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Ages of Silurian radiolarians from the Kurosegawa terrane, southwest Japan constrained by U/Pb SHRIMP data

Jonathan C. Aitchison,* Shigeki Hada,† Trevor Ireland‡ and Shin-ichi Yoshikura§

*Department of Earth Sciences, University of Hong Kong, Pokfulam Rd, Hong Kong; †Research Institute for Higher Education, Kobe University, Tsurukabuto, Nada-ku, Kobe 657, Japan; ‡Research School of Earth Sciences, Australian National University, Canberra, ACT 2601, Australia; §Department of Geology, Kochi University, Akebono-cho, Kochi 780, Japan

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Abstract—Radiolarians are abundant in mid-Paleozoic tuffs of the Kurosegawa terrane of southwest Japan. Well preserved Silurian radiolarian faunas recovered from several localities are described herein and include four new species: *Ceratoikiscum kurosegum* n. sp., *Fusalfanus? konomoriensis* n. sp., *Futobari? jingamoriensis* n. sp., and *Futobari? tosaensis* n. sp. The absence, within the same strata, of fossils belonging to other taxonomic groups has presented difficulties in determining the precise ages of the Kurosegawa radiolarian faunas. U/Pb SHRIMP ages of pyroclastic zircons from tuff units within the succession indicate Wenlockian [427.2 ± 7.6] and Pridolian [408.9 ± 7.6] ages and remove ambiguity regarding the Silurian age of tuffaceous rocks in the Kurosegawa sequence. Copyright © 1996 Elsevier Science Ltd

Introduction

The Kurosegawa terrane, which transects SW Japan (Fig. 1), is a narrow, disrupted, composite, tectonostratigraphic entity of predominantly Paleozoic age lying between Mesozoic terrranes (Yoshikura *et al*., 1990; Aitchison *et al*., 1991). The discovery of the fossil coral *Halysites* by Kobayashi and Iwaya (1940) was the first indication of a Silurian age for any strata within the terrane. The rocks are strikingly anomalous in age and lithology with respect to surrounding terranes and their occurrence represents a distinct break in the overall SE younging progression of terranes across SW Japan.

Ordovician igneous and metamorphic basement rocks are locally overlain disconformably by a distinctive volcaniclastic sequence (Yasui, 1984). These rocks form a characteristic element of the terrane and their lithostratigraphy is well established (Fig. 2) and can be readily correlated between several well separated tectonic lenses of the terrane. Pyroclastic rocks including ignimbrites and voluminous vitric, crystal, and lithic tuffs are the dominant lithologies and they attest to the continental margin volcanic arc derivation of most of the sediments. The occurrences of welded ignimbrite at Yokokurayama (Yoshikura and Sato, 1976), rare accretionary lapilli (Yoshikura and Okubo, 1993) together with diverse sponge spicule assemblages are interpreted as indicating deposition in a marginal to shallow marine setting (Aitchison *et al*., 1991).

A distinctive stratigraphic horizon of limestone (G3) occurs near the base of the clastic succession. Numerous corals (halysitids, favositids), stromatoporids, cephalopods, trilobites and conodonts have been recovered from the limestones (Hamada, 1958; Kobayashi and Hamada, 1974; Kuwano, 1976; Nakai 1981) and these have become famous for their mid-Silurian (Wenlockian–Ludlovian) faunas. The carbonates are overlain by a thick (up to 1500 m) sequence of silicic vitric tuffs (G4) and tuffaceous sandstones. These rocks are, in turn, succeeded by thickly bedded terrigenous sandstones and pebbly conglomerates (Ochi Formation; Yasui, 1984).

The Kurosegawa terrane volcaniclastic sequence is significant because of the presence of an abundance of well-preserved radiolarians in fine-grained tuffaceous lithologies. Radiolarians are renowned for their potential to assist in the resolution of stratigraphy in deformed accretionary complex rocks and general terrane analysis worldwide (Aitchison and Murchey, 1992). The sequence has potential for contributing to the establishment of a global mid-Paleozoic radiolarian biostratigraphy and several faunas from this region have previously been described (Furutani, 1983; Ishiga, 1988; Wakamatsu *et al*., 1990; Aitchison *et al*., 1991; Umeda, 1994a, b). However, the utility of radiolarians in the Kurosegawa terrane has been impaired by a lack of confidence regarding the absolute age of the upper (G4) volcaniclastic succession. No Silurian fossils (other than radiolarians) have been recovered from the pyroclastic and epiclastic strata. The only reports of diagnostic fossils from demonstrably *in situ* lithologies at higher stratigraphic levels are of possible latest Devonian (Famennian) conodonts from vitric tuffs close to the top of the sequence at Yokokurayama (Nikawa, 1986) and the Upper Devonian/Lower Carboniferous plant fossils *Leptophloeum rhombicum* and *Lepidodendropsis* sp. which occur in volcaniclastic sandstones slightly higher in the succession (Ochi Formation; Hirata, 1966). Furutani (1983), Ishiga (1988), and Wakamatsu *et al*. (1990), assigned Silurian–Middle Devonian ages to radiolarians extracted from vitric tuffs below the level of plant-bearing sandstones at Yokokurayama based on their stratigraphic position between strata containing Silurian and Upper Devonian fossils. Aitchison *et al*. (1991) pointed out that although some of the limestones might be allochthonous there is no *a priori* reason why the ages of limestone blocks should be the same as that of the sediments into which they were redeposited. Given the proximal nature of the volcaniclastic succession and known arc sedimentation rates Aitchison *et al.* (1991) suggested that the Kurosegawa terrane succession was either of considerably shorter temporal duration than the inferred Silurian to mid-Devonian age range or that it contained some cryptic hiatus(es).

In order to resolve this problem and to assist in the development of a reliable global radiolarian biostratigraphy we have undertaken reconnaissance radiometric dating of magmatic zircons within tuffs at basal and uppermost stratigraphic levels of the sequence. Several tuffs were collected from the Kurosegawa terrane at the Yokokurayama and Konomori localities where the stratigraphy is well established. Samples were mechanically abraded and heavy mineral concentrates prepared by graduate students of Professor Hada at Kochi University. Two samples, Ykt-2 and Kt-3, representing levels close to the base and top of the succession respectively, were chosen for analysis using the Sensitive High Resolution Ion Microprobe (SHRIMP) at the Australian National University (ANU).

In the Yokokurayama area 30 km west of Kochi City, a virtually unmetamorphosed sequence, the Yokokurayama Formation, represents the most complete mid-Paleozoic sedimentary succession within the terrane. The formation is 1.5 km thick and subdivided into four members G1, G2, G3 and G4 in ascending order (Hamada, 1959) (Fig. 2). The G1 unit unconformably overlies Ordovician granitic rocks in the eastern part of the area and consists of three welded tuff layers with intercalations of alternations of silicic vitric tuff, pumiceous crystal tuff, tuffaceous sandstone and mudstone. Unit G2 consists of tuff, tuffaceous shale, calcareous sandstone, and limestone (Wakamatsu *et al.*, 1990) which contains upper Llandoverian to lower Wenlockian conodonts (Kuwano, 1976). The G3 member is composed almost entirely of limestone with a few thin vitric tuff beds and very minor sandstone (Yoshikura, 1985). The G4 member is up to 1000 m thick and dominated by volcaniclastic sedimentary rocks. Lithologies include vitric tuff, pumiceous vitric crystal tuff, vitric crystal tuff, tuffaceous sandstone and minor conglomerate (Yoshikura, 1985). It is within the G4 member that radiolarians are most abundant.

Sample Ykt-2 is a light green vitric crystal tuff sampled from a 30 m thick intercalation just below the uppermost and thickest welded tuff of G1 exposed along the road to Oda Park on the eastern flank of Yokokurayama (Ohsaki 1:25000 map sheet N1-53-28-15-2; Lat. 33°31′49″27‴N, Long. 133°12′52″02‴E). Results for zircons from the Yokokurayama tuff Ykt-2 give a concordant $^{206}Pb/^{238}U$ age of 427.2 ± 7.6 Ma (2σ) (Fig. 3).

Sample Kt-3 was collected from a radiolarian-bearing outcrop at the southern flank of Mt Konomori located to the north of Kochi City (Lat. 33°35′00″N, Long. 133°29′59″E; Locality Kh22 in Wakamatsu *et al.*, 1990, Fig. 4). Mt Konomori primarily consists of a silicic volcaniclastic sequence which is in faulted contact with Lower Cretaceous sandstones to the south and serpentinite to the north. Fine-grained granitoid rocks have locally intruded the sequence. The dominant lithologies within the silicic volcaniclastic sequence in this area are vitric tuff, vitric crystal tuff, tuffaceous

