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Middle Ordovician Radiolarians from the Lachlan Fold Belt, Southeastern Australia

Masaki UMEDA*, Hirokazu GOTO**
and Hiroaki ISHIGA*

**Department of Geology, Faculty of Science, Shimane University, Matsue, 690 JAPAN*
****Tokusyu Plant Industry Co. Ltd., 2-1-18 Shikitu-nishi, Naniwa-ku, Osaka, 558 JAPAN*
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Microfossil biostratigraphy and examination of pelagic sedimentary feature reveal the biotic event and environmental change in the Early Paleozoic. Radiolarians, conodonts and acritarchs occurred from black organic bedded cherts of the Mt. Stavely Complex in the Stawell Terrane of the Lachlan Fold Belt, western Victoria. This Fold Belt is regarded to be consist of Cambrian to early Carboniferous rocks, but paleontological investigation of conodonts and radiolarians indicates supposed Middle Ordovician or younger age for the examined siliceous rocks which previously supposed to be Cambrian.

Acritarchs regarded to be a cause of "red tide" occurred from lower horizon of radiolarian bearing bed, which is an important trigger of the Oceanic Anoxic Events in Late Ordovician. Middle Ordovician radiolarians are characterized by simple shell construction with randomly ornamented spicules and small thick shell. They are grouped into seven of basic skeleton forms and some show close relationship to Late Ordovician radiolarians.

Introduction

Palaeozoic radiolarians have been reported from many places of the world, and recognition of the outlined evolutionary history has been understood in during recent years (Nazarov and Ormiston, 1986). Microfossils from the Early Paleozoic siliceous rocks commonly remain very poor preservation, therefore, the reports on Early Paleozoic radiolaria have not been well documented.

As Late Ordovician radiolarians well diversified (Webby and Blom, 1986; Goto et al., 1992) occurred from western margin of Lachlan Fold Belt, this indicates possible appearence of radiolarians in lower Ordovician or Cambrian. They provide information on the clue to the history related to the origin and evolution that have not been well recognized yet enough. These radiolarians are described briefly in this paper, and significance of organic rich siliceous sediments are discussed in taking account to the Oceanic Anoxic Event at the Late Ordovician time.

Geologic setting of the Lachlan Fold Belt and radiolarian locations

The Tasman Orogenic Belt in eastern margin of Australia is dominated tectonic collage of terranes (Miyashiro, 1991). Three fold belts comprise southeastern Australia. The Cambrian to early Carboniferous rocks are widely distributed in the Lachlan Fold Belt, which is an ancient continental margin geotectonic setting (Gray, 1988) of Lower Paleozoic southeastern Gondwanaland. Victorian part of the Lachlan Fold Belt was grouped into four tectonostratigraphic terranes, *i.e.* the Benambra terrane, Melbourne terrane, Ballarat terrane and Grampians-Ararat terrane (Fergusson et al., 1987). The Benambra terrane consists mainly of Ordovician arc/back-arc basin association, while the Melbourne terrane consists of Cambrian to Late Ordovician continental margin sequence and thrust over the Benambra terrane. The Ballarat terrane consists of Cambrian to Late Ordovician representing another continental margin sequence, and thrusts over the Melbourne terrane. The western limit of Ballarat terrane placed by "Wedderburn Line", the so-called "graptolite line" marking the westernmost occurrence of Ordovician graptolite (VandenBerg, 1988). The Stawell terrane, further west of the Wedderburn Line, is distributed extensively at possible Cambrian unfossiliferous rocks. They are assumed to be Cambrian age because of absence of graptolites, and of their tectonic position that they usually form antiformal part.

Early Paleozoic radiolarians

Shell constructions in Early Paleozoic radiolarians are characterized by thick and simple spicules and rather small in shell size. They are assigned to spumellaria with spherical shell (Nazarov and Ormiston, 1984). Development of the skeleton in the most ancient radiolaria took place in the Early Cambrian period. Cambrian is the phase of development of the radiolarian faunal group (Nazarov and Ormiston, 1986).

As the report of the first appearance of radiolaria, David and Howchin (1896) noted Pre-Cambrian radiolarians from the Brighton Limestone in South Australia. Later, the age of the limestone was modified to be Cambrian age. To interpret these Cambrian radiolarians is difficult now, because the slide had been already lost, and only illustrated sketches are remained. Cambrian radiolarians, however were reported as Entactiniidae from Batenevskya Mountains in eastern Siberia (Nazarov, 1973). Subsequently, Nazarov (1975) reported polycystines from Lower Cambrian of the Altai-Sayaregion. Photos of these radiolarians are poorly shown, therefore, stratigraphic distribution of Cambrian radiolarians are still unknown, and only some no adequate reports have been contributed (Holdsworth, 1977).

