Bulletin of the Geological Survey of Japan, vol. 76 (1/2), p. 31–50, 2025

Article

Middle Jurassic radiolarians from manganese nodules obtained in the western part of the Kado District, northern Kitakami Mountains

MUTO Shun[1,*], ITO Tsuyoshi[1] and OZEKI Masanori[1, 2]

MUTO Shun, ITO Tsuyoshi and OZEKI Masanori (2025) Middle Jurassic radiolarians from manganese nodules obtained in the western part of the Kado District, northern Kitakami Mountains. *Bulletin of the Geological Survey of Japan*, vol. 76 (1/2), p. 31–50, 8 figs, 1 table and 5 plates.

Abstract: The accretionary history of the Jurassic accretionary complex of the North Kitakami Belt in Northeast Japan is obscured by the metamorphism of Cretaceous plutons that hinder extraction of radiolarian fossils. Some of the most successful cases of radiolarian extraction in this area treated manganese nodules. In this study, we obtained well-preserved radiolarians from three manganese nodules embedded in argillaceous rocks in the western part of the 1: 50,000 quadrangle series Kado District. The age of the radiolarian fossil assemblages is assigned to the early Bajocian and Aalenian to Bajocian (Middle Jurassic) for two samples from grey bedded mudstone and Bajocian (Middle Jurassic) for a sample from mudstone that possibly experienced tectonic mixing. The age of the assemblages approximates the accretionary age of the studied rocks. This is the first report of age diagnostic radiolarians from the western part of the Kado District.

Keywords: Aalenian, accretionary age, Bajocian, Jurassic accretionary complex, Nassellaria, North Kitakami–Oshima Belt, Otori Unit, Quadrangle Series, Toarcian

1. Introduction

The North Kitakami–Oshima Belt in Northeast Japan (e.g., Isozaki and Maruyama, 1991) mainly consists of an accretionary complex that was formed mostly during the Jurassic (Ehiro *et al.*, 2005; Kojima *et al.*, 2016). Works on radiolarian fossils and zircon dating clarified that the age of accretion, approximated by the age of trench-fill clastic rocks, was from the latest Triassic to Early Cretaceous, although the oldest accretionary complex may date back to the late Permian (Fig. 1B and references therein). The accretionary complex of the North Kitakami–Oshima Belt is much less studied in terms of accretionary history compared to its counterparts in Southwest Japan. One of the reasons is the difficulty in obtaining radiolarians due to metamorphism related to Cretaceous plutons that intrude the accretionary complex (Fig. 1B).

The best results of radiolarian investigation in the North Kitakami–Oshima Belt are arguably the works on manganese nodules (Mn-nodules) that are found in mudstone or siliceous mudstone (Yoshihara *et al.*, 2002; Suzuki and Ogane, 2004; Suzuki *et al.*, 2007a, b; Ehiro *et al.*, 2008; Muto *et al.*, 2023). Manganese nodules investigated in these works have yielded radiolarians with clearly observable external and internal test structures, even when radiolarians extracted from the surrounding argillaceous rocks are poorly preserved. However, Mn-nodules are relatively rare and not always easy to spot in the field, reflected in the few number of works.

The first author (Muto, S.) conducted surveys to produce the 1: 50,000 geological map of the Kado District for the Quadrangle Series of the Geological Survey of Japan, AIST. The district is located within the area of the North Kitakami Belt (the part of the North Kitakami–Oshima Belt distributed in Honshu). As part of this project, we investigated newly found Mn-nodules for radiolarians, in order to obtain further controls on the accretionary age of the surveyed strata. The Mn-nodules were found in the western part of the Kado District, in Iwaizumi Town and Kuzumaki Town in northeast Iwate Prefecture. This is the first time that age diagnostic radiolarians have been successfully extracted from rocks in this area.

2. Geological outline

The Kado District of the 1:50,000 Quadrangle Series is situated in the central area of the North Kitakami Belt and straddles the Omotogawa Fault (Omotogawa is the

[1] AIST, Geological Survey of Japan, Research Institute of Geology and Geoinformation

[2] Graduate School of Life and Environmental Sciences, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki, 305-8572, Japan

* Corresponding author: MUTO, S., AIST Tsukuba Central 7, 1-1-1 Higashi, Tsukuba, Ibaraki 305-8567, Japan. Email: s-muto@aist.go.jp

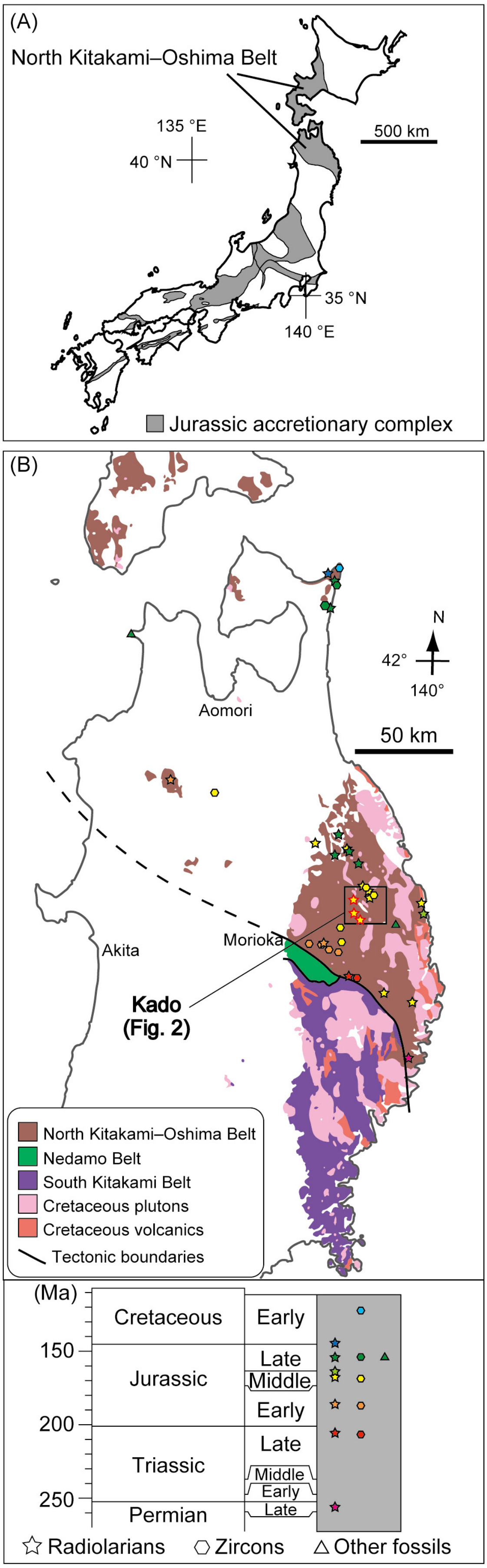

Fig. 1 (A) Distribution of the Jurassic accretionary complex in Japan (after Isozaki *et al.*, 2010). (B) Geology of the basement rocks of the northern Tohoku Region (modified from Geological Survey of Japan, AIST, 2020). Age constraints for time of accretion are based on the compilation by Uchino and Suzuki (2020) and additional references in Muto *et al.* (2023). Data plots closed in red were obtained in this study.

Japanese for the Omoto River) (Figs. 1B, 2). The area northeast of the Omotogawa Fault includes one of the better studied areas of the North Kitakami Belt. Sugimoto (1974) provided some of the first detailed geological maps and lithostratigraphic framework of the North Kitakami Belt in the Akka–Kuji area. Sugimoto (1980) extended the survey area to the Iwaizumi area. Following the wide acceptance of plate tectonics, the geology was revised based on the concept of accretionary complexes (Ehiro *et al.*, 2008; Takahashi *et al.*, 2016; Nakae *et al.*, 2021; Muto *et al.*, 2023), although fundamentals of the lithostratigraphic division by Sugimoto (1974, 1980) still stands. The more recent studies showed that the strata of the Akka–Kuji area comprise Middle to Late Jurassic accretionary complexes that generally trend NW–SE and become younger to the northeast. The age of the strata was determined by radiolarians (Nakae and Kamada, 2003; Suzuki *et al.*, 2007b; Ehiro *et al.*, 2008; Muto *et al.*, 2023) and detrital zircons (Muto *et al.*, 2023).

On the other hand, the area stretching from close to the Omotogawa Fault to the southwest part of the Kado district is less studied. Onuki (1969) proposed a rough stratigraphic division of this area. Yamaguchi (1981) published a geological map with more details in the eastern part of the map by Onuki (1969). Murai *et al.* (1985, 1986) extended the geological map by Sugimoto (1974, 1980) to the northwest part of Iwaizumi Town, updating the stratigraphic division by Onuki (1969). While these maps were informative about the general characteristics of lithofacies and geological structures in the area, these works lacked detailed traverse maps of main routes. These studies also did not obtain age data from clastic rocks that would constrain the time of accretion. Therefore, correlation of stratigraphic units or re-interpretation of the units as accretionary complexes are somewhat difficult. The first author (S. Muto) revised the stratigraphic division by the above works from the viewpoint of subduction–accretion, based on a geological field survey of the entire Kado District (Fig. 2). By this revision, most of the Jurassic accretionary complex mapped by Onuki (1969), Yamaguchi (1981) and Murai *et al.* (1985, 1986) is included in a tectonostratigraphic unit called the Otori Unit (sensu Muto *et al.*, 2023), except for strata that were already classified as other units by Takahashi *et al.* (2016) and Nakae *et al.* (2021). The strata of the Otori Unit are composed mainly of chert, mudstone and sandstone, which is in agreement to maps by previous workers.

