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Report

Radiolarians from Jurassic accretionary complex of the Ashio belt in the Kiryu and Ashikaga District (Quadrangle series 1:50,000), central Japan

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Abstract: Jurassic accretionary complex of the Ashio belt is distributed in the Ashio Mountains, central Japan. The Jurassic accretionary complex is composed of the Kurohone–Kiryu, Omama, Kuzu and Gyodosan complexes. This article presents new radiolarian occurrences from 42 samples of the Jurassic accretionary complex in the Kiryu and Ashikaga District (Quadrangle series 1:50,000). Permian radiolarians occurred in nine chert samples of the Gyodosan Complex. Triassic radiolarians were obtained from four chert samples of the Kuzu Complex. Jurassic radiolarians occurred in one siliceous mudstone sample of the Kurohone–Kiryu Complex; two chert, four siliceous mudstone and two mudstone samples of the Kuzu Complex; and one mudstone sample of the Gyodosan Complex. In addition, the fossil occurrences and their ages are compiled by present and previous studies on the Jurassic accretionary complex in the Ashio Mountains. On that basis, the ocean plate stratigraphy of each complex is reconstructed.

Keywords: radiolarian, Ashio belt, Jurassic accretionary complex, Ashio Mountains, ocean plate stratigraphy, Tochigi Prefecture, Gunma Prefecture, central Japan

1. Introduction

Jurassic accretionary complex of the Ashio belt is widely exposed in the Ashio Mountains, central Japan (Fig. 1). Geological studies on the Jurassic accretionary complex of the Ashio Mountains began in the late 19th century (e.g. Harada, 1886; Suzuki, 1898a, b). First reports of radiolarians were described from the “slate” of the Ashio Copper Mine by Suzuki (1898a, b). Thereafter, radiolarian occurrences were rarely reported from the Jurassic accretionary complex in the Ashio Mountains until the 1970s. Since the 1980s, reports of radiolarians increased from the Jurassic accretionary complex in the Ashio Mountains. Abundant radiolarian occurrences have been reported from the Tochigi District (e.g. Aono, 1985; Arakawa, 1986, 1997, 1998; Kamata, 1995, 1996, 1997a, b, 1999, 2000; Isogawa *et al.*, 1998; Ootaka *et al.*, 1998; Suzuki *et al.*, 2002), whereas fewer occurrences have been reported from the Kiryu and Ashikaga District (Masuda, 1989; Hayashi *et al.*, 1990; Kamata, 1996; Takayanagi *et al.*, 2001; Motoki and Sashida, 2004).

The author has surveyed the Jurassic accretionary complex in the Kiryu and Ashikaga District for making a geological map, and recently reported radiolarian occurrences from the district (e.g. Ito, 2019, 2020a, b). This article is an additional report of Permian, Triassic and Jurassic radiolarian occurrences from the Jurassic accretionary complex in the district. Further, fossil occurrences from the Jurassic accretionary complex (including neighbor districts) are compiled by the present and previous studies. On that basis, the author attempts to reconstruct the ocean plate stratigraphy of each complex of the Jurassic accretionary complex.

2. Geologic outline of the Jurassic accretionary complex in the Ashio Mountains

In the 1960–1980s, Mesozoic conodonts and radiolarians were discovered in the Jurassic accretionary complex in the Ashio Mountains (e.g. Hayashi, 1963, 1968a, b; Koike *et al.*, 1970, 1971; Hayashi and Hasegawa, 1981; Sashida *et al.*, 1982a, b). Kamata (1996) divided the Jurassic accretionary complex in the southern Ashio Mountains into three tectonostratigraphic units, namely the Kurohone–Kiryu, Omama and Kuzu complexes based on geological scheme of accretionary complex. Recently, Ito (2021) identified the Gyodosan Complex, which thrusts over the Kuzu Complex.

The Kurohone–Kiryu Complex, presenting broken to coherent facies, consists mainly of mudstone and chert and moderate amounts of siliceous claystone, with small amounts of basaltic rocks, carbonate rocks, siliceous

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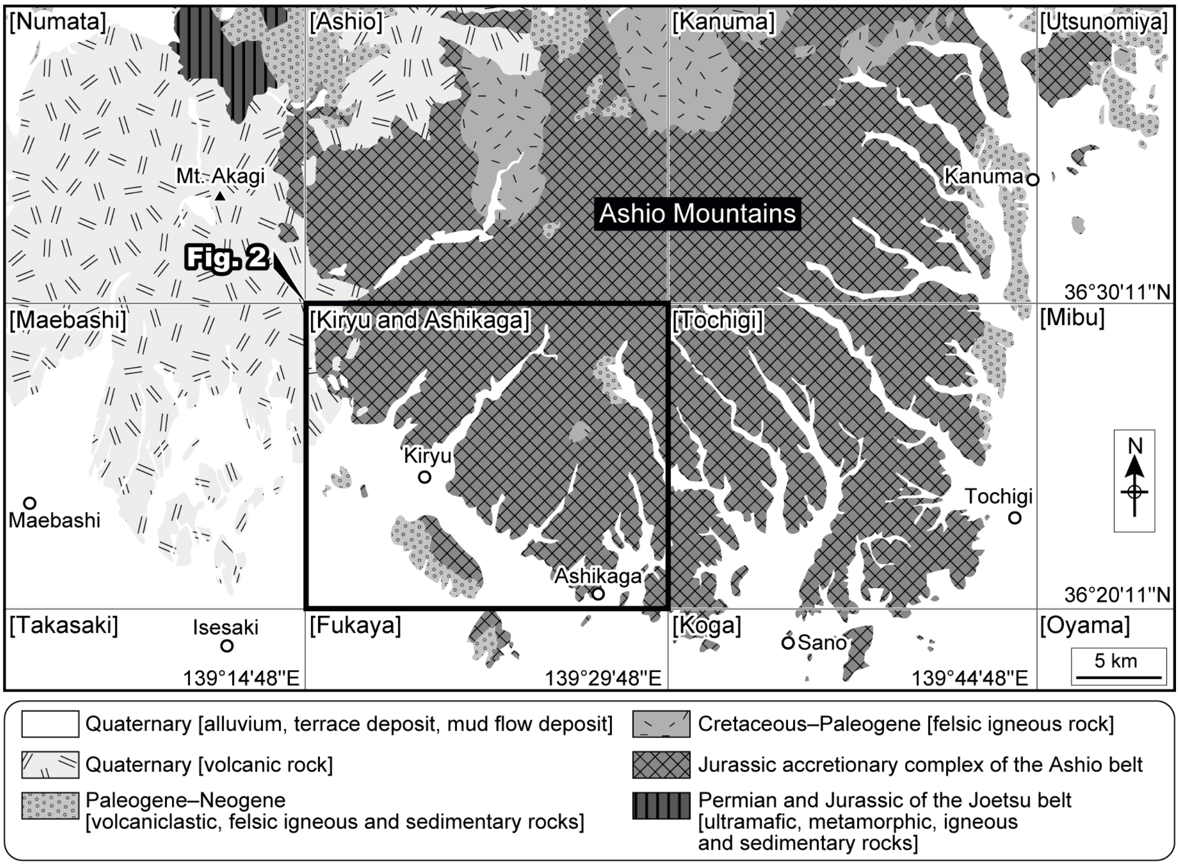


Fig. 1 Index and simplified geologic maps of the Ashio Mountains (modified after from Sudo *et al.*, 1991; Geological Survey of Japan, AIST, 2018). The geographical names in brackets indicate 1:50,000 topographic maps published by the Geospatial Information Authority of Japan.

mudstone, sandstone and pelitic mixed rock. This complex is composed of the upper and lower parts. The upper part is characterized by dominant of mudstone and small amounts of siliceous claystone, compared with the lower part. The upper part contains pelitic mixed rock including blocks of chert and sandstone.

The Omama Complex, presenting broken to mélange facies, mainly comprises basaltic rocks, chert and mudstone, with small amounts of carbonate rocks, siliceous mudstone, sandstone and pelitic mixed rock. This complex is composed of the upper and lower parts. The lower part is characterized by dominant of basaltic rocks and chert, whereas the upper part is composed mainly of pelitic mixed rock including blocks of basaltic rocks, carbonate rocks, chert and sandstone.

The Kuzu Complex comprises three units, namely units 1, 2 and 3. Units 1 and 3, presenting coherent facies, are composed of chert, siliceous mudstone, mudstone, alternations of sandstone and mudstone and sandstone. In addition, Unit 3 includes small amounts of basaltic rocks and carbonate rocks. Unit 2 is composed of basaltic rocks and carbonate rocks with conglomerate, siliceous mudstone and mudstone.

The Gyodosan Complex presents mélange facies. It consists mainly of pelitic mixed rock and chert, with siliceous mudstone, mudstone and sandstone.

3. Materials and methods

In total, 321 samples including the author's previous studies (Ito, 2019, 2020a, b; Ito and Nakamura, 2021) underwent the following method to extract radiolarian fossils. The samples, crushed into approximately 1-cm fragments, were soaked in 5% hydrofluoric acid at room temperature (ca. 20–25 °C). Approximately 24 h later, the residues were collected by a sieve with a mesh diameter of 0.054 mm. Part of the residues were enclosed within a slide prepared with a photocrosslinkable mounting medium (GJ-4006, Gluelabo Ltd.). The slides were analyzed using a transmitted light microscope and then photographed. Several specimens from the residues were mounted on stubs and photographed using scanning electron microscopy.

4. New radiolarian occurrences from the Kiryu and Ashikaga District

This article reports new radiolarians occurrences from

42 samples. Of these, nine samples yielded Permian radiolarians and four samples yielded Triassic ones. Eight samples yielded Jurassic radiolarians. Specimens of undetermined age occurred in 19 samples. Figure 2 show the localities of radiolarian occurrences in the Kiryu and Ashikaga District by the present and previous studies.

4. 1 Permian radiolarians

Figure 3 is a traverse map including the Hachioji section studied by Ito (2020a) along a hiking trail in the southwest of Mt. Karasawa of the Hachioji Hills. Permian radiolarians were obtained from chert of the Gyodosan Complex (Fig. 4).

The red chert sample (IT19120902) and gray chert sample (IT19120905) yielded *Pseudoalbaillella japonica* Nestell and Nestell (Figs. 4.2–4.6, 4.8, 4.9, 4.27, 4.28, 4.31–34) and *Pseudoalbaillella postscalprata* Ishiga (Figs. 4.7, 4.29, 4.30). According to Unitary Association Zones (UAZ) of the Permian proposed by Xiao *et al.* (2018), the co-occurrence of *Pseudoalbaillella japonica* and *Pseudoalbaillella postscalprata* indicates that the average of the statistical likelihood is the highest at UAZ 6 (Kungurian, Cisuralian).

The gray chert sample (IT19120908) yielded *Parafollicucullus* sp. cf. *P. monacanthus* (Ishiga and Imoto) (Fig. 4.44). According to the occurrence range of Zhang *et al.* (2014), *Parafollicucullus monacanthus* occurred in the *Parafollicucullus monacanthus* Interval Zone–lower *Follicucullus porrectus* Interval Zone (upper Wordian–lower Capitanian, Guadalupian).

The gray chert sample (IT19120910) yielded *Ishigaconus scholasticus* (Ormiston and Babcock) (Fig.4.50) in addition to the short form of *Parafollicucullus monacanthus* (Figs. 4.46–4.49). According to Zhang *et al.* (2014), the co-occurrence range of *Parafollicucullus monacanthus* and *Ishigaconus scholasticus* is limited to the lower *Ishigaconus scholasticus* Interval Zone (middle Capitanian).

There is no certain radiolarian age of five samples (IT19120901, IT19120903, IT19120904, IT19120906 and IT19120907); however, their stratigraphic relationships (Fig. 3) likely indicate that they are the Permian in age.

4. 2 Triassic radiolarians

Triassic radiolarians were obtained from four chert samples of Unit 3 of the Kuzu Complex in the Kiryu and Ashikaga District (Fig. 5).

Triassocampe sp. (Fig. 5.10) and *Triassocampe*? sp. (Fig. 5.6) were extracted from the gray chert samples, IT17021004 and IT16072004, respectively. *Triassocampe* Dumitrica, Kozur and Mostler and its allied genera, such as *Yeharaia* Nakaseko and Nishimura, occurred in the Triassic, mainly in the Anisian–middle Norian (e.g. Kozur and Mostler, 1994; Sugiyama, 1997; Tekin, 1999; O'Dogherty *et al.*, 2009b).

Triassocampe sp. cf. *T. deweveri* Nakaseko and Nishimura (Figs. 5.16, 29) occurred in the gray chert sample (IT18012403) and the red chert sample (IT18110702). The occurrence range of *Triassocampe deweveri* shown by Sugiyama (1997) is TR2B–TR4A, middle Anisian–middle Ladinian. The age of these samples may be the middle Anisian–middle Ladinian. Sample IT18110702 yielded *Annulotriassocampe* sp. (Figs. 5.26, 5.27). The genus *Annulotriassocampe* Kozur occurred mainly in the Ladinian (e.g. Kozur and Mostler, 1994; O'Dogherty *et al.*, 2009b), which supports the age assignment of the sample.

4. 3 Jurassic radiolarians]

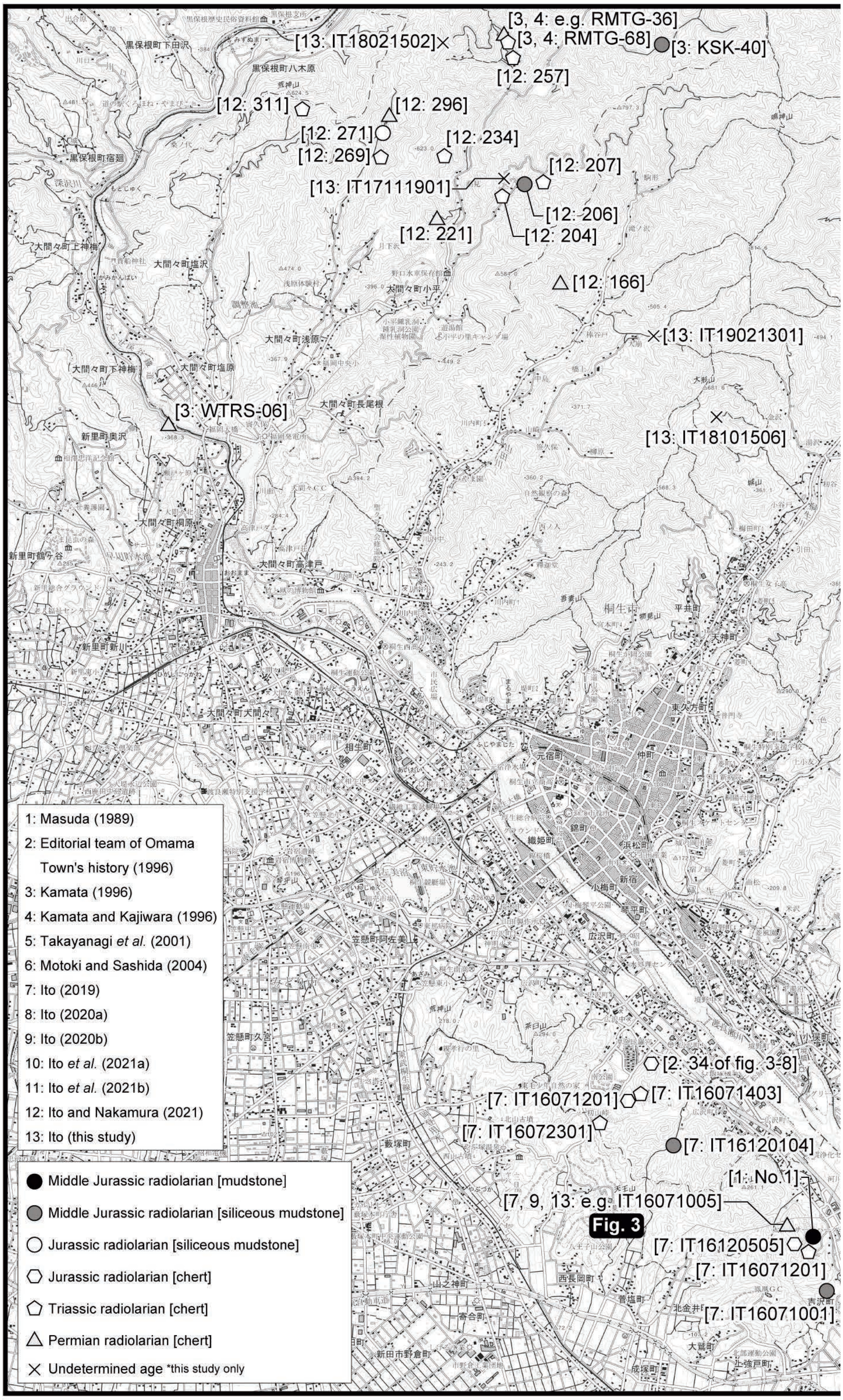
4. 3. 1 Chert of Unit 3 of the Kuzu Complex

The gray chert sample (IT16072003) yielded *Eucyrtidiellum gunense* Cordey (Fig. 6.11), *Parahsuum simplum* Yao (Fig. 6.16) and *Parahsuum transiens* Hori and Yao (Figs. 6.13, 6.14). The occurrence ranges of *Eucyrtidiellum gunense* group and *Parahsuum simplum* are UA8–UA29 (lower Pliensbachian–middle Toarcian) and UA1–UA36 (Sinemurian–Aalenian), respectively (Carter *et al.*, 2010). Based on the occurrence ranges, this sample is the early Pliensbachian–middle Toarcian, Early Jurassic, in age. *Parahsuum transiens* has intermediate characteristics between *Parahsuum simplum* and "*Parahsuum*" *grande* Hori and Yao (Hori and Yao, 1988). The sample yielded *Parahsuum transiens* but not "*Parahsuum*" *grande*, so that the sample may be older during the above-mentioned age, probably Pliensbachian.

The gray chert sample (IT19022101) yielded three-segmented closed nassellarian (Figs. 7.1, 7.2, 7.4). Three-segmented closed nassellarian is known mainly in the Family Williriedellidae Dumitrica, such as *Williriedellum* Dumitrica, *Zhamoidellum* Dumitrica, *Hemicryptocapsa* Tan Sin Hok, *Holocryptocanium* Dumitrica and *Cryptamphorella* Dumitrica. Three-segmented closed nassellarian is also known in *Japonocapsa* Kozur and *Striatojaponocapsa* Kozur of the Family Diacanthocapsidae O'Dogherty. These taxa occurred in the Jurassic–Cretaceous (e.g. Pessagno, 1977b; Matsuoka, 1991, 1998; Hull, 1997; Sykora *et al.*, 1997; Yao, 1997; Hori, 1999; Kiessling, 1999; Kiessling *et al.*, 1999; Chiari *et al.*, 2002; O'Dogherty *et al.*, 2006, 2009a). Consequently, the sample indicates wide range of the Jurassic–Cretaceous in age.

