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Actinocyclus haradaae (Pantocsek) comb. nov. (Bacillariophyta) from a Miocene lacustrine deposit in Setana, southwestern Hokkaido, Japan

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Abstract A fossil diatom species from a Miocene deposit in Setana, southwestern Hokkaido, Japan was re-examined. Discoidal frustules originally described as *Coscinodiscus haradaae* Pantocsek and *Coscinodiscus hokkaidoensis* Okuno are characterised by a nearly flat or concentrically undulated valve face with a shallow mantle, a bullulate valve wall, loculate areolae with external cribra, fascicles composed of independent areolar rows divided by short hyaline stripes (occasionally lost), rimoportulae at the ends of the hyaline stripes in the mantle, a single pseudonodulus at the valve face/mantle junction, and a ring of small nodules interior to the pseudonodulus. Based on these observations the new taxon *Actinocyclus haradaae* (Pantocsek) comb. nov. is proposed, with *C. hokkaidoensis* Okuno as a synonym.

Key words: early Miocene, Tsukunai Member, Futoro Formation, lacustrine diatom, *Actinocyclus*

Introduction

Diatom fossils were first reported from a lacustrine diatomite in Setana, southwestern Hokkaido, Japan by Hungarian paleontologist Joseph Pantocsek at the end of the 19th century (Pantocsek, 1905). He described 23 new taxa from material sent to him by Prof. Kotora Jinbo, but the source of the material was not recorded. The next taxonomic study was performed by Sato (1940), who only reported species in the genus *Melosira* Agardh from a diatomite outcrop 80 m wide and 5 m thick intercalated in a tuff breccia, and located beside an entrance to the Abura Tunnel. Prof. Haruo Okuno conducted more detailed studies (e.g., Okuno, 1958a; b; 1959a; b; c). He correlated this freshwater diatomite with the Kunnui Formation, later changed to the Futoro Formation (Sagawa and Ueda, 1970). According to Okuno (1958a), plant fossils from this deposit identified by Prof. Shigeru Miki may have been deposited in the Miocene.

Melosira species, which should be re-combined into the genus *Aulacoseira*, were overwhelmingly dominant in the deposits (Okuno, 1958b). Three of the four outcrops examined by Okuno included relative abundances of *Aulacoseira* species of up to 99%. Additional species were reported by Okuno (1959a; b; c), including a new species of *Coscinodiscus* Ehrenberg, *C. hokkaidoensis* Okuno, which was described by Okuno (1959a) with an accompanying drawing. One broken valve of *Cosmiodiscus elegans* Greville var. *inermis* (Pantocsek) Fricke was also reported with an accompanying drawing in that study. Okuno (1959a), however, did not discuss the similarity between his new species and *Coscinodiscus haradaae* Pantocsek, identified by Pantocsek (1905) from a diatomite in the same region.

This study re-examines the diatom specimens from the lacustrine diatomite in Setana, southwestern Hokkaido. A discoidal diatom species from this deposit is conspecific with *Coscinodiscus hokkaidoensis* Okuno, and is likely also conspecific with *Coscinodiscus haradaae* Pantocsek. The pseudonodules on the valve face/mantle junction and other morphological features

of the valves suggest that these specimens should be assigned to the genus *Actinocyclus* Ehrenberg. A new combination is proposed here for the non-marine *Actinocyclus*, which is widely distributed in North America and Eurasia from the early to middle Miocene.

Materials and Methods

The early Miocene Futoro Formation is composed primarily of an andesitic volcanic rock complex distributed around Kitahiyama, southwestern Hokkaido (Sagawa and Ueda, 1970). Its uppermost part, the Tsukunai Member, is exposed in the coastal area to the north of Setana, and consists of white or pale grey diatomaceous siltstone with well-developed parallel lamination (Sagawa and Ueda, 1970). This diatomaceous siltstone is a non-marine deposit, containing plant fossils corresponding to a boreal variation of the Daijima flora (Tanai, 1963).

Studied specimens were sampled from an outcrop exposed on the left bank of Tsukunai-sawa (Fig. 1). A well-laminated pale yellow diatomite >8 m thick was observed. The lower limit of the diatomite was not determined, but the uppermost section is overlain by the scoriaceous deposits of the Babagawa Formation (Sagawa and Ueda, 1970). This outcrop is not one of those studied by Okuno (i.e., Abura, Tsukunai, Nakauta, Baikatsu A and B), but it is located on the opposite bank of Okuno's Tsukunai locality.