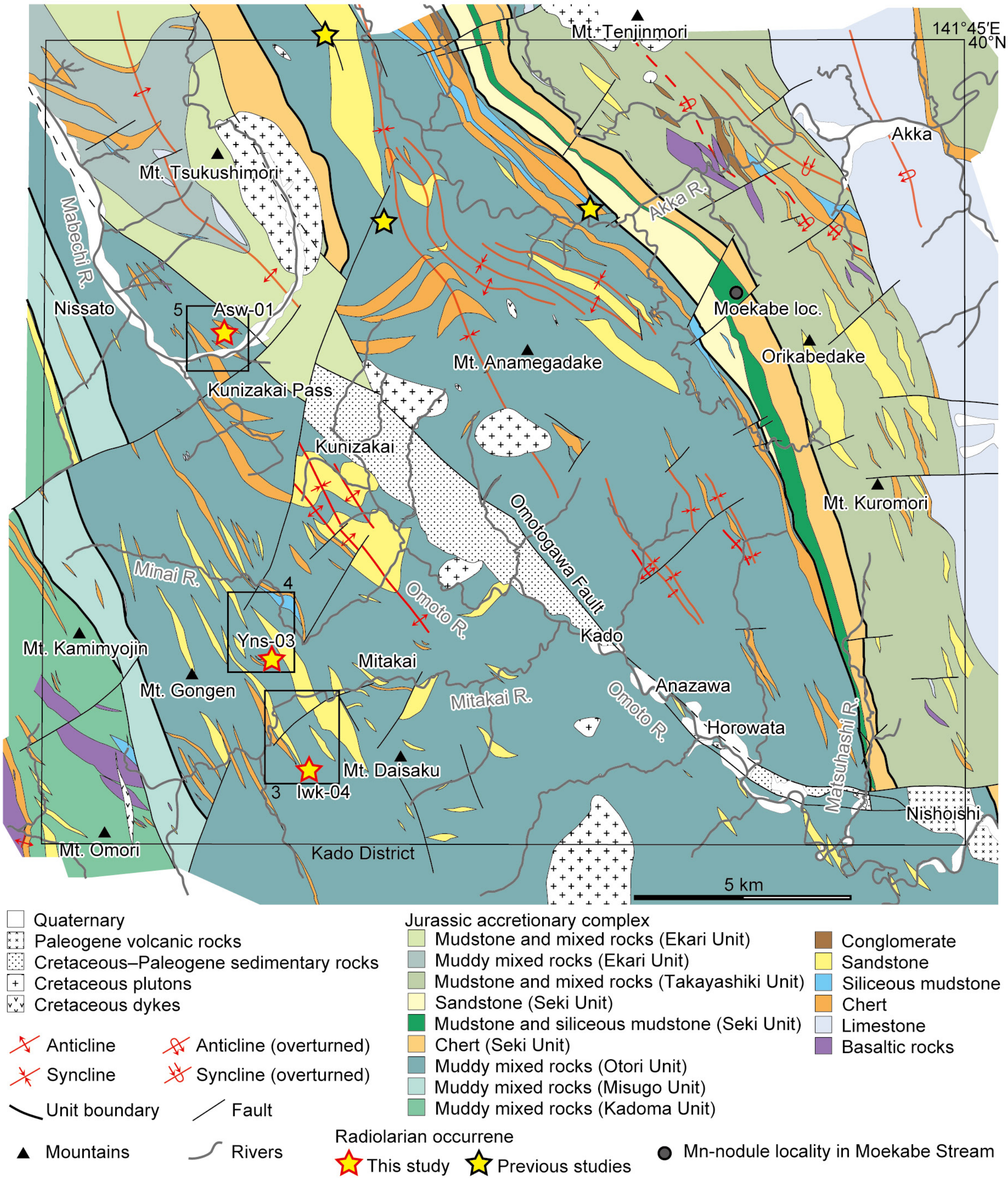

Fig. 2 Geological outline of the Kado District based on geological surveys conducted for the 1: 50,000 geological map of the "Kado" District for the Quadrangle Series of the Geological Survey of Japan, AIST by Muto, S. Locations of Figs. 3–5 are shown.

The samples investigated in this study were collected from the southwest part of the Otori Unit (Fig. 2). The accretionary age of the northeast part of the Otori Unit is the Middle Jurassic (Suzuki *et al.*, 2007b; Ehiro *et al.*, 2008; Muto *et al.*, 2023). To the southwest lie Middle Jurassic accretionary complexes belonging to another unit, the Kadoma Unit (Uchino and Komatsubara, 2024). Thus, strata of the studied area are expected to belong to a Middle Jurassic accretionary complex.

3. Materials and Methods

We investigated manganese nodule (Mn-nodule) samples from three localities for extraction of radiolarians

(Figs. 2–5).

Sample Iwk-04 was obtained from grey mudstone in a locality south of Mt. Iwakura in Gongen, Iwaizumi Town, along a small valley branching from the north bank of Orikabe Stream, a tributary of the Mitakai River (Figs. 2, 3). A major part of the lithofacies distributed around the locality are muddy mixed rocks with blocks of sandstone and chert (Fig. 6A). The muddy mixed rocks are accompanied by smaller amounts of sandstone, mudstone without blocks of other lithologies, siliceous mudstone and chert. Of these, grey bedded mudstone without exotic blocks (Fig. 6B) hosted Mn-nodules in the studied locality. The Mn-nodules are black and lenticular with their long axis parallel to the bedding and cleavage plain of the host mudstone. At the outcrop surface, the Mn-nodules tend to be preferentially eroded and appear as holes (Fig. 6C). The lack of exotic blocks of other lithologies in the grey mudstone that hosts the nodules imply that the Mn-nodules were not introduced by tectonic mixing.

Sample Yns-03 was obtained from grey mudstone exposed along Yunashigi Stream, a tributary of the Minai River in Minaikawa, Iwaizumi Town (Figs. 2, 4). The Yunashigi Stream locality is situated close to the lateral extension of the Mt. Iwakura locality (Fig. 2). The lithofacies distributed in the Yunashigi Stream locality is the same as that of the Mt. Iwakura locality, and is composed mostly of muddy mixed rocks with sandstone, mudstone, siliceous mudstone and chert (Fig. 4). The mode of occurrence of Mn-nodules is also same as that of the Mt. Iwakura locality (Fig. 6D).

Sample Asw-01 was obtained from dark brown weathered mudstone exposed to the north of Arasawaguchi in Ekari, Kuzumaki Town (Figs. 2, 5). Outcrops in this area are generally isolated and small, and in many cases the rocks are strongly weathered. Judging from the available outcrops, the lithofacies is composed of muddy mixed rocks with blocks of sandstone, siliceous mudstone and chert (Figs. 5, 6E), similar to the other two localities. The sample was collected from a very small outcrop of weathered mudstone (Fig. 6F). The mudstone contains no outstanding blocks of other lithologies, but is not distinguishable from mudstone matrix of mixed rocks in the area, which is usually black prior to strong weathering. Therefore, we consider that this sample was either originally contained in mudstone that later became the matrix of muddy mixed rocks, or was introduced into the present position from other lithologies, most likely grey mudstone or siliceous mudstone, which are the host of all other radiolarian-bearing Mn-nodules in the North Kitakami Belt.

In thin sections, all Mn-nodule samples are composed of metalliferous parts cemented by opaque minerals, most likely Mn-oxides, and silicified parts cemented with microcrystalline to cryptocrystalline quartz matrix (Figs. 7A–D). The metalliferous and silicified parts are amalgamated in a mosaic manner. This microfabric is quite different from Mn-nodules obtained from siliceous mudstone in the Jurassic accretionary complex in Southwest Japan (the Inuyama area; Nakada *et al.*, 2014). Radiolarian tests are present in both metalliferous (Fig. 7D) and silicified (Fig. 7B) parts, while preservation is better in the former. The grey mudstone that hosts the Mn-nodules in the Mt. Iwakura and Yunashigi Stream localities is composed of clay minerals and quartz grains in thin section (Fig. 7E). Coarse clastic grains of silt-size or greater are rare, indicating that these rocks represent clastic sedimentation close to the hemipelagic area.

A Mn-nodule sample was also collected near Moekabe Stream (Moebake loc. in Fig. 2), but this sample yielded no radiolarians, and will not be discussed further.

Manganese nodule samples were crushed into pieces a few centimetres across and treated with 36 % hydrochloric (HCl) acid for 24 h. The residues were rinsed and dried. Specimens were prepared into slides and photographed with an optical microscope with transmitted light, or mounted on metal stubs, coated with carbon and photographed by a scanning electron microscope (Hitachi SU3500) at the Geological Survey of Japan.

4. Radiolarian assemblage

The three samples Iwk-04, Yns-03 and Asw-01 yielded radiolarians with preservations well enough to observe internal and external test structures (Plate 1–5; Table 1). On the other hand, Our failed attempt on the sample from the Moekabe Stream shows that not all Mn-nodules are radiolarian-productive, as mentioned in Muto *et al.* (2023). Below, the age of the radiolarian assemblages is discussed based on stratigraphic ranges by Baumgartner *et al.* (1995) and O'Dogherty *et al.* (2009) (Fig. 8). The two samples from grey bedded mudstone that are lithostratigraphically well-controlled are explained first, followed by the sample from possibly mixed mudstone.

4. 1. Mt. Iwakura locality (Iwk-04)

Sample Iwk-04 had the poorest preservation of radiolarians among the three samples. This sample yielded *Eucyrtidiellum unumaense*, *Parahsuum*? *grande*, *Unuma* cf. *echinatus* and *Hexasaturnalis tetraspinus* (Plate 1, 5; Table 1). *Parahsuum*? *grande* is the characteristic species of the *Parahsuum*? *grande* Assemblage Zone of Hori (1990). According to stratigraphic ranges of radiolarians by Baumgartner *et al.* (1995), co-occurrence of *Eucyrtidiellum unumaense* and *Parahsuum*? *grande* is limited in the lower Bajocian, Middle Jurassic (Fig. 8A). The age of the sample is therefore estimated as early Bajocian (Fig. 8B). This is consistent with the occurrence

(→ p. 35)

Fig. 3 Geological traverse map of the Mt. Iwakura locality. Gongen, Iwaizumi Town. Base map produced from XYZ tiles provided by the Geospatial Information Authority of Japan.

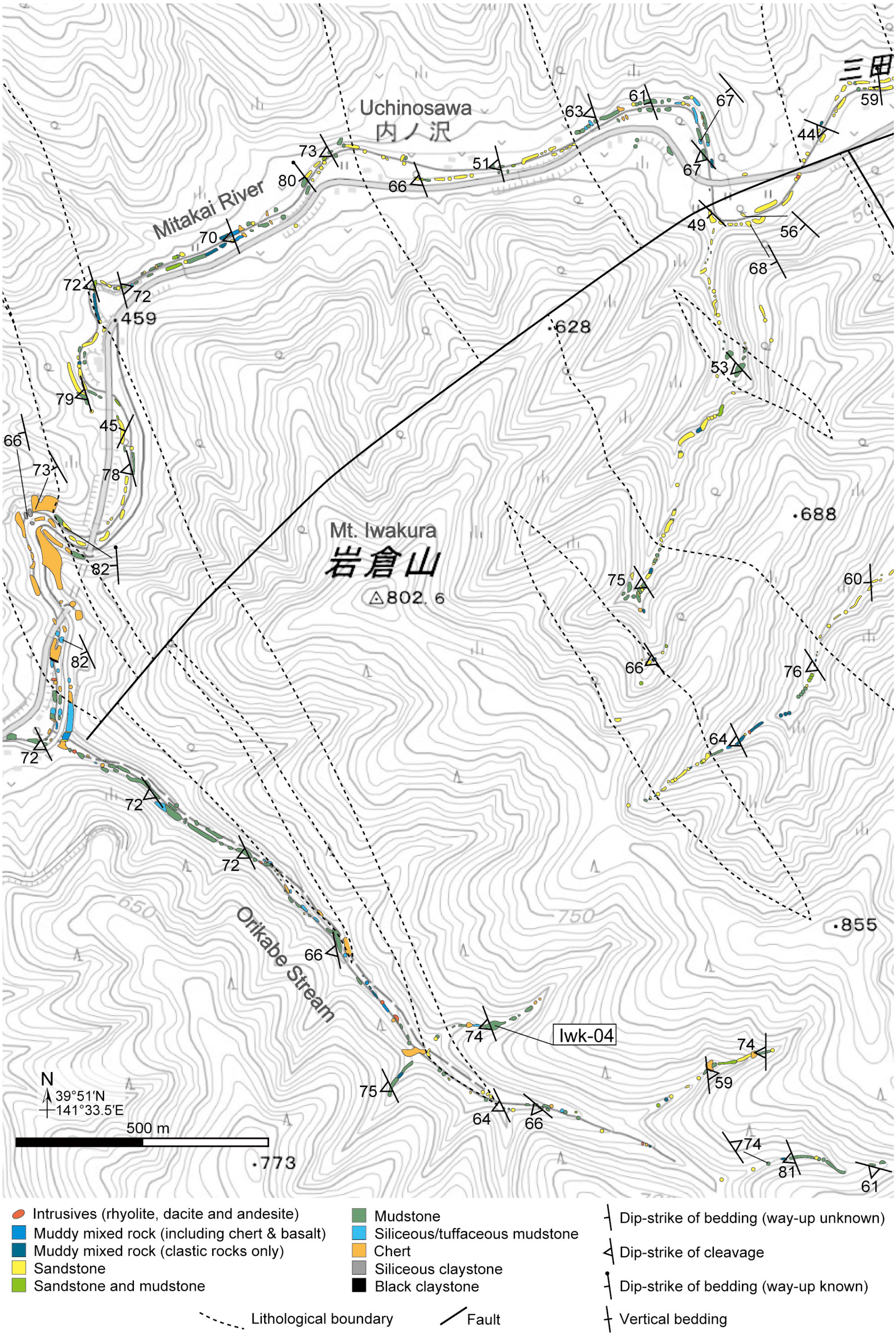
Uchinosawa
内ノ沢
Mitakai River
三田
Mt. Iwakura
岩倉山
△802.6
.459
.628
.688
.855
.773
650
750
Orikabe Stream
Iwk-04
N
39°51′N
141°33.5′E
500 m
Intrusives (rhyolite, dacite and andesite)
Muddy mixed rock (including chert & basalt)
Muddy mixed rock (clastic rocks only)
Sandstone
Sandstone and mudstone
Mudstone
Siliceous/tuffaceous mudstone
Chert
Siliceous claystone
Black claystone
Dip-strike of bedding (way-up unknown)
Dip-strike of cleavage
Dip-strike of bedding (way-up known)
Vertical bedding
Lithological boundary
Fault