4. 3. 2 Siliceous mudstone of the Lower part of the Kurohone–Kiryu Complex

The siliceous mudstone sample (IT19021701) yielded closed nassellarian (Figs. 8.1, 8.2, 8.5, 8.8). Closed nassellarian is known in the Mesozoic–Cenozoic, such as *Praeprotunuma* Tekin in the Triassic (Tekin, 1999), *Calocyclas* Ehrenberg in the Paleogene (e.g. Takemura and Ling, 1998) and *Crytocapsella* Haeckel in the Neogene (e.g. Sanfilippo and Riedel, 1970), in addition to three-segmented closed nassellarian that occurred in the Jurassic–Cretaceous as mentioned in subsection 4.3.1. The sample presents wide age of the Mesozoic–Cenozoic.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[13: IT18101506]
1: Masuda (1989)
2: Editorial team of Omama Town's history (1996)
3: Kamata (1996)
4: Kamata and Kajiwara (1996)
5: Takayanagi et al. (2001)
6: Motoki and Sashida (2004)
7: Ito (2019)
8: Ito (2020a)
9: Ito (2020b)
10: Ito et al. (2021a)
11: Ito et al. (2021b)
12: Ito and Nakamura (2021)
13: Ito (this study)
[2: 34 of fig. 3-8]
[7: IT16071201]
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Fig. 3
[7: IT16120505]
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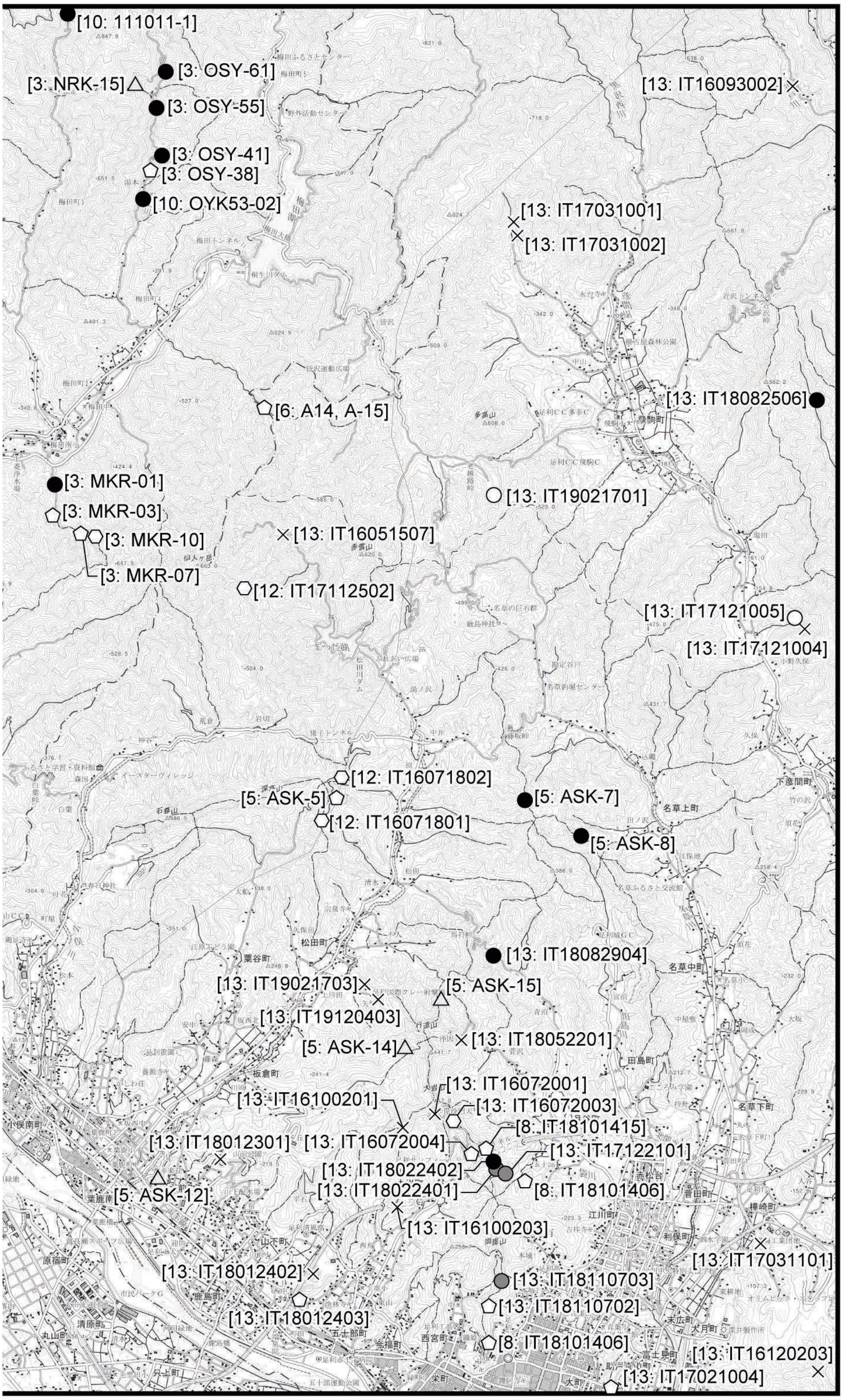
[7: IT16071001]
Middle Jurassic radiolarian [mudstone]
Middle Jurassic radiolarian [siliceous mudstone]
Jurassic radiolarian [siliceous mudstone]
Jurassic radiolarian [chert]
Triassic radiolarian [chert]
Permian radiolarian [chert]
Undetermined age *this study only



(p. 290, 291)

Fig. 2 Locality map of radiolarian occurrence sites in the present and major previous studies. Sample numbers in Fig. 3 are omitted. Base from the Geospatial Information Authority of Japan with its approval (Approval number: R2JHs 66-GISMAP44702). This map uses GISMAP50000R+ "Kiryu and Ashikaga" by Hokkaido-Chizu Co. Ltd.

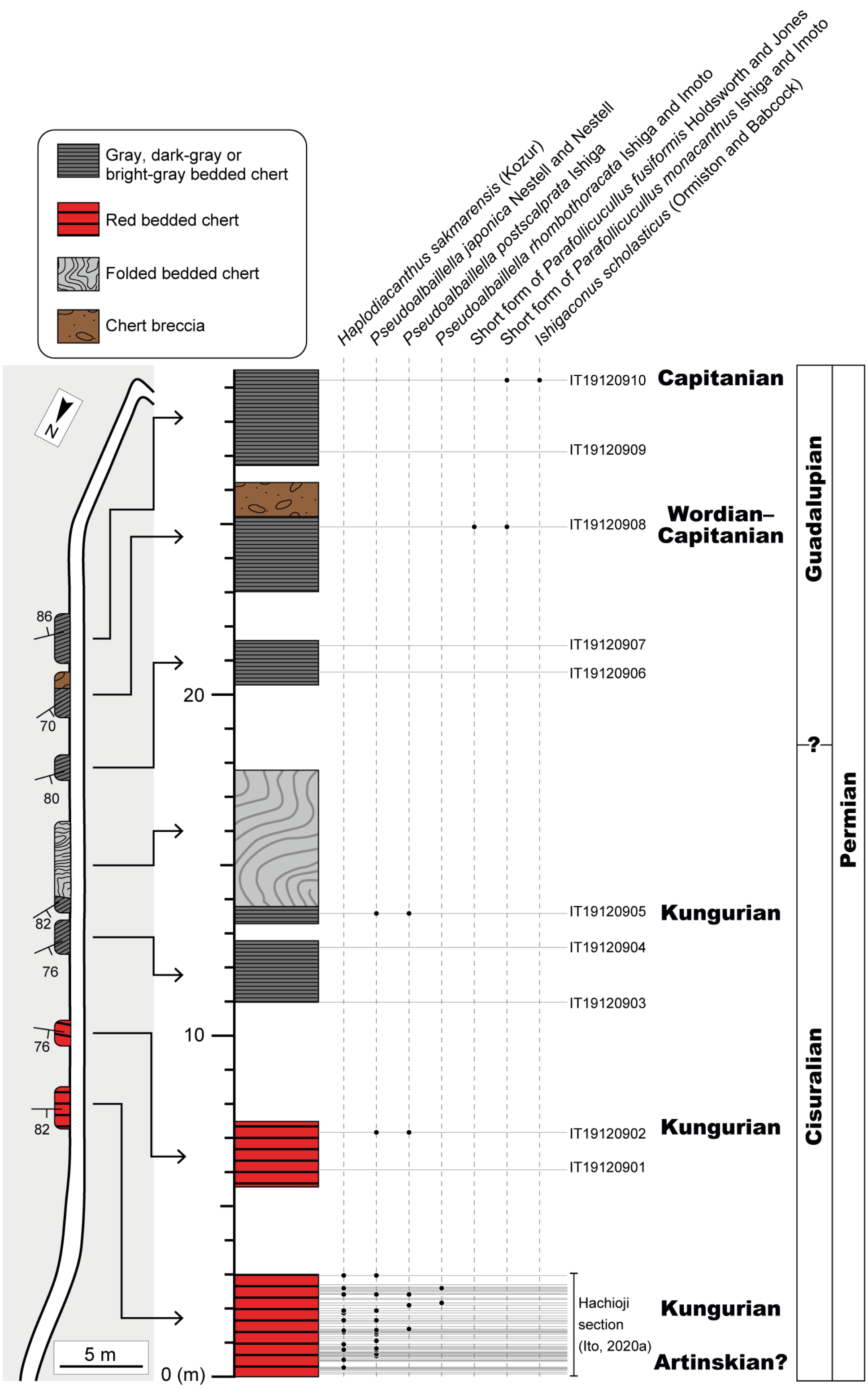


Fig. 3 Traverse map of chert sections including the Hachioji section studied by Ito (2020a) along a hiking trail at southwest of Mt. Karasawa of the Hachioji Hills.

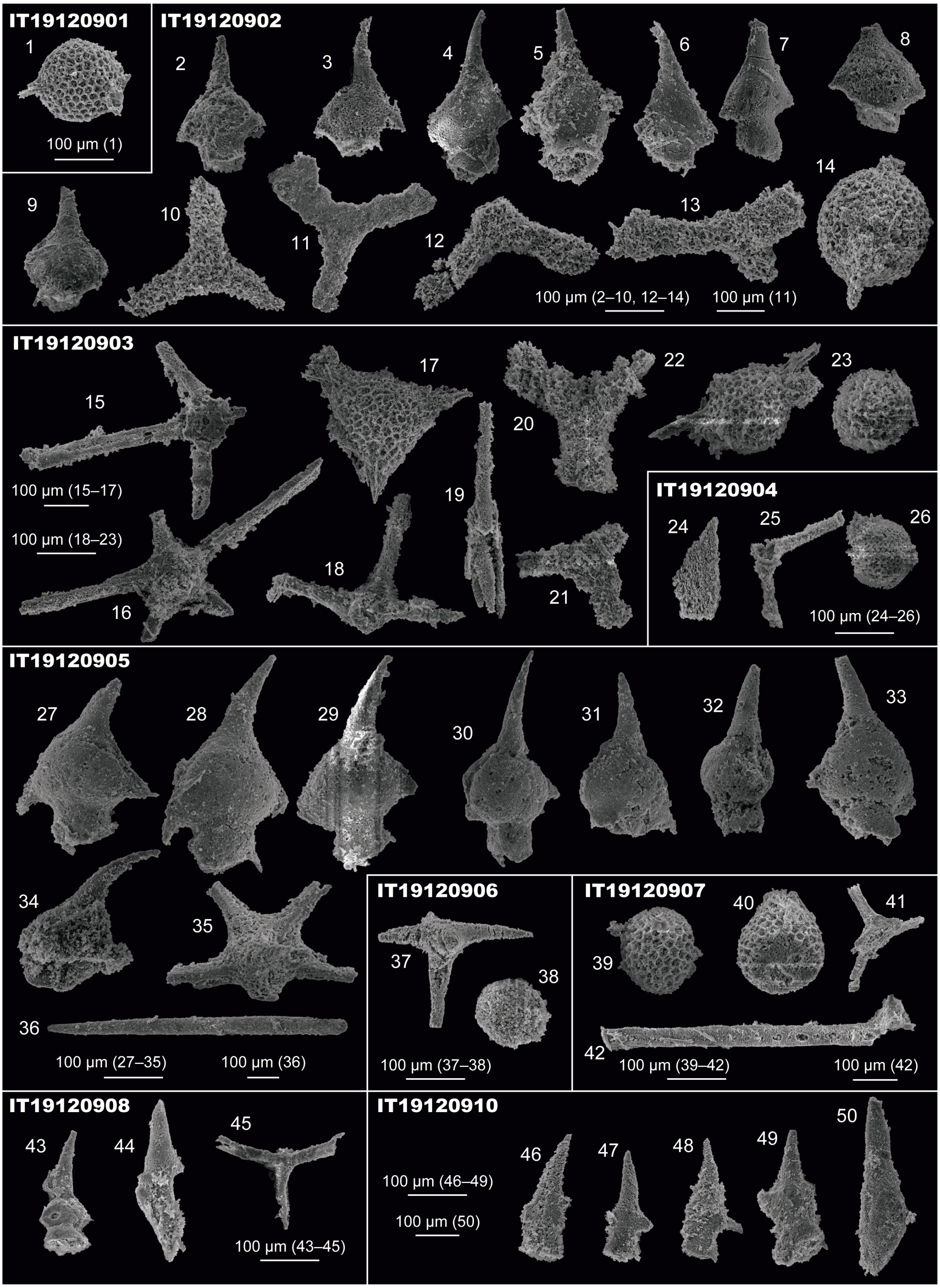


Fig. 4 Permian and possible Permian radiolarians from the chert of the Gyodosan Complex. (1, 14, 22) *Stigmosphaerostylus*? sp. (2–6, 8, 9, 27, 28, 31–33) *Pseudoalbaillella japonica* Nestell and Nestell. (7, 29, 30) *Pseudoalbaillella postscalprata* Ishiga. (10–13, 20, 21) *Latentifistula*? spp. (15) *Polyfistula* sp. (16, 35) *Polyfistula* sp. aff. *P. hexalobata* Nazarov and Ormiston. (17) *Scharfenbergia*? sp. (18, 25, 41, 45) *Quadricaulis*? spp. (19, 36, 37) Sponge spicule. (23, 26, 38–40) Spherical polycystine. (24) Albaillellaria gen. et sp. indet. (34) *Pseudoalbaillella*? sp. (42) Arm of Latentifistularia gen. et sp. indet. (43) Short form of *Parafollicucullus fusiformis* Holdsworth and Jones. (44) *Parafollicucullus* sp. cf. *P. monacanthus* (Ishiga and Imoto). (46–49) Short form of *Parafollicucullus monacanthus* (Ishiga and Imoto). (50) *Ishigaconus scholasticus* (Ormiston and Babcock).

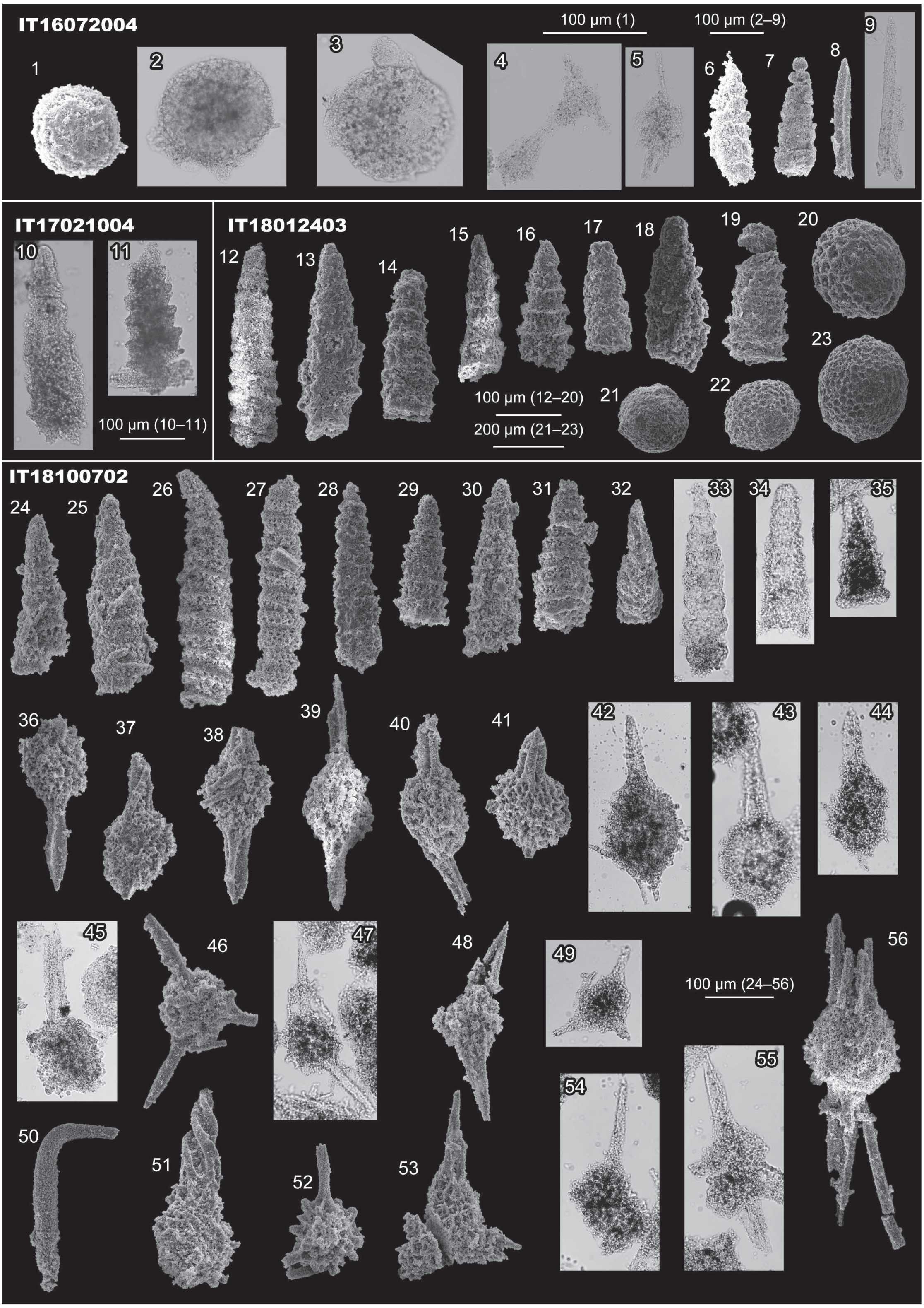


Fig. 5 Triassic radiolarians from the chert of the Kuzu Complex. (1–3, 20–23) Spherical polycystine. (4, 46, 47, 49) Three-coplaner-spine-bearing spherical polycystine. (5) *Pseudostylosphaera*? sp. (6, 11–15, 17–19, 24, 25, 28, 31, 33, 35) *Triassocampe*? sp. (7) Multi-segmented nassellarian. (8, 9) Grooved spine. (10, 30, 34) *Triassocampe* sp. (16, 29) *Triassocampe* sp. cf. *T. deweveri* Nakaseko and Nishimura. (26, 27) *Annulotriassocampe* sp. (32) *Yeharaia* sp. (36, 38, 41, 44) *Pseudostylosphaera* sp. cf. *P. japonica* (Nakaseko and Nishimura). (37, 39, 40, 42, 43, 45, 55, 56) *Pseudostylosphaera* sp. (48) *Eptingium* sp. cf. *E. nakasekoi* (Kozur and Mostler). (50) Spine A2 of Sugiyama (1997). (51) *Muelleritortis*? sp. (52) *Xenorum*? sp. (53) *Capnuchosphaera*? sp. (54) Spine-bearing spherical polycystine.

