Late Silurian radiolarians from a radiolarite pebble within a conglomerate, Kotaki, Itoigawa, Niigata Prefecture, central Japan

Tsuyoshi ITO*, Toshiyuki KURIHARA**, Hiroaki HAKOIWA**,
Yousuke IBARAKI*** and Atsushi MATSUOKA****

Abstract

This article describes radiolarians from a radiolarite pebble within conglomerate from a float block that was collected along the banks of the Kotaki River in the Kotaki area, Itoigawa, Niigata Prefecture, central Japan. *Futobari morishitai* Furutani, Inaniguttidae gen. et sp. indet., and Palaeoscenidiidae gen. et sp. indet. were recognized on etched surfaces of the pebble. *Pseudospongoprunum* sp., *Zadrappolus* sp., and *Rotasphaera* sp. were discovered in residues obtained by chemically treating the conglomerate. This assemblage may be compared to the assemblage around the boundary between the *Pseudospongoprunum tauversi* to *Futobari solidus–Zadrappolus tenuis* assemblage zones and corresponds to the late Silurian. This report marks the first identification of Silurian radiolarians in Niigata Prefecture, which also makes them the oldest recorded fossils from the prefecture. The clasts are also the oldest recorded radiolarian-bearing clasts within conglomerates of the Japanese Islands and the Korean Peninsula.

Key words: conglomerate, etched surface, Silurian radiolaria, Jurassic, Kuruma Group, Niigata Prefecture, Japanese Islands, Korean Peninsula.

* Research Institute of Geology and Geoinformation, Geological Survey of Japan, AIST, Tsukuba 305-8567, Japan
** Graduate School of Science and Technology, Niigata University, Niigata 950-2181, Japan
*** Fossa Magna Museum, Ichinomiya 1313, Itoigawa 941-0056, Japan
**** Department of Geology, Faculty of Science, Niigata University, Niigata 950-2181, Japan
Corresponding author: T. Ito,
ito-t@aist.go.jp

(Manuscript received 4 December, 2016; accepted 12 February, 2017)

Introduction

Microfossils from clasts within conglomerates may provide clues about provenance. Radiolarians have been reported from siliceous and argillaceous rock clasts in Cretaceous strata in the Hokuriku district (e.g., Saida, 1987; Ito et al., 2012, 2014, 2015b), as represented by the Itoshiro and Akaiwa subgroups of the Tetori Group. In contrast, few studies have reported radiolarian-bearing clasts from Jurassic strata in the district.

The Lower Jurassic Kuruma Group (Kobayashi et al., 1957) is distributed over Niigata, Nagano, and Toyama Prefectures, central Japan. There has been only one brief report of radiolarian-bearing clasts from the Kuruma Group by Kumazaki and Kojima (1996), but no images were included.

Recently, Devonian corals were discovered in pebbles within conglomerate from a float block collected along the banks of the Kotaki River in the Kotaki area, Itoigawa, Niigata Prefecture (Niko et al., 2014, 2015, 2016). Previous studies reported that the conglomerate was derived from Mesozoic strata, possibly the Kuruma Group.

During sample processing of the conglomerate, we discovered a late Silurian radiolarian assemblage. This article describes the assemblage and is the first report of radiolarians from the Kuruma Group that includes images. This report also marks the first identification of Silurian radiolarians from Niigata Prefecture, which also makes them the oldest fossils recorded in the prefecture. Furthermore, the clasts are the oldest recorded radiolarian-bearing clasts within conglomerates in the Japanese Islands and the Korean Peninsula.

Sample locality and geologic background

Paleozoic basement rocks, overlying Mesozoic sedimentary strata, and Paleozoic through Cenozoic igneous rocks are exposed in the Itoigawa and adjacent regions (e.g., Nagamori et al., 2010) (Fig. 1A). The float block was collected along the banks of the Kotaki River in the Kotaki area, Itoigawa (Fig. 1B) by Kanako Ito. The float block is reposited in the Fossa Magna Museum in Itoigawa.

The float block is about 1 meter (m) in diameter and consists of subrounded to rounded pebbles in a sandy matrix (Niko et al., 2014). The pebbles include abundant volcanic and siliceous rocks, common limestones and mudstones, and relatively rare sandstones (Niko et al., 2014). Devonian corals occurred within the limestone and mudstone pebbles (Niko et al., 2014, 2015, 2016).

The Kuruma Group (Kobayashi et al., 1957) is widely distributed in the upper reaches of the Kotaki River and includes conglomeratic layers in most formations (e.g., Kobayashi et al., 1957; Shiraishi, 1992; Kumazaki and Kojima, 1996; Nagamori et al., 2010). Consequently, Niko

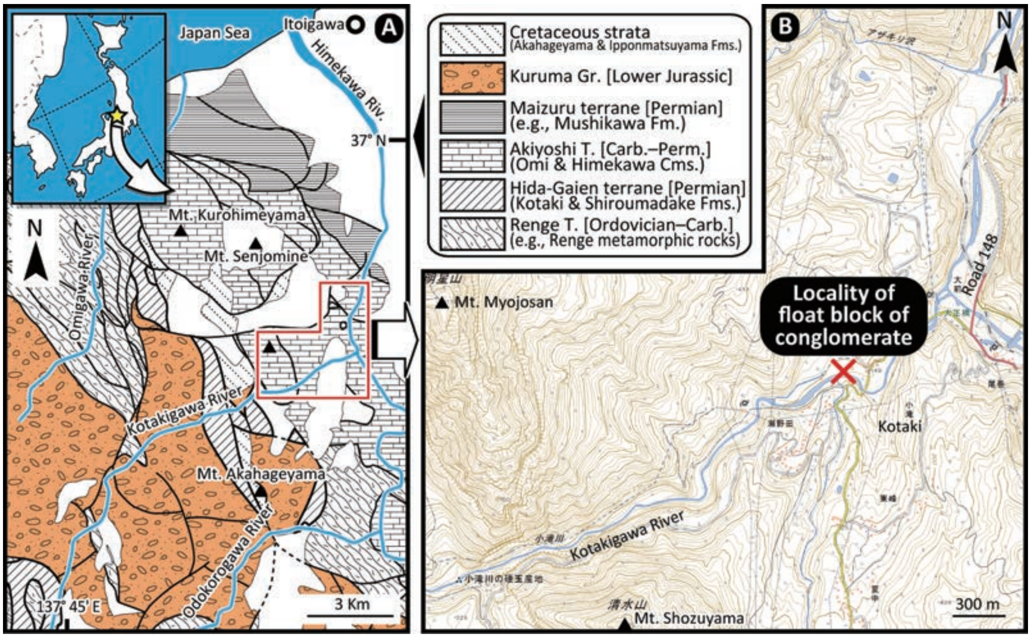

Fig. 1. Index map showing the location of the conglomerate float block in Kotaki, Itoigawa City, Niigata Prefecture, central Japan. (A) Geologic map of the Itoigawa area modified from Nagamori et al. (2010). (B) Map of Kotaki modified from topographic map "Kotaki" scale 1:25000 published by Geospatial Information Authority of Japan.

et al. (2014) concluded that the conglomerate was probably derived from the Kuruma Group. An exposure of the conglomerate layer from which the float block was derived, however, has never been discovered.