Sampling horizons are shown in Fig. 2. Sediments were dried at 60ºC for 2 days, boiled in 15% H_2O_2 solution, and rinsed four times with water. A portion of the suspension was mounted on cover slips with Styrax (gum storax, Sigma-Aldrich Japan K.K., Tokyo) for observation with a differential interference contrast light microscope (Olympus BX51). The same suspension was filtered with Millipore HAWP membrane filters (Merck Millipore, Japan), mounted on stubs, and coated with gold for scanning electron microscopy. A JEOL JSM 6510 scanning electron microscope (JEOL Inc., *Massachusetts*, *USA)* with a LaB6 unit was used for scanning electron microscopy in the National Museum of Nature and Science, Tsukuba, Japan. Terminology follows Ross *et al.* (1979), Round *et al.* (1990), and Bradbury and Krebs (1995).

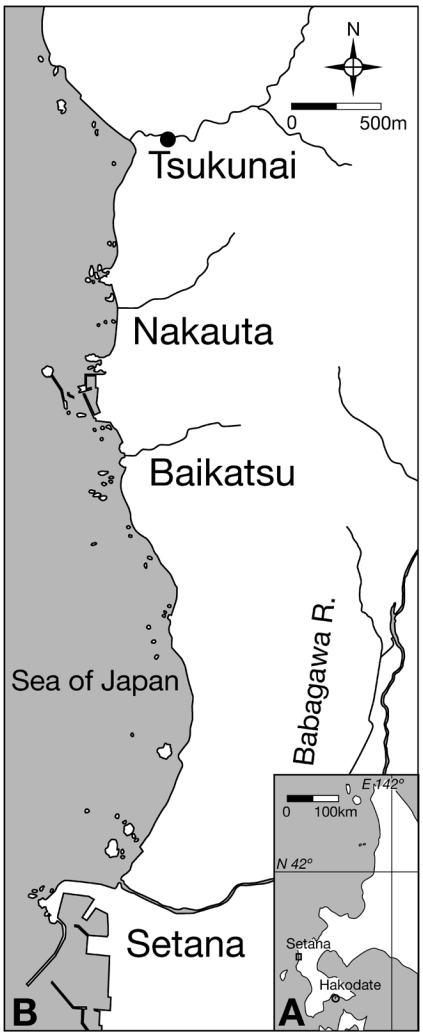


Fig. 1. Map showing sampling locality of this study, Tsukunai, Setana, Hokkaido. Sampling locality (solid circle) in B which corresponds to open square under characters "Setana" in A.

Observations

Discoidal 12–39-μm-diameter valves of *Actinocyclus* sp. (Fig. 3) constitute less than 1% of the diatom flora in the sediments. Areolae on the