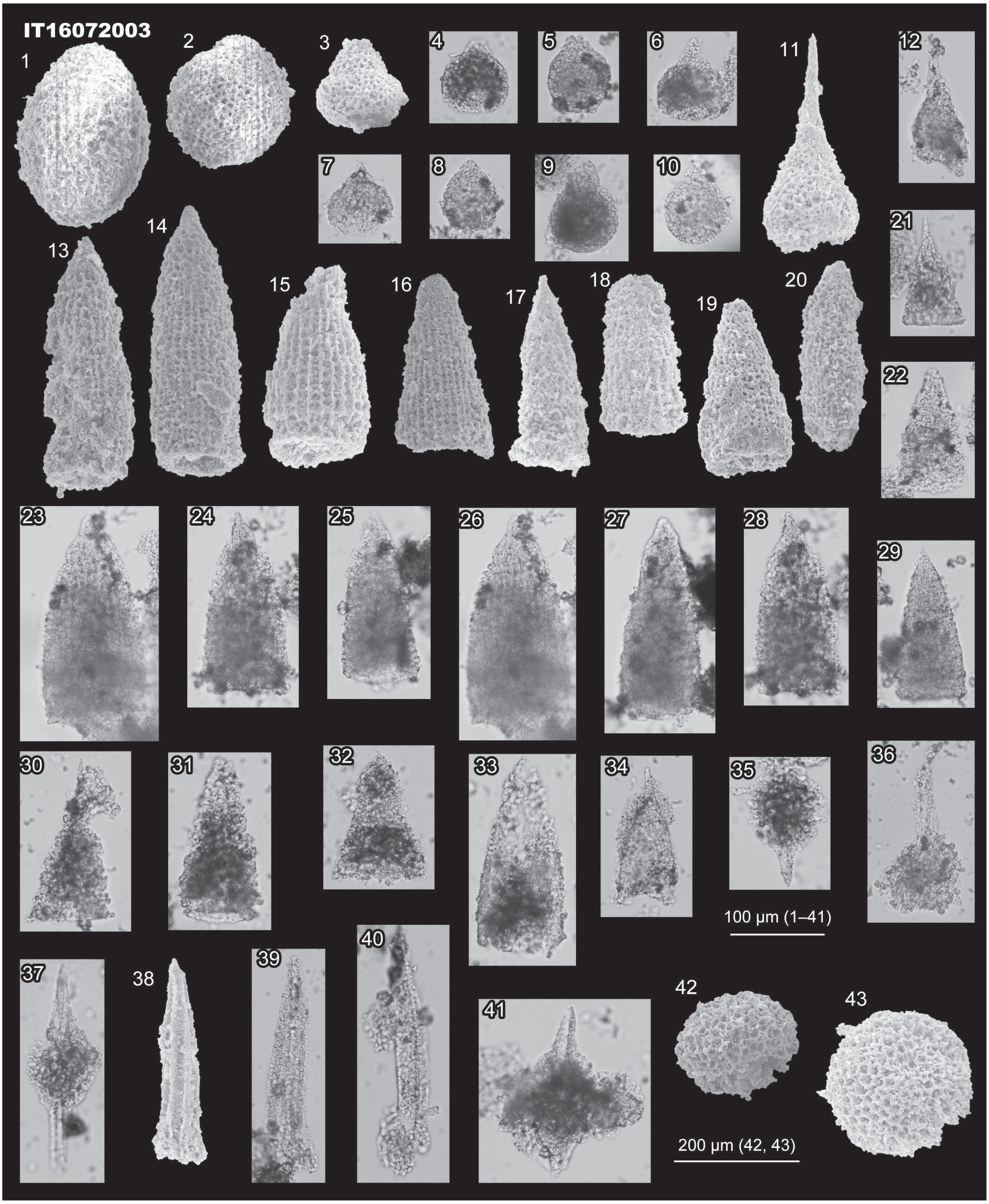


Fig. 6 Early Jurassic radiolarians from the chert of the Kuzu Complex. (1, 2) Closed nassellarian. (3, 6, 12) *Eucyrtidiellum* sp. (4, 5, 7–10) Three-segmented closed nassellarian. (11) *Eucyrtidiellum gunense* Cordey. (13, 14) *Parahsuum transiens* Hori and Yao. (15) *Parahsuum* sp. cf. *P. simplum* Yao. (16) *Parahsuum simplum* Yao. (17–21, 24, 25, 27–34) Multi-segmented nassellarian. (23, 26) *Parahsuum*? sp. (35–37) *Pantanellium*? sp. (38–40) Grooved spine. (41) *Trillus*? sp. (42, 43) Spherical polycystine.

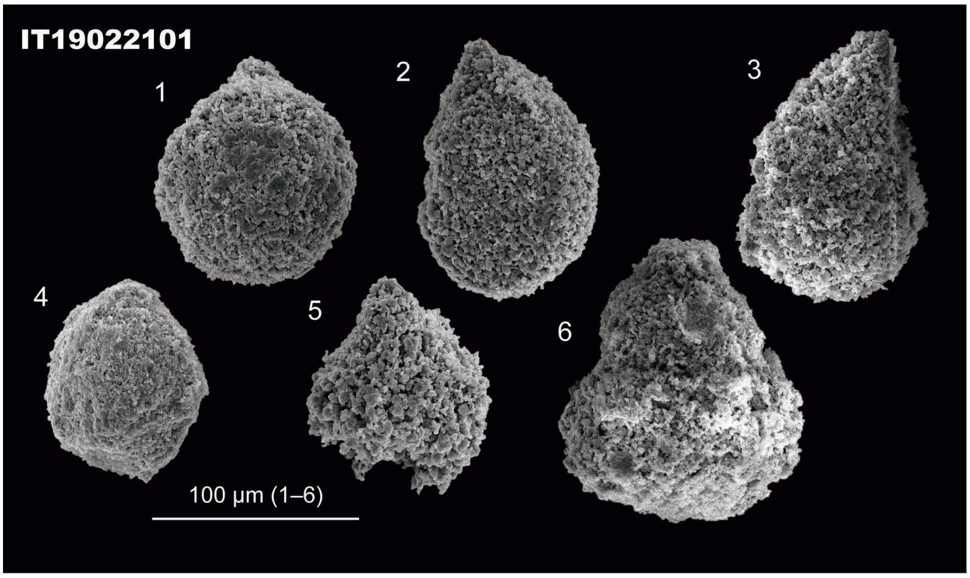


Fig. 7 Possible Jurassic radiolarians from the chert of the Kuzu Complex. (1, 2, 4) Three-segmented closed nassellarian. (3, 5, 6) Closed nassellarian.

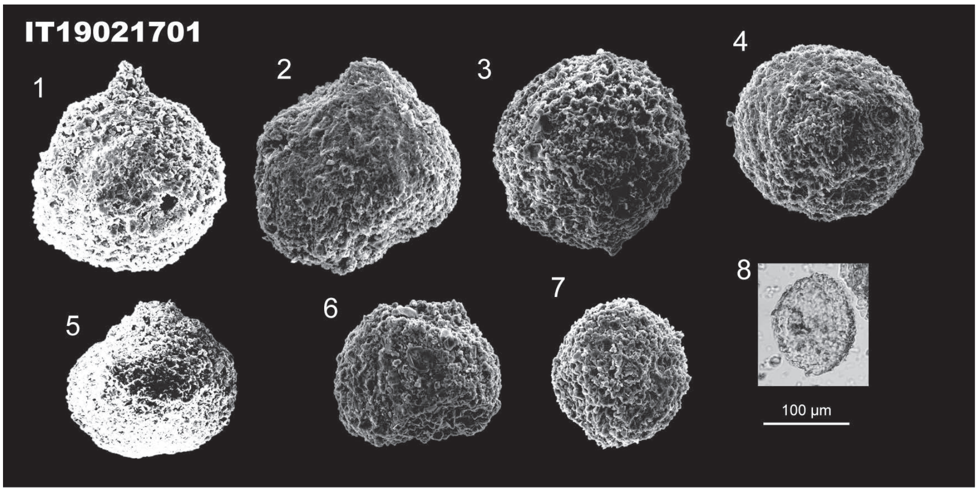


Fig. 8 Possible Jurassic radiolarians from the siliceous mudstone of the Kurohone–Kiryu Complex. (1, 2, 5, 8) Closed nassellarian. (3, 4, 6, 7) Spherical polycystine.

4. 3. 3 Siliceous mudstone of Unit 3 of the Kuzu Complex

The bright-gray siliceous mudstone sample (IT17121005) yielded three-segmented closed nassellarian (Figs. 9.1, 9.2). As mentioned in subsection 4.3.1, three-segmented closed nassellarian occurred in the Jurassic–Cretaceous, so the age of this sample presents wide range of the Jurassic–Cretaceous.

The gray siliceous mudstone sample (IT17122101) yielded *Japonocapsa* sp. aff. *J. fusiformis* (Yao) sensu Matsuoka (1983) (Fig. 9.5). Matsuoka (1983) stated that *Japonocapsa fusiformis* changes gradually into *Japonocapsa* sp. aff. *J. fusiformis* near the biohorizon of the first appearance of *Striatojaponocapsa conexa* (Matsuoka). *Striatojaponocapsa conexa* is the characteristic species of JR5 (*Striatojaponocapsa conexa* Zone) of the upper Bathonian–Callovian, Middle Jurassic (Matsuoka and Ito, 2019). *Japonocapsa* sp. aff. *J. fusiformis* occurred also in JR6 (*Kilinora spiralis* Zone) (Matsuoka, 1983) corresponding to the uppermost Callovian–Oxfordian, Middle–Upper Jurassic (Matsuoka and Ito, 2019); however, the sample did not yield characteristic species of JR6. Consequently, the age of this sample is probably the late Bathonian–Callovian, Middle Jurassic.

Mizukidella? sp. (Fig. 9.31) occurred in the dark-gray siliceous mudstone sample (IT18022401). *Mizukidella* occurred in the Bajocian–Berriasian, Middle Jurassic–earliest Cretaceous (O'Dogherty *et al.*, 2017). This sample presents wide age of the Bajocian–Berriasian.

The gray siliceous mudstone sample (IT18110703) yielded *Striatojaponocapsa synconexa* O'Dogherty, Goričan and Dumitrica (Fig. 10.1). The occurrence range of *Striatojaponocapsa synconexa* is from upper JR4 (*Striatojaponocapsa plicarum* Zone) to lower JR5 (*Striatojaponocapsa conexa* Zone), Bathonian, Middle Jurassic (Matsuoka and Ito, 2019). Consequently, this sample corresponds to the Bathonian.

4. 3. 4 Mudstone of the Kuzu Complex

The dark-gray mudstone sample (IT18022402), considered to be Unit 3 of the complex, yielded *Striatojaponocapsa* sp. (Fig. 11.1). Species of *Striatojaponocapsa* Kozur, such as *Striatojaponocapsa plicarum* (Yao), *Striatojaponocapsa synconexa*, *Striatojaponocapsa riri* O'Dogherty, Goričan and Dumitrica and *Striatojaponocapsa conexa*, occurred mainly in the Bajocian–Oxfordian (e.g. Yao, 1979; Matsuoka, 1983, 1988; Hull, 1997; Hatakeda *et al.*, 2007; O'Dogherty *et al.*, 2006, 2009a). Thus, the age of the sample is most probably the Bajocian–Oxfordian.

The dark-gray mudstone sample (IT18082506) yielded three-segmented closed nassellarian (Figs. 11.6, 11.7). As mentioned in subsection 4.3.1, three-segmented closed nassellarian occurred in the Jurassic–Cretaceous. Thus, this sample presents wide age of the Jurassic–Cretaceous.

4. 3. 5 Mudstone of the Gyodosan Complex

Pelitic mixed rock (IT18082904) yielded *Archaeodictyomitra* sp. (Fig. 12.11). Species of *Archaeodictyomitra* Pessagno occurred mainly in the Jurassic–Cretaceous (e.g. Pessagno, 1977b; Pessagno and Whalen, 1982; Aita, 1987; Yang, 1993; Dumitrica-Jud, 1995; Hori, 1999; Kozai *et al.*, 2006; O'Dogherty *et al.*, 2006, 2009a). Matsuoka (1986) discussed lineages and occurrence ranges of several multi-segmented nassellarian including *Archaeodictyomitra*. According to the description, this genus appeared around the Pliensbachian, middle Early Jurassic. Although the detailed age is unknown, this sample presents wide age of the middle Early Jurassic–Cretaceous.

4. 4 Undetermined-age radiolarians

Poorly preserved radiolarians were obtained from 19 samples (Fig. 13). The ages of these samples cannot be determined.

5. Fossil age of each lithology of the Jurassic accretionary complex of the Ashio Mountains

Radiolarian occurrences from the Jurassic accretionary complex in the Kiryu and Ashikaga District were presented in chapter 3. Figure 14 shows the age assignment of the samples. On the basis of the radiolarian occurrences in this study and previously-reported fossil occurrences (e.g. radiolarian, conodont, fusulinid), fossil age of lithology presents for each complex in the Jurassic accretionary complex in this chapter. Figure 15 represents the relationships of the fossiliferous rocks and occurrence fossils.

5. 1 Kurohone–Kiryu Complex

The Kurohone–Kiryu Complex is distributed mainly in the Kurohone and Kiryu areas. The Kurohone area is around Kurohone-cho of Kiryu City (former Kurohone Village) located northwest of the Watarase River. The Kiryu area (eastern part of the current Kiryu City = former Kiryu City before merger with Kurohone and Niisato villages) is mainly between the Yamada and Kiryu rivers. These areas are separated by the distributional area of the Omama Complex.

Based on lithology by the present and previous studies, the lower and upper parts of the Kurohone–Kiryu Complex is distributed in the Kiryu area whereas the lower part is solely exposed in the Kurohone area. The fossil occurrences from the areas have slightly differences. For these reasons, the fossil age is described by each area, following previous studies (e.g. Kamata, 1996; Takayanagi *et al.*, 2001).

5. 1. 1 Lower part (Kiryu area)

(1) Carbonate rocks

Igo (1985) and Koike *et al.* (1991) discovered Triassic conodont from limestone blocks in the Kanuma District. The limestone blocks are probably located in the distributional area of the lower part of the Kurohone–Kiryu Complex. A mixed fauna of Early–Late Triassic conodonts was obtained from the limestone blocks. In particular, *Epigondolella bidentata* Mosher occurred in the limestone blocks (Koike *et al.*, 1991). The occurrence range of this species is the late Norian–early Rhaetian, Late Triassic (Rigo *et al.*, 2018), and it is the youngest conodont species in the mixed fauna. Therefore, the youngest part of the limestone blocks was deposited near the late Norian–early Rhaetian at least.

(2) Siliceous claystone

Olenekian (Early Triassic) conodont species, such as *Triassospathodus abruptus* (Orchard) and *Triassospathodus homeri* (Bender), have been reported from the siliceous claystone (Sashida *et al.*, 1992; Motoki and Sashida, 2004; Muto and Ito, 2021).

Hayashi (1964) reported conodonts from the "Narutaki Grindstone." Although its age was given, Hayashi (1964) mentioned that the "Narutaki Grindstone" occurs in Umeda (Kiryu City) and Hikoma (Sano City). These localities contain the distributional area of the Kurohone–Kiryu Complex and possibly the Omama Complex.

(3) Chert

Triassic conodonts and radiolarians have been discovered in chert (e.g. Hayashi, 1963; Aono, 1985; Hayashi *et al.*, 1990; Kamata, 1996; Motoki and Sashida, 2004).

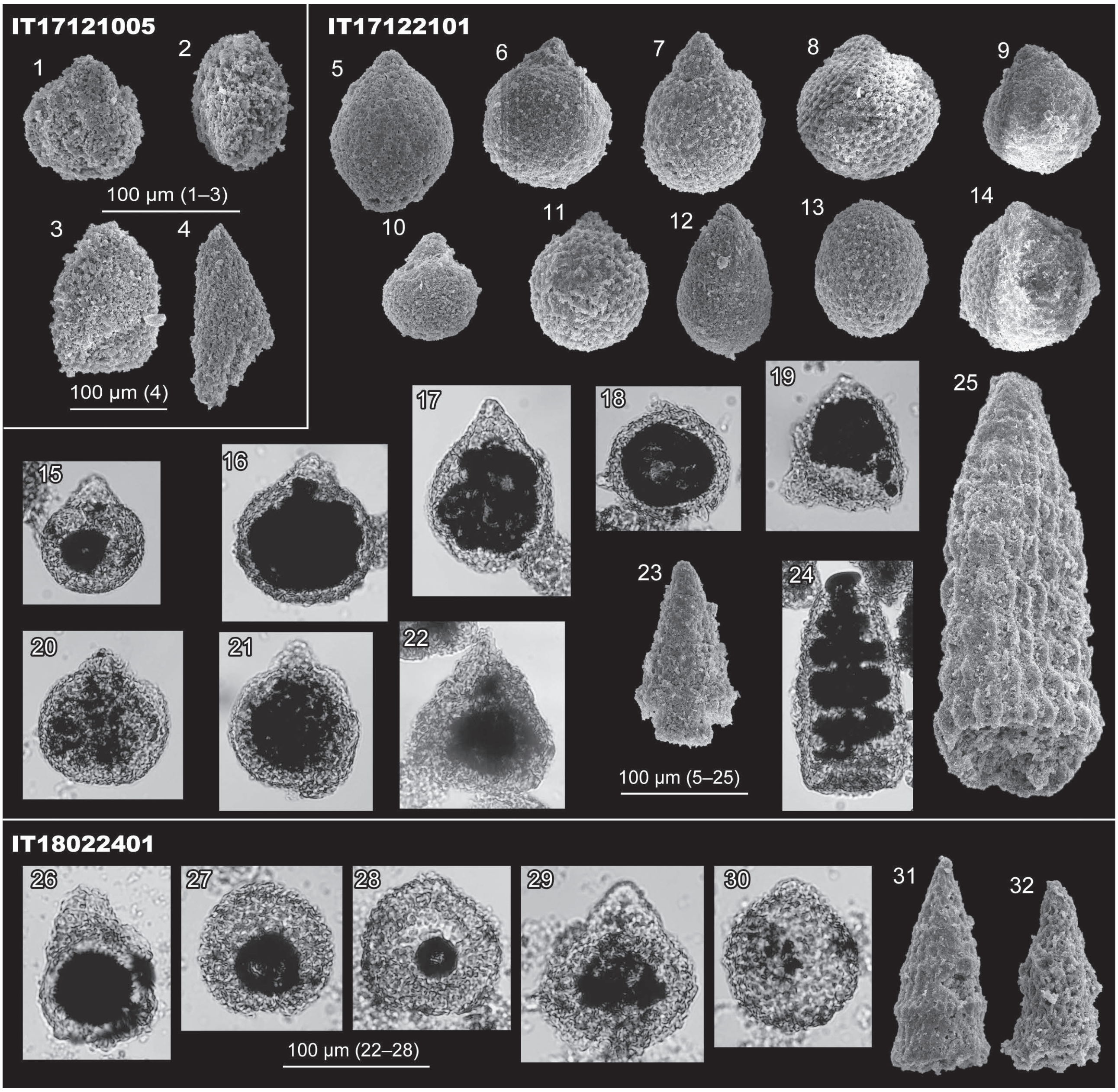


Fig. 9 Jurassic and possible Jurassic radiolarians from the siliceous mudstone of the Kuzu Complex. (1, 2, 6–11, 13–22, 27–30) Three-segmented closed nassellarian. (3, 4) Nassellaria gen. et sp. indet. (5) *Japonocapsa* sp. aff. *J. fusiformis* (Yao) sensu Matsuoka (1983). (12, 26) Closed nassellarian. (23, 24, 32) Multi-segmented nassellarian. (25) *Hsuum maxwelli* Pessagno. (31) *Mizukidella*? sp.