Assemblages of well-dated faunas occurred from Ordovician (see Renz, 1990a). Among the major studies are; from New York State (Ruedemann and Wilson, 1936), Spitsbergen of Sweeden (Forty and Holdsworth, 1972), at Hanson Creek Formation of Eureka in Nevada (Dunham and Murphy, 1976; Renz, 1990a, b), Kazakhstanin Estonia, (Nazarov and Nolvak, 1983; Nazarov and Ormiston, 1986), Belubula valley in central N. S. W., Australia (Webby and Blom, 1986).

Ruedemann and Wilson (1936) observed and described poorly preserved radiolarians in thin section study. The species, similar to this study, were described by Forty and Holdsworth (1972). They discriminated 3 basic skeletal forms and noted that Entactiniidae are represented by primitive shelled forms among the Lower Ordovician radiolarians. Dunham and Murphy (1976) and Renz (1990) indicated wide variety of radiolarians in Ordovician time. Among them, species seems to be similar to specimens which show common forms are *Kalimnasphaera* sp. aff. *K. maculosa* and *Entactinia* sp. aff. *E. subulata.* The age of this assemblage is, on the basis of co-occurred conodonts, dated Caradocian (Late Ordovician). Common species reported by Nazarov and Nolvak (1983) and Nazarov and Ormiston (1986) from the Ordovician is *Anakrusa myriacantha.* Webby and Blom (1986) reported radiolarians from calcareous silt associated to Late Ordovician (Late Caradoc-Ashgill) limestone breccias of the Malongulli Formation. They included *Kalimnasphaera maculosa, Entactinia* sp., *Entactinia subulata,* and *Auliela taplowensis* and these resemble in materials of this paper.

Examination of the possible Middle Ordovician radiolarians from Victoria points a similarity between the Late Ordovician radiolarians from New South Wales (Goto et al., 1992) and those described here. Many well-preserved radiolarians, grouped into 14 genera and 26 species, obtained from Late Ordovician black siliceous mudstones and black cherts. Among them, species of *Entactinia,* other newly described forms *Entactinia, Kalimnasphaera,* and gen. A sp. B are showing intimate relation of shell construction to Middle Ordovician radiolarians, but they have rather ornamented and complicated forms.

The age of The Mt. Stavely Complex

The Mt. Stavely Complex has been regarded to be Cambrian, but no direct biostratigraphic evidence was not documented yet untill in the recent book (VandenBerg, 1988). However, as mentioned below, seven radiolarians and one conodont element were obtained from Mt. Stavely Complex which indicate supposed Middle Ordovician or younger age. Among these radiolarians, Anakrusidae indicates the Middle Ordovician age and didn't persist beyond the Ordovician (Nazarov and Ormiston, 1986). On the other hand, presumed form genus "*Oulodus* Branson & Mehl, 1933" of coocurring conodonts ranges Middle Ordovician to Devonian (identified by B. G. Fordham per. comm.). Thus this Complex, at least, may apparently includes possibly Middle Ordovician or younger Ordovician age.

Formational process and timing of the orogenic belt has been discussed due to the geologic examination of the Paleozoic terrane in Southeast Australia, especially in the New England Fold Belt. The belt was regarded to have formed in a long time span from Cambrian to Carboniferous, but the micropaleontologic examination reveals that the accretion occurred in Late Devonian to Early Carboniferous which means the time gap between the accretion and granitic rock intrusions was actually very short, or intrusions occurred subsequent to the accretion and/or subduction (see Leitch et al., 1990). The Lachlan Fold Belt may not be an exception of this sort of orogenic belt, for dominant age of pelagic cherts and siliceous shales could be restricted in mainly Late Ordovician (see Goto et al., 1992) with some Middle Ordovician (in this paper).

Acritarchs

Among the organic microfossils from the examined rocks, acritarchs is significant for understanding oceanic condition of black cherts which occupy the lower bed than that of radiolarian bearing beds (Plate 1). Acritarchs, like fossil "dinoflagellates" is regarded to be a primary cause of the "red tide" and are possibly assigned to a modern phytoplankton species, class Prasinophyceae (Williams, 1988). They appeared to represent the acme of development in the Ordovician age (Williams, 1988). As the other acmes, acritarchs were flourished in Frasnian/Famennian (Late Devonian) and Toarcian (Early Jurassic) (Williams, 1988). This oceanic microfossil event concures well with period of the Oceanic Anoxic Event and subsequent global extermination of life.

