Neogene biosiliceous sedimentary sequence and radiolarian biostratigraphy in the Tainai area, Niigata Prefecture

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Abstract

Middle Miocene–Pliocene biosiliceous and microfossil-bearing-siliciclastic sediments are exposed at the Natsui Section along the Tainai River. This outcrop comprises the Shimoseki, Uchisugawa, and Kuwae Formations. Radiolarians and other microfossils extracted from these formations have been investigated by many geologists and paleontologists for regional correlation and paleoenvironmental reconstruction of the Japan Sea. Here we present a radiolarian biostratigraphy of the Middle to Upper Miocene siliceous sedimentary sequence of the Natsui Section.

Key words: Miocene, Pliocene, Radiolaria, microfossil, Tainai River, Natsui Section, Niigata Prefecture

Introduction

In the Japan Sea side region of the Japanese Islands there are thick Neogene deposits that rest unconformably on pre-Neogene rocks. In this region the Neogene is made up of four depositional sequences; Lower Miocene pyroclastic and volcanic rocks deposited in terrestrial environments, uppermost Lower to lowermost Middle Miocene shallow marine deposits representing the initial transgression, Middle to Upper Miocene biogenic deep sea sediments, and Plio-Pleistocene siliciclastic sediments (Kobayashi and Tateishi, 1992;

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Kobayashi, 2002; Takano, 2002). This temporal facies change largely reflects the development of the Japan Sea, a marginal sea with deep basins (maximum water depth of 3,700 m), which probably did not exist before the Middle Miocene and was generated through the extension and opening of the eastern margin of the Asian Continent in