Aono (1985) reported *Epigondolella primitia* Mosher. Muto and Ito (2021) changed the belongingness of this species as *Metapolygnathus primitius* and concluded that the age is the late Carnian–early Norian (Late Triassic).

Kamata (1996) reported *Yeharaia* sp. and *Pseudostylosphaera* sp. from chert samples (e.g. MKR-18). Occurrence ranges by Sugiyama (1997) show that the *Yeharaia* species and *Pseudostylosphaera* species occurred in the uppermost Anisian–middle Ladinian and the Anisian–middle Carnian, respectively. The age of these samples is assigned as the latest Anisian–middle Ladinian.

Takayanagi *et al.* (2001) reported *Capnodoce* sp. from sample ASK-5. Species of the genus *Capnodoce* De Wever occurred in the upper Carnian–middle Norian, Upper Triassic (e.g. Sugiyama, 1997; O'Dogherty *et al.*, 2009b).

Motoki and Sashida (2004) reported *Pseudostylosphaera japonica*, *Pseudostylosphaera longispinosa* Kozur and Mostler and *Oertlispongus diacanthus* Sugiyama. *Pseudostylosphaera japonica* and *Oertlispongus diacanthus* occurred in TR2B–TR5A (middle Anisian–middle Carnian) and TR2A–TR2C (early–middle Anisian), respectively (Sugiyama, 1997). Consequently,

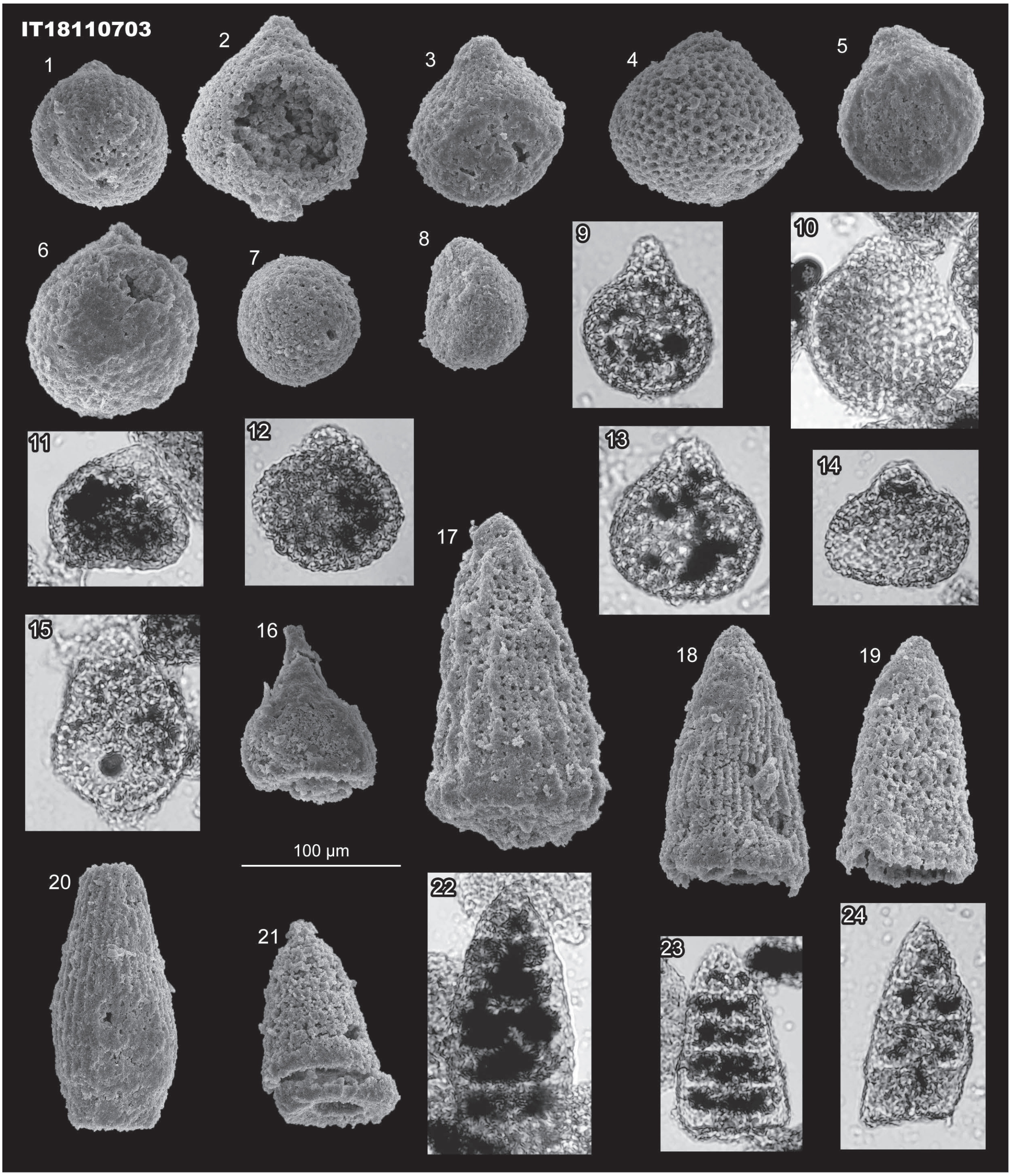


Fig. 10 Jurassic radiolarians from the siliceous mudstone of the Kuzu Complex. (1) *Striatojaponocapsa synconexa* O'Dogherty, Goričan and Dumitrica. (2) "*Stichocapsa*" sp. E sensu Baumgartner *et al.* (1995). (3, 5, 10) *Striatojaponocapsa*? sp. (4, 6–9, 11–14) Three-segmented closed nassellarian. (15) *Yaocapsa*? sp. (16) *Eucyrtidiellum* sp. cf. *E. unumaense* (Yao). (17) *Hsuum maxwelli* Pessagno. (18, 20) *Archaeodictyomitra* sp. (19) *Takemuraella* sp. cf. *T. japonica* (Takemura). (21–24) Multi-segmented nassellarian.

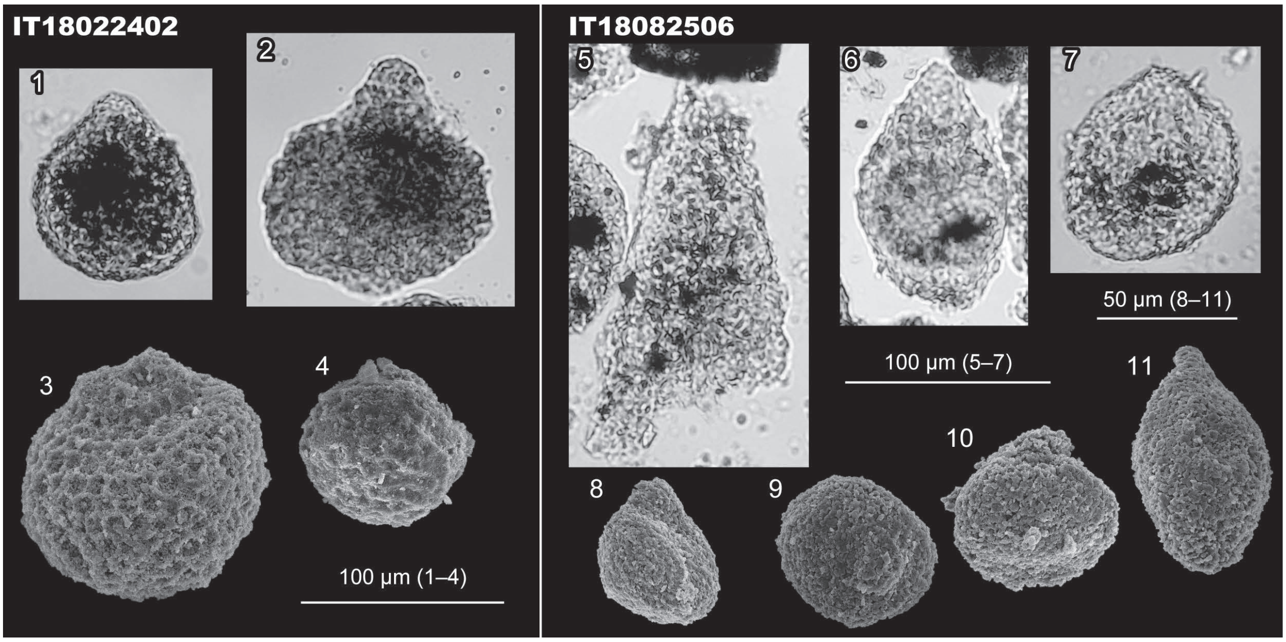


Fig. 11 Possible Jurassic radiolarians from the mudstone of the Kuzu Complex. (1) *Striatojaponocapsa* sp. (2) *Williriedellum*? *marcucciae* Cortese. (3, 6, 7) Three-segmented closed nassellarian. (4, 8–11) Closed nassellarian. (5) Multi-segmented nassellarian.

the age of the sample is the middle Anisian.

(4) Siliceous mudstone

Sample IT19021701 in this study yielded closed nassellarian. Such radiolarians occurred in the Mesozoic–Cenozoic in age, as mentioned in subsection 4.3.2.

5. 1. 2 Upper part (Kiryu area)

(1) Chert

Triassic and Jurassic radiolarian occurrences were reported by Kamata (1996). Permian conodont, previously identified as the "Carboniferous" conodont by Hayashi *et al.* (1990), was reported from the possible distributional area of the upper part.

Hayashi *et al.* (1990) reported a specimen identified as late Carboniferous *Neogondolella* cf. *clarki* (Koike) from "Omama Town, Atago-jinjiya" (fig. 28, pl. 1, Hayashi *et al.*, 1990). Muto and Ito (2021) re-identified the specimen as *Mesogondolella* sp. cf. *M. gujioensis* (Igo), concluding that the age is the late Artinskian–early Kungurian (Cisuralian, early Permian). The occurrence site is possibly Atago-jinja Shrine in Kasagake-machi Azami, Midori City, the distributional area of the upper part.

Two samples (MKR-07 and OSY-38) reported by Kamata (1996) yielded *Yeharaia* sp. and *Pseudostylosphaera* sp. *Yeharaia* species and *Pseudostylosphaera* species occurred in the uppermost Anisian–middle Ladinian and the Anisian–middle Carnian, respectively (Sugiyama, 1997); therefore, the sample is the latest Anisian–middle Ladinian in age.

Sample MKR-03 reported by Kamata (1996) yielded *Canoptum triassicum* Yao and *Livarella validus* Yoshida. The former is a characteristic species of the *Canoptum triassicum* assemblage from the middle Norian–Rhaetian (Yao, 1982); the latter occurred mainly in the Rhaetian (Yoshida, 1986). This sample is therefore the Rhaetian in age.

Sample MKR-10 reported by Kamata (1996) yielded *Acanthocircus* sp. This genus appeared in the Bathonian, Middle Jurassic (O'Dogherty *et al.*, 2009a). Thus, Middle Jurassic chert may exist in the Lower part although it is not shown in Fig. 15.

(2) Mudstone

Middle Jurassic radiolarians occurred in mudstone (Kamata, 1996; Ito *et al.*, 2021a).

Kamata (1996) reported *Striatojaponocapsa plicarum* (Yao) and/or *Striatojaponocapsa* sp. cf. *S. plicarum* from mudstone samples (e.g. MKR-01). Ito *et al.* (2021a) also reported *Striatojaponocapsa plicarum* from sample OYK53-02. *Striatojaponocapsa plicarum* occurred mainly in lower–middle JR4, Bajocian, Middle Jurassic based on the occurrence range by Matsuoka and Ito (2019). These samples are therefore the Bajocian in age.

Ito *et al.* (2021a) reported *Yaocapsa* sp. cf. *Y. mastoidea* (Yao) from sample HTH12-01. The occurrence range of *Yaocapsa mastoidea* is limited to upper JR4, Bathonian, Middle Jurassic (Matsuoka, 1995).

5. 1. 3 Kurohone area (Lower part)

(1) Carbonate rocks

Hayashi *et al.* (1990) reported a Triassic conodont species, *Metapolygnathus* sp., from limestone. Muto and Ito (2021) re-identified it as *Epigondolella* sp. cf. *E. rigoi* (Budurov). *Epigondolella rigoi* occurred in the uppermost

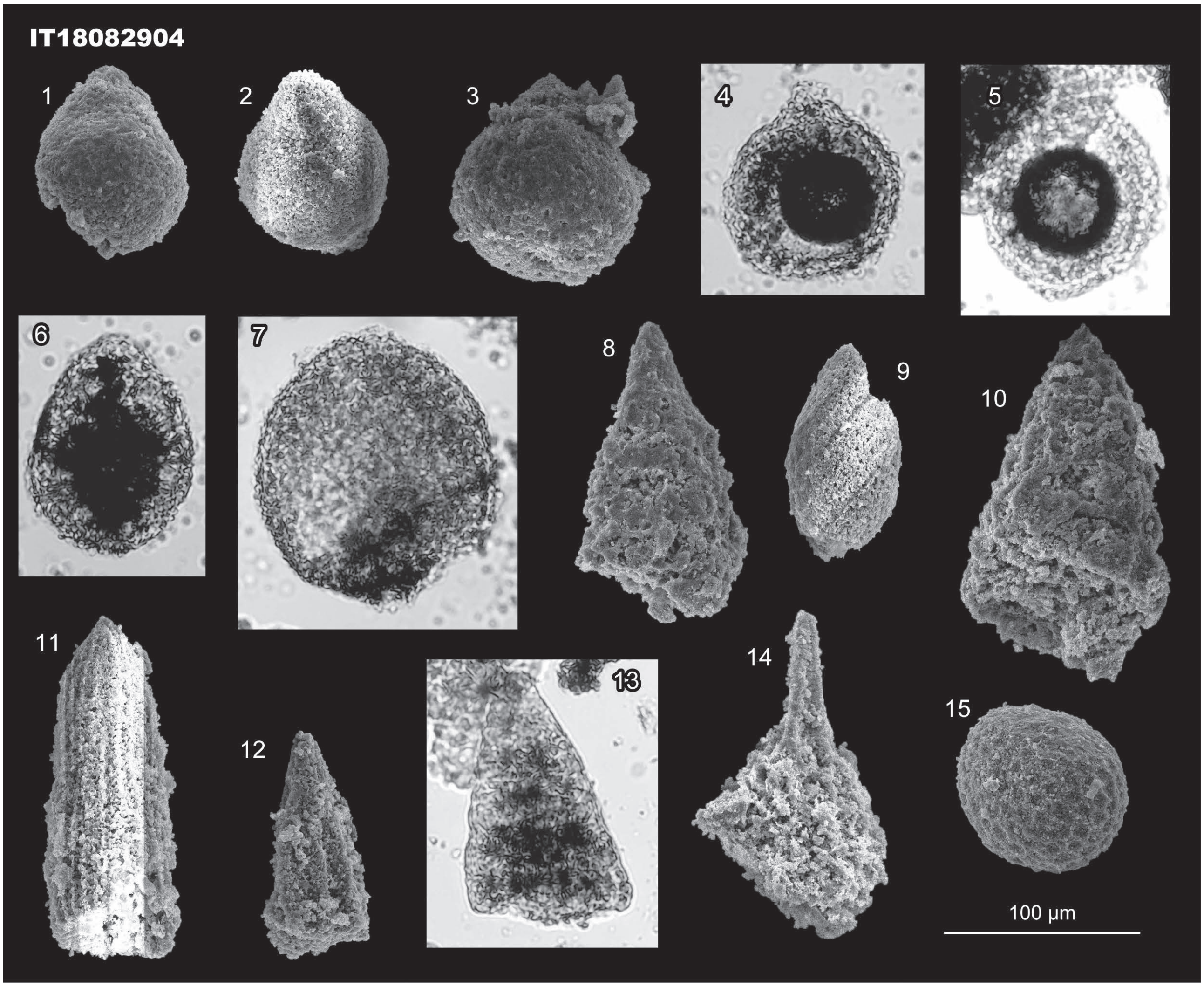


Fig. 12 Jurassic radiolarians from mudstone of the Gyodosan Complex. (1–6) Three-segmented closed nassellarian. (7, 9) Closed nassellarian. (8, 10, 12, 13) Multi-segmented nassellarian. (11) *Archaeodictyomitra* sp. (14) *Emilvia*? sp. (15) Spherical polycystine.

Carnian–lower Norian, Upper Triassic (Rigo *et al.*, 2018).

(2) Chert

Permian and Triassic conodont and Triassic and Jurassic radiolarians occurred in chert (Hayashi *et al.*, 1990; Kamata, 1996).

The Permian conodont species reported by Hayashi *et al.* (1990) is *Neogondolella serrata* (Clark and Ethington). Muto and Ito (2021) indicated the possibility that this specimen is *Jinogondolella nankingensis* (Ching). This is a characteristic species of the Roadian, Guadalupian, middle Permian (Henderson, 2018).

The Triassic conodont species reported by Hayashi *et al.* (1990) is *Metapolygnathus* sp. Muto and Ito (2021) re-identified this specimen as *Epigondolella* sp. cf. *E. rigoi*. *Epigondolella rigoi* occurred in the uppermost Carnian–lower Norian, Upper Triassic (Rigo *et al.*, 2018).

