The dating of radiolarian biostratigraphic zones from the Silurian to Devonian is only partially understood. Dating the zircons in radiolarian-bearing tuffaceous rocks has enabled us to ascribe practical ages to the radiolarian zones. To extend knowledge in this area, radiometric dating of magmatic zircons within the radiolarian-bearing Yoshiki Formation, Japan, was undertaken. The Yoshiki Formation is mainly composed of alternating beds of tuffaceous sandstones, tuffaceous mudstones, and felsic tuff. The felsic tuff and tuffaceous mudstone yield well-preserved radiolarian fossils. Radiolarians and zircon grains were collected from 21 tuffaceous mudstone and 30 tuff horizons of the Yoshiki Formation. The following radiolarian species which can be ascribed to the *Zadrappolus yoshikiensis*-Futobari solidus assemblage were identified: *Oriundogutta* (?) *kingi*, *Oriundogutta* (?) *varispina*, *Zadrappolus yoshikiensis*, *Zadrappolus tenuis*, *Zadrappolus hitoeganensis*, *Zadrappolus lunaris*, *Zadrappolus* (?) *nudus*, *Zadrappolus* (?) sp., *Futobari solidus*, *Futobari morishitai*, *Rotasphaera* (?) sp., and *Ceratoikiscum armiger*. U-Pb SHRIMP ages of 420.5 ± 2.5 Ma and 421.0 ± 1.9 Ma were obtained from the zircon grains. Thus the lower limit of the *Zadrappolus yoshikiensis*-Futobari solidus assemblage, that has previously been assigned to an age from Přídolian to Pragian, is in reality before Ludlowian. The technique in this paper has the capability of refining and making more accurate the dating of many radiolarian zones worldwide, and potentially of changing the direction of the entire study of radiolarian biostratigraphy. • Key words: U-Pb SHRIMP age, Silurian, Devonian, radiolarian, biostratigraphy.

Many studies have now given us a clear picture of worldwide post-Carboniferous radiolarian biostratigraphy, and radiolarians nowadays receive wide recognition as an important tool, especially in tectonics, for revealing the Earth’s history. In contrast, the biostratigraphy of pre-Devonian radiolarians is still not well understood. Although studies of Silurian to Devonian radiolarians in Australia, North America, Urals and Japan have made significant advances in establishing biostratigraphic zonation, assigning an age to each zone is still controversial (Aitchison & Stratford 1997, Aitchison et al. 1999, Amon et al. 1995, Furutani 1990, Kurihara 2004, Kurihara & Sashida 2000, Noble 1994, Noble & Aitchison 2000, Obut & Shcherbanenko 2008, Stratford & Aitchison 1997, Umeda 1998). Some Silurian to Devonian formations in Japan which yield radiolarian fossils are intercalated with felsic tuff layers with euhedral zircons. Determining the isotopic age of the zircons therefore enables us to confirm the practical ages of the Silurian to Devonian radiolarian zones.

In order to determine the age of upper Silurian to Lower Devonian radiolarian zones, we have undertaken radiometric dating of magmatic zircons within the radiolarian bearing beds of the Yoshiki Formation in the Fukuji area, Takayama City, Southwest Japan.

**Geological outline of the Fukuji area**

The study area is in the Hida Gaien belt, Southwest Japan. The Hida Gaien belt is composed largely of Ordovician to Cretaceous sedimentary and volcanic rocks with minor amounts of ultramafic rocks and crystalline schist. This belt occurs in a narrow zone between the Hida belt, which is mainly composed of Paleozoic gneiss and meta-granite,
and the Mino belt, which is composed of Jurassic to Cretaceous accretionary complexes.

