, 1974, p. 125, pl. 1, figs. 2, 3; pl. 2, fig. 1; pl. 4, fig. 6; Ding and Qi, 1983, p. 283, pl. 96, fig. 9; Duan and Li, 1985, p. 108, pl. 35, figs. 2, 3; Wang and Zhang, 2003, p. 94, pl. 9, figs. 5–7; pl. 15, figs. 8–10; Tazawa and Shintani, 2010, p. 56, figs. 4.1–4.5; Tazawa and Shintani, 2015, p. 45, fig. 4.1.

Waagenoconcha imperfecta Prendergast: Tazawa, 1974, p. 127, pl. 2, fig. 6 only.

Material.—Eight specimens from localities KF121 and KF217: (1) internal mould of a conjoined shell, UHR19819; (2) external and internal moulds of two ventral valves,

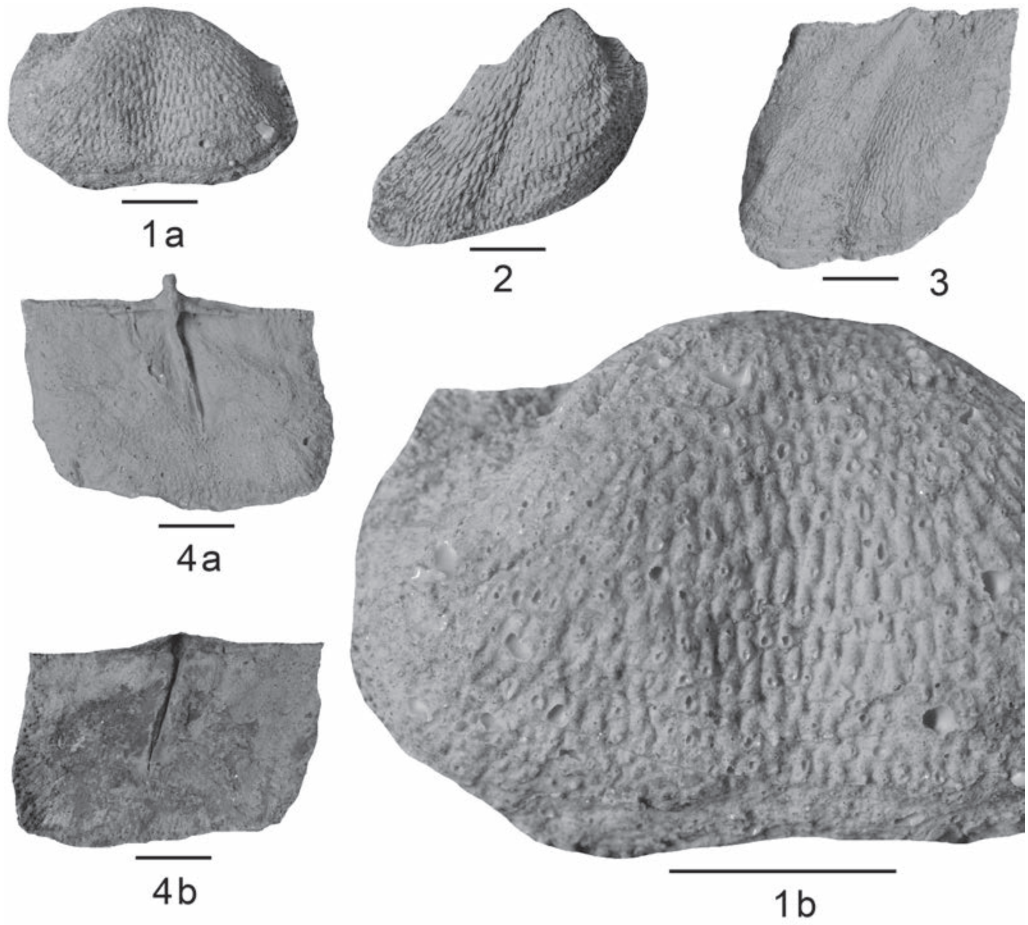

Fig. 9. 1–4, *Waagenoconcha humboldti* (d'Orbigny): 1, external latex cast (1a, 1b) of ventral valve, UHR12596; 2, external latex cast of ventral valve, UHR19847; 3, external latex cast of dorsal valve, UHR19846; 4, internal latex cast (4a) and internal mould (4b) of dorsal valve, UHR19842. Scale bars represent 1 cm.

UHR12133, 19847; (3) external moulds of two ventral valves, UHR12595, 12596; (4) external mould of a dorsal valve, UHR19846; and (5) internal moulds of two dorsal valves, UHR19842, 19843.

Description.—Shell medium in size for genus, transversely subrectangular in outline; hinge slightly narrower than maximum width at midlength; length about 33 mm, width about 45 mm in the largest specimen (UHR12596). Ventral valve moderately convex in lateral profile; umbo tapering, strongly incurved beyond hinge line; ears small, triangular in shape, obscurely demarcated from visceral region; sulcus broad and shallow; lateral slopes rounded. Dorsal valve with large, flat to slightly concave visceral disc, geniculated at anterior margin, and followed by short trail; fold broad and low, occurring just anterior to umbonal depression and extending to anterior margin. External surface of ventral valve ornamented with some strong concentric rugae and numerous, elongate, and quincunxially arranged spine bases (tubercles); numbering 4–5 spine bases in 5 mm width at midlength. External ornament of dorsal valve similar to that of opposite valve, but rugae more regularly and closely spaced, and spine bases finer. Ventral valve interior with large, longitudinally striated diductor scars. Dorsal interior with trilobed cardinal process followed by thick, long median septum, extending to nearly two-thirds length of valve; adductor scars dendritic.

Remarks.—These specimens are referred to *Waagenoconcha humboldti* (d'Orbigny, 1842), originally described from the lower Permian (Asselian) of Yarbichambi, Bolivia, on account of size, shape and external ornament of both valves, particularly, in having elongate, rather coarse spine bases and strong rugae on the ventral valve. *Waagenoconcha abichi* (Waagen, 1884, p. 697, pl. 74, figs. 1–7), from the Wargal and Chhidru formations of the Salt Range, Pakistan, is also a medium-sized species, but the Pakistani species differs from *W. humboldti* in having coarser and sparser spine bases on the ventral valve.

Distribution.—Gzhelian–Capitanian: northeastern Japan (Nagaiwa–Sakamotozawa and Kamiyasse–Imo in the South Kitakami Belt), northern Russia (Timan and Pechora Basin), western Russia (Moscow Basin), northwestern China (Gansu), northern China (Inner Mongolia), eastern Russia (South Primorye) and Bolivia.

Waagenoconcha irginae (Stuckenberg, 1898)

Fig. 10

Productus irginae Stuckenberg, 1898, p. 220, pl. 2, fig. 16; Tschernyschew, 1902, p. 273, 618, pl. 30, figs. 3, 4; pl. 52, figs. 1–4; Miloradovich, 1935, p. 67, 133, pl. 5, figs. 1, 2.

Productus cf. *humboldti irginae* Stuckenberg: Fredericks, 1925, p. 19, pl. 4, fig. 117.

Waagenoconcha humboldti var. *irginae* (Stuckenberg): Solomina, 1960, p. 31, pl. 2, figs. 1–4.

Waagenoconcha irginae (Stuckenberg): Muir-Wood and Cooper, 1960, pl. 89, figs. 15, 16; Gobbett, 1963, p. 76, pl. 5, fig. 7; pl. 6, figs. 1–5; Zavodowsky and Stepanov, 1970, p. 89, pl. 3, figs. 3, 4; Ifanova, 1972, p. 103, pl. 3, figs. 14–16; Lee and Gu, 1976, p. 252, pl. 155, figs. 3, 4; pl. 170, fig. 3; Kalashnikov, 1986, pl. 118, figs. 2, 3; Kalashnikov, 1993, p. 70, pl. 36, figs. 3–5; Tazawa and Araki, 2016, p. 157, figs. 4.1–4.6.

Waagenoconcha imperfecta Prendergast: Tazawa, 1974, p. 127, pl. 1, figs. 4–6; pl. 2, figs. 2–7; pl. 3, figs. 1–3; pl. 4, figs. 1–4, 7 (excluding pl. 2, fig. 6; pl. 3, fig. 2); Tazawa, 1976, pl. 2, fig. 6; Minato et al., 1979, pl. 65, figs. 1, 2; Manankov, 1991, p. 112, pl. 23, figs. 4–7; Tazawa. 2002, figs. 10.12; Tazawa, 2007, fig. 4.12.

Waagenoconcha sp. Tazawa and Ibaraki, 2001, p. 9, pl. 1, fig. 4.

Waagenoconcha cf. *imperfecta* Prendergast: Tazawa, 2001, p. 293, fig. 7.24.

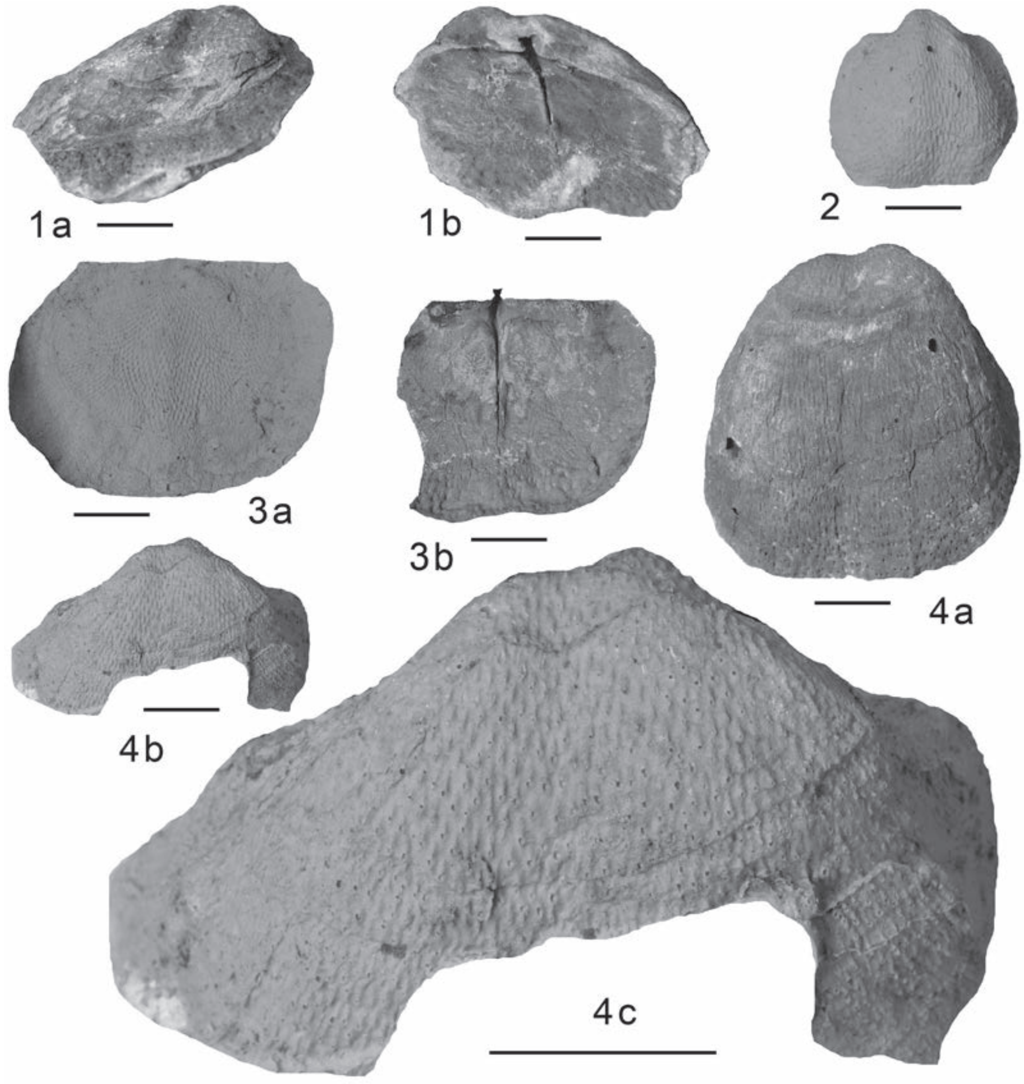

Fig. 10. 1–4, *Waagenoconcha irginae* (Stuckenberg): 1, ventral view (1a) and dorsal view (1b) of internal mould of conjoined shell, KCG028; 2, external latex cast of ventral valve, UHR19838; 3, external latex cast (3a) and internal mould (3b) of dorsal valve, UHR19826; 4, internal mould (4a) and external latex cast (4b, 4c) of ventral valve, UHR19818. Scale bars represent 1 cm.

Material.—Twenty-nine specimens from localities KF9, KF11 and KF39: (1) external and internal moulds of two conjoined shells, UHR19823, 19841; (2) internal moulds of three conjoined shells, with external moulds of the dorsal valves, UHR19816, 19817, 19827; (3) internal moulds of two conjoined shells, UHR19834, 19839; (4) external and internal moulds of six ventral valves, UHR19812, 19818, 19822, 19828, 19838, 19840; (5) external mould of a ventral valve, UHR19823; (6) internal moulds of six ventral valves, NU-B1659, UHR19815, 19825, 19830, 19832, 19835; (7) external and internal moulds of eight dorsal valves, UHR19814, 19821, 19824, 19826, 19829, 19831, 19836, 19837; and (8) external mould of a dorsal valve, UHR19820.

Description.—Shell medium in size for genus, equidimensional to slightly longer subrectangular in outline, with greatest width at about two-thirds length from umbo; length 44 mm, width 43 mm in the largest specimen (UHR19818); length 34 mm, width 34 mm in the average-sized specimen (UHR19835); length 10 mm, width 12 mm in the smallest specimen (UHR19816). Ventral valve moderately convex in lateral profile, most convex at umbo, not geniculated; ears small; sulcus narrow and moderately deep, commencing at umbo and extending to anterior margin; lateral slopes steep. Dorsal valve nearly flat on visceral disc, strongly geniculated, and followed by short trail; fold narrow and low on anterior half of valve. External surface of ventral valve ornamented with several irregular concentric rugae and numerous spine bases; spine bases fine, elongate, quincunxially arranged, and smaller in size anteriorly, numbering 8–9 in 5 mm width at midlength. External ornament of dorsal valve same as that of opposite valve, although spine bases being finer in dorsal valve. Ventral interior with large, longitudinally striated diductor scars and small, elongate dendritic adductor scars; coarse irregular pustules occurring around anterior margin. Dorsal interior with moderately large, trifid cardinal process bearing a groove on ventral face; median septum thin and long, extending to half or more length of valve; lateral ridges short and straight; adductor scars large and dendritic in anterior ones and small, elongate and smooth in posterior ones; numerous pustules becoming coarser anteriorly.

Remarks.—The specimens available are referred to *Waagenoconcha irginae* (Stuckenberg, 1898), redescribed and refigured by Tschernyschew (1902, p. 273, 618, pl. 30, figs. 3, 4; pl. 52, figs. 1–4) from the lower Permian (*Cora–Schwagerina* horizons) of Ufa, central Russia, in size, shape and external ornament of both valves, in particular, fine quincunxially arranged spine bases becoming finer anteriorly. Tazawa (1974) described most of the Kitakami specimens as *Waagenoconcha imperfecta* Prendergast, 1935. But the Australian species differs from *W. irginae* in its much larger size (see Archbold, 1993, p. 20, figs. 11–13) and in having finer spine bases on the ventral valve. The type species, *Waagenoconcha humboldti* (d'Orbigny, 1842), is distinguished from *W. irginae* by the coarser spine bases on the ventral valve.

Distribution.—Asselian–Capitanian: northeastern Japan (Setamai and Kamiyasse–Imo in the South Kitakami Belt), central Japan (Moribu in the Hida Gaien Belt), Spitsbergen, northern Russia (Kanin Peninsula, Timan, Pechora Basin, northern Urals and Kolyma), central Russia (southern Urals), southern Mongolia, northern China (Inner Mongolia) and eastern Russia (South Primorye).

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Catalogue of living polycystine radiolarians in surface waters in the East China Sea around Sesoko Island, Okinawa Prefecture, Japan

Atsushi MATSUOKA*

Abstract

This catalogue contains 14 spumellarian and 15 nassellarian species commonly occurring in surface waters in the East China Sea around Sesoko Island, Okinawa Prefecture, Japan. Each panel consists of live and skeleton images with transmitted light microscopy and skeleton images with scanning electron microscopy of each species. The fauna is composed of shallow dwellers in subtropical waters.

Key words: living radiolaria, light microscopy, scanning electron microscopy, East China Sea, Kuroshio, Sesoko Island, Okinawa.

Introduction

The Okinawa plankton workshops known as “Okinawa Radiolarian Tours” have been held since 1997 at the Sesoko Station of the Tropical Biosphere Research Center, the University of the Ryukyus on Sesoko Island, Motobu Town, Okinawa Prefecture, Japan. More than 200 radiolarian specialists and students participated in the tours to enjoy marine plankton. This activity includes sampling by a research boat, microscopic observations, and an introduction to a wide variety of techniques for living plankton research. The brief guides for panticipants were published in Japanese (Matsuoka, 2002) and in English (Matsuoka, 2007). One of the most frequently asked questions from the participants in observing a living radiolarian under a microscope is on taxonomic name of radiolarian species. Participants are generally familiar with light microscopy (LM) or scanning electron

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microscopy (SEM) images of radiolarian skeletons. On the other hand, they may not be so familiar with a living radiolarian individual. This catalogue provides a quick reference of live and skeleton images and includes 14 spumellarian and 15 nassellarian species commonly occurring in surface waters in the East China Sea. Each panel in the catalogue consists of three kinds of photomicrographs of a single species; LM images of living specimens, LM and SEM images of skeletons. This can be used as a pictorial guidebook for "Okinawa Radiolarian Tours" along with other pictorial publications showing LM images of living radiolarians (Matsuoka, 1993) and SEM images of radiolarian skeletons (Matsuoka, 2009).

Materials and methods

Sesoko Island (26° 38' 46" N, 127° 51' 54"E) is located 600 m west off the Motobu Peninsula of Okinawa Island (Fig. 1). Okinawa belongs to subtropical climates. Marine organisms around Sesoko Island are affected by the Kuroshio Current, characterized by warm, high salinity, and low nutrient. As a consequence the radiolarians around Sesoko Island represent a subtropical fauna.