Fig. 4 Geological traverse map of the Yunashigi Stream locality. Minaikawa, Iwaizumi Town. Base map produced from XYZ tiles provided by the Geospatial Information Authority of Japan.

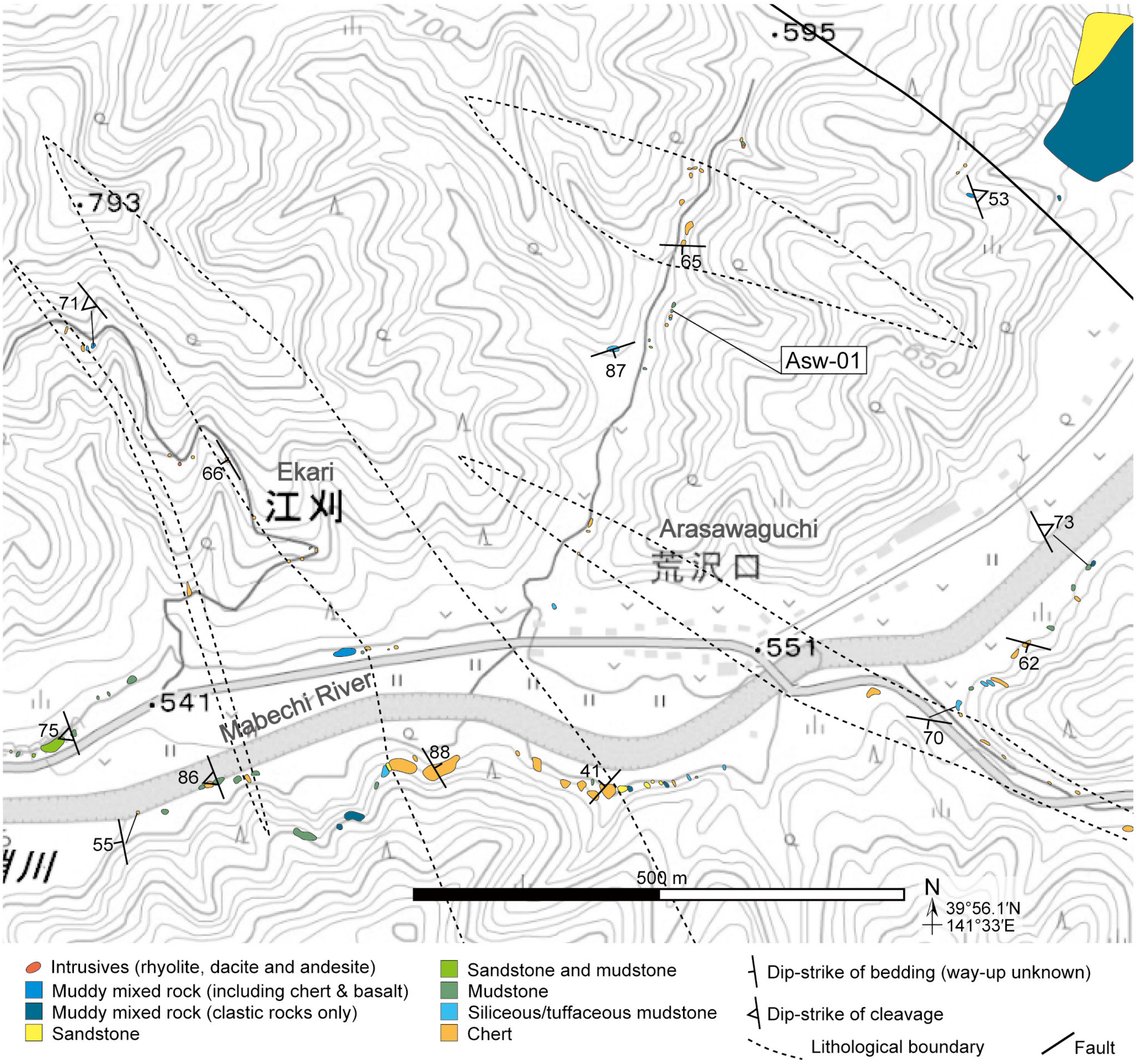

Fig. 5 Geological traverse map of the Arasawaguchi locality. Ekari, Kuzumaki Town. Base map produced from XYZ tiles provided by the Geospatial Information Authority of Japan.

ranges of *Unuma echinatus* and *Hexasaturnalis tetraspinus* (Fig. 8A), although the specimen of the former species from this sample is identified with confer. The occurrence of other specimens identified to the generic level from this sample (*Japonocapsa*, *Higumastra*, *Paronaella*, *Homeparonaella*, *Tritrabs* and *Xiphostylus*) is consistent with the estimated age according to occurrence ranges of Jurassic to Cretaceous radiolarian genera shown by O'Dogherty *et al.* (2009) (Fig. 8A).

4. 2. Yunashigi Stream locality (Yns-03)

Sample Yns-03 yielded *Napora nipponica*. This species occurs in the Aalenian to Bajocian (Baumgartner *et al.*, 1995) (Fig. 8A). Therefore, the age of this sample is within the Aalenian to Bajocian interval (Fig. 8B). This sample also yielded *Unuma* cf. *echinatus*, and the occurrence range of *Unuma echinatus* includes the Aalenian to Bajocian (Fig. 8A). The occurrence of other radiolarian genera from this sample (*Eucyrtidiellum*, *Hexasaturnalis*, *Higumastra*, *Paronaella* and *Tritrabs*) is consistent with this estimated age (Fig. 8A).

4. 3. Arasawaguchi locality (Asw-01)

Sample Asw-01 yielded most of the closed nassellarians obtained in this study. Among the stratigraphically important species, the occurrence range of *Unuma typicus* is restricted to the Bajocian (Baumgartner *et al.*, 1995) (Fig. 8A). Based on this occurrence range, the age of this sample is most probably the Bajocian (Fig. 8B). The occurrence of other species (*Japonocapsa fusiformis*,

Fig. 6 Photographs of outcrops of the Mn-nodules and surrounding lithofacies. (A) Mixed rock composed of muddy matrix and sandstone (Ss). Minai River. (B) Bedded grey mudstone. Same lithofacies as the host of Mn-nodule samples Iwk-04 and Yns-03. (C) Mn-nodule sample Iwk-04 (Mn), Mt. Iwakura locality. (D) Mn-nodule sample Yns-03 (Mn), Yunashigi Stream locality. (E) Mixed rock composed of muddy matrix, chert (Ch) and sandstone (Ss). (F) Mn-nodule sample Asw-01 (Mn), Arasawaguchi locality. The hammer in A, B, D and E is 30 cm long. The blue board in C and F is 20 cm wide.

Praewilliriedellum convexum, *Quarkus japonicus*, *Unuma echinatus* and *Eucyrtidiellum unumaense*) and genera (*Higumastra*, *Homoeoparonaella*, *Triactoma* and *Xiphostylus*) is consistent with the estimated age (Fig. 8A).

5. Accretionary age of the Otori Unit

This study obtained age constraints of clastic rocks in the southwest part of the Otori Unit for the first time. Previous data were obtained from the Akka area in the northeast part