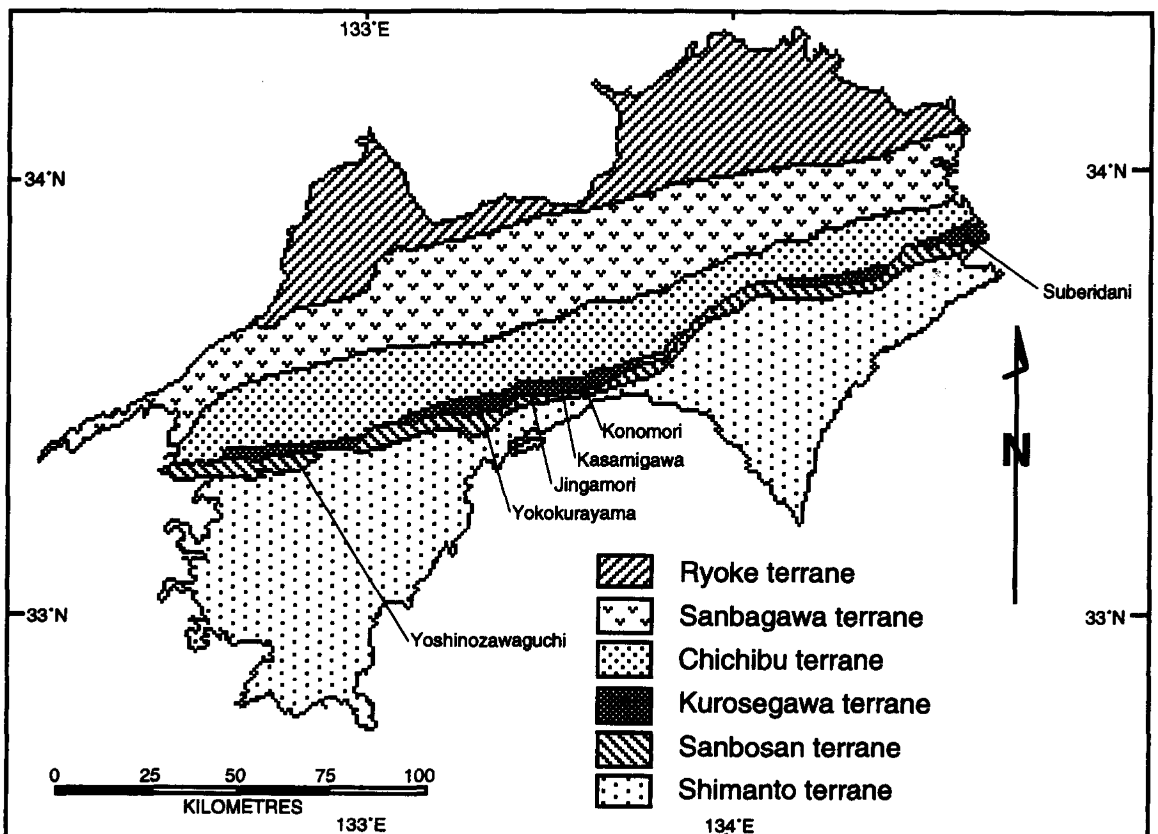

Fig. 1. Lithotectonic terrane map of Shikoku, Japan indicating locations of outcrops of Silurian volcaniclastic sediments within the Kurosegawa terrane from which the samples reported in this paper were collected.

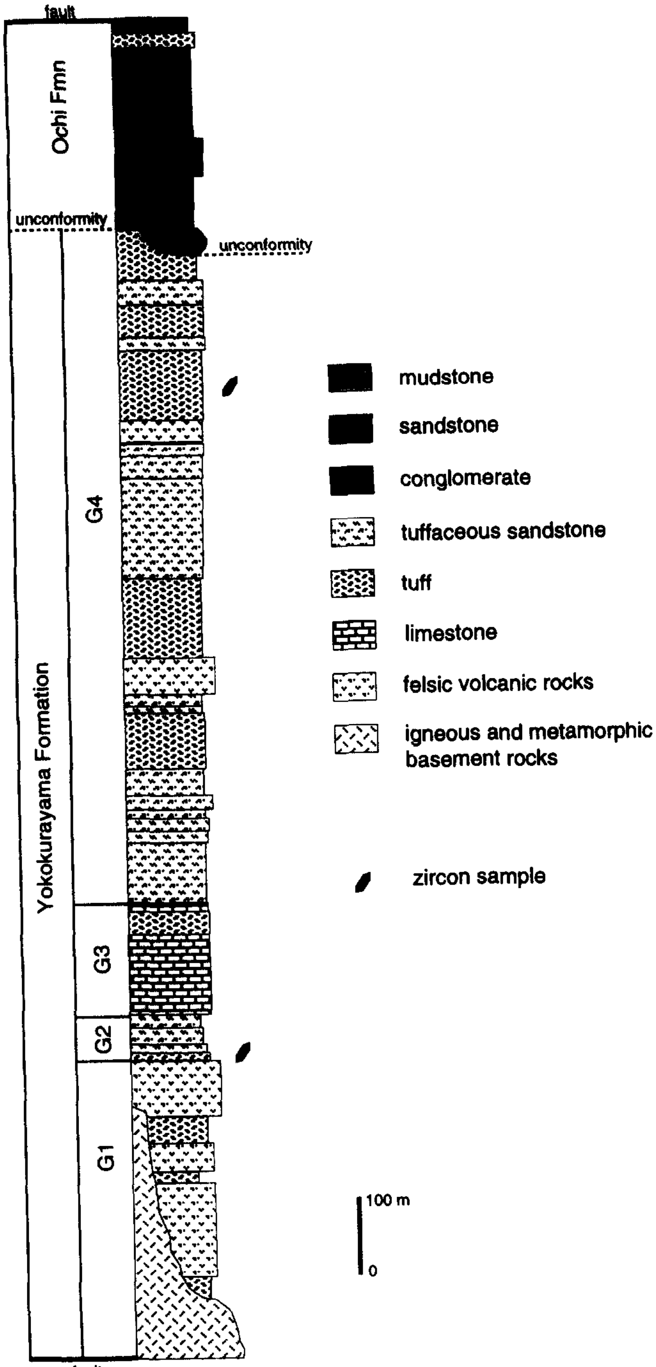

Fig. 2. Idealised stratigraphic column of Silurian lithologies within the Kurosegawa terrane. Approximate thicknesses and relative proportions of various lithologies present in units G1–G4 are indicated (after Yasui, 1984) as are the approximate stratigraphic levels from which zircon samples were collected from SHRIMP analysis.

sandstone and tuffaceous siltstone. The sequence is several hundred metres thick, homoclinal with an E–W trend, and dips at 60° to the north. It is correlated with Unit G4 of the Yokokurayama Formation. Kt-3 is a dark brownish gray vitric crystal tuff sample from an exposure consisting of alternations of 5–25 cm thick vitric tuff or vitric crystal tuff and 1–3 cm thick light brown tuffaceous siltstone. The sample came from the uppermost levels of the Konomori section and the lithology collected is characteristic of upper levels of unit G4. The locality from which Kt-3 was collected has yielded well-preserved radiolarian faunas (Ishiga, 1988; Wakamatsu *et al.*, 1990; Aitchison *et al.*, 1991; this paper). Results for zircons from the Konomori tuff give a concordant $^{206}Pb/^{238}U$ age of 408.9 ± 7.6 Ma (2σ).

The new radiometric age constraints remove a considerable degree of uncertainty about the age range of mid-Paleozoic volcaniclastic sediments within the Kurosegawa terrane. Previously it had been proposed that the sediments may have been deposited through a time span covering Silurian to Devonian, an interval of around 600 Ma (Harland *et al.*, 1989). The SHRIMP data provide direct age constraints on the G1–G4 succession within the Kurosegawa terrane and bracket the duration of silicic calc-alkaline volcanic arc activity. The maximum age range for deposition, at the 2σ limits of our data, is 33 Ma which is in much closer accord with what would be expected given normal volcanic arc sedimentation rates. Within a relatively large uncertainty, the age for the Ykt-2 sample correlates with basal Wenlock (Harland *et al.*, 1989) which is consistent with the fossil age constraints of limestones in the G1–G2 members and resolves any question of possible large scale temporal allochthoneity of these limestones.

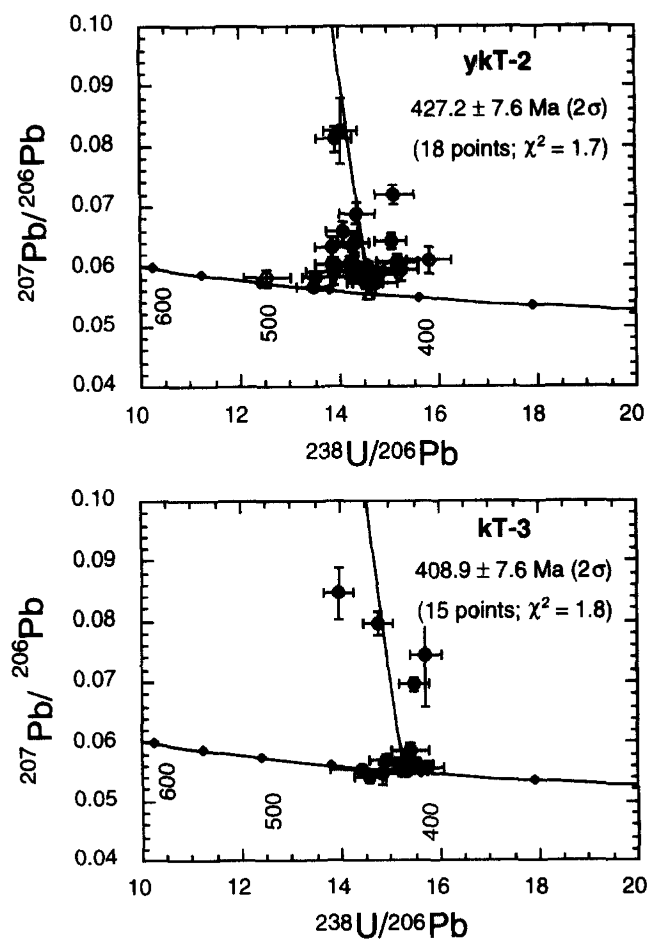

Fig. 3. Tera–Wasserburg concordia plots of U–Pb SHRIMP data for Kurosegawa terrane samples. [Unfilled points are omitted from age calculations; for discussion of common lead correction and data analysis methods see Aitchison and Ireland (1995); Errors and error bars are 2σ].

Silurian Radiolarian biostratigraphy

Understanding of global radiolarian biostratigraphy has advanced rapidly since the development of techniques whereby these siliceous microfossils can be extracted from an enveloping siliceous matrix. By the early 1980s (Holdsworth and Jones, 1980) the biostratigraphy had been refined back as far as the Upper Devonian permitting a radiolarian-led revolution in the understanding of complex terranes of oceanic origin accreted to continental margins. Despite this obvious potential for aiding the understanding of ancient tectonic collages, a useful biostratigraphy has not yet been produced for the Lower Paleozoic. Although some faunas have been described, these tend to be exceptionally well-preserved material from isolated localities (e.g., Goodbody, 1982, 1986; Webby and Blom, 1986; Aitchison, 1993a) and the true stratigraphic range of most taxa that have been described is not constrained.