The Paleozoic rocks in the Fukuji area trend ENE and are divided into the following five formations in ascending order; 1) upper Silurian (?) to Devonian Yoshiki Formation (felsic tuff and tuffaceous clastic rocks), 2) Devonian Fukuji Formation (mainly limestone), 3) Carboniferous Ichinotani Formation (mainly limestone), 4) Lower Permian Mizuyagadani Formation (mainly clastic rocks), 5) Lower Permian Sorayama Formation (mainly mafic volcanic rocks) (e.g. Igo 1990, Tsukada & Takahashi 2000). The Yoshiki Formation is unconformably overlain by the Fukuji Formation (Igo 1990, Kurihara 2003). Although the Fukuji, Ichinotani, and Mizuyagadani formations are in fault contact with each other, they are likely to form conformable or unconformable succession. The Sorayama Formation conformably overlies the Mizuyagadani Formation (Tsukada et al. 1999, Tsukada & Takahashi 2000). The Paleozoic formations in the Fukuji area are folded around the axis that plunges steeply southeast, and are cut by several younger North-south sub-vertical oblique-slip faults (Tsukada et al. 1999, Tsukada & Takahashi 2000). All these formations are intruded by many small dikes of felsic to intermediate rocks, and are unconformably covered by Cenozoic volcaniclastic rocks.

The Yoshiki Formation is mainly composed of alternating beds of tuffaceous sandstone, tuffaceous mudstone and felsic tuff and it yields well-preserved radiolarian fossils. Although this formation was once believed to be Ordovician in age, based on the ostracods from a mudstone float beside outcrop (Igo et al. 1980), it is now assigned to from upper Silurian to Lower Devonian as a result of recent radiolarian studies (Kurihara 2004).

**Geological description of the Yoshiki Formation**

The stratotype section of the Yoshiki Formation (Igo et al. 1980, Tsukada et al. 1999) along the Ichinotani Valley, south hillside of Mt. Sorayama, Fukuji area was examined in this study. Here, a 30 m thickness of fine- to coarse-grained felsic tuff and alternating beds of tuffaceous sandstone, tuffaceous mudstone and felsic tuff is continuously exposed. The rocks of this formation can be divided into lower, middle, and upper members. The
The lower member consists of bedded medium- to coarse-grained felsic tuff (Fig. 3). Each bed, 5 to 7 cm thick, strikes E-W to N 74° E and dips 65° to 70° north. Well-bedded fine- to coarse-grained felsic tuff is the major facies of the middle member. The felsic tuff exhibits graded beddings indicating northward facing, strikes N 75° E and dips 86° north. Each bed is from 7 to 10 cm thick. The felsic tuff of the lower and middle members includes many phenocrysts of euhedral to subhedral laths of plagioclase, biotite, quartz and zircon with scattered flakes of opaque minerals, volcanic rock fragments and flattened pumice. A swirly mass of irregularly shaped altered volcanic glass shards is seen in some parts in the matrix of the tuff. Zircons are included not only in the matrix but also in the volcanic rock fragments. The upper member consists of alternating beds of tuffaceous sandstone, tuffaceous mudstone and fine-grained felsic tuff. The beds are graded, indicating northward facing, and each bed is from 5 to 10 cm thick. The fine-grained felsic tuff and tuffaceous mudstone generally includes radiolarian fossils (Fig. 4). Layers of coarse-grained felsic tuff, less than 7 cm thick, with numerous felsic volcanic rock fragments are intercalated in the alternating beds. The tuff of this member includes phenocrysts of euhedral to subhedral laths of plagioclase, biotite, quartz and zircon with scattered flakes of opaque minerals, volcanic rock fragments and flattened pumice similarly with that of the lower and middle members.

