Middle Miocene radiolarians from the Oidawara Formation, Mizunami Group, Gifu Prefecture, central Japan

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中部中新統瑞浪層群生俵累層産の放散虫化石

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(要　　旨)

中部中新統瑞浪層群生俵累層（*Calocycletta costata*帯，Riedel and Sanfilippo, 1978）からは，保存状態のきわめて良い放散虫化石が多産するものの，その全体像については今までにほとんど明らかにされていない．今回はフォーナ全体を論ずる為の予備的研究として，4新種を含む47種の産出を報告した．

(Abstract)

The radiolarians are abundant microfossils through the Middle Miocene Oidawara Formation, Mizunami Group, Gifu Prefecture. In order to provide their fundamental information, this paper reports the occurrence of 47 characteristic radiolarians including four new species.

Introduction

Many geologists and paleontologists have studied the Lower to Middle Miocene Mizunami Group distributed in the Mizunami basin, Gifu Prefecture, or its bearing fossils. However, radiolarian studies on this group are very far from sufficiently extensiveness, although the uppermost Oidawara Formation is extremely rich in siliceous organic remains.

Our provisional investigations have proved that the radiolarian preservation is excellent, perhaps the best in the Japanese Neogene deposits, and the diversity is also very high. Such a situation will be favorable for considering paleoecology of radiolarians, taking account of results obtainable in future from the neighboring Morozaki, Ichishi and Iwamura Groups which also abundantly yield radiolarians (Fig. 1)： These deposits are thought to be contemporaneous heterotopic facies accumulated in a gulf and, further fortunately, well understood about paleoenvironmental problems based on other fossils or geological

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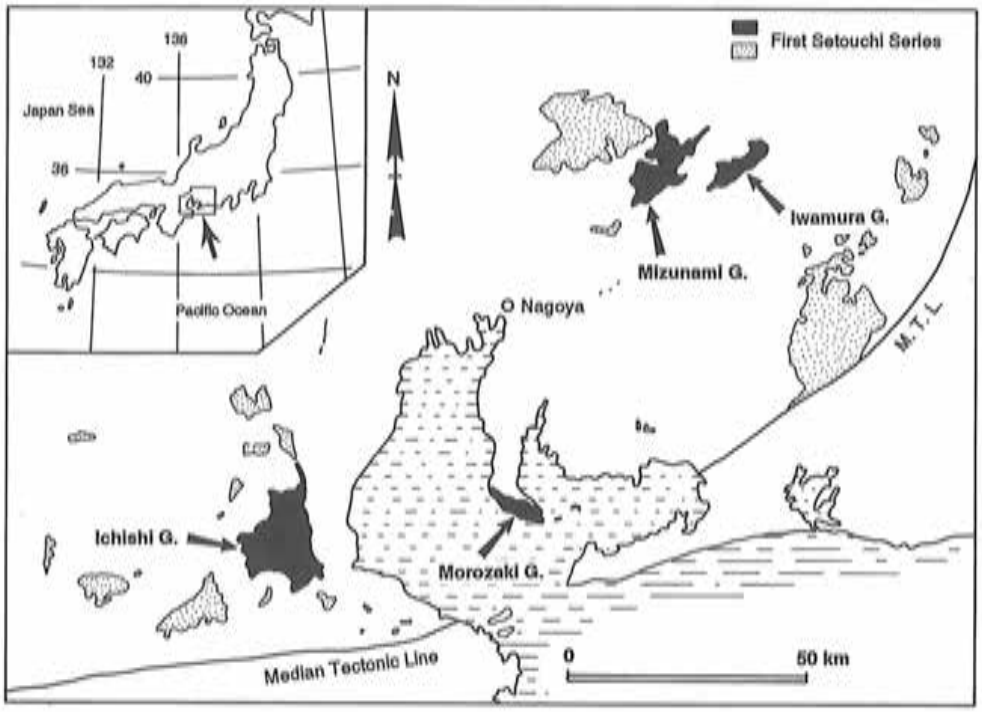


Fig 1 : Index map showing the locations of Miocene deposits in central Japan.

evidence (Itoigawa and Shibata, 1973 ; Shibata, 1985, etc.).

In order to attain the intention, we are now accumulating information about stratigraphic distribution of radiolarians from those Miocene. Therefore, this study preliminarily aims at describing some of characteristic radiolarians from the Oidawara Formation, which is apparently below the first appearance datum plane of *Eucyrtidium asanoi* Sakai, 1980 (Sakai, 1984 ; Funayama, 1988) and correlative with the *Calocycletta costata* Zone by Riedel and Sanfilippo (1978). Spongodiscids and litheliids, main constituent of the Oidawara fauna, are unfortunately omitted in this time because of their insufficiently known taxonomy. Hexalonchids, pyloniids, artostrobiids, etc., are also excluded for lack of space.

The location of the studied section shown in Fig. 2 and other details of the geologic setting are mentioned in Sugiyama (in press).

Systematic paleontology

Some descriptive terms are given in Sugiyama (in press). Type and figured specimens are deposited in the Department of Earth and Planetary Sciences, School of Science, Nagoya University (ESN).

Spongoplegma nipponicum (Nakaseko)

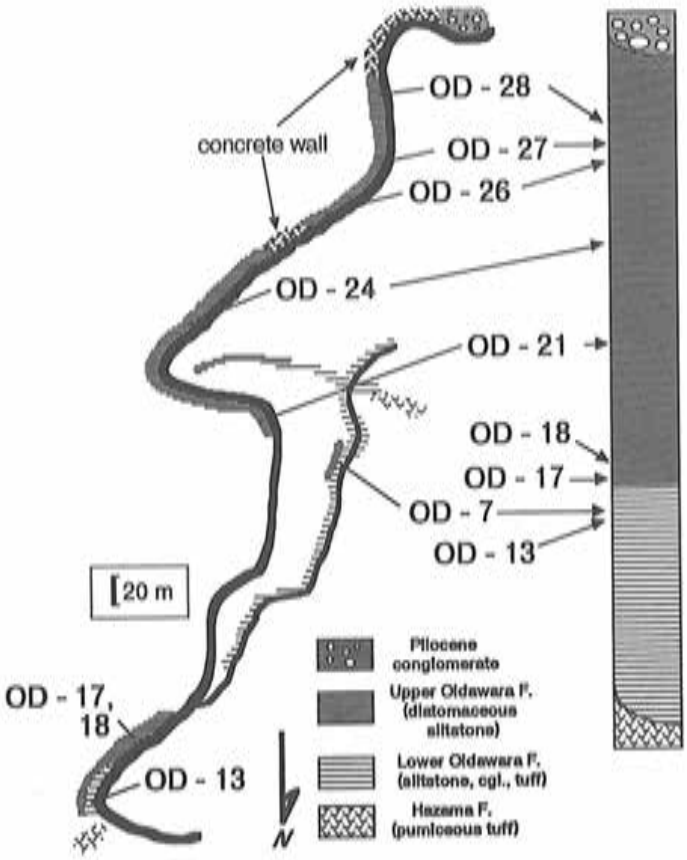


Fig. 2: Route map of the studied section. The location is given in Sugiyama (in press).

Pl. 15, figs. 8 a, 8 b

Rhodosphaera nipponica Nakaseko, 1955, p. 75, figs. 5 a-6.

Spongoplegma variabilium Nakaseko

Pl. 15, figs. 5, 9 a-10

Spongoplegma variabilium Nakaseko, 1971, p. 54, pl. 1, figs. 1 a-3.

The cortex is variable from single to double or possibly composed of more layers. In this study specimens without a rough sphere between the cortical and medullary shells are admitted to this species. However, as pointed out by Nakaseko and Nishimura (1974), this species may be a junior objective synonym of *S. nipponicum*.

Didymocyrtis tubaria (Haeckel)

Pl. 16, fig. 1

Pipettaria tubaria Haeckel, 1887, p. 339, pl. 39, fig. 15.

Didymocyrtis violina (Haeckel)

Pl. 16, fig. 2

Cannartus violina Haeckel, 1887, p. 358, pl. 39, fig. 10.

Excentrosphaerella sphaeroconcha Dumitrica
Pl. 12, figs. 1, 2 ; Pl. 16, fig. 3

Excentrosphaerella sphaeroconcha Dumitrica, 1978, p. 238, pl. 5, figs. 17, 18, 22.

The externality of the cortical shell is considerably variable from smooth to spinous. Moreover, there are many individuals having a single or triple cortical shell.

Excentrococcus annulatus Dumitrica
Pl. 12, fig. 4 ; Pl. 16, fig. 4

Excentrococus annulatus Dumitrica, 1978, p. 238, pl. 2, fig. 12 ; pl. 5, figs. 19, 23.

Heliodiscus sp. aff. *H. echiniscus* Haeckel
Pl. 16, fig. 8

aff. *Heliodiscus echiniscus* Haeckel, 1887, p. 448, pl. 34, fig. 5.

The shell natures, including its internal structure, is similar to *H. echiniscus*, except that this species does not have thicker radial spines at all.

Periphaena decora Ehrenberg group
Pl. 16, figs. 5, 6

Periphaena decora Ehrenberg, 1873, p. 246 ; 1875, pl. 28, fig. 6.

Heliodiscus (*Heliodiscoma*) *saturnalis* Clark and Campbell, 1942, p. 41, pl. 3, figs.

Eccentricity of the inner medullary shell is hardly recognized.

Stylosphaera (?) *magnaporulosa* (Clark and Campbell)
Pl. 12, figs. 5-7, 10 ; Pl. 15, figs. 3, 4, 6, 7

Carposphaera (*Melittosphaera*) *magnaporulosa* Clark and Campbell, 1942, p. 21, pl. 5, figs. 15, 17, 21, 23.

Melittosphaera (*Melittosphaera*) *magnaporulosa* (Clark and Campbell) - Nakaseko, 1955, p.