Living radiolarians were collected using a 44 μm opening plankton net from a research vessel near Sesoko Island (Fig. 1). Samples were taken in short durations (ca. 3 min.) tow from surface waters in the East China Sea. Plankton samplings have been carried out since 1992.

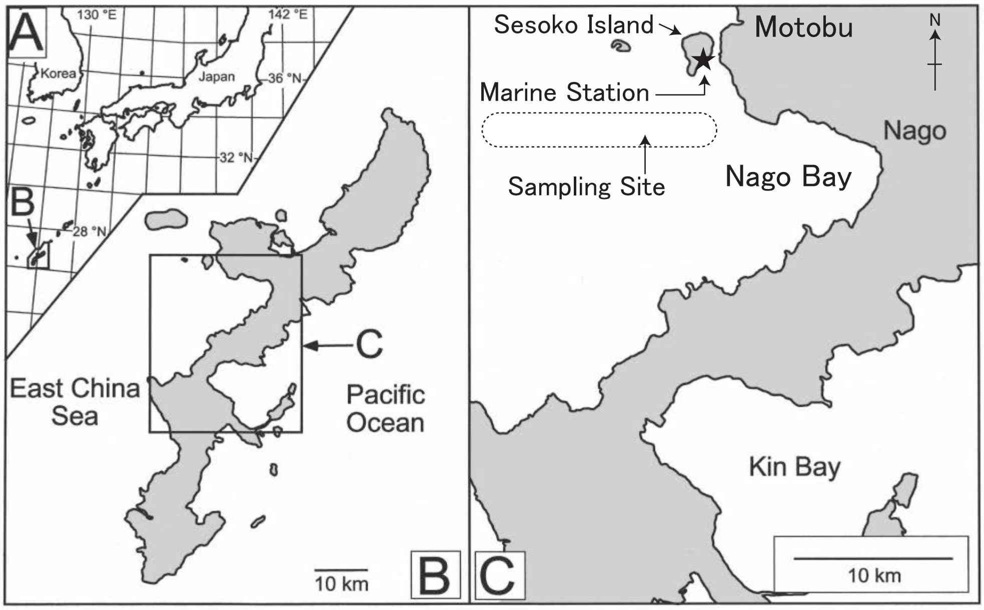

Fig. 1. Index map showing the sampling site.

Microscopic images of living radiolarians were taken during our activities at the Sesoko Station. Photomicrographs using negative color films were taken with a camera attached to an inverted microscope in early stages of our activities (1992–1999). After 2000, images of living radiolarians were captured wth a digital camera system by using the same microscope.

Radiolarian skeletons were prepared by the methods mentioned below. The plankton samples were placed in ca. 50% sulfuric acid for a day to eliminate the organic matter. Following this, residues were rinsed with distilled water and dried. Radiolarian specimens were picked from the dried residues and mounted on aluminum stubs for SEM observations. For LM images of radiolarian skeletons, the residues were mounted on slide glass using synthetic medium "Entellan New" without picking.

Catalogue

This catalogue contains 14 spumellarian and 15 nassellarian species (Table 1, Figs. 2–30). All of scales put at the right-upper margin of each photograph are 0.1 mm. A simple synonymy is prepared for each species. It includes the article in which the species was described as a new species. Several papers which reported the occurrence of the species from subtropical realms in the Pacific (Nishimura and Yamauchi, 1984; Takahashi, 1991; Cheng and Yeh, 1999; Sashida and Kurihara, 1999) are included. Articles of which scientific results were obtained during the tours (Suzuki and Sugiyama, 2001; Takahashi et al., 2003; Suzuki, 2005; Sugiyama et al., 2008; Suzuki et al., 2009) are also added in the synonymy. Further complete synonymy to some species is referred to Matsuzaki et al. (2015).

Acknowledgements

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Table 1. A list of radiolarian species treated in the catalogue, composed of 14 spumellarians and 15 nassellarians.

SPUMELLARIA	
Diplosphaera hexagonalis Haeckel	Fig. 2
Cladococcus cervicornis Haeckel	Fig. 3
Rhizosphaera trigonacantha Haeckel	Fig. 4
Haliommilla capillaceum (Haeckel)	Fig. 5
Spongosphaera streptacantha Haeckel	Fig. 6
Hexacontium hostile Cleve	Fig. 7
Stylosphaera melpomene Haeckel	Fig. 8
Didymocyrtis tetrathalamus tetrathalamus (Haeckel)	Fig. 9
Spongaster tetras tetras Ehrenberg	Fig. 10
Spongodiscus biconcavus Haeckel	Fig. 11
Myelastrum trinibrachium Takahashi	Fig. 12
Dictyocoryne truncatum (Ehrenberg)	Fig. 13
Dictyocoryne profunda Ehrenberg	Fig. 14
Euchitonia elegans (Ehrenberg)	Fig. 15
NASSELLARIA	
Acanthodesmia vinculata (Müller)	Fig. 16
Neosemantis distephanus Popofsky	Fig. 17
Lophospyris pentagona pentagona (Ehrenberg)	Fig. 18
Pseudocubus obeliscus Haeckel	Fig. 19
Callimitra emmae Haeckel	Fig. 20
Peromelissa phalacra Haeckel	Fig. 21
Lophophaena hispida (Ehrenberg)	Fig. 22
Pterocanium praetextum praetextum (Ehrenberg)	Fig. 23
Eucyrtidium hexagonatum Haeckel	Fig. 24
Eucyrtidium hexastichum (Haeckel)	Fig. 25
Pterocorys zancleus Müller	Fig. 26
Pterocorys campanula Haeckel	Fig. 27
Theocorythium trachelium trachelium (Ehrenberg)	Fig. 28
Spirocyrtis scalaris Haeckel	Fig. 29
Botryocyrtis scutum (Harting)	Fig. 30

Diplosphaera hexagonalis Haeckel

Diplosphaera hexagonalis Haeckel, 1887, p. 246, pl. 19, fig. 3.
Astrosphaera hexagonalis Haeckel, 1887, p. 250, pl. 19, fig. 4.
Astrosphaera hexagonalis Haeckel: Nishimura and Yamauchi, 1984, p. 24, pl. 14, figs. 1-2.
Astrosphaera hexagonalis Haeckel: Cheng and Yeh, 1989, p. 183, pl. 8, fig. 13.
Astrosphaera hexagonalis Haeckel: Takahashi, 1991, p. 69, pl. 11, figs. 1-3.
Diplosphaera hexagonalis Haeckel: Suzuki and Sugiyama, 2001, p. 138-139, figs. 2-3.

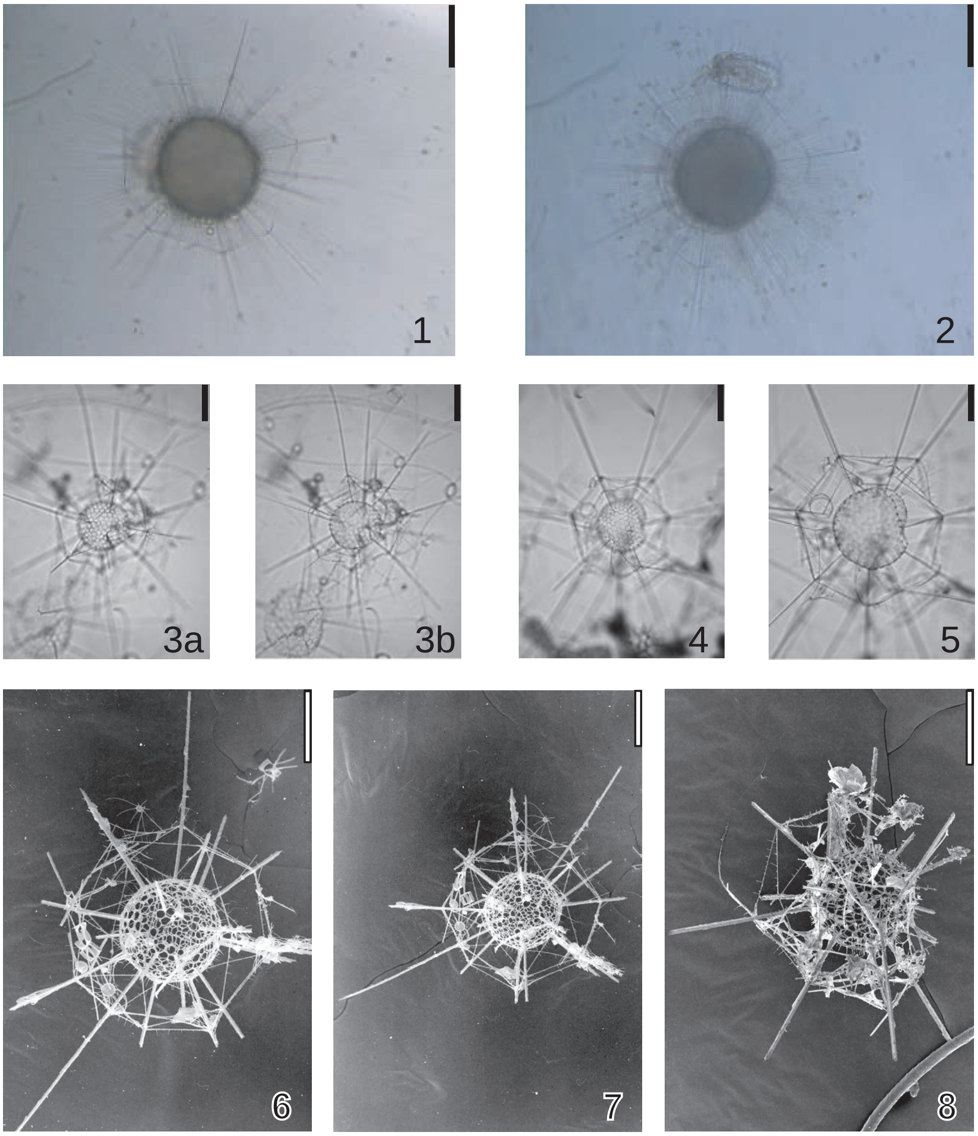

Fig. 2. Photomicrographs of *Diplosphaera hexagonalis* Haeckel. Scales are 0.1 mm.

Cladococcus cervicornis Haeckel

Cladococcus cervicornis Haeckel, 1861, p. 801; 1862, p. 370, pl. 14, figs. 4-6.
Cladococcus cervicornis Haeckel: Nishimura and Yamauchi, 1984, p. 24, pl. 11, figs. 1-6, 9, pl. 49, fig. 4, pl. 50, fig. 10.
Cladococcus cervicornis Haeckel: Takahashi, 1991, p. 67, pl. 10, figs. 8-10.

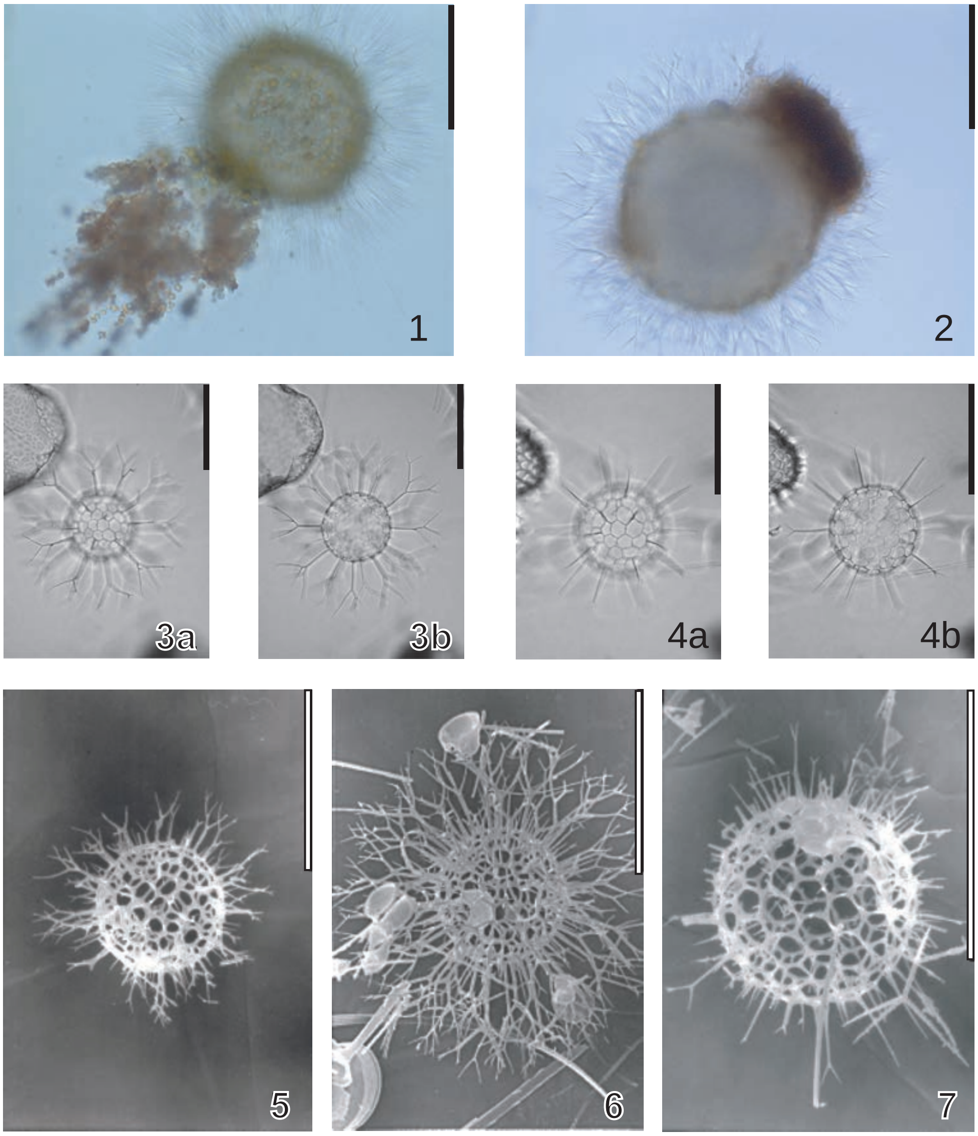

Fig. 3. Photomicrographs of *Cladococcus cervicornis* Haeckel. Scales are 0.1 mm.

Rhizosphaera trigonacantha Haeckel

Rhizosphaera trigonacantha Haeckel, 1861, p. 840.
Rhizosphaera trigonacantha Haeckel: Haeckel, 1862, p. 452-453, pl. 25, figs. 1-7.
Rhizosphaera serrata Haeckel: Nishimura and Yamauchi, 1984, p. 32, pl. 6, figs. 5, 8, pl. 10, figs. 2, 10, pl. 45, fig. 6.
Actinomma aracadophorum Haeckel: Takahashi, 1991, p. 65, pl. 8, fig. 8.
Rhizosphaera serrata Haeckel: Sashida and Kurihara, 1999, p. 138, fig. 9.3.
Rhizosphaera trigonacantha Haeckel, Suzuki, 2005, pl. 1, figs. 1-8, pl. 2, figs. 1-18.

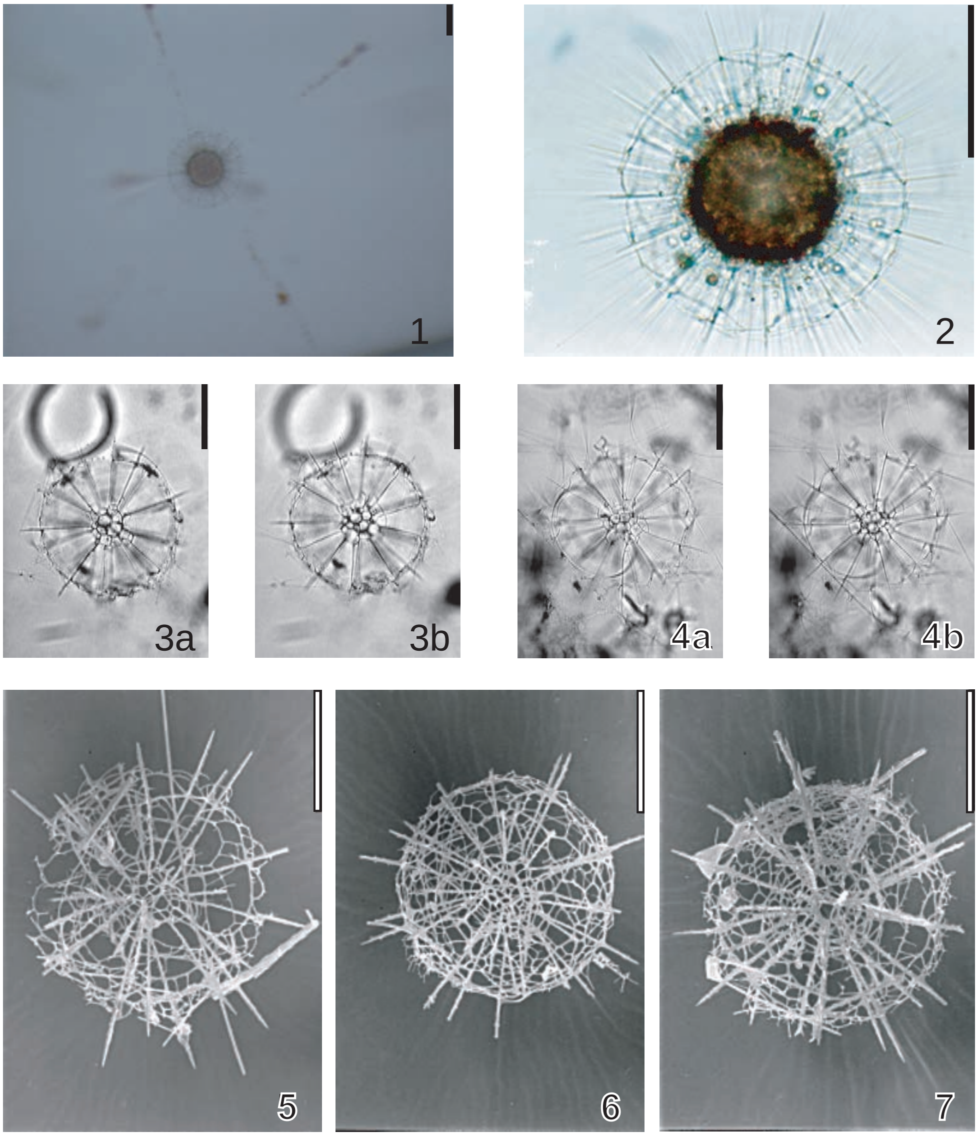

Fig. 4. Photomicrographs of *Rhizosphaera trigonacantha* Haeckel. Scales are 0.1 mm.