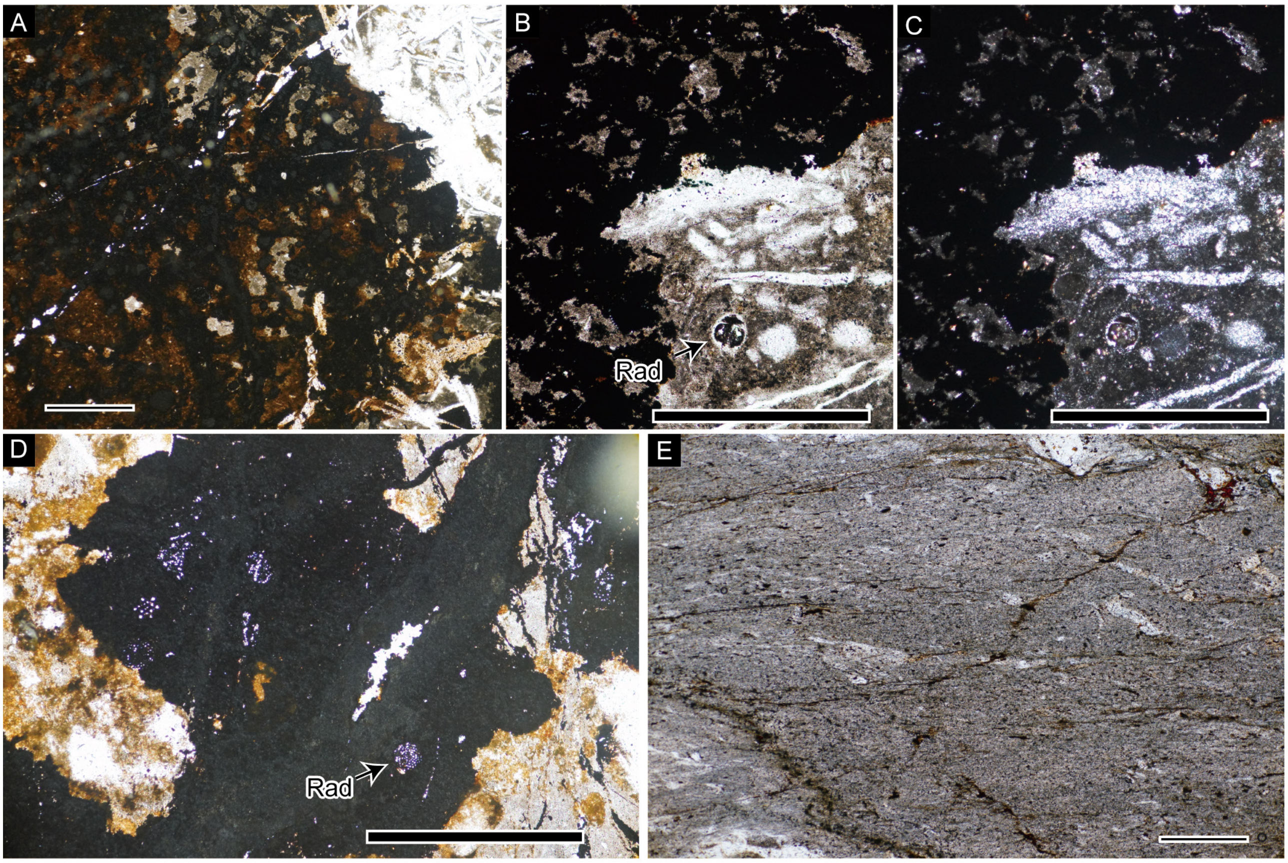

Fig. 7 Thin section micrographs of the Mn-nodules and host mudstone. All pictures except C were taken with transmitted plane-polarized light. C was taken with cross-polarized light. (A) Mn-nodule. Sample Asw-01. (B) Mn-nodule. Sample Asw-01. (C) Mn-nodule. Same field of view as B. (D) Mn-nodule. Sample Yns-03. (E) Mudstone hosting Mn-nodule sample Yns-03. Scale bars are 0.5 mm. Rad: radiolarian tests.

of the Otori Unit, where the unit was originally defined (Suzuki *et al.*, 2007b; Ehiro *et al.*, 2008; Muto *et al.*, 2023). These studies examined radiolarians from Mn-nodules in siliceous mudstone and identified radiolarians that indicate the Bajocian to early Bathonian (Suzuki *et al.*, 2007b; Ehiro *et al.*, 2008) or the Bathonian (Muto *et al.*, 2023). New U–Pb age of a tuff bed within mudstone is Bathonian at 166.69 ± 0.95 Ma, consistent with the above (Muto, 2025).

The three localities in this study are around 5–10 km away from the previously studied localities (Fig. 2). Radiolarians from samples Iwk-04 and Yns-03 indicate an Aalenian to Bajocian age for the lower part of trench-fill clastic sedimentary rocks. The original stratigraphic position of sample Asw-01 that yielded Bajocian radiolarians is not strictly known, and we propose two possibilities. The first possibility is that the nodule was contained in mudstone deposited in the trench area. The other possibility is that the nodule was introduced by tectonic mixing processes into mudstone from hemipelagic siliceous mudstone, which is the host of some Mn-nodules in the northeast part of the Otori Unit. In the former case, sample Asw-01 demonstrates that the age of fine trench-fill clastics in the southwest part of the Otori Unit is at least partly Bajocian. In the latter case, two accretionary complexes, an older one with Aalenian to Bajocian mudstone (bearing samples Iwk-04 and Yns-03) and a younger one with Bajocian siliceous mudstone (bearing Asw-01), coexists in an apparently similar structural position within the southwest part of the Otori Unit. At present, it is not possible to determine which of the two possibilities is true. Regardless, we can conclude that the depositional age of clastic rocks in the Otori Unit includes the Bajocian to Bathonian interval and also perhaps the Aalenian. Muto (2025) provides age constraints on the hemipelagic and trench-fill sedimentary rocks of the Otori Unit from zircon U–Pb dating of tuffs and sandstones. The obtained ages in the southwest part of the Otori Unit are 174–175 Ma (Toarcian to Aalenian) for tuffs from the hemipelagic–trench transitional area, 172 Ma (Aalenian) for a tuff within mudstone and 168 Ma (Bathonian) for sandstone (for details, see Muto, 2025). Thus, the zircon U–Pb ages and radiolarian ages in this study are consistent with the order of lithological succession expected from the conceptual oceanic plate stratigraphy. The combined data also implies a northeastward younging

Table 1 Occurrence list of radiolarians.

Sample id	*Archaeohagiostrum* ? sp.	*Cryptocapsa* ? sp.	*Emiluvia* ? sp.	*Eucyrtidiellum unumaense* (Yao)	*Eucyrtidiellum* sp.	*Hexasaturnalis* sp.	*Higumastra* sp.	*Homoeparonaella elegans* (Pessagno)	*Homoeparonaella bronnimanni* (Pessagno)	*Homoeparonaella* sp.	*Hsuum* ? sp.	*Japonocapsa convexa* (Yao)	*Japonocapsa fusiformis* (Yao)	*Japonocapsa aff. mastoidea* (Yao)	*Japonocapsa mastoidea* (Yao)	*Japonocapsa cf. parvipora* (Tan Sin Hok) *sensu* Yao (1979)	*Japonocapsa yaoi* (Kozur)	*Japonocapsa?* sp.
Iwk-04			+	+	+		+	+	+		+							+
Yns-03			+		+	+	+		+									
Asw-01	+	+	+	+			+	+		+		+	+	+	+	+	+	

Sample id	*Napora nipponica* Takemura	*Napora* sp.	*Napora* ? sp.	*Pantanellium* sp.	*Paronaella mulleri* Pessagno	*Parvicingula* ? sp.	*Perispyridium* ? sp.	*Protunuma japonica* Ichikawa and Yao	*Sethocapsa* sp.	*Spongotripus* ? sp	*Stauroloche* ? sp.	*Striatojaponocapsa plicarum* (Yao)	*Stylosphaera* ? sp.	*Triactoma* sp.	*Unuma echinatus* Ichikawa and Yao	*Parahsuum* ? sp.	*Xiphostylus gasquetensis* Pessagno and Yang in Pessagno *et al.*	*Xiphostylus sinuosus* Pessagno and Yang in Pessagno *et al.*
Iwk-04					+					+					+			+
Yns-03	+	+			+	+	+			+	+	+						
Asw-01			+	+		+	+	+	+				+	+	+	+	+	

trend of the age of accretion within the Otori Unit.

6. Conclusions

Radiolarians were obtained from Mn-nodules embedded in mudstone within the Jurassic accretionary complex of the North Kitakami Belt in the western part of the Kado District, northeast Iwate Prefecture. We investigated three samples from the Otori Unit: samples Iwk-04 and Yns-03 from grey bedded mudstone in the southwestern area of the unit and sample Asw-01 from weathered mudstone. Surface and internal test structure was well observed despite the widespread metamorphism by Cretaceous plutons. Radiolarians indicate the early Bajocian for Iwk-04, Aalenian to Bajocian for Yns-03 and Bajocian for Asw-01. The radiolarians provide the first approximation of accretionary age in the area. The new age data on accretionary age indicates the wide distribution of Middle Jurassic accretionary units.

7. Palaeontological notes

(by Tsuyoshi Ito)

The taxonomic classification in this chapter mainly employs the scheme of O'Dogherty *et al.* (2009, 2017). The specimens identified at the species level are described here.

Order **NASSELLARIA** Ehrenberg, 1875
Family **HSUUIDAE** Pessagno and Whalen, 1982
Genus ***Parahsuum*** Yao, 1982
Type species *Parahsuum simplum* Yao, 1982

Parahsuum*? *grande Hori and Yao, 1988

Plate 1, fig. 7

Remarks: The specimen has an elongate conical test composed of more than 11 segments. Continuous longitudinal costae are present on the surface. In the distal part, some circumferential ridges and discontinuous costae are observed. The characteristics are the same as those of *Parahsuum*? *grande* described by Hori and Yao (1988).

Family **WILLIRIEDELLIDAE** Dumitrica, 1970
Genus ***Hemicryptocapsa*** Tan, 1927
Type species *Hemicryptocapsa capita* Tan, 1927

Hemicryptocapsa yaoi (Kozur, 1984)

Plate 2, fig. 1; Plate 3, figs. 5, 8, 9; Plate 5, fig. 11

Remarks: The specimens have a spherical three-segmented test with a truncate-conical cephalis, a conical or oval upper half and a spherical lower half. The surface of the test is ornamented with large hexagonal frames with narrow ridges and small pores in each frame. The characteristics are the same as those of *Praezhamoidellum yaoi* described by Kozur (1984). This species was later included into *Hemicryptocapsa* Tan, 1927 by O'Dogherty *et al.* (2017).

Hemicryptocapsa*? cf. *parvipora (Tan, 1927) sensu Yao (1979)

Plate 3, fig. 6

Remarks: The specimens have a three-segmented test with a conical or oval upper half and spherical lower half. The pores on the surface of the test are sparse, small and circular. They are the same as *Tricolocapsa* cf. *parvipora* described by Yao (1979) in the characteristics of the test. This species was included by Kozur (1984) in a newly erected genus *Praezhamoidellum*. However, O'Dogherty *et al.* (2009, 2017) later considered that *Praezhamoidellum* is a junior synonym of *Hemicryptocapsa* Tan, 1927. Because they did not mention the attribution of *T.* cf. *parvipora* sensu Yao (1979), we tentatively assign the