Materials and methods

The sample was prepared for an etched surface observation using the method described by Ito et al. (2015b). The sample was sliced into three chips with a rock cutter. The chips were observed using a loupe to assess the presence of radiolarian tests in siliceous and argillaceous rock clasts. Abundant radiolarian tests were recognized in a dark-cyan radiolarite clast (Fig. 2). Two chips, including the radiolarite clast, were soaked in a solution of approximately 5% hydrofluoric acid (HF) for one day at room temperature. After the removal of the HF solution, the etched chips were resoaked in fresh water. After the removal of the water, the etched chips were dried in an oven. A gold coating was applied to the etched chips, which were observed and photographed using a scanning electron microscope (SEM).

Residues from the chips were obtained when the HF solution was removed. The residues were collected through a sieve with a mesh diameter of 0.054 mm. All residues

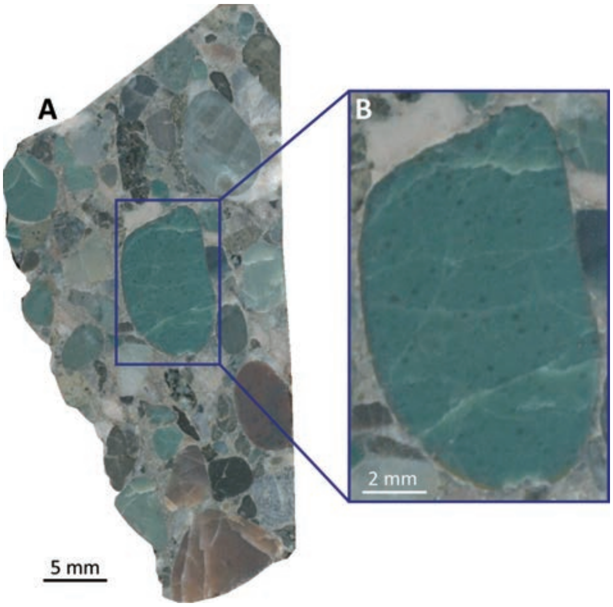

Fig. 2. Polished surface of the conglomerate. (A) Overall view. (B) Enlarged view of the radiolarian-bearing pebble (radiolarite).

were prepared on slides with a mounting medium (Entellan New). The slides were observed and photographed using a transmitted light microscope.

Radiolarian occurrences

The etched surfaces of the radiolarite clast were characterized by a predominance of spherical radiolarians with common spicules (Fig. 3). Terrestrial clastic grains did not appear on the etched surfaces, which implied that the clast is fossil supported. The spherical radiolarians and the spicules did not seem to be sorted and a preferred orientation of the spicules was not observed. Fossil preservation on the etched surfaces and in the residues was generally poor.

A few better-preserved specimens were recognized on the etched surfaces (Fig. 4). *Futobari morishitai* Furutani is characterized by several main spines and rounded pores on the surfaces (Fig. 4.1), which are major characteristics of the species (Furutani, 1990; Kurihara, 2007). Inaniguttidae gen. et sp. indet. display two major spines that are bladed at the base (Fig. 4.2). These characteristics are the same as for some genera of the family, such as *Futobari* and *Zadrappolus* (e.g., Furutani, 1990; Kurihara and Sashida, 2000; Kurihara, 2007). Palaeoscenidiidae gen. et sp. indet. display six thorny spines without rings formed by the basal spines (Fig. 4.3), which is typical of Palaeoscenidiidae genera; an example is *Palaeoscenidium* Deflandre, which is characterized by thorny spines (Deflandre, 1953) and