Materials

Middle Ordovician radiolarians were obtained from black organic chert of the Mt. Stavely Complex of the Stawell Terrane. Fossil localities are described below and are shown in Fig. 2.

Outcrop of roadside examined is along the farmroad about 40 km east of Hamilton, western Victoria. At this location, 142′20 of east longitude and 37′40 of south latitude, well-bedded black cherts and shales are exposed. Twenty six samples were collected bed by bed through a thickness of 30 m. The thickness of a single bed ranges from 3 to 5 cm.

These samples were broken into small fragments and were processed with 5% HF solution for 20 hours. Subsequently, a small amount of radiolarian remains were obtained from VL-8B, C, Q samples, conodonts from VL-8Q and acritarchs from VL-8N, W.

Systematic Paleontology

Radiolarians obtained from the Mt. Stavely Complex are hard to assigned the previously proposed taxonomic framework except one form. Thus, they are nominated as types, and discuss their possible belonging briefly.

Subclass Radiolaria Müller, 1858

Order Polycystina Ehrenberg, 1838 emend.
Riedel, 1967
Suborder Spumellaria Ehrenberg, 1875

Type A
Plate 2, Figure 1

Material. One specimen, figured in this paper, and more than 5 specimens from SD VL-8B. Q.

Description. Single spherical shell with one long and strong spine extending from near surface. This spine tapered distally and recourved. Rod-like by-spines are extending at the surface of shell. The detailed structure of shell was not understood clearly for recrystallization, but this form can be distinguished from other radiolarians by a single characteristic thick and recourved spine.

Measurements. Diameter of spherical shell about 120 μm; length of spine about 200 μm.

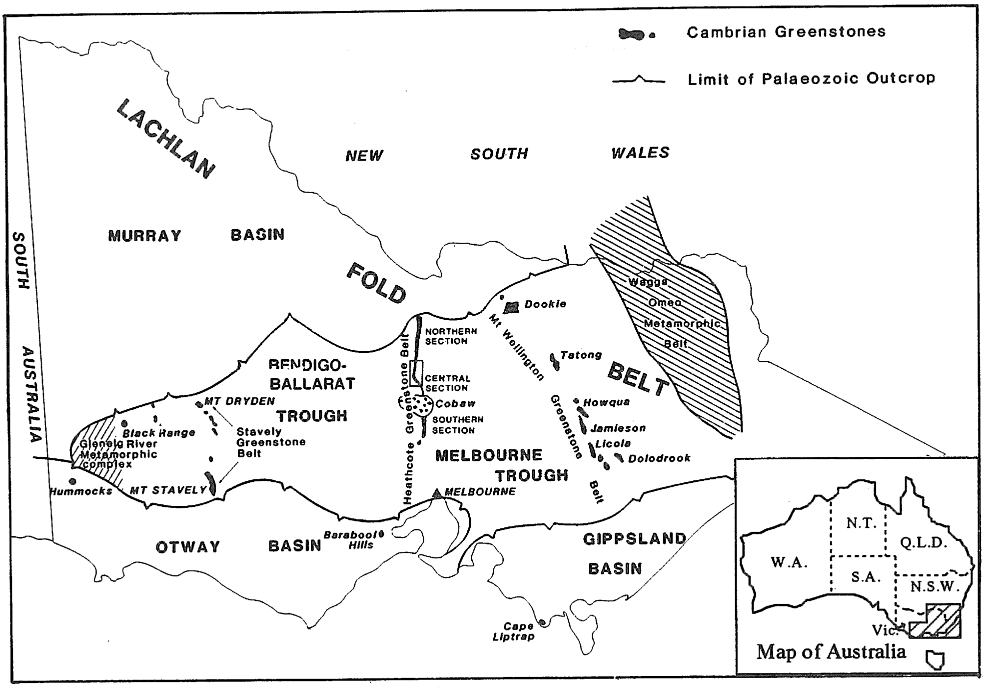

Fig. 1. Map showing distribution of Paleozoic Terranes and their classification, indicating the Mt. Stavely Complex examined in this study. Terrane map after Crawford (1988).