Radiolarian fossils

Radiolarians were recovered from the fine-grained felsic tuff and the tuffaceous mudstone by etching in dilute hydrofluoric acid for 24 hours. Individual radiolarians liberated from the matrix were washed and sieved at 63 and...
108-micron fractions. Radiolarians were picked from the dried residues and identified with the aid of reflected light and scanning electron microscopes. Well-preserved radiolarians were obtained only from the upper member, but some poorly-preserved unidentifiable radiolarians were also extracted from the middle member. The following species of radiolarians were identified from 15 tuffaceous mudstone and 5 fine-grained felsic tuff horizons of the upper member (Fig. 5); Oriundogutta (?) kingi, O. (?) varis-pina Noble, 1994, Zadrappolus yoshikiensis Furutani, 1990, Z. tenuis Furutani, 1990, Z. hiteoganensis Furutani, 1990, Z. lunaris Noble, 1994, Z. (?) nudus Kurihara 2007, Z. (?) sp. in Kurihara, 2007, Futobari solidus Furutani, 1990, F. morishitai Furutani, 1990, Rotasphaera (?) sp., Ceratoikiscum armiger Furutani, 1990. The most characteristic species of this assemblage is Z. yoshikiensis, Z. te-nuis, Z. (?) nudus, and F. solidus. The species present, Z. yoshikiensis, Z. tenuis, F. solidus and F. morishitai, are characteristic of the Z. yoshikiensis assemblage of Furutani (1990) that have been previously presumed to be latest Silurian to early Devonian (Furutani 1990). Kurihara (2007) proposed the F. solidus-Z. tenuis assemblage as an equivalent of the Z. yoshikiensis assemblage. Kurihara (2007) supposed that the F. solidus-Z. tenuis assemblage ranges from Přídolian to Pragian.

Description of zircons and U-Pb SHRIMP age

Eight rock samples, Nos. 1, 5, 9 and 16 from upper member and Nos. 24 to 26 from middle member, were used for U-Pb SHRIMP dating. Each sample (ca 1 kg) was collected from a single outcrop. Zircons were concentrated using conventional mineral-separation techniques, including crushing and pulverizing, followed by separation using hand magnetic and heavy liquid techniques. About 233 zircon grains were mounted with standard materials in a mega-mount epoxy resin disc (Niihara et al. 2010), and diamond polished to expose the interior. In order to investigate internal structures of individual zircon grains, backscattered electron (BSE) images were obtained by electron probe microanalyzer (EPMA) and cathodoluminescence (CL) images by scanning electron microscope (SEM) at Nagoya University. Both images provided a guide for selection of the SHRIMP spots.

Observation and interpretation of zircon morphology is critical for understanding the isotopic data. For example, euhedral, concentric oscillatory zoning (in CL) and euhedral, prismatic external morphology are generally regarded as evidence for crystallization of zircon from a magma. In contrast, zircon that forms in a high-grade metamorphic environment tends to have patchwork zoning and a multifaceted, equant, tabular external morphology (Kroner et al. 2000, Pidgeon et al. 2000, van Breemen et al. 1986, Vavra et al. 1999). At very high metamorphic grade, these distinctions of origin become
less obvious, particularly if metamorphic temperatures become high enough to cause partial melting. Under anatectic conditions, it becomes a semantic issue as to whether a zircon is considered to be igneous or metamorphic in origin. Zircons that have equant morphology occur in both igneous and sedimentary rocks and can superficially resemble equant zircons.
of metamorphic origin. However, equant igneous zircons can be distinguished from metamorphic zircons by their simpler crystallography (lower-order crystal faces) and concentric oscillatory zoning in CL. Equant zircons of detrital origin in sedimentary rocks tend to be spherical (not discoidal), usually have pitted or frosted, rounded surfaces (not flat faces), and truncated zoning in CL.

Fifteen zircon grains from sample 1, one from sample 5, six from sample 9, fifteen from sample 16, two from sample 24, three from sample 25, fifty-one from sample 26 were analyzed. The analyzed zircons occur in different colors, including brown, yellow and colorless. The zircons are about 70 μm in length and their length-to-width ratio is ~2–1.5. These zircons mostly occur as subhedral to euhedral prisms, and commonly contain distinct cores with concentric zoning, consistent with crystallization from a viscous magma, and overgrowths (Fig. 6). The U-Pb zircon analyses were performed at 74 analytical spot on 67 grains. U-Pb measurement was conducted using the SHRIMP at National Institute for Polar Research. An O2 primary ion beam of ~1.5 was used to sputter an analytical spot of 10 μm diameter on the polished mount. The procedures for Pb and U isotopic analyses of zircon follow (Williams 1998, Horie et al. 2006). In this study, TEMORA2 (206Pb/238U age: 416.78 ± 0.33 Ma (Black et al. 2004)) and SL13 (U concentration: 238 ppm, Claoué-Long et al. 1995) were used as standard materials for the U-Pb analysis. The U-Pb data were reduced by using the SQUID2 Excel macro.