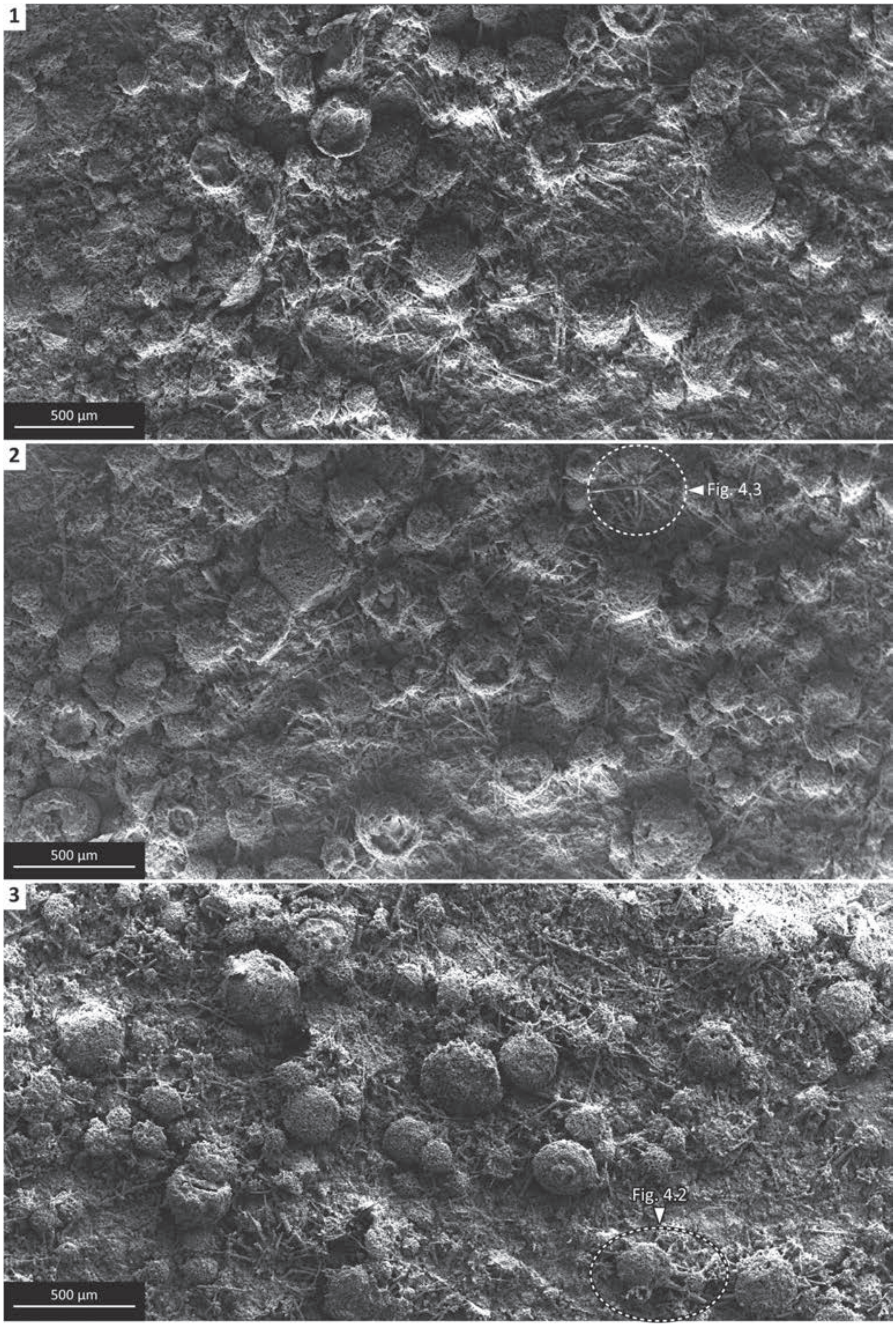

Fig. 3. Scanning electron microscope (SEM) images of the etched surfaces of the radiolarite pebble.

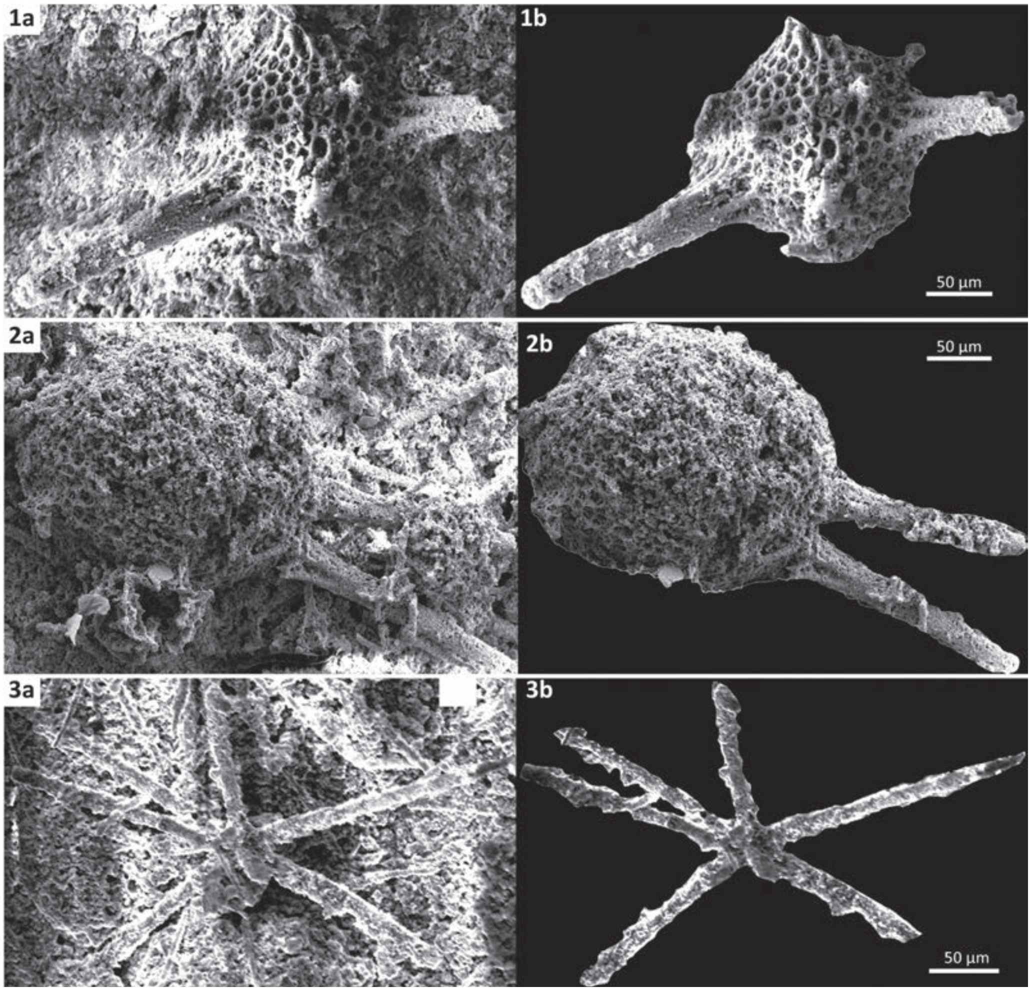

Fig. 4. Scanning electron microscope (SEM) images of radiolarians on etched surfaces (a) and trimmed images (b) from the radiolarite pebble. 1: *Futobari morishitai* Furutani, 1990. 2: Inaniguttidae gen. et sp. indet. 3: Palaeoscenidiidae gen. et sp. indet.

an absence of rings (Furutani, 1983).

In the residues, spinous and spineless spherical radiolarians were observed (Fig. 5); however, no specimen could be identified at the species level. *Pseudospongoprunum* sp. possess an elliptical spongy shell and probably two polar spines (Figs. 5.1, 5.2), which are diagnostic characteristics of the genus (Wakamatsu et al., 1990; Noble, 1994; Umeda, 1998). *Zadrappolus* sp. appear to possess a single cortical shell and double medullary shells (Figs. 5.3–5.5), which are diagnostic characteristics of the genus (Furutani, 1990). *Rotasphaera* sp. appear to have a web-like structure on the shell surface (Fig. 5.6), which is similar to the surface structure consisting of primary and secondary spines of the genus (Noble, 1994).