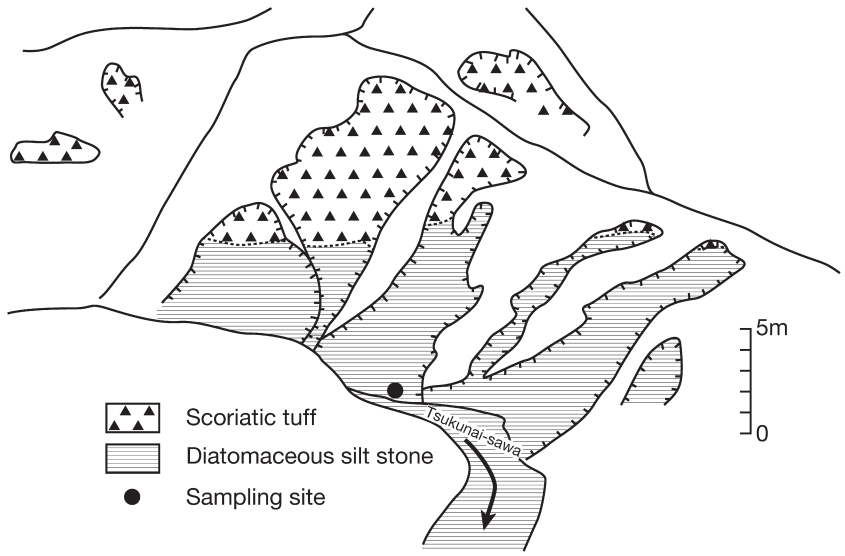


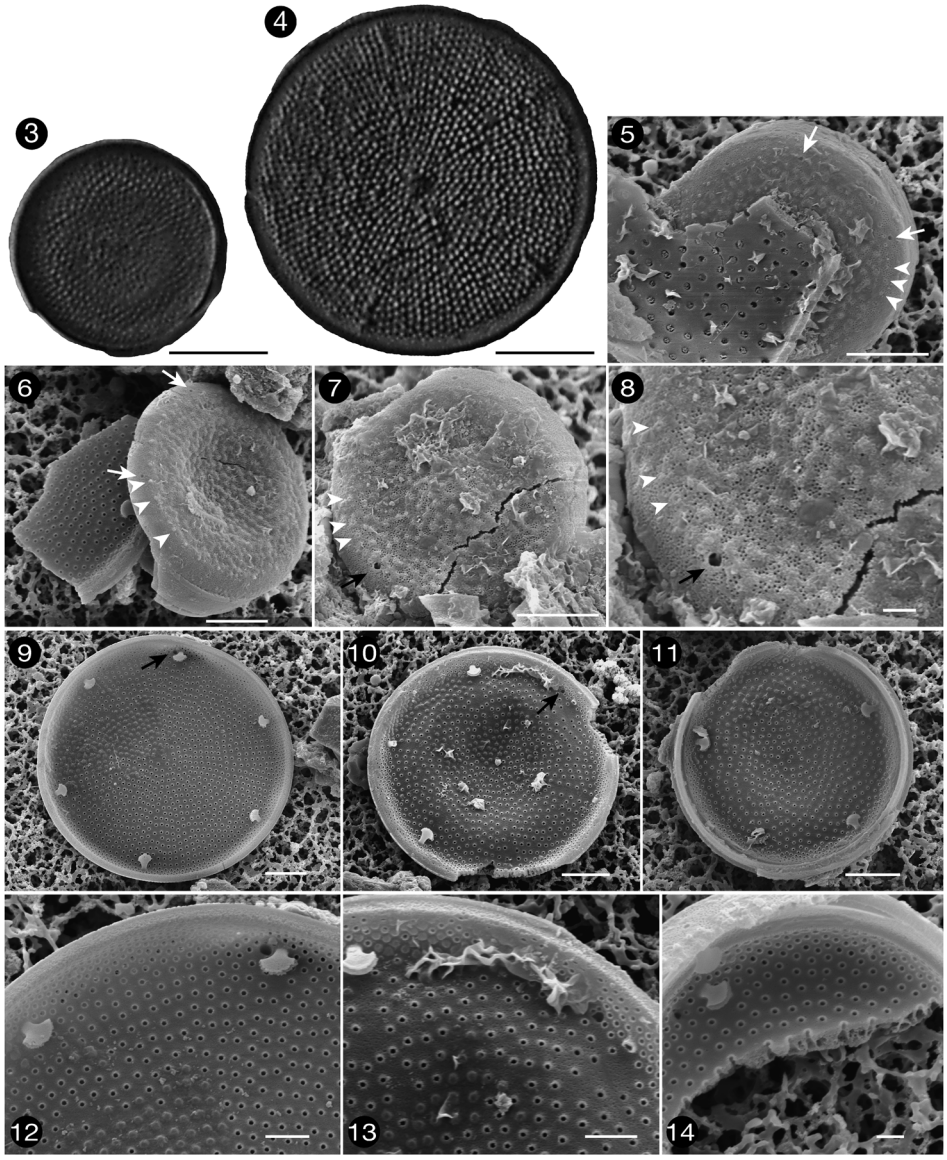
Fig. 2. Schematic sketch of sampling site on the left bank of Tsukunai-sawa, Setana, Hokkaido.