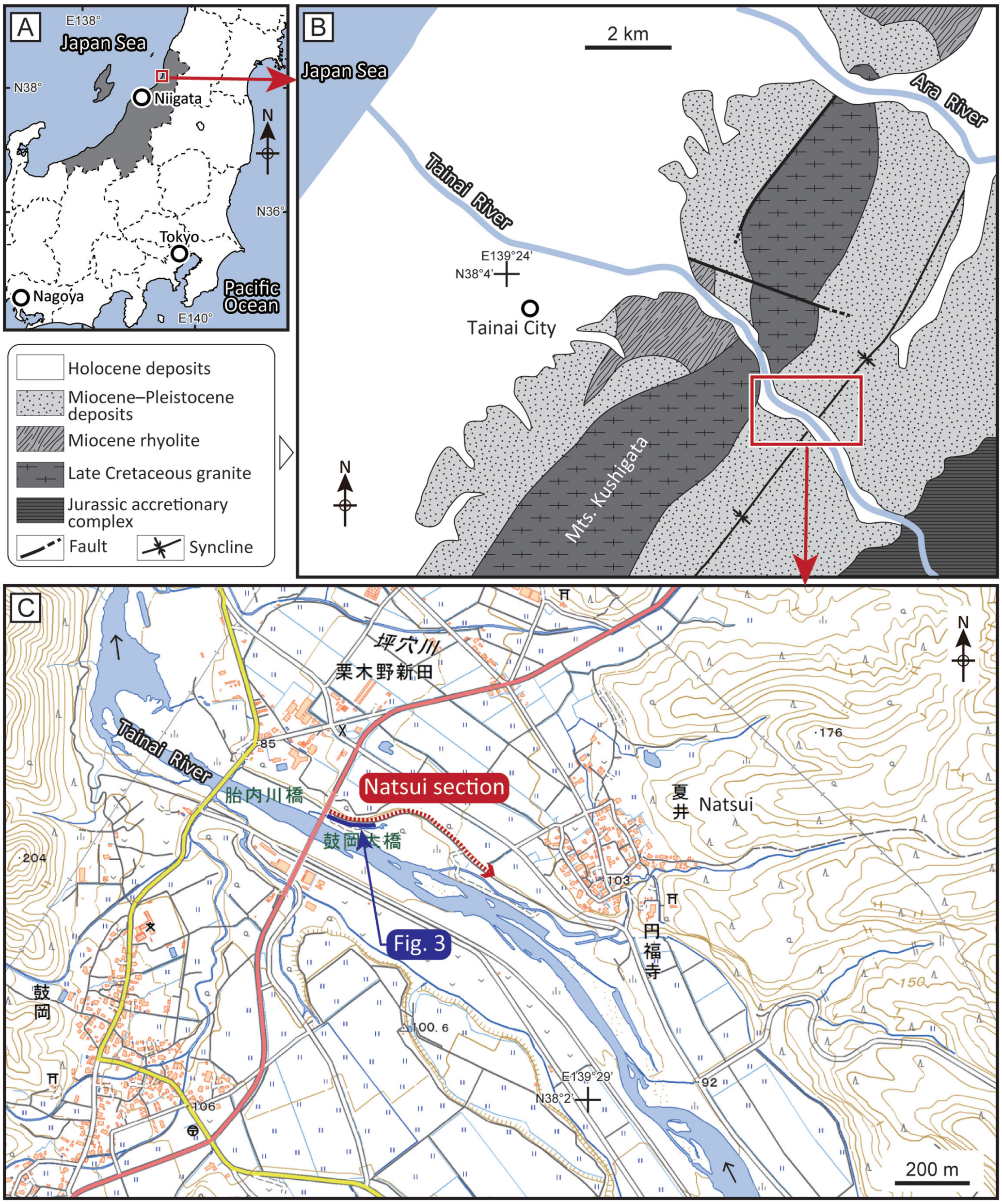

Fig. 1. Index map of the Tainai area of northern Niigata Prefecture. Map A: location of Niigata Prefecture (shaded area). Map B: schematic geologic map of the Tainai area (modified from Niigata Prefecture, 2000). Map C: location of the Natsui Section (modified from topographic map "Nakajo" scale 1:25,000 published by Geospatial Information Authority of Japan).

association with an ~500 km southeastward drift of the Japanese archipelago during a short time interval of one to two million years around 16–15 Ma (e.g., Van Horne et al., 2016). The basins subsided to bathyal depths (usually >1,000 m) after 15 Ma and accumulated biogenic siliceous sediments until the latest Miocene in nearshore areas or until the Pliocene in offshore areas (Yamaji and Sato, 1989; Iijima and Tada, 1990). Since the Pliocene, the basins of nearshore areas were buried with siliciclastic sediments that were brought from the emerged land areas as the Japanese Islands uplifted. These Neogene formations were finally uplifted and folded during the last two million years.

In the Tainai area, northern Niigata Prefecture (Fig. 1), the Neogene deposits are subdivided into the Kamagui, Shimoseki, Uchisugawa, and Kuwae Formations, in ascending order (Nishida and Tsuda, 1961) (Fig. 2). The Kamagui Formation consists of conglomerate and sandstone with fossils of subtropical fauna, representing the initial transgression as well as the mid-Miocene global warming event. The subsequent basinal deepening and climatic cooling resulted in deposition of the Shimoseki and Uchisugawa Formations which are composed of siliceous hard mudstone and diatomaceous mudstone, respectively. Local variations in the diagenesis of biogenic opal resulted in a diachronous boundary between these two formations across the region. The Pliocene Kuwae Formation is dominated by sandy siltstone occasionally including molluscan fossils and records facies changes in the outer shelf to slope environments reflecting local tectonics and relative sea-level changes (Takano et al., 2001). Radiolarians are common in the Uchisugawa Formation and rare in the Shimoseki and Kuwae Formations (Sugano and Nakaseko, 1971, 1972). Diatoms are abundant in the Uchisugawa and Kuwae Formations and calcareous microfossils are present within the Kuwae Formation (see the literature cited below for details).

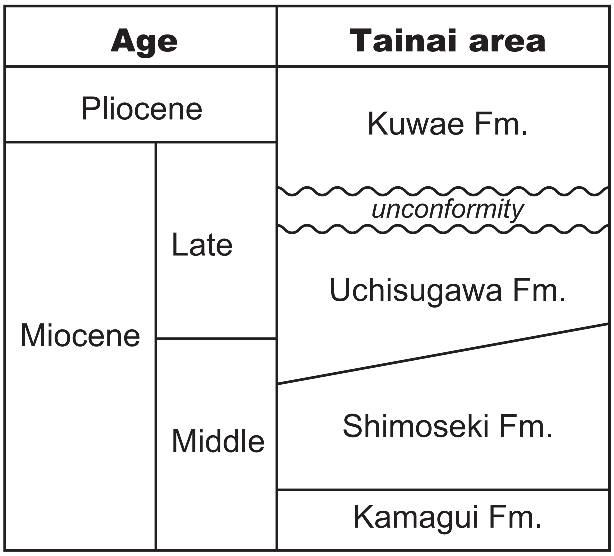

Fig. 2. Schematic Neogene stratigraphy in the Tainai area.