Haliommilla capillaceum (Haeckel)

Haliomma capillaceum Haeckel, 1861, p. 814; 1862, p. 426, pl. 23, fig. 2; 1887, p. 236.
Actinosphaera capillacea (Haeckel) group: Nishimura and Yamauchi, 1984, p. 22-23, pl. 9, figs. 1-10, pl. 48, fig. 7.
Actinosphaera capillacea (Haeckel): Takahashi, 1991, p. 68, pl. 9, figs. 4-5.
Actinosphaera capillacea (Haeckel): Sashida and Kurihara, 1999, p. 133, figs. 9.4, 12.
Haliommilla capillaceum (Haeckel): Suzuki et al., 2009, p. 158, figs. 1.1-10.

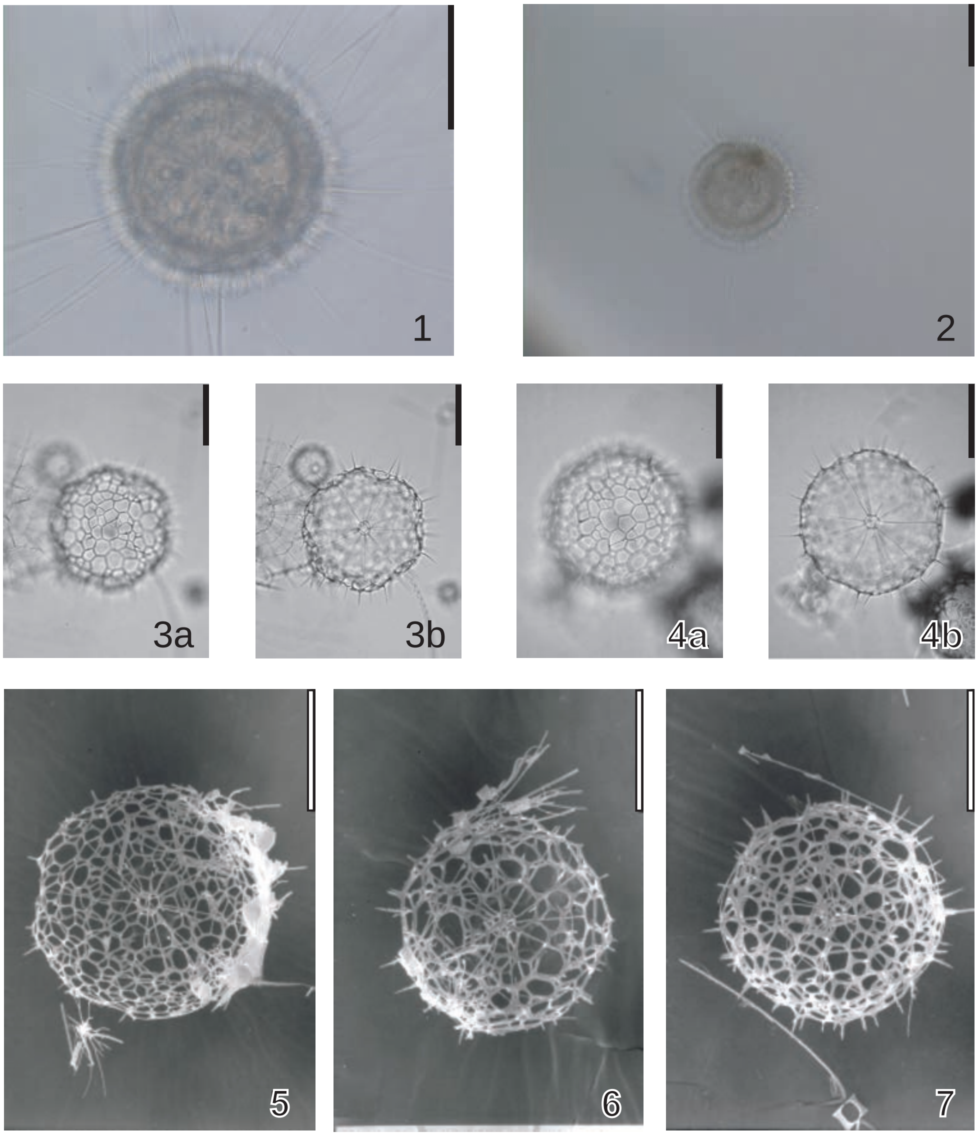

Fig. 5. Photomicrographs of *Haliommilla capillaceum* (Haeckel). Scales are 0.1 mm.

Spongosphaera streptacantha Haeckel

Spongosphaera streptacantha Haeckel, 1861, p. 840-841; 1862, p. 455-456, pl. 26, figs. 1-3.
Spongosphaera streptacantha Haeckel: Nishimura and Yamauchi, 1984, p. 33, pl. 15, fig. 4, pl. 52, fig. 2.
Spongosphaera streptacantha Haeckel: Takahashi, 1991, p. 65, pl. 7, fig. 6.

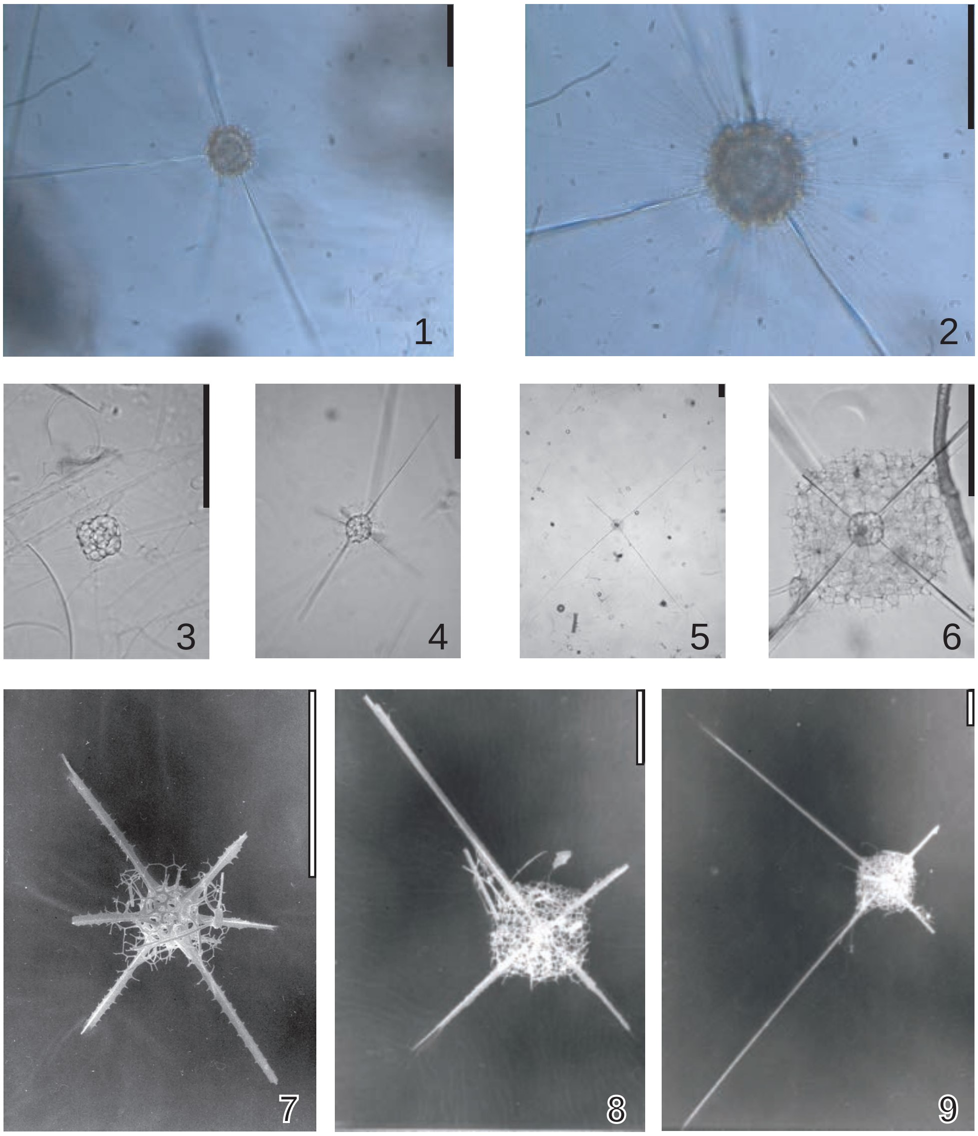

Fig. 6. Photomicrographs of *Spongosphaera streptacantha* Haeckel. Scales are 0.1 mm.

Hexacontium hostile Cleve

Hexacontium hostile Cleve, 1900, p. 9, pl. 6, fig. 4.
Hexacontium hostile Cleve: Nishimura and Yamauchi, 1984, p. 30, pl. 3, figs. 2, 7, pl. 45, fig. 5, non pl. 46, fig. 5.
Hexacontium hostile Cleve: Takahashi, 1991, p. 72, pl. 13, fig. 1-2.
Hexacontium hostile Cleve: Sashida and Kurihara, 1999, p. 135, figs. 9.6-7.

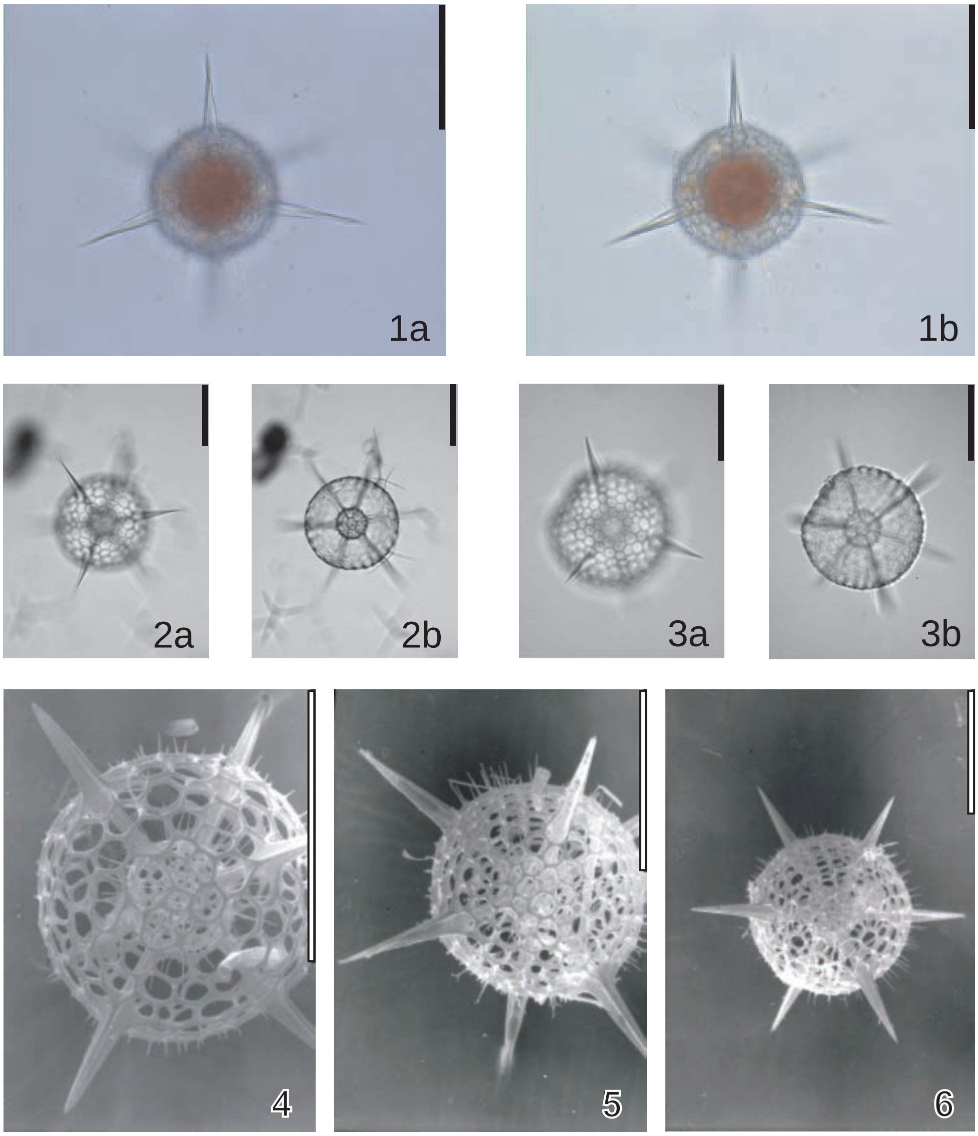

Fig. 7. Photomicrographs of *Hexacontium hostile* Cleve. Scales are 0.1 mm.

Stylosphaera melpomene Haeckel

Stylosphaera melpomene Haeckel, 1887, p. 135, pl. 16, fig. 1.
Stylatractus melpomene (Haeckel): Nishimura and Yamauchi, 1984, p. 34, pl. 6, fig. 2, pl. 51, fig. 4.
Stylosphaera melpomene Haeckel: Takahashi, 1991, p. 75, pl. 14, figs. 1-2.

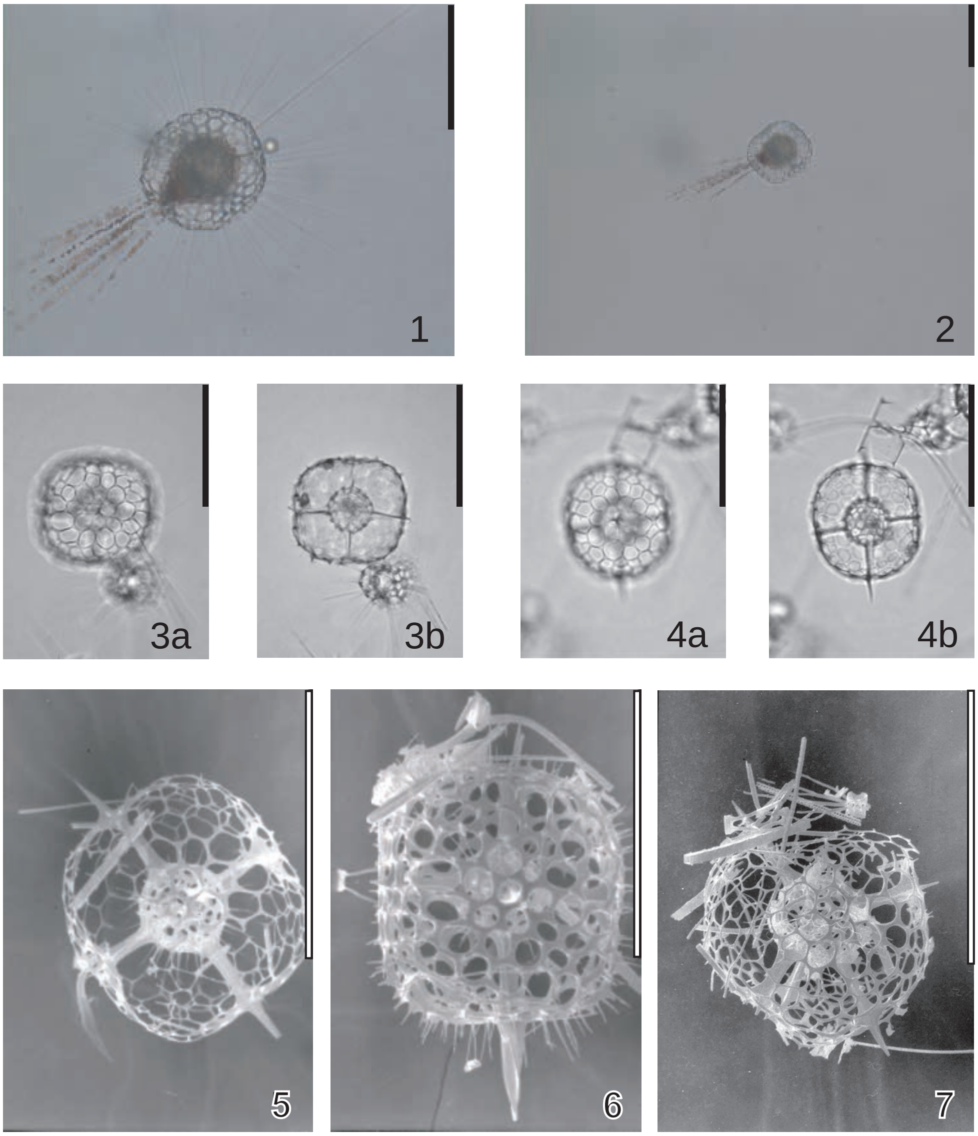

Fig. 8. Photomicrographs of *Stylosphaera melpomene* Haeckel. Scales are 0.1 mm.

Didymocyrtis tetrathalamus tetrathalamus (Haeckel)

Panartus tetrathalamus Haeckel, 1887, p. 378, pl. 40, fig. 3.
Ommatartus tetrathalamus tetrathalamus (Haeckel): Nishimura and Yamauchi, 1984, p. 36, pl. 16, figs. 1-4, 7-9, pl. 52, fig. 12.
Didymocyrtis tetrathalamus tetrathalamus (Haeckel): Takahashi, 1991, p. 79, pl. 21, figs. 1-14.
Didymocyrtis tetrathalamus tetrathalamus (Haeckel): Sashida and Kurihara, 1999, p. 138, figs. 8.13-14, 16, fig. 12.8, 20.