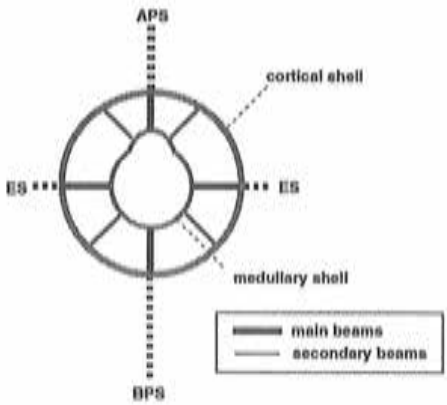


Fig. 3 : Schematic illustration of stylosphaerid shell structure.

71, pl. 1, fig. 2.

Melittosphaera (*Melittosphaera*) *magnaporulosa* (Clark and Campbell) *spinulosa* Nakaseko, 1955, p. 72, pl. 1, fig. 4.

Dorylonchidium (*Dorylonchidium*) *magnaporulosum* Nakaseko, 1955, p. 77, pl. 2, fig. 6.

? *Stylosphaera* (*Stylosphaerantha*) aff. *megaxyphos megaxyphos* Clark and Campbell - Nakaseko, 1955, p. 78, pl. 5, figs. 1 a, 1 b.

Sphaerostylus (*Sphaerostylus*) *yatsuoensis* Nakaseko, 1955, p. 79, pl. 3, figs. 1 a, 1 b.

Cortical shell small, spherical to subspherical; pores relatively large, circular; bars thick, oval in cross section, variable from smooth to nodulated. Secondary meshes sometimes developed from the bars to cover the pores. Medullary shell single, pyriform, composed of a smaller upper hemisphere and a larger lower hemisphere; pores small, circular; bars thin, circular in cross section. Intervening bars between the cortical and medullary shells consisting of two groups; vertically and horizontally placed main beams and secondary beams developed less than 45 up- or downward (termed by Nishimura, 1982). Main beams are thick and always three-bladed, whereas secondary beams are much thinner and variable from cylindrical to three-bladed. Secondary beams from the upper hemisphere are sometimes absent (Pl. 4, fig. 6). Two polar spines considerably variable from simple vestiges to long and three-bladed; the apical polar spine (APS) is as long as or shorter than the basal polar spine (BPS). Both of them are sometimes absent. Equatorial spines (ES) needle-like or bladed, variable in length and often absent.

Schematic illustration of the shell structure is given in Fig. 3. Nakaseko (1955) distinguished three species based on the development of spines, but his action was undoubtedly artificial. It is supported by the presence of infinite intermediate forms between them. Although we are unfortunately uncertain whether Nakaseko's (1958) materials are truly identical to Clark and Campbell's (1942) original *Melittosphaera magnaporulosa* or not, those forms are provisionally synonymized to it. Moreover, the generic assignment should be changed to a stylosphaerid genus because of the pyriform medullary shell, but the precise determine cannot be done due to our insufficiently known stylosphaerid taxonomy.

Stylosphaera (?) *timmsi* (Campbell and Clark)

Pl. 12, figs. 3, 4 ; Pl. 15, figs. 1, 2

Lithatractus timmsi Campbell and Clark, 1944, pp. 18, 19, pl. 2, figs. 18, 19.

This species is conspecific to *Lithatractus tochigiensis* illustrated by Nakaseko and Sugano (1973, 1975) but the latter species is *nomen nudum*. The original description by Campbell and Clark (1944) mentioned that the species has equal polar spines, but it is obviously mistaken. The relationship between the external spines and internal shell structure completely agrees with the preceding species except that APS of this species is never so long. Moreover, many individuals have polar spines crossing one another at an obtuse angle. The generic assignment is tentative as well as the preceding species.

Axoprunum bispiculum (Popofsky) group

Pl. 12, fig. 9 ; Pl. 16, figs. 7, 9 a, 9 b

Stauracontarium bispiculum Popofsky, 1912, p. 91, pl. 2, fig. 2.
Druppatractus aquilonius Hays, 1970, p. 214, pl. 1, figs. 4, 5.

Stylatractus yatsuoensis Nakaseko and *S. japonica* Nakaseko illustrated by Nakaseko and Sugano (1975) are conspecific to this species but they are *nomen nudum*.

Xiphosphaerantha angelina (Campbell and Clark) group
Pl. 16, figs. 10, 11 a, 11 b
Stylosphaera angelina Campbell and Clark, 1944, p. 12, pl. 1, figs. 14-20.

Dendrospyris (?) *suganoi* sp. nov.
Pl. 13, figs. 4, 5; Pl. 20, figs. 5-6 c

Primary cephalic bars thick, oval in cross section, bearing large, irregularly sculptured nodes at the junctions. In typical specimens delicate secondary meshes, free from the cephalic bars, are densely present among the nodes. A extending upward from sagittal ring to form a small spine outside. Two I thicker than two L, connected to a basal ring which is formed of arches two DI, two LI and LL, and always independent of dorsal side of shell wall. The development of Ax is weak, sometimes hardly recognized. Collar stricture indistinct externally. Thorax elliptical in cross section, slightly tapered or flared distally, with three or more bladed terminal teeth including prolongations of D and two L. Thoracic bars thicker than cephalic ones, forming irregular shaped pores of various size. Characteristic cephalic nodes gradually disappeared onto thorax and, instead of them, small and simple nodes appear on thoracic bars. Secondary meshes rarely developed between thoracic pores.

This species is one of the most abundant acanthodesmiids from the Oidawara Formation. Its generic assignment remains uncertain because acanthodesmiid taxonomy is poorly understood.

Height of test 120-180 μm; maximum width of test 95-140 μm; based on 35 specimens.

This species is named after Dr. Kozo Sugano of Osaka kyoiku University, who first investigated radiolarians from the Oidawara Formation, in honor of his contribution on Cenozoic radiolarian study.

Dendrospyris (?) *sakaii* sp. nov.
Pl. 13, figs. 3, 6; Pl. 20, figs. 3-4 c

Cephalis clearly two-lobate externally, without an apical spine; bars thinner than those of the preceding species, forming small, circular to oval cephalic pores and relatively large sagittal-lattice pores (Goll, 1958), bearing many, simple nodes on themselves. Secondary meshes are often present, but they are independent of the nodes and developed between pores. Two I are completely fused with the basal ring when one views from the base. Ax moderately developed. Thorax roughly latticed; the proximal part generally consisting of six or more longitudinal bars, one of which is a prolongation of D, and pierced by subcircular pores of large size, and the middle to distal part formed of thinner bars,

terminated in needle-like or distally forked teeth. Thoracic pores change into angular shape of smaller size. Secondary meshes possibly developed on the proximal part of thorax.

This species resembles *D.* (?) *suganoi* from which it is distinguished externally by the feature of cephalic secondary meshes and lacking an apical spine and internally by the amalgamation of two I and the basal ring and the development of Ax. It is also provisionally assigned to *Dendrospyris* in this study as well as the preceding species, but they should be separated at generic level in future judging from their skeletal differences. *D.* (?) *sakaii* also represents one of characteristic acanthodesmiids from the Oidawara Formation.

Height of test 115–185 μm; maximum width of test 95–143 μm; based on 22 specimens.

This species is named after Prof. Toyosaburo Sakai of Utsunomiya University in honor of his contribution on Cenozoic radiolarian study.

Dorcadospyris forcipata (Haeckel)

Dipodospyris forcipata Haeckel, 1887, p. 1037, pl. 85, fig. 1.

The specific concept follows Sanfilippo et al. (1985). For the illustration see Sugiyama (in press).

Ceratocyrtis stoermeri Goll and Bjørklund

Ceratocyrtis stoermeri Goll and Bjørklund, 1989, p. 731, pl. 5, figs. 5–9.

For the description and illustration see Sugiyama (in press).

Ceratocyrtis (?) *cantharoides* sp. nov.

Pl. 13, figs. 1, 2 ; Pl. 20, figs. 1–2 b

Eucephalis hemispherical, with numerous conical to needle-like by-spines, pierced by small, circular to oval pores; bars circular to oval in cross section. Ante- and postcephalic lobes moderately developed. Internal skeleton as with genus (see Sugiyama, in press) but Ax is always wart-like. A extending outside cephalis and having one or two, possibly more short branches on the dorsal side. They form a flat, characteristic apical spine. V also extending into a short spine which is bladed or non-bladed and flatted in the sagittal plane. Thorax variable in shape from inflated conical to nearly cylindrical; bars thicker than cephalic ones; pores subcircular, distally aligned in longitudinal rows. Thoracic margin with numerous needle-like terminal teeth prolonged from thoracic ribs.

The generic assignment remains tentative since its smaller test and wart-like Ax are rather different from other species of *Ceratocyrtis*.

Height of test except apical spine 85–140 μm; maximum width of thorax 78–118 μm; length of apical spine up to 53 μm; based on 24 specimens.

The name is derived from the Greek *kanhtaros*, a beetle, alluding to its spines.

Ceratocyrtis (?) sp. aff. *Ceratocyrtis stigi* (Bjørklund)

Pl. 13, fig. 13 ; Pl. 18, figs. 6 a, 6 b.

aff. *Lithomelissa stigi* Bjørklund, 1976, p. 1125, pl. 15, figs. 12–17.

This species somewhat resembles *C. stigi* in its general shape, but differs from it in having smaller pores aligned in longitudinal rows on the lower thorax and numerous terminal teeth at the thoracic margin. Its antecephalic lobe is not so pronounced externally, and thoracic shape is truncated frustum rather than campanulate. The internal skeletal structure is similar to *C.* (?) *cantharoides* sp. nov., but the apical spine of this species is not a prolongation of A but free from skeletal elements.

Pseudodictyophimus gracilipes (Bailey)

Pl. 18, fig. 2

Dictyophimus gracilipes Bailey, 1856, p. 4, pl. 1, fig. 8.

Eucenarium joergenseni (Dumitrica)

Pl. 18, figs. 1 a, 1 b

Clathromitra joergenseni Dumitrica, 1978, p. 240, pl. 7, fig. 1.

The thoracic length and ornamentations are variable among the examined specimens. This species represents one of the most characteristic radiolarians from the Toyohama Formation, Morozaki Group (listed as *Euscenium* sp. aff *E. tricolpium* in Table 1 of Sugiyama, 1992). Against the fact its occurrence in the Oidawara Formation is extremely rare.