The Natsui Section, comprising cliffs on both sides of the Tainai River, is located in the middle part of Tainai City, northern Niigata Prefecture (Fig. 1). A typical sedimentary sequence from the Shimoseki to Kuwae Formations is exposed there.

Geology and biostratigraphy of the Natsui Section

At the Natsui Section (Fig. 1C), Middle to Upper Miocene biosiliceous deposits of the Shimoseki and Uchisugawa Formations and Pliocene sandstone and sandy siltstone of the Kuwae Formation crop out in terrace cliffs along the Tainai River (Fig. 3). We will visit a cliff on the north side of the river. The Shimoseki Formation appears near the Tsuzumioka Bridge and is composed of bedded siliceous hard mudstone interbedded with rhyolitic tuffs.

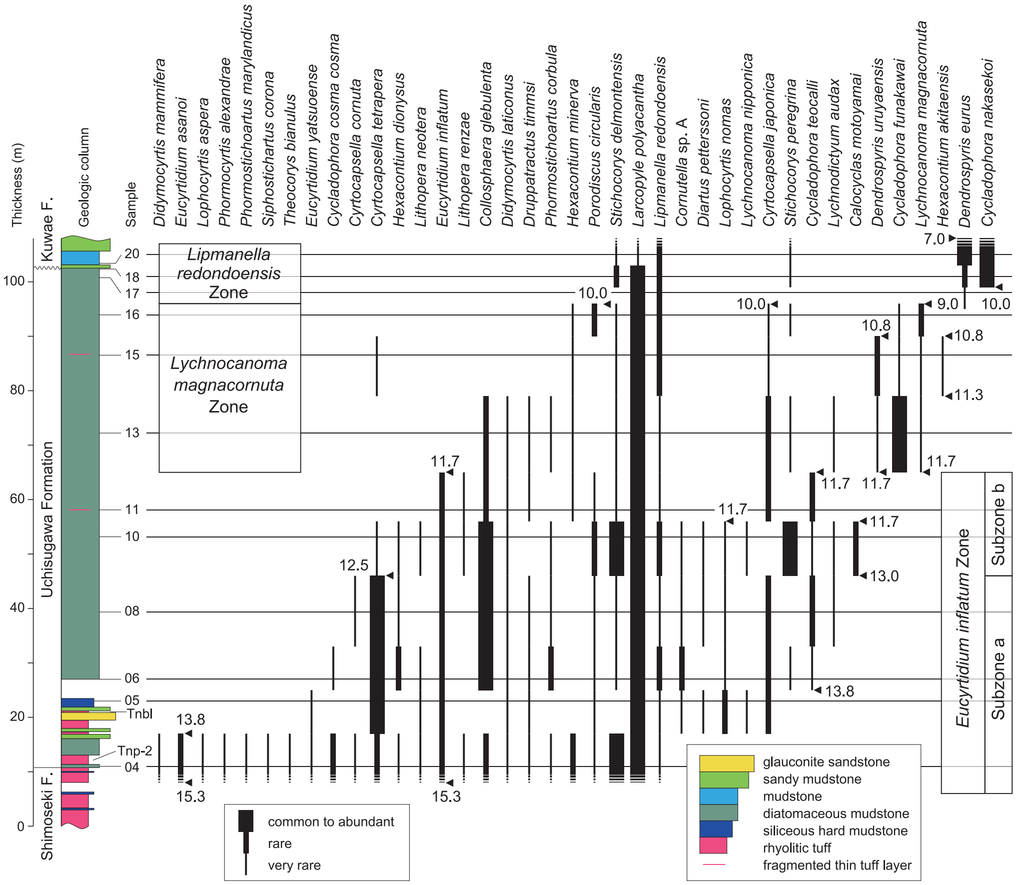

Fig. 3. Middle to Upper Miocene radiolarian biostratigraphy of the Uchisugawa Formation, Natsui Section. Relative abundances of species are estimated by eye under the transmitted light microscope. Tnp-2 and Tnbl are rhyolitic tuff layers described by Kurokawa et al. (1999). The Uchisugawa Formation can be divided into three zones, *E. inflatum*, *L. magnacornuta*, and *L. redondoensis* Zones. The lowest part of the Kuwae Formation belongs to the *L. redondoensis* Zone. Numerical ages (in Ma) for bioevents are those estimated by Kamikuri et al. (2007) and Kamikuri (2010). The location of the section is shown in Fig. 1C.