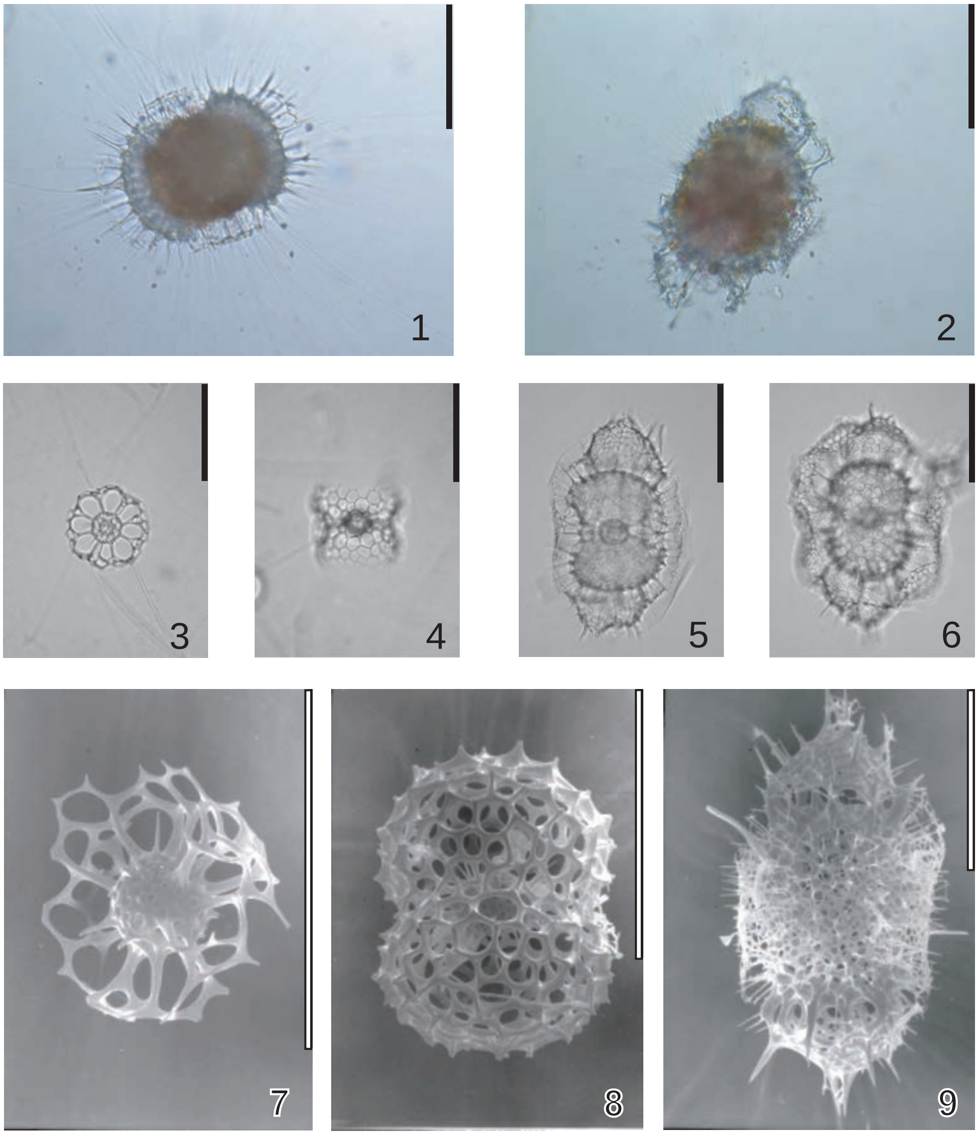

Fig. 9. Photomicrographs of *Didymocyrtis tetrathalamus tetrathalamus* (Haeckel). Scales are 0.1 mm.

Spongaster tetras tetras Ehrenberg

Spongaster tetras Ehrenberg, 1862, p. 301; 1873b, p. 299, pl. 6, fig. 8.
Spongaster tetras tetras Ehrenberg: Nishimura and Yamauchi, 1984, p. 39, pl. 19, figs. 14-15.
Spongaster tetras tetras Ehrenberg: Cheng and Yeh, 1989, p. 185, pl. 3, figs. 16, 20, pl. 6, fig. 17.
Spongaster tetras tetras Ehrenberg: Takahashi, 1991, p. 86, pl. 17, figs. 10-11.

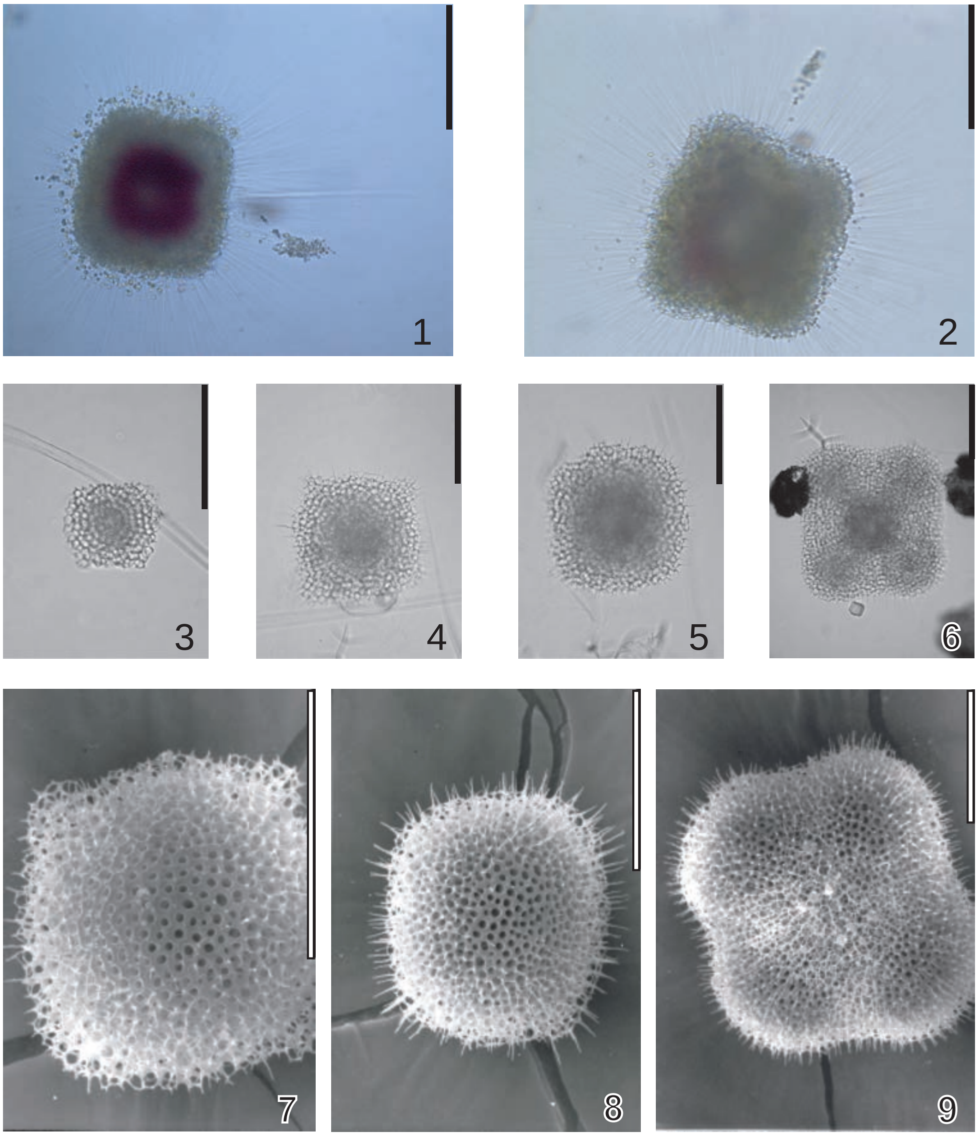

Fig. 10. Photomicrographs of *Spongaster tetras tetras* Ehrenberg. Scales are 0.1 mm.

Spongodiscus biconcavus Haeckel

Spongodiscus biconcavus Haeckel, 1887, p. 577.
Spongodiscus biconcavus Haeckel: Nishimura and Yamauchi, 1984, p. 40, pl. 20, fig. 14, pl. 53, fig. 1.
Spongodiscus resurgens Ehrenberg: Cheng and Yeh, 1989, p. 185, pl. 1, fig. 19, non pl. 8, fig. 15.
Spongodiscus biconcavus Haeckel: Takahashi, 1991, p. 84, pl. 19, figs. 4-6.

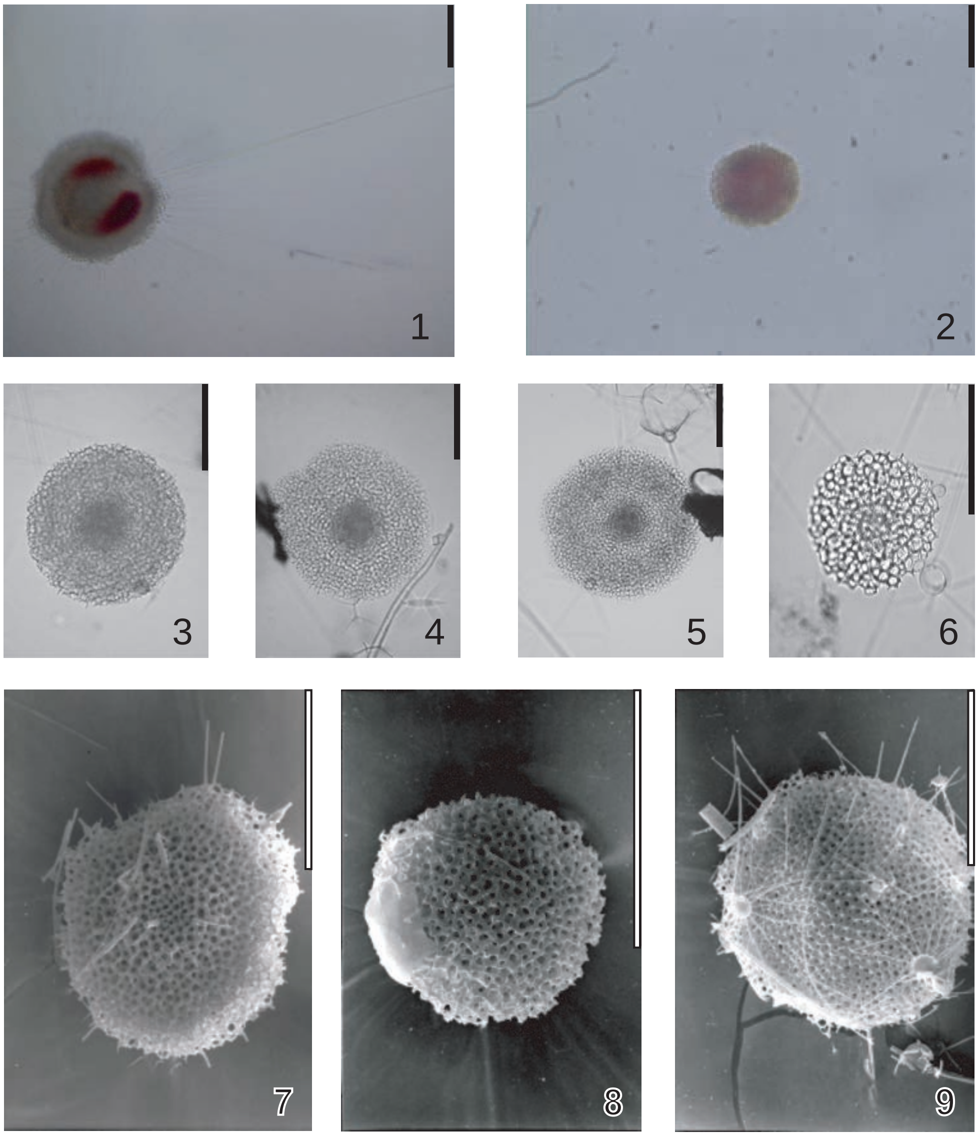

Fig. 11. Photomicrographs of *Spongodiscus biconcavus* Haeckel. Scales are 0.1 mm.

Myelastrum trinibrachium Takahashi

Myelastrum trinibrachium Takahashi, 1991, p. 88, pl. 18, figs. 7-12.

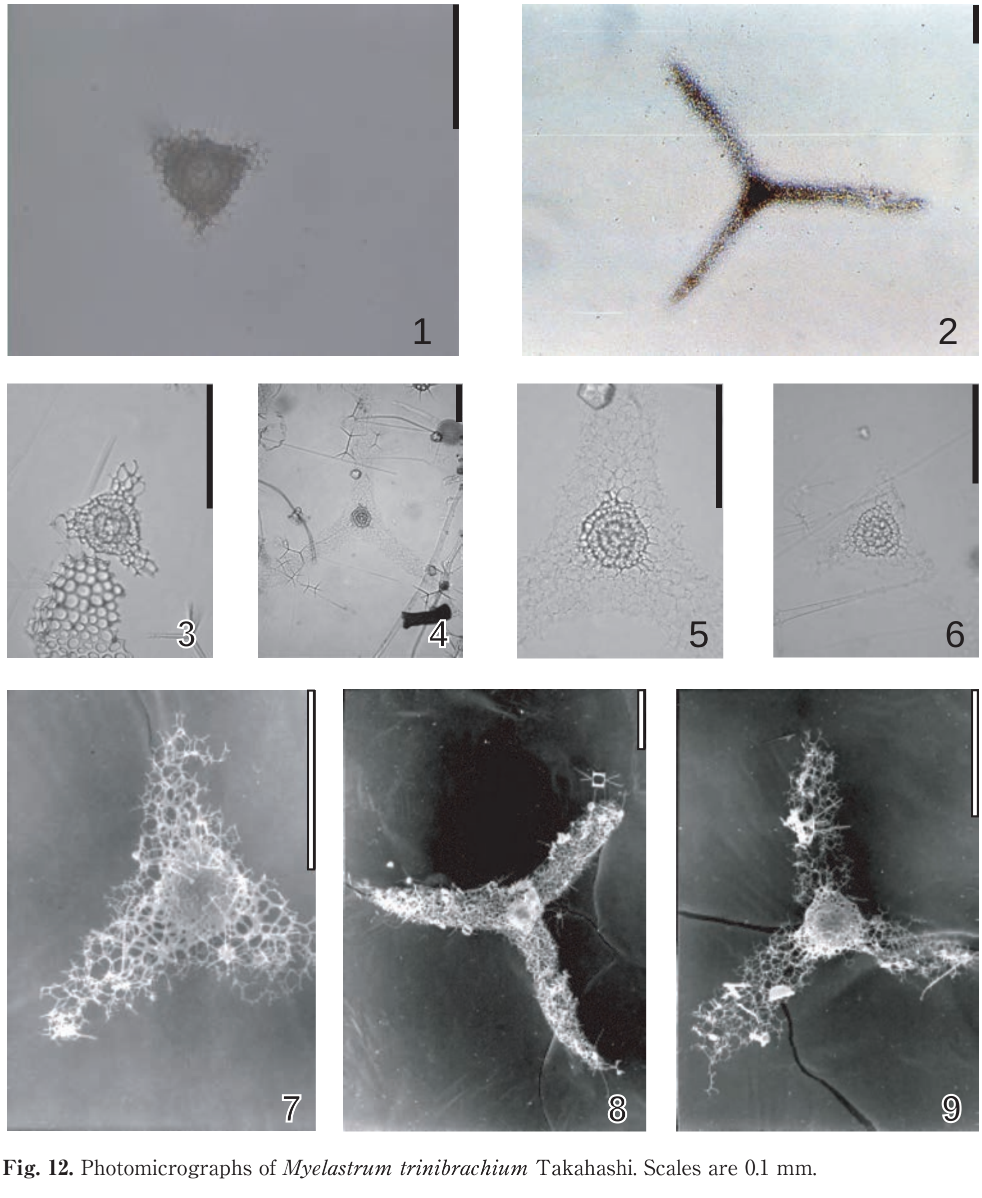

Fig. 12. Photomicrographs of *Myelastrum trinibrachium* Takahashi. Scales are 0.1 mm.

Dictyocoryne truncatum (Ehrenberg)

Rhopalodictyum truncatum Ehrenberg, 1862, p. 301.
Dictyocoryne truncatum (Ehrenberg), Nishimura and Yamauchi, 1984, p. 39, pl. 20, figs. 8, 10-12, pl. 53, figs. 3, 12.
Dictyocoryne truncatum (Ehrenberg), Sashida and Kurihara, 1999, p. 141, fig. 10.3.

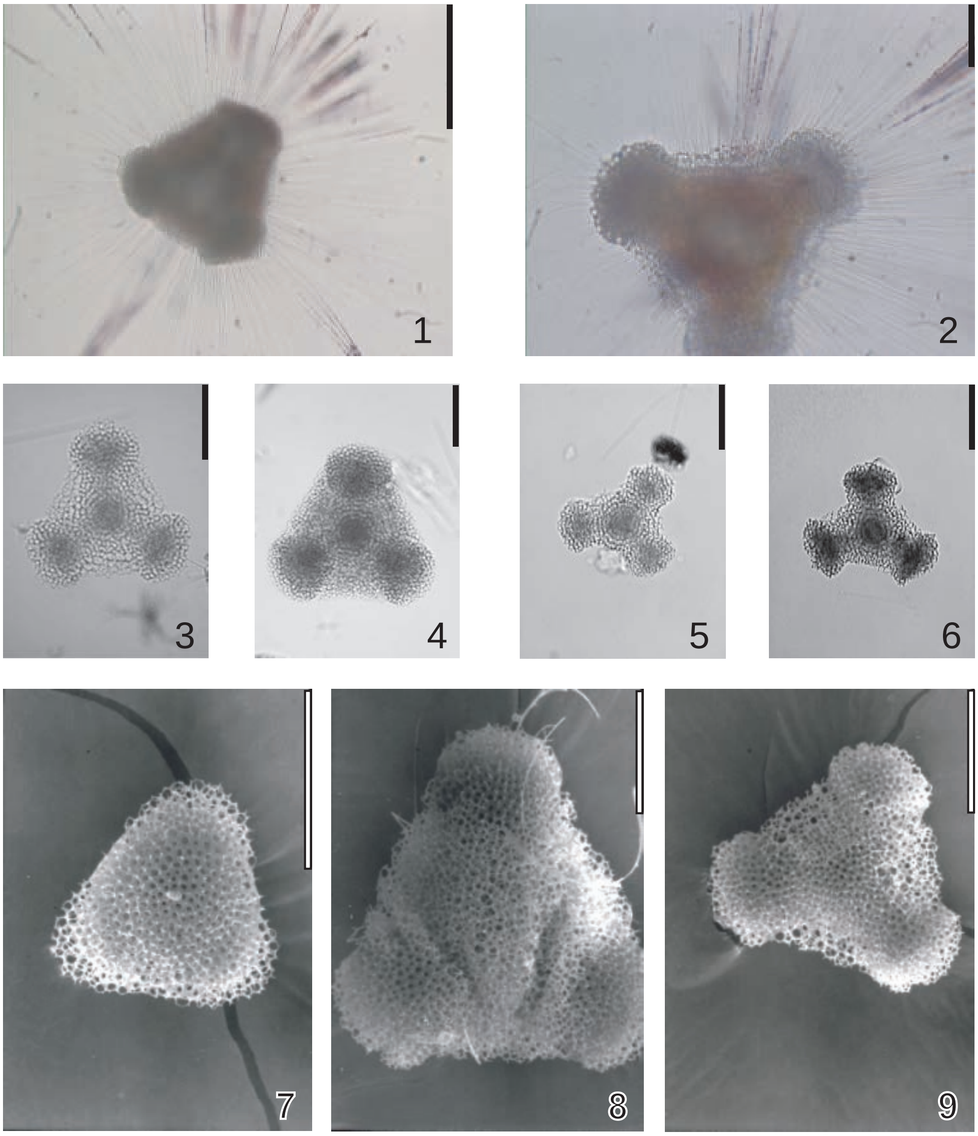

Fig. 13. Photomicrographs of *Dictyocoryne truncatum* (Ehrenberg). Scales are 0.1 mm.