Calocycletta (*Calocycletta*) *virginis* Haeckel

Pl. 19, fig. 6

Calocyclas (*Calocycletta*) *virginis* Haeckel, 1887, p. 1381

Calocycletta (*Calocyclissima*) costata (Riedel)

Pl. 14, fig. 11 ; Pl. 19, fig. 9

Calocyclas costata Riedel, 1959, p. 296, pl. 2, fig. 9.

Calocycletta mizunamiensis sp. nov.

Pl. 14, fig. 10 ; Pl. 19, fig. 2–5, 7 a-8

Calocycletta sp. - Sugano, 1976, pl. 8, figs. 5 a, 5 b.

aff. *Theocyrtis* a sp. - Nakaseko, 1963, p. 180, text-fig. 13, pl. 2, figs. 6 a, 6 b, 9 a, 9 b.

aff. *Theocyrtis* b sp. - Nakaseko, 1963, p. 181, text-fig. 14, pl. 2, fig. 5.

Cephalis small, subspherical, pierced by small number of circular pores, having a relatively short, proximally or completely three-bladed apical spine. Cephalic wall thickens as the blades become acute and complete, and the ornamentation by microgranular silica also disappears. Internal skeleton composed of A, D, two L, two I, V and Ax. A extending into the base of one blade situating on the dorsal side. D and two L extending downward along thoracic wall. Two arches AL as with genus, distinct from basal view. Ax generally well-developed, twiggy, extending to the base of thorax. Collar stricture distinct

externally, often marked by subcircular pores of relatively large size. Thorax hemispherical, with many longitudinal ridges between which circular pores are aligned in a line and hexagonally arranged. Lumbar stricture is fairly indistinct externally, whereas thorax and abdomen are internally partitioned by a thick septum which has two rows of circular pores on the circumference. Abdomen short, thin, cylindrical to inverted frustum, with many terminal lamella-like feet which are fragile and often broken off. Abdominal pores smaller than thoracic ones, aligned in lines between longitudinal ridges continued from thorax.

This species is distinguished from *C. virginis* by having longitudinal ridges on the thorax, although the shape of its cephalothorax is apparently common to *C. virginis*. Specimens with thick walled cephalis (Pl. 19, figs. 2, 3) have somewhat similar outline to *C. costata*, but differs from it in having a relatively short, bladed apical spine. Recently, Sanfilippo and Riedel (1992) distinguished three subgenera in *Calocycletta*, but the subgeneric assignment of *C. mizunamiensis* is reserved. Moreover, it is uncertain whether this species is an intermediate representative from *C. virginis* to *C. costata* or not.

Height of cephalothorax except apical spine 85–110 μm; maximum width of thorax 80–100 μm; length of apical spine 30–70 μm; based on 20 specimens.

The specific name is derived from the Mizunami Group, Mizunami City.

Lamprocyclas margatensis (Campbell and Clark)

Pl. 18, fig. 7

Calocyclas (*Calocycletta*) *margatensis* Campbell and Clark, 1944, p. 47, pl. 6, figs. 17, 18.

Lamprocyrtis hannai (Campbell and Clark)

Pl. 14, fig. 8 ; Pl. 18, figs. 5 a, 5 b

Calocyclas (*Calocycletta*) *hannai* Campbell and Clark, 1944, p. 48, pl. 6, figs. 21, 22.

Theocorythium cylindricum (Nakaseko)

Pl. 19, figs. 1 a-1 c

Calocyclas (*Calocycletta*) *cylindrica* Nakaseko, 1955, p. 101, pl. 9, figs, 8 a, 8 b.

Internal spicule of pterocorythid type: A extending upward, becoming a part of cephalic bars beyond the junction of two arches AL, and finally prolonged into one blade on the apical spine. D and two L extending downward along thoracic wall. Ax generally small.

Cycladophora subhumerus Lombari and Lazarus group

Pl. 13, figs. 11, 12 ; Pl. 18, fig. 3

cf. *Diplocyclas* ? a sp. - Nakaseko, 1963, p. 178, Text-fig. 11, pl. 2, figs. 3 a, 3 b.

Cycladophora cabrilloensis subhumerus Lombari and Lazarus, 1988, p. 120, pl. 8, figs. 7–12.

The examined specimens generally have well-developed cylindrical abdomen on which two or three horizontal alignment of pores are present. The lower thorax is also often cylindrical. The internal skeleton of theoperid type; A extending into a stout,

Abdomen is absent but other features well agree with *L.* (*C.*) *tanythorax*.

Lychnocanoma conica (Clark and Campbell)

Pl. 14, fig. 9

Lychnocanium (*Lychnocanella*) *conicum* Clark and Campbell, 1942, p. 71, pl. 9, fig. 38.
Lychnocanium nipponicum Nakaseko · Sugano, 1976, pl. 7, figs. 3 a, 3 b.

Lychnocanoma elongata (Vinassa de Regny)

Pl. 17, figs. 2 a, 2 b

Tetrahedrina elongata Vinassa de Regny, 1900, p. 243, pl. 2, fig. 31.

Internal spicule of theoperid type; D extends downward into the base of one foot; two L also extending into thoracic wall but without forming protrusions outside shell wall. Another foot situating at the ventral side of the sagittal plane is free from all internal skeleton.

This species has a quite peculiar relationship between the arrangement of two feet and the internal skeleton. Such a type of skeletal protrusion is somewhat similar to Jurassic species of the genera *Ares* De Wever, 1981, *Turanta* Pessagno and Blome, 1982, and *Parares* Takemura, 1986. The ventral foot of this species is, however, not a prolongation of V in contrast to those of the three genera.

Stichocorys armata (Haeckel)

Pl. 14, fig. 5

Cyrtophormis armata Haeckel, 1887, p. 1460, pl. 78, fig. 17.

Stichocorys delmontensis (Campbell and Clark)

Pl. 14, fig. 6

Eucyrtidium (*Eucyrtis*) *delmontense* Campbell and Clark, 1944, p. 56, pl. 7, figs. 19, 20.

Stichocorys (?) *johnsoni* Caulet group

Pl. 17, fig. 4

Stichocorys johnsoni Caulet, 1985, p. 851, pl. 6, figs. 5, 6.

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References

Bailey, J. W. (1856), Notice of microscopic forms found in the soundings of the Sea of

Kamtschatka. *Am. Jour. Sci. Arts*, ser. 2, **22**, 1-6.

Bjørklund, K. R. (1976), Radiolaria from the Norwegian Sea, Leg 38 of the Deep Sea Drilling Project. *In* Talwani, M., Udintsev, G., *et al.*, *Init. Repts. DSDP*, Washington (U. S. Govt. Printing Office), **38**, 1101-1168, pls. 1-24.

Campbell, A. S. and Clark, B. L. (1944), Miocene radiolarian faunas from southern California. *Geol. Soc. Am. Spec. Pap.*, no. 51, 1-76, pls. 1-7.

Caulet, J.-P. (1985), Radiolarians from the southwest Pacific. *In* Kennett, J. P., von der Borch, C. C., *et al.*, *Init. Repts. DSDP*, Washington (U. S. Govt. Printing Office), 90, 835-861, pls. 1-6.

Chen, P.-H. (1974), Some new Tertiary Radiolaria from Antarctic deep-sea sediments. *Micropaleont.*, **20** (4), 480-492, pls. 1-4.

Clark, B. L. and Campbell, A. S. (1942), Ecene radiolarian faunas from the Mt. Diablo area, California. *Geol. Soc. Amer. Spec. Paper*, no. 39, 1-112, pls. 1-9.

De Wever, P. (1981), Nassellaria (Radiolaires polycystines) du Lias de Turquie. *Rev. Micropaleont.*, **24** (4), 189-232.

Dumitrica, P. (1978), Badenian Radiolaria from Central Paratethys. *In* Brestenska, E., *Chronostratigraphie und Neostratotypen, Miozan der Zentralen Paratethys*, VEDA, Bratislava, **6**, 231-261.

Ehrenberg, C. G. (1873), Grössere Felsproben des Polycystinen-Mergels von Barbados mit weiteren Erlauterungen. *Kgl. Preuss. Akad. Wiss. Berlin, Ber.*, Jahre 1873, 213-263.

———1875 : Fortsetzung der mikrogeologischen Studien als Gesammt-Uebersicht der mikroskopischen Paläontologie gleichartig analysirter Gebirgsarten der Erde, mitspecieller Rucksicht auf den Polycystinen-Mergel von Barbados. *Kgl. Akad. Wiss. Berlin, Abh.*, Jahre 1875, 1-225, pls. 1-30.

Funayama, M. (1988), Miocene radiolarian stratigraphy of the Suzu Area, northeastern part of the Noto Peninsula, Japan. *Contr. Inst. Geol. Pal., Tohoku Univ.*, no. 91, 15-41, pls. 3-5 (in Japanese with English abstract and species description).

Goll, R. M. (1958), Classification and phylogeny of Cenozoic Trissocyclidae (Radiolaria) in the Pacific and Caribbean Basins. *Jour. Paleont.*, **42** (6), 1409-1432, pls. 173-176.

——— and Bjørklund, K. R. (1989), A new radiolarian biostratigraphy for the Neogene of the Norwegian Sea: ODP Leg 104. In Eldholm, O., Thiede, J., Taylor, E., *et al.*, *Proc. ODP, Sci. Results*, College Station TX (Ocean Drilling Program), **104**, 697,-737, pls. 1-5,

Hays, J. D. (1970), Stratigraphy and evolutionary trends of Radiolaria in north Pacific deep sea sediments. *In* Hays, J. D., *Geological Investigations of the North Pacific, Mem. Geol Soc. Am*, no. 126, 185-218.

Haeckel, E. (1887), Report on the Radiolaria collected by H. M. S. Challenger during the years 1873-76. *Rept. Voy. Challenger, 1873-1876, Zool.*, **18**, pts. 1-2, i-clxxxviii, 1-1803, pls. 1-140, 1 map.