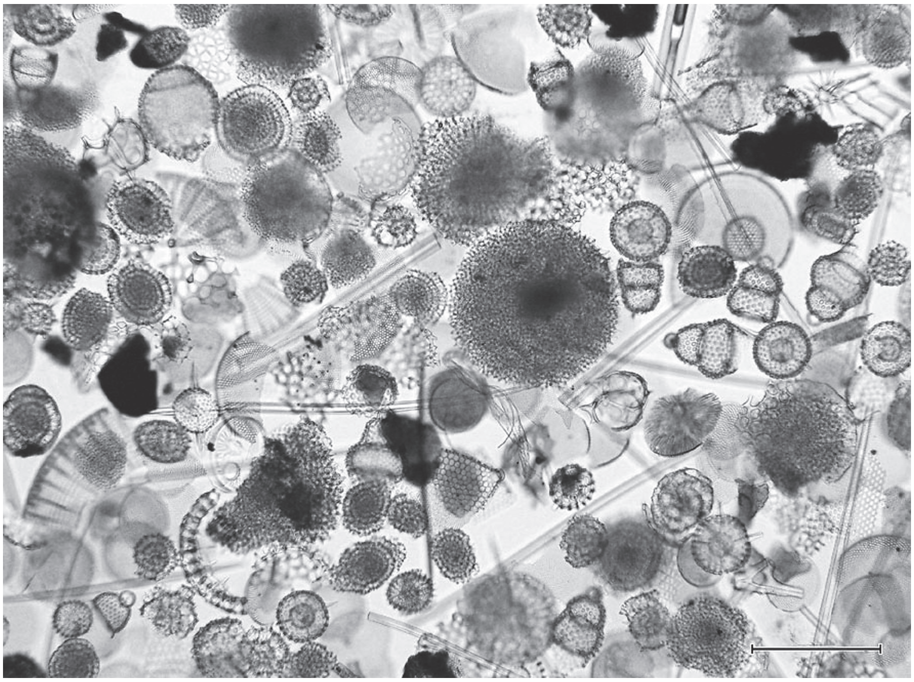

Fig. 4. Photograph of radiolarian assemblage of the Middle Miocene Subzone a of the *Eucyrtidium inflatum* Zone from Sample 04. Scale bar = 200 μm.

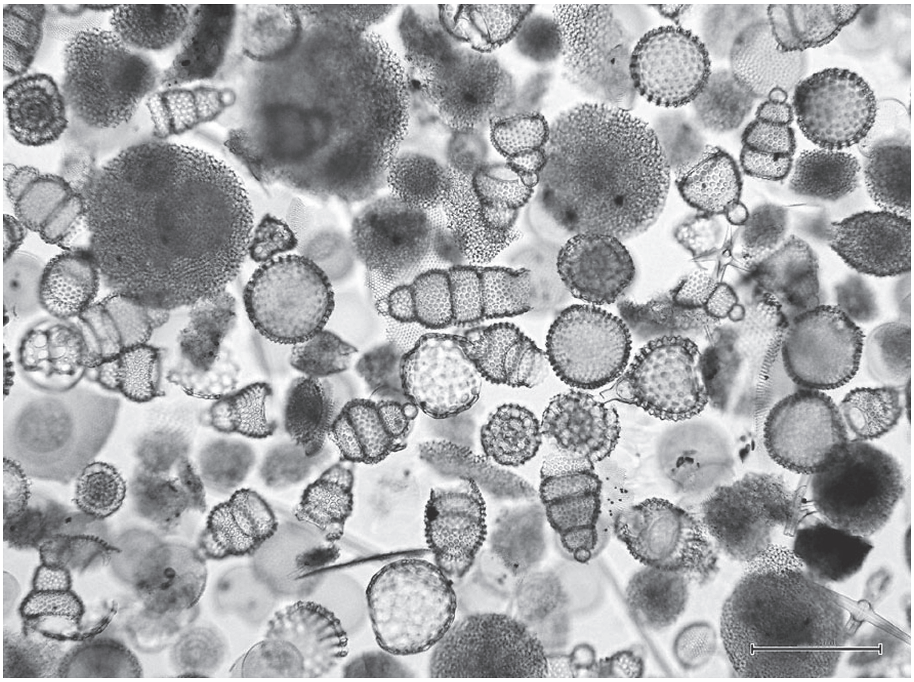

Fig. 5. Photograph of radiolarian assemblage of the Middle Miocene Subzone b of the *Eucyrtidium inflatum* Zone from Sample 10. *Stichocorys delmontensis/peregrina* dominates the assemblage. Scale bar = 200 μm.