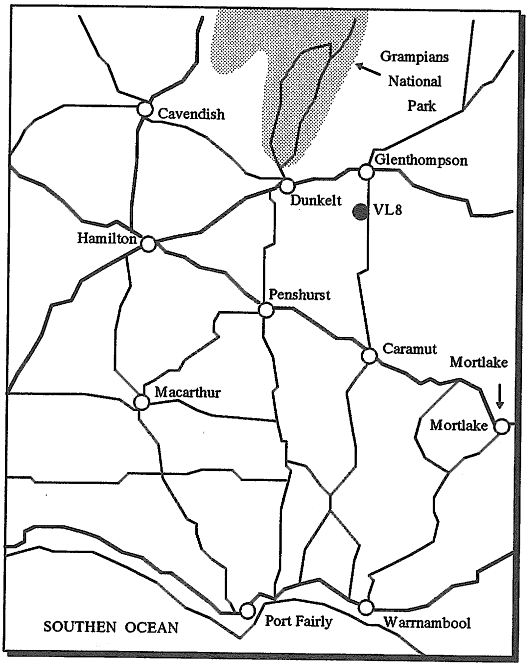

Fig. 2. Map indicating location of VL8 of the examined section.

		Nevada U.S.A. (Dunham and Murphy, 1976; Renz, 1990)	Belubula valley, central N.S.W. Australia (Webby and Blom, 1986)	Kazakhstan, Estonia U.S.S.R. (Nazarov and Nolvak, 1983; Nazarov and Ormiston, 1986)	Taralga, N.S.W. Australia (Goto et al., 1992)	Mt. Stavely Australia (This paper)
Late	Ashgillian		*Entactinia subulata* *Entactinia* sp. Entactiniidae n. gen. and n. sp. A Entactiniidae n. gen. and n. sp. B Entactiniidae (*incerti generis*) sp. 1	*Entactinia eiklaensis* *Astroentactinia sp. ?* *polyentactinia? estonica* *Haplentactinia baltica*	Inaniguttidae Entactiniidae Haplentactiniidae Palaeoscenidiidae Ceratoikiscidae?	
	Caradocian	*Kalimnasphaera maculosa* *Palaeotrifidus ballator* *Palaeoephippium octaramosum* *Palaeosphaera micra* *Entactinia subulata* *Palaeotripus sexabrachiatus* *Palaeotrifidus imbifurcus* *Secuicollacta stelligera*	*Auliela taplowensis* *Kalimnasphaera maculosa*			
Middle (part)	Llandeilian			*Anakrusa myriacantha* *Inanigutta complanata* *Inanigutta unica* *Inanigutta elongata* *Haplentactinia armillata* *Ramificans* sp. *Pylentonema aperta*		*Anakrusa* sp. and six simple forms

Fig. 3. List of Middle to Late Ordovician radiolarian faunas. For references see text.

Type B
Plate 2, Figures 2, 3

Material. Two specimens, figured in this paper, and more than 3 specimens from SD VL-8B, Q.

Description. Small spherical shell with two long straight spines. Spines are connected with each other at the central point of shell and formed one long straight spine. Some rather thick spines are extending from the surface of shell. Shell surface is ornamented meshlike complexed rough spongy shell, but the detail has not been clearly observed.

Measurements. Diameter of shell about 140 μm; length of spines about 260 μm.

Discussion. This specimens has simple form and they are assumed to be a kind of ancient Entactiniidae radiolaria which have been reported from Late Ordovician rocks (see Renz, 1990; Webby and Blom, 1986; Goto et al., 1992 etc.).

Type C
Plate 2, Figure 4; Plate 3, Figure 1

Material. Two specimens, figured in this paper, and other 3 specimens from SD VL-8B, Q.

Description. Undeveloped small spherical or sub-spherical shell is accompanied by 4 basic spines.

Measurements. Diameter of shell about 50 μm; length of spines about 200 μm.

Type D
Plate 3, Figures 2, 3

cfr. *Kalimnasphaera* sp. Goto, et al., 1992

Material. Two specimens, figured in this paper, and 3 specimens from VL-8B.

Description. More than 4 spicules, as a fundamental framework, with small spherical shell. Structure and form of this species is not clear because of poor preservation.

Measurements. Diameter of shell about 80 μm; length of spines about 120 μm.

Comparison. This specimens have developed from Type C because of relatively complicated from than that. In case this specimens are compared with Goto et al. (1992), relatively similar to *Kalimnasphaera* sp. in that point from of spines.

Type E
Plate 3, Figure 4; Plate 4, Figure 1

Material. Two specimens, figured in this paper, and one specimens from VL-8B.

Description. More than 4 thick spines and thinner and shorter spicules are fundamental structure of small spherical shell. Thick spines connect at central portion of shell. By spines extending nearly vertically from main spines.