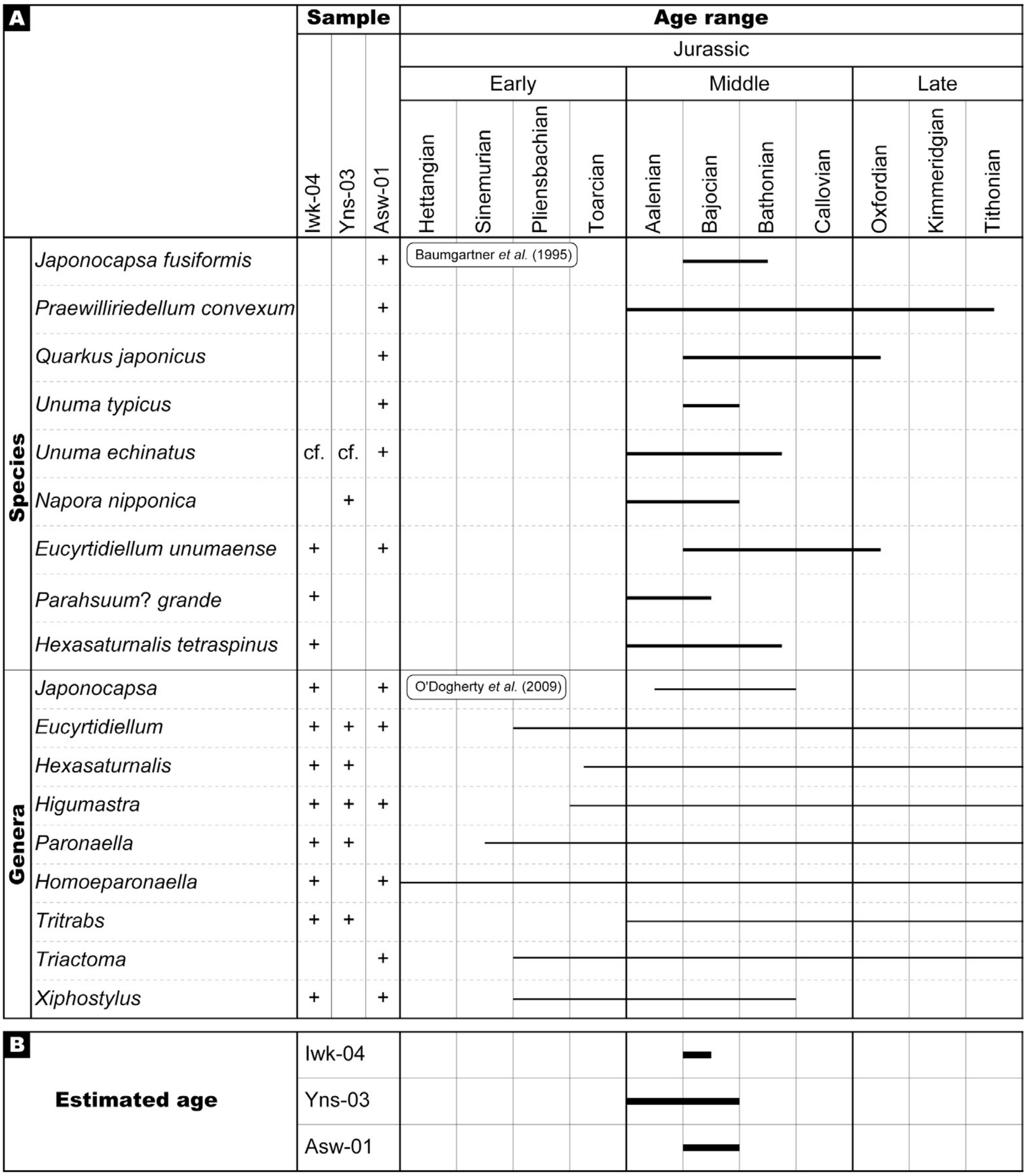

Fig. 8 (A) Stratigraphic range of important radiolarian species and genera. (B) Estimated age of the radiolarian assemblages obtained in this study.

specimens to *Hemicryptocapsa* with a question mark.

Family **DIACANTHOCAPSIDAE** O'Dogherty, 1994
Subfamily **JAPONOCAPSINAE** Kozur, 1984
Genus ***Japonocapsa*** Kozur, 1984
Type species *Tricolocapsa*? *fusiformis* Yao, 1979

Japonocapsa fusiformis (Yao, 1979)
Plate 3, figs. 10–12

Remarks: The specimens have a fusiform four-segmented test. A dish-like fourth segment was recognized. The characteristics are the same as those of *J. fusiformis* (Yao, 1979).

Genus ***Yaocapsa*** Kozur, 1984
Type species *Cyrtocapsa mastoidea* Yao, 1979

Yaocapsa* aff. *mastoidea (Yao, 1979)
Plate 3, figs. 13, 14

Remarks: The test of the specimens has a large basket-like fourth segment. In outline, it closely resembles *Yaocapsa mastoidea*; however, the species has a five-segmented test in the original description by Yao (1979). Our specimens seem to have a four-segmented test; therefore, these specimens were identified as a separate species.

Family **EUCYRTIDIELLIDAE** Takemura, 1986
Genus ***Eucyrtidiellum*** Baumgartner, 1984
Type species *Eucyrtidium*? *unumaensis* Yao, 1979

Eucyrtidiellum unumaense (Yao, 1979)
Plate 1, figs. 5, 6; Plate 3, fig. 18
Remarks: The specimens have a test composed of a small cephalis with an apical horn and a truncate-conical thorax. The characteristics are same as those of *Eucyrtidiellum unumaense* (Yao, 1979), although features such as surface microstructure and the fourth segment are partly or entirely lost.

Family **UNUMIDAE** Kozur, 1984
Genus ***Unuma*** Ichikawa and Yao, 1976
Type species *Unuma typicus* Ichikawa and Yao, 1976

Unuma typicus Ichikawa and Yao, 1976
Plate 3, fig. 15
Remarks: The specimen has a spindle-shaped multi-segmented test. Longitudinal plicae without spines were recognized on the surface. These characteristics are the same as those of *U. typicus* Ichikawa and Yao, 1976.

Unuma echinatus Ichikawa and Yao, 1976
Plate 3, fig. 16
Remarks: The specimen has a spindle-shaped multi-segmented test. Longitudinal plicae and some stout radial spines from the plicae were recognized on the surface. These characteristics are the same as those of *U. echinatus* Ichikawa and Yao, 1976.

Family Unnamed pro **STICHOCAPSIDAE** Haeckel, 1881
Genus ***Praewilliriedellum*** Kozur, 1984
Type species *Praewilliriedellum cephalospinosum* Kozur, 1984

Praewilliriedellum convexum (Yao, 1979)
Plate 3, figs. 1, 2
Remarks: The specimens have a four-segmented test with a conical upper half and spherical lower half. The pores on the surface of the test are small and circular. The specimens are identical to *Praewilliriedellum convexum* in these test characteristics (Yao, 1979).

Genus ***Quarkus*** Pessagno, Blome and Hull, 1993
Type species *Quarkus madstonensis* Pessagno, Blome and Hull, 1993

Quarkus japonicus (Yao, 1979)
Plate 3, figs. 4
Remarks: The specimen has a four-segmented test with a conical upper half and flattened-spherical lower half. The pores on the surface of the test are small, circular and arranged sparsely. These characteristics are the same as those of *Quarkus japonicus* (Yao, 1979).

Family **ULTRANAPORIDAE** Pessagno 1977b
Genus ***Napora*** Pessagno 1977a
Type species *Napora bukryi* Pessagno 1977a

Napora nipponica Takemura, 1986
Plate 2, fig. 4; Plate 5, fig. 7
Remarks: The specimens have a small cephalis with straight apical horn, hemispherical thorax and three feet. Circular pores on the cephalis are arranged transversely and the feet are curved convexly. These characteristics are the same as those of *Napora nipponica* Takemura, 1986.

Order **SPUMELLARIA** Ehrenberg, 1875
Family **SPONGURIDAE** Haeckel, 1862
Subfamily **HEXASATURNALINAE** Kozur and Mostler, 1983
Genus ***Hexasaturnalis*** Kozur and Mostler, 1983
Type species *Spongosaturnalis*? *hexagonus* Yao, 1972

Hexasaturnalis tetraspinus (Yao, 1972)
Plate 5, fig. 3
Remarks: The specimen seems to have a hexagonal ring with four short strong spines, although the ring is partially broken. These characteristics are the same as those of *Hexasaturnalis tetraspinus* (Yao, 1972).

Acknowledgements: We are grateful to the members of the Geological Sample Preparation Group of the Geoinformation Service Center, GSJ for preparing thin sections for this study. We thank Satoshi Nakae for numerous review comments that helped improve the manuscript, editor Tomonori Naya for handling the manuscript and Rie S. Hori for sharing her knowledge on radiolarian assemblages.

References

Baumgartner, P. O. (1984) A Middle Jurassic–Early Cretaceous low latitude radiolarian zonation based on unitary associations and age of Tethyan radiolarites. *Eclogae geologicae Helvetiae*, **77**, 729–841.

Baumgartner, P. O., O'Dogherty, L., Goričan, S., Dumitrica-Jud, R., Dumitrica, P., Pillevuit, A., Urquhart, E., Matsuoka, A., Danelian, T., Bartolini, A., Carter, E. S., De Wever, P., Kito, N., Marcucci, M. and Steiger, T. (1995) Radiolarian catalogue and systematics of Middle Jurassic to Early Cretaceous Tethyan genera and species. *Mémoires de Géologie (Lausanne)*, **23**, 37–685.

Dumitrica, P. (1970) Cryptocephalic and cryptothoracic

Nassellaria in some Mesozoic deposits of Romania. *Revue Roumaine de Géologie, Géophysique et Géographie (série Géologie)*, **14**, 45–124.

Ehiro, M., Kawamura, M. and Kawamura, T. (2005) 1.1 Summary and Tectonostratigraphic divisions. *In* The Publishing Committee of the Geology of Japan ed., *The Geology of Japan. The Supplement*. Kyoritsu Publishing Co. Ltd, Tokyo, 49–50. (in Japanese)

Ehiro, M., Yamakita, S., Takahashi, S. and Suzuki, N. (2008) Jurassic accretionary complexes of the North Kitakami Belt in the Akka-Kuji area (in Japanese). *The Journal of the Geological Society of Japan*, **114**, 121–139.

Ehrenberg, C. G. (1875) *Fortsetzung der mikrogeologischen Studien als Gesammt-Uebersichtder mikroskopischen Palaontologie gleichartig analysirter Gebirgsarten der Erde, mit specieller Rucksicht auf den Polycystinen-Mergel von Barbados*. Abhandlungen der königlichen preussichen Akademie der Wissenschaften zu Berlin, 1–225.

Geological Survey of Japan, AIST (2020) Seamless digital geological map of Japan 1: 200,000. Geological Survey of Japan, AIST. https:// gbank.gsj.jp/seamless/ v2full/ (Accessed: 2021-10-08)

Haeckel, E. (1862) Die Radiolarien (Rhizopoda Radiaria). Eine Monographie, Reimer, Berlin, 572p.

Haeckel, E. (1881) Entwurf eines Radiolarien-Systems auf Grund von Studien der Challenger-Radiolarien. Jenaische Zeitschrift für Naturwissenschaft, **15**, 418–472.

Hori, R. (1990) Lower Jurassic radiolarian zones of SW Japan. *Transactions and Proceedings of the Palaeontological Society of Japan, New Series*, no. 159, 562–586.

Hori, R. and Yao, A. (1988) *Parahsuum* (Radiolaria) from the Lower Jurassic of the Inuyama area, central Japan. *Journal of Geosciences, Osaka City University*, **31**, 47–61.

Ichikawa, K. and Yao, A. (1976) Two new genera of Mesozoic cyrtoid radiolarians from Japan. *In* Takayanagi, Y. and Saito, T., eds. *Progress in Micropaleontology, Special Publication*, Micropaleontology Press, The American Museum of Natural History, New York, 110–117.

Isozaki, Y. and Maruyama, S. (1991) Studies on Orogeny based on Plate Tectonics in Japan and New Geotectonic Subdivision of the Japanese Islands. *Journal of Geography (Chigaku Zasshi),* **100**, 697–761. doi: 10.5026/jgeography.100.5_697.

