MIDDLE PALEOZOIC RADIOLARIANS OF THE GENUS CERATOIKISCUM FROM JAPAN

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ABSTRACT—Three species (including one new species) of the radiolarian genus Ceratoikiscum are described from Silurian silicic rocks of the Hida-gaien Belt, Central Japan, and Devonian silicic tuffs of the Kurosegawa Tectonic Zone, Shikoku. The middle Devonian species are important because they are transitional forms between the simple Silurian Ceratoikiscum species and more complex Early Carboniferous ones.

Key words: Ceratoikiscum, Albaillellaria, Radiolaria, Silurian, Devonian, Hida-gaien Belt, Kurosegawa Tectonic Belt, Fukui, Konomori, Central Japan, Shikoku

INTRODUCTION

The advent of a triangular internal framework with the appearance of Ceratoikiscum Deflandre, 1953, in the Late Silurian (formally described by Renz, 1988) was an important development in the evolution of Paleozoic radiolarians. The triangular frame was a new kind of organization, which was once internalized in Late Devonian time, led to a rapid radiation of Albaillellaria and the production of many short-ranged, biostratigraphically useful Late Carboniferous and Permian taxa (Nazarov and Ormiston, 1986; Ishiga, 1986). The study of Paleozoic radiolarians, especially the Late Carboniferous through Permian radiolarian biostratigraphy of Japan, has improved much over the past several years (see Ishiga, 1986). However, reports of middle Paleozoic Ceratoikiscum radiolarians have been less common than descriptions of Carboniferous forms. The oldest Ceratoikiscum known is from the Wenlockian of the Canadian Arctic (Holdsworth, 1977), and has recently been described by Renz (1988). Devonian species of Ceratoikiscum from Japan are important evolutionary intermediates between Silurian and Carboniferous ones. Species of Ceratoikiscum from Devonian rocks of the Kurosegawa Tectonic Zone and Silurian strata of the Hida-gaien Belt of Japan are here described, and morphological changes of the genus in the Silurian-Devonian interval are discussed.

RADIOLARIAN BIOSTRATIGRAPHY OF THE JAPANESE SILURIAN AND DEVONIAN

Middle Paleozoic radiolarian faunas in Japan are composed mainly of palaeactinomids, palaescenidi, rotasphaerids, entactinids and ceratoikiscids. Several radiolarian assemblages have been proposed, based on the study of radiolarian faunas from the Kurosegawa Tectonic Zone in the Yokokura area, Shikoku (Wakamatsu, 1986; Furutani, 1981, 1983, 1985, 1986) and from the Hida-gaien Belt in the Fukui area, Central Japan (Furutani and Nishiyama, 1980; Furutani, 1985) (Fig. 1). Furutani’s (1985) four radiolarian assemblages in the Fukui area comprise, in ascending order, the Yoshiki, Osobudani I, Osobudani II and Osobudani III Assemblages, and range in age from Silurian to about Middle Devonian (Fig. 2). The exact age of the Yoshiki Assemblage, which was once regarded as Ordovician (Igo et al., 1980), is now considered to be Silurian (Furutani, 1986). The Late Devonian Tcellera horrida Assemblage was reported from the Yokokura area by Furutani (1983, 1986), and recently, six radiolarian assemblages were discriminated in the Silurian and Devonian of this area: the “Rotasphaerids”, Spongocelea sp. 1, Spongocelea sp. 2, Konomori, Parentactinids sp. 1 and Tcecellera horrida Assemblages in ascending order (Fig. 2) (Wakamatsu, 1986).

These two successions of the assemblages can be correlated with each other on the basis of their specific composition as reported in the literature (Fig. 2). However, the composition of the Osobudani III Assemblage in the Fukui area differs from that of the Konomori Assemblage in the Yokokura area as given by Wakamatsu (1986) and their correlation is quite difficult (Furutani, oral com.). The Konomori Assemblage is
regarded to be about Middle Devonian in age (Wakamatsu, 1986).

GEOLOGIC SETTING AND MATERIALS

Ceratoikiscum-bearing rocks have been examined in the Konomori and the Fukui areas. Brief descriptions of their geologic setting are given below.

Konomori area. Radio]arian faunas from siliceous tuff of the Konomori lenticular body of the Kurosegawa Tectonic Zone (Yoshikura, 1985) have been termed the Konomori Assemblage (Wakamatsu, 1986). The outcrop of the Konomori lenticular body is located to the north of Kochi City, Shikoku, Japan (133°31'3"E, 33°35'30"N). According to Wakamatsu (1986), the assemblage comprises Trienaosphera? sp., Palaeoscenidium sp., Parentactinia sp., Trilone? sp., and Ceratoikiscum sp. A paleontological study of Ceratoikiscum Deflandre from the Konomori section has been undertaken and two new species have been described (Ishiga, 1988).