No radiolarian tests were observed in other clasts within the chips that were treated

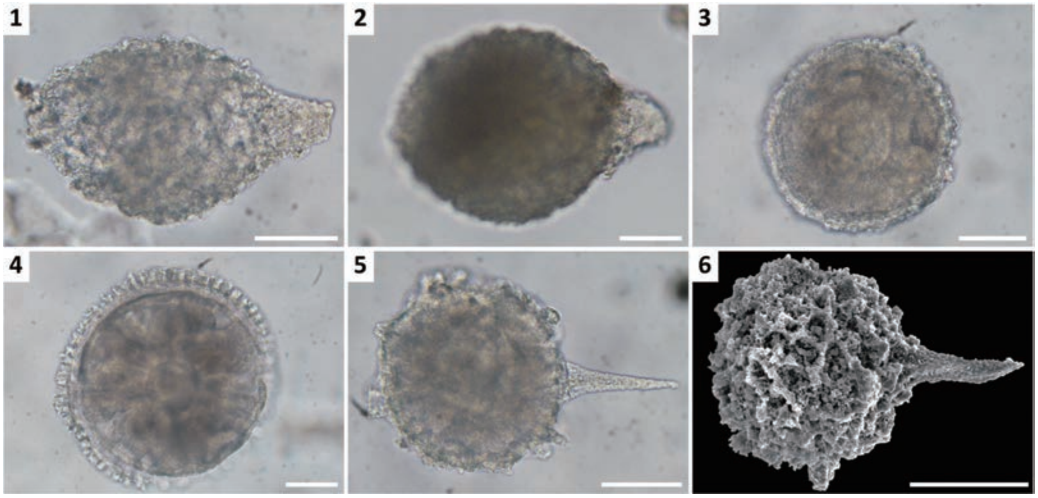

Fig. 5. Photomicrographs of radiolarians obtained from residues of the conglomerate sample. 1, 2: *Pseudospongoprunum* sp. 3–5: *Zadrappolus* sp. 6: *Rotasphaera* sp. All scale bars are 50 micrometers (μm).

with HF solution. Moreover, we determined that the matrices of the chips did not include radiolarians. Therefore, we can say with certainty that the radiolarians obtained from the residues were most likely derived from the radiolarite pebble, not the matrix.

Age assignment of the radiolarite pebble

The radiolarian tests on the etched surfaces, such as *F. morishitai*, are characteristic of the *Futobari solidus–Zadrappolus tenuis* Assemblage Zone of Kurihara (2004, 2007), which corresponds to the uppermost Pridoli (latest Silurian) to Lower Devonian (Pragian) according to Kurihara (2004, 2007).

Pseudospongoprunum, obtained from the residues, occurred in the *Pseudospongoprunum tauversi* Assemblage Zone of Kurihara (2004, 2007). Kurihara (2004, 2007) concluded that the *P. tauversi* Assemblage Zone corresponds to the Pridoli on the basis of the conodont-based age by Noble (1994) and Noble and Aitchison (2000).

Other radiolarians, which were observed on the etched surfaces and were obtained from the residues, are consistent with the components of the *P. tauversi* and *F. solidus–Z. tenuis* assemblage zones (Kurihara, 2004, 2007).

Because we are assuming that the residues were derived from the radiolarite pebble, the assemblage in the pebble can be compared to the assemblage around the boundary between the *P. tauversi and F. solidus–Z. tenuis* assemblage zones. In addition to the conodont-based age (Noble,1994; Noble and Aitchison, 2000), a U–Pb zircon age (Manchuk et al., 2013) indicated that the age around the boundary between the *P. tauversi* and *F. solidus–*

Zadrappolus tenuis assemblage zones is Ludlow to Pridoli (late Silurian). On the basis of these previous studies, we conclude that the age of the radiolarian assemblage of this study is late Silurian. If we assume that the radiolarians in the residues are derived from other clasts, then the pebble includes radiolarians that are at least as old as late Silurian.

Implications

Fossil records in Niigata Prefecture

Paleozoic radiolarian occurrences have been reported from Paleozoic strata in the Itoigawa area. In addition, Paleozoic and Mesozoic radiolarians have occurred in clasts within conglomerates in Mesozoic strata of the area. However, the age of the these previously reported radiolarians is Carboniferous(?), Permian, Triassic, and Jurassic, as documented below. The results of this study indicate that these are the first Silurian radiolarians to be identified in the Itoigawa area (Fig. 6).

Tazawa et al. (1984) found *Pseudoalbaillella* sp. aff. *P. longicornis* Ishiga and Imoto from mudstone of the Kotaki Formation (Nagamori et al., 2010), which is assigned to the Hida-Gaien terrane. The specimen of *Pseudoalbaillella* sp. aff. *P. longicornis* is similar to the short form of *Pseudoalbaillella fusiformis* (Holdsworth and Jones) sensu Ito et al. (2015a). *Pseudoalbaillella fusiformis* occurred generally in the upper Cisuralian (lower Permian) to the Guadalupian (middle Permian) (e.g., Ishiga, 1990; Zhang et al., 2010; Wang and Yang, 2011; Ito et al., 2015a). Ujihara (1985) reported occurrences of *Pseudotormentus* sp. from siliceous mudstone of the Kotaki Formation. *Pseudotormentus* occurred during all of the Permian (Ito et al., 2016), although *Pseudotormentus delawarensis* Schwartzapfel and Holdsworth also occurred in the upper Mississippian (Lower Carboniferous) (Schwartzapfel and Holdsworth, 1996). Kawai and Takeuchi (2001) found *Follicucullus* sp. in chert and siliceous mudstone of the Kotaki Formation. *Follicucullus* occurred generally in the Lopingian (Upper Permian) (e.g., Ishiga, 1990; Zhang et al., 2014).

The Himekawa Complex (Kawai and Takeuchi, 2001; redefined by Nagamori et al., 2010) is assigned to the Akiyoshi terrane. Cherts of this complex yielded *Pseudotormentus* sp. (Kawai and Takeuchi, 2001); siliceous mudstones yielded *Pseudoalbaillella fusiformis, Pseudoalbaillella* sp. cf. *P. globosa* Ishiga and Imoto, *F. porrectus* Rudenko (originally described as *F. scholasticus* Ormiston and Babcock), and *Pseudoalbaillella monacantha* (Ishiga and Imoto) (Tazawa et al., 1984); siliceous mudstones yielded *Pseudoalbaillella fusiformis, F. porrectus,* and *Pseudoalbaillella monacantha* (Kawai and Takeuchi, 2001); siliceous mudstone containing manganese carbonate spherules yielded *Albaillella asymmetrica* Ishiga and Imoto (Kawai and Takeuchi, 2001). According to Zhang et al. (2014), the co-occurrence range of *Pseudoalbaillella fusiformis, Pseudoalbaillella monacantha*, and *F. porrectus* is restricted to the *F. porrectus* Interval Zone of the lower Capitanian,