Isozaki, Y., Maruyama, S., Aoki, K., Nakama, T., Miyashita, A. and Otoh, S. (2010) Geotectonic subdivision of the Japanese Islands revisited: categorization and definition of elements and boundaries of Pacific-type (Miyashiro-type) orogen. *Chigaku Zasshi (Jounal of Geography)*, **119**, 999–1053, doi:10.5026/ jgeography.119.235. (in Japanese with English abstract)

Kojima, S., Hayasaka, Y., Hiroi, Y., Matsuoka, A., Sano, H., Sugamori, Y., Suzuki, N., Takemura, S., Tsujimori, T. and Uchino, T. (2016) 2b Pre-Cretaceous accretionary complexes. *In*: Moreno, T., Wallis, S., Kojima, T. and Gibbons, W. (eds) *The Geology of Japan*, 61–100.

Kozur, H. (1984) New radiolarian taxa from the Triassic and Jurassic. *Geologisch Paläontologische Mitteilungen Innsbruck*, **13**, 49–88.

Kozur, H. and Mostler, H. (1983) The polyphyletic origin and the classification of the Mesozoic saturnalids (Radiolaria). *Geologisch Paläontologische Mitteilungen Innsbruck*, **13**, 1–47.

Murai, T., Okami, K. and Oishi, M. (1985) *Geology of the Pre-Cretaceous in Iwaizumi Town. Part 1*. The Education Board of the Iwaizumi Town, Iwaizumi, 1–47. (in Japanese, reference information translated by Suzuki *et al.*, 2007)

Murai, T., Okami, K., Ehiro, M. and Oishi, M. (1986) *Geology of the Pre-Cretaceous in Iwaizumi Town. Part 2*. The Education Board of the Iwaizumi Town, Iwaizumi 1–43. (in Japanese, reference information translated by Suzuki *et al.*, 2007)

Muto, S. (2025) Accretionary age of the Jurassic accretionary complex of the North Kitakami Belt: new data from zircon geochronology in the Kado District. *Bulletin of the Geological Survey of Japan*, **76**, 49–98.

Muto, S., Ito, T. and Murayama, M. (2023) Geology and accretionary age of the Otori Unit, North Kitakami Belt. *Bulletin of the Geological Survey of Japan*, **74**, 1–40.

Nakada, R., Shirai, T., Takahashi, S., Suzuki, N., Ogawa, K. and Takahashi, Y. (2014) A geochemical constraint on the formation process of a manganese carbonate nodule in the siliceous mudstone of the Jurassic accretionary complex in the Mino Belt, Japan. *Journal of Asian Earth Sciences*, **96**, 59–68. doi: 10.1016/j. jseaes.2014.08.032.

Nakae, S. and Kamada, K. (2003) Late Jurassic radiolarians from the Rikuchu-Seki district in the North Kitakami Belt, Northeast Japan. *The Journal of the Geological Society of Japan*, **109**, 722–725. (in Japanese with English abstract)

Nakae, S., Kamada, K., Kubo, K. and Kudo, T. (2021) *Geology of the Rikuchu Seki District*. Quadrangle Series, 1:50,000, Geological Survey of Japan, AIST. (in Japanese with English abstract)

O'Dogherty, L. (1994) Biochronology and paleontology of mid-Cretaceous radiolarians from Northern Apennines (Italy) and Betic Cordillera (Spain). *Mémoires de Géologie (Lausanne)*, **21**, 1–415.

O'Dogherty, L., Carter, E. S., Dumitrica, P., Goričan, Š., De Wever, P., Bandini, A. N., Baumgartner, P. O. and Matsuoka, A. (2009) Catalogue of Mesozoic radiolarian genera. Part 2: Jurassic–Cretaceous. *Geodiversitas*, **31**, 271–356.

O'Dogherty, L., Goričan, Š. and Gawlick, H.-J. (2017)

Middle and Late Jurassic radiolarians from the Neotethys suture in the Eastern Alps. *Journal of Paleontology*, **91**, 25–72.
Onuki, Y. (1969) Geology of the Kitakami Massif, Northeast Japan. *Tohoku University, Institute of Geology and Paleontology Contributions*, **69**, 1–239.
Pessagno, E. A. (1977a) Upper Jurassic Radiolaria and radiolarian biostratigraphy of the California Coast Ranges. *Micropaleontology*, **23**, 56–113.
Pessagno, E. A. (1977b) Lower Cretaceous radiolarian biostratigraphy of the Great Valley Sequence and Franciscan Complex, California Coast Ranges. *Contribution Cushman Foundation for foraminiferal Research, special Publication*, **15**, 1–87.
Pessagno, E. A. and Whalen, P. (1982) Lower and Middle Jurassic Radiolaria (multicyrtid Nassellariina) from California, east-central Oregon and the Queen Charlotte Islands, B. C. *Micropaleontology*, **28**, 111–169.
Pessagno, E. A., Blome, C. D. and Hull, D. M. (1993) Radiolaria. *In* Pessagno, E. A., Blome, C. D., Hull, D. M. and Six, W. M., eds., *Jurassic Radiolaria from the Josephine ophiolite and overlying strata, Smith River subterrane (Klamath Mountains), northwestern California and southwestern Oregon: Micropaleontology*, **39**, 93–166.
Sugimoto, M. (1974) Stratigraphical study in the outer belt of the Kitakami Miassif, Northeast Japan. *Tohoku University, Institute of Geology and Paleontology Contributions*, **74**, 1–48. (in Japanese with English abstract)
Sugimoto, M. (1980) Geological structure of the Akka-Iwaizumi District, Northern Kitakami Massif, Northeast Japan (Preliminary report). *In: Report on the Multidiscipline Research Project A with 1979 Foundation of Grant-in-Aid for Scientific Research by the Education Ministry of Japan*, Tokyo Print Insatsu, Ltd., Tokyo 37–44. (in Japanese)*
Suzuki, N. and Ogane, K. (2004) Paleoceanographic affinities of radiolarian faunas in late Aalenian time (Middle Jurassic) recorded in the Jurassic accretionary complex of Japan. *Journal of Asian Earth Sciences*, **23**, 343–357. doi: 10.1016/S1367-9120(03)00113-5.
Suzuki, N., Ehiro, M., Yoshihara, K., Kimura, Y., Kawashima, G., Yoshimoto, H. and Nogi, T. (2007a) Geology of the Kuzumaki-Kamaishi Subbelt of the North Kitakami Belt (a Jurassic accretionary complex), Northeast Japan: Case study of the Kawai-Yamada area, eastern Iwate Prefecture. *Bulletin of the Tohoku University Museum*, **6**, 103–174.
Suzuki, N., Yamakita, S., Takahashi, S. and Ehiro, M. (2007b) Middle Jurassic radiolarians from carbonate manganese nodules in the Otori Formation in the eastern part of the Kuzumaki-Kamaishi Subbelt, the North Kitakami Belt, Northeast Japan. *The Journal of the Geological Society of Japan*, **113**, 274–277. doi: 10.5575/geosoc.113.274. (in Japanese with English abstract)
Takahashi, S., Ehiro, M., Suzuki, N. and Yamakita, S. (2016) Subdivisional scheme of the North Kitakami Belt, Northeast Japan and its tectonostratigraphic correlation to the Oshima and South Chichibu belts: an examination of the Jurassic accretionary complex in the west Akka area. *The Journal of the Geological Society of Japan*, **122**. 1–22, doi:10.5575/geosoc.2015.0034. (in Japanese with English abstract)
Takemura, A. (1986) Classification of Jurassic Nassellarians (Radiolaria). *Palaeontographica Abteilung A: Palaozoologie-Stratigraphie*, no. 195, 29–74.
Tan, S. H. (1927) Over de samenstelling en het onstaan van krijt- en mergel-gesteenten van de Molukken. *Jaarboek van het mijnwezen in Nederlandsch Oost-Indië*, jaargang 55, 1926, verhandelingen, 3rd gedeelte, 5–165.
Uchino, T. and Komatsubara, T. (2024) *Geology of the Sotoyama District*. Quadrangle Series, 1:50,000, Geological Survey of Japan, AIST, 131p. (in Japanese with English abstract)
Uchino, T. and Suzuki, N. (2020) Late Jurassic radiolarians from mudstone near the U–Pb-dated sandstone of the North Kitakami Belt in the northeastern Shimokita Peninsula, Tohoku, Japan. *Bulletin of the Geological Survey of Japan*, **71**, 313–330. doi:10.9795/bullgsj.71.313.
Yamaguchi, Y. (1981) Geological structure of the eastern part of the North Kitakami Mountains, Japan—with special reference to structural subdivision. *Tohoku University, Institute of Geology and Paleontology Contributions*, **83**, 1–19.
Yao, A. (1972) Radiolarian fauna from the Mino Belt in the northern part of the Inuyama Area, central Japan, Part I: Spongosaturnalids. *Journal of Geosciences, Osaka City University*, **15**, 21–65.
Yao, A. (1979) Radiolarian fauna from the Mino belt in the northern part of the Inuyama Area, central Japan, Part II: Nassellaria 1. *Journal of Geosciences, Osaka City University*, **22**, 21–72.
Yao, A. (1982) Middle Triassic to Early Jurassic radiolarians from the Inuyama area, central Japan. *Journal of Geosciences, Osaka City University*, **25**, 53–70.
Yoshihara, K., Suzuki, N. and Ehiro, M. (2002) Middle Jurassic radiolarian-bearing manganese nodules from the Kuzumaki-Kamaishi Belt in the Northern Kitakami Massif and its significance. *The Journal of the Geological Society of Japan*, **108**, 536–539. (in Japanese with English abstract)

*English translation from the original written in Japanese

Recieved February 13, 2024
Accepted November 6, 2024

北上山地北部「門」地域西部から産出したマンガンノジュールから得られたジュラ紀中期放散虫化石

武藤　俊・伊藤　剛・大関　仁智

要　旨

東北日本の北部北上帯ジュラ紀付加体においては，白亜紀深成岩類の接触変成作用により放散虫化石の分離が困難であるため，付加体形成史の解明が妨げられている．本地域で放散虫化石の分離に成功した研究例には，マンガンノジュールを扱ったものがある．本研究では，5 万分の 1 地質図幅「門」地域西部の 3 地点にて泥質岩中に胚胎されるマンガンノジュールを採取し，これらから保存良好な放散虫化石を抽出した．得られた放散虫化石群集の年代は，灰色層状泥岩から採取した 2 試料についてはそれぞれ前期バッジョシアン期とアーレニアン期からバッジョシアン期（いずれも中期ジュラ紀）と，構造的混在化を受けた可能性がある泥岩から採取した 1 試料についてはバッジョシアン期（中期ジュラ紀）と推定した．これらの年代は検討した層準の付加時期を近似できる．「門」地域西部からの年代指標となる放散虫化石の報告は，本研究が初めてである．

難読･重要地名

Arasawaguchi：荒沢口，Gongen：権現，Mt. Iwakura：岩倉山，
Yunashigi Stream：ユナシギ沢，Minai River：見内川，Orikabe Stream：オリカベ沢