The examined section is composed mainly of silicic tuff and alternating beds of silicic tuff and mudstone. The total thickness of the section is estimated to be about 22 m and 54 samples were collected at about 20 cm intervals (Fig. 3). The strata in this outcrop are overturned, as judged from sedimentary structures. Radiolarians occur in all samples, and samples Ko-41, Ko-33 and Ko-22 yielded well-preserved radiolarians. Radiolarians from this section are composed mainly of palaeo-actinomids, enactinids and small numbers of Palaeoscenidium, Parentactinia and Ceratoikiscum. The vertical

![Fig. 3. Columnar section showing the stratigraphy of the examined section of the Konomori lenticular body of the Kurosegawa Tectonic Zone, Kochi City, Shikoku.](image)

![Fig. 4. List of selected radiolarian species from the Konomori section, Kurosegawa Tectonic Zone, Shikoku (after Ishiga, 1988).](image)
and represents the lower part of the section (from horizons Ko-41 to Ko-31), while the other, characterized by the absence of this species, occupies the upper part. C. liratum Ishiga shows a rather long stratigraphic range.

**Fukuji area.** The Yoshiki Formation (Igo et al., 1980) occurs in the Ichinotani Valley in the Fukuji area, Hidagaien Belt, Central Japan. It is composed mainly of silicic shale and alternating beds of tuff and silicic shale. The Yoshiki Formation is unconformably overlain by the Devonian Fukuji Formation (Fig. 5). The limestone lens, which yielded the supposed Ordovician ostracodes, is intercalated in the upper part of the Yoshiki Formation (Igo et al., 1980).

Well-preserved radiolarians occur in this section of the Yoshiki Formation (Furutani, 1985). Rock samples were collected at about 20 cm intervals within a 20-m thick section (Fig. 5). The radiolarian fauna in this section is called the Yoshiki Assemblage and is composed of *Haliomma* sp., *Actinomma* sp., "Rotasphaerids", *Palaeoscentium* (s.l.) sp., and "Familia nova" of Forty and Holdsworth (1972) (Furutani, 1985; 1986). The Yoshiki Formation was once regarded to be Ordovician in age on the basis of ostracodes from the limestone lens, but it is now considered to be Silurian. This age is based on specific components of the radiolarian fauna and on a comparison with faunas reported from the Silurian of Cornwallis Island in the Canadian Arctic (Furutani, 1981; 1986). *Ceratoikiscum* from the Yoshiki Formation possesses more complicated spicule structures than those from the Silurian of Cornwallis Island (person. com. from Holdsworth in Furutani, 1981), and the precise age of the Yoshiki fauna should be determined from other co-existing fossils and/or on the basis of detailed radiolarian biostratigraphical data to be reported in the future. Among the rock samples, Yo-19 yielded rather well-preserved radiolarians which are described herein.

**SYSTEMATIC PALEONTOLOGY**

Subclass Radiolaria Müller, 1958
Order Polyctene Ehrenberg, 1838, emend. Riedel, 1967

**Remarks.**—Cheng (1986) proposed a taxonomic framework for Albaillellaria radiolarians which include the superfamilies Albaillellacea and Follicucullacea. The Albaillellacea is characterized by having three rods forming a closed triangular framework, and includes the Ceratoikiscidae Holdsworth, the Albaillellidae Deflandre and the Holocicicidae Cheng. The Follicucullacea is characterized by a central skeleton forming an open framework without a b-rod (transverse bar). This superfamily includes the Follicucullidæe Omiston and Babcock, Pseudoalbaillellidæ Holdsworth and Jones and Neosalbaillellidæ Takemura and Nakaseko. Cheng's observation of the difference between these two superfamilies is of great importance for understanding the process of construction of the shell. This is considered to develop from the apical cone (terminal point of "a" and "i"-rods) to the basal part of pseudoabdomen, and was clarified by the examination of ontogenetic changes in *Haplogracanthus* Nazarov and Rudenko (Pseudoalbaillella) (Panasenko and Rudenko, 1987). No specimens with the end of the "b" and "i"-rods have yet been found. This means that the Albaillellaria was greatly evolved by the time of development of Pseudoalbaillella in the Late Carboniferous (Fig. 6).