Despite their exquisite beauty, these faunas are often of little stratigraphic utility with respect to those from chert-dominated orogenic collages. To be useful in these areas biostratigraphies need to be based on commonly occurring, robust taxa. More recently work has begun to concentrate on successions where useful biostratigraphies can be developed (Silurian; Noble, 1994; Devonian; Aitchison and Stratford, 1994, in prep; Stratford and Aitchison, 1994, 1996 in press). Although based mostly on spot occurrences, Nazarov and Ormiston (1993) recently published a major work summarizing the state of knowledge on Lower Paleozoic radiolarians which includes a rudimentary biozonation. In a major work on mostly Upper Silurian material from the Caballos Novaculite in west Texas, USA Noble (1994) demonstrated the potential for a useful Lower Paleozoic biozonation by introducing seven biozones based on distinctive robust taxa.

Kurosegawa terrane radiolarians

Wakamatsu *et al.* (1990) described six radiolarian assemblages from localities within the Kurosegawa terrane some of which we have resampled. They described 4 new genera, 11 new species and 17 radiolarians of indeterminate affinity. The radiolarian assemblages were not accompanied by any other fossils and were thus assigned ages based on their stratigraphic level in what was inferred to be a Lower Silurian to Upper Devonian succession (the Yokokurayama Formation and its correlatives). They discussed, at length, globally known ranges of radiolarians similar to those in their assemblages before making their tentative age assignments. Furutani (1990) described similar radiolarians from the Hida Gaien Belt, another section characterised by rapidly sedimented volcaniclastic rocks. Exposure in this unit is, however, anything but continuous with most localities densely vegetated and heavily affected by faulting. Until now, no independent age control has been available for the sediments which have produced the radiolarians.

Noble (1994) compared her Texas assemblages with those described from Japan. She suggested, on the basis of correlation with her faunas, that all of the Hida Gaien (Furutani, 1990) faunas occur within her Rotasphaerid Superzone. Noble placed four of the Kurosegawa terrane assemblages *Secuicollacta? exquisita*, *Pseudospongoprunum tazukawaensis*, *Devoniglansus unicus* and *Pseudospongoprunum sagittatum* within the Silurian. No comment was made on the possible age of the *Palaeoscenidium ishigai* and *Tlecerina-Glanta* assemblages presumably because they differ from the Caballos material and were clearly thought to be Middle Devonian by Wakamatsu *et al.* (1990). Ishiga (1992) described some radiolarians including two new species of *Ceratoikiscum* from the upper (G4) unit at Konomori and followed previous workers by inferring a Middle Devonian age.

Having examined the Devonian of eastern NSW, Australia, our study was initially commenced partly in order to further extend known radiolarian biostratigraphy. In an early re-examination of Hinde's (1899) Yarrimie Formation material from NSW, Aitchison (1990) considered the possibility that this material was Upper Devonian. This was based in part on reports of conodonts indicative of the Upper Devonian in the Yarrimie Formation and partly on considerations that entactinids with three bladed spines were uncommon below the Upper Devonian (Holdsworth and Jones, 1980). Current work in progress in which radiolarians are closely tied to an intensive conodont and chitinozoan sampling project shows that the Yarrimie 'facies' in New England is mostly Lower to Middle Devonian. Well preserved radiolarian assemblages have been recovered and will be described elsewhere (Aitchison and Stratford, 1994, 1996 in press, Stratford and Aitchison, 1994, 1996 in press). Notably, they are markedly different from most of those previously reported from the Kurosegawa terrane and the studies of both these independent successions have done much to resolve previously poorly constrained sections of the Silurian to Devonian radiolarian biostratigraphy. Early Devonian radiolarian faunas reported from Germany (Kiessling and Tragelehn, 1994) also differ from those described from the Kurosegawa terrane. Significant evolutionary change in radiolarian faunas must have occurred between the end of the Silurian and the Early Devonian.

Preliminary examination of reputedly Middle Devonian radiolarians from Konomori revealed little similarity with inferred correlatives in Australia. The Konomori radiolarian fauna is entirely different from faunas in the Lower and Middle Devonian of eastern Australia. As the Kurosegawa terrane supposedly formed at a similar latitude this result is surprising. In an attempt to resolve unanswered questions about the age of the Kurosegawa terrane radiolarian assemblages, we have undertaken radiometric age dating of magmatic zircons (SHRIMP U–Th–Pb) from within the radiolarian-bearing tuffs. Radiometric age data demonstrate that the revision of age assignments of Japanese radiolarian assemblages, as suggested by Noble (1994), is appropriate. Significantly, the radiometric ages from the top of the succession at Konomori indicate that the *Palaeoscenidium ishigai* assemblage is also Silurian, albeit latest Silurian. Despite our own intensive sampling of the Yokokurayama succession we recovered neither this assemblage nor the *Tlecerina-Glanta* assemblage, which we suspect to be younger (probably Early Devonian) and which occurs near the top of the Yokokurayama section.

Well preserved faunas which have now been found at numerous localities indicate that there is a considerable deal of overlap between the assemblages reported by

Wakamatsu *et al.* (1990) and Furutani (1990). The assemblages described are simply the faunas recovered at various levels in the succession and do not strictly represent assemblages which define a biozonation. More work is required on better exposed sections than those available in Japan before this can be achieved. There is also some overlap between Japanese assemblages and the zonation of Noble (1994). It is not yet clear if this overlap is a result of local differences in the range of some taxa or related to paleoenvironmental or preservational factors. Nevertheless, results of work in Japan and the USA indicate the feasibility of development of a workable Silurian radiolarian biozonation.

Work recently presented by Umeda (1994a, b) indicates that younger, probably Devonian, material may indeed be present in the Kurosegawa terrane upsection of the faunas we describe herein. Umeda (1994b) reported the occurrence of *Holoeciscus* sp. A. On examination of this material the fauna clearly includes *Protoholoeciscus hindea* Aitchison and an undescribed form of *Circulaforma* which recent work from eastern NSW (Aitchison and Stratford, 1994, in prep, Stratford and Aitchison, 1994, 1996 in press) shows to be Middle Devonian (Eifelian).

Kurosegawa terrane radiolarian localities

Many radiolarian samples were collected from outcrops of mid-Paleozoic volcaniclastic successions along the Kurosegawa terrane on the island of Shikoku (Fig. 1). The only locality which did not produce identifiable radiolarians was at Suzaki Peninsula in the west of the island. However, Umeda (1994a) has recently reported better preserved material from this area. Details of the content of the radiolarian faunas recovered from various localities are given in Table 1. All radiolarian specimens described herein are housed in collections at the Department of Earth Sciences, University of Hong Kong.

Yokokurayama. Fine-grained, thinly bedded, tuffaceous cherts and mudstones are intercalated with coarser volcaniclastic sediments on Yokokurayama as part of a 1500 m thick sequence in central Shikoku. Limestones occur near the base of the succession which overlies an igneous basement. Details of geology in this region are given by Yoshikura (1985) and Yasui (1984). Radiolarians were obtained from samples collected along the road through Oda Park and from the streams above the hamlet of Nakaohira along the southeastern flank of the mountain. Material recovered from our samples was poorly preserved and readers are referred to the more successful study of Wakamatsu *et al.* (1990) for details of radiolarian stratigraphy in this region.

Yoshinozawa-guchi. Fine-grained, thinly bedded, tuffaceous cherts and mudstones abut Silurian limestone blocks in a small river-worn outcrop along the banks of the Yoshino River in western Shikoku city (Lat. 33°44′N, Long. 132°44′E). Several moderately preserved radiolarians were recovered from samples at this locality.

Jingamori. Several productive radiolarian-bearing tuffaceous chert sample were collected from outcrops along a track located 1500 m NW of Okabana railway station west of Ino township Yokokurayama (Ochi 1:25000 map sheet N1-53-28-11-4; Lat. 33°32′09″47‴N, Long. 133°20′38″28‴E).

Kasamigawa. A small outcrop (30 m width) of tuffaceous cherts was exposed adjacent to the highway along the east bank of the Kasamigawa on the western outskirts of Kochi city (Ino 1:25000 Map Sheet N1-53-28-11-2; Lat. 33°34′23″30‴‴N, Long. 133°28′55″01‴17‴′E). These rocks remained exposed until February 1990 when the outcrop was vandalised by road maintenance engineers through the application of spray-on concrete.

Konomori. Radiolarian-bearing tuffaceous cherts are well exposed in road embankments cut through mikan orchards at high levels on Konomori a small mountain which overlooks Kochi city (Ino 1:25000 Map Sheet N1-53-28-11-2; Lat. 33°34′30″N, Long. 133°29′59″E). These rocks are in faulted contact with other elements of the Kurosegawa terrane and are locally intruded by felsic intrusives. Geological mapping in this area indicates that the volcaniclastic succession is essentially continuous. These rocks are widely interpreted to represent sediments from the upper level of the G4 unit as Devonian plant fossils (*Leptophloeum* sp.) have been recorded in the vicinity. The localities collected include Kh13, 22 and 24 of Wakamatsu *et al.* (1990, Fig. 4) and elsewhere on top of and on the side of this mountain. No differences in radiolarian assemblages were noted other than preservational variation.

Suberidani. Radiolarians occur in tuffaceous cherts collected from immediately adjacent to Silurian limestone lenses in the Suberidani area west of Tokushima city (Lat. 33°53′N, Long. 134°25′E). The locality corresponds with the Tazukawa area of Wakamatsu *et al.* (1990, Fig. 4) locations Ts15 and Ts14. The exact stratigraphic relationships between the tuffs and limestones are uncertain due to the poor exposure.

Age significance of Kurosegawa terrane radiolarians

Although radiometric dating has resolved the absolute ages of the Kurosegawa terrane radiolarian assemblages reported herein, several important questions remain. The ranges of the assemblages and individual taxa within the assemblages are not yet clearly established. Some work remains before Silurian radiolarian biostratigraphy can be widely used for precise, fine-scale age determinations. Further study of several key taxa reported from assemblages which have been used to establish a tentative biostratigraphy elsewhere (Furutani, 1990; Wakamatsu *et al.*, 1990; Noble, 1994) reveals that they occur at unexpected levels in the Kurosegawa terrane (Table 1). This is most likely related to preservational factors which precluded their earlier discovery at these levels. Nevertheless, it indicates that the age ranges of several taxa are greater than previously estimated.