Dictyocoryne profunda Ehrenberg

Dictyocoryne profunda Ehrenberg, 1873a, p. 307; 1873b, p. 288-289, pl. 7, fig. 23.
Dictyocoryne profunda Ehrenberg group, Nishimura and Yamauchi, 1984, p. 38-39, pl. 19, fig. 13, pl. 20, figs. 1-7, 9, pl. 54, figs. 1-6.
Hymeniastrum euclidis Haeckel, Cheng and Yeh, 1989, p. 184, pl. 3, figs. 7, 11, non figs. 12-13, pl. 6, fig. 11.
Dictyocoryne profunda Ehrenberg, Takahashi, 1991, p. 83, pl. 16, figs. 10, 12-13, non fig. 15.
Dictyocoryne profunda Ehrenberg, Sashida and Kurihara, 1999, p. 141, figs. 10.1-2.

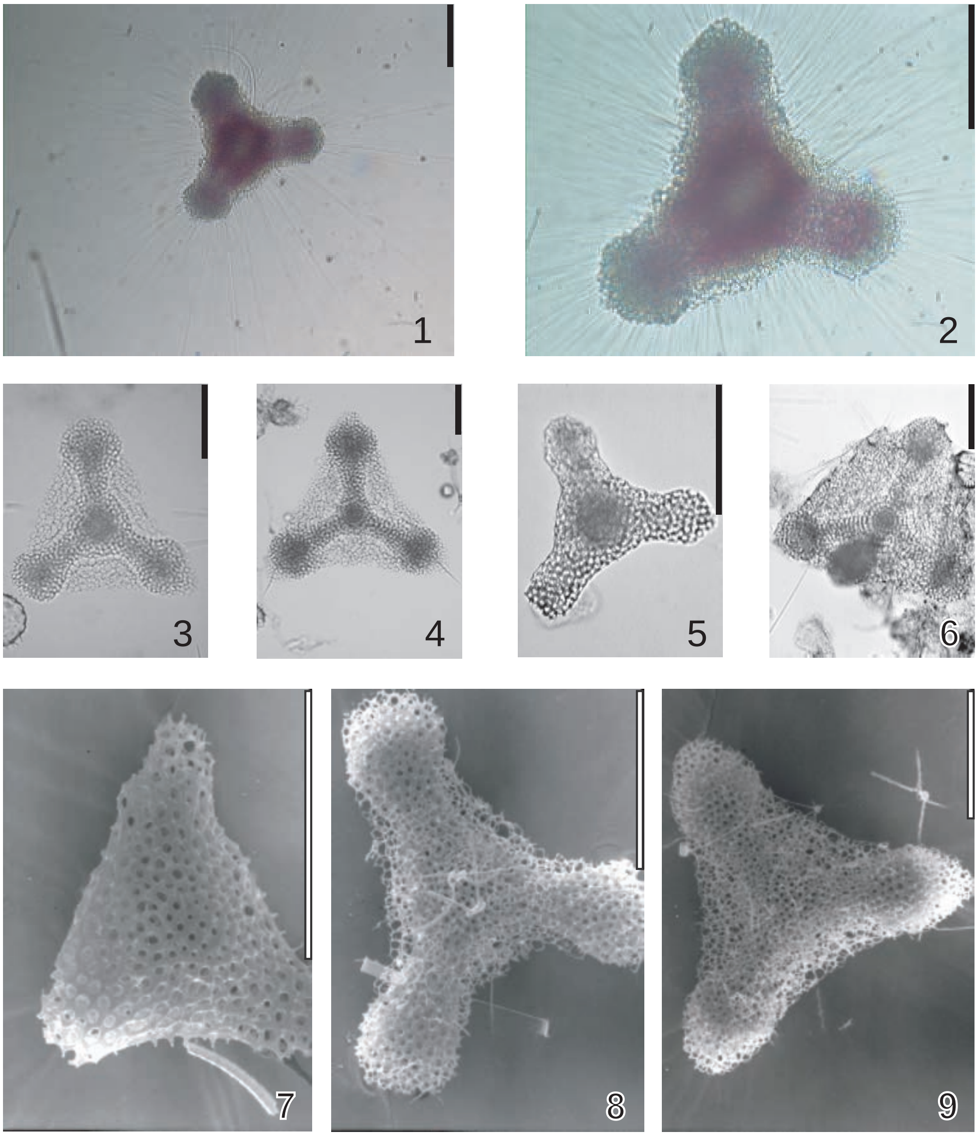

Fig. 14. Photomicrographs of *Dictyocoryne profunda* Ehrenberg. Scales are 0.1 mm.

Euchitonia elegans (Ehrenberg)

Pteractis elegans Ehrenberg, 1873a, p. 319; 1873b, p. 299, pl. 8, fig. 3.
Euchitonia elegans (Ehrenberg), Nishimura and Yamauchi, 1984, p. 37-38, pl. 19, figs. 1-3, 7-9, 11, pl. 53, fig. 11.
Euchitonia elegans (Ehrenberg), Cheng and Yeh, 1989, p. 184, pl. 3, figs. 6, 14, 17, pl. 6, figs. 7, 13.
Euchitonia elegans (Ehrenberg), Takahashi, 1991, p. 80, pl. 16, figs. 1-6
Euchitonia elegans (Ehrenberg), Sashida and Kurihara, 1999, p. 139, fig. 10.5, fig. 12.3.

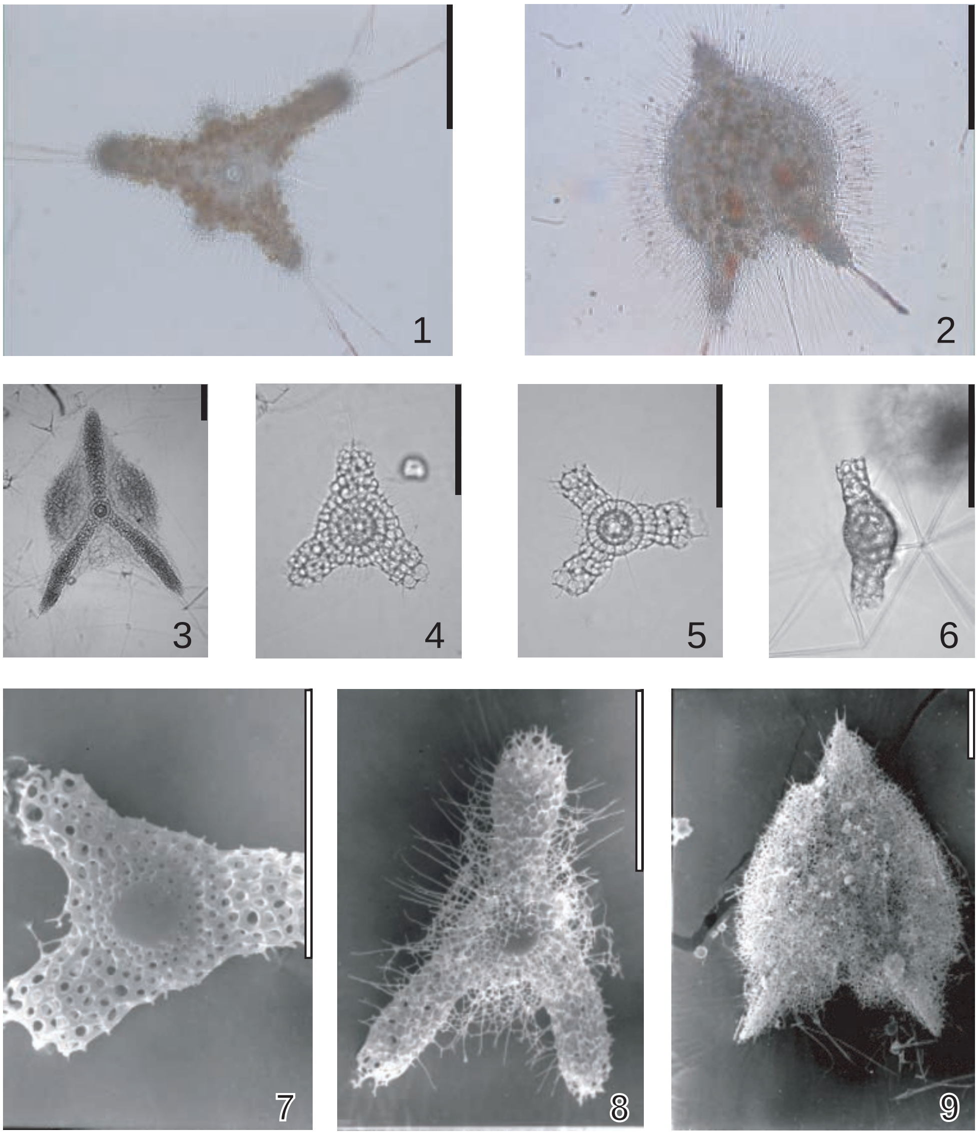

Fig. 15. Photomicrographs of *Euchitonia elegans* (Ehrenberg). Scales are 0.1 mm.

Acanthodesmia vinculata (Müller)

Lithocircus vinculatus Müller, 1856, p. 484.
*Acanthodesmia vinculata (*Müller): Müller, 1859, p. 30, pl. 1, figs. 4-7.
*Acanthodesmia vinculata (*Müller) group: Nishimura and Yamauchi, 1984, p. 67, pl. 22, figs. 1-3, 5-6, 8.
*Acanthodesmia vinculata (*Müller): Cheng and Yeh, 1989, p. 185, pl. 10, figs. 3-4, 7-8.
*Acanthodesmia vinculata (*Müller): Takahashi, 1991, p. 102, pl. 28, figs. 6-8.

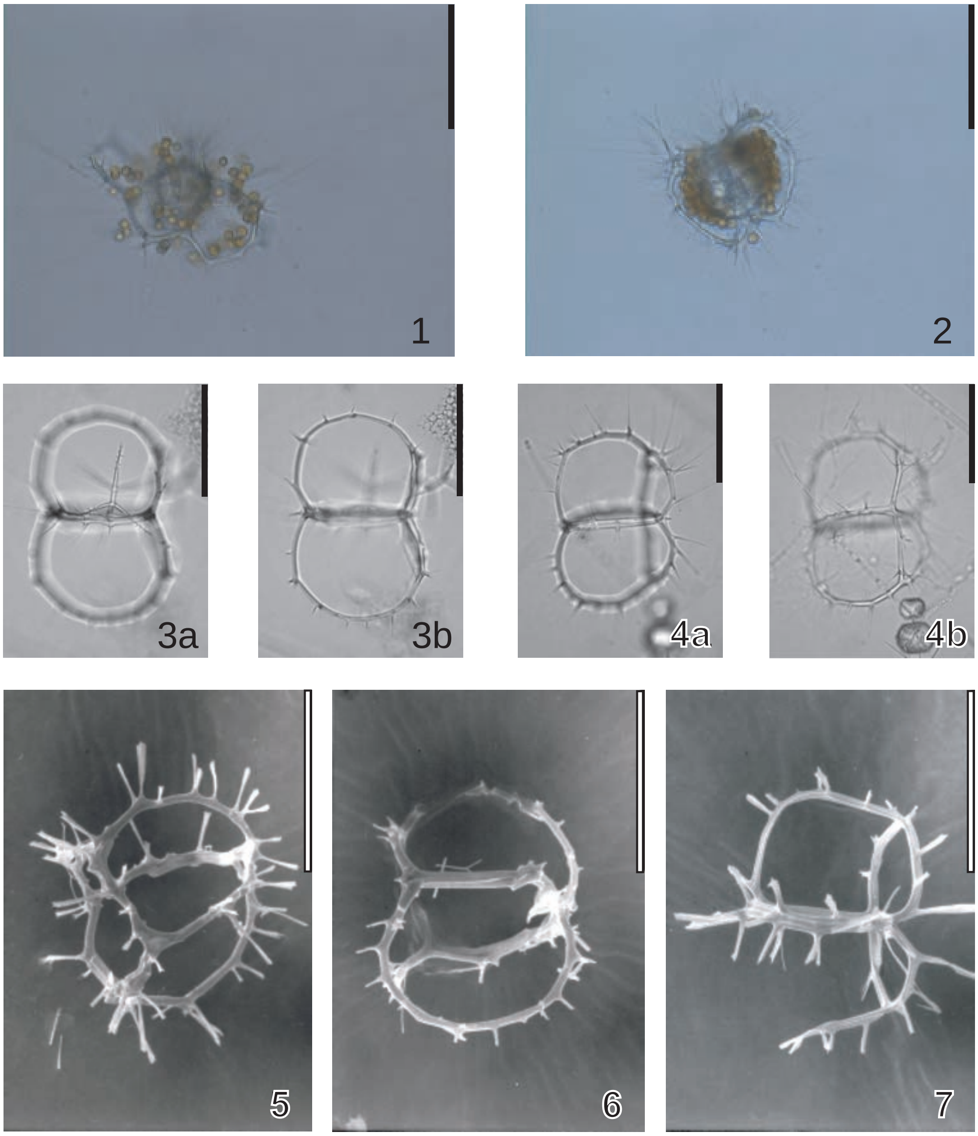

Fig. 16. Photomicrographs of *Acanthodesmia vinculata* (Müller). Scales are 0.1 mm.

Neosemantis distephanus Popofsky

Neosemantis distephanus Popofsky, 1913, p. 299, pl. 29, fig. 2.
Neosemantis distephanus Popofsky: Nishimura and Yamauchi, 1984, p. 47, pl. 22, figs. 7, 10.
Neosemantis distephanus Popofsky: Takahashi, 1991, p. 95, pl. 27, fig. 12.

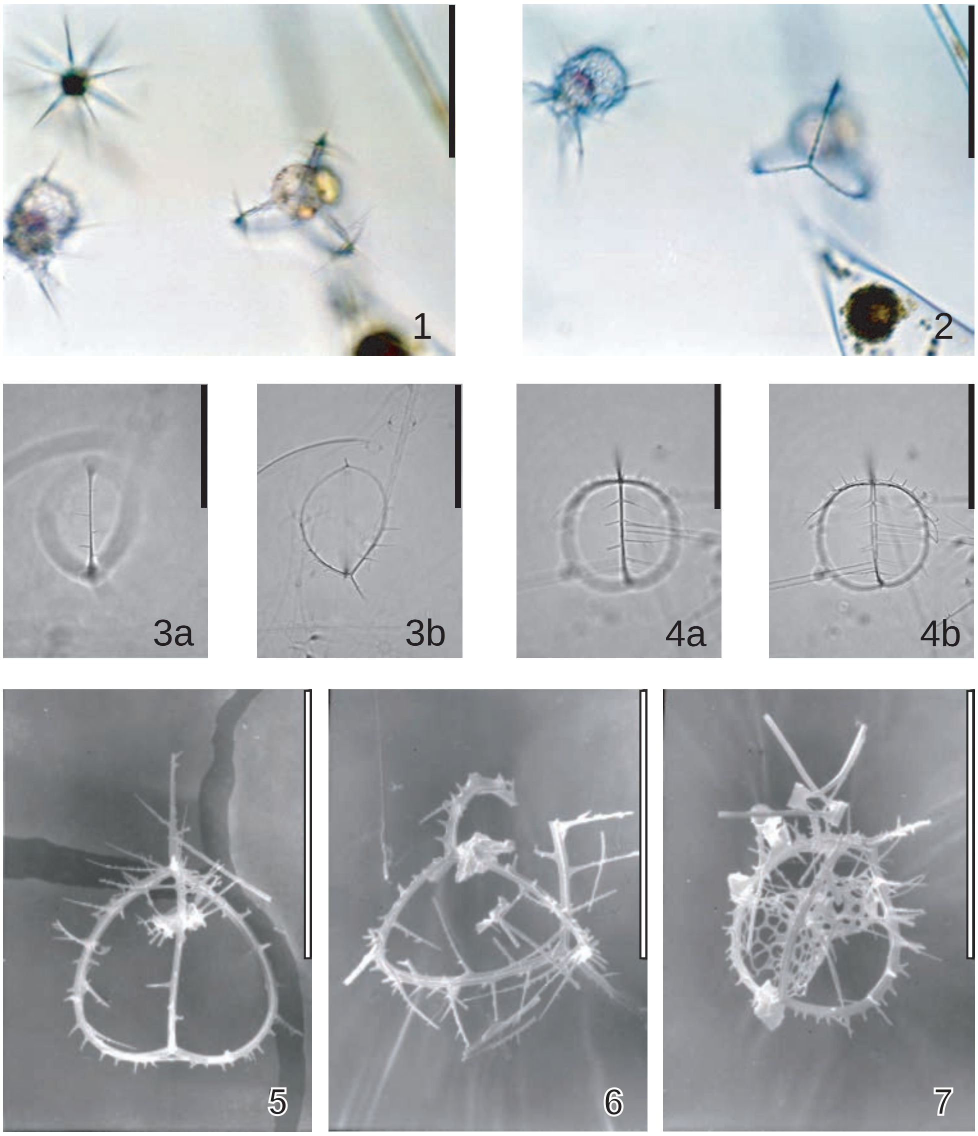

Fig. 17. Photomicrographs of *Neosemantis distephanus* Popofsky. Scales are 0.1 mm.