Figure 6. Scanning electron microscope (SEM, left side) and cathode luminescence (right side) images of representative zircons from the felsic tuff of the Yoshiki Formation. White circles on the SEM images show the SHRIMP analytical spots.
of (Ludwig 2009). A correction for common Pb was made on the basis of the measured $^{206}$Pb and the model for common Pb compositions proposed by Stacey & Kramers (1975). The pooled ages presented in this study are all after correction for common Pb and were calculated using the Isoplot/Ex software (Ludwig 2008). The SHRIMP analyses yielded concordant U-Pb data are scattered from ca 410.2 ± 4 to 434.3 ± 5.6 Ma (Fig. 8). Weighted means of $^{206}$Pb/$^{238}$U ages are ca 420.5 ± 2.5 Ma (95% confidence) in the upper member, and at ca 421.0 ± 1.9 Ma (95% confidence) in the middle member (Fig. 8).

**Discussion**

**Origin of zircons**

The felsic tuff of the Yoshiki Formation is of volcanic origin as evidenced by: (1) many euhedral to subhedral crystals of plagioclase, quartz and biotite are contained in the tuff, (2) many fragments of volcanic rock and flattened pumice parallel to the bedding plane are included, (3) the presence of irregularly shaped altered volcanic glass shards. All of the dated zircons occur as polygonal prisms, and show simple crystallography and concentric oscillatory zoning in CL. In addition, many volcanic rock fragments containing zircons are included in the tuff. If some of the dated zircons are detrital from an older source of rocks than the volcanism, bi- to multi-modal peaks of ages would be expected, however the results of SHRIMP dating clearly show a single peak of age around 420 Ma. This strongly suggests that the dated zircons were brought together with the other volcanic materials such as euhedral to subhedral crystals, volcanic rock fragments, pumice and glass, and their age is considered to be nearly same with the age of the rock’s sedimentation.

**Range of F. solidus-Z. tenuis assemblage**

Noble (1994) considered that the Z. yoshikiensis assemblage (Furutani 1990) of the Yoshiki Formation could be correlated with the upper part of her Praespongocoelia-Stylosphaera(?) magnaspina zone to St.(?) magnaspina zone from Marathon uplift, USA due to the abundance of Z. yoshikiensis and Z. tenuis. These species are, however, not diagnostic because they range through the St.(?) magnaspina zone and into the Devoniglansus unicus-Rotaspheara zone as Noble (1994) has mentioned. In addition, Z. yoshikiensis and Z. tenuis were also reported from horizons above the Pseudospongoprannum sagittatum assemblage (Umeda 1998) and the Ps. tauversi assemblage (Kurihara 2004) which are correlative to the D. unicus-Ps.(?) tauversi zone of Noble (1994) (Kurihara 2004, Umeda 1998). Therefore, the Z. yoshikiensis assemblage is not correlated with the St.(?) magnaspina zone of Noble (1994).

Umeda (1998) and Kurihara (2004) put the equivalents of the Z. yoshikiensis assemblage (F. solidus assemblage in Umeda 1998 and the F. solidus-Z. tenuis assemblage in Kurihara 2004) above the D. unicus-Ps.(?) tauversi zone (Ps. sagittatum assemblage in Umeda 1998 and Ps. tauversi assemblage in Kurihara 2004) based on biostratigraphic correlation. The D. unicus-Ps.(?) tauversi zone has been assigned to the Přídolian because of the co-occurrence of a Ludlowian–Přídolian conodont fauna with in (Noble 1994), and Kurihara (2004) regarded the lower limit of the F. solidus-Z. tenuis assemblage as Přídolian. However, the co-yielding of the F. solidus-Z. tenuis assemblage and ca 420 Ma zircons in the present study suggests that the lower limit of the F. solidus-Z. tenuis assemblage might be before the Ludlowian, and therefore the D. unicus-Ps.(?) tauversi zone should more correctly be assigned to the lower Ludlowian.
Aitchison et al. (1996) provided a U-Pb SHRIMP age of 408.9 ± 7.6 Ma using zircons from tuffaceous rock of the G4 Member (Yasui 1984) in the Kurosegawa terrane, Konomori area, Shikoku Island, Japan. They reported *F. solidus* and *F. morishitai* from the same locality as the zircons and so suggested that the *Palaeoscenidium ishigai* assemblage was assigned to the Silurian based on the geological time scale that existed at the time (Odin 1994). But, Kurihara (2007) pointed out that the age 408.9 ± 7.6 Ma is equivalent to the Pragian with error bars extending from the uppermost Přídolian into the Emsian, based on a revaluation using the latest geologic time scale by Gradstein et al. (2004). In addition, the precise stratigraphic level of the dated zircon is unknown and it is not clear whether the age is practical in thinking the boundary between the *F. solidus-Z. tenus* assemblage
and the Pa. ishigai assemblage. Although Kurihara (2007), in his summary of radiolarian studies, suggested an Emsian upper limit for the F. solidus-Z. tenus assemblage, the practical range of this assemblage is still open to discussion.