Helenifore speciosus occurs in samples from Konomori, Kasamigawa and Jingamori. Synonymous material was previously reported from the *Tlecerina-Glanta* assemblage in unit Y4 at Yokokurayama (Wakamatsu *et al.*, 1990). This taxon was also reported by Furutani (1990) from the *Fusalfanus osobudaniensis* assemblage in the Hida–Gaien region which Noble (1994) suggested correlated with her latest Wenlockian/Ludlovian *Palaeoactinosphaera* (?) *asymmetrica* zone. This may indicate a similar Silurian range for the taxon to that reported from the southern Urals by Nazarov and Ormiston (1993).

Pseudospongoprunum sagittatum originally reported (Wakamatsu *et al.*, 1990) from upper levels of unit 4 at

Table 1. Occurrences of various radiolarian taxa in samples of this study and those previously reported by Furutani (1990) and Wakamatsu *et al.* (1990). χ = present in samples, A = abundant (>10 per residue), C = common (5–10 per residue), R = rare (<5 per residue)

Localities of this paper / Taxa	*Ceratoikiscum lyratum*	*Ceratoikiscum kurosegum* n. sp.	*Ceratoikiscum vimineum*	*Ceratoikiscum armiger*	*Ceratoikiscum* spp.	*Ceratoikiscum* sp.	*Helenifore* sp.	*Helenifore speciosus*	*Glanta fragilis*	*Glanta triangularis*	*Glanta* spp.	*Pactarentinia holdsworthi*	*Pactarentinia* sp.	*Deflantrica vetustum*	*Deflantrica solidum*	*Deflantrica* sp.	*Palaeoscenidium cladophorum*	*Palaeoscenidiidae* gen. spp.	*Palaeoscenidium* spp.	*Goodbodium* spp.
Konomori	A	A	A					A							A		A			
Kasamigawa	R	A	A									A			A		A			
Jingamori	R	A	C														A			
Suberidani																				
Yokokurayama																				
Yoshinozawa-guchi																				
Assemblages of Wakamatsu *et al.* and Furutani (1990)																				
Tlecerina-Glanta			χ		χ		χ		χ	χ	χ	χ	χ	χ		χ			χ	
Palaeoscenidium ishigai	χ	χ			χ										χ	χ	χ		χ	
Pseudospongoprunum sagittatum					χ														χ	
Devoniglansus unicus					χ														χ	
Stylosphaera sp. C																				
Stylosphaera sp. A																				
Zadrappolus yoshikiensis						χ													χ	χ
Spongocoelia parvus—S. kamitakaraensis																				
Pseudospongoprunum tazukawaensis																		χ		χ
Fusalfanus osobundaniensis				χ				χ												χ
Secuicollacta? exquisita																		χ	χ	χ

Localities of this paper / Taxa	*Holdsworthum* sp.	Spum, *gen. indet.* sp. M	*Tlecerina* spp.	*Devoniglansus unicus*	*Pseudospongoprunum sagittatum*	*Pseudospongoprunum* sp.	*Pseudospongoprunum tazukawaensis*	*Secuicollacta* spp.	*Rotasphaera beckwithensis*	*Auliela?* sp.	*Fusalfanus osobudaniensis*	*Fusalfanus? konomoriensis* n. sp.	*Futobari solidus*	*Futobari morishita*	*Futobari? tosaensis* n. sp.	*Futobari? jingamoriensis* n. sp.	*Oriundogutta*	*Oriundogutta* so. cf. *O. kingi*	*Zadrappolus tenuis*	*Inanihella* sp. cf. *I. duroacus*
Konomori					A							A	A	A	A	A			A	A
Kasamigawa																			A	
Jingamori													A	A	A	A			A	A
Suberidani							A													
Yokokurayama																				
Yoshinozawa-guchi		χ					χ										χ	χ		
Assemblages of Wakamatsu *et al.* and Furutani (1990)																				
Tlecerina-Glanta																				
Palaeoscenidium ishigai																				
Pseudospongoprunum sagittatum					χ	χ														
Devoniglansus unicus				χ																
Stylosphaera sp. C											χ									
Stylosphaera sp. A													χ	χ						
Zadrappolus yoshikiensis	χ												χ	χ					χ	
Spongocoelia parvus—S. kamitakaraensis																				
Pseudospongoprunum tazukawaensis							χ	χ												
Fusalfanus osobundaniensis	χ							χ			χ									
Secuicollacta? exquisita		χ						χ		χ										

Gion-yama in Kyushu is common in samples from Konomori and Jingamori at the equivalent level to the *Palaeoscenidium ishigai* assemblage of Wakamatsu *et al.* (1990). *Futobari solidus* and *F. morishitai* of the *Stylospheara* sp. A to *Zadrappolus yoshikiensis* assemblages which occur at levels interpreted to be stratigraphically high in the Hida–Gaien succession. These taxa were not reported to be present in any of the samples studied by Noble (1994). Our study indicates that both taxa also occur at the upper (uppermost Silurian) levels of the Kurosegawa terrane succession.

Systematic Descriptions

Subclass Radiolaria Müller, 1858
Order Polycystida Ehrenberg, 1838
Suborder Albaillellaria Deflandre, 1953 emend. Holdsworth, 1969
Superfamily Albaillellacea Cheng, 1986
Family Ceratoikiscidae Holdsworth, 1969

Genus *Ceratoikiscum* Deflandre, 1953
Type species: *Ceratoikiscum avimexpectans* Deflandre, 1953

Ceratoikiscum lyratum Ishiga, (pl. 1, Figs 3–4; pl. 2, Fig. 1; pl. 3, Figs 4, 5)
Synonymy
1988 *Ceratoikiscum lyratum*—Ishiga pl. 1, Figs 4, 5
1992 *Ceratoikiscum lyratum*—Ishiga Fig. 9, 1–6
Material
Abundant in samples from unit G4, Konomori, Kochi City, also rare in samples from Kasamigawa and Jingamori, Kurosegawa terrane, Shikoku.
Description
Several pairs of keel shaped caveal ribs, some of which exhibit weakly developed caveal vanes. Patagial tissue is well developed around and between *a* and *i* rods.
Comparison
Ceratoikiscum vimineum Wakamatsu *et al.*, 1990 appears to be a poorly preserved but closely similar ceratoikiscid and is possibly synonymous. Caveal vanes can be observed on many of the specimens of *Ceratoikiscum lyratum* Ishiga (1988) collected from Konomori during this study.
Distribution
Japan: Konomori NW of Kochi city and Jingamori are both correlatives of the upper levels of the G4 unit of the Kurosegawa terrane, Upper Sillurian.

Ceratoikiscum sp. (pl. 1, Fig. 9)
Material
Rare in samples from unit G4, Konomori, Kochi City, Kurosegawa terrane, Shikoku.
Description
Imperfectly preserved ceratoikiscid covered by dense patagial tissue. There are several bladed caveal ribs and a single conspicuous pair of strong caveal ribs which project perpendicular to the central skeletal framework.
Distribution
Upper Silurian, unit G4, Konomori, Kochi City, Kurosegawa terrane, Shikoku so far as is known.

Ceratoikiscum kurosegum n. sp. (pl. 1, Figs 7, 8)
Synonymy
?1990 *Ceratoikiscum* sp. A—Ishiga 1988 Figs 1–3, 6
Material
Common in samples from unit G4, Konomori, Kochi City, Kurosegawa terrane, Shikoku. Holotype pl. 1, Fig. 7.
Etymology
Named for the terrane in which it was first found.
Diagnosis
Ceratoikiscid with three main rods. Rods are generally rather straight. Rod extensions two or three times the length of triangular portions of the rods. Loose patagial tissue is developed around entire frame. Three or four pairs of short ribs are commonly developed.
Comparison
Possibly similar to specimens figured but not described by Ishiga (1988). This species is rather fragile and patagial tissue is easily destroyed during processing.
Remarks
Several Ceratoikiscidae are present in samples from the G4 unit of the Kurosegawa terrane. U/Th/Pb SHRIMP dating of magmatic zircons in the radiolarian-bearing tuffs from Konomori localities clearly establishes that the radiolarians present must be Silurian. Prior to this radiometric dating study Ishiga (1992) discussed evolutionary changes in the Ceratoikiscidae. Results presented herein and in other papers (Stratford and Aitchison, in press; Aitchison and Stratford, in prep) on hitherto undescribed Middle Devonian radiolarian faunas in which *Circulaforma* Cheng and *Helenifore* Nazarov and Ormiston occur indicate that revision of interpretation of Ceratoikiscid evolution is required. Diversification within the Ceratoikiscidae occurred much earlier than previously thought. This family thus appears to have significantly greater biostratigraphic potential than previously recognised.
Distribution
Upper Silurian, unit G4, Konomori, Kochi City, Kurosegawa terrane, Shikoku so far as is known.

Genus *Helenifore* Nazarov and Ormiston, 1983
Type species: *Helenifore laticlavium* Nazarov and Ormiston, 1983

Helenifore speciosus (Furutani) (pl. 1, Figs 11–14, 16; pl. 3, Fig. 17)
Synonymy
1986 undescribed ceratoikiscid—Nazarov and Ormiston pl. II, Fig. 9
1988 *Helenifore* sp.—Nazarov p. 189, pl. XII, Fig. 4
1990 *Nazaromistonella speciosus*—Furutani pl. 12, Figs 5–7
1990 *Helenifore* sp.—Wakamatsu *et al.* pl. 13, Fig. 8
1993 *Helenifore fasciola*—Nazarov and Ormiston pl. 6, Figs 12, 15
Material
Abundant in samples from unit G4, Konomori and Kasamigawa in Kochi City, also present at Jingamori, Kurosegawa terrane, Shikoku.
Description
Bilaterally symmetrical skeleton consists of an *a*-rod, *b*-rod, intersector, caveal ribs or vanes and an extra triangular rod arising from b.v. The rods comprise a somewhat ellipsoidal structure in the centre of the specimen. The intersector is nearly straight and passes through the center of the ring. Caveal ribs or vanes arise mainly from *a.t.* but also from the base of *a.p.* These ribs or vanes are elongate parallel to the long axis of the ring.