Lophospyris pentagona pentagona (Ehrenberg)

Ceratospyris pentagona Ehrenberg, 1873a, p. 303; 1873b, p. 286-287, pl. 10, fig. 15.
Lophospyris pentagona pentagona (Ehrenberg): Nishimura and Yamauchi, 1984, p. 68, pl. 22, figs. 14-15.
Lophospyris pentagona pentagona (Ehrenberg): Cheng and Yeh, 1989, p. 185-186, pl. 5, figs. 11-12, 14-16.
Lophospyris pentagona pentagona (Ehrenberg): Takahashi, 1991, p. 102, pl. 28, figs. 9-14.

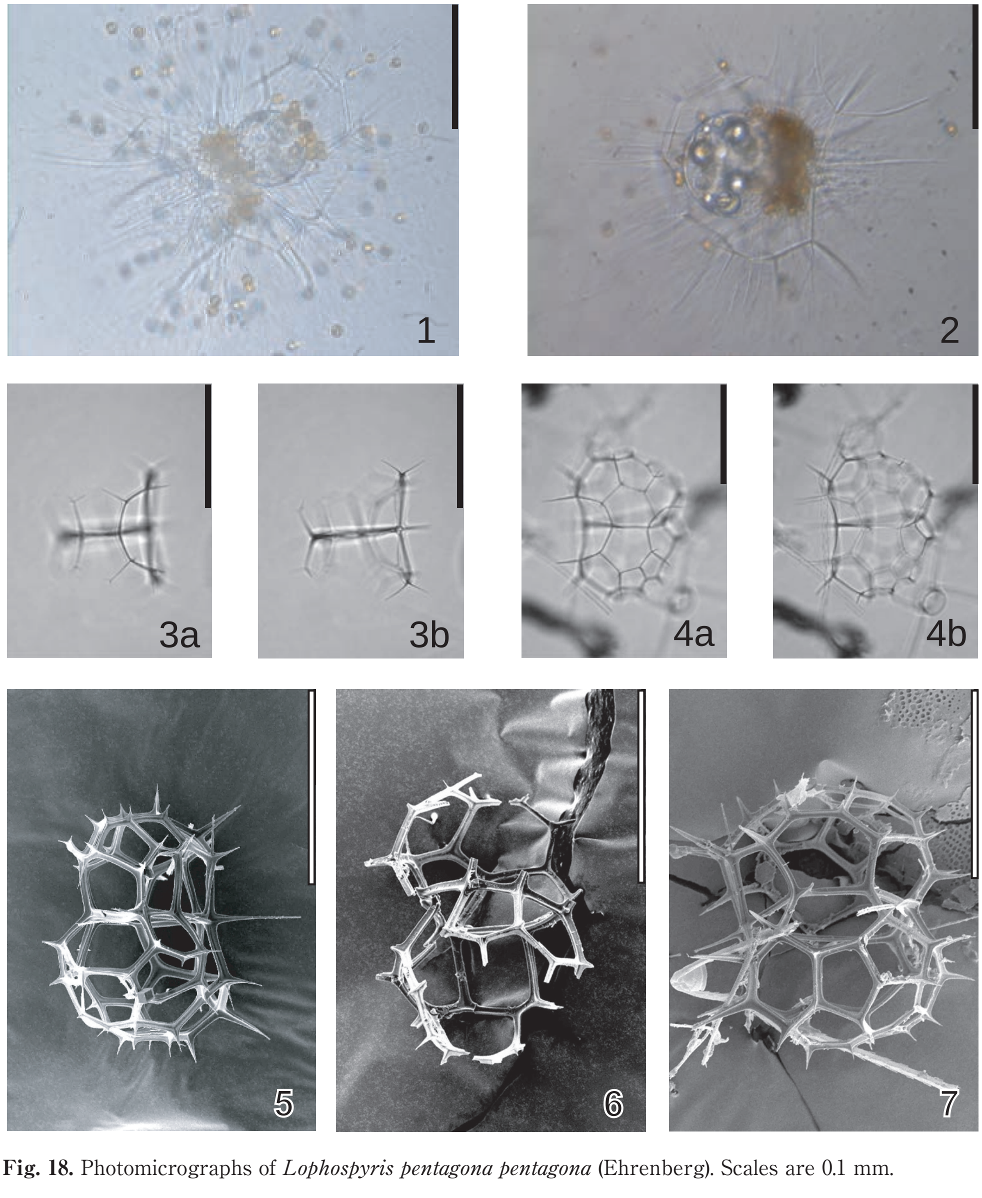

Fig. 18. Photomicrographs of *Lophospyris pentagona pentagona* (Ehrenberg). Scales are 0.1 mm.

Pseudocubus obeliscus Haeckel

Pseudocubus obeliscus Haeckel, 1887, p. 1010, pl. 94, fig. 11.
Pseudocubus obeliscus Haeckel: Takahashi, 1991, p. 95, pl. 26, fig. 1.
Pseudocubus obeliscus Haeckel: Sashida and Kurihara, 1999, p. 125, 127, figs. 7. 20-21.

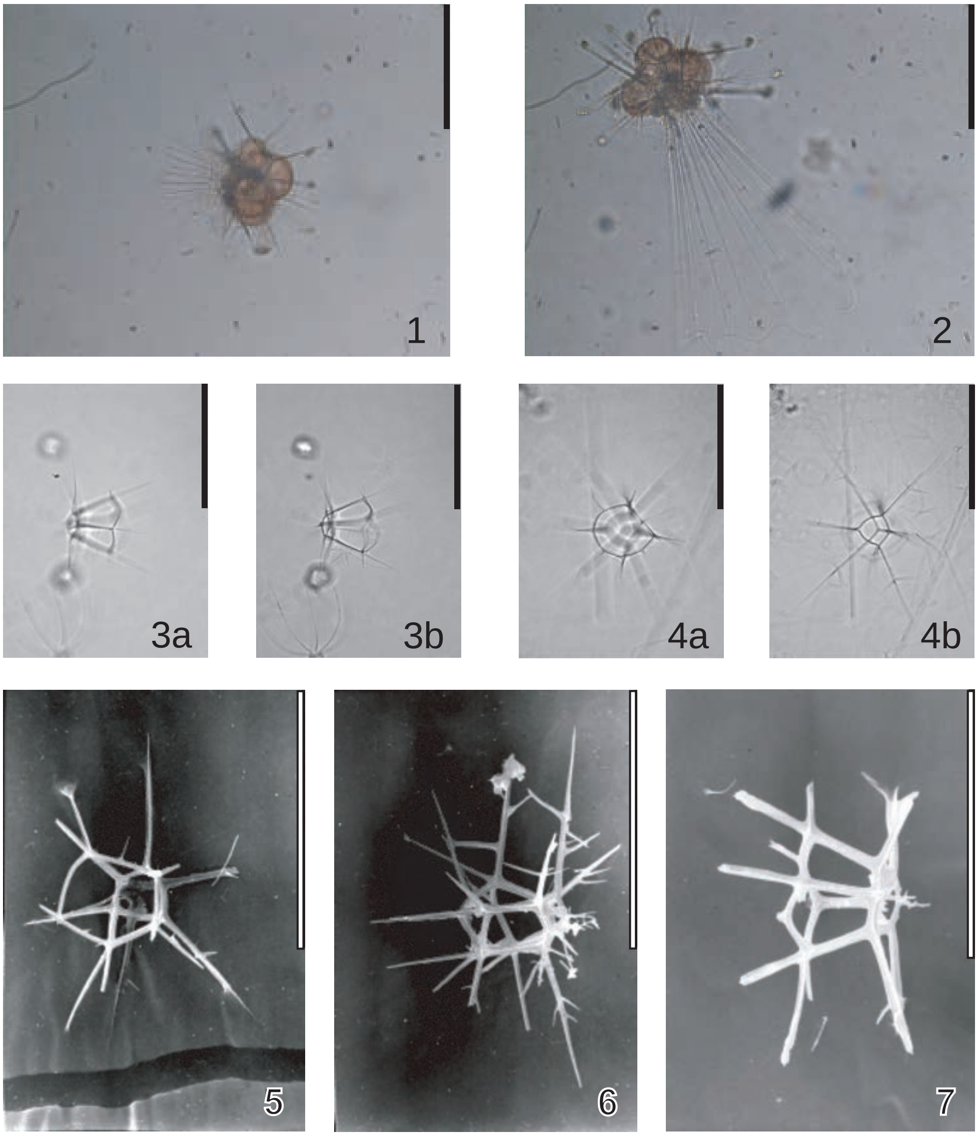

Fig. 19. Photomicrographs of *Pseudocubus obeliscus* Haeckel. Scales are 0.1 mm.

Callimitra emmae Haeckel

Callimitra emmae Haeckel, 1887, p. 1218, pl. 63, fig. 3-4.
Callimitra emmae Haeckel: Takahashi, 1991, p. 99, pl. 26, fig. 14.

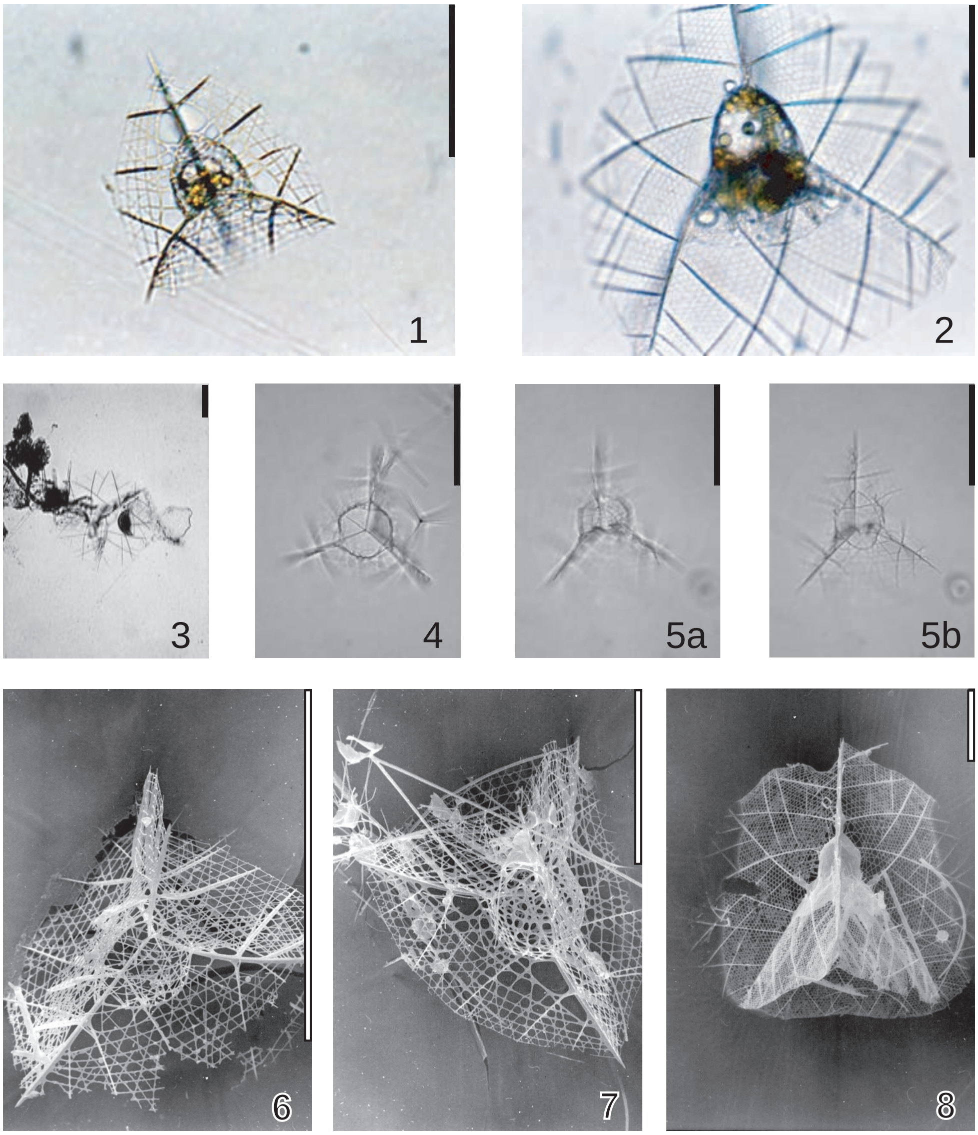

Fig. 20. Photomicrographs of *Callimitra emmae* Haeckel. Scales are 0.1 mm.

Peromelissa phalacra Haeckel

Peromelissa phalacra Haeckel, 1887, p. 1236-1237, pl. 57, fig. 11.
Peromelissa phalacra Haeckel: Nishimura and Yamauchi, 1984, p. 47, pl. 32, figs. 1, 12.
Peromelissa phalacra Haeckel: Takahashi, 1991, p. 97, pl. 25, figs. 11-15.
Peromelissa phalacra Haeckel: Sashida and Kurihara, 1999, p. 125, fig. 7.12, fig. 11.4.

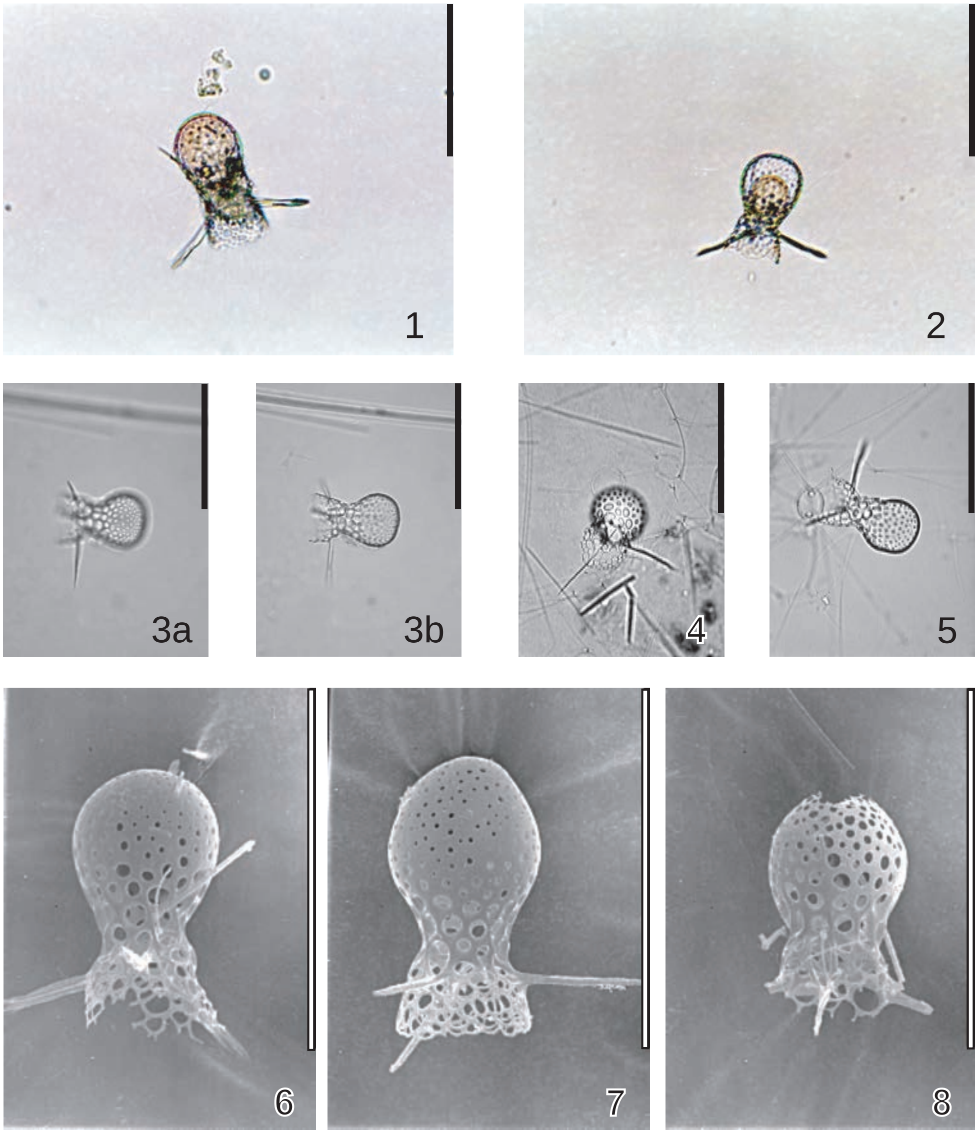

Fig. 21. Photomicrographs of *Peromelissa phalacra* Haeckel. Scales are 0.1 mm.

Lophophaena hispida (Ehrenberg)

Dictyocephalus hispidus Ehrenberg, 1862, p. 298; 1873b, p. 288-289, pl. 5, fig. 18.
Lophophaena hispida (Ehrenberg): Nishimura and Yamauchi, 1984, p. 46, pl. 32, figs. 6-7.
Lophophaena cylindrica (Cleve): Takahashi, 1991, p. 96, pl. 25, figs. 4-5, non fig. 3.