Dating the zircons in radiolarian-bearing tuffaceous rocks has enabled us to ascribe practical ages to the radiolarian zones in our study area. Detailed comparison between radiolarian assemblages and zircon radiometric ages is a technique that could be used elsewhere to determine the practical range of other early Paleozoic radiolarians. The technique has the capability of refining and making more accurate the dating of many radiolarian zones worldwide, and potentially of changing the direction of the entire study of radiolarian biostratigraphy.

**Systematic palaeontology**

Order Spumellaria Ehrenberg, 1875

**Genus Oriundogutta Nazarov, 1988**

*Oriundogutta (?) kingi* Noble, 1994

Figure 11A

1994 *Oriundogutta (?) kingi* Noble, p. 31, pl. 6, figs 1, 4.
1998 *Oriundogutta (?) kingi* Kurihara & Sashida, pl. 1, fig. 7.

2000 *Oriundogutta (?) kingi* Kurihara & Sashida, p. 58, pl. 1, figs 5, 6.
2003 *Oriundogutta (?) kingi* Kurihara, fig. 8-2.
2007 *Oriundogutta (?) kingi* Kurihara, p. 229, pl. 1, figs 15–18.

**Remarks.** – This species is characterized by one thick cortical shell with 15 to 20 long robust spines per hemisphere. Spines are highly tapered at the proximal end and contain four to five grooves. Cortical shell is very large in diameter (250 μm). Medullary shell is connected to cortical shell by rod-shaped primary bars. This species is superficially similar to species of *Zadrappolus*, especially *Zadrappolus yoshikiensis*. However, the structure and number of the medullary shells is still unclear in *Oriundogutta (?) kingi*, so its taxonomic position is tentative. This species differs from *Oriundogutta (?) varispina* Noble in possessing a larger number of robust spines and its shell is slightly smaller in diameter.

**Range and occurrence.** – Upper Silurian. Hitoegane area in the Hida-gaien terrane; Southern Urals; Marathon uplift in west Texas; Yoshiki Formation in the Hida-gaien terrane.

*Oriundogutta (?) varispina* Noble, 1994

Figure 11B–F

1994 *Oriundogutta (?) varispina* Noble, p. 31, pl. 6, figs 2, 3, pl. 9, fig. 4.
2007 *Oriundogutta (?) varispina* Kurihara, p. 229, pl. 1, figs 19, 20.

**Remarks.** – This species is characterized by a thick, latticed large cortical shell 270–300 μm in diameter with 6 or more
robust external spines per hemisphere. The spine of this species, which is weakly grooved at its proximal portion and slightly to highly tapered, bears a strong morphological similarity to that of *Oriundogutta (?) kingi* Noble. This species, however, differs from *O. (?) kingi* in having thinner and fewer external spines.

**Range and occurrence.** – Uppermost Silurian. Hitoegane area in the Hida-gaien terrane; Marathon uplift in west Texas; Yoshiki Formation in the Hida-gaien terrane.

**Genus Zadrappolus Furutani, 1990**

**Type species.** – *Zadrappolus yoshikiensis* Furutani, 1990.

**Zadrappolus yoshikiensis Furutani, 1990**

Figures 11N–R, 12A–D

1990 *Zadrappolus yoshikiensis* Furutani, pp. 35, 36, pl. 2, figs 4–6; pl. 3, figs 1, 2.