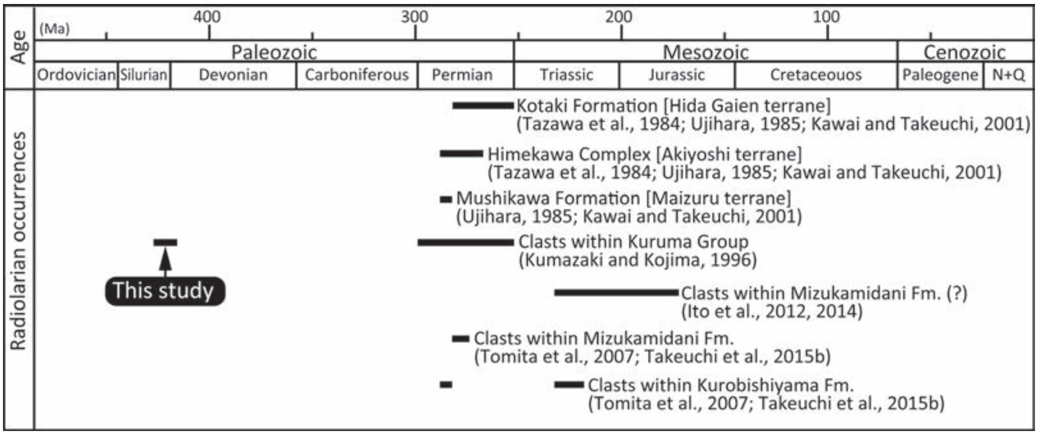

Fig. 6. Radiolarian occurrences from the Itoigawa area, Niigata Prefecture. Geologic ages are after Ogg et al. (2016).

Guadalupian. The range of *A. asymmetrica* is restricted to the Kungurian of the Cisuralian according to Zhang et al. (2010).

Mudstones of the Mushikawa Formation (Ujihara, 1985; redefined by Nagamori et al., 2010), which is assigned to the Maizuru terrane, yielded *A. asymmetrica* Ishiga and Imoto, *Pseudoalbaillella fusiformis*, and *Pseudoalbaillella longtanensis* Sheng and Wang (Ujihara, 1985; Kawai and Takeuchi, 2001). These species co-occurred in the *P. longtanensis* Assemblage Zone of Ishiga (1990), which corresponds to the Kungurian Age of the Cisuralian Epoch.

Kumazaki and Kojima (1996) reported *Pseudoalbaillella* sp. and *Pseudotormentus*? sp. from siliceous mudstone clasts within conglomerates of the lower part of the Gamaharazawa Formation in the Lower Jurassic Kuruma Group exposed along the Kotaki River, although they did not provide images. *Pseudoalbaillella* occurred in the Upper Carboniferous (Pennsylvanian) to the lower Permian (e.g., Holdsworth and Jones, 1980; Nazarov and Ormiston, 1986); *Pseudotormentus* occurred in the Permian (Ito et al., 2016).

Tomita et al. (2007) and Takeuchi et al. (2015b) reported Permian radiolarians (e.g., *Pseudoalbaillella* sp. cf. *P. fusiformis*) and Middle Triassic radiolarians (*Pseudostyloshaera japonica* (Nakaseko and Nishimura) and *Triassocampe* sp.) from chert clasts within the Lower Cretaceous Kurobishiyama Formation (Kobayashi et al., 1957; redefined by Takeuchi et al., 2015a).

Mudstone clasts within the Lower Cretaceous Mizukamidani Formation (Kobayashi et al., 1957; redefined by Takeuchi et al., 2015a) yielded *F. porrectus* and *Pseudoalbaillella* sp. cf. *P. fusiformis* (Tomita et al., 2007; Takeuchi et al., 2015b). These species occurred in the Guadalupian to Lopingian of the Permian (Zhang et al., 2014; Ito et al., 2015a).

Chert clasts within conglomerates of sections exposed in the right bank of the Sakaigawa

River yielded Middle to Late Triassic and Jurassic radiolarians (Ito et al., 2012); siliceous mudstone clasts within the conglomerate yielded Bajocian to early Bathonian (Middle Jurassic) radiolarians (Ito et al., 2014). Ito et al. (2012, 2014) assigned the conglomerate to the Mizukamidani Formation. However, Takeuchi et al. (2015a) designated the conglomerate section as the type locality of the middle Cretaceous Shiritakayama Formation (Yoshimura and Adachi, 1976) and redefined the formation.

Paleozoic radiolarian fossils have also occurred in several areas of the Niigata Prefecture other than the Itoigawa area (e.g., Matsumoto et al., 2001; Suzuki and Kuwahara, 2003; Uchino et al., 2010); however, all are Permian. Consequently, the radiolarians from the Itoigawa area are the first Silurian radiolarians to be identified in the Niigata Prefecture.

The radiolarians are the oldest fossils recorded in Niigata Prefecture. Previously reported Paleozoic fossil taxa from Niigata Prefecture, such as brachiopods (e.g., Hayasaka, 1918; Tazawa et al., 1983; Tazawa, 2004), foraminifers (e.g., Ueno and Nakazawa, 1993; Ichida et al., 2010), corals (e.g., Niikawa, 2001; Ibaraki et al., 2009; Ibaraki and Niko, 2012), bryozoans (e.g., Kobayashi et al., 1982; Nakazawa, 2001), and conodonts (e.g., Sato et al., 1975; Watanabe, 1975) range in age from Devonian to Permian. Although Nakamizu (1981) described occurrences of middle Paleozoic corals and trilobites from a lenticular limestone block within mélanges of the Renge terrane, detailed information and images were not provided.

Silurian fossils have been reported in some geologic units in limited areas of Japan, such as in the Kurosegawa terrane in Kochi Prefecture (e.g., Furutani, 1983; Wakamatsu et al., 1990; Umeda, 1997, 1998), the Hida-Gaien terrane in Gifu and Fukui prefectures (e.g., Furutani, 1990; Tazawa and Kaneko, 1991; Kurihara and Sashida, 2000; Kurihara, 2004, 2007), and the South Kitakami terrane in Iwate Prefecture (e.g., Kawamura et al., 1984; Ehiro et al., 1986). This study provides a new location in Japan for Silurian fossils.