Comparison
Identical to *Helenifore fasciola* described by Nazarov and Ormiston (1993) with which it is synonymised. Nazarov and Ormiston stated that the diameter of the ring is 120 μm but re-examination of their figures indicates that the size of the ring is much closer to the 60 μm of *Helenifore speciosus* (Furutani).
Remarks
Furutani (1990) introduced a new family Nazaromistonellidae which he distinguished from the Ceratoikiscidae by virtue of the presence of a ring structure with an intersector. He included his new species *Nazaromistonella speciosus* within this family. Application of strict terminology for the Ceratoikiscidae is difficult with *Helenifore* but the genus has traditionally been assigned to this family and we consider that this remains appropriate. Extremely well preserved specimens of *Helenifore laticlavium* were described from the species type locality by Aitchison (1993). This material is better preserved than that originally described by Nazarov and Ormiston (1984) and the nature of the genus can be seen more clearly. It is considered herein that *Nazaromistonella* Furutani is synonymous with *Helenifore* Nazarov and Ormiston and species placed within this genus should correctly be assigned to the senior synonym. Synonymy of this genus also renders the new family Nazaromistonellidae superfluous. Furutani (1990) also mentions another species *N. usitatus* in his text (p. 13) but this species is neither figured, nor described.
Distribution
Japan: Yokokurayama Formation member G4, Kurosegawa terrane, Kochi Prefecture, Shikoku (Upper Silurian), (Konomori, Kasamigawa and Jingamori, this study; several localities in G4 on Yokokurayama *Tlecerina-Glanta* assemblage of Wakamatsu *et al.*, 1990); Osobudani Valley, Hida Gaien, Honshu (*Fusalfanus osobudaniensis* assemblage of Furutani 1990 ?Wenlockian); Upper Sakmarskaya Suite, Southern Urals, northwestern Mugodzhar, Former USSR, (?Wenlockian–Ludlovian) (Nazarov and Ormiston, 1993).

Suborder Spumellariina Ehrenberg, 1838
Superfamily Rotasphaeracea Noble, 1994
Family Rotasphaeridae Noble, 1994

Genus *Rotasphaera* Noble, 1994
Type species: *Rotasphaera marathonensis* Noble, 1994

Rotasphaera beckwithensis Noble (pl. 2, Fig. 8)
Synonymy
1994 *Rotasphaera beckwithensis* Noble pls 2.7–12, pls 8.4, 8.5
Material
Rare in samples from unit G1, Yoshinozawa-guchi, Kurosegawa terrane.
Description
Several robust tapering spines observed on specimens. Remnants of some small secondary spinules are observed as nodes on the shell.
Comparison
Specimens are comparable in size and other features to *Rotasphaera beckwithensis* as described by Noble (1994).
Distribution
Silurian. Present in correlatives of the lower Yokokurayama Formation, Yoshinozawaguchi, western Shikoku, Japan. Type locality East Bourland Mountains, Marathon uplift, west Texas, U.S.A.

Superfamily Incertae sedis

Genus *Pseudospongoprunum* Wakamatsu *et al.*, 1990
Type species: *Pseudospongoprunum tazukawaensis* Wakamatsu *et al.*, 1990

Pseudospongoprunum sagittatum Wakamatsu *et al.* (pl. 1, Fig. 5; pl. 3, Fig. 9)
Synonymy
1990 *Pseudospongoprunum sagittatum*—Wakamatsu *et al.* pl. 3, Figs 1–4
1994 *Pseudospongoprunum* (?) *tauversi*—Noble pl. 7, Figs 13–15
Material
Abundant in samples from unit G4, Konomori, Kochi City, Kurosegawa terrane, Shikoku, also present at Jingamori.
Description
Two polar spines of unequal length. One is considerably shorter than the other which is commonly bent. Shell comprises several concentric spongy layers. Although this genus does have concentric layers which were initially recognised by Wakamatsu *et al.* (1990) it differs from *Copiellintra* Nazarov and Ormiston (1985) in that it lacks rays (spines) which prevail through layers from the center to the outer edge of the cortical shell. Specimens also differ considerably from *Spongocoelia* Hinde (1899) which has a large internal cavity and polar spines which are clearly three bladed (Aitchison and Stratford, in press).
Remarks
Noble (1994) placed the genus *Pseudospongoprunum* within the higher level taxonomic groupings: Superfamily Songodiscacea Haeckel, emend Pessagno 1971 and Family Songuridae Haeckel, emend Pessagno 1973. As no phylogenetic links can yet be demonstrated we favour a more conservative approach regarding the genus *Pseudospongoprunum* Wakamatsu *et al.* as incertae sedis until more evidence is available.
Noble (1994) assigned comparable specimens to a new species *Pseudospongoprunum* (?) *tauversi* suggesting her new species has a slightly looser meshwork and more obvious concentric layering. We suggest that it is probable that this falls within the realm of intra-specific variation and/or that such layering can be masked by preservational factors as with Wakamatsu *et al.* specimens. Hence *Pseudospongoprunum* (?) *tauversi* Noble might be best regarded as a junior synonym.
Distribution
Japan: Yokokurayama Formation member G4, Kurosegawa terrane, Kochi Prefecture, Shikoku (Upper Silurian), (Konomori, this study; several localities in G4 on Yokokurayama *Tlecerina-Glanta* assemblage of Wakamatsu *et al.*, 1990); Osobudani Valley, Hida Gaien, Honshu (*Fusalfanus osobundaniensis* assemblage of Furutani 1990 ?Wenlockian).

Pseudospongoprunum tazukawaensis Wakamatsu *et al.* (pl. 2, Figs 10–12)
Synonymy
1990 *Pseudospongoprunum tazukawaensis*—Wakamatsu *et al.* pl. 2, Figs 1–4
Material
Abundant in samples from the type locality at Suberidani, Kurosegawa terrane, Shikoku.

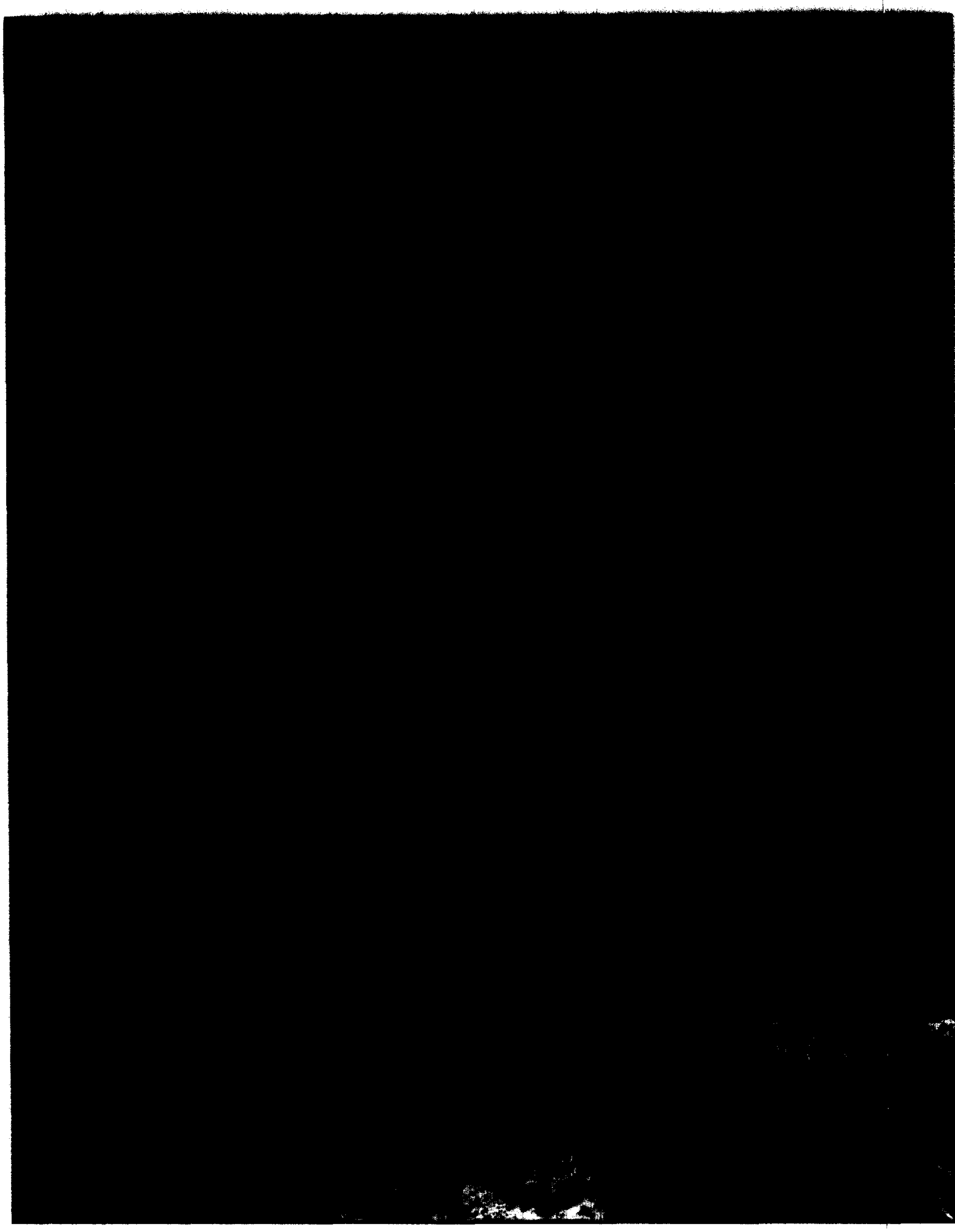

Plate 1. Radiolarians from Konomori. Length of scale bar in microns is indicated in parentheses.
1.1 *Zadrappolus tenuis* Furutani (160 μm). 1.2 *Deflantrica solidum* Wakamatsu *et al.* (100 μm). 1.3 *Ceratoikiscum lyratum* Ishiga (110 μm). 1.4 *Ceratoikiscum lyratum* Ishiga (110 μm). 1.5 *Pseudospongoprunum sagittatum* Wakamatsu *et al.* (120 μm). 1.6 *Zadrappolus tenuis* Furutani (130 μm). 1.7 *Ceratoikiscum kurosegum* n. sp. (100 μm). 1.8 *Ceratoikiscum kurosegum* n. sp. (100 μm). 1.9 *Ceratoikiscum* sp. (120 μm). 1.10 *Palaeoscenidium cladophorum* Deflandre group (100 μm). 1.11 *Helenifore speciosus* (Furutani) (130 μm). 1.12 *Helenifore speciosus* (Furutani) (100 μm). 1.13 *Helenifore speciosus* (Furutani) (110 μm). 1.14 *Helenifore speciosus* (Furutani) (130 μm). 1.15 *Fusalfanus? konomoriensis* n. sp. (160 μm). 1.16 *Helenifore speciosus* (Furutani) (100 μm). 1.17 *Fusalfanus? konomoriensis* n. sp. (150 μm). 1.18 *Futobari* sp. cf. *F. morishitai* Furutani (200 μm). 1.19 *Fusalfanus? konomoriensis* n. sp. (33 μm). 1.20 *Fusalfanus? konomoriensis* n. sp. Furutani (50 μm).