Itoigawa, J. and Shibata, H. (1973), Paleoenvironmental change and correlation based on molluscan assemblage. *Mem. Geol. Soc. Japan*, no. 8, 125-135 (in Japanese with English abstract).

Kling, S. A. (1973), Radiolaria from the eastern North Pacific, Deep Sea Drilling Project Leg 18. *In* Kulm, L. D., von Huene, R., *et al., Init. Repts. DSDP*, Washington (U. S. Govt. Printing Office), **18**, 617-971, pls. 1-15.

Lombari, G. and Lazarus, D. B. (1988), Neogene cycladophorid radiolarians from North Atlantic, Antarctic, and North Pacific deep-sea sediments. *Micropaleont.*, **34** (2), 97-135, pls. 1-11.

Martin, G. C. (1904), *Radiolaria. In* Maryland Geological Survey (Miocene), Baltimore, Johns Hopkins Press, 447-459, pl. 130.

Nakaseko, K. (1955), Miocene radiolarian Fossil Assemblage from the southern Toyama Prefecture. *Sci. Repts. Coll. Educ. Osaka Univ.*, no. 4, 65-127, pls. 1-11.

——— (1963), Neogene Cyrtoidea (Radiolaria) from the Isozaki Formation in Ibaraki Prefecture, Japan. *Ibid.*, **12**, 165-198, pls. 1-4.

——— (1971), On *Spongoplegma antarcticum* Haeckel. *Ibid.*, 20, 51-57, pl. 1.

——— and Nishimura, A. (1974), Miocene radiolarian fossils of the Oki Islands in Shimane Prefecture, Japan. *Ibid.*, **23**, 45-73, pls. 1-7.

——— and Sugano, K. (1973), Neogene radiolarian zonation in Japan. *Mem. Geol. Soc. Japan*, no. 8, 23-33, pls. 1-4 (in Japanese witgh English abstract).

——— and ——— (1975), Late Cenozoic radiolarian fossils from Japan. *In* Tsukiji Shokan Publishing, *Atlas of Japanese fossils*, no. 37, 217-222.

Nishimura, A. (1982), Shell structure of *Sphaerostylus yatsuoensis* Nakaseko and *Stylatractus universus*. *News of Osaka Micropaleontologists*, spec. vol. 5, 427-436, pls. 1-4 (in Japanese with English abstract).

Pessagno, E. A., Jr. and Blome, C. D. (1982), Bizarre Nassellariina (Radiolaria) from the Middle and Upper Jurassic of North America. *Micropaleont.*, **28** (3), 289-318, pls. 1-8.

Petrushevskaya, M. G. (1975), Cenozoic radiolarians of the Antarctic, Leg 29, DSDP. *In* Kennett, J. P., Houtz, R. E., *et al., Init. Repts. DSDP*, Washington (U. S. Govt. Printing Office), **29**, 541-675, pls. 1-44.

——— and Kozlova, G. E. (1979), Description of the radiolarian genera and species. *Issled. Fauny Morei*, **23** (31), 86-157 (in Russian).

Popofskey, A. (1912), Die Sphaerellarien des Warmwassergebietes. *Deutsche Südpolar-Expedition* 1901-1903, **13** (Zool. vol. 5), 73-159, pls. 1-8.

Riedel, W. R. (1959), Oligocene and Lower Miocene Radiolaria in tropical Pacific sediments. *Micropaleont.*, **5** (3), 285-302, pls. 1-3.

——— and Sanfilippo, A. (1978), Stratigraphy and evolution of tropical Cenozoic radiolarians. *Ibid.*, **23** (1), 61-96, pls. 1-10.

Sakai, T. (1980), Radiolarians from Sites 434, 435, and 436, Northwest Pacific, Leg 56, Deep Sea Drilling Project. *In* Scientific Party, *Init. Repts. DSDP*, Washington (U. S. Govt. Printing Office), **56**, **57**, pt. 2, 695-733, pls. 1-10.

——— (1984), Neogene radiolarian datum planes of the equatorial and northern Pacific. *In* Ikebe, N. and Tsuchi, R., *Pacific Neogene Datum Planes*, Tokyo (Univ. Tokyo Press), 35-39.

Sanfilippo, A. and Riedel, W. R. (1970), Post-Eocene "closed" theoperid radiolarians. *Micropaleont.*, **16** (4), 446-462, pls. 1, 2.

——— and ———(1992), The origin and evolution of Pterocorythidae (Radiolaria): A Cenozoic phylogenetic study. *Ibid.*, **38** (1), 1-36, pls. 1-7.

——— Westberg-Smith, M. J. and Riedel, W. R. (1985), Cenozoic radiolaria. In Bolli, H. M. *et al.*, *Plankton stratigraphy*, Cambridge Univ. Press, 631-712.

Shibata, H. (1985), Miocene history of the Setouchi Province, Southwest Japan. *Monogr. Assoc. Geol. Coll. Japan*, no. 29, 15-24 (in Japanese with English abstract).

Sugano, K. (1976), Miocene radiolarian fossils from the Oidawara formation, Mizunami group, central Japan. *Bull. Mizunami Fossil Mus.*, no. 3, 17-24, pls. 4-7 (in Japanese with English abstract).

Sugiyama, K. (1992), Early Miocene radiolarians from the Toyohama Formation, Morozaki Group, Aichi Prefecture, central Japan. *Jour. Geol. Soc. Japan*, **98** (1), 65-67, pl. 1 (in Japanese).

———(in press), Skeletal structures of Lower and Middle Miocene lophophaenids from central Japan. *Trans. Proc. Palaeont. Soc. Japan*, N. S.

Takemura, A. (1986), Classification of Jurassic nassellarians (Radiolaria). *Palaeontographica*, Abt. A, **195**, 29-74, pls. 1-12.

Vinassa de Regny, P. E. (1900), Radiolari Miocenici Italiani. *Mem. Reale Accad. Sci. Ist. Bologna*, ser. 5, **8**, 565-595, pls. 1-3.

Plate 12

Figs. 1, 2 : *Excentrosphaerella sphaeroconcha* Dumitrica.
1 : ESN 146901, OD-26.
2 : ESN 146902, OD-26.
Figs. 3, 8 : *Stylosphaera* (?) *timmsi* (Campbell and Clark).
3 : ESN 146903, OD-26.
8 : ESN 146904, OD-18.
Fig. 4 : *Excentrococcus annulatus* Dumitrica, ESN 146905, OD-26.
Figs. 5-7, 10 : *Stylosphaera* (?) *magnapolulosa* (Campbell and Clark).
5 : ESN 146906, OD-28, odd specimen with a thin spine prolonged from a secondary beam.
6 : ESN 146907, OD-18.
7 : ESN 146908, OD-27.
10 : ESN 146909, OD-26, specimen with well-developed secondary meshes.
Fig. 9 : *Axoprunum bispiculum* (Popofskey) group, ESN 146910, OD-26, sectioned specimen.
All Scale bar = 50 μm.

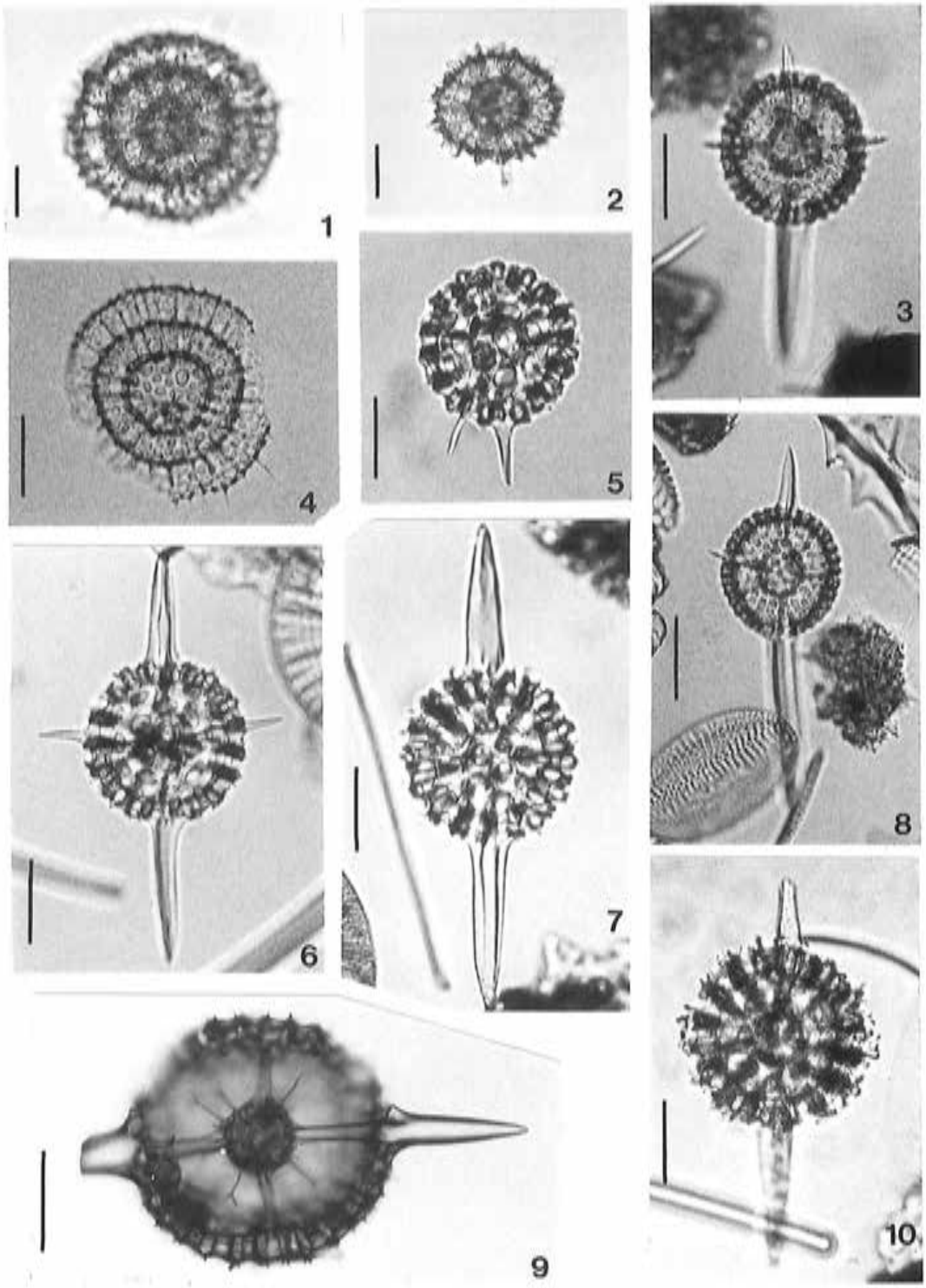
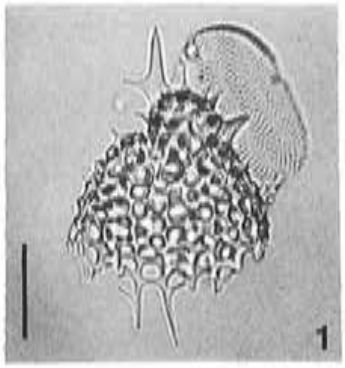
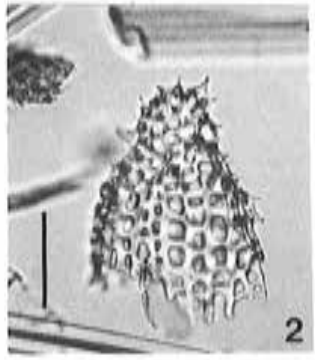
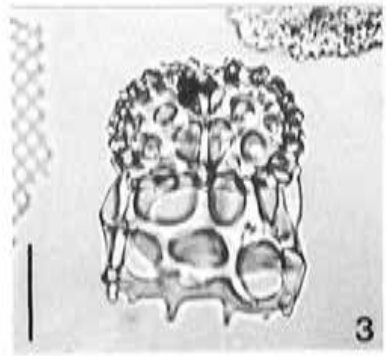