Actinocyclus valves are arranged in radial rows and are divided into broad sectors (Figs. 3 and 4). Short hyaline stripes are sometimes present on the valve face at the sector boundaries (Fig. 4), but are not conspicuous on most of the specimens (Fig. 3). External cribra (Fig. 5) and simple pores of the rimoportulae appear on the mantle just below the valve face/mantle junction (Figs. 5 and 6). A ring of small nodules is present on the valve face/mantle junction (Figs. 5–8, arrow heads), and an external opening of the pseudonodulus occurs on this ring (Figs. 7 and 8). Hyaline stripes are not conspicuous (Figs. 9, 11), but 4–9 rimoportulae are present on the areolar sector boundaries (Figs. 9–11). Fan-shaped rimoportulae expand parallel to the valve face, with short stalks that appear as a flattened circle in cross-section (Figs. 10 and 11). A pseudonodulus is located close to (Fig. 12) or apart from a rimoportula (Figs. 13 and 14), which is slightly depressed internally and surrounded by smaller areolae. The valve wall has a bulleted spongy structure penetrated by areolae that are narrow but slightly flared toward the external side of the valve (Fig. 14).

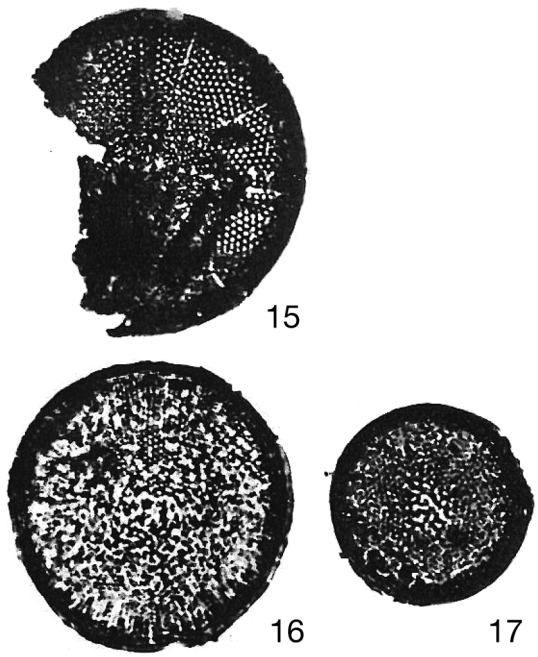
Discussion

Only the description and a drawing by Pantocsek (1905) remain for *Coscinodiscus haradaae*, because the type specimen was not found in the Pantocsek collection in the Hungarian National Museum (Dr. Akihiro Tuji, personal communication). Based on the description (Pantocsek, 1905), specimens of *C. haradaae* are circular, flattened, 20–30 μm in diameter, with a small areola radiating without interruption that is 10 areolae in 10 μm in the central area, with a 8-μm-wide hyaline marginal band.

Okuno (1959a) found circular discoidal diatoms from the diatomaceous deposits, but only one specimen of *Cosmiodiscus elegans* Greville var. *inermis* (Pantocsek) Fricke, and described *Coscinodiscus hokkaidoensis* Okuno as a new species. Okuno (1959a) published drawings of both taxa based on light micrographs (Figs. 15–17), which are stored with his observational notes in the National Museum of Nature and Science. In the notes he assigned the specimens that he photographed to "*Cos. haradaae*". Photograph number 2311 (Fig. 15) shows a broken valve illustrated in Okuno's (1959a) fig. 1c as *Cosmiodiscus elegans* var. *inermis*, which has conspicu-



Figs. 3–14. LM and SEM images of *Actinocyclus haradaae* comb. nov. observed in this study. Fig. 3, lectotype, MPC-26783, LM, scale bar = 10 μm; Fig. 4, specimen with conspicuous marginal hyaline stripes, LM, scale bar = 10 μm; Fig. 5, external view showing openings of rimoportulae (arrows) and a ring of small nodules (arrow heads), SEM, scale bar = 5 μm; Fig. 6, tilting valve showing marginal ring of small nodules (arrow heads) slightly inward of rimoportula openings (arrows), SEM, scale bar = 5 μm; Fig. 7, external valve showing pseudonodule (brack arrow) on valve face/mantle junction and a ring of small nodules (arrow heads), SEM, scale bar = 5 μm; Fig. 8, enlarged image of pseudonodulues in Fig. 7, SEM, scale bar = 1 μm; Fig. 9, internal view with 6 fan-shaped rimoportulae and pseudonodule (black arrow), SEM, scale bar = 5 μm; Fig. 10, internal view of specimen with long marginal hyaline stripes, SEM, scale bar = 5 μm ; Fig. 11, internal view of specimen without conspicuous marginal hyaline stripes, SEM, scale bar = 5 μm; Fig. 12, enlarged image of Fig. 9, SEM, scale bar = 2 μm; Fig. 13, enlarged image of Fig. 10, SEM, scale bar = 2 μm; Fig. 14, broken valve with rimoportula and pseudonodule showing bulluate structure of valve wall, SEM, scale bar = 2 μm