Several chert samples (e.g. OGR-81) reported by Kamata (1996) yielded *Triassocampe deweveri*. This species occurred in TR2C–TR4A, middle Anisian–middle Ladinian, Middle Triassic (Sugiyama, 1997).

Two chert samples (TZW-104 and OGR-74) yielded *Parahsuum simplum* (Kamata, 1996). This is a characteristic species of JR1 (*Parahsuum simplum* Zone) of the upper Sinemurian–lower Pliensbachian, Lower Jurassic (Matsuoka and Ito, 2019). The samples are probably the late Sinemurian–early Pliensbachian in age.

(3) Siliceous mudstone

Striatojaponocapsa sp. cf. *S. plicarum* occurred in two siliceous mudstone samples (e.g. TZW-105 of Kamata, 1996). *Striatojaponocapsa plicarum* occurred mainly in lower–middle JR4, Bajocian, Middle Jurassic (Matsuoka and Ito, 2019). *Striatojaponocapsa conexa* occurred in the siliceous mudstone (TZW-111 and OGR-69 of Kamata, 1996). It is a characteristic species of JR5 of the upper

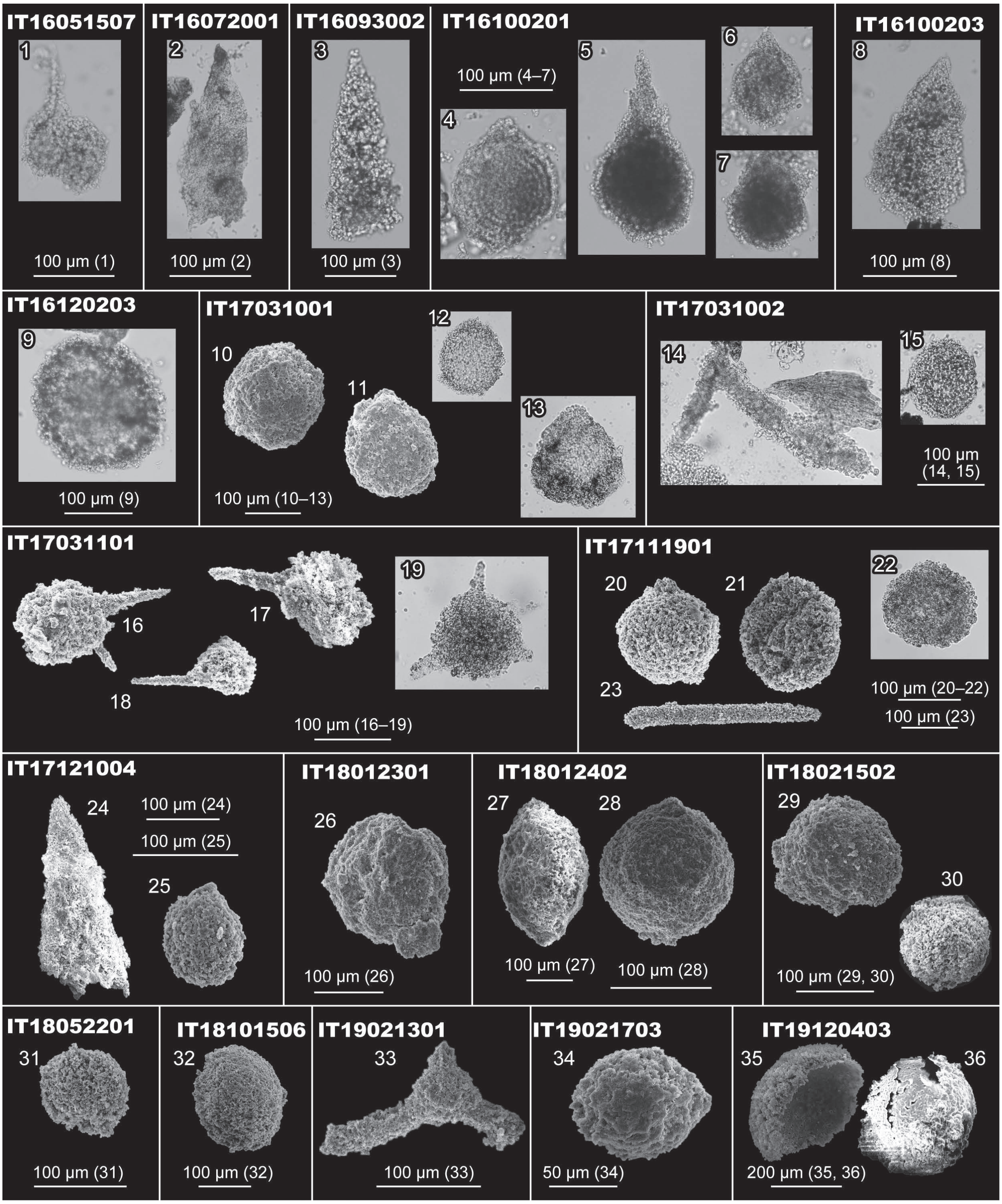


Fig. 13 Radiolarians (undetermined age) from the Jurassic accretionary complex. (1, 4–7, 9–13, 15, 20–22, 25–32, 34–36) Spherical polycystine. (2, 3, 8, 24) Multi-segmented nassellarian. (19, 33) Three-coplaner-spine-bearing spherical polycystine. (14, 16–18) Spine-bearing spherical polycystine. IT16051507: Chert of the Kurohone–Kiryu Complex. IT16072001: Siliceous mudstone of the Gyodosan Complex. IT16093002: Chert of the Kurohone–Kiryu Complex. IT16100201: Chert of the Gyodosan Complex. IT16100203: Chert of the Kuzu Complex. IT16120203: Chert of the Kuzu Complex. IT17031001: Chert of the Kurohone–Kiryu Complex. IT17031002: Chert of the Kurohone–Kiryu Complex. IT17031101: Chert of the Kuzu Complex. IT17111901: Chert of the Omama Complex. IT17121004: Mudstone of the Kuzu Complex. IT18012301: Chert of the Gyodosan Complex. IT18012402: Chert of the Kuzu Complex. IT18021502: Chert of the Omama Complex. IT18052201: Chert of the Gyodosan Complex. IT18101506: Chert of the Omama Complex. IT19021301: Chert of the Omama Complex. IT19021703: Mudstone of the Kuzu Complex. IT19120403: Mudstone of the Gyodosan Complex.

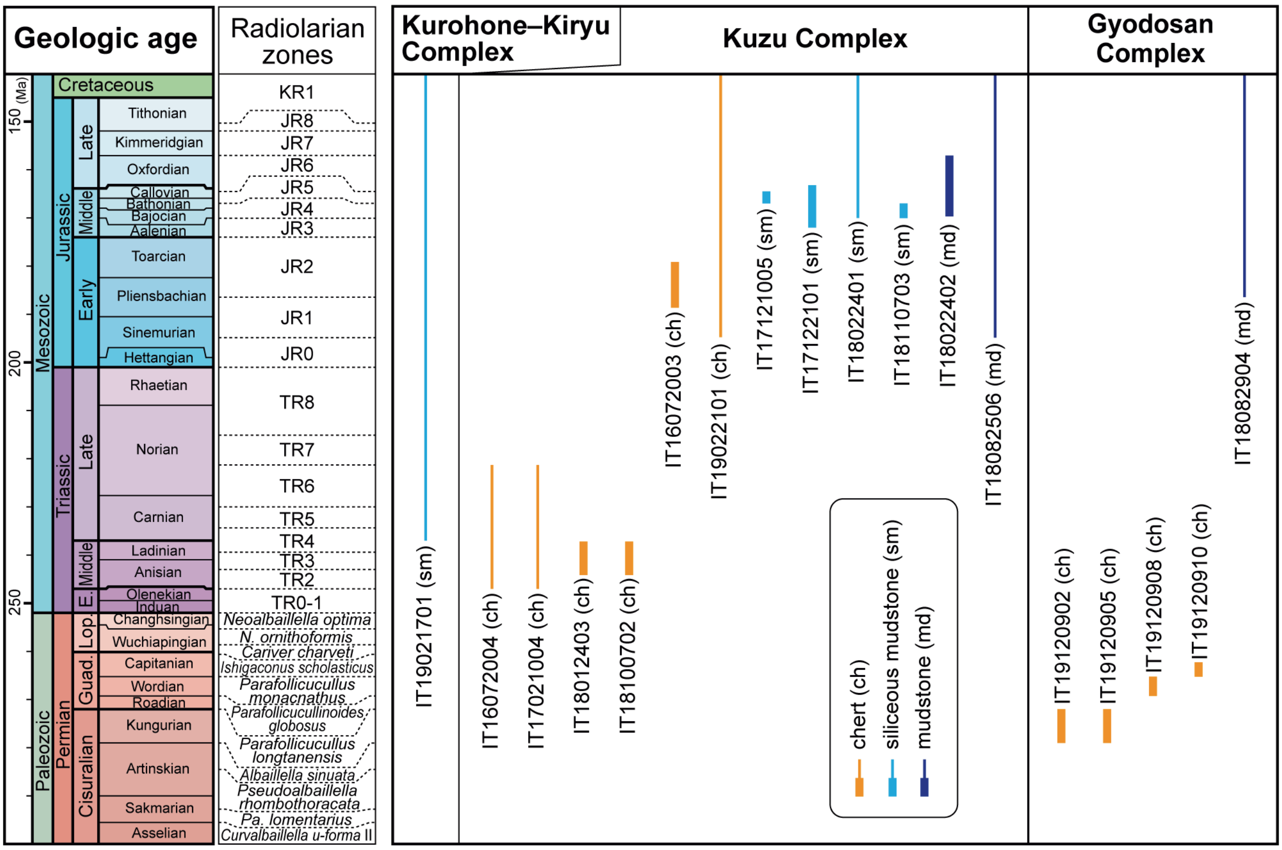


Fig. 14 Age assignment of the samples reported in this study. Geologic age follows Ogg *et al.* (2016). Radiolarian zones are based on Ishiga (1986, 1990), Sugiyama (1997), Kuwahara *et al.* (1998) and Matsuoka and Ito (2019). The names of Permian radiolarian zones are changed according to taxonomic reevaluation by Xiao *et al.* (2020, 2021). E.: Early; Lop.: Lopingian; Guad.: Guadalupian; *N.*: *Neoalbaillella*; *Pa.*: *Parafollicucullinoides*. Samples reliable in age are presented as thick bars, whereas those unreliable as thinner bars.

Bathonian–middle Callovian (Matsuoka and Ito, 2019).

(4) Mudstone

Striatojaponocapsa plicarum occurred in mudstone (e.g. OGR-17 of Kamata, 1996). *Striatojaponocapsa plicarum* occurred mainly in the lower–middle JR4, Bajocian, Middle Jurassic (Matsuoka and Ito, 2019).

5. 2 Omama Complex

5. 2. 1 Lower part

(1) Carbonate rocks

Carbonate rocks of the Omama Complex have yielded several types of fossils, such as fusulinids (Kawata and Ozawa, 1955; Hayashi and Hasegawa, 1981; Editorial team of Omama Town's history, 1996; Ito, 2021; Ito *et al.*, 2021b), brachiopods (Hayashi and Hasegawa, 1981; Editorial team of Omama Town's history, 1996; Tazawa and Takakuwa, 2009; Tazawa *et al.*, 2012), corals (Editorial team of Omama Town's history, 1996; Igo *et al.*, 2000), trilobites (Kobayashi and Hamada, 1984; Koizumi *et al.*, 1988; Editorial team of Omama Town's history, 1996) and chondrichthyes (Yabe, 1903; Reif and Goto, 1979; Takakuwa and Okabe, 2011; Takakuwa, 2021).

Occurrences of pre-Permian conodonts from the carbonate rocks have been reported by previous studies. Hayashi *et al.* (1990) and Editorial team of Omama Town's history (1996) claimed the presence of the "Devonian" and "Carboniferous" carbonate rocks, respectively, based on conodont occurrences such as *Neogondolella* sp. cf. *N. clarki*. However, Muto and Ito (2021) re-identified the conodont fossils and re-considered their ages as the Triassic. No certain evidence indicates the presence of the pre-Permian conodont from the carbonate rocks to date, thus the pre-Permian carbonate rocks are not shown in Fig. 15.

(2) Siliceous claystone

Kamata and Kajiwara (1996) investigated a continuous section composed of siliceous claystone and alternations of chert and siliceous claystone. They found conodonts (*Neogondolella bulgarica* (Budurov and Stefanov)) and radiolarians (*Triassocampe myterocorys* Sugiyama and *Oertlispongus diacanthus*). *Neogondolella bulgarica* is currently assigned as *Paragondolella bulgarica*, which is indicative of being the middle Anisian (Nicora, 1977; Chen *et al.*, 2016).

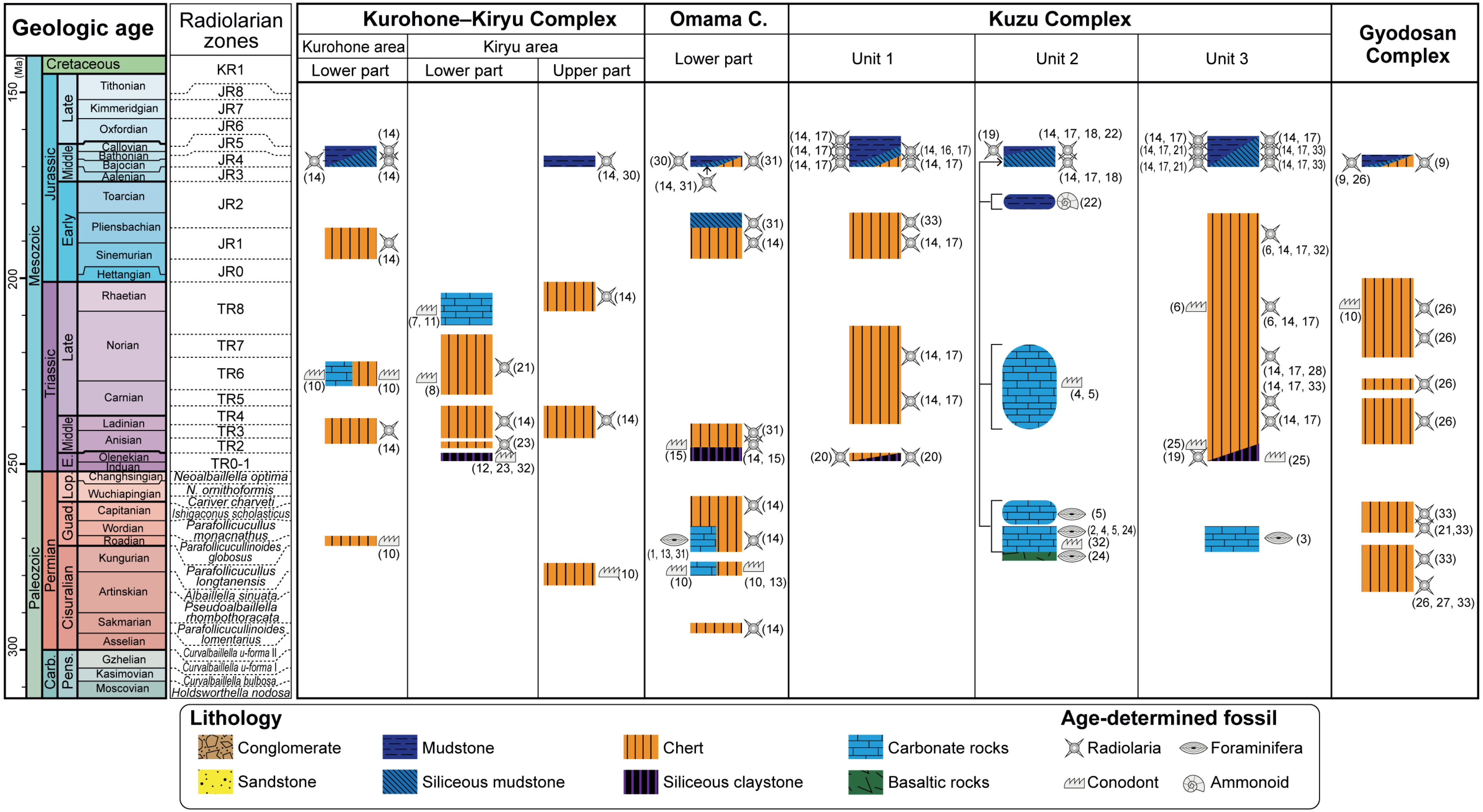


Fig. 15 Age of fossiliferous lithology of the Jurassic accretionary complex of the Ashio belt. Geologic age follows Ogg *et al.* (2016). Radiolarian zones are based on Ishiga (1986, 1990), Sugiyama (1997), Kuwahara *et al.* (1998) and Matsuoka and Ito (2019). The names of Permian radiolarian zones are changed according to taxonomic reevaluation by Xiao *et al.* (2020, 2021). Carb.: Carboniferous; Pens.: Pennsylvanian; E.: Early; Lop.: Lopingian; Guad.: Guadalupian; *N.*: *Neoalbaillella*. Parenthetic numbers indicate references for major fossil occurrences that determined the ages: 1: Kawata and Ozawa (1955); 2: Morikawa and Horiguchi (1956); 3: Yoshida (1957); 4: Conodont Research Group (1974); 5: Igo and Igo (1977); 6: Igo and Nishimura (1984); 7: Igo (1985); 8: Aono (1985); 9: Masuda (1989); 10: Hayashi *et al.* (1990); 11: Koike *et al.* (1991); 12: Sashida *et al.* (1992); 13: Editorial team of Omama Town's history (1996); 14: Kamata (1996); 15: Kamata and Kajiwara (1996); 16: Arakawa (1997); 17: Kamata (1997a); 18: Arakawa (1998); 19: Isogawa *et al.* (1998); 20: Kamata (1999); 21: Takayanagi *et al.* (2001); 22: Kamata *et al.* (2003); 23: Motoki and Sashida (2004); 24: Kobayashi (2006a); 25: Muto *et al.* (2018); 26: Ito (2019); 27: Ito (2020a); 28: Ito (2020b); 29: Muto *et al.* (2021); 30: Ito *et al.* (2021a); 31: Ito *et al.* (2021b); 32: Muto and Ito (2021); 33: this study.

(3) Chert

Permian, Triassic and Jurassic radiolarians occurred in chert (Kamata, 1996; Ito *et al.*, 2021b).

Parafollicucullinoides lomentarius (Ishiga) was obtained from sample NRK-15 of Kamata (1996). This species is a characteristic species of *Parafollicucullinoides lomentarius* Zone of the Sakmarian of Ishiga (1990). *Parafollicucullus fusiformis* Holdsworth and Jones occurred in sample WTRS-06 of Kamata (1996). This species occurred abundantly in the Guadalupian (e.g. Ishiga, 1990; Zhang *et al.*, 2014). *Follicucullus japonica* Ishiga, currently identified as *Follicucullus porrectus* Rudenko, was obtained from several samples (e.g. RMTG-36 of Kamata, 1996). *Follicucullus porrectus* was the characteristic species of the *Follicucullus porrectus* Interval Zone (lower Capitanian) of Zhang *et al.* (2014).