Plate 1

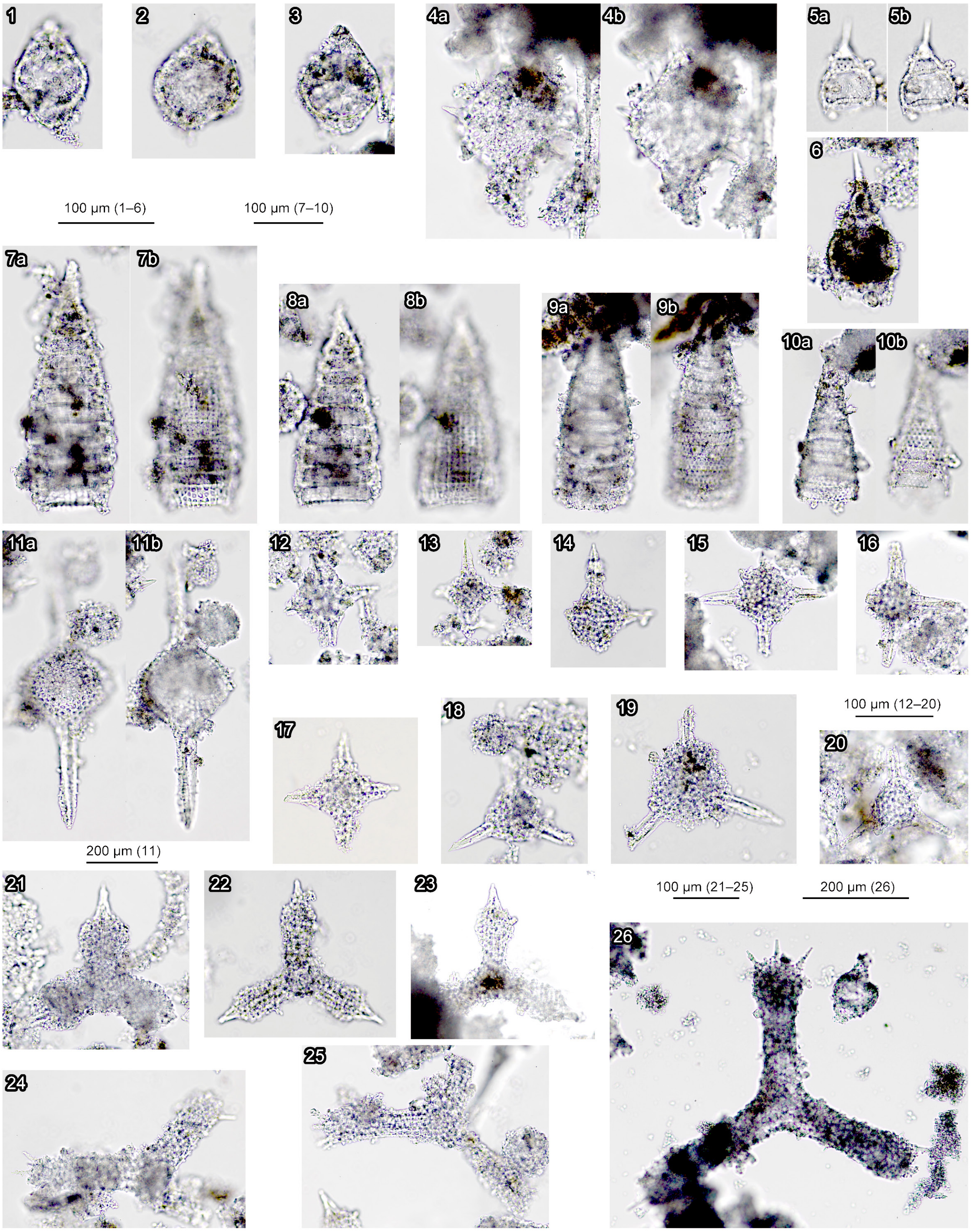

Plate 1 Middle Jurassic radiolarians from sample Iwk-04. 1, 3: *Japonocapsa* sp.; 2: Diacanthocapsidae? gen. et sp. indet.; 4: *Unuma* cf. *echinatus* Ichikawa and Yao, 1976; 5, 6: *Eucyrtidiellum unumaense* (Yao, 1979); 7: *Parahsuum*? *grande* Hori and Yao, 1988; 8: *Parahsuum*? sp.; 9, 10: *Praeparvicingula*? sp.; 11: *Xiphostylus* sp.; 12–16: *Emiluvia*? sp.; 17: *Higumastra* sp.; 18–20: *Acaeoniotylopsis*? sp.; 21: *Paronaella* sp.; 22, 23: *Homoeoparonaella* sp.; 24: *Tritrabs*? sp.; 24–26: *Tritrabs* sp.

Plate 2

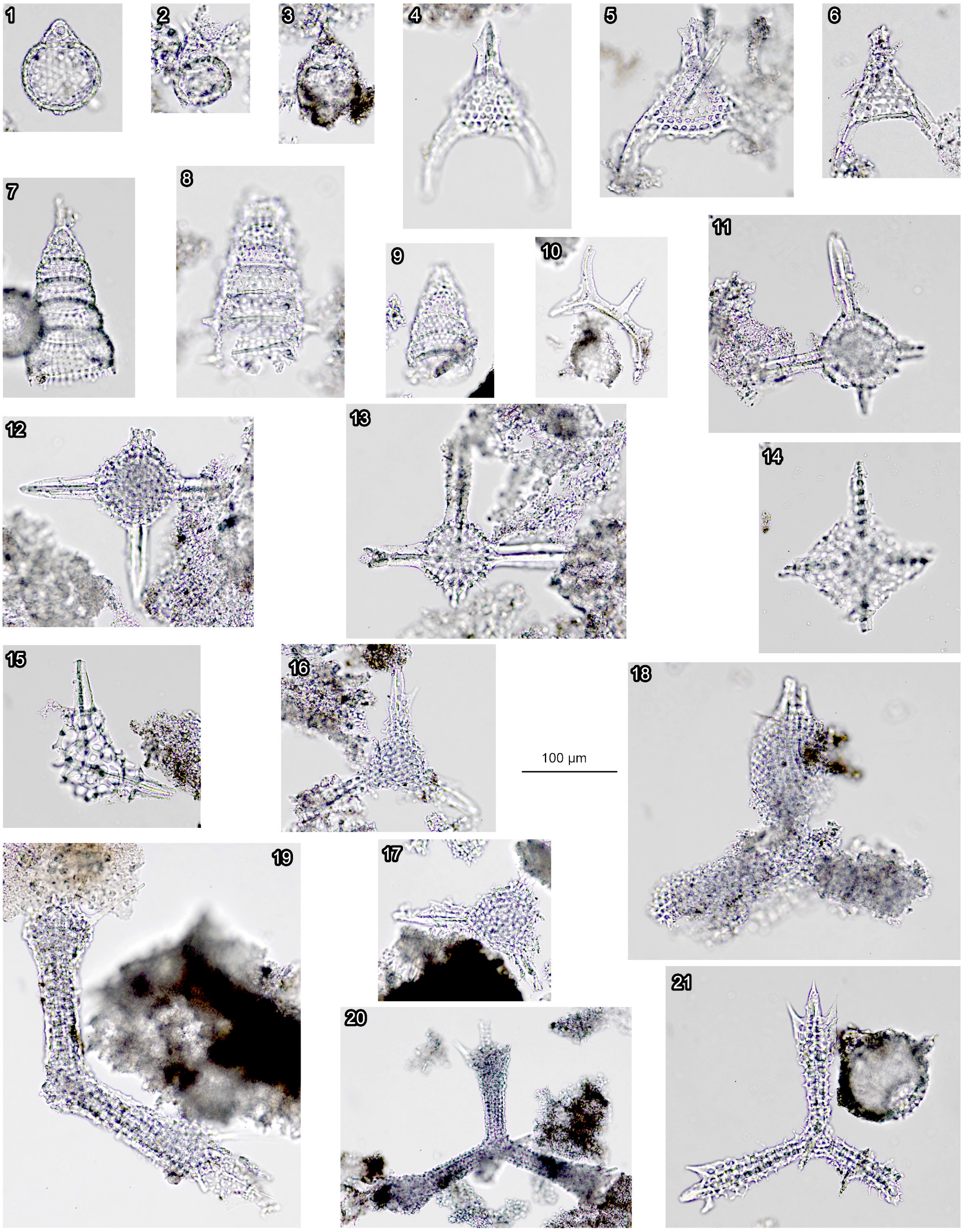

Plate 2 Middle Jurassic radiolarians from sample Yns-03. 1: *Hemicryptocapsa yaoi* (Kozur, 1984); 2, 3: *Eucyrtidiellum* sp.; 4: *Napora nipponica* Takemura, 1986; 5, 6: *Napora* sp.; 7–9: *Stichomitra*? sp.; 10: *Hexasaturnalis* sp.; 11: *Staurolonche*? sp.; 12, 13: *Higumastra*? sp.; 14: *Higumastra* sp.; 15: *Perispyridium*? sp.; 16, 17: *Cryptostephanidium*? sp.; 18: *Paronaella* sp.; 19-21: *Tritrabs* sp.