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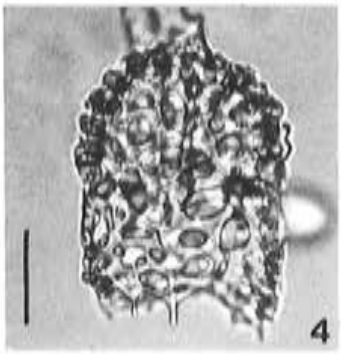
Plate 13

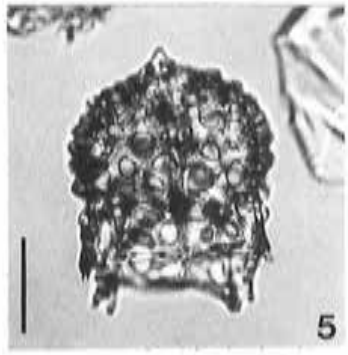
Figs. 1, 2 : *Ceratocyrtis* (?) *cantharoides* sp. nov.
1 : ESN 146911, OD-26.
2 : ESN 146912, OD-18, specimen with a weakly developed apical spine.
Figs. 3, 6 : *Dendrospyris* (?) *sakaii* sp. nov.
3 : ESN 146913, OD-28.
6 : ESN 146914, OD-27.
Figs. 4, 5 : *Dendrospyris* (?) *suganoi* sp. nov.
4 : ESN 146915, OD-27.
5 : ESN 146916, OD-27.
Figs. 7, 8 : *Lipmanella hister* (Petrushevskaya).
7 : ESN 146917, OD-28.
8 : ESN 146918, OD-27.
Fig. 9 : *Lipmanella* sp., ESN 146919, OD-26.
Fig. 10 : *Lipmanella* sp. A, ESN 146920, OD-26.
Figs. 11, 12 : *Cycladophora subhumerus* Lombari and Lazarus group
11 : ESN 146921, OD-18.
12 : ESN 146922, OD-18.
Fig. 13 : *Ceratocyrtis* (?) sp. aff. *C. stigi* (Bjørklund), ESN 146923, OD-26.
All scale bar = 50 μm.


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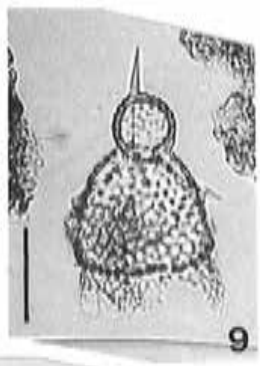

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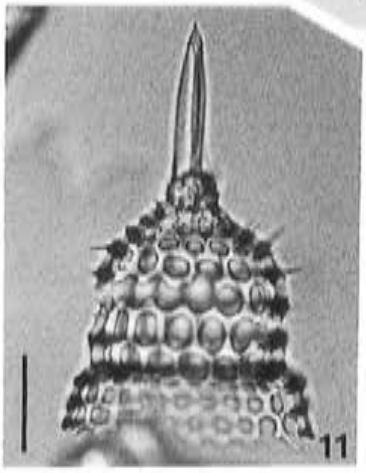

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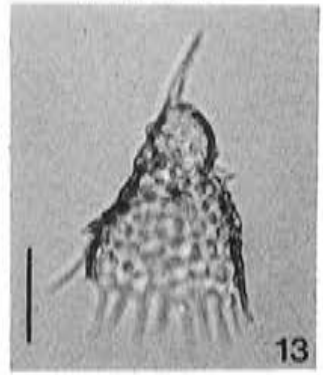
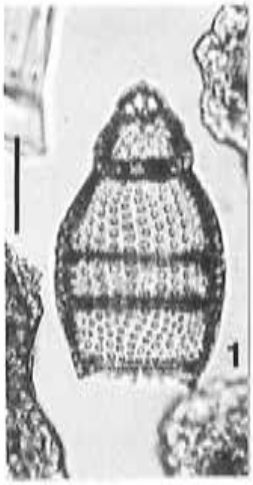
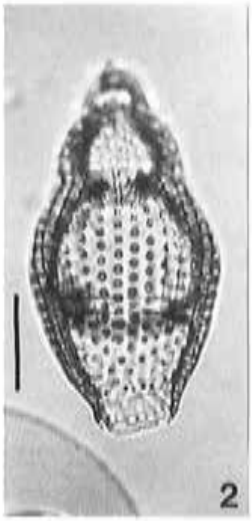
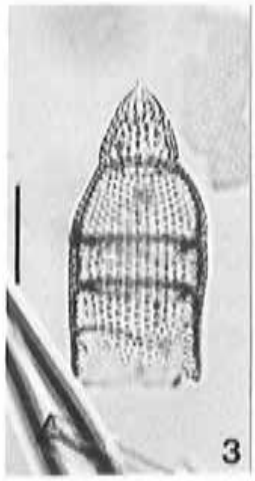

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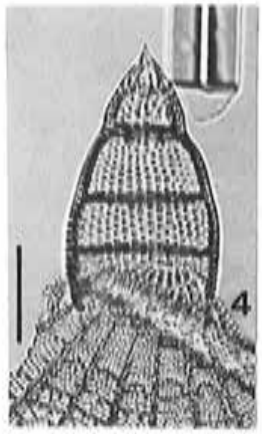
Plate 14

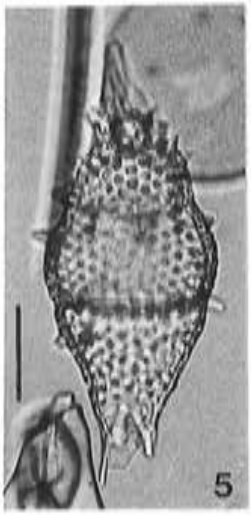
Fig. 1 : *Eucyrtidium calvertense* Martin group, ESN 146924, OD-28.
Fig. 2 : *Eucyrtidium* sp., ESN 146925, OD-26.
Figs. 3, 4 : *Eucyrtidium cienkowskii* Haeckel group.
3 : ESN 146926, OD-18.
4 : ESN 146927, OD-28.
Fig. 5 : *Stichocorys armata* (Haeckel), ESN 146928, OD-28.
Fig. 6 : *Stichocorys delmontensis* (Campbell and Clark), ESN 146929 OD-27.
Fig. 7 : *Cyrtocapsella* (?) *isopera* Chen, ESN 146930, OD-26.
Fig. 8 : *Lamprocyrtis hannai* (Campbell and Clark), ESN 146931, OD-28.
Fig. 9 : *Lychnocanoma conica* (Clark and Campbell), ESN 146932, OD-28.
Fig. 10 : *Calocycletta mizunamiensis* sp. nov., ESN 146933, OD-27.
Fig. 11 : *Calocycletta* (*Calocyclissima*) *costata* (Riedel), ESN 146934, OD-26.
All scale bar = 50 μm.