1994 *Zadrappolus yoshikiensis* Noble, p. 32, pl. 6, figs 14–16.

1997 *Zadrappolus yoshikiensis* Umeda, p. 421, pl. 4, fig. 10.

1998 *Zadrappolus yoshikiensis* Kurihara & Sashida, pl. 1, figs 1, 2.


**Remarks.** – This species is characterized by a spherical cortical shell having 10 to 15 strongly tapered spines per hemisphere. The cortical shell is latticed and 120 to 200 μm in diameter (150 μm in average) based on 8 specimens. In the proximal part of the spines, 4 to 6 grooves are shallowly developed. Although two medullary shells have been observed by Furutani (1990), detailed structures are unknown, especially in the inner medullary shell. *Zadrappolus tenuis* differs from *Z. yoshikiensis* in bearing long and cylindrical spines. *Zadrappolus yoshikiensis* is distinguished from

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Figure 10. Comparison between the radiolarian assemblages and zones of Furutani (1990), Noble (1994), Umeda (1998), Kurihara (2004) and this study. Numerical ages (Ma) are from Gradstein et al. (2004).

Zadrappolus spinosus and Zadrappolus hitoeganensis by its short, thin, and numerous cylindrical spines. Zadrappolus lunaris is similar to Z. yoshikiensis in external appearance; however, the former differs from the latter in having a larger cortical shell with a smaller number of conical spines. Zadrappolus nudus is distinguished from Z. yoshikiensis by possessing a larger cortical shell with few very small spines.

Range and occurrence. – Upper Silurian to Lower Devonian. Fukuji, Ise, Hitoegane areas and Yoshiki Formation in the Hida-gaien terrane; Konomori, Gionyama, Kasamigawa, and Jingamori areas in the Kurosegawa terrane; Marathon uplift in west Texas; Mayila area in west Junggar, China.

Zadrappolus tenuis Furutani, 1990

Remarks. – Thick spherical, latticed shell 120–150 μm in diameter; 15 to 20 spines visible per hemisphere. Pores are rather regular in shape and size, round or ellipsoidal in shape. Spines are long and cylindrical but strongly tapered at proximal end with three grooves near base. This species differs from Zadrappolus spinosus and Zadrappolus hitoeganensis in possessing thicker and less numerous spines.

Range and occurrence. – Upper Silurian to Lower Devonian. Fukuji, Ise, Hitoegane areas and Yoshiki Formation in the Hida-gaien terrane; Konomori, Gionyama, Kasamigawa, and Jingamori areas in the Kurosegawa terrane; Marathon uplift in west Texas; Mayila area in west Junggar, China.

Zadrappolus hitoeganensis Furutani, 1990

Remarks. – This species is composed of a spherical cortical shell with more than 20 short external spines per hemisphere. Cortical shell diameter 140 μm. Shape and size of the pores variable round, oval, rounded-triangular, and rounded-recyaangular in shape, 5–9 in diameter. This species is somewhat similar to Zadrappolus spinosus, except that it has a rather small shell diameter and a smaller number of external spines.

Range and occurrence. – Upper Silurian to Lower Devonian. Fukuji, Ise, Hitoegane areas and Yoshiki Formation in the Hida-gaien terrane.

Zadrappolus lunaris Noble, 1994

Remarks. – Large spherical latticed cortical shell diameter 250 to 300 μm with approximately 10 spines per hemisphere. Spines short, conical, and tapered distally. Spine bases are approximately 15 to 20 μm in diameter and have 5 to 6 alternating grooves and ridges which are...
approximately 50% of the spine length. Distal half of spines are rod-shaped and circular in cross section. Pore frames are irregular polygonal, approaching pentagonal, and measure 5 to 8 μm diameter. This species differs from other species of *Zadrappolus* in the presence of few short conical external spines. *Zadrappolus lunaris* is similar to *Z. yoshikiensis* in external appearance; however, the former differs from the latter in having a larger cortical shell with large number of conical spines. But. *Zadrappolus* (?) sp. differs from *Zadrappolus nudus* in bearing a large number of conical spines.