Plate 3

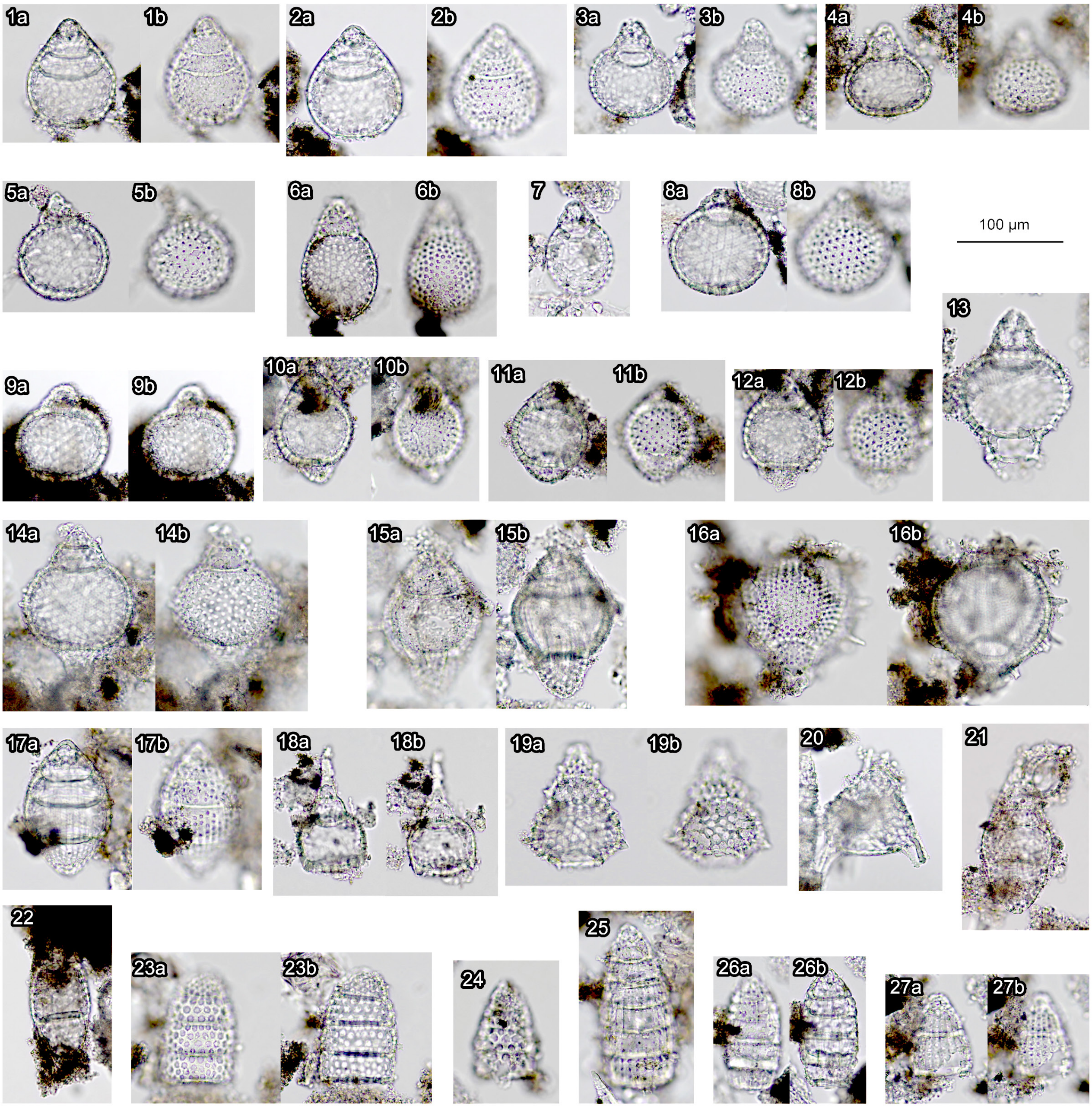

Plate 3 Middle Jurassic radiolarians (Nassellaria) from sample Asw-01. 1, 2: *Praewilliriedellum convexum* (Yao, 1979); 3, 7: *Praewilliriedellum*? sp.; 4: *Quarkus japonicus* (Yao, 1979); 5, 8, 9: *Hemicryptocapsa yaoi* (Kozur, 1984); 6: *Hemicryptocapsa*? cf. *parvipora* (Tan, 1927) sensu Yao (1979); 10–12: *Japonocapsa fusiformis* (Yao, 1979); 13, 14: *Yaocapsa* aff. *mastoidea* (Yao, 1979); 15: *Unuma typicus* Ichikawa and Yao, 1976; 16: *Unuma echinatus* Ichikawa and Yao, 1976; 17: *Helvetocapsa*? sp.; 18: *Eucyrtidiellum unumaense* (Yao, 1979), 19: *Eucyrtidiellum* sp.; 20: *Farcus*? sp.; 21, 22: Closed nassellarian; 23: *Mizukidella*? sp.; 24: *Takemuraella*? sp.; 25–27: *Archaeodictyomitra*? sp.

Plate 4

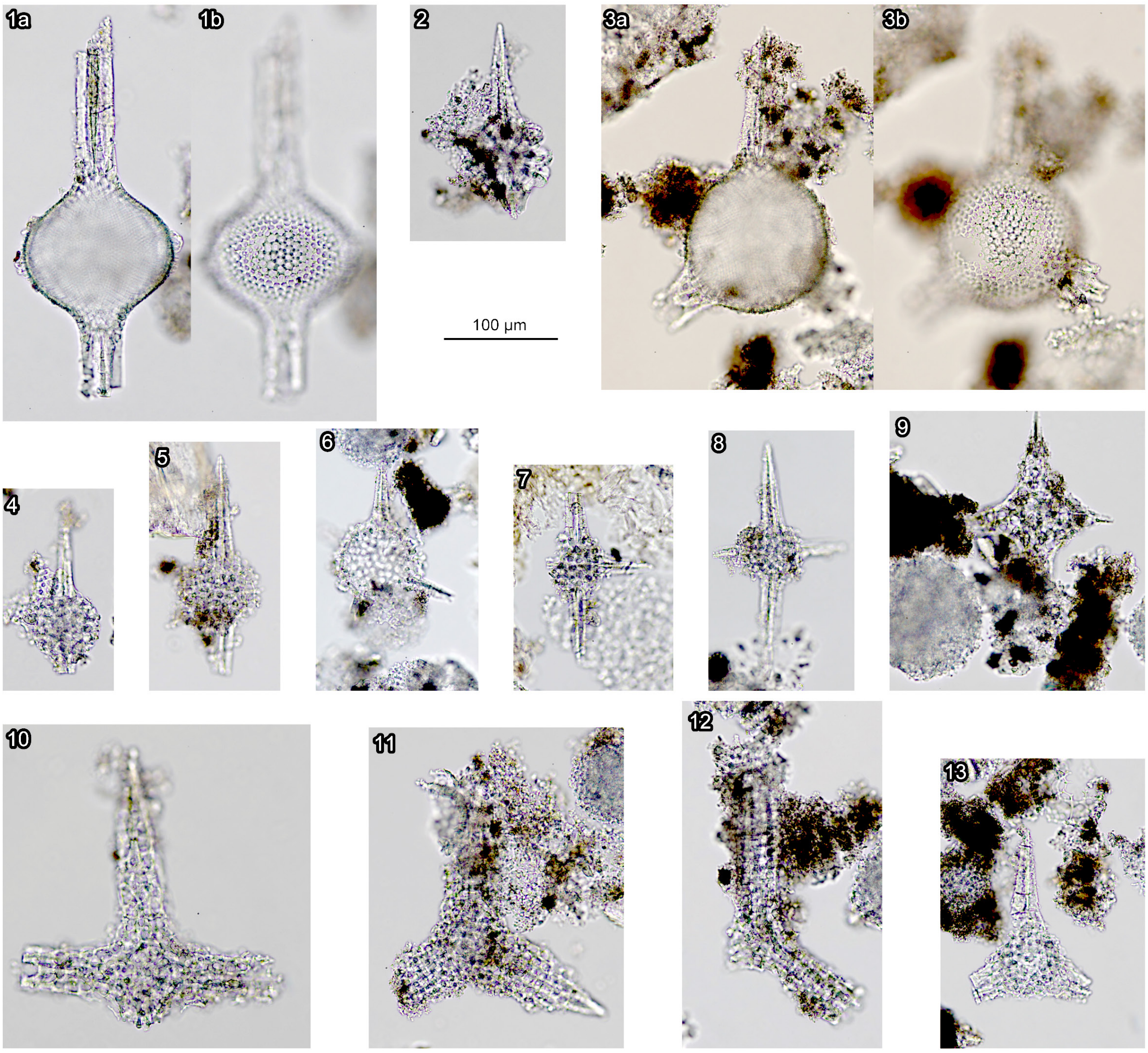

Plate 4 Middle Jurassic radiolarians (Spumellaria) from sample Asw-01. 1: *Xiphostylus* sp.; 2: *Pantanellium*? sp.; 3: *Triactoma* sp.; 4, 5: *Stylosphaera*? sp.; 6–8: *Emiluvia*? sp.; 9: *Higumastra* sp.; 10: *Archaeohagiostrum*? sp.; 11, 12: *Homoeoparonaella* sp.; 13: *Perispyridium*? sp.

Plate 5

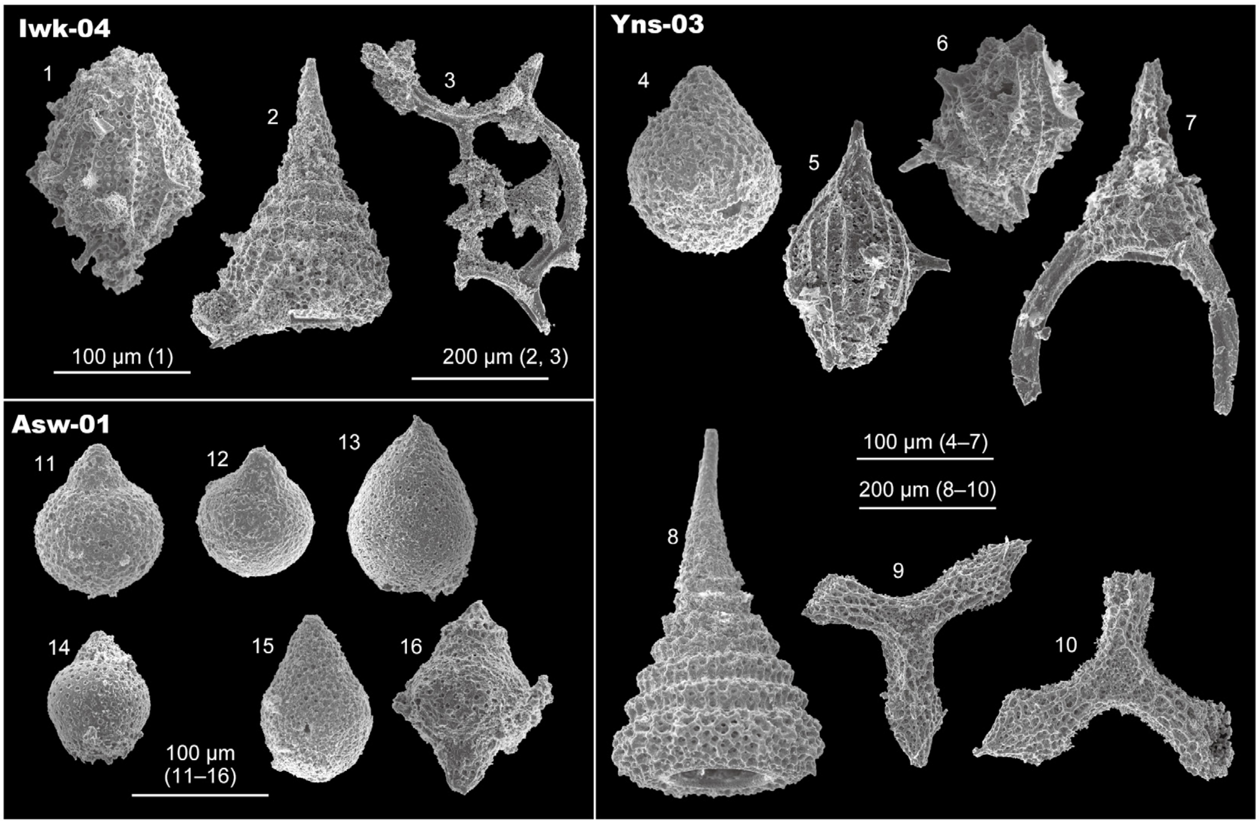

Plate 5 Middle Jurassic radiolarians (Spumellaria) from sample Iwk-04, Yns-03 and Asw-01. 1, 5, 6: *Unuma* cf. *echinatus* Ichikawa and Yao, 1976; 2, 8: *Palinandromeda*? sp.; 3: *Hexasaturnalis tetraspinus* (Yao, 1972); 4: *Praewilliriedellum*? sp.; 7: *Napora nipponica* Takemura, 1986; 9, 10: *Paronaella* sp.; 11: *Hemicryptocapsa yaoi* (Kozur, 1984); 12–15: Diacanthocapsidae? gen. et sp. indet.; 16: *Quarticella*? sp.