Measurements. Diameter of shell about 80 μm; length of spines about 130–170 μm.

Comparison. This specimens have developed from Type C because of relatively much ornamented form and addition of numbers of spines. If this form consists of six radiating spines, this may be assigned to *Haplentactinia* Forman.

Type F
Plate 4, Figure 2

Material. One specimen, figured in this paper, and 3 specimens from VL-8B, C, Q.

Description. Small spherical shell are composed of thick spicules irregularity arranged, but totally form very rough meshwork.

Measurements. Diameter of shell about 150 μm.

Anakrusidae Nazarov, 1977

Anakrusa sp. Nazarov, 1977
Plate 4, Figure 3

aff. *Anakrusa myriacantha* Nazarov, 1986
cfr. *Auliela taplowensis* Webby and Blom, 1986

Material. One specimen, figured in this paper, and 5 specimens from VL-8B, Q.

Description. Small spherical shell with many short, straight and thin spines radiating at shell surface. These spines have relatively uniform in diameter without butressing.

Measurements. Shell diameter about 130 μm; length of spine about 160 μm.

Comparison. The specimens is similar to *Anakrusa myriacantha* (Nazarov, 1986) from the Middle Ordovician Bestamakian suite of eastern Kazakhstan in Estonia, and *Auliela taplowensis* (Webby and Blom, 1986) from Late Ordovician calcareous mudstone of N. S. W., Australia. However, *Auliela taplowensis* has relatively much longer and thinner spines.

Remarks. This family indicates Ordovician age (Nazarov, 1986). Nazarov (1986) proposed that Anakrusidae didn't persist beyond the Ordovician because no thick-walled forms have been reported from the post Ordovician. Possibly, it may have interrupted floating.

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Explanation of Plates

Plate 1

1. General feature of radiolaria bearing black chert (from SD VL-8Q of western margin of Lachlan Fold Belt)
2. Acritarchs
3. Acritarchs
4. Acritarchs
5. General feature of Acritarchs bearing organic mudstone
6. Organic materials, possible graptorite

All scale bars: 200 μm. (Figs. 2–6 from SD VL-8N)

Plate 2

1. Type A
2. Type B
3. Type B
4. Type C

All scale bars: 100 μm. (Figs. 1–4 from SD VL-8B, Q)

Plate 3

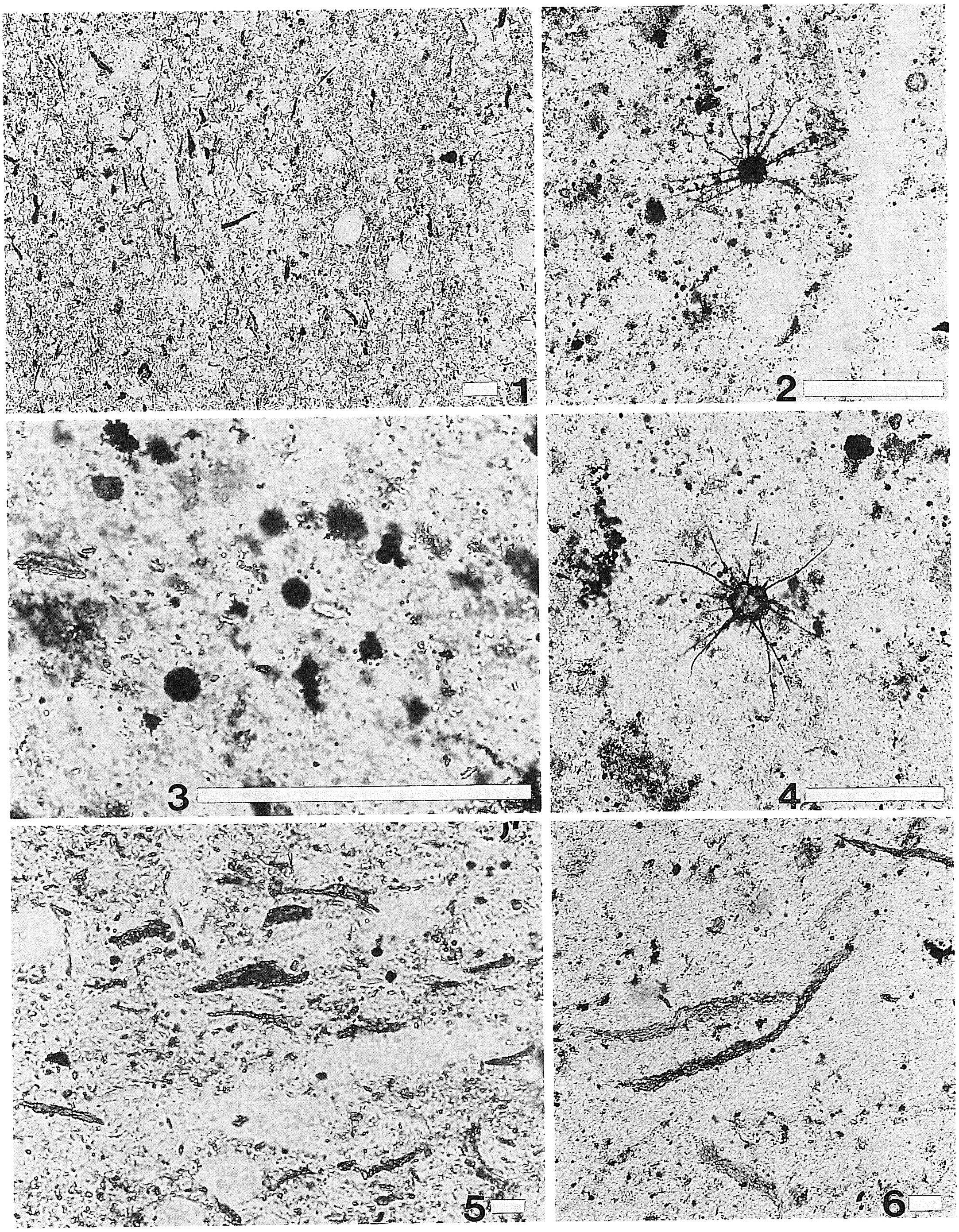
1. Type C (from SD VL-8B, Q)
2. Type D
3. Type D
4. Type E