**Remarks.** – This species is easily distinguished from other species of *Zadrappolus yoshikiensis* by its very large cortical shell with only a few very small conical spines.

**Range and occurrence.** – Upper Silurian to Lower Devonian. Hitoegane area and Yoshiki Formation in the Hida-gaien terrane; Marathon uplift in west Texas.

### Zadrappolus (?) nudus Kurihara, 2007

Figure 13E–K, Q

1996 Oriandogutta sp. Aitchinson, Hada, Ireland & Yoshi-
kura, pp. 66, 67, pl. 2, fig. 14.  

**Remarks.** – This species is easily distinguished from other species of *Zadrappolus yoshikiensis* by its very large cortical shell with only a few very small conical spines.

**Range and occurrence.** – Upper Silurian to Lower Devonian. Hitoegane area and Yoshiki Formation in the Hida-gaien terrane; Marathon uplift in west Texas.

### Zadrappolus (?) sp.

Figure 13L–N


**Remarks.** – Large, spherical, irregular porous cortical shell with 13 to 19 short conical spines per hemisphere; spines are moderately deeply grooved in the proximal parts. This species is easily distinguished from other species of *Zadrappolus* by its very large cortical shell with many conical spines. *Zadrappolus* (?) sp. differs from *Z. yoshikiensis* in bearing long and cylindrical spines. *Zadrappolus yoshikiensis* is distinguished from *Zadrappolus spinosus* and *Zadrappolus hitoeganiensis* by its numerous short, thin, cylindrical spines. *Zadrappolus lunaris* is similar to *Z. yoshikiensis* in external appearance; however, the former differs from the latter in having a larger cortical shell with large number of conical spines. But. *Zadrappolus* (?) sp. differs from *Zadrappolus nudus* in bearing a large number of conical spines.

**Range and occurrence.** – Upper Silurian to Lower Devonian. Hitoegane area and Yoshiki Formation in the Hida-gaien terrane; Jingamori and Konomori areas in the Kurosegawa terrane.

### Genus Futobari Furutani, 1990

**Type species.** – *Futobari solidus* Furutani, 1990.

### Futobari solidus Furutani, 1990

Figure 11G–K

1990 *Futobari solidus* Furutani, p. 34, pl. 1, figs 1–4.  
1996 *Futobari solidus* Aitchinson, Hada, Ireland & Yoshi-
kura, p. 65, pl. 6, figs 3, 8.  
1997 *Futobari solidus* Umeda, p. 422, pl. 4, figs 14–17.  
1998 *Futobari solidus* Umeda, figs 9–12.  
1990 Spumellaria gen. indet. sp. A Wakamatsu, Sugiyama & Furutani, p. 174, pl. 8, figs 1a, b.  
1990 Spumellaria gen. indet. sp. E Wakamatsu, Sugiyama & Furutani, p. 175, pl. 8, fig. 5.

**Remarks.** – The cortical shell is single, spherical, latticed, and 100 to 150 μm in diameter. Pores of the cortical shell are regular in shape and size. Furutani (1990) noted that this species has doubled medullary shells; the outer medullary shell is spherical and consists of an irregular mesh of bars, whereas the features of the inner medullary shell are not clear. Main spines are very long, thick, gently tapered from the proximal to distal parts, and five to seven in number. The proximal part of the spines is deeply grooved, and the middle and distal parts are circular in the cross section. This species is distinguished from *Futobari morishitai* Furutani by possessing fewer main spines and slightly larger cortical shell diameter.

**Range and occurrence.** – Upper Silurian to Lower Devonian. Fukuji, Hitoegane areas and Yoshiki Formation in the Hida-gaien terrane; Marathon uplift in west Texas.

Hida-gaien terrane; Konomori and Jingamori areas of the Kurosegawa terrane.

**Futobari morishitai Furutani, 1990**

Figures 11L, M, 13O, P

1990 *Futobari morishitai* Furutani, p. 35, pl. 1, fig. 5, pl. 2, figs 1–3.