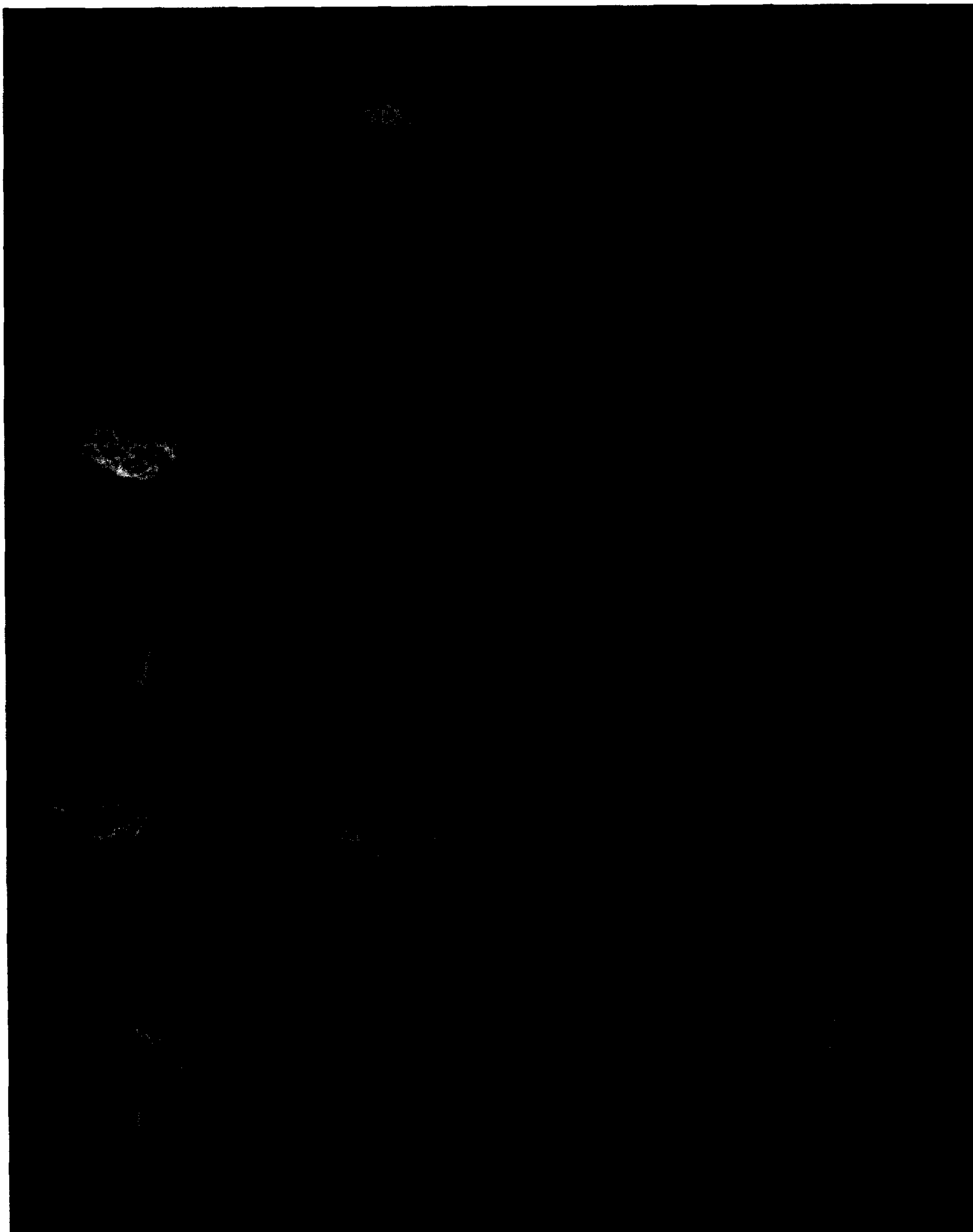

Plate 2. Radiolarians from Kasamigawa, Yoshinozawa-guchi and Suberidani. Length of scale bar in microns is indicated in parentheses.

2.1 *Ceratoikiscum lyratum* Ishiga (Kasamigawa) (110 μm). 2.2 *Pactarentinia holdsworthi* Furutani (Kasamigawa) (110 μm). 2.3 *Pactarentinia holdsworthi* Furutani (Kasamigawa) (110 μm). 2.4 *Palaeoscenidium cladophorum* Deflandre group (Kasamigawa) (75 μm). 2.5 *Deflantrica solidum* Wakamatsu *et al.* (Kasamigawa) (90 μm). 2.6 *Zadrappolus tenuis* Furutani (Kasamigawa) (100 μm). 2.7 *Inanihella?* sp. (Yoshinozawa-guchi) (110 μm). 2.8 *Rotasphaera beckwithensis* Noble (Yoshinozawa-guchi) (95 μm). 2.9 Inaniguttid gen. et sp. indet. (Suberidani) (160 μm). 2.10 *Pseudospongoprunum tazukawaensis* Wakamatsu *et al.* (Suberidani) (60 μm). 2.11 *Pseudospongoprunum tazukawaensis* Wakamatsu *et al.* (Suberidani) (65 μm). 2.12 *Pseudospongoprunum tazukawaensis* Wakamatsu *et al.* (Suberidani) (70 μm). 2.13 *Futobari* sp. cf. *F. morishitai* Furutani (Yoshinozawa-guchi) (110 μm). 2.14 *Oriundogutta* sp. (Yoshinozawa-guchi) (160 μm). 2.15 *Oriundogutta?* sp. cf. *O. kingi* Noble (Yoshinozawa-guchi) (12) μm). 2.16 *Auliela* sp. (Yoshinozawa-guchi) (120 μm).

Plate 3. Radiolarians from Jingamori. Length of scale bar in microns is indicated in parentheses. 3.1 *Zadrappolus tenuis* Furutani (145 μm). 3.2 *Zadrappolus tenuis* Furutani (120 μm). 3.3 *Futobari solidus* Furutani (190 μm). 3.4 *Ceratoikiscum lyratum* Ishiga (110 μm). 3.5 *Ceratoikiscum lyratum* Ishiga (85 μm). 3.6 *Futobari? jingamoriensis* n. sp. (170 μm). 3.7 *Futobari? jingamoriensis* n. sp. (175 μm). 3.8 *Futobari solidus* Furutani (130 μm). 3.9 *Pseudospongoprunum sagittatum* Wakamatsu *et al.* (95 μm). 3.10 *Inanihella?* sp. cf. *I. duroacus* Nararov and Ormiston (150 μm). 3.11 *Futobari* sp. cf. *F. morishitai* Furutani (190 μm). 3.12 *Futobari? tosaensis* n. sp. (145 μm). 3.13 *Inanihella?* sp. cf. *I. duroacus* Nazarov and Ormiston (130 μm). 3.14 *Futobari? jingamoriensis* n. sp. (125 μm). 3.15 *Zadrappolus tenuis* Furutani (90 μm). 3.16 *Futobari? tosaensis n. sp.* (130 μm). 3.17 *Helenifore speciosus* (Furutani) (65 μm).

Description

Two short conical polar spines of subequal length. Shell coarse meshwork of irregular pores. Concentric layering can be clearly observed on figured specimens.

Comparison

Wakamatsu *et al.* (1990) commented that this taxon is distinguished from *Pseudospongoprunum sagittatum* which has a larger and more elongated shell and robust polar spines.

Distribution

Japan: Abundant in samples from the type locality at Suberidani, Kurosegawa terrane, Shikoku, Wenlockian, Silurian.

Family Inaniguttidae Nazarov and Ormiston, 1984, emend Noble, 1994

Genus *Futobari* Furutani

Type species: *Futobari solidus* Furutani

Futobari solidus Furutani, (pl. 3, Figs 3, 8)

Synonymy

1990 *Futobari solidus*—Furutani pl. 1, Figs. 1–4

1990 ?spumellarian gen. indet. sp. A.—Wakamatsu *et al.* pl. 8, Figs. 1a, b

1990 ?spumellarian gen. indet. sp. C.—Wakamatsu *et al.* pl. 8, Figs 3a, b, 5

Material

Abundant in samples from unit G4, Konomori and Jingamori, Kochi City, Kurosegawa terrane, Shikoku.

Description

Single, moderately large cortical shell. Five to seven long rod-like spines (fewer remain on fragmentary specimens). Basal portions of the spines are deeply grooved.

Comparison

This species is similar to *Futobari morishitai* Furutani which was described as having a smaller cortical shell. The measured size range for both species overlaps considerably but the two species can be distinguished as *Futobari morishitai* Furutani has more spines than *Futobari solidus* Furutani.

Remarks

Spines are commonly broken off specimens and this may lead to an underestimate of the original number of spines present.