**Family Ceratoikiscidae Holdsworth, 1969**
**Genus Ceratoikiscum Deflandre, 1953, emend. Won, 1983**

**Type species.**—*Ceratoikiscum avimpectans* Deflandre, 1953

![Fig. 5. Columnar section showing the stratigraphy of the examined part of the Yoshiki Formation in the Hida-gaien Belt, Fukuji area, Central Japan.](image)

![Fig. 6. Phylogeny of Albaillellaria Radiolaria in the Paleozoic.](image)
Remarks.—The radiolarian genus *Ceratoikiscum* was first mentioned by Deflandre (1953) from the Visean (Carboniferous) of the Montagne Noir in southern France, but he did not give a formal description. The first adequate description of this genus was given by Foreman (1963) who classified it from rocks of the Upper Devonian Ohio Shale of USA. Recently the radiolarian faunas of the Montagne Noir were re-examined by Gourmelon (1987). Renz (1988) described four new species of the genus *Ceratoikiscum* from the Wenlockian Cape Phillips Formation on Cornwallis Island in the Canadian Arctic. With respect to the Late Devonian and Early Carboniferous species of *Ceratoikiscum*, much progress has been made on their description, and the phylogenetic change from *Ceratoikiscum* to *Holoeiscus* has been discussed (see Cheng, 1986; Gourmelon, 1987).

TERMINOLOGY OF *CERATOIKISCUM*

The shell construction of *Ceratoikiscum* is characterized by three principal rods crossing to form a closed triangle with extratriangular extensions. The terminology of structures of *Ceratoikiscum* was proposed by Foreman (1963) and later settled by Holdsworth (1969) who discussed comparisons with *Albailelleta*. (For abbreviation and explanations of *Ceratoikiscum* see Fig. 7). In most specimens, one spine, the intersector or “i”-rod, is straight or slightly curved. The other two spines, “a”- and “b”-rods, are curved. The extensional rods of “a”-rod are recurved in some Devonian and Carboniferous specimens. Paired spines of caveal ribs usually originate from a-rod in post-Late Devonian *Ceratoikiscum*, but in Devonian and Silurian *Ceratoikiscum* they extend from both a- and b-rods simultaneously (Ishiga, 1988; Renz, 1988). Irregular blade-like ornamentation (patagial vane) and spongy tissue, named patagium, may arise from any of the main rods.

The basic *Ceratoikiscum* was first orientated by Holdsworth (1969) who described extratriangular rods as the ventral and dorsal or anterior and posterior. Renz (1988) kept these terms, and in addition he specified upper and lower rods for the extratriangular spines (see Fig. 7). The important characteristics of the Devonian *Ceratoikiscum*, which are in transition between Silurian and Carboniferous forms, are the structure of caveal ribs. The Devonian examples described here possess blade-like ribs which closely resemble the caveal rib vane of Carboniferous ones. According to Renz (1988), taxa of the Silurian *Ceratoikiscum* are characterized by simple rod-like caveal ribs. Even the Devonian *Ceratoikiscum* has several pairs of caveal ribs of blade-like shape (e.g., *C. konomoriensis* Ishiga). The caveal ribs of *C. lyratum* Ishiga are ornamented by a single or several rows of pores called vanes in the Namurian *Ceratoikiscum* species of Holdsworth (1969).

DEFINING CHARACTER OF THE GENUS *CERATOIKISCUM*

The defining characteristics of the genus *Ceratoikiscum* were amended by Renz (1988), following consideration of the character of Silurian *Ceratoikiscum*, as follows:

1. The a-rod is not the only one that bears caveal ribs. Ribs often originate from the b-rod. The rod bearing the majority of ribs can be defined as the a-rod.

2. Ribs can originate from the extratriangular extensions.

3. The intersector i-rod is often almost straight but is not always the straightest of the three rods. Specimens of *Ceratoikiscum* with a bent intersector have been described (Renz, 1988).

4. The caveal ribs, which curve toward the junction of the b- and i-rods in many forms (Foreman, 1963; Holdsworth, 1969), do not do so in Silurian and Devonian *Ceratoikiscum*.

DESCRIPTION OF SPECIES

*Ceratoikiscum lyratum* Ishiga

Figs. 8-1–6

*Ceratoikiscum lyratum* Ishiga, 1988, p. 69-76, pls. 2.

Diagnosis.—*Ceratoikiscum* Deflandre, emend. Won with seven or more pairs of caveal rib vanes carried by anterior a.t. and b.t. rods.