Radiolarian-bearing clasts within upper Paleozoic and Mesozoic strata of the Japanese Islands and the Korean Peninsula

Radiolarian-bearing clasts have been identified in the upper Paleozoic to Mesozoic terrigenous strata of the Japanese Islands and the Korean Peninsula, such as in the Maizuru Group (Takemura et al., 1996), the Nariwa Group (Kametaka, 1997), the Choshi Group (Kashiwagi and Isaji, 2015), the Sasayama Group (Umeda et al., 1995), the Tetori Group (Saida, 1987; Ito et al., 2015b), and the Hayang Group (Chang et al., 1990; Kamata et al., 2000). The age of these clasts ranges from Permian through Cretaceous but may be as old as Carboniferous (e.g., Ishida et al., 2003; Ito et al., 2017). This study identified Silurian radiolarian-bearing clasts within conglomerate, making them the oldest radiolarian-bearing clasts within upper Paleozoic through Mesozoic strata in the Japanese Islands and the Korean Peninsula.

Concluding remarks

Limestone and mudstone pebbles and Devonian corals are present in the conglomerate examined during this study (Niko et al., 2014, 2015, 2016). Microscopic observations identified the presence of a Silurian radiolarian-bearing pebble (radiolarite) in the conglomerate. The conglomerate was probably derived from the Lower Jurassic Kuruma Group. The age of the radiolarians in the pebble implies that a geologic unit (or units) that included Silurian radiolarites, as well as younger Devonian limestones and mudstones, was exposed and eroded in the provenance of the Kuruma Group in the Kotaki area by the time the conglomerate was deposited.

Meanwhile, the source exposure for the conglomerate is unknown, which allows for the possibility that the conglomerate was derived from other geologic units. The discovery of the original bed will provide the further knowledge, such as the origin of the conglomerate and a more precise date for the time of deposition.

Acknowledgments

We give our thanks to Mrs. Kanako Ito for providing the conglomerate samples for this study. The manuscript was greatly improved by comments and suggestions by Dr. Shuji Niko (Hiroshima University). This work was partially supported by JSPS KAKENHI Grant Numbers 15K05329 and 15H02142E to A. Matsuoka.

References

Chang, K. H., Woo, B., Lee, J., Park, S. O. and Yao, A., 1990, Cretaceous and Early Cenozoic stratigraphy and history of eastern Kyongsang Basin, S. Korea. *Jour. Geol. Soc. Korea*, **26**, 471–487.

Deflandre, G., 1953, Radiolaires fossiles. *In* Traité de Zoologie. P. P. Grassé (ed.). *Traité de Zoologie, 1*. Masson et Cie, Paris, 390–435.

Ehiro, M., Tazawa, J., Oishi, M. and Okami, K., 1986, Discovery of *Trimerella* (Silurian Brachiopoda) from the Odagoe Formation, south of Mt. Hayachine in the Kitakami Massif, Northeast Japan and its significance. *Jour. Geol. Soc. Japan*, **92**, 753–756 (in Japanese).

Furutani, H., 1983, Middle Palaeozoic Palaeoscenidiidae (Radiolaria) from Mt. Yokokura, Shikoku, Japan. Part 1. *Trans. Proc. Palaeont. Soc. Japan, New Ser.*, no. 130, 96–116.

Furutani, H., 1990, Middle Paleozoic radiolarians from Fukuji area, Gifu Prefecture, central Japan. *Jour. Earth Sci., Nagoya Univ.*, **37**, 1–56.

Hayasaka, I., 1918, Paleozoic brachiopods from the Omi-mura area, Nishikubiki District, Niigata Prefecture (Preliminary report). *Jour. Geol. Soc. Japan*, **25**, 304–310 (in Japanese). *The title was translated by the authors.

Holdsworth, B. K. and Jones, D. L., 1980, Preliminary radiolarian zonation for the Late Devonian through Permian time. *Geology*, **8**, 281–285.

Ibaraki, Y., Niko, S., Hosaka, R. and Tazawa, J., 2009, Devonian tabulate from limestone float in the Kotakigawa River, Omi area, Niigata Prefecture. *Jour. Geol. Soc. Japan*, **115**, 423–426 (in Japanese with English abstract).

Ibaraki, Y. and Niko, S., 2012, Devonian corals from the Renge area, Itoigawa, Niigata Prefecture, Japan. *Bull.*

Grad. School Integrated Arts Sci., Hiroshima Univ. II, Studied Environmental Sci., **7**, 105–110 (in Japanese with English abstract).

Ichida, M., Suzuki, H., Kondo, M. and Nogami, Y., 2010, Report of Middle Permian fusulinids from Kosado Hill, Sado Island, Japan. *Fossils*, no. 87, 29–34 (in Japanese with English abstract).

Ishida, K., Kozai, T., Park, S. O. and Mitsugi, T., 2003, Gravel bearing radiolarian as tracers for erosional events: a review of the status of recent research in SW Japan and Korea. *Jour. Asian Earth Sci.*, **21**, 909–920.

Ishiga, H., 1990, Paleozoic radiolarians. *In* Ichikawa, K., Mizutani, S., Hara, I., Hada, S., Yao, A. (eds.), *Pre-Cretaceous Terrane of Japan*. Publication of IGCP project No. 224, Pre-Jurassic Evolution of Eastern Asia, 285–295.

Ito, T., Feng, Q. L. and Matsuoka, A., 2015a, Taxonomic significance of short forms of middle Permian *Pseudoalbaillella* Holdsworth and Jones, 1980 (Follicucullidae, Radiolaria). *Rev. Micropaléont.*, **58**, 3–12.

Ito, T., Feng, Q. L. and Matsuoka, A., 2016, Uneven distribution of *Pseudotormentus* De Wever et Caridroit (Radiolaria, Protozoa): Provincialism of a Permian planktonic microorganism. *Acta Geol. Sinica (English Edition)*, **90**, 1598–1610.

Ito, T., Sakai, Y., Feng, Q. L. and Matsuoka, A., 2015b, Middle Jurassic radiolarians from chert clasts within conglomerates of the Itsuki Formation of the Itoshiro Subgroup (Tetori Group) in the Taniyamadani Valley, Fukui Prefecture, central Japan. *Sci. Rep., Niigata Univ. (Geol.)*, no. 30, 1–13.

Ito, T., Sakai, Y., Feng, Q. L. and Matsuoka, A., 2017, Review of microfossil-bearing clasts within upper Mesozoic strata in East Asia: staged denudation of mid-Mesozoic accretionary complexes. *Ofioliti*, **42**, 39–54.

Ito, T., Sakai, Y., Ibaraki, Y. and Matsuoka, A., 2014, Middle Jurassic radiolarians from a siliceous mudstone clast within conglomerate of the Tetori Group in the Itoigawa area, Niigata Prefecture, central Japan. *Sci. Rep., Niigata Univ. (Geol.)*, no. 29, 1–11.