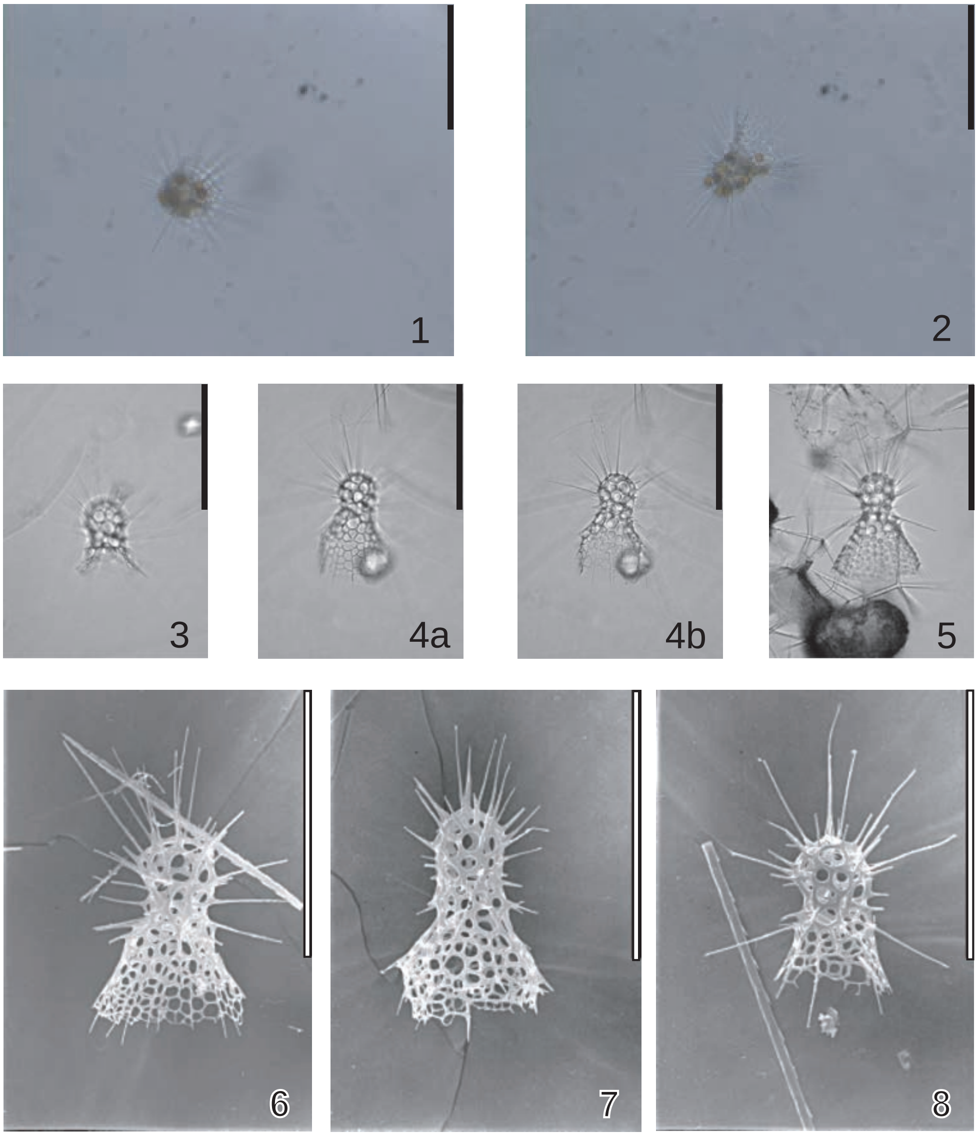

Fig. 22. Photomicrographs of *Lophophaena hispida* (Ehrenberg). Scales are 0.1 mm.

Pterocanium praetextum praetextum (Ehrenberg)

Lychnocanium praetextum Ehrenberg, 1873a, p. 316; 1873b, p. 296-297, pl. 10, fig. 2.
Pterocanium praetextum praetextum (Ehrenberg): Nishimura and Yamauchi, 1984, p. 60-61, pl. 30, figs. 1-2, 4, 7.
Pterocanium praetextum praetextum (Ehrenberg): Cheng and Yeh, 1989, p. 187, pl. 4, fig. 1, pl. 9, figs. 3-6.
Pterocanium praetextum praetextum (Ehrenberg): Takahashi, 1991, p. 115, pl. 36, figs. 15-18.
Pterocanium praetextum praetextum (Ehrenberg): Sashida and Kurihara, 1999, p. 130, figs. 6. 1-3, 5, 8-10, fig. 11. 10.

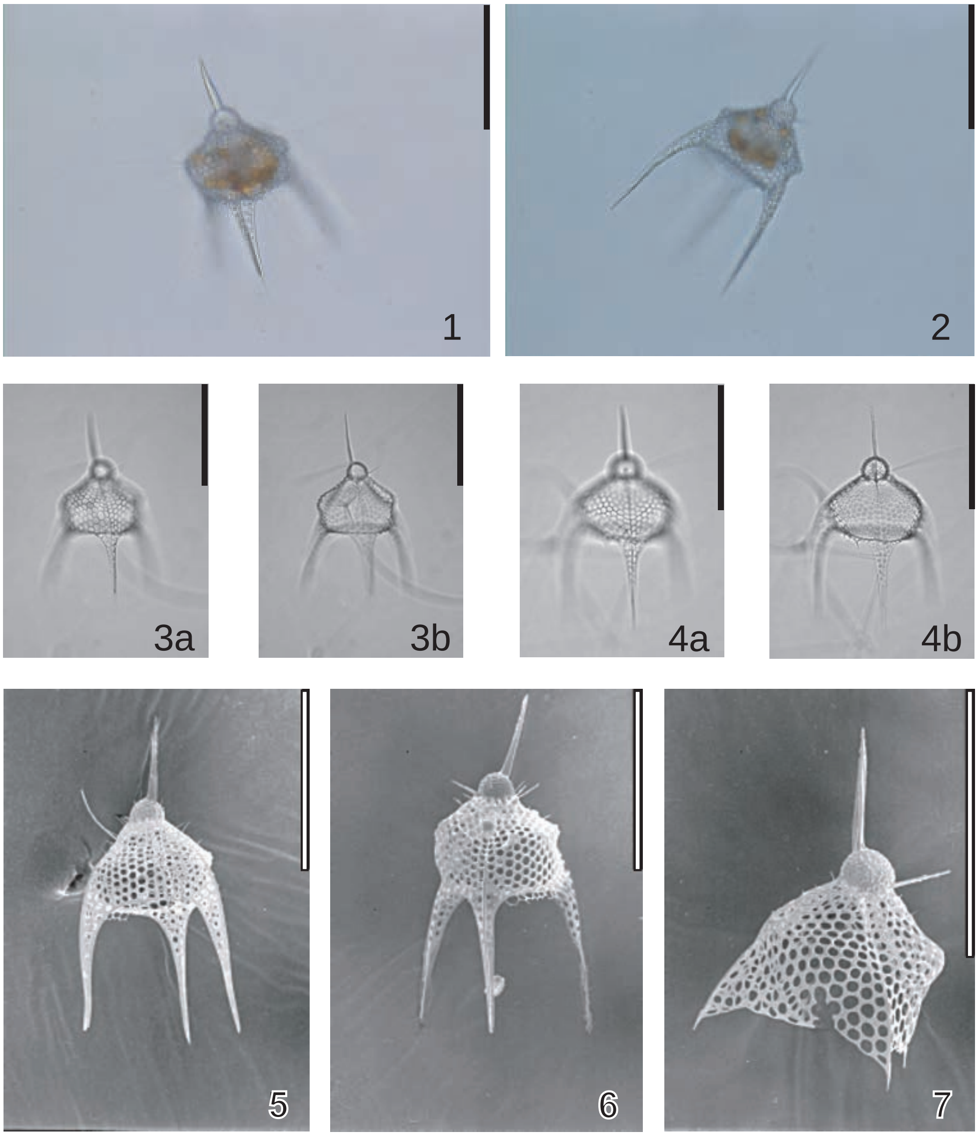

Fig. 23. Photomicrographs of *Pterocanium praetextum praetextum* (Ehrenberg). Scales are 0.1 mm.

Eucyrtidium hexagonatum Haeckel

Eucyrtidium hexagonatum Haeckel, 1887, p. 1489, pl. 80, fig. 11.
Eucyrtidium hexagonatum Haeckel: Nishimura and Yamauchi, 1984, p. 57, pl. 39, fig. 2, non fig. 11, pl. 56, fig. 4.
Eucyrtidium cienkowskii Haeckel: Cheng and Yeh, 1989, p. 186, pl. 4, fig. 5, non fig. 4, pl. 9, figs. 13-16.
Stichopodium dictyopodium Haeckel: Cheng and Yeh, 1989, p. 187, pl. 4, fig. 9.
Eucyrtidium hexagonatum Haeckel: Takahashi, 1991, p. 124, pl. 42, figs. 18-19.
Eucyrtidium hexagonatum Haeckel: Sashida and Kurihara, 1999, p. 121, figs. 5.3-6, 15-16, 19, fig. 11.11.
Eucyrtidium hexagonatum Haeckel: Sugiyama et al., 2008, p. 121, 214, 216, figs. 3.1-5, figs. 4.1-5, figs. 5.1-4, figs. 6.1-2.

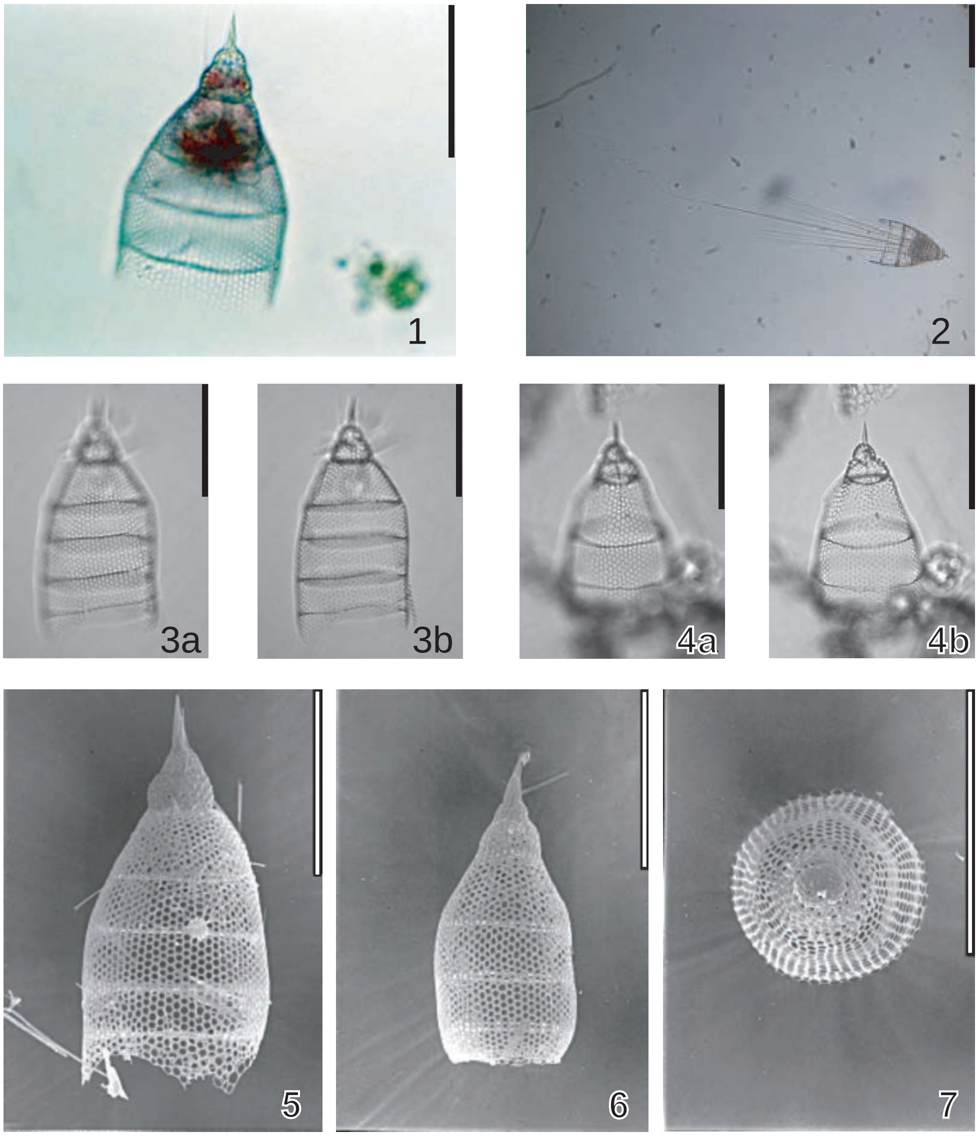

Fig. 24. Photomicrographs of *Eucyrtidium hexagonatum* Haeckel. Scales are 0.1 mm.

Eucyrtidium hexastichum (Haeckel)

Lithostrobus hexastichus Haeckel, 1887, p. 1470, pl. 80, fig. 15.
Eucyrtidium hexastichum (Haeckel): Nishimura and Yamauchi, 1984, p. 57, pl. 39, figs. 9-10.
Eucyrtidium hexastichum (Haeckel): Takahashi, 1991, p. 125, pl. 42, fig. 22.
Eucyrtidium hexastichum (Haeckel): Sashida and Kurihara, 1999, p. 121, figs. 5.7-8, non fig. 11.6.

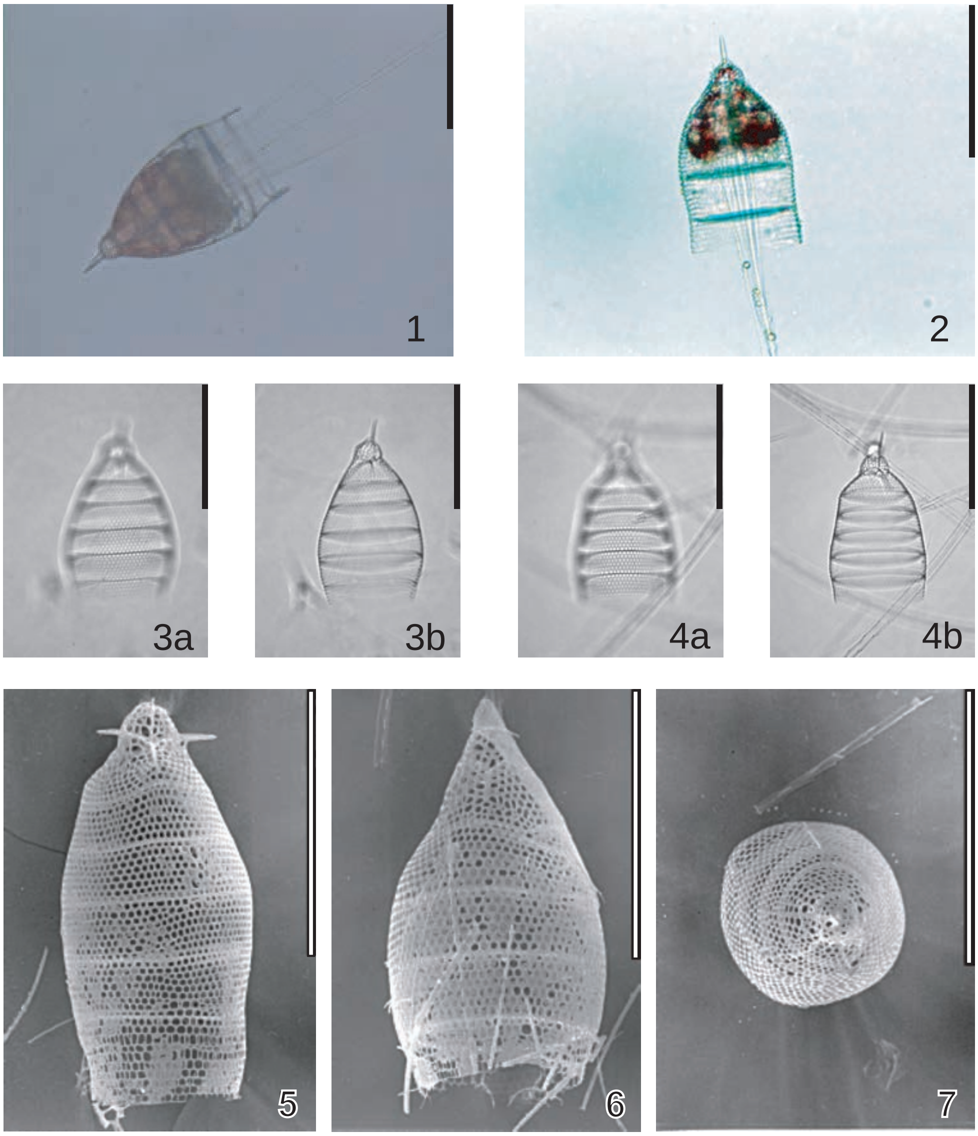

Fig. 25. Photomicrographs of *Eucyrtidium hexastichum* (Haeckel). Scales are 0.1 mm.

Pterocorys campanula Haeckel

Pterocorys campanula Haeckel, 1887, p. 1316, pl. 71, fig. 3.
Stichopilium campanulatum Haeckel: Nishimura and Yamauchi, 1984, p. 62, pl. 35, fig. 7.
Pterocorys campanula Haeckel: Cheng and Yeh, 1989, p. 186, pl. 9, figs. 11-12.
Pterocorys campanula Haeckel: Takahashi, 1991, p. 124, pl. 42, figs. 5-8.
Pterocorys campanula Haeckel: Sashida and Kurihara, 1999, p. 127, fig. 6.14, fig. 11.3, non figs. 5.17-18, fig. 6.18.

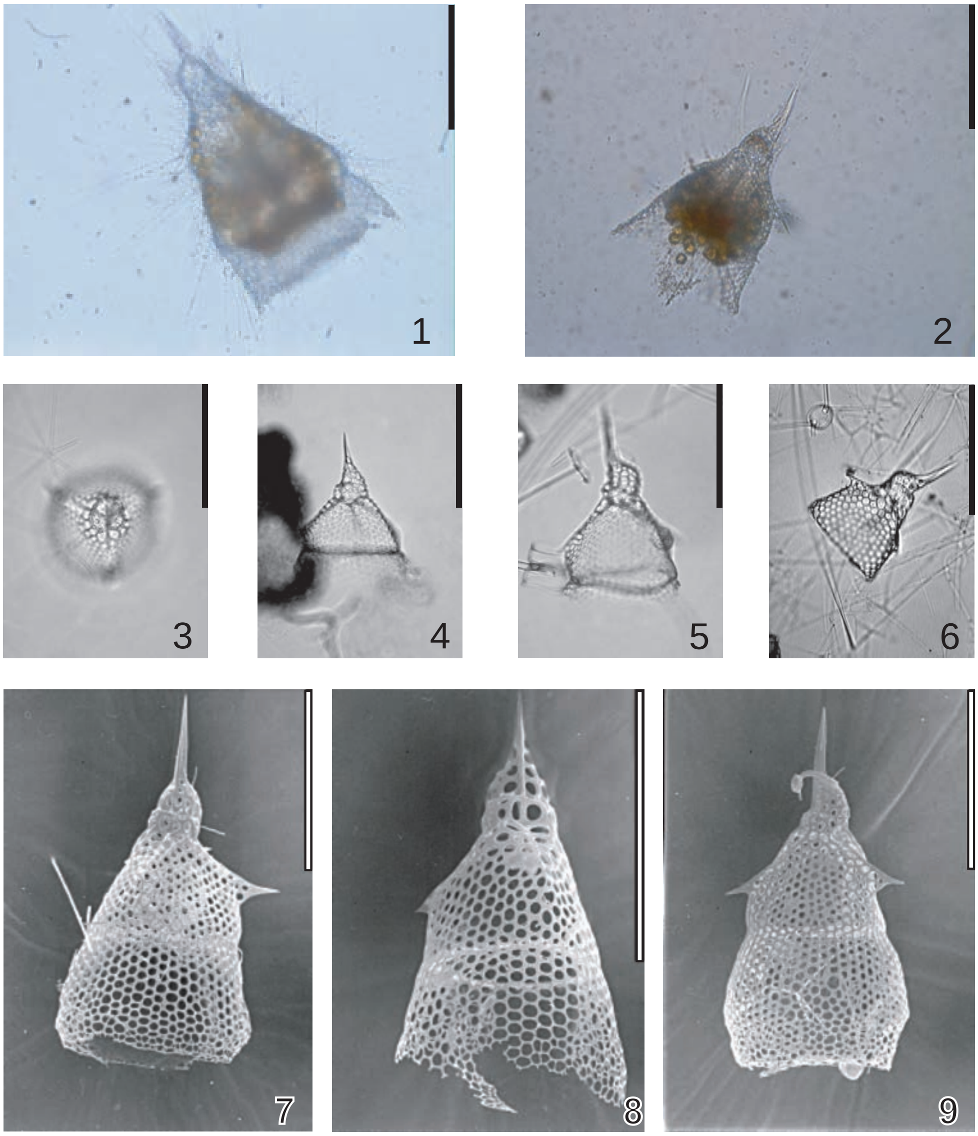

Fig. 26. Photomicrographs of *Pterocorys zancleus* Müller. Scales are 0.1 mm.