Description.—All three principal rods are well developed. Distal portion of external a.p. is tri-bladed and has a weakly developed narrow groove. External rods with small spines; those proximal to each junction of the main rods are stronger than more distal ones. Rods gradually diminish in thickness and length. Six to seven pairs of caveal ribs are attached to a- and b-rods, which together can be termed a “caveal rib vane”. Its ornamentation is either a single row or double rows of elongated pores (this is well shown in stereoscopic pair photos, Fig. 9-4). Caveal rib is keel-shaped. Dorsal edge of the rib (rib vane) bears delicate, tapered spines arising out of groove.
Figs. 8-1-3. *Ceratoikiscum ichinotaniense* Ishiga, n. sp. 1, holotype, DGSU PR 1031, ×167; 2–3, paratypes, DGSU PR 1032, 1034, ×279, ×391 respectively. All are stereoscopic pairs.

Figs. 8-4–6. *Ceratoikiscum konomoriense* Ishiga, 4, ×372; 5, ×279 and 6, ×279, toptype specimens. All are stereoscopic pairs.
Figs. 9-1–6. *Ceratoikiscum lyratum* Ishiga, 1–6, topotype specimens. 1, 5, ×279; 2, ×335; 3, ×558; 4, ×446; 6, ×223. All are stereoscopic pairs.
Some specimens show vertical interbore bars. The bars form irregular or longitudinally elongated pores. Patagial tissue is well developed on each internal and extratriangular rod. Delicate, perforated sheets (patagial vane) are developed in the lower part between a- and i-rods and surround the lower part of the triangle formed by main internal rods (Figs. 9-I, 6). The ventral portion of cavel valvulae extends to connect patagial tissue at the near junction of b- and i-rods (Figs. 9-I, 2).

Measurements.—
Length of a.a. 35–40 μm average 37 μm
Length of a.p. 36–75 average 55
Length of v.i. 28–50 average 35
Length of d.i. 36–60 average 58
Length of b.d. 30–43 average 38

Remarks.—This species differs from other species of Ceratoikiscus in having keel-shaped ribs. Specimens with thick patagial tissue resemble the form Circularformata Cheng in outline.

Material.—Ten specimens from siliceous tuff from horizon Ko-41 in the Konomori lenticular body of the Kurosegawa Tectonic Zone, north of Kochi City.

Occurrence.—This species occurs in a Middle Devonian siliceous tuff in the Konomori lenticular body of the Kurosegawa Tectonic Zone, Shikoku, Japan.

Repository.—Holotype, DGSU PR 1023 (given in Ishiga, 1988, pl. 1, fig. 4) and paratype, DGSU PR 1024 (pl. 1, fig. 5), and toptype specimens described herein are deposited in the Department of Geology, Faculty of Science, Shimane University.

Ceratoikiscus konomoriense Ishiga

Figs. 8-4–6

Diagnosis.—Ceratoikiscus Deflandre, emend. Won with blade-like a- and b-rods, and three pairs of cavel rib vanes carried by anterior a.t. and b.t.

Description.—All principal rods equally developed and rather flattened. A-rod much flattened to form a blade-like structure with a serrated outer margin. Among the three pairs of cavel ribs, the central, strongest one, is attached to the junction of a- and b-rods. The other two pairs of ribs are attached on both sides of the central rib to a- and b-rods, respectively. Cavel ribs crescent-shaped, and strongly tapered distally. The a.t. and b.t. both curved and forming an almost continuous arc, so that the “triangle” is actually D-shaped.

Measurements.—
Length of a.a. 35–40 μm average 37 μm
Length of a.p. 36–75 average 55
Length of v.i. 28–50 average 35
Length of d.i. 36–60 average 58
Length of b.d. 30–43 average 38

Remarks.—This species differs from the Silurian Ceratoikiscus described by Renz (1988) in that C. konomoriense possesses flattened primary rods and cavel rib vanes. However, both species are characterized by having several pairs of cavel rib vanes, of which one is attached to b-rod.

Material.—Twenty specimens from a siliceous shale from horizon Ko-33 in the Konomori lenticular body of the Kurosegawa Tectonic Zone.

Occurrence.—This species occurs from a Middle Devonian silicic tuff in the Konomori lenticular body of the Kurosegawa Tectonic Zone, Shikoku, Japan.

Repository.—Holotype, DGSU PR 1025 (given in Ishiga, 1988, pl. 2, fig. 1) and paratype, DGSU PR 1026, 1028 (pl. 2, figs. 2, 3), and toptype specimens described herein are deposited in the Department of Geology, Faculty of Science, Shimane University.

Ceratoikiscus ichinotaniense Ishiga, n. sp.