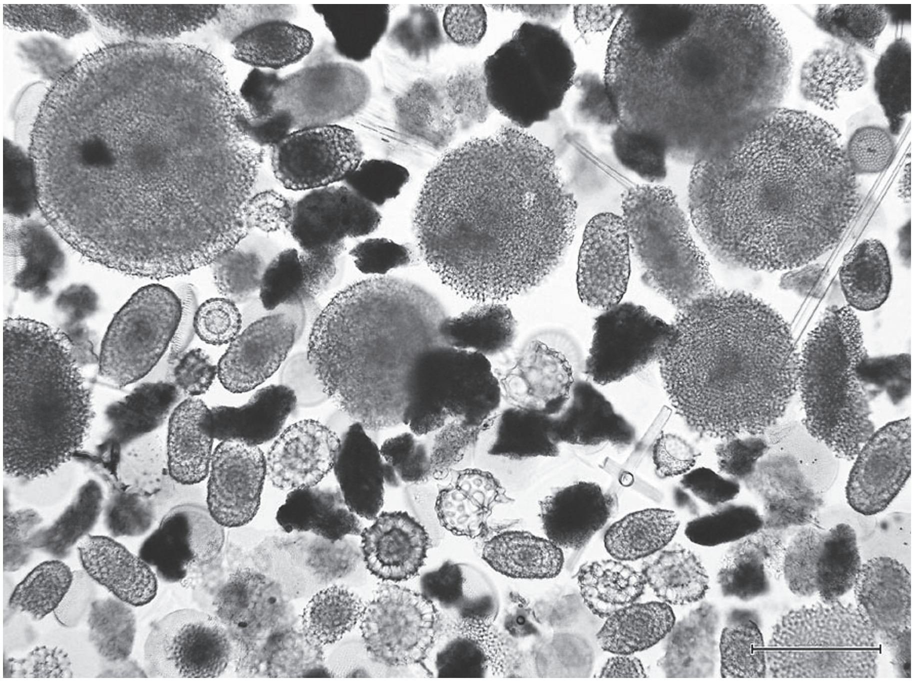

Fig. 6. Photograph of radiolarian assemblage of the Upper Miocene *Lychnocanoma magnacornuta* Zone from Sample 15. *Larcopyle polyacantha* is abundant. Large discoidal forms, *Spongopyle setosa* Dreyer, are remarkable. Scale bar = 200 μm.

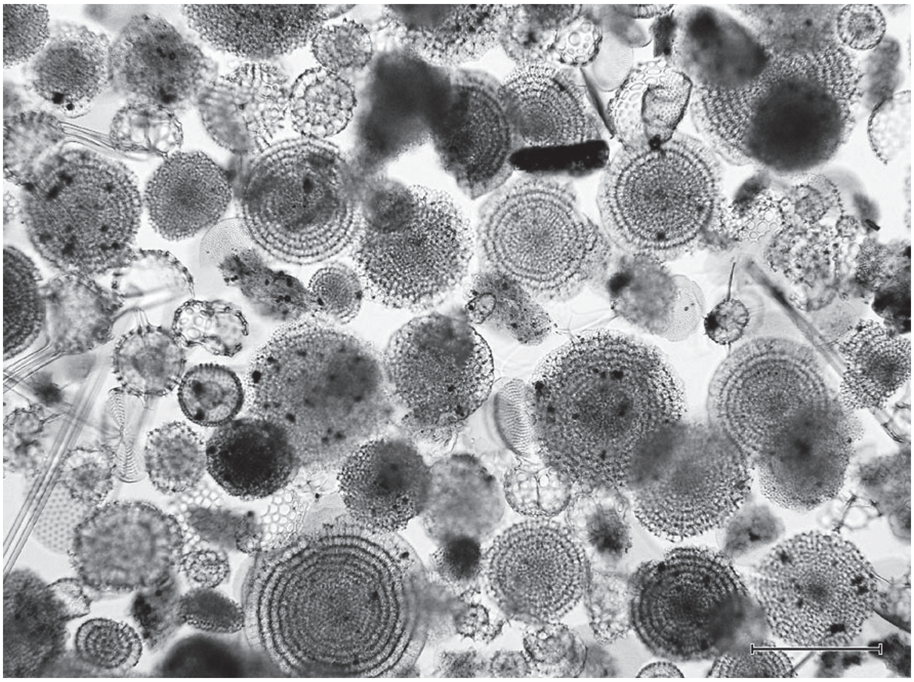

Fig. 7. Photograph of radiolarian assemblage of the Upper Miocene *Lychnocanoma magnacornuta* Zone from Sample 16. Discoidal forms with concentric rings, *Perichlamydium scutaeforme* Campbell and Clark, are dominant. Scale bar = 200 μm.