Pseudostylosphaera japonica and *Oertlispongus diacanthus* Sugiyama were obtained from sample RMTG-68 of Kamata (1996). The former and latter species occurred in TR2B–TR5A (middle Anisian–middle Carnian) and TR2A–TR2C (early–middle Anisian), respectively (Sugiyama, 1997). The co-occurrence of these genera is limited to the middle Anisian (Sugiyama, 1997).

Two samples (#204 and #269) yielded *Triassocampe* sp. cf. *T. coronata* Bragin (Ito *et al.*, 2021b). *Triassocampe coronata* occurred in the Anisian, Middle Triassic (Sugiyama, 1997).

Sample KSK-28 reported by Kamata (1996) yielded *Parahsuum simplum*. This is a characteristic species of the JR1 of the upper Sinemurian–lower Pliensbachian (Matsuoka and Ito, 2019); thus, this sample is probably the late Sinemurian–early Pliensbachian.

Protunuma sp. cf. *P. fusiformis* Ichikawa and Yao occurred in sample #271 reported by Ito *et al.* (2021b). *Protunuma fusiformis* occurred with *Striatojaponocapsa plicarum*, the characteristic species of JR4 of the Bajocian–lower Bathonian in previous studies (e.g. Matsuoka, 1985). Based on the occurrence, this sample is probably the Bajocian–Bathonian in age.

Hayashi *et al.* (1990) reported "early Carboniferous" conodonts from the Asabara area, the distributional area of the Omama Complex. Based on re-identification by Muto and Ito (2021), many of the illustrated specimens by Hayashi *et al.* (1990) were identified as Late Triassic species and some specimens are similar to Permian ones, while early Carboniferous species were not confirmed. Therefore, no certain evidence indicates the presence of the pre-Permian conodont from the chert to date.

Hayashi *et al.* (1990) reported *Neogondolella* sp. cf. *N. clarki* from the chert (fig. 34, pl. 1, Hayashi *et al.*, 1990). Muto and Ito (2021) re-identified them as *Mesogondolella gujioensis* (Igo). The occurrence range of this species is the late Artinskian–early Kungurian (Henderson, 2018).

(4) Siliceous mudstone

Middle Jurassic radiolarians occurred in siliceous mudstone (Kamata, 1996; Ito *et al.*, 2021b).

Sample KSK-40 reported by Kamata (1996) yielded *Striatojaponocapsa plicarum*. *Striatojaponocapsa plicarum* occurred mainly in the lower–middle JR4, Bajocian, Middle Jurassic (Matsuoka and Ito, 2019).

Sample #206 reported by Ito *et al.* (2021b) yielded *Archaeodictyomitra* sp. cf. *A. exiguum* Blome. *Archaeodictyomitra exiguum* was described on the basis of the specimens from the Callovian in the North America (Blome, 1984). This species also cooccurred with *Striatojaponocapsa plicarum* (Hattori, 1987), which occurred mainly in lower–middle JR4, Bajocian (Matsuoka and Ito, 2019). Consequently, the occurrence range of *Archaeodictyomitra exiguum* include the Bajocian–Callovian at least.

Sample #154 reported by Ito *et al.* (2021b) yielded *Eucyrtidiellum* sp. aff. *E. omanojaponicum* Dumitrica, Goričan and Hori. *Eucyrtidiellum omanojaponicum* (= *Eucyrtidiellum*? sp. C of Hori, 1990, 1997) occurred in the upper JR 1 corresponding approximately to the Pliensbachian (Hori, 1990, 1997).

(5) Mudstone

Ito *et al.* (2021a) reported two mudstone samples that yielded Middle Jurassic radiolarians based on the occurrence ranges of Matsuoka (1995) and Matsuoka and Ito (2019). Sample 111013-4 corresponds to lower–middle JR4, Bajocian; sample 111011-1 corresponds to upper JR4, lower Bathonian.

5. 2. 2. Upper part

Due to the lacking detail information, the upper part is not presented in Fig. 15. However, the Carboniferous carbonate rocks may exist in the upper part.

Fujimoto (1960) reported corals (*Amygdalophyllum naosoidea* Minato, *Lithostrotion pseudomartini* Yabe and Hayasaka and *Chaetetes* sp.) from "limestone lenses" of the Kawamo Formation in the Takatsudo Gorge in Midori City. Pelitic mixed rock around the Takatsudo Gorge is a typical representation of the upper part of the Omama Complex, so the "limestone lenses" are probably the blocks within the pelitic mixed rock. The age of the corals is assigned as the Visean (Mississippian, early Carboniferous) based on description by Minato (1951, 1955). Although the photographs were not presented, the upper part might include Carboniferous carbonate rocks as blocks within the pelitic mixed rock.

5. 3 Kuzu Complex

5. 3. 1 Unit 1

(1) Siliceous claystone

Early Triassic radiolarians and conodonts occurred in the siliceous claystone and intercalated chert within the siliceous claystone (Kamata, 1995, 1999). Kamata (1999) reported Spathian conodonts, such as *Triassospathodus curtatus* Orchard (Originally described as *Neospathodus triangularis* (Bender)), from sample TNK-R-09.

(2) Chert

Triassic conodonts and Triassic and Jurassic radiolarians occurred in chert (e.g. Hayashi, 1968a, b; Koike *et al.*, 1970, 1971; Kamata, 1995, 1996, 1997a, 1999).

Kamata (1996, 1997a) reported abundant Middle Triassic–Early Jurassic radiolarians from the chert. Yao *et al.* (1982) recognized four radiolarian assemblages from Middle Triassic–Early Jurassic, namely *Triassocampe deweveri*, *Triassocampe nova*, *Canoptum triassicum* and *Parahsuum simplum* assemblages. Characteristic species of these assemblages were obtained from the chert samples excluding *Canoptum triassicum* Yao.

Striatojaponocapsa plicarum was obtained from sample KS-01 of (Kamata, 1996, 1997a). This is a characteristic species of JR4, Bajocian–lower Bathonian (Matsuoka and Ito, 2019).

Kamata (1997b) described a float block of radiolarian-bearing chert breccia in the distributional area of Unit 1. He extracted Permian and Triassic radiolarians from the chert breccia. The chert breccia is not presented in Fig. 15.

(3) Siliceous mudstone

Middle Jurassic radiolarians occurred in siliceous mudstone (Kamata, 1996, 1997a; Arakawa, 1997).

Striatojaponocapsa plicarum were reported from siliceous mudstone samples (e.g. IZW-31 of Kamata, 1996, 1997a; SAY-02 of Arakawa, 1997). This is a characteristic species of JR4, Bajocian–lower Bathonian (Matsuoka and Ito, 2019). *Striatojaponocapsa conexa,* characteristic species of JR5 of the upper Bathonian–middle Callovian (Matsuoka and Ito, 2019), occurred in the siliceous mudstone samples (SPS-04 of Kamata, 1996, 1997a; SAY-01 of Arakawa, 1997). Consequently, the age of the mudstone ranges from the Bajocian to middle Callovian.

(4) Mudstone

Middle–Late Jurassic radiolarians occurred in mudstone (Kamata, 1996, 1997a).

The mudstone samples (e.g. AOKI-09 of Kamata, 1996, 1997a) yielded *Striatojaponocapsa plicarum* and *Striatojaponocapsa conexa*, which are characteristic species of JR4 and JR5, respectively. *Kilinora spiralis* (Matsuoka) was discovered from the mudstone (e.g. IZW-30 of Kamata, 1996, 1997a). This is a characteristic species of JR6 of the upper Callovian–Oxfordian (Matsuoka and Ito, 2019). Consequently, the age of the mudstone ranges from the Bajocian to Oxfordian.

5. 3. 2 Unit 2

Unit 2 comprises basaltic rocks, carbonate rocks, siliceous mudstone and mudstone, in ascending order. The siliceous mudstone intercalates limestone conglomerate layers.

(1) Basaltic rocks

Middle Permian foraminifers were obtained from limestone clasts included within basaltic rocks (Kobayashi, 2006a, b). According to Kobayashi (2006a, b), foraminifers from the limestone clasts correspond to the *Parafusulina nakamigawai* Zone to the lowermost *Parafusulina yabei* Zone. The *Parafusulina yabei* Zone corresponds to the middle Kungurian, lower Permian, based on the global fusuline biostratigraphy by Zhang and Wang (2018). This study tentatively regards the basaltic rocks as the middle Kungurian.

(2) Carbonate rocks

Carbonate rocks yielded abundant fossils, such as brachiopods (Hayasaka 1926, 1944; Tazawa *et al.*, 2016), foraminifers (Yabe, 1899; Hujimoto, 1938; Yoshida, 1956, 1957; Morikawa and Horiguchi, 1956; Morikawa and Takaoka, 1961; Fujimoto, 1961; Igo, 1964; Hatori, 1965; Saito and Kato, 1971; Conodont Research Group, 1972, 1974; Igo *et al.*, 1976; Igo and Igo, 1977; Kobayashi, 1979, 2006a, b), conodonts (Hayashi, 1971; Conodont Research Group, 1972, 1974; Koike *et al.*, 1974; Igo *et al.*, 1976; Muto *et al.*, 2021), trilobites (Fujimoto, 1961; Koizumi *et al.*, 1979), coral (Yamagiwa and Tsuda, 1980) and chondrichthyes (Goto, 1975, 1984, 1994; Reif and Goto, 1979).

The carbonate rocks correspond to the middle *Parafusulina yabei* to *Parafusulina tochigiensis* zones, according to fusuline biostratigraphy constructed by Kobayashi (2006a, b). The *Parafusuina yabei* Zone corresponds to the middle Kungurian (Zhang and Wang, 2018); middle *Parafusulina tochigiensis* Zone corresponds to the Wordian (Kobayashi, 2006a). Muto *et al.* (2021) reported conodont fossils, *Mesogondolella idahoensis* (Youngquist, Hawley and Miller) and *Sweetognathus hanzhonensis* (Wang), from samples (e.g. 2014-215) belonging to the middle *Parafusulina yabei* Zone. The conodont species indicate the late Kungurian in age. Thus, the carbonate rocks are the late Kungurian–Wordian, early–middle Permian in age.

(3) Siliceous mudstone

Middle Jurassic radiolarians occurred in siliceous mudstone (Kamata, 1996, 1997a; Arakawa, 1998; Kamata and Mizobe, 2001; Kamata *et al.*, 2003).

Striatojaponocapsa plicarum occurred in siliceous mudstone samples (e.g. YZK-14 of Kamata, 1996, 1997a). This is a characteristic species of JR4, Bajocian–lower Bathonian, Middle Jurassic (Matsuoka and Ito, 2019).

Striatojaponocapsa conexa were obtained from sample YZK-13 of Kamata (1996, 1997a). This is a characteristic species of JR5, upper Bathonian–Callovian, Middle Jurassic (Matsuoka and Ito, 2019).

Arakawa (1998) extracted radiolarian assemblages from manganese dioxide nodules (KUS01, KUS02, KUS03) in the siliceous mudstone. The former two samples yielded *Striatojaponocapsa plicarum*, and the latter one sample yielded *Striatojaponocapsa conexa*.

The limestone conglomerate is intercalated in the siliceous mudstone. Middle Permian foraminifers and Middle–Upper Triassic conodonts were obtained from limestone gravels within the conglomerate (e.g. Morikawa and Horiguchi, 1956; Conodont Research Group, 1974; Igo and Igo, 1977). In addition, Kamata *et al.* (2003) discovered ammonite, *Cleviceras* sp. cf. *C. chrysanthemum* (Yokoyama), from a mudstone pebble within the conglomerate. The age of the ammonite is assigned as the early–middle Toarcian, Early Jurassic (Kamata *et al.*, 2003). Kamata and Mizobe (2001) and Kamata *et al.* (2003) also determined the radiolarians of siliceous mudstone beds that intercalates the ammonite-bearing conglomerate and extracted radiolarians of JR4 (Bajocian–lower Bathonian, Middle Jurassic) of Matsuoka and Ito (2019).

Based on these occurrences, Fig. 15 shows that middle Permian and Middle–Upper Triassic limestone gravels and Lower Jurassic mudstone gravels are included in the Middle Jurassic siliceous mudstone.

(4) Mudstone

Isogawa *et al.* (1998) described radiolarian assemblages including *Striatojaponocapsa conexa* from mudstone samples (YZB-02, 03, 05). This is a characteristic species of JR5 of the upper Bathonian–Callovian (Matsuoka and Ito, 2019).

5. 3. 3 Unit 3

(1) Carbonate rocks

Yoshida (1957) and Fujimoto (1961) described Permian fusulinids (e.g. *Parafusulina* sp.) from limestone in the distributional area of Unit 3. The limestone was considered as the component of Unit 3 (e.g. Yoshida, 1957; Kamata, 1997a). Meanwhile, several researchers mentioned another opinion that it is the component of Unit 2 (e.g. Fujimoto, 1961; Yanagimoto, 1973).

(2) Siliceous claystone

Muto *et al.* (2018) investigated a continuous section consisting of siliceous claystone and chert, namely the Ogama section, and extracted conodonts and radiolarians. According to their work, almost of the siliceous claystone beds correspond to the Olenekian–lower Anisian.

(3) Chert

Several studies reported Triassic conodonts and Triassic and Jurassic radiolarians from chert (Kamata, 1996, 1997a; Isogawa *et al.*, 1998; Ootaka *et al.*, 1998; Takayanagi *et al.*, 2001; Suzuki *et al.*, 2002; Ito, 2020b).

Isogawa *et al.* (1998) reported Early Triassic radiolarians, such as *Parentactinia nakatsugawaensis*. Muto *et al.* (2018) discovered middle Anisian conodont, *Paragondolella bulgarica* Budurov and Stefanov.

Igo and Nishimura (1984) discovered conodont and radiolarian occurrences from Upper Triassic–Lower Jurassic continuous sections. Kamata (1996, 1997a) reported abundant Middle Triassic–Early Jurassic radiolarians. All characteristic species of the four assemblages proposed by Yao *et al.* (1982), namely *Triassocampe deweveri*, *Triassocampe nova*, *Canoptum triassicum* and *Parahsuum simplum* assemblages, were obtained. Sample IT16072003 is the early Pliensbachian–middle Toarcian of the Early Jurassic as mentioned in subsection 4.3.1. Due to the abundant fossil occurrences of Triassic–Early Jurassic, the chert of this unit is represented as a continuous sequence in Fig. 15.

(4) Siliceous mudstone

Striatojaponocapsa plicarum, *Striatojaponocapsa conexa* and *Kilinora spiralis* were discovered in siliceous mudstone samples (e.g. KOM-05 of Kamata, 1996, 1997a). These are characteristic species of JR4 (Bajocian–lower Bathonian), JR5 (upper Bathonian–Callovian) and JR6 (uppermost Callovian–Oxfordian), respectively (Matsuoka and Ito, 2019). As mentioned in subsection 4.3.3, the ages of samples IT17122101 and 18110703 are late Bathonian–Callovian and Bathonian, respectively. Thus, the age of the siliceous mudstone ranges from the Bajocian to Oxfordian.

(5) Mudstone

Striatojaponocapsa plicarum and *Striatojaponocapsa conexa* occurred in mudstone samples (e.g. KD-05 of Kamata, 1996, 1997a; ASK-8 of Takayanagi *et al.*, 2001). *Kilinora spiralis* was obtained from sample KOM-04 of Kamata (1996, 1997a). The age of the mudstone ranges from the Bajocian to Oxfordian.

5. 4 Gyodosan Complex

(1) Chert

Permian, Triassic and Jurassic radiolarians with a few conodonts have been reported from chert (Masuda, 1989; Hayashi *et al.*, 1990; Takayanagi *et al.*, 2001; Sashida, 2008; Ito, 2019, 2020a).

Ito (2019) reported early Permian radiolarians from the red chert samples (IT16071005 and IT16071006). Thereafter, Ito (2020a) investigated the radiolarian fauna from the Hachioji section including the sample horizons of Ito (2019). Based on the occurrences of *Haplodiacanthus sakmarensis* (Kozur), *Pseudoalbaillella japonica*, *Pseudoalbaillella postscalprata* and *Pseudoalbaillella rhombothoracata* Ishiga and Imoto, Ito (2020a) concluded that the lower to middle parts of the Hachioji section partially correspond to the lower Kungurian and may include the uppermost Artinskian. In addition, the Wordian and Capitanian chert near the Hachioji section was identified in this study (Fig. 3) as mentioned in section 4.1.

Ito (2019) reported Triassic radiolarians from the following samples. Sample IT16071201 yielded spines A2, B5, D1 and D2 of Sugiyama (1997). The co-occurrence range of these spines is restricted to TR6A, uppermost Carnian–lowermost Norian (Sugiyama, 1997). Sample IT16071403 yielded spines C and D1 of Sugiyama (1997). Co-occurrence range of these spines is limited in the TR5A, Carnian (Sugiyama, 1997). Sample IT16071405 yielded *Mesosaturnalis octospinus* Sugiyama. This species occurred in TR7–TR8A, middle Norian (Sugiyama, 1997). Sample IT16071402 yielded *Praehexasaturnalis* sp. cf. *P. tenuispinosus* (Kozur and Mostler). The occurrence range of the *Praehexasaturnalis tenuispinosus* group is TR7–JR0A, middle Norian–lower Hettanginian, Upper Triassic–lowermost Jurassic (Sugiyama, 1997). Sample IT16112604 yielded *Tritortis kretaensis* (Kozur and Krahl). This species occurred in TR4A–TR5A, upper Ladinian–lower Carnian, Middle–Upper Triassic (Sugiyama, 1997).

Hayashi *et al.* (1990) reported Triassic conodont, *Misikella* sp., from the "Ota City, Maruyama" (figs. 7, 8, pl. 1, Hayashi *et al.*, 1990). This is possibly located in the distributional area of the Gyodosan Complex. According to age re-consideration by Muto and Ito (2021), the age is the latest Norian–Rhaetian, Late Triassic.

Some possible Jurassic radiolarians were obtained from chert. For example, Takayanagi *et al.* (2001) reported *Pantanellium*? sp. from two samples (ASK-13 and ASK-15); Ito (2019) reported *Parahsuum* sp. from sample IT16071206. Certain Jurassic radiolarians were reported by Masuda (1989): a chert sample (No. 9) yielded *Eucyrtidiellum unumaense* (Yao) and *Unuma echinatus* Ichikawa and Yao. The former species occurred mainly in JR4–JR5 of the Bajocian–lower Callovian (Matsuoka, 1995); the latter species occurred in JR3–JR4, Aalenian–Bathonian (Matsuoka and Yao (1986). Based on the co-occurrence, the chert sample is JR4, Bajocian–lower Bathonian in age.