Distribution

Japan: Yokokurayama Formation member G4, Kurosegawa terrane, Kochi Prefecture, Shikoku (Upper Silurian), (Konomori, this study and Konomori *Palaeoscendidium ishigai* assemblage of Wakamatsu *et al.*, 1990); Ichinotani Valley, Hida Gaien, Honshu (*Zadrappolus yoshikiensis* assemblage of Furutani 1990 ?Ludlovian).

Futobari sp. cf. *F. morishitai* Furutani, (pl. 1, Fig. 18; pl. 2, Fig. 13; pl. 3, Fig 11)

Material

Abundant in samples from unit G4, Konomori and Jingamori, Kochi City, Kurosegawa terrane, Shikoku.

Description

Latticed moderately small cortical shell. Shell has numerous small round pores. Several (4–6 per hemisphere) large long main spines the length of which is 2 or 3 times the diameter of the cortical shell.

Comparison

See comments on *Futobari solidus* Furutani above. Similar to *Futobari morishitai*—Furutani, (1990 pl. 1, Figs 1–40).

Remarks

Spines are commonly broken off specimens and this may lead to an underestimate of the original number of spines present.

Distribution

Japan: Yokokurayama Formation member G4, Kurosegawa terrane, Kochi Prefecture, Shikoku (Upper Silurian), Konomori, this study; Ichinotani Valley, Hida Gaien, Honshu (*Zadrappolus yoshikiensis* assemblage of Furutani, 1990 ?Ludlovian).

Futobari? tosaensis n. sp. (pl. 3, Figs 12, 16)

Material

Common in samples from unit G4, Jingamori and Konomori, Kurosegawa terrane, Shikoku Holotype pl. 3, Fig. 12.

Etymology

Named for the Tosa region. Tosa is an earlier name for the area of Shikoku in which this fossil was first found.

Diagnosis

Extremely robust large radiolarian with a single large cortical shell. Four to six massive robust spines per hemisphere. Spines are deeply and multiply grooved at their proximal end and taper to rods distally. Numerous small pores (80–100 per hemisphere) upon cortical shell.

Comparison

Differs from *Futobari? jingamoriensis* n. sp. in both the size and number of spines present.

Remarks

Internal details of this species are uncertain and it is only tentatively assigned to *Futobari* as the nature of the lattice shell remains indeterminate. However, by comparison with the original definition of *Futobari* Furutani we note that spines are fewer and much stronger than those of the superficially similar genus *Zadrappolus*. Our assignment to *Futobari* is only tentative and we also note superficial similarity with *Oriundogutta* Nazarov.

Distribution

Upper Silurian, unit G4, Kurosegawa terrane, Shikoku so far as is known.

Futobari? jingamoriensis n. sp. (pl. 3, Figs 6, 7, 14)

Material

Common in examples from unit G4, Jingamori and Konomori, Kurosegawa terrane, Shikoku. Holotype pl. 3, Fig. 6.

Etymology

Named for the locality at which it was first found.

Diagnosis

Extremely robust large radiolarian with a single large cortical shell. Ten to twelve massive robust spines per hemisphere. Spines are deeply and multiply grooved at their proximal end and taper to rods distally. Abundant small pores (60–80 per hemisphere) upon cortical shell.

Comparison

Differs from *Futobari? tosaensis* n. sp. in both the size and number of spines present. Spines on *Futobari? jingamoriensis* n. sp. tend to be less robust but longer than those of *Futobari? tosaensis* n. sp.

Remarks

As for *Futobari? tosaensis* n. sp.

Distribution

Upper Silurian, unit G4, Kurosegawa terrane, Shikoku so far as is known.

Genus *Inanihella* Nazarov and Ormiston
Type species: *Inanihella bakanasensis* Nazarov, 1975
Remarks
The diagnosis [republished in Nazarov and Ormiston (1993)] of this genus includes only those species with two porous cortical shells. The proposed emendment of Noble (1994) differs little in its stated purpose again restricting this genus to taxa possessing two cortical shells. As this is already explicit in the Nazarov and Ormiston diagnosis we feel that the proposed emendment is superfluous.

Inanihella? sp. cf. *I. duroacus* Nazarov and Ormiston (pl. 3, Figs 10, 13)
Material
Common in samples from unit G4, Konomori and Jingamori, Kochi City, Kurosegawa terrane, Shikoku.
Description
Spherical, porous cortical shell with small irregular shaped pores. Spines, 10–15 per hemisphere, are strongly tapered, broad and deeply grooved at their base.
Comparison
Similar to material figured by Nazarov and Ormiston (1993, pl. 3, Figs 9, 12).
Remarks
Specimens from Japan which are assigned to this species are not well preserved and assignment is tentative as internal details cannot be observed.
Distribution
Konomori and Jingamori; Yokokurayama Formation member G4 (Upper Silurian), Kurosegawa terrane, Kochi Prefecture, Shikoku; Silurian (Ludlovian) Upper Sakmarskaya Suite, south Urals, northwestern Mugodzhar, Russia.

Inanihella? sp. (pl. 2, Fig. 7)
Material
Several broken specimens observed in samples from unit G1, Yoshinozawa-guchi, Kurosegawa terrane, western Shikoku.
Description
Broken specimens. Several tapering spines. Remnants of irregularly porous inner cortical shell can be observed on most specimens. Vestiges of a more delicate outer cortical shell are also present.
Distribution
Present in correlatives of the (Lower Silurian) lower Yokokurayama Formation, Yoshinozawa-guchi, western Shikoku, Japan.

Genus *Fusalfanus* Furutani, 1990
Type species: *Fusalfanus osobundaniensis* Furutani, 1990

Fusalfanus? konomoriensis n. sp. (pl. 1, Figs 15, 17, 19, 20)
Synonymy
1990 Spum. gen. indet. sp. D—Wakamatus *et al.* 1990 pl. 8, Fig. 4
Material
Abundant in samples from unit G4, Konomori, Kochi City, Kurosegawa terrane, Shikoku. Holotype pl. 1, Figs 15, 19.
Etymology
Named for the locality at which it was first found.
Description
Large spherical cortical shell, with numerous (8 per hemisphere) short robust deeply grooved spines. The outer shell has a spongy meshwork of sub-round small pores. One spine may be distended and opened into a pylome. The pylome is surrounded by a thick rim with small rod-like spinules.
Comparison
Plate 13, Fig. 4 of Furutani (1990) depicts a similar "indeterminate spumellarian with a large spherical lattice shell" from a sample collected from Ichinotani (*Zadrappolus yoshikiensis* assemblage). Furutani (1990) plate 13, Fig. 9 illustrates another similar "indeterminate Supmellaria (sic) with a pylome" (*Fusalfanus osobundaniensis* assemblage). Wakamatsu *et al.* (1990, pl. 8, Fig. 4) describe similar specimens from the same locality where we obtained our samples (*Palaeoscenidium ishigai* assemblage).
Remarks
The nature of the medullar shell remains uncertain. Many specimens were broken in an attempt to determine its nature but always distintegrated when this was attempted. For this reason assignment to the genus *Fusalfanus* is only made tentatively. Specimens are nevertheless outwardly similar to *Fusalfanus osobundaniensis* the type species. The cortical shell appears to be spongy. There is no sign of any delicate outer cortical shell on even the most well preserved specimens examined.
Distribution
Japan: Yokokurayama Formation member G4, Kurosegawa terrane, Kochi Prefecture, Shikoku (Upper Silurian), (Konomori, this study; several localities in G4 on Yokokurayama *Tlecerina-Glanta* assemblage of Wakamatsu *et al.*, 1990); Osobundani Valley, Hida Gaien, Honshu (*Fusalfanus osobundaniensis* assemblage of Furutani 1990 ?Wenlockian).

Inaniguttid gen. et sp. indet. (pl. 2, Fig. 9)
Material
Fragments are common in samples from Suberidani, Kurosegawa terrane, Shikoku.
Description
Large spherical cortical shell, with numerous (8 per hemisphere) short robust deeply grooved spines. The outer shell has a spongy meshwork of sub-round small pores.
Comparison
Outwardly similar to specimens assigned to *Fusalfanus* but poor preservation of material prevents more detailed taxonomic assignment.
Distribution
Japan: Present in samples from Suberidani, Kurosegawa terrane, Shikoku, Wenlockian.

Genus *Oriundogutta* Nazarov, 1988
Type species: *Oriundogutta ramificans* Nazarov, 1975

Oriundogutta sp. (pl. 2, Fig. 14)
Material
Rare poorly preserved specimens in samples from Yoshinozawa-guchi, western Shikoku, Japan.
Description
Poorly preserved specimen exhibiting one porous thick walled cortical shell surrounding a small spherical medullary shell. Several spines connect between the shell but are not preserved beyond the cortical shell.
Distribution
Present in correlatives of the lower Yokokurayama Formation, Yoshinozawa-guchi, western Shikoku, Japan, ?Lower Silurian.

Oriundogutta? sp. cf. *O. kingi* Noble (pl. 2, Fig. 15)
Material
Rare poorly preserved specimens in samples from Yoshinozawa-guchi, western Shikoku, Japan.
Description
Specimens are poorly preserved but numerous spine bases are seen indicating possible similarity to *Oriundogutta kingi* of Noble (1994).
Distribution
Present in correlatives of the lower Yokokurayama Formation, Yoshinozawa-guchi, western Shikoku, Japan, ?Lower Silurian.