Ito, T., Sakai, Y., Ibaraki, Y., Yoshino, K., Ishida, N., Umetsu, T., Nakada, K., Matsumoto, A., Hinohara, T., Matsumoto, K. and Matsuoka, A., 2012, Radiolarian fossils from siliceous rock pebbles within conglomerates in the Mizukamidani Formation of the Tetori Group in the Itoigawa area, Niigata Prefecture, central Japan. *Bull. Itoigawa City Mus.*, no. 3, 13–25 (in Japanese with English abstract).

Kamata, Y., Hisada, K. and Lee, Y. I., 2000, Late Jurassic radiolarians from pebbles of Lower Cretaceous conglomerates of the Hayang Group, southeastern Korea. *Geosci. Jour.*, **4**, 165–174.

Kametaka, M., 1997, Radiolarian fossils from conglomerate of the Upper Triassic Nariwa Group, and their geological significance. *News Osaka Micropaleontol. (NOM), Spec. Vol.*, no. 10, 127–131 (in Japanese with English abstract).

Kashiwagi, K. and Isaji, S., 2015, Paleozoic and Mesozoic radiolarians from chert pebbles and cobbles of the Lower Cretaceous Choshi Group, Japan. *Nat. Hist. Res.*, **14**, 35–46.

Kawai, M. and Takeuchi, M., 2001, Permian radiolarians from the Omi area in the Hida-gaien Tectonic Zone, central Japan. *News Osaka Micropaleontol. (NOM), Spec. Vol.*, no. 12, 23–32 (in Japanese with English abstract).

Kawamura, T., Nakai, H. and Kawamura, M., 1984, A new occurrence of Silurian fossils in the northern marginal part of the Southern Kitakami belt. *Jour. Geol. Soc. Japan*, **90**, 61–64 (in Japanese).

Kobayashi, I., Sakagami, S., Hasegawa, Y., Watanabe, E. and Saito, R., 1982, Discovery of the Carboniferous–Permian bryozoans from Akadomari in Sado Island. *Jour. Geol. Soc. Japan*, **88**, 141–143 (in Japanese).

Kobayashi, T., Konishi, K., Sato, T., Hayami, I. and Tokuyama, A., 1957, On the Lower Jurassic Kuruma Group. *Jour. Geol. Soc. Japan*, **63**, 182–194 (in Japanese with English abstract).

Kumazaki, N. and Kojima, S., 1996, Depositional history and structure development of the Kuruma Group (lower Jurassic) on the basis of clastic rock composition. *Jour. Geol. Soc. Japan*, **102**, 285–302 (in Japanese with English abstract).

Kurihara, T., 2004, Silurian and Devonian radiolarian biostratigraphy of the Hida-gaien belt, central Japan. *Jour. Geol. Soc. Japan*, **110**, 620–639 (in Japanese with English abstract).

Kurihara, T., 2007, Uppermost Silurian to Lower Devonian radiolarians from the Hitoegane area of the Hida-gaien terrane, central Japan. *Micropaleontology*, **53**, 221–237.

Kurihara, T. and Sashida, K., 2000, Taxonomy of Late Silurian to Middle Devonian radiolarians from the

Kuzuryu Lake district of the Hida Gaien Belt, Fukui Prefecture, central Japan. *Micropaleontology*, **46**, 51–71.

Manchuk, N., Kurihara, T., Tsukada, K., Kochi, Y., Obara, H., Fujimoto, T., Orihashi, Y. and Yamamoto, K., 2013. U–Pb zircon age from the radiolarian-bearing Hitoegane Formation in the Hida Gaien Belt, Japan. *Island Arc*, **22**, 494–507.

Matsumoto, Y., Sashida, K. and Hori, N., 2001, Paleozoic and Mesozoic radiolarians from the east of Koide Town, Kitauonuma County, Niigata Prefecture, central Japan. *News Osaka Micropaleontol. (NOM), Spec. Vol.*, no. 12, 99–112 (in Japanese with English abstract).

Nakamizu, M., 1981, The Renge melange complex. *Research Report No. 1 -Hida Gaien Belt-*, 12–28 (in Japanese).

Nakazawa, T., 2001, Carboniferous reef succession of the Panthalassan open-ocean setting: Example from Omi Limestones, central Japan. *Facies*, **44**, 183–210.

Nagamori, H., Takeuchi, M., Furukawa, R., Nakazawa, T. and Nakano, S., 2010, *Geology of the Kotaki district. Quadrangle Series, 1:50,000*, Geol. Surv. Japan, AIST, 130p. (in Japanese with English abstract).

Nazarov, B. B. and Ormiston, A. R., 1986, Origin and biostratigraphic potential of the stauraxon polycystine radiolaria. *Marine Micropaleont.*, **11**, 33–54.

Niikawa, I., 2001, The genus *Echigophyllum* from the Omi Limestone, central Japan. *Bull. Tohoku Univ. Mus.*, no. 1, 70–76.

Niko, S., Ibaraki, Y. and Tazawa, J., 2014, Devonian tabulate corals from pebbles in Mesozoic conglomerate, Kotaki, Niigata Prefecture, central Japan Part 1: Favositina. *Sci. Rep., Niigata Univ. (Geology)*, no. 29, 53–66.

Niko, S., Ibaraki, Y. and Tazawa, J., 2015, Devonian tabulate corals from pebbles in Mesozoic conglomerate, Kotaki, Niigata Prefecture, central Japan Part 2: Alveolitina. *Sci. Rep., Niigata Univ. (Geology)*, no. 30, 15–25.

Niko, S., Ibaraki, Y. and Tazawa, J., 2016, Devonian tabulate corals from pebbles in Mesozoic conglomerate, Kotaki, Niigata Prefecture, central Japan Part 3: Heliolitida. *Sci. Rep., Niigata Univ. (Geology)*, no. 31, 1–6.

Noble, P. J., 1994, Silurian radiolarian zonation for the Gaballos Novaculite, Marathon Uplift, West Texas. *Bull. American Paleont.*, **106**, 1–55.

Noble, P. and Aitchison, J., 2000, Early Paleozoic radiolarian biozonation. *Geology*, **28**, 367–370.

Ogg, J. G., Ogg, G. M. and Gradstein, F. M., 2016, *A Concise Geologic Time Scale 2016*. Elsevier, Amsterdam. 234p.

Saida, T., 1987, Triassic and Jurassic radiolarians in chert clasts of the Tetori Group in Tamodani area of Izumi Village, Fukui Prefecture, central Japan. *Jour. Geol. Soc. Japan*, **93**, 57–59 (in Japanese).

Sato, T., Yoshida, S. and Kimura, T., 1975, Permian–Triassic in the Kuromata-gawa area, Niigata Prefecture. *Jour. Geol. Soc. Japan*, **81**, 709–711 (in Japanese).