(2) Siliceous mudstone

Ito (2019) discovered *Striatojaponocapsa synconexa* from sample IT167071001. This species occurred in upper JR4–lower JR5, Bathonian (Matsuoka and Ito, 2019).

(3) Mudstone

Masuda (1989) reported a radiolarians assemblage indicating JR4 (Bajocian–lower Bathonian) from the chert. He noted that a similar radiolarian assemblage was obtained from the manganese nodule (sample No. 1) in the mudstone, although photographs were not shown. The mudstone of this complex is the Bajocian–lower Bathonian in age.

6. Reconstruction of ocean plate stratigraphy

In this article, the author reported Permian, Triassic and Jurassic radiolarian occurrences from the Kiryu and Ashikaga District and determined their ages (Fig. 14). In addition, previous fossil occurrences from the Jurassic accretionary complex including neighbor districts (e.g. Kuzu District) were summarized (Fig. 15).

This article provides basic data on age of the Jurassic accretionary complex in the Ashio Mountains and essential information for reconstruction of ocean plate stratigraphy (OPS) of each complex of the Jurassic accretionary complex. The OPS of an accretionary complex presents lithologic change reflecting history of an ocean plate from birth at a mid ocean ridge to subduction at a trench via an abyssal plain. The OPS of the Jurassic accretionary complexes in Japan is generally composed of basaltic rocks, carbonate rocks, chert, siliceous mudstone, mudstone and sandstone, in ascending order (e.g. Isozaki *et al.*, 1990; Matsuda and Isozaki, 1991; Nakae, 2000; Wakita and Metcalfe, 2005; Wakita, 2015).

The OPS of each complex of the Jurassic accretionary complex in the Ashio Mountains is reconstructed here (Fig. 16). The fossil occurrences were described by each distributed area and stratigraphic part for the Kurohone–Kiryu and Omama complexes in chapter 5. In this chapter, the author reconstructs the OPS of the complexes using the merged data from each area and part.

The Kurohone–Kiryu Complex comprises basaltic rocks (possibly early Permian), chert (early–middle Permian, Middle–Late Triassic and Early Jurassic), siliceous claystone (Early Triassic), carbonate rocks (Late Triassic), siliceous mudstone (Middle Jurassic), mudstone (Middle Jurassic) and sandstone (possibly Middle Jurassic).

The Omama Complex comprises basaltic rocks (possibly early Permian), chert (early–middle Permian, Middle Triassic and Early Jurassic), carbonate rocks (early–middle Permian), siliceous claystone (possibly Early Triassic), siliceous mudstone (Early–Middle Jurassic), mudstone (Middle Jurassic) and sandstone (possibly Middle Jurassic).

In the Kuzu Complex, Unit 1 comprises siliceous claystone (Early Triassic), chert (Early–Late Triassic and Early–Middle Jurassic), siliceous mudstone (Middle Jurassic), mudstone (Middle–Late Jurassic) and sandstone (possibly Late Jurassic). Unit 2 comprises basaltic rocks (early Permian), carbonate rocks (early–middle Permian), siliceous mudstone (Middle Jurassic) and mudstone (Middle Jurassic). The siliceous mudstone of Unit 2 interbeds conglomerate layers containing gravels of carbonate rocks (early–middle Permian and Middle–Late Triassic) and mudstone (Early Jurassic). Unit 3 comprises basaltic rocks (possibly middle Permian), carbonate rocks (middle Permian), siliceous claystone (Early Triassic), chert (Early–Late Triassic and Early Jurassic), siliceous mudstone (Middle–Late Jurassic), mudstone (Middle–Late Jurassic) and sandstone (possibly Late Jurassic).

The Gyodosan Complex is composed of chert (early–middle Permian, Middle–Late Triassic and Middle Jurassic), siliceous mudstone (Middle Jurassic), mudstone (Middle Jurassic) and sandstone (possibly Middle Jurassic).

7. Paleontological note

The taxonomic classification in this chapter mainly employs the scheme of De Wever *et al.* (2001), O'Dogherty *et al.* (2009a, b) and Noble *et al.* (2017).

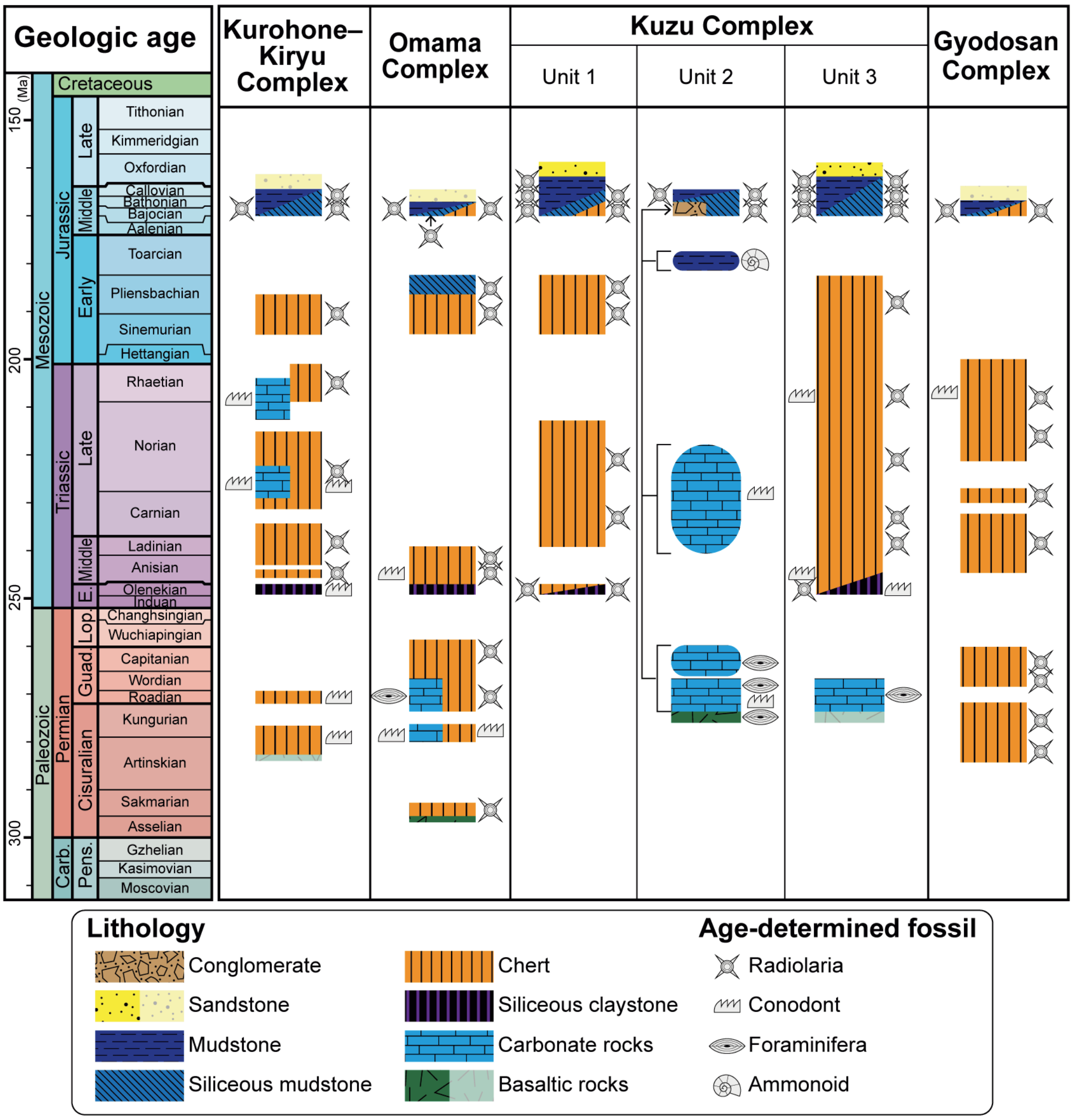


Fig. 16 Reconstructed ocean plate stratigraphy of the Jurassic accretionary complex of the Ashio belt. Geologic age follows Ogg *et al.* (2016). Deep-colored lithology with fossil illustration: its age is relatively-precisely determined by fossil. Deep-colored lithology without fossil illustration: although its component rock has never yielded age-determined fossil, its age can be speculated based on stratigraphical relationships with overlying and underlying fossiliferous rocks. Pale-colored lithology: its component rock has never yielded age-determined fossil and its age cannot be speculated by stratigraphical relationships. Carb.: Carboniferous; Pens.: Pennsylvanian; E.: Early; Lop.: Lopingian; Guad.: Guadalupian.

The belongingness of the subfamily Japonocapsinae Kozur follows O'Dogherty *et al.* (2009a). The generic classification of Permian albaillellarians employs recent studies by Xiao *et al.* (2020, 2021). Description of some non-taxonomic names (e.g. spine, spherical polycystine, three-segmented closed nassellarian) is also shown in this chapter, in addition to the taxonomic names.

7. 1 Taxonomic name

Subclass **RADIOLARIA** Müller, 1858
Order **ENTACTINARIA** Kozur and Mostler, 1982
Family **ENTACTINIIDAE** Riedel, 1967

Genus ***Stigmosphaerostylus*** Rüst, 1892, emend Foreman, 1963
Type species *Stigmosphaerostylus notabilis* Rüst, 1892

***Stigmosphaerostylus*? sp.**
Figs. 4.1, 4.14, 4.22
Remarks: The specimens are characterized by a spherical shell with some spicules. *Stigmosphaerostylus* is presented with a question mark because of the poor preservation.

Family **EPTINGIIDAE** Dumitrica, 1978
Genus ***Eptingium*** Dumitrica, 1978

Type species *Eptingium manfredi* Dumitrica, 1978

Eptingium* sp. cf. *E. nakasekoi (Kozur and Mostler, 1994)

Fig. 5.48

Remarks: The specimen examined has two main spines which are three-bladed but not twisted, although one main spine seems to be lost. It closely resembles *Eptingium nakasekoi* Kozur and Mostler (Kozur and Mostler,1994).

Genus ***Xenorum*** Blome, 1984

Type species *Xenorum largum* Blome, 1984

***Xenorum*? sp.**

Fig. 5.52

Remarks: The specimen possesses an outer layer consisting of polygonal pore frames with massive nodes. The form resembles the genus *Xenorum* Blome established by Blome (1984).

Family **HINDEOSPHAERIDAE** Kozur and Mostler, 1981

Genus ***Pseudostylosphaera*** Kozur and Mostler, 1981

Type species *Pseudostylosphaera gracilis* Kozur and Mock in Kozur and Mostler, 1981

Pseudostylosphaera* sp. cf. *P. japonica (Nakaseko and Nishimura, 1979)

Figs. 5.36, 5.38, 5.41, 5.44

Remarks: The specimens have two opposite polar spines that are moderately long, massive and three bladed. These characteristics closely resemble those of *Pseudostylosphaera japonica* Nakaseko and Nishimura described by Nakaseko and Nishimura (1979) although the preservation of the specimens is poor.

***Pseudostylosphaera* sp.**

Figs. 5.37, 5.39, 5.40, 5.42, 5.43, 5.45, 5.55, 5.56

Remarks: The specimens have two opposite polar three-bladed spines. The characteristics closely resemble *Pseudostylosphaera* Kozur and Mostler established by Kozur and Mostler (1981).

***Pseudostylosphaera*? sp.**

Fig. 5.5

Remarks: The specimen seems to have two opposite polar three-bladed spines and resembles *Pseudostylosphaera*. However, the detailed structure of the spines cannot be observed because of poor preservation. The specimen is therefore presented as *Pseudostylosphaera* with a question mark.

Order **LATENTIFISTULARIA** Caridroit, De Wever and Dumitrica, 1999

Family **LATENTIFISTULIDAE** Nazarov and Ormiston, 1983

Genus ***Latentifistula*** Nazarov and Ormiston, 1983

Type species *Latentifistula crux* Nazarov and Ormiston, 1983

***Latentifistula*? sp.**

Figs. 4.10–4.13, 4.20, 4.21

Remarks: The specimens possess thick, spongy shells with three coplanar arms. The characteristics are similar to those of the genus *Latentifistula* Nazarov and Ormiston established by Nazarov and Ormiston (1983); however, they are presented as *Latentifistula* with the question mark because of poor preservation.

Family **RUZHENCEVISPONGIDAE** Kozur, 1980

Genus ***Scharfenbergia*** Won, 1983, emend. Kozur and Mostler (1989)

Type species *Spongotripus concentricus* Rüst, 1892

***Scharfenbergia*? sp.**

Fig. 4.17

Remarks: The specimen is characterized by triangular spongy test with short arms originating from the corners of the triangular test. The form is similar to the genus *Scharfenbergia* Won established by Won (1983); however, the detailed structure cannot be observed because of the poor preservation. The specimen is therefore presented as *Scharfenbergia* with a question mark.

Family **ORMISTONELLIDAE** De Wever and Caridroit, 1984, emend. Dumitrica in De Wever *et al.*, 2001

Genus ***Quadricaulis*** Caridroit and De Wever, 1986

Type species *Quadricaulis femoris* Caridroit and De Wever, 1986

***Quadricaulis*? sp.**

Figs. 4.18, 4.25, 4.41, 4.45

Remarks: The specimens have a nonporous shell composed of a sphere with at least two arms. The characteristics resemble those of the genus *Quadricaulis* Caridroit and De Wever established by Caridroit and De Wever (1986); however, the detailed structure cannot be observed because of the poor preservation. The specimen is therefore presented as *Quadricaulis* with a question mark.

Genus ***Polyfistula*** Nazarov and Ormiston, 1984

Type species *Polyfistula longiquitas* Nazarov and Ormiston, 1984

Polyfistula* sp. aff. *P. hexalobata Nazarov and Ormiston, 1989

Figs. 4.16, 4.35

Remarks: The specimens have several horizontal slender arms originating from a platy disc. The characteristics are consistent with those of the genus *Polyfistula* Nazarov and Ormiston established by Nazarov and Ormiston (1984). The specimens are similar to *Polyfistula hexalobata* Nazarov and Ormiston in terms of having five horizontal slender rays. However, the specimens differ from *Polyfistula hexalobata* as they lack a clear vertical ray originating from the center of the platy disc.

Polyfistula **sp.**

Fig. 4.15

Remarks: The specimen has at least three horizontal slender arms originating from a platy disc. However, the exact number of rays and surface structure of the platy disc, which are the diagnostic characteristics of species level of the genus, cannot be observed.

Family **MUELLERITORTIIDAE** Kozur, 1988

Genus ***Muelleritortis*** Kozur, 1988

Type species *Emiluvia*? *cochleata* Nakaseko and Nishimura, 1979

Muelleritortis**? sp.**

Fig. 5.51

Remarks: One twisted thick spine remained in the specimen. This type of spine is known in *Muelleritortis cochleata* (Nakaseko and Nishimura), which was originally described as *Emiluvia*? *cochleata* by Nakaseko and Nishimura (1979). Thus, the specimen may be a *Muelleritortis cochleata* that lost three arms. Meanwhile, some species of other genera, such as *Pseudostylosphaera nazarovi* (Kozur and Mostler) and *Tritortis kretaensis* Kozur and Krahl, also possess a twisted thick spine. The specimen is therefore identified as *Muelleritortis* Kozur with a question mark in this article.

Order **NASSELLARIA** Ehrenberg, 1875

Family **RUESTICYRTIIDAE** Kozur and Mostler, 1979

Genus ***Triassocampe*** Dumitrica, Kozur and Mostler, 1980

Type species *Triassocampe scalaris* Dumitrica, Kozur and Mostler, 1980

Triassocampe **sp. cf. *T. deweveri*** (Nakaseko and Nishimura, 1979)

Figs. 5.16, 5.29

Remarks: The specimens have a subcylindrical multi-segmented shell with dome-shaped cephalis. The segments are characterized by well-developed ridges. The characteristics resemble those of *Triassocampe deweveri* (Nakaseko and Nishimura) described by Nakaseko and Nishimura (1979). Because the specimens are partially broken, they are presented as the species with confer.

Triassocampe **sp.**

Fig. 5.10, 5.30, 5.34

Remarks: The specimens are characterized by a subcylindrical multi-segmented shell without an apical horn. In addition, pores are arranged in transverse rows for each segment. The characteristics resemble those of the genus *Triassocampe* Dumitrica, Kozur and Mostler (Dumitrica *et al.*, 1980).

Triassocampe**? sp.**

Figs. 5.6, 5.11–5.15, 5.17–5.19, 5.24, 5.25, 5.28. 5.31, 5.33, 5.35

Remarks: The specimens have subcylindrical a multi-segmented shell. Because of the poor preservation in an apical part and surface pores, they are presented as *Triassocampe* with a question mark.

Genus ***Annulotriassocampe*** Kozur and Mostler, 1994

Type species *Annulotriassocampe campanilis* Kozur and Mostler, 1994

Annulotriassocampe **sp.**

Figs. 5.26, 5.27

Remarks: The specimens have a long-conical shell. The segments are hoop-like and possess one ring of pores. These characteristics closely resemble those of the genus *Annulotriassocampe* Kozur and Mostler established by Kozur and Mostler (1994).

Genus ***Yeharaia*** Nakaseko and Nishimura, 1979

Type species *Yeharaia elegans* Nakaseko and Nishimura, 1979

Yeharaia **sp.**

Fig. 5.32

Remarks: The specimen has a well-developed apical horn. This characteristic closely resembles that of the genus *Yeharaia* Nakaseko and Nishimura established by Nakaseko and Nishimura (1979).

Family **DIACANTHOCAPSIDAE** O'Dogherty, 1994

Subfamily **JAPONOCAPSINAE** Kozur, 1984

Genus ***Japonocapsa*** Kozur, 1984

Type species *Tricolocapsa*? *fusiformis* Yao, 1979

Japonocapsa **sp. aff. *J. fusiformis*** (Yao, 1979) sensu Matsuoka (1983)

Fig. 9.5

Remarks: The specimen is characterized by a fusiform shell with a fourth segment that is dish-like and sparsely pored. Such characteristics resemble those of *Japonocapsa fusiformis* (Yao) originally described as *Tricolocapsa*? *fusiformis* by Yao (1979). Matsuoka (1983) described *Japonocapsa* sp. aff. *J. fusiformis* that has smaller basal appendage than *Japonocapsa fusiformis*. The specimen also has the small basal appendage and closely resembles *Japonocapsa* sp. aff. *J. fusiformis*.

Genus ***Striatojaponocapsa*** Kozur, 1984

Type species *Tricolocapsa plicarum* Yao, 1979

Striatojaponocapsa synconexa O'Dogherty, Goričan and Dumitrica, 2006

Fig. 10.1

Remarks: The specimen has a small basal appendage with a circular depression. It is closely similar to

Striatojaponocapsa synconexa O'Dogherty, Goričan and Dumitrica studied by O'Dogherty *et al.* (2006) and Hatakeda *et al.* (2007).

***Striatojaponocapsa* sp.**
Fig. 11.1
Remarks: The specimen is closely similar to *Striatojaponocapsa conexa* (Matsuoka) in outline of the shell. The specimen is presented as *Striatojaponocapsa* sp. because its surface structure and basal appendage, major criteria for identification, cannot be observed.