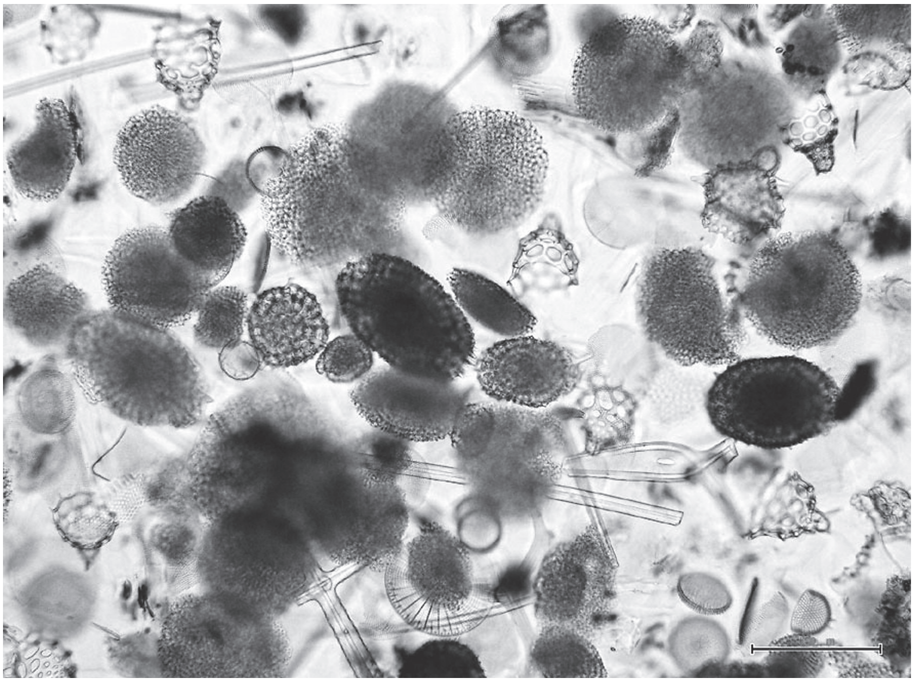

Fig. 8. Photograph of radiolarian assemblage of the Upper Miocene *Lipmanella redondoensis* Zone from Sample 18. *Larcopyle polyacantha* and *Spongodiscus* spp. are dominant. *Cycladophora nakasekoi* is characteristic. Scale bar = 200 μm.

The Uchisugawa Formation is a 90-m-thick sequence of massive olive-gray colored diatomaceous mudstone intercalated with a glauconitic sandstone bed, hard mudstones, and tuffs in its basal part. The Kuwae Formation, unconformably overlying the Uchisugawa Formation (Kobayashi and Watanabe, 1985; Hiramatsu and Miwa, 1998), consists of 200 m of gray to greenish-gray sandy siltstone and sandstone. Hiramatsu and Miwa (1998) suggested that this unconformity spans ~3.5 million years from 10 to 6.5 Ma. The Natsui Section belongs to the west wing of the syncline that lies between two topographic highs, Kushigata Mountains to the west and Iide Mountains to the east, and runs in a NNE to SSW direction (Fig. 1B). The strata from the Shimoseki to lower part of the Kuwae Formations at this section are steeply dipping to the east (80–70° E) and become gentler (40–10° E) closer to the synclinal axis.

Because of its accessible continuous exposure, the Natsui Section has been investigated for biostratigraphy and paleoenvironmental studies using various microfossils. These include a pioneering study of radiolarian biostratigraphy for the Niigata oil field by Sugano and Nakaseko (1972). The others are pollen stratigraphy (Yamanoi, 1976), diatom stratigraphy (Kobayashi and Watanabe, 1985; Hiramatsu and Miwa, 1998; Watanabe et al., 2003), planktonic foramaminiferal stratigraphy (Hiramatsu and Miwa, 1998; Miwa et al., 2004), calcareous nannofossil stratigraphy (Watanabe et al., 2003), and analysis of ostracoda fauna