Shiraishi, S., 1992, The Hida Marginal Tectonic Belt in the middle reaches of the River Hime-kawa with special reference to the lower Jurassic Kuruma Group. *Earth Sci. (Chikyu Kagaku)*, **46**, 1–20 (in Japanese with English abstract).

Schwartzapfel, J. A. and Holdsworth, B. K., 1996, Upper Devonian and Mississippian radiolarian zonation and biostratigraphy of the Woodford, Sycamore, Caney and Goddard formations, Oklahoma. *Cushman Found. Spec. Publ.*, **33**, 1–275.

Suzuki, H. and Kuwahara, K., 2003, Permian radiolarians from the Kosado area of Sado Island, central Japan. *Jour. Geol. Soc. Japan*, **109**, 489–492 (in Japanese with English abstract).

Takemura, S., Umeda, M., Yao, A. and Suzuki, S., 1996, Middle and Late Permian radiolarian fossils yielding from siliceous rock pebbles in the Middle and Upper Permian Maizuru Group, Southwest Japan. *Jour. Geol. Soc. Japan*, **102**, 820–823 (in Japanese with English Abstract).

Takeuchi, M., Ohkawa, M., Kawahara, K., Tomita, S., Yokota, H., Tokiwa, T. and Furukawa, R., 2015a, Redefinition of the Cretaceous terrigenous strata in the northeastern Toyama Prefecture based on U–Pb ages of zircon. *Jour. Geol. Soc. Japan*, **121**, 1–17 (in Japanese with English abstract).

Takeuchi, M., Takenouchi, K. and Tokiwa, T., 2015b, Range Metamorphic rocks and the Mesozoic terrigenous strata. *Jour. Geol. Soc. Japan*, **121**, 193–216 (in Japanese).

Tazawa, J., 2004, Early Carboniferous brachiopods from Tsuchikurazawa in the Omi area, central Japan: A fossil evidence for the Permian accretionary site of the Akiyoshi terrane. *Earth Sci. (Chikyu Kagaku)*, **58**, 413–416 (in Japanese with English abstract).

Tazawa, J., Aita, Y., Yuki, T. and Otsuki, K., 1984, Discovery of Permian radiolarians from the "non-calcareous Paleozoic strata" of Omi, central Japan. *Earth Sci. (Chikyu Kagaku),* **38**, 264–267 (in Japanese).

Tazawa, J. and Kaneko, A., 1991, *Encrinurus* (Silurian trilobite) from tuff in Hitoegane of the Fukuji district, Hida Mountains, central Japan and its significance. *Earth Sci. (Chikyu Kagaku)*, **45**, 61–64 (in Japanese).

Tazawa, J., Nakamura, K., Eto, M. and Kato, M., 1983, Carboniferous brachiopods *Delepinea* and *Rhipidomella* from basic tuff of the lowest part of the Omi Limestone Group. Central Japan. *Earth Sci. (Chikyu Kagaku),* **37**, 279–282 (in Japanese).

Tomita, S., Takeuchi, M. and Kametaka, M., 2007, Radiolarian fossils obtained from conglomerate of the Tetori Group in the northeastern part of Toyama Prefecture and its geological significance. *Abst. 114th Ann. Meet. Geol. Soc. Japan*, 243 (in Japanese).

Uchino, T., Ueno, K. and Kuwahara, K., 2010, Radiolarian and fusulina fossils from oceanic rocks in the Ashio Terrane of the Kambara Massif, Niigata Prefecture, Southwest Japan. *Jour. Geol. Soc. Japan*, **116**, 118–123 (in Japanese with English abstract).

Ueno, K. and Nakazawa, T., 1993, Carboniferous foraminifers from the lowermost part of the Omi Limestone Group, Niigata Prefecture, central Japan. *Sci. Rep., Inst. Geosci., Univ. Tsukuba, Sec. B*, **14**, 1–51.

Ujihara, M., 1985, Permian olistostrome and clastics along the Himekawa River in the northeast part of the Hida Gaien belt. *Research Report No. 2 -Joetsu terrane and Ashio terrane-*, 69–84 (in Japanese). *The title was translated by the authors.

Umeda, M., 1997, Late Silurian and Early Devonian radiolarians from the Konomori area in the Kurosegawa Terrane, Southwest Japan. *Earth Sci. (Chikyu Kagaku),* **51**, 413–432.

Umeda, M., 1998, Some Late Silurian characteristic radiolarians from the Yokokurayama Group in the Kurosegawa Terrane, Southwest Japan. *Earth Sci. (Chikyu Kagaku)*, **52**, 203–209.

Umeda, M., Takemura, S., and Yao, A., 1995, Mesozoic and Paleozoic radiolarians from the chert pebbles of the Lower Cretaceous Sasayama Group in the eastern part of Hyogo Prefecture, Southwest Japan. *Jour. Geol. Soc. Japan*, **101**, 937–939 (in Japanese with English abstract).

Wakamatsu, H., Sugiyama, K. and Furutani, H., 1990, Silurian and Devonian radiolarians from the Kurosegawa Tectonic Zone, Southwest Japan. *Jour. Earth Sci., Nagoya Univ.*, **37**, 157–192.

Watanabe, K., 1975, Mississippian conodonts from the Omi Limestone, Niigata prefecture, central Japan. *Trans. Proc. Palaeont. Soc. Japan, New Ser.*, no. 99, 156–171.

Wang, Y. J. and Yang, Q., 2011, Biostratigraphy, phylogeny and palaeobiogeography of Carboniferous–Permian radiolarians in South China. *Palaeoworld*, **20**, 134–145.

Yoshimura, T. and Adachi, H., 1976, Futomiyama Group in Niigata Prefecture. *Contrib. Dept. Geol. Mineral. Niigata Univ.*, no. 4, 131–136 (in Japanese with English abstract).

Zhang, N., Henderson, C. M., Wang, W. C., Wang, G. Q. and Shang, H. J., 2010, Conodonts and radiolarians through the Cisuralian–Guadalupian boundary from the Pingxiang and Dachongling sections, Guangxi region, South China. *Alcheringa*, **34**, 135–160.

Zhang, L., Ito, T., Feng, Q. L., Caridroit, M. and Danelian, T., 2014, Phylogenetic model of *Follicucullus* lineages (Albaillellaria, Radiolaria) based on high-resolution biostratigraphy of the Permian Bancheng Formation, Guangxi, South China. *Jour. Micropalaeont.*, **33**, 179–192.