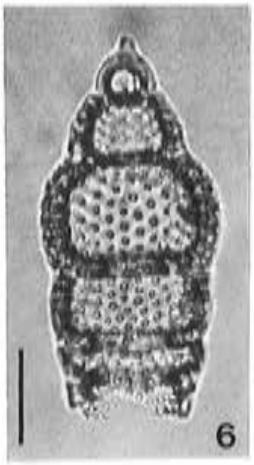

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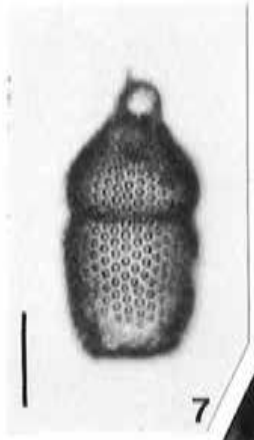

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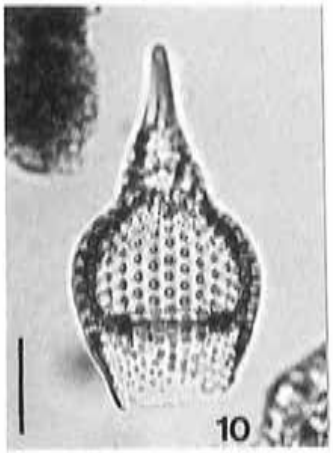

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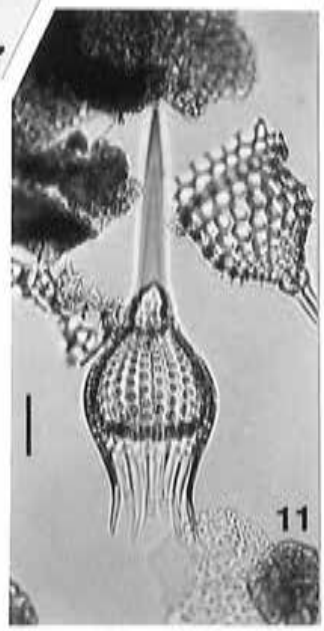

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Plate 15

Figs. 1, 2 : *Stylosphaera* (?) *timmsi* (Campbell and Clark).
1 : ESN 146935, OD-26.
2 : ESN 146936, OD-26.
Figs. 3, 4, 6, 7 : *Stylosphaera* (?) *magnapolurosa* (Campbell and Clark).
3 : ESN 146937, OD-26.
4 : ESN 146938, OD-28.
6 : ESN 146939, OD-13.
7 : ESN 146934, OD-27.
Figs. 5, 9 a-10 : *Spongoplegma variabilium* Nakaseko
5 : ESN 146941, OD-28.
9 : ESN 146943, OD-28.
10 : ESN 146944, OD-28.
Figs. 8 a, 8 b: *Spongoplegma nipponicum* (Nakaseko), ESN 146942, OD- 28.
Scale bars: 8 b and 9 b = 20 μm; others = 50 μm.

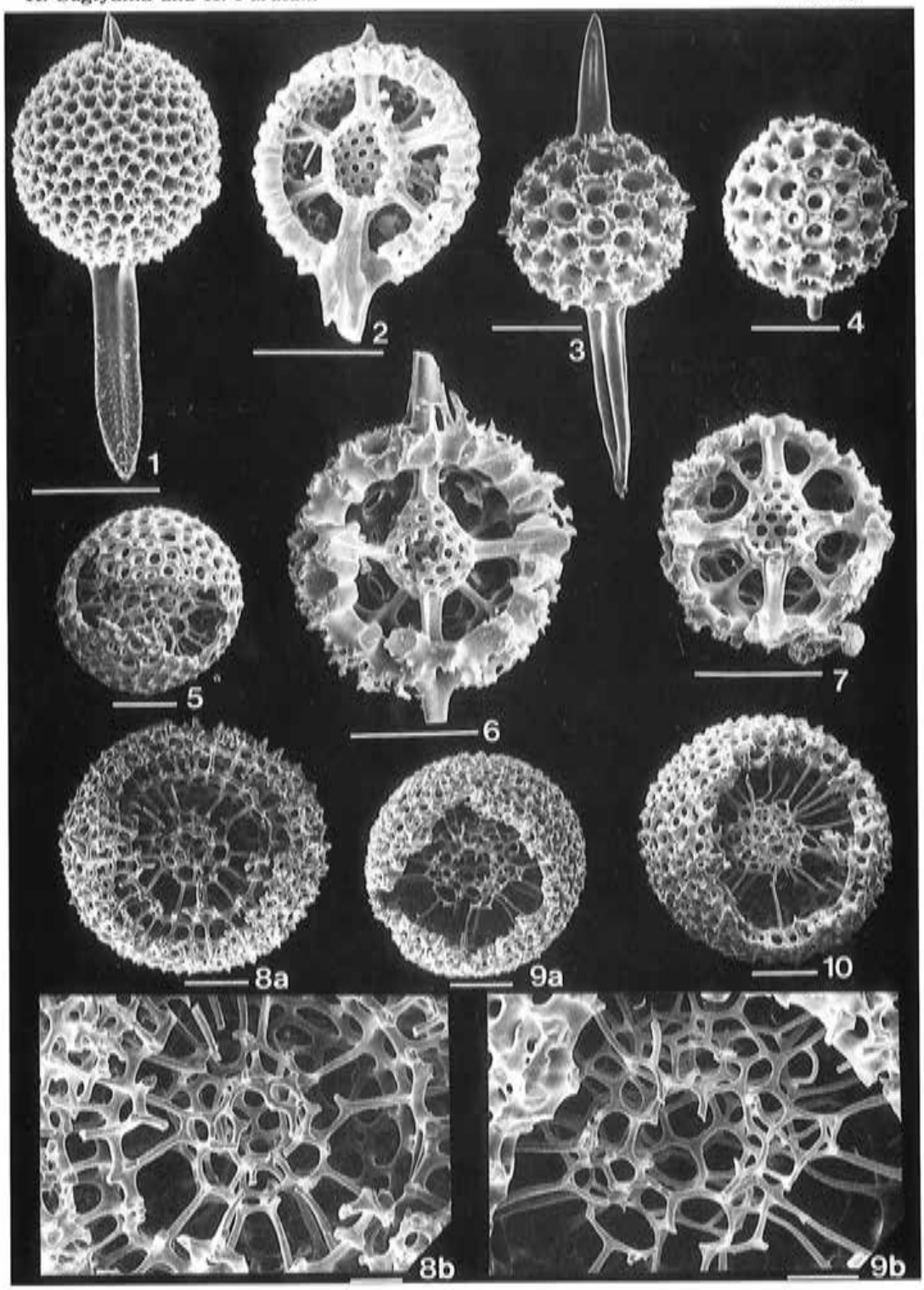

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Plate 16

Fig. 1 : *Didymocyrtis tubaria* (Haeckel), ESN 146945, OD-26.

Fig. 2 : *Didymocyrtis violina* (Haeckel), ESN 146946, OD-18.

Fig. 3 : *Excentrosphaerella sphaeroconcha* Dumitrica, ESN 146947, OD-26, sectioned specimen. Note excentrically situated inner medullary shell.

Fig. 4 : *Excentrococcus annulatus* Dumitrica, ESN 146948, OD-18, sectioned specimen. Note excentrically situated inner medullary shell.

Figs. 5, 6 : *Periphaena decora* Ehrenberg group.

5 : ESN 146949, OD-26, sectioned specimen showing the inner medullary shell.

6 : ESN 146950, OD-28.

Figs. 7, 9 a, 9 b: *Axoprunum bispiculum* (Popofskey) group.

7 : ESN 146951, OD-26.

9 : ESN 146952, OD-26, sectioned specimen. This specimen has an unusual, obliquely developed connecting bar between the cortical and medullary shell. 9 b is an enlargement of the medullary shell from oblique sagittal view. A half of the heteropolar microsphere is broken. MB is pointed by an arrow.

Fig. 8 : *Heliodiscus* sp. aff. *H. echiniscus* Haeckel, ESN 146953, OD-26.

Figs. 10, 11 a, 11 b: *Xiphosphaerantha angelina* (Campbell and Clark) group.

10 : ESN 146954, OD-28.

11 : ESN 146955, OD-26, sectioned specimen. 11 b is an enlargement of the medullary shell from sagittal view. MB is pointed by an arrow. Scale bars: 9 b and 11 b = 20 μm; others = 50 μm.

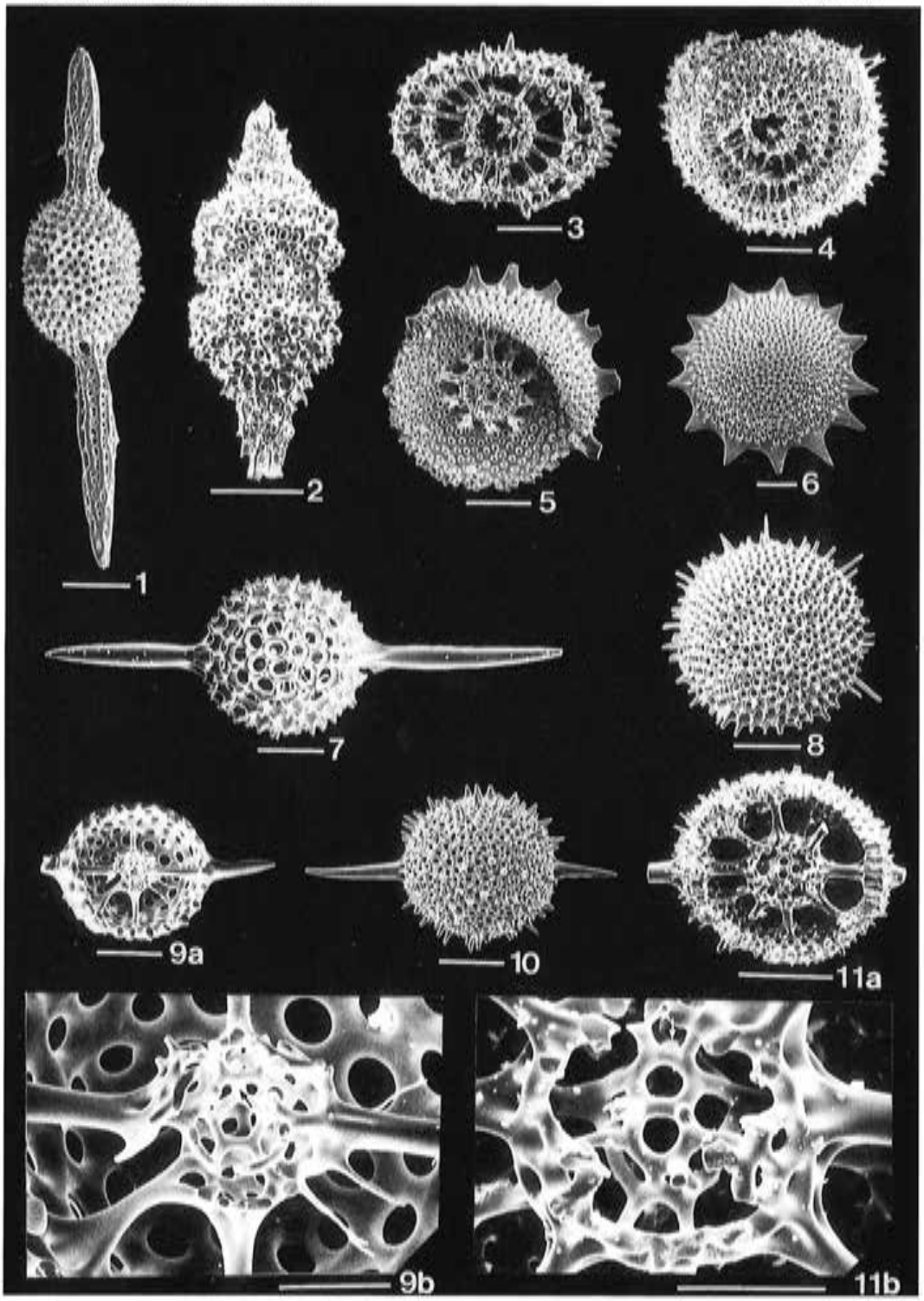

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Plate 17

Figs. 1 a, 1 b: *Lipmanella* sp. aff. *L. redondoensis* (Campbell and Clark), ESN 146956, OD-18.