Pterocorys zancleus (Müller)

Eucyrtidium zancleus Müller, 1855, p. 672; 1859, p. 41, pl. 6, figs. 1-3.
Pterocorys zancleus (Müller): Nishimura and Yamauchi, 1984, p. 63, pl. 38, figs. 1, 3-5, pl. 56, fig. 9.
Pterocorys zancleus (Müller): Takahashi, 1991, p. 123, pl. 42, figs. 1-4.
Pterocorys zancleus (Müller): Sugiyama et al., 2008, p. 216, 219, figs. 7.1-6.

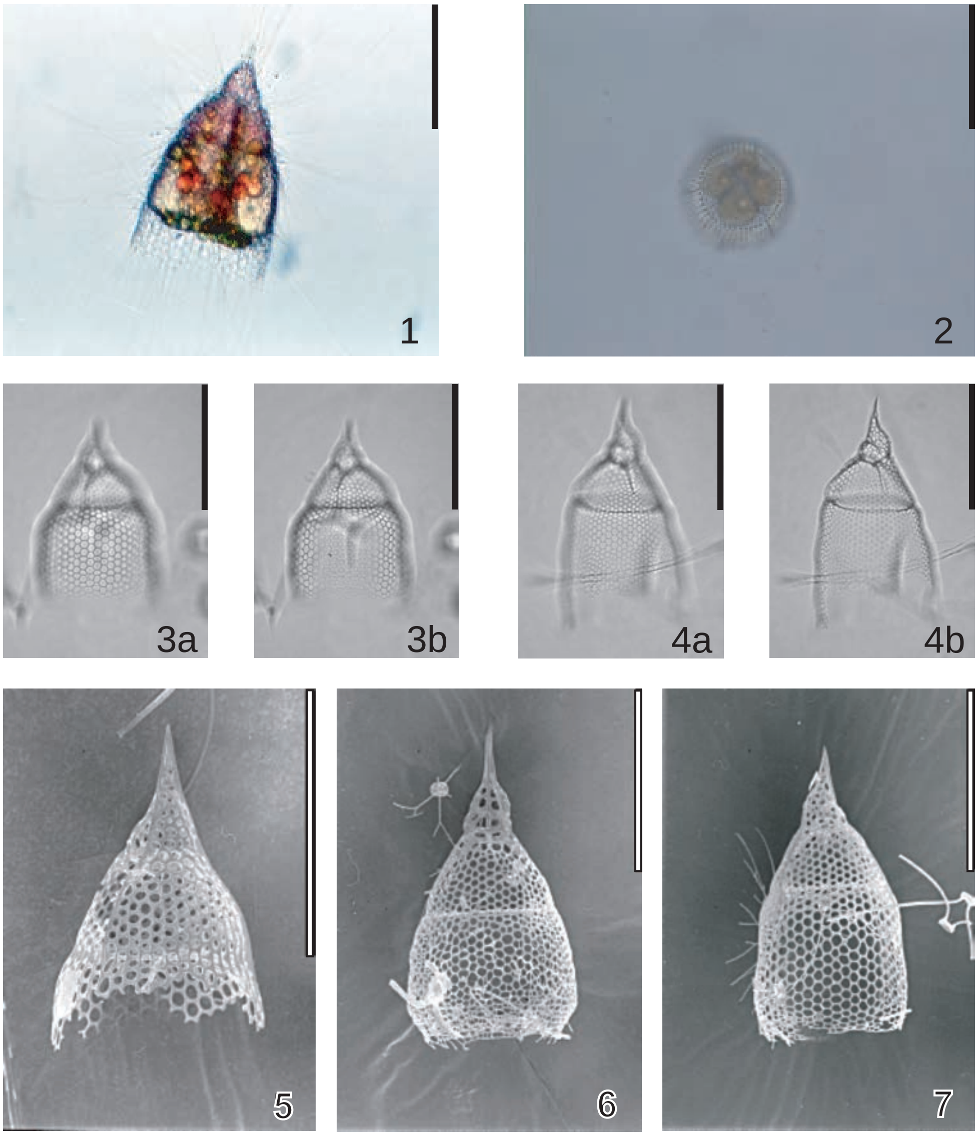

Fig. 27. Photomicrographs of *Pterocorys campanula* Haeckel. Scales are 0.1 mm.

Theocorythium trachelium trachelium (Ehrenberg)

Eucyrtidium trachelius Ehrenberg, 1873a, p. 312; 1873b, p. 292-293, pl. 7, fig. 8.
Theocorythium trachelium trachelium (Ehrenberg): Nishimura and Yamauchi, 1984, p. 64, pl. 38, figs. 9-12.
Theocorythium trachelium (Ehrenberg): Cheng and Yeh, 1989, p. 187, pl. 10, figs. 11-13.
Theocorythium trachelium trachelium (Ehrenberg): Takahashi, 1991, p. 121, pl. 40, figs. 15-16.
Theocorythium trachelium trachelium (Ehrenberg): Sashida and Kurihara, 1999, p. 132, figs. 5.20-21, fig. 7.8.

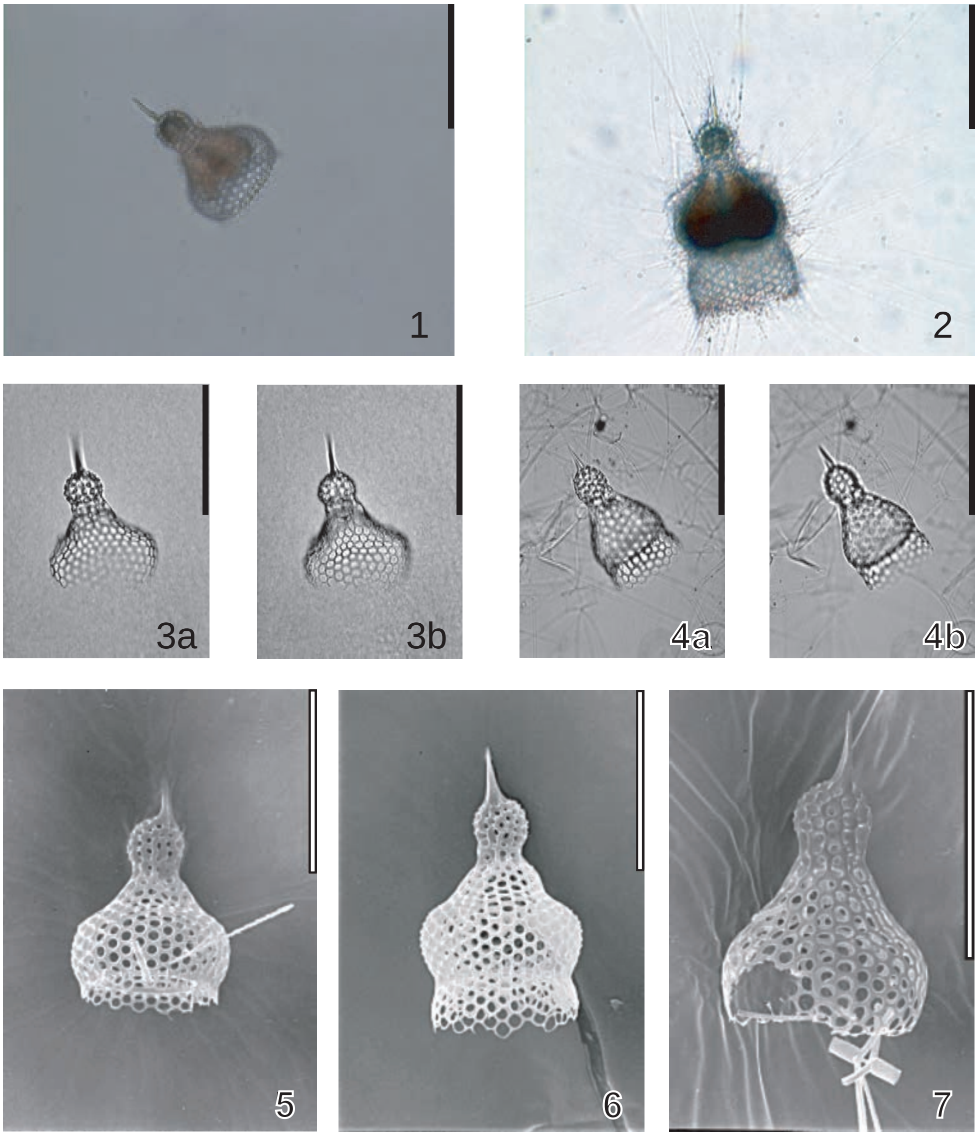

Fig. 28. Photomicrographs of *Theocorythium trachelium trachelium* (Ehrenberg). Scales are 0.1 mm.

Spirocyrtis scalaris Haeckel

Spirocyrtis scalaris Haeckel, 1887, p. 1509, pl. 76, fig. 14.
Spirocyrtis scalaris Haeckel: Nishimura and Yamauchi, 1984, p. 65, pl. 40, figs. 6, 9-10, 14.
Spirocyrtis scalaris Haeckel: Cheng and Yeh, 1989, p. 186, pl. 9, fig. 17.
Spirocyrtis scalaris Haeckel: Takahashi, 1991, p. 127, pl. 44, figs. 1-2.

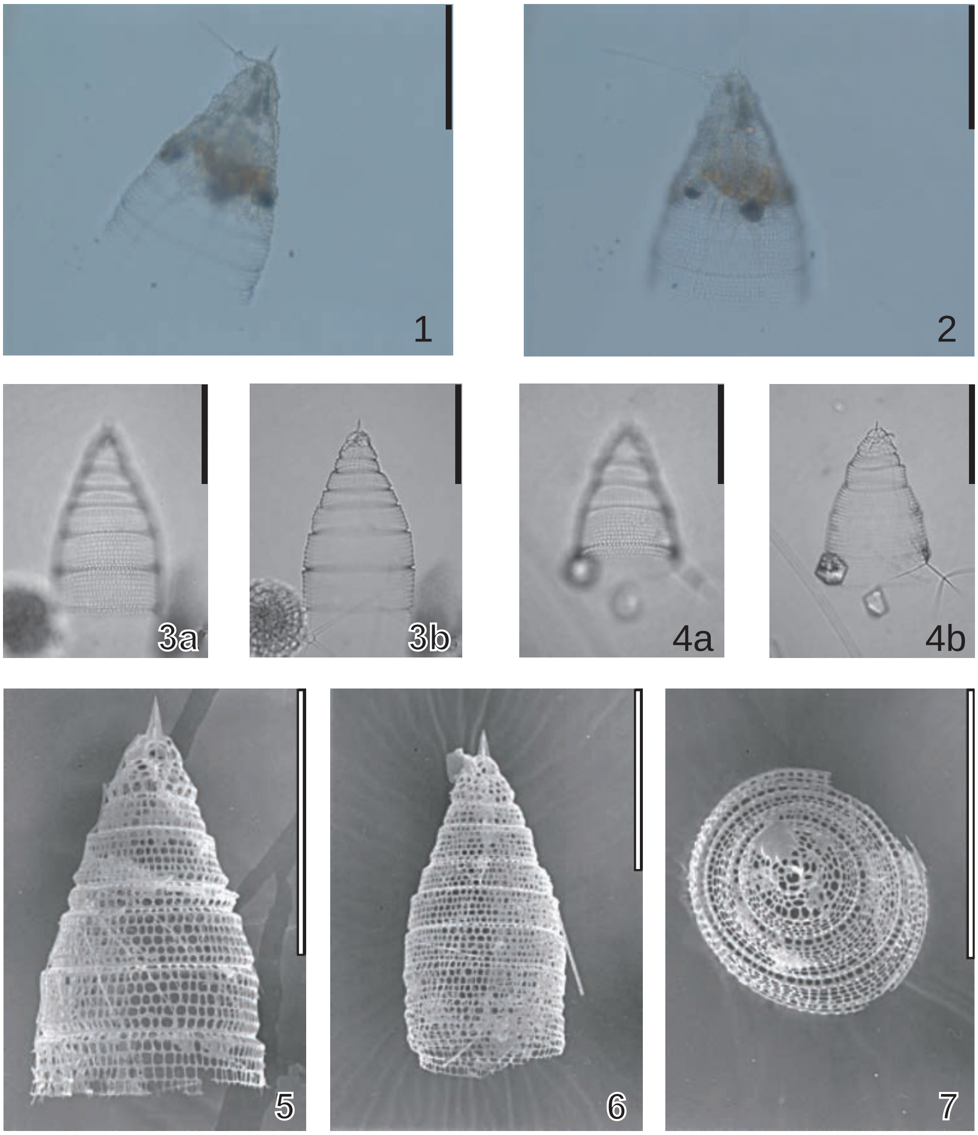

Fig. 29. Photomicrographs of *Spirocyrtis scalaris* Haeckel. Scales are 0.1 mm.

Botryocyrtis scutum (Harting)

Haliomma scutum Harting, 1863, p. 11, pl. 1, fig. 18.
Botryocyrtis scutum (Harting): Takahashi, 1991, p. 135, pl. 46, figs. 6-7.

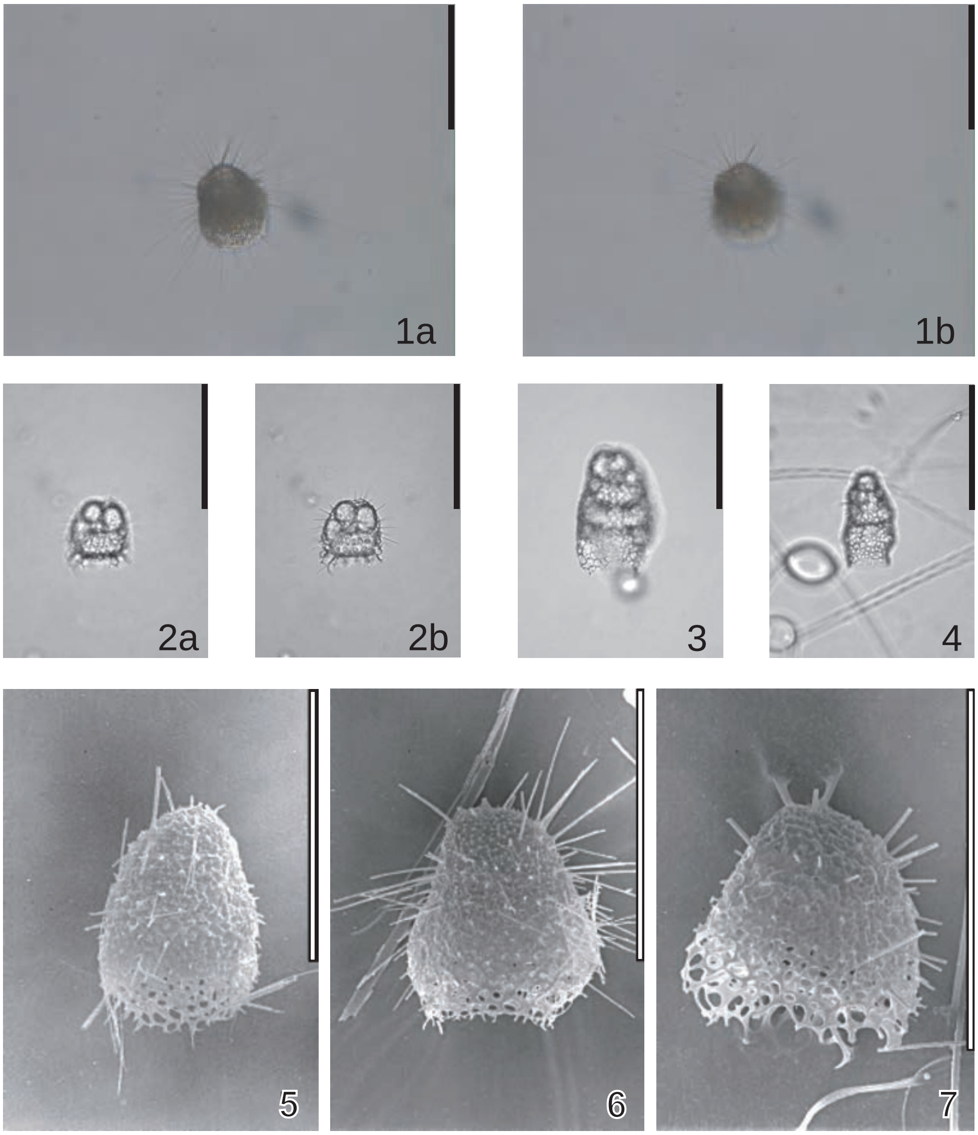

Fig. 30. Photomicrographs of *Botryocyrtis scutum* (Harting). Scales are 0.1 mm.

CONTENTS

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