Figs. 8-1–3

Ceratoikiscus sp., Furutani in Igo et al., 1980, p. 500, fig. 2-2.

Diagnosis.—Three simple and strong principal rods with or without several small pairs of ribs.

Description.—All principal rods equally developed with several pairs of small ribs attached to internal triangle of both a- and b-rods. Rods are ornamented by patagial tissue. Distal part of a- and b-rods recurved and tapered. External rods with irregularly developed, small spines.

Measurements.—
Length of a.a. 98–112 μm average 103 μm
Length of a.p. 110–120 average 113
Length of v.i. 113–124 average 116
Length of d.i. 140–166 average 155
Length of b.d. 122–134 average 125
Length of v.h. 133–155 average 142

Remarks.—This species is distinguished from other species of Silurian Ceratoikiscus described by Renz (1988) in that C. ichinotaniense n. sp. possesses recurved extratriangle rods and small ribs.

Material.—Twelve specimens from a siliceous shale from horizon Yo-19 in the Silurian.

Occurrence.—This species occurs in a Silurian siliceous shale of the Yoshiki Formation of the Hida-gaien Belt, Central Japan.

Repository.—Holotype; DGSU PR 1031 (Fig. 8-1) and paratypes; DGSU PR 1032 (Fig. 8-2) and DGSU PR 1034 (Fig. 8-3) described herein are deposited in the Department of Geology, Faculty of Science, Shimane University.

EVOLUTIONARY CHANGE OF CERATOIKISCUS

Groups of ceratoikiscids have been reported from the Silurian to Early Carboniferous interval. Although the record of the genus is not continuous, probable evolutionary changes of these forms are summarized below, and the most important evolutionary changes affecting the structures of inner and extensional triangle spicules and the development of cavel ribs in middle to late Paleozoic time are discussed.

A. SILURIAN CERATOIKISCUS

Specimens of Ceratoikiscus from the Wenlockian of the Canadian Arctic (Renz, 1988) are composed of simple basic Ceratoikiscus spicules, namely, three triangular rods and cavel ribs. Internal and external triangular rods are of the same diameter. Some specimens have four or more paired cavel ribs, but Japanese specimens from the Fukui area are characterized by
showing a simpler structure of several small, thin and delicate paired caveal ribs. The Devonian Ceratoikiscum konomoriense is similar in structure to the Silurian Ceratoikiscum with respect to the number and extension of caveal ribs attached to both a- and b-rods, but the caveal ribs of Devonian forms are characterized by a blade-like shape and a serrated outer margin.

**B. DEVONIAN AND EARLY CARBONIFEROUS CERATOIKISCUM**

Reported occurrences of Early Devonian Ceratoikiscum are rare, whereas reports of Middle and Late Devonian forms are more common. As described above, *C. lyra* already has some important characteristics typical of the Carboniferous Ceratoikiscum with respect to caveal rib vanes and patagial vane. In this sense Middle Devonian species can be regarded as intermediate forms between the Silurian and Late Devonian ones. Forms of Ceratoikiscum from the Upper Devonian (Nazarov andOrmiston, 1983) are ornamented with a rather complicated structure of patagial vanes and tissue, and closely resemble those of the Carboniferous. It is said that Late Devonian and Early Carboniferous members of some radiolarian groups are quite similar, but it is apparent that precisely at this time essential morphological changes affecting all parts of the skeleton occurred in other groups; changes are also known in the spherical polyhystines (Nazarov and Ormiston, 1986). A major radiation was triggered in Ceratoikiscum at this time. In the Late Devonian, Ceratoikiscum was greatly diversified and gave rise to many unique species; for examples, *C. planistellare* Foreman is characterized by a well-developed and thickened star-shaped spicule (Nazarov and Ormiston, 1986). New genera were derived from the Late Devonian Ceratoikiscum including Hellenisra Nazarov and Ormiston and Circularforma Cheng. The former is ornamented by a thick spongy structure forming a single elongated ring of platy fabric with a circular central opening, while the latter is characterized by a ring-like central skeletal form without continuous straight rods. Several stratigraphically valuable species and/or genera arose at this time because of a wide diversification of the genus Ceratoikiscum.

After this radiolarian datum event, other important evolutionary changes occurred in the Early Carboniferous. Although there is disagreement on the origin of Albailiella in Early Carboniferous time (Won, 1983; Holdsworth and Jones, 1980; Nazarov and Ormiston, 1986), Early Carboniferous Albailiella are regarded as having been derived from Ceratoikiscum via Protoalbaillella (Cheng, 1986).

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