Figs. 2 a, 2 b: *Lychnocanoma elongata* (Vinassa de Regny), ESN 146957, OD-18.

Fig. 3 : *Lithopera thorunburgi* Sanfilippo and Riedel, ESN 146958, OD-26.

Fig. 4 : *Artophormis johnsoni* (Caulet), ESN 146959, OD-27.

Fig. 5 : *Eucyrtidium calvertense* Martin group, ESN 146960, OD-7.

Fig. 6 : *Eucyrtidium cienkowskii* Haeckel group, ESN 146961, OD-13.

Fig. 7 : *Eucyrtidium yatsuoense* Nakaseko, ESN 146962, OD-24.

Fig. 8 : *Lophocyrtis* (*Cyclampterium*) sp. cf. *L.* (*C.*) *tanythorax* (Sanfilippo and Riedel), ESN 146963, OD-21.

Figs. 9 a, 9 b: *Cyrtocapsella* (?) *isopera* Chen, ESN 146964, OD-26.

Fig. 10 : *Cyrtocapsella japonica* Nakaseko, ESN 146965, OD-26.

Fig. 11 : *Cyrtocapsella cornuta* Haeckel, ESN 146966, OD-18.

Fig. 12 : *Cyrtocapsella tetrapera* Haeckel, ESN 146967, OD-28.

Scale bars: 1 b, 2 b, 5 and 6 = 20 μm; others = 50 μm.

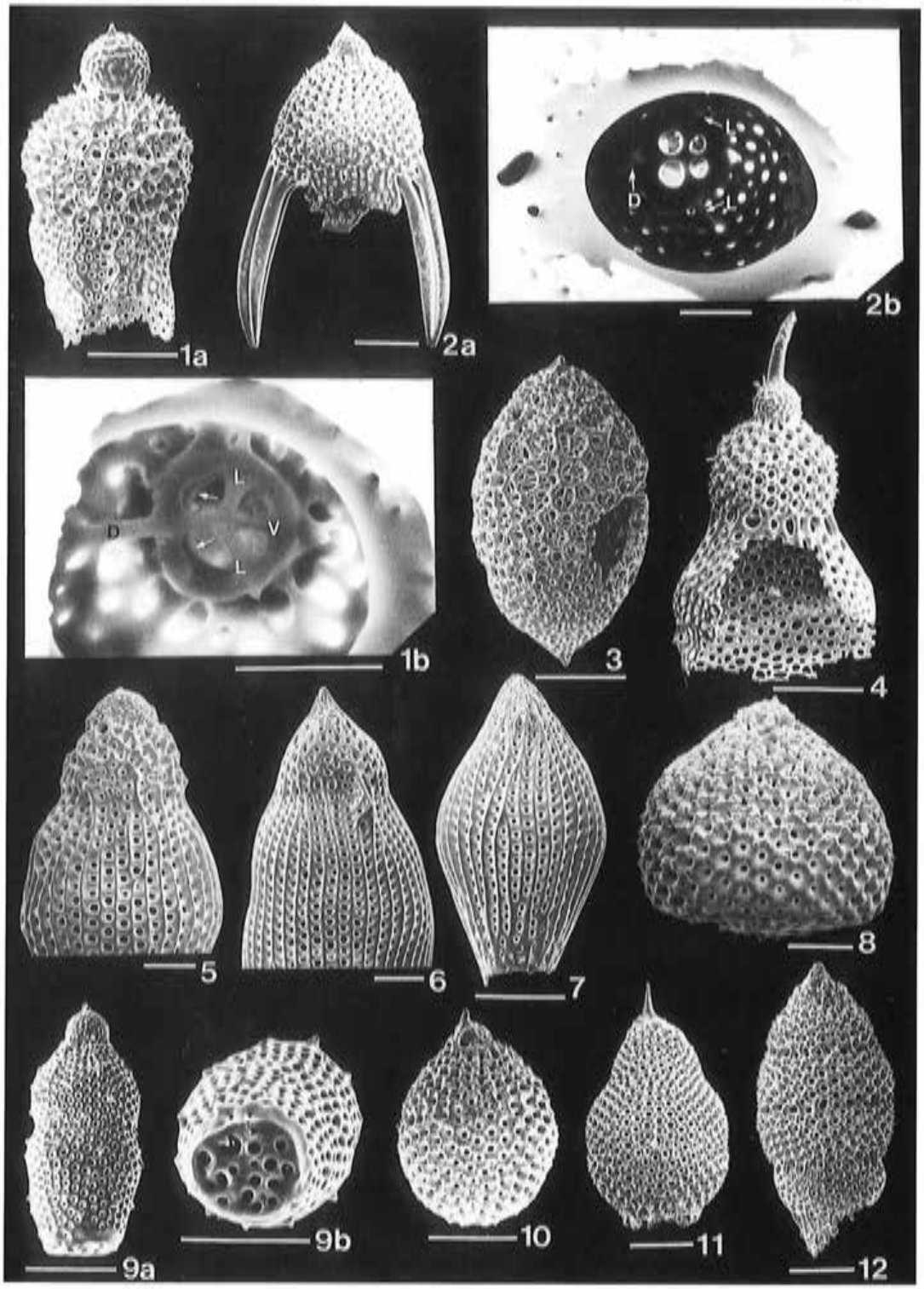

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Plate 18

Figs. 1 a, 1 b: *Eucenarium joergenseni* (Dumitrica), ESN 146968, OD- 18. AL in Fig. 1 b means an arch connecting A and L.

Fig. 2 : *Pseudodictiophimus gracilipes* (Bailey), ESN 146969, OD 18.

Fig. 3 : *Cycladophora subhemis* Lombari and Lazarus group, ESN 146970, OD-18.

Figs. 4 a, 4 b: *Cycladophora cosma* Lombari and Lazarus, ESN 146971, OD-18.

Figs. 5 a, 5 b: *Lamprocyrtis hannai* (Campbell and Clark), ESN 146972, OD-27.

Figs. 6 a, 6 b: *Ceratocyrtis* (?) sp. aff. *C. stigi* (Bjørklund), ESN 146973, OD-24.

Fig. 7 : *Lamprocyclas margatensis* (Campbell and Clark), ESN 146974, OD-28.

Scale bars: 2 b, 4 b, 5 b and 6 b = 20 μm; others = 50 μm.