Genus *Zadrappolus* Furutani, 1990
Type species: *Zadrappolus yoshikiensis* Furutani, 1990

Zadrappolus tenuis Furutani (pl. 1, Figs 1, 6; pl. 2, Fig. 6; pl. 3, Figs 1, 2, 15)
Synonymy
1990 *Zadrappolus tenuis*—Furutani pl. 3, Figs 3, 6
1990 Spumellaria gen. indet. sp. I—Wakamatsu *et al.*, pl. 3, Figs 9–11, ?6
1994 *Zadrapopolus tenuis*—Noble pl. 6, Figs 10, 12, 13
1994 *Zadrappolus* sp. aff. *tenuis*—Noble pl. 6, Fig. 11
Material
Abundant in samples from unit G4, Konomori, Kochi City, Kurosegawa terrane, Shikoku. Also present at Kasamigawa and Jingamori.
Description
Spherical thick latticed cortical shell. Pores are somewhat irregularly shaped. Single thin medullary shell. Radial beams from all main spines connect the cortical to medullary shells. Main spines up to 18 per hemisphere. Spines are cylindrical and gently tapering and may be of considerable length. Some have grooves on the base and may be twisted distally.
Remarks
Many of the spines are of considerable length and are commonly bent.
Distribution
Upper Silurian of the Kurosegawa terrane, Konomori (this study), Shikoku, and *Pseudospongoprunum sagittatum* assemblage at Gion-yama, Kyushu (Wakamatsu *et al.*, 1990); Hida Gaien, Honshu, (Furutani, 1990) Japan; Silurian of West Texas (Noble, 1994).

Family *Palaeoscenidiidae* Riedel, 1967; emend Holdsworth, 1977; Goodbody, 1982; Furutani, 1983; Goodbody, 1986
Remarks
Considerable variation exists within the genus *Palaeoscenidium* (e.g. Aitchison, 1993) and this is often complicated by preservational factors. Furutani (1983) presented an extensive discussion of the phylogeny of various radiolarians assigned to the Palaeoscenidiidae and suggested relationship to the Entactiniidae. However, this has lead to some problems in understanding of the taxonomic status of the family Palaeoscenidiidae. The Silurian form *Tlecerina* Furutani it is an entactinid which has been incorrectly assigned (Furutani, 1982) to the Palaeoscenidiidae. If one examines the size and location of the spicule this becomes clear. The spicule is small and eccentrically placed within the medullary shell of an entactinid. Development of a tent on this spicule gives rise to the illusion that it is a miniature Palaeoscenid. Other fundamental differences include the presence of latticed shells and rodded spines on *Deflantrica* and *Pactarentinia* cf. porous shells and bladed spines on *Tlecerina*. The spines of these genera are rod-like whereas those of *Tlecerina* are three-bladed. These observations suggest development of superficially similar (analogous) structures but no direct phylogenetic relationship. *Tlecerina* should therefore be reassigned to the Entactiniidae. Kurosegawa Terrane Paleozoic genera such as *Deflantrica* and *Pactarentinia* both have much more in common with the Palaeoscenidiidae than the Entactiniidae. They are forms of Palaeoscenidiidae which have evolved dense sets of spinules which have fused to form a latticed shell-like structure rather than a tent. Spicules remain well-rodded and in that the apical spines are not enveloped by the shell-like structure, they are clearly different from Entactiniidae in which the entire spicule and rays are contained within the shell.

Goodbody (1986) provided an extensive discussion on the Palaeoscenidiidae together with additional emendment which is cautiously accepted herein. Although several faunas exist in which Palaeoscenidiidae are well preserved (e.g. Goodbody, 1986; Aitchison, 1993b) the final taxonomic placement of this family awaits more detailed studies of successions which contain well preserved faunas for which phylogenetic relationships can be clearly established.

A further taxonomic problem is the assignment of Mesozoic genera to the Palaeoscenidiidae. True Palaeoscenidiidae are unknown in latest Paleozoic and younger strata. Phylogenetic links to similar looking Mesozoic forms (Dumitrica, 1978; Sashida, 1983) cannot be demonstrated. Thus, they are not true descendants but are more likely to have arisen as analogous forms through iterative or convergent evolution. Wakamatsu *et al.* (1990) also draw attention to this matter and the present author agrees that it must be recognised and suggests that similar Mesozoic forms could be assigned to a new family.

Subfamily Palaeoscenidiinae Riedel, 1967, emend Furutani, 1981, 1982; Goodbody, 1986

Genus *Palaeoscenidium* Deflandre, 1953 emend Goodbody, 1986
Type species: *Palaeoscenidium cladophorum* Deflandre, 1953

Palaeoscenidium cladophorum Deflandre group (pl. 1, Fig. 10; pl. 2, Fig. 4)
Synonymy
1953 *Palaeoscenidium cladophorum*—Deflandre, p. 408, text-Fig. 308
1960 *Palaeoscenidium cladophorum*—Deflandre, p. 214, pl. 1, Fig. 21
1963 *Palaeoscenidium cladophorum*—Foreman, p. 302, pl. 8, Fig. 10; pl. 9, Fig. 6
1973 *Palaeoscenidium cladophorum*—Holdsworth, p. 128, pl. 1, Fig. 19
1975 *Palaeoscenidium cladophorum*—Nazarov, p. 96, pl. 13, Figs 4–5, pl. 14, Figs 5–6
1982 *Palaeoscenidium cladophorum*—Nazarov *et al.*, p. 172, Figs 5D–F
1983 *Palaeoscenidium cladophorum*—Nazarov and Ormiston, p. 465, pl. 2, Figs 6–7
1990 *Palaeoscenidium ishigai*—Wakamatsu *et al.*, pl. 7, Figs 1–5

1993 *Palaeoscenidium cladophorum*—Aitchison, pl. 1, Figs 15–17, 19, pl. 2, Figs 17, 20

Material

Abundant in samples from unit G4 at Konomori and Kasamigawa, Kochi City, also Jingamori, Kurosegawa terrane, Shikoku.

Description

Four subequal apical rays arising at approximately 45°. Apical rays may be subequal in length or in some specimens one ray is considerably longer than the others. Length of apical rays one-half to subequal to that of basal rays. Four tapering basal rays descending at approximately 45°. Numerous spinules developed on and normal to the basal rays below a small subquadrate tent-like structure.

Remarks

The Konomori specimens all exhibit characteristics (notably one apical spine which is considerably longer than others) which indicate that it should fall within the expected natural range of variation for a single species: *Palaeoscenidium cladophorum* Deflandre. Considerable intra-specific variation exists within this species. With excellent preservation the existence of sub-populations which can be grouped as distinct species, between which there is not a continuous range of variation (Aitchison 1993 cf. Kiessling and Tragelehn, 1994).

Distribution

Japan: Konomori, Yokokurayama Formation member G4, Kurosegawa terrane, Kochi Prefecture, Shikoku (Upper Silurian); Upper Silurian to Lower Carboniferous, Worldwide.

Genus *Deflantrica* Wakamatsu *et al.*

Type species: *Deflantrica vetustum* (Furutani)

Deflantrica solidum Wakamatsu *et al.* (pl. 1, Fig. 2; pl. 2, Fig. 5)

Synonymy

1990 *Deflantrica solidum*—Wakamatsu *et al.*, pl. 8, Figs 6, 7; pl. 9, Figs 1–3

Material

Abundant in samples from unit G4, Konomori and Kasamigawa, Kochi City, Kurosegawa terrane, Shikoku.

Description

Bar centered skeleton comprising four apical and four basal spines with an incomplete lattice shell. One apical spine is more strongly developed than the others. All apical spines lie above the lattice shell.

Comparison

All specimens are closely similar to *Deflantrica solidum* as figured by Wakamatsu *et al.* (1990). They differ from *D. vetustum* Furuntani in that they do not have spinules developed on distal portions of basal spines.

Remarks

Specimens of this genus were originally described by Furutani (1983) who assigned them to the genus *Parentactinia* Dumitrica. They were reassigned to a new genus *Deflantrica* established by Wakamatsu *et al.*, 1990. The reason given was that, although similar to *Parentactinia* Dumitrica which is known from the Triassic, no late Paleozoic examples of this genus or undisputed Palaeoscenidiidae in general are known. Late Carboniferous and Permian radiolarians are now well enough known to establish that this is not related to any sampling bias and suggest that these homologous Mesozoic radiolarians have arisen through iterative evolution.

Distribution

Japan: Yokokurayama Formation member G4, Kurosegawa terrane, Kochi Prefecture, Shikoku (Upper Silurian), (Konomori, Kasamigawa, this study; several localities in G4 on Yokokurayama *Tlecerina-Glanta* assemblage of Wakamatsu *et al.*, 1990).

Genus *Pactarentinia* Furutani

Type species: *Pactarentinia holdsworthi* Furutani

Pactarentinia holdsworthi Furutani (pl. 2, Figs 2–3)

Synonymy

1983 *Pactarentinia holdsworthi*—Furutani, pl. 22, Figs 5, 6; pl. 23, Figs 1–6

Material

Abundant in samples from unit G4, Kasamigawa, Kochi City, Kurosegawa terrane, Shikoku.

Description

Eight-spined, bar-centered spicule with a single spherical lattice shell. One apical spine is rod-like and considerably longer than the others. Basal spinules intricately fused to form crude porous shell.

Comparison

Specimens are very similar to specimens of *Pactarentinia holdsworthi* Furutani previously described from Mt Yokokurayama by Furutani (1983).

Distribution

Japan: Yokokurayama Formation member G4, Kasamigawa, Kurosegawa terrane, Kochi Prefecture, Shikoku (Upper Silurian), (Konomori, this study; several localities in G4 on Yokokurayama *Tlecerina-Glanta* assemblage of Wakamatsu *et al.*, 1990); Osobudani Valley, Hida Gaien, Honshu (*Fusalfanus osobudaniensis* assemblage of Furutani 1990 ?Wenlockian).

Family Anakrusidae Nazarov, 1977

Genus *Auliela* Nazarov, 1977

Type species: *Auliela aspersa* Nazarov, 1977

Auliela sp. (pl. 2, Fig. 16)

Material

Rare in samples from strata correlated with the lower Yokokurayama Formation, Yoshinozawa-guchi, western Shikoku, Japan.

Description

Highly spinose small spherical shell with numerous (100+) rod-like straight spines.

Comparison

Similar to other examples of this genus described from Kazahkstan and Australia.

Remarks

This genus is known from elsewhere in Ordovician strata. The assemblage it occurs with at Yoshinozawa-guchi is poorly preserved and of uncertain age.

Distribution

Present in correlatives of the lower Yokokurayama Formation, Yoshinozawa-guchi, western Shikoku, Japan.

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