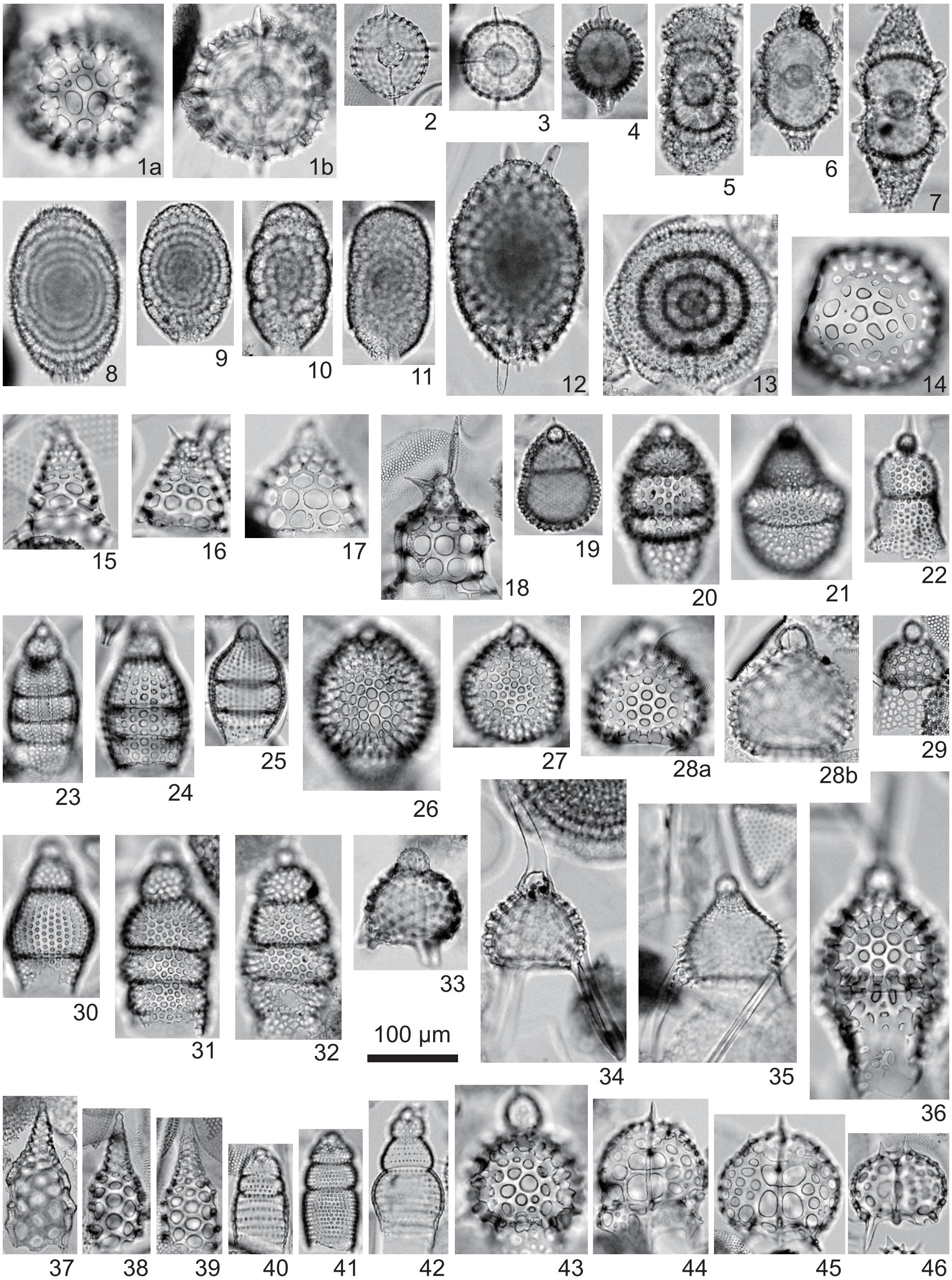
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Fig. 9. Photographs of radiolarian species.

1. *Hexacontium akitaensis* (Nakaseko), Sample 15.
2. *Hexacontium dionysus* Kamikuri, Sample 6.
3. *Hexacontium minerva* Kamikuri, Sample 13.
4. *Druppatractus timmsi* (Campbell and Clark), Sample 4.
5. *Diartus petterssoni* (Riedel and Sanfilippo), Sample 5.
6. *Didymocyrtis mammifera* (Haeckel), Sample 4.
7. *Didymocyrtis laticonus* (Riedel), Sample 10.

8–12. *Larcopyle polyacantha* (Campbell and Clark) group: 8, 9, Sample 05; 10, Sample 13; 11, Sample 15; 12, Sample 18.