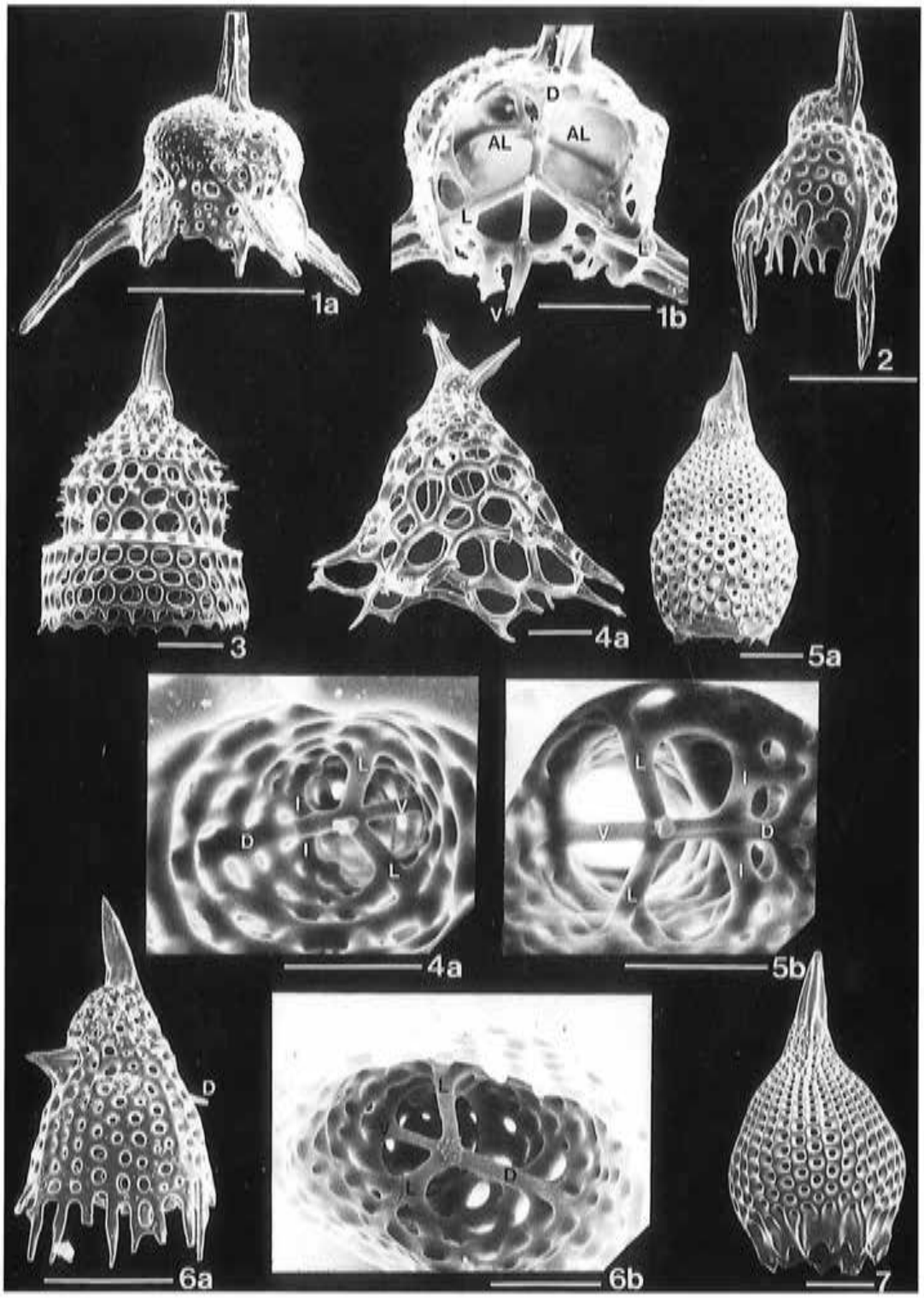

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Plate 19

Figs. 1 a-1 c: *Theocorythium cylindricum* (Nakaseko), ESN 146975, OD-26.
Figs. 2-5, 7 a-8 : *Calocycletta mizunamiensis* Sugiyama sp. nov.
2 : ESN 146976, OD-21.
3 : ESN 146977, OD-18.
4 : ESN 146978, OD-26.
5 : ESN 146979, OD-7.
7 : ESN 146980, OD-27.
8 : Holotype, ESN 146981, OD-26.
Fig. 6 : *Calocycletta* (*Calocycletta*) *virginis* Haeckel, ESN 146982, OD-26.
Fig. 9 : *Calocycletta* (*Calocyclissima*) *costata* (Riedel), ESN 146983, OD-26.
Scale bars: 1 b, 1 c and 7 b = 20 μm; others = 50 μm.

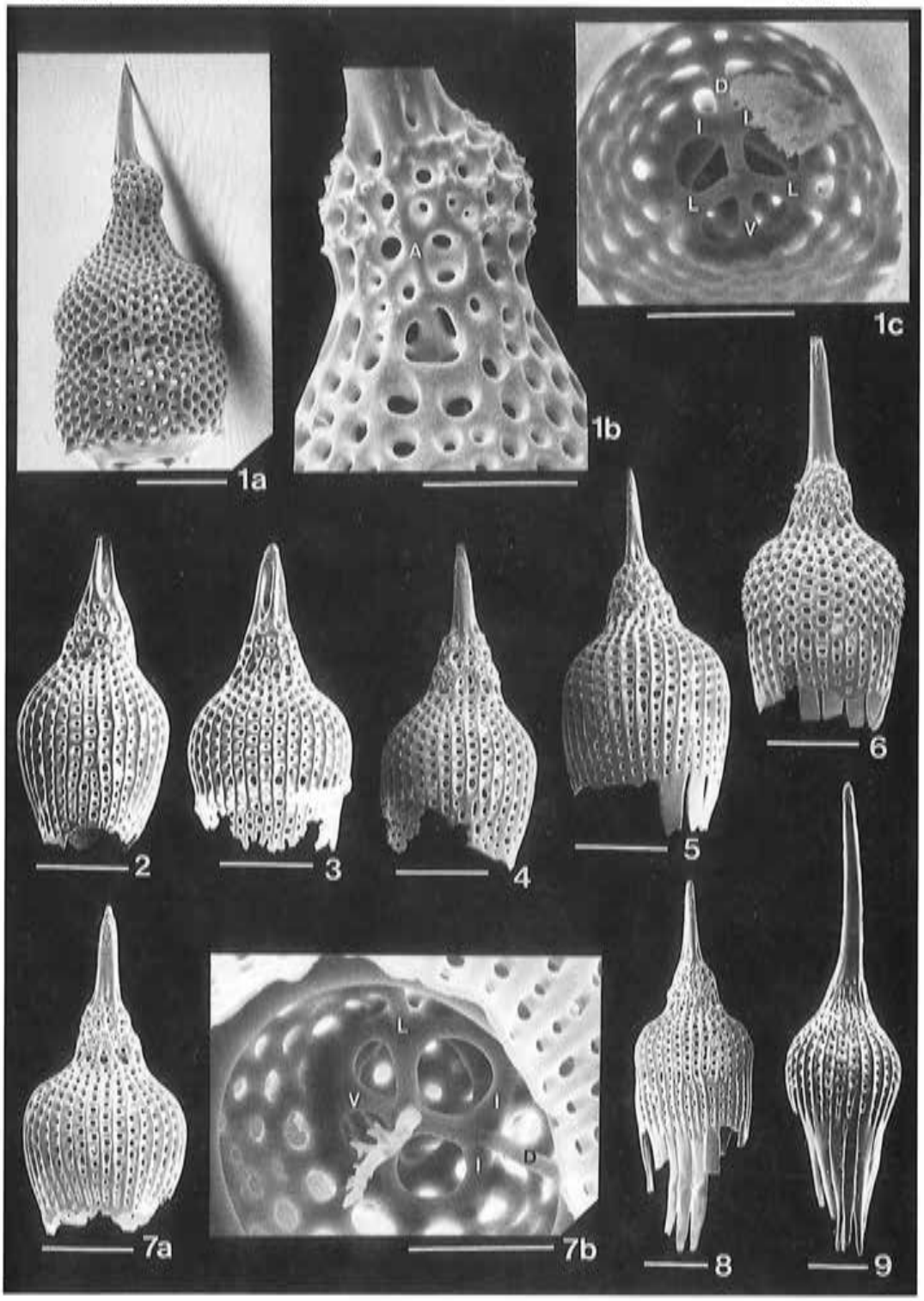
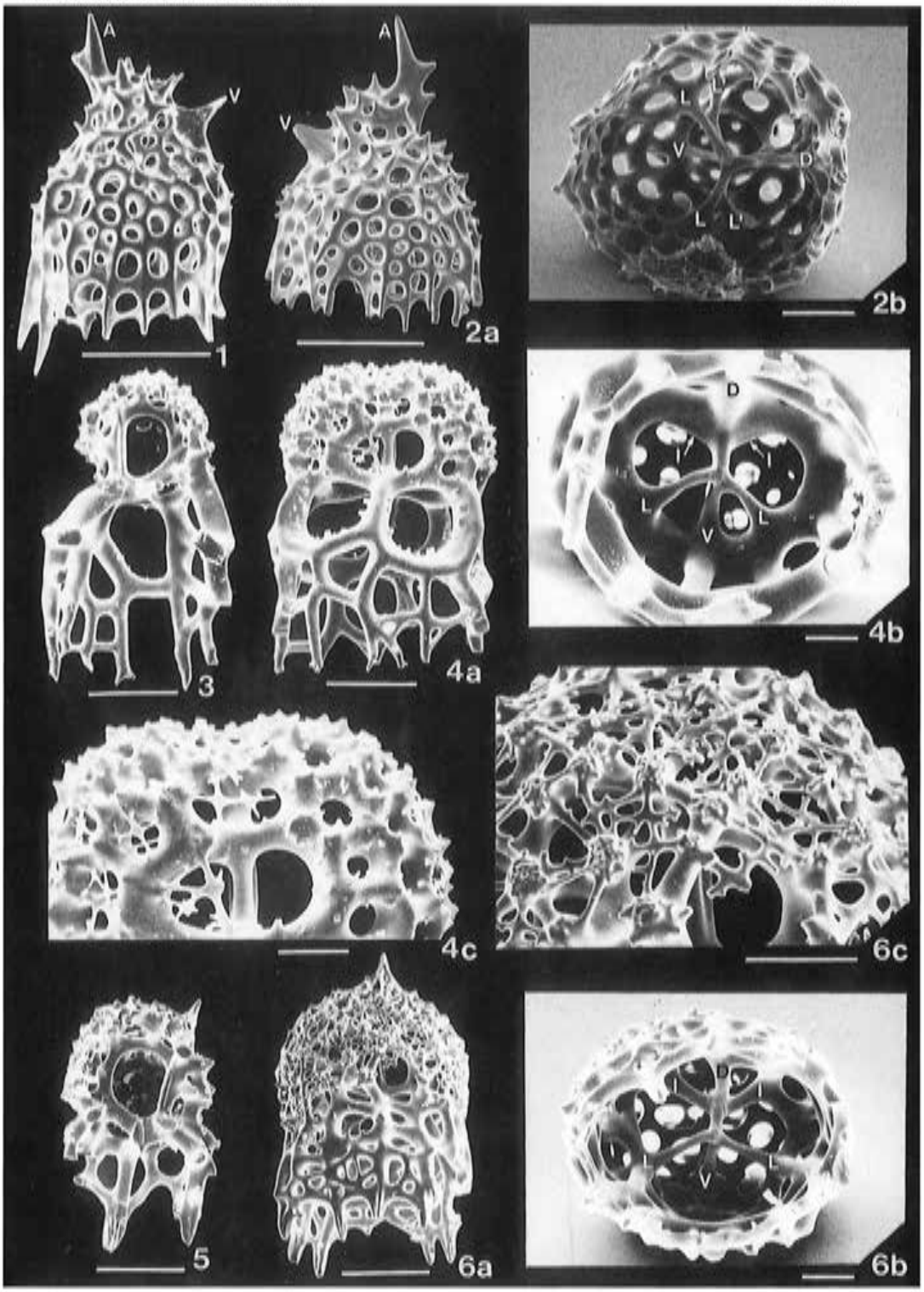

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Plate 20

Figs. 1–2 b: *Cerarocyrtis* (?) *cantharoides* sp. nov.
1 : ESN 146984, OD-27.
2 : Holotype, ESN 146985, OD-26.
Figs. 3–4 c: *Dendrospyris* (?) *sakaii* sp. nov.
3 : ESN 146986, OD-18.
4 : Holotype, ESN 146987, OD-27.
Figs. 5–6 c: *Dendrospyris* (?) *suganoi* sp. nov.
5 : ESN 146988, OD-26.
6 : Holotype, ESN 146989, OD-26.
Scale bars: 2 b, 4 b, 4 c, 6 b and 6 c = 20 μm; others = 50 μm.


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