All scale bars: 100 μm. (Figs. 2–4 from SD VL-8B)

Plate 4

1. Type E (from SD VL-8B)
2. Type F (from SD VL-8B, C, Q)
3. *Anakrusa* sp. (from VL 8Q)
4. form genus *Oulodus* sp. (from VL 8Q)

All scale bars: 100 μm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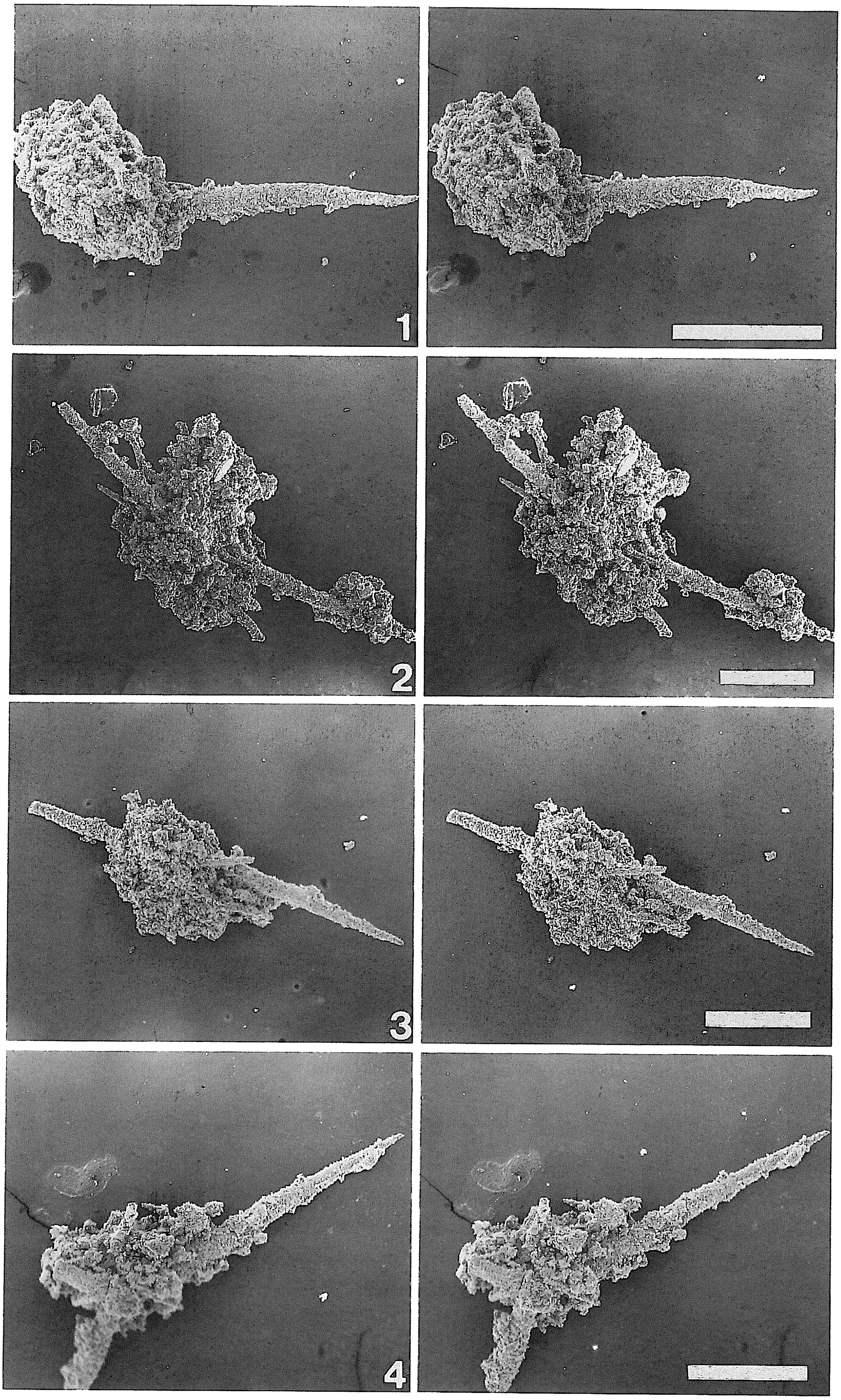
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