***Striatojaponocapsa*? sp.**
Figs. 10.3, 10.5, 10.10
Remarks: The outline of the specimens resemble some species of *Striatojaponocapsa*, such as *S. conexa* and *S. synconexa*. The specimens are presented as *Striatojaponocapsa* with a question mark because of poor preservation.

Genus ***Yaocapsa*** Kozur, 1984
Type species *Cyrtocapsa mastoidea* Yao, 1979
***Yaocapsa*? sp.**
Fig. 10.15
Remarks: The specimen has a large last segment. The genus *Yaocapsa* Kozur is also characterized by a large last segment. Meanwhile, the preservation of the specimen is very poor, and the segment cannot be clearly observed. The specimen is therefore presented as *Yaocapsa* with a question mark.

Family **STICHOCAPSIDAE** Haeckel, 1881
Genus ***Stichocapsa*** Haeckel, 1881
Type species *Stichocapsa jaspidea* Rüst, 1885

"*Stichocapsa*" sp. E sensu Baumgartner *et al.* (1995)
Fig. 10.2
Remarks: The specimen has spherical cephalis without apical horn and truncate-conical thorax and abdomen. The large last segment can be observed, although the last segment is partially broken. The characteristics are similar those of "*Stichocapsa*" sp. E sensu Baumgartner *et al.* (1995). *Stichocapsa* Haeckel is currently considered as *nomen dubium* (O'Dogherty *et al.*, 2009a), so the generic name is presented as *Stichocapsa* with double quotations.

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

Eucyrtidiellum* sp. cf. *E. unumaense (Yao, 1979)
Fig. 10.16
Remarks: The specimen is characterized by having a small cephalis with apical horn and truncate-conical thorax. The characteristics are similar as those of *Eucyrtidiellum unumaense* (Yao), although some structures (e.g. surface, fourth segment) were lost.

Eucyrtidiellum gunense Cordey, 1998
Fig. 6.11
Remarks: *Eucyrtidiellum gunense* Cordey has stout and longer apical horn in the cephalis with conical thorax (Cordey, 1998; Goričan *et al.*, 2006). The characteristics of the specimen closely resemble those of *Eucyrtidiellum gunense*.

***Eucyrtidiellum* sp.**
Figs. 6.3, 6.6, 6.12
Remarks: The specimens have a small cephalis and dome-shaped thorax. These characteristics are similar to those of the genus *Eucyrtidiellum* Baumgartner established by Baumgartner (1984).

Family **PSEUDODICTYOMITRIDAE** Pessagno, 1977b
Genus ***Mizukidella*** O'Dogherty, Goričan and Gawlick, 2017
Type species *Dictyomitrella*? *kamoensis* Mizutani and Kido, 1983

***Mizukidella*? sp.**
Fig. 9.31
Remarks: *Mizukidella* O'Dogherty, Goričan and Gawlick is characterized by a multicyrtid conical to subcylindrical shell having nodose circumferential ridges (O'Dogherty *et al.*, 2017). The specimen also has nodose circumferential ridges and resembles some species of the genus, such as *Mizukidella kamoensis* (Mizutani and Kido), a type species of the genus. However, the preservation is poor and other characteristics cannot be observed, so that it is presented as the genus with a question mark.

Family **PARVICINGULIDAE** Pessagno, 1977a
Genus ***Takemuraella*** O'Dogherty, Goričan and Gawlick, 2017
Type species *Triversus japonicus* Takemura, 1986

Takemuraella* sp. cf. *T. japonica (Takemura, 1986)
Fig. 10.19
Remarks: *Takemuraella japonica* (Takemura), originally described as *Triversus japonicus* by Takemura (1986), has a shell composed of small cephalis and conical thorax with irregularly distributed pores and pore frames (Takemura, 1986; O'Dogherty *et al.*, 2017). The characteristics of the specimen is similar to the species, although the surface is poorly preserved.

Family **ARCHAEODICTYOMITRIDAE** Pessagno, 1976
Genus ***Archaeodictyomitra*** Pessagno, 1976
Type species *Archaeodictyomitra squinaboli* Pessagno, 1976

***Archaeodictyomitra* sp.**
Figs. 10.18, 10.20, 12.11
Remarks: The specimens have linearly arranged,

continuous costae with pores in a single row between the costae. They are similar to species of the genus *Archaeodictyomitra* Pessagno established by Pessagno (1977a).

Family **HSUIDAE** Pessagno and Whalen, 1982
Genus ***Hsuum*** Pessagno, 1977a
Type species *Hsuum cuestaensis* Pessagno, 1977a

Hsuum maxwelli Pessagno, 1977a
Figs. 9.25, 10.17
Remarks: The specimens are characterized by discontinuous, diverging costae. In particular, the cephalis of the specimens has the clear costae and lacks an apical horn. *Hsuum maxwelli* Pessagno has these characteristics (Pessagno, 1977a), whereas other major species of *Hsuum* Pessagno lack clear costae in the cephalis and/or have an apical horn.

Genus ***Parahsuum*** Yao, 1982
Type species *Parahsuum simplum* Yao, 1982

Parahsuum simplum Yao, 1982
Fig. 6.16
Remarks: According to some studies (e.g. Yao, 1982; Hori and Yao, 1988), *Parahsuum simplum* Yao possesses a conical shell with smooth-edged, continuous, longitudinal costae and differs from other species of *Parahsuum* Yao in having shorter, smaller apical horn. The specimen has the characteristics in the shell.

Parahsuum* sp. cf. *P. simplum Yao, 1982
Fig. 6.15
Remarks: The specimen possesses a conical shell with smooth-edged, continuous, longitudinal costae. Although these characteristics are similar to those of *Parahsuum simplum*, the shell of the specimens were partially broken and thereby the distinguished characteristics (e.g. shorter, smaller apical horn) cannot be observed.

Parahsuum transiens Hori and Yao, 1988
Figs. 6.13, 6.14
Remarks: The specimens have a long, conical shell with smooth-edged, continuous, longitudinal costae. The distal portion of the shell bears weak circumferential ridges. These characteristics closely resemble those of *Parahsuum transiens* Hori and Yao described by Hori and Yao (1988).

***Parahsuum*? sp.**
Figs. 6.23, 6.26
Remarks: The specimen has linearly arranged, continuous costae. *Parahsuum* has these characteristics (Yao, 1982). However, the pores are unclear because of the poor preservation. Other genera of Hsuidae Pessagno and Whalen, such as *Hsuum* Pessagno, is also characterized by linearly arranged, continuous costae and distinguished from *Parahsuum* by features of the pores. Thus, the specimens are represented as *Parahsuum* with a question mark.

Family **WILLIRIEDELLIDAE** Dumitrica, 1970
Genus ***Williriedellum*** Dumitrica, 1970
Type species *Williriedellum crystallinum* Dumitrica, 1970

Williriedellum*? *marcucciae Cortese, 1993
Fig. 11.2
Remarks: The specimen seems to have an oval shell with its surface cut by numerous polygonal depressing facets. The outline of the shell is closely similar to *Williriedellum*? *marcucciae* Cortese described as *Williriedellum*? *marcuccii* by Cortese (1993).

Order **SPUMELLARIA** Ehrenberg, 1875
Family **PANTANELLIDAE** Pessagno, 1977b
Genus ***Pantanellium*** Pessagno, 1977a
Type species *Pantanellium riedeli* Pessagno, 1977a

***Pantanellium*? sp.**
Figs. 6.35–6.37
Remarks: The specimens have a subspherical shell and possibly two polar spines. They are similar to some species of the genus *Pantanellium* Pessagno described by Pessagno (1977a).

Genus ***Trillus*** Pessagno and Blome, 1980
Type species *Trillus seidersi* Pessagno and Blome, 1980

***Trillus*? sp.**
Figs. 6.41
Remarks: The specimen has bipolar massive spines characterized by wide ridges and wide grooves. Such characteristics are known in species of genus *Trillus* Pessagno and Blome, such as *Trillus elkhornensis* Pessagno and Blome (Pessagno and Blome, 1980), so this specimen may be the species.

Family **CAPNUCHOSPHAERIDAE** De Wever, 1979 in De Wever *et al.*, 1979
Genus ***Capnuchosphaera*** De Wever, 1979 in De Wever *et al.*, 1979
Type species *Capnuchosphaera triassica* De Wever, 1979 in De Wever *et al.*, 1979

***Capnuchosphaera*? sp.**
Fig. 5.53
Remarks: The specimen has a spongy shell with one conical arm and two arms possibly broken. Although the preservation is very poor, the outline is similar to some species of the genus *Capnuchosphaera* De Wever established by De Wever *et al.* (1979). Here, the specimen is represented as *Capnuchosphaera* with a question mark because the very poor preservation.

Family **EMILUVIDAE** Dumitrica, 1995
Genus *Emiluvia* Foreman, 1973
Type species *Emiluvia chica* Foreman, 1973

***Emiluvia*? sp.**
Fig. 12.14
Remarks: The specimen possesses a rectangle shell with at least two spines. It seems to be broken specimen of *Emiluvia* Foreman, which has a rectangle shell with four spines, one at each corner arranged to form a cross (Foreman, 1973). The specimen is represented as *Emiluvia* with a question mark because the preservation condition.

Nassellaria gen. et sp. indet.
Figs. 9.3, 9.4
Remarks: The specimens seem to conical shell. However, they lack detailed structure. One specimen (Fig. 9.3) looks like closed nassellarian; however, the closed part is not preserved. Another specimen (Fig. 9.4) slightly resembles multi-segmented nassellarian in shell outline; however, segments on the surface cannot be observed. Consequently, these specimens are represented as Nassellaria gen. et sp. indet.

Order **ALBAILLELLARIA** Deflandre, 1953
Family **FOLLICUCULLIDAE** Ormiston and Babcock, 1979
Genus ***Parafollicucullus*** Holdsworth and Jones, 1980, emend. Xiao and Suzuki in Xiao *et al.* (2021)
Type species *Parafollicucullus fusiformis* Holdsworth and Jones, 1980

Parafollicucullus* sp. cf. *P. monacanthus (Ishiga and Imoto, 1982) in Ishiga *et al.*, 1982
Fig. 4.44
Remarks: The specimen has a dorsal wing and lacks a ventral wing. Such characteristics are known in *Parafollicucullus monacanthus* (Ishiga and Imoto) (Ishiga *et al.*, 1982). The pseudoabdomen is partially broken.

Genus ***Pseudoalbaillella*** Holdsworth and Jones, 1980, emend. Xiao and Suzuki in Xiao *et al.* (2021)
Type species *Pseudoalbaillella scalprata* Holdsworth and Jones, 1980

Pseudoalbaillella japonica Nestell and Nestell, 2020
Figs. 4.2–4.6, 4.8, 4.9, 4.27, 4.28, 4.31–4.33
Remarks: The specimens have a triangular pseudothorax and short pseudoabdomen. Such structures are known in *Pseudoalbaillella japonica* Nestell and Nestell described by Nestell and Nestell (2020).

Pseudoalbaillella postscalprata Ishiga, 1983
Figs. 4.7, 4.29, 4.30
Remarks: The specimens are slightly similar to *Pseudoalbaillella japonica*; however, they have a longer pseudoabdomen. Such characteristics are known in *Pseudoalbaillella postscalprata* Ishiga, which is considered as a progeny species of *Pseudoalbaillella japonica* (Ishiga, 1983).

***Pseudoalbaillella*? sp.**
Fig. 4.34
Remarks: The specimen has an apical cone and pseudoabdomen. This outline is known in *Pseudoalbaillella* Holdsworth and Jones and similar genera such as *Parafollicucullus* Holdsworth and Jones. The specimen is therefore presented as *Pseudoalbaillella* with a question mark.

Genus ***Ishigaconus*** Kozur and Mostler, 1989
Type species *Follicucullus scholasticus* Ormiston and Babcock, 1979

Ishigaconus scholasticus (Ormiston and Babcock, 1979)
Fig. 4.50
Remarks: The specimen is characterized by a conical shell without wing(s) and segmentation(s). Such shell is known in *Ishigaconus scholasticus* (Ormiston and Babcock), which was originally described as *Follicucullus scholasticus* by Ormiston and Babcock (1979).

7. 2 Non-taxonomic name

Arm of Latentifistularia gen. et sp. indet.
Fig. 4.42
Remarks: The form of the specimen is rod-like, and one end is branched. The branched end is composed of at least four platy parts. This is possibly arm of any taxa of Latentifistularia Caridroit, De Wever and Dumitrica, although appropriate species is unknown.

Short form of *Parafollicucullus fusiformis* Holdsworth and Jones, 1980, sensu Ito *et al.*, 2015
Fig. 4.43
Remarks: The specimen has skirt-like short pseudoabdomen seems to lack most of its pseudoabdomen. Ito *et al.* (2015) described the type of form as a short form of *Parafollicucullus fusiformis* Holdsworth and Jones.

Short form of *Parafollicucullus monacanthus* (Ishiga and Imoto, 1982) in Ishiga *et al.*, 1982 sensu Ito *et al.*, 2015
Figs. 4.46–4.49
Remarks: The specimens have a dorsal wing and lack a ventral wing, sharing the characteristics of *Parafollicucullus monacanthus* (Ishiga and Imoto). They have skirt-like short pseudoabdomen and seem to lack most of their pseudoabdomen. Ito *et al.* (2015) described this type of form as a short form.

Spine A2 of Sugiyama (1997)
Fig. 5.50
Remarks: The specimen is rod-like, curved spine.

Sugiyama (1997) speculated that Spine A2 is possibly derived from *Oertlispongus inaequispinosus* Dumitrica, Kozur and Mostler or *Flexispongus cornuhovis* Larm.

Grooved spine
Figs. 5.8, 5.9, 6.38–6.40
Remarks: The specimens are grooved spines. The spines are slightly curved. Several taxa of radiolarian orders in the Paleozoic–Cenozoic, such as Entactinaria Kozur and Mostler, Spumellaria Ehrenberg and Nassellaria Ehrenberg, possess grooved spines (e.g. De Wever *et al.*, 2001).

Multi-segmented nassellarian
Figs. 5.7, 6.17–6.21, 6.24, 6.25, 6.27–6.34, 9.23, 9.24, 9.32, 10.21–10.24, 11.5, 12.8, 12.10, 12.12, 12.13, 13.2, 13.3, 13.8, 13.24
Remarks: The specimens are characterized by multi-segmented tower-like shell. Such radiolarians are generally known in the Mesozoic–Cenozoic nassellarian (e.g. De Wever *et al.*, 2001).

Three-segmented closed nassellarian
Figs. 6.4, 6.5, 6.7–6.10, 7.1, 7.2, 7.4, 9.1, 9.2, 9.6–9.11, 9.13–9.22, 9.27–9.30, 10.4, 10.6, 10.9, 10.11–10.14, 11.3, 11.6, 11.7, 12.1–12.6
Remarks: Three-segmented closed nassellarian has a spindle-shaped shell composed of cephalis, thorax and abdomen. Such nassellarians are known mainly in the Family Williriedellidae Dumitrica. Representative genera of the family are *Williriedellum* Dumitrica, *Zhamoidellum* Dumitrica, *Hemicryptocapsa* Tan Sin Hok, *Holocryptocanium* Dumitrica and *Cryptamphorella* Dumitrica. *Japonocapsa* Kozur and *Striatojaponocapsa* Kozur belonging to the Family Syringocapsidae also have these characters. The specimens are possibly identified as any of the genera.

Closed nassellarian
Figs. 6.1, 6.2, 7.3, 7.5, 7.6, 8.1, 8.2, 8.5, 8.8, 9.12, 9.26, 11.4, 11.8–11.11, 12.7, 12.9
Remarks: Closed nassellarian has spindle form which a distal end is closed. They differ from three-segmented closed nassellarian in unobservable segmentation in the shell. However, a specimen identified as closed-end nassellarian could be three-segmented closed nassellarian that lost segmentation structure because of poor preservation, i.e. closed-end nassellarian includes three-segmented nassellarian.

Spherical polycystine
Figs. 4.23, 4.26, 4.38–4.40, 5.1–5.3, 5.20–5.23, 6.42, 6.43, 8.3, 8.4, 8.6, 8.7, 12.15, 13.1, 13.4–13.7, 13.9–13.13, 13.15, 13.20–13.22, 13.25–13.32, 13.34–13.36
Remarks: As its name indicates, spherical polycystine possesses spherical shell. Radiolarian having a spherical shell is known in the Orders Entactinaria and Spumellaria. A specimen of the Order Nassellaria observed from distal side also looks spherical-shaped shell.

Spherical polycystine, i.e. Entactinaria, Spumellaria or Nassellaria, occurred in the Paleozoic to recent (e.g. De Wever *et al.*, 2001), so that it is not valuable for age assignment.

Spine-bearing spherical polycystine
Figs. 5.54, 13.14, 13.16–13.18
Remarks: Specimens having spherical shell with spines are called as spine-bearing spherical polycystine in this article. Such radiolarians are known in some taxa of the orders Entactinaria and Spumellaria.

Entactinaria and Spumellaria occurred in the Paleozoic to recent (e.g. De Wever *et al.*, 2001), so that it is not valuable for age assignment.

Three-coplaner-spine-bearing spherical polycystine
Figs. 5.4, 5.46, 5.47, 5.49, 13.19, 13.33
Remarks: Specimens having spherical shell with three coplaner spines are called as three-coplaner-spine-bearing spherical polycystine in this article. Such radiolarians are known in some taxa of Order Spumellaria.

Spumellaria occurred mainly in the Mesozoic to recent (e.g. De Wever *et al.*, 2001), so that it is not valuable for age assignment.

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5 万分の 1 地質図幅「桐生及足利」地域の足尾帯ジュラ紀付加体から産出した放散虫

伊藤　剛

要　旨

足尾山地には足尾帯ジュラ紀付加体が分布する．このジュラ紀付加体は，黒保根 – 桐生コンプレックス・大間々コンプレックス・葛生コンプレックス・行道山コンプレックスの 4 コンプレックスからなる．本論では，5 万分の 1 地質図幅「桐生及足利」地域の足尾帯ジュラ紀付加体の 42 試料から新たに産出した放散虫について報告する．ペルム紀放散虫は，行道山コンプレックスのチャート 9 試料から産出した．三畳紀放散虫は，葛生コンプレックスのチャート 4 試料から産出した．また，ジュラ紀放散虫は，黒保根 – 桐生コンプレックスの珪質泥岩 1 試料，葛生コンプレックスのチャート 2 試料，葛生コンプレックスの珪質泥岩 4 試料，葛生コンプレックスの泥岩 2 試料及び行道山コンプレックスの泥岩 1 試料から産出した．加えて，足尾山地ジュラ紀付加体におけるこれまでの化石産出とその年代についてとりまとめた．これらを踏まえ，各コンプレックスの海洋プレート層序を復元した．