13. *Porodiscus circularis* Clark and Campbell, Sample 10.
14. *Collosphaera glebulenta* Bjørklund and Goll, Sample 8.
15. *Cycladophora cosma cosma* Lombari and Lazarus, Sample 4.
16. *Cycladophora teocalli* Kamikuri, Sample 10.
17. *Cycladophora funakawai* Kamikuri, Sample 13.
18. *Cycladophora nakasekoi* Motoyama, Sample 18.
19. *Cyrtocapsella japonica* (Nakaseko), Sample 11.
20. *Cyrtocapsella tetrapera* Haeckel, Sample 5.
21. *Cyrtocapsella cornuta* Haeckel, Sample 4.
22. *Lophocyrtis aspera* (Ehrenberg), Sample 4.
23. *Eucyrtidium asanoi* Sakai, Sample 4.
24. *Eucyrtidium inflatum* Kling, Sample 4.
25. *Eucyrtidium yatsuoense* Nakaseko. Sample 4.
26. *Lithopera renzae* Sanfilippo and Riedel, Sample 4.
27. *Lithopera neotera* Sanfilippo and Riedel, Sample 10.
28. *Lophocyrtis nomas* Sanfilippo and Caulet, Sample 8.
29. *Theocorys bianulus* O'Connor, Sample 4.
30. *Phormocyrtis alexsandrae* O'Connor, Sample 4.
31. *Stichocorys delmontensis* (Campbell and Clark), Sample 10.
32. *Stichocorys peregrina* (Riedel), Sample 10.
33. *Lychnocanoma nipponica* (Nakaseko), Sample 5.
34. *Lychnocanoma magnacornuta* Sakai, Sample 16.
35. *Lychnodictyum audax* Riedel, Sample 13.
36. *Calocyclas motoyamai* Kamikuri, Sample 10.

37–39. *Cornutella* sp. A, Sample 6.

40. *Phormostichoartus marylandicus* (Martin), Sample 4.
41. *Phormostichoartus corbula* (Harting), Sample 4.
42. *Siphostichartus corona* (Haeckel), Sample 4.
43. *Lipmanella redondoensis* (Campbell and Clark), Sample 16.

44, 45. *Dendrospyris eurus* Kamikuri, Sample 20.

46. *Dendrospyris uruyaensis* Kamikuri, Sample 13.

(Irizuki et al., 2007). Studies of tephrochronology (Kurokawa et al., 1999), magnetostraigraphy (Inoue et al., 2003), geochemistry (Sampei et al., 2009) and sequence stratigraphy (Takano et al., 2001) were also performed on this section.

Here, we present a new Middle to Upper Miocene radiolarian biostratigraphy for the Natsui Section along the north-side of the Tainai River (Fig. 3). The samples were treated with lamp oil and H_2O_2 and washed through a 63 μm mesh sieve. Disaggregated particles were pipetted onto a glass slide and mounted with a cover slip to make a permanent slide for transmitted light microscope observation.

Diatom and radiolarian fossils occurred abundantly through the sequence from the Uchisugawa Formation to the basal part of the Kuwae Formation (Figs. 3–9). The observed radiolarian assemblages are similar to those reported from the Middle to Upper Miocene sequences in the Japan Sea (Funayama, 1988; Motoyama, 1996; Kamikuri et al., 2017) and the middle-to-high latitude North Pacific (Motoyama, 1996; Kamikuri et al., 2004, 2007; Kamikuri, 2010). The studied sequence can be divided into three radiolarian zones, *Eucyrtidium inflatum*, *Lychnocanoma magnacornuta*, and *Lipmanella redondoensis* Zones in ascending order. A combination of the occurrence of *E. inflatum* and the absence of *L. magnacornuta* indicates the *E. inflatum* Zone (Samples 04 to 11). The *L. magnacornuta* Zone is defined by the total range of *L. magnacornuta* (Samples 13 to 16). The *L. redondoensis* Zone corresponds to the interval between the last occurrence of *L. magnacornuta* and the first occurrence of *Lychnocanoma parallelipes* (Samples 17 to 20). The *E. inflatum* Zone can be subdivided into Subzones a and b in ascending order. The rapid decrease of *Cyrtocapsella tetrapera* was recognized between Sample 08 and Sample 10, indicating the boundary between the two subzones. The contact between the Uchisugawa and Kuwae Formations falls within the *L. redondoensis* Zone, and thus we do not have any radiolarian evidence to support the unconformable relationship. The present radiolarian data, however, suggest that the time range represented by the unconformity is shorter than previously thought, being less than 2 million years in duration between 9.0 and 7.0 Ma.

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