Figs. 15–17. LM images corresponding to line drawings in Okuno 1959a. Fig. 15, photograph number 2311, broken valve illustrated in fig. 1c of Okuno (1959a) as *Cosmiodiscus elegans* var. *inermis*; Figs 16 and 17, photograph number 2312 and 2313 respectively, with handwriting of H. Okuno "*Cos. Haradaae*" and corresponding to originals of fig. 1d of Okuno (1959a) as *Coscinodiscus hokkaidoensis*.

ous marginal hyaline stripes. The others (Figs. 16 and 17) show smaller valves that are the original images that Okuno (1959a) drew as fig. 1d.

Actinocyclus species observed in this study correspond without doubt to Pantocsek's *C. haradaae* and Okuno's *C. hokkaidoensis* in terms of valve size, areolar arrangement, and in the typically rare occurrence in the sediment. Locality details for the materials studied by Pantocsek and Okuno are unknown. However, the diatomaceous siltstones examined by Pantocsek, Okuno and in this study were taken from the same sediment of a Miocene lake, the Tsukunai Member (Sagawa and Ueda, 1970) that is distributed around the Abura-Baikatsu area in Setana. The small pseudonodulus (Figs. 7 and 8) on the valve is difficult to see by light microscopy, and so they must have misidentified the specimens as *Coscinodiscus* species. Hyaline stripes are not conspicuous in most of the specimens, but some long examples were observed (Figs. 4 and 10) just as in *Cosmiodiscus elegans* var. *inermis* as reported by Okuno (1959a). A new taxonomic and nomenclatural combination is proposed, as follows.

Actinocyclus haradaae (Pantocsek) comb. nov**.**

Basionym: *Coscinodiscus haradaae* Pantocsek 1905, p. 35, pl. VIII, fig. 139.

Synonym: *Cosmiodiscus elegans* Greville var. *inermis* (Pantocsek), in Okuno (1959a), p. 26–27, fig. 1c; *Coscinodiscus hokkaidoensis* Okuno 1959a, p. 27, fig. 1d;

Lectotype: MPC-26783 in the National Museum of Nature and Science, Tsukuba, Japan

The simple morphology of this taxon and its occurrence in freshwater environments are similar to those of *Actinocyclus normanii* f. *subsalsa* (Juhlin-Dannfelt) Hustedt (Hasle, 1977). *A. haradaae* can be discriminated from *A. normanii* f. *subsalsa* (Hasle, 1977) by a ring of small nodules on the valve face/mantle junction, a thicker and bulleted valve wall separating each areola, and shorter remoportular stalks. Some of non-marine species from the western United States (Bradbury and Krebs, 1995) also resemble *A. haradaae*, but most demonstrate morphological differences. *Actinocyclus cedrus* Bradbury and Krebs has larger valves, coarser areolar density, and polygonal areolae. *Actinocyclus claviolus* Bradbury and Krebs has conspicuous irregular hyaline stripes. *Actinocyclus tubulosus* Khursevich has external tubes on the hyaline stripes. However, *A. krasskei* (Krasske) Bradbury and Krebs and *A. haradaae* are alike in valve size, areolar density, the ambiguous hyaline stripes, and the shape of the rimoportulae. Further research is required to clarify if *A. krasskei* is a synonym of *A. haradaae*, because the original description of *A. krasskei* as *Coscinodiscus miocenicus* in 1934 by Krasske (Bradbury and Krebs, 1995) occurred later than that of *A. haradaae* as *C. haradaae* by Pantocsek (1905).

This taxonomic work will be important for elucidating the authentic geographic distribution of *A. haradaae*, with the seven sites in the western United States from which *A. krasskei* has already been reported (Bradbury and Krebs, 1995).

Non-marine *Actinocyclus* species are diverse and widely distributed in the early to middle Miocene (Bradbury and Krebs, 1995; Hayashi *et al.*, 2012). This study adds a species, a locality, and an age to the history of non-marine *Actinocyclus*. The phylogeny and changes in the biogeography of these taxa require further study and discussion.

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