1997 *Futobari morishitai* Umeda, pp. 421–422, pl. 2, fig. 16; pl. 4, fig. 13.

1998 *Futobari morishitai* Umeda, fig. 9-6.

2007 *Futobari* sp. cf. *F. morishitai* Furutani, p. 65, pl. 1, fig. 18; pl. 2, fig. 13; pl. 3, fig. 11.

**Remarks.** - This species characteristically has latticed moderately small cortical shell 150 to 200 μm in diameter. Shell has numerous small round pores. The spines are four to six external per hemisphere. The proximal part of the spines is deeply grooved. The external spines are slightly thinner than those of *Futobari solidus*.

**Range and occurrence.** – Uppermost Silurian to Lower Devonian. Fukuji, Hitoegane areas and Yoshiki Formation in the Hida-gaien terrane; Konomori, Yoshinosawa-guchi, and Jingamori areas in the Kurosegawa terrane.

**Family Rotasphaeridae Noble, 1994, emend. MacDonald, 1998; Noble & Maletz, 2000; Won, Blodgett & Nestor, 2002**


**Type species.** – *Rotasphaera marathonensis* Noble, 1994.

*Rotasphaera* sp.

Figure 13S

1990 *Secuicollacta* sp. indet. Furutani, pl. 13, fig. 2.

2007 *Rotasphaera* sp. Kurihara, pl. 2, fig. 25.

**Remarks.** – The specimens four or more robust tapering spines observed on per hemisphere. The shell is single spherical, latticed, and 80 μm in diameter. The specimens bear a strong morphological similarity to genus *Rotasphaera*. This genus was originally erected by Noble (1994) for taxa possessing a single lattice shell formed by the coalescence of two or more primary spine units (morphological terminology of this genus follows Noble 1994). Noble (1994) suggested that this genus is distinguished from the genus *Secuicollacta* Nazarov and Ormiston by having a smaller number of primary spines and more differentiation between primary and secondary spine morphology. However, subsequent taxonomic work by MacDonald (1998) shows that specimens belonging to the genus *Secuicollacta* have one ectopically placed spicle and additional primary spine units. As MacDonald (1998) pointed out, all species described as *Secuicollacta* by Furutani (1990) have no ectopic spicle and only primary spine units. Herein, I follow MacDonald’s (1998) opinion and include the following three species within the genus *Rotasphaera*; namely, *Secuicollacta itoigawai* Furutani, *Secuicollacta horrida* Furutani, and *Secuicollacta vulgaris* Furutani.

**Genus Ceratoikiscum Deflandre, 1953**

**Type species.** – *Ceratoikiscum avimexpectans* Deflandre, 1953.

*Ceratoikiscum armiger* Furutani, 1990

Figure 13R

1990 *Ceratoikiscum armiger* Furutani, pp. 51, 52, pl. 12, figs 2–4.

1995 *Ceratoikiscum armiger* Amon, Braun & Ivanov, p. 4, pl. 1, figs 1, 2.

1997 *Ceratoikiscum armiger* Umeda, p. 419, pl. 1, fig. 19; pl. 3, figs 15–17.

1998 *Ceratoikiscum armiger* Umeda, fig. 9.

1998 *Ceratoikiscum armiger* Kurihara & Sashida, pl. 1, figs 11, 12.

2000 *Ceratoikiscum armiger* Kurihara & Sashida, p. 63, pl. 1, figs 12, 13.

2007 *Ceratoikiscum armiger* Kurihara, pl. 2, fig. 29.

1996 *Ceratoikiscum* sp. Furutani, figs 5–7.

**Remarks.** – This species bears a strong morphological similarity to *Ceratoikiscum armiger* Furutani. *Ceratoikiscum armiger* differs from other species of the genus *Ceratoikiscum* by possessing a simple skeleton consisting of three rods and caveal ribs (morphological terminology of the genus *Ceratoikiscum* follows Wakamatsu et al. 1990).

**Range and occurrence.** – Upper Silurian to Lower Devonian. Fukuji, Hitoegane areas and Yoshiki Formation in the Hida-gaien terrane; Konomori, and Yokokurayama areas in the Kurosegawa terrane; Southern Urals.
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