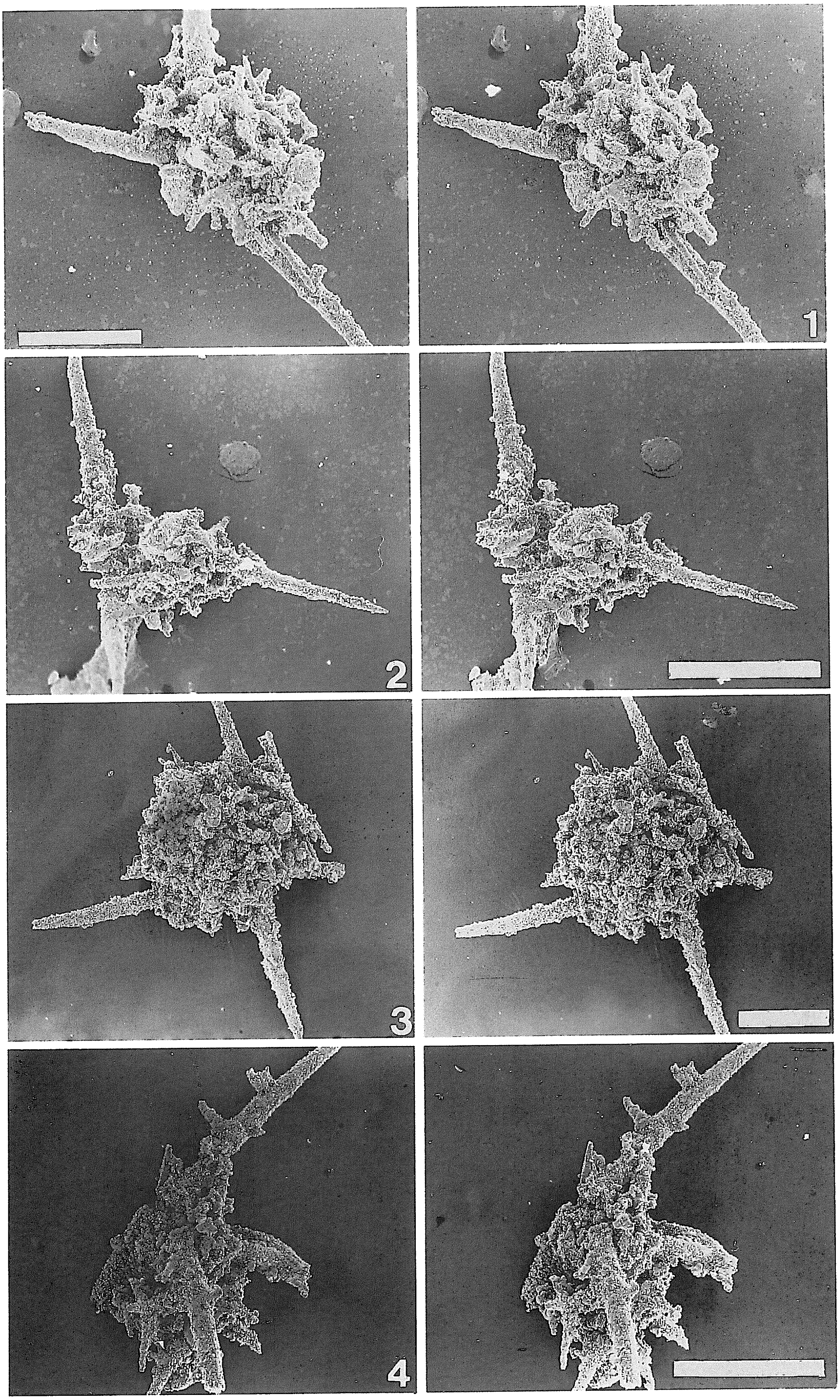
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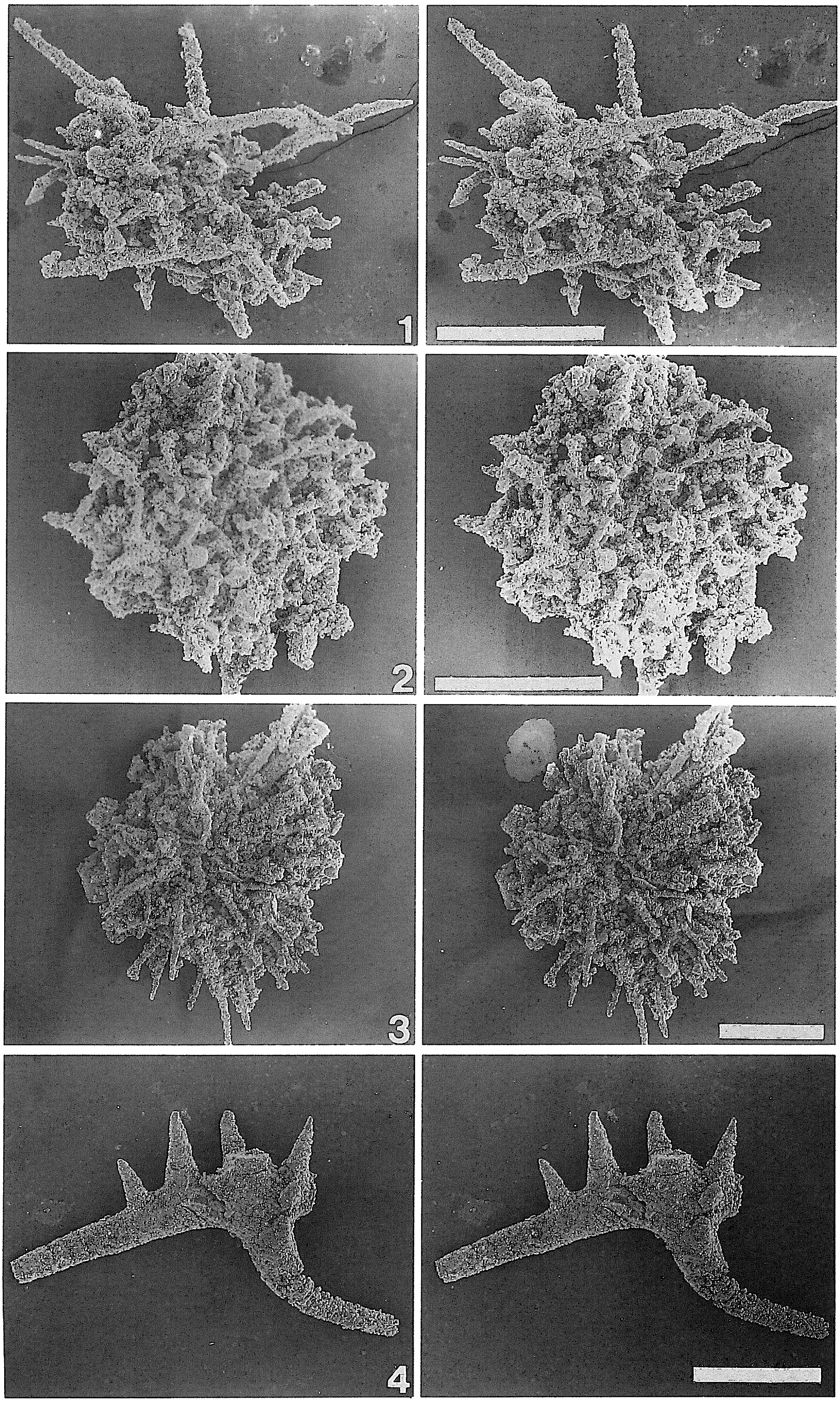
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