

Observations of *Navicula mobiliensis* var. *minor* Patr. and *N. goeppertiana* (Bleisch) H.L. Sm.

Observations sur *Navicula mobiliensis* var. *minor* Patr.
et *N. goeppertiana* (Bleisch) H.L. Smith.

by

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With 4 plates and 1 text figure

Abstract: Ultrastructural studies were carried out on *Navicula mobiliensis* var. *minor* Patr. and *N. goeppertiana* (Bleisch) H.L. Sm. *N. mobiliensis* var. *minor* is characterized by the unique rica sheets, and we have suggested that each rica sheet covering inner striated areas on both sides of the valve may be produced by the separate formation and subsequent assembly of whole discrete ricae. These rica sheets are supported by the struts locating on the intersections of interstriae and their linking bars. Each stria of *N. goeppertiana* is occluded by the transapical assembly of rica and by the marginal uni-series assembly of rica. In addition to the pore occlusions, the fine structure of stigma and cingulum are also discussed.

Key-words: diatoms, ultrastructure, taxonomy, fresh water diatoms, *Navicula*.

Résumé: L'étude ultrastructurale de *Navicula mobiliensis* var. *minor* Patr. et de *N. goeppertiana* (Bleisch) H.L. Sm. montre que *N. mobiliensis* var. *minor* est caractérisée par la présence de rica monolamellaire et il est suggéré que chaque rica, recouvrant des parties striées sur les deux côtés de la valve, est produit de façon particulière. Ces rica sont soutenus par des piliers placés à l'intersection des interstries et par leurs barres de liaison. Chaque strie de *N. goeppertiana* est fermée par des rica en disposition transapicale et par une série de rica disposée en un alignement marginal. La structure fine du stigma et du cingulum est également abordée.

Mots-cléfs: diatomées, ultrastructure, taxonomie, diatomées d'eau douce, *Navicula*.

Introduction

Few observations have been carried out on the fine structure of the subgenus *Punctulata* (Grun.) Patr. The subgenus is distinguished by clearly punctate striae among other features compared with those of other groups of the genus *Navicula* Bory. Some SEM observations of *N. mutica* Kütz. were presented by Cox (1977).

Examining original material Lange-Bertalot & Bonik (1978) showed differences with regard to a raphe system and stigma on the valve surface in *N. mutica*, *N. cohnii* (Hilse) Grun., *N. goeppertiana* (Bleisch) H.L. Sm. and *N. saxophila* Hust. The fine structure of *N. neoventricosa* Hust. was observed by authors (Mayama & Kobayasi 1982). Recently Phipps & Rosowski (1983) presented the fine structure of the valve of *N. mutica* together with the band morphology. *Navicula mobiliensis* Boyer var. *minor* Patr. has been collected from Japanese spring pools as reported in Kobayasi & Haraguchi (1969). With light microscopy its striation is quite similar to that of the taxa mentioned above, though it differs in its larger valve size, a distinct stigma and the presence of several isolated puncta near the ends of the striae on the side of central area opposite to the side bearing the stigma.

The present paper deals with the fine structural comparisons between *N. mobiliensis* var. *minor* and *N. goeppertiana* with special attention to the occlusions of the areolae.

Material and Methods

The specimens examined are all epilithic. They were collected from the following locations. *Navicula mobiliensis* var. *minor*: spring pool in the Sohrosenen, a scenic garden in Koganei-shi, 21 Feb. 1983. K-1583. *Navicula goeppertiana*: moat in the Matsu-moto Castle, 2 May 1981. N-743; the Chikugo-gawa (river) near Komorino, 5 Aug. 1977. K-1884; the Kinu-gawa (river) at the Hohsui Bridge, 30 Jan. 1980. K-1865; the Karabori-gawa (river) above its confluence with the Yanase-gawa (river), 14 May 1980. K-798; the Naka-gawa (river) at the Iizuka Bridge, 2 Dec. 1981. K-1243. Most material was cleaned by ultraviolet radiation which was very effective in cleaning without destroying the weakly silicified structure. Otherwise cells were cleaned with sulfuric acid and potassium dichromate, followed by washing with distilled water. SEM and TEM observations were made using JEOL F15 and JEOL 100B respectively.

Results

1. *Navicula mobiliensis* Boyer var. *minor* Patr. (figs 3-23).

SEM observation revealed that the outer valve face bears radiate rows of foramina (fig. 6). The mantle bears double rows of foramina and sometimes one poroid is added transapically in some place (fig. 10). The intervals of each foramen on the mantle correspond with those of the striae on the valve face (fig. 10). In the central area there are depressions near the ends of the short striae on the side of the central area opposite to the side bearing the stigma but these do not penetrate the valve (fig. 6). These depressions are obscure in the light microscope. The rectangular and/or hexagonal ricae join into a single layered sheet and extend over the inner surface of the striated areas of the valve (figs 1a-a', 1c-c', 8, 9, 13, 14). The interstriae and linking bars between interstriae are almost equal in thickness (fig. 12). On the

eroded inner surface of the valve, the lattice work shows concave smooth surfaces, forming saddle-like appearance between elevated intersectional portions of the interstriae and the linking bars (figs 1b-b', 1d-d', 11, 12). Therefore each rica does not contact to the basal siliceous layer directly (fig. 13) but are supported by short struts on the intersectional portions. Each rica covering the pore adjacent to the valve margin and the pore on the mantle of the same stria is supported by elongated struts (figs 1d-d', 15, 16, 17). The perforations of the ricae are of the regular scatter type (Mann 1981) (fig. 23). Externally the central raphe endings are bent towards the side opposite the stigma, where they are somewhat expanded (fig. 6) and the raphe slit is buried deep within the groove on which side wall a pleat like structure is visible (fig. 7). The terminal fissures turn to the opposite direction to that of the central raphe endings and it is to this side that Voigt faults are found (figs 3-5, 10). Internally the raphe slit is straight and ends in a helictoglossa at the pole (figs 8, 9). In the cross section of the plicate raphe system the notch is located on the side opposite to the side bearing the stigma (fig. 12). As the axial area is thicker than interstriae, the longitudinal row of punctae along it is refracted strongly under the light microscope (figs 3, 4, 5, 12). The external opening of the stigma is linear, situated in a elliptical depression on the central area and near the valve margin (fig. 6). The stigma is circular or reniforme internally ($1.3-1.5 \times 1.1-1.4 \mu\text{m}$), located near the central nodule (fig. 9). The internal opening is covered with a thin siliceous layer which is connected with the basal siliceous layer laterally near to the mantle (figs 18, 19). When the covering is lost a large depression can be seen (fig. 20). Here, a stump of the covering projects from one side just above the small circular opening of the stigma. The mature cingulum consists of six open bands with alternating orientation (figs 21, 22). The valvocopula, band 1, bears two rows of poroids with a single row around both poles and bears a distinctly stepped suture (fig. 22) corresponding to a similar step on the valve mantle (fig. 15). Bands 2 to 6 bear a single row of poroids.

2. *Navicula goeppertiana* (Bleisch) H.L. Smith (figs 24-48)

Specimens collected from various habitats showed considerable variations in valve shape. However, fine structural observations revealed that these variants should be included in a single species. The isolated depressions near the ends of the central short striae opposite the stigma varied in number and were sometimes absent (figs 24-33). This structure was illustrated by Lange-Bertalot & Bonik (1978, pl. 3, f. 4) from the original material though without comment. On the inner surface of the valve, each stria is occluded by a narrow rica and two pore occlusion systems can be seen (figs 2, 37, 38, 40). When eroded the valve face reveals linking bars between interstriae (fig. 39). The interstriae coincide with the axial area in thickness but the linking bars are thinner. The minute struts supporting ricae are seen on both sides of the upper surface of the interstriae near the linking bars. The marginal longitudinal sheet is supported by pairs of short struts, one at the center of the interstriae on the valve face and the other at the corresponding area on the mantle (figs 2d-d', 39, 42). The perforations in the ricae are in regular scatter (Mann 1981) (fig. 48). Externally

Discussion

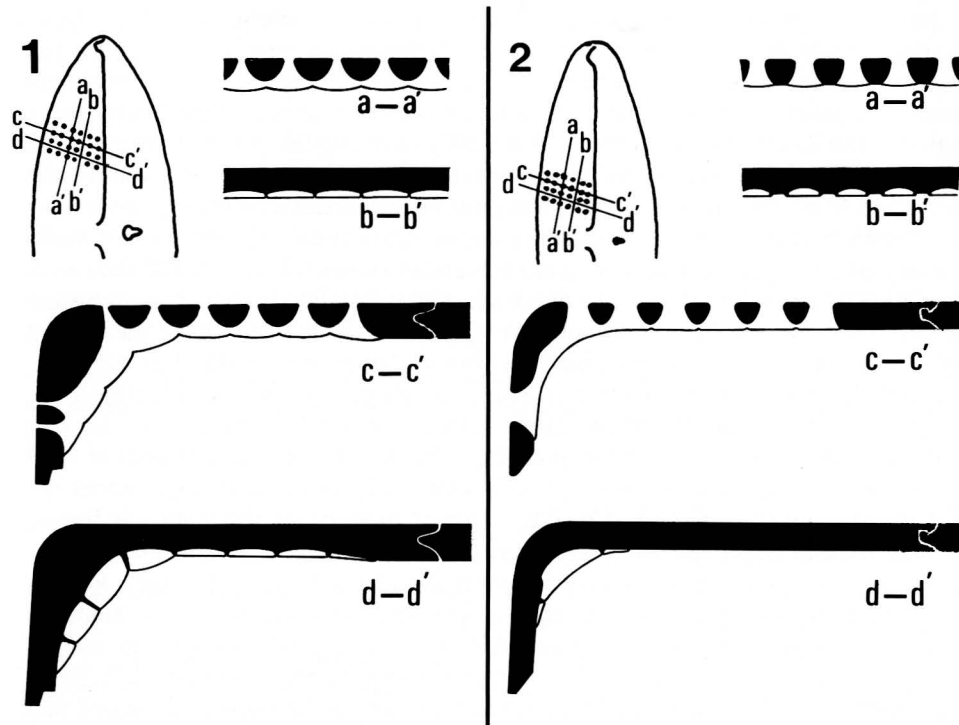


Fig. 1. - Diagram of sections of *N. mobiliensis* var. *minor*. - Fig. 2. Diagram of sections of *N. goeppertiana*.

the central raphe endings are curved away from the stigma (fig. 35). They are somewhat expanded (fig. 34) and bear the pleat-like structure observed in *N. mobiliensis* var. *minor*. In a section of the central nodule, the pleat-like structure is visible in side view (fig. 43). The terminal fissures of the raphe turn to the side bearing the stigma and the Voigt faults (fig. 36). In a cross section the raphe system is revealed to be a plicate raphe of which the blade occurs on the same side as the stigma (fig. 46). The stigma is a linear slit externally (fig. 35) and a circular or reniform structure internally ($0.7-1.0 \times 0.6-0.9 \mu\text{m}$) (figs 37, 43). The internal covering of the stigma is a thin siliceous layer with a central depression and connected to the basal siliceous layer laterally near the mantle (fig. 44). A circular opening occurs just beneath the stalk of the covering (fig. 45). The elevation bordering the depression is not so prominent when compared with that of *N. mobiliensis* var. *minor*. In the mature theca the cingulum consists of five alternating open bands (fig. 47). The valvocopula, band 1, bears double row of poroids. Bands 2 to 4 bear a single row of poroids along the advalver edge, but band 5 bears no poroid.

The areolae of the two taxa are structurally a little different from that summarized by Ross et al. (1979) and Krammer (1982) in having rica system attached above the surface of the valve. However, the rica system seen in *N. goeppertiana* seems to be general among the taxa with plugged stigma of *Navicula* subg. *Punctulata* (fig. 2). Though information is scarce in the literature, the same structure can be seen in the photomicrographs of *N. mutica* sensu Cox (1977), *N. mutica* sensu Lange-Bertalot & Bonik, *N. goeppertiana* from the type material (Lange-Bertalot & Bonik 1978) and *N. neoventricosa* (Mayama & Kobayasi 1982). Conversely, the rica system seen in *N. mobiliensis* var. *minor* is unique (fig. 1). The rica join to form a single layered sheet. We propose that each rica sheet covering the inner striated areas on both sides of the valve may be derived from the separate formation and subsequent assembly of whole discrete rica. If rica occluding only one areola is supposed to be a primitive type, the laterally joined rica band as seen in *N. goeppertiana* is considered to be an intermediate type and ricae joined into one sheet of the *N. mobiliensis* var. *minor* might be regarded to be a most advanced type.

As emphasized by Mann (1982), the right-left differentiation is also constant in the two species observed. The Voigt faults and stigma lie on the side of the valve enclosed by the terminal fissures. The central external raphe endings are curved away from the Voigt fault and stigma.

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References

- COX, E.J. (1977) - Raphe structure in naviculoid diatoms as revealed by the scanning electron microscope. *Nova Hedwigia*, Beih. **54**, 261-274.
 KRAMMER, K. (1982) - Observations on the alveoli and areolae of some Naviculaceae. *Nova Hedwigia*, Beih. **73**, 55-80.
 KOBAYASI, H. & K. HARAGUCHI (1969) - Diatom-association from spring pools in the vicinity of Kawagoe City, Saitama Pref. *Bull. Chichibu Mus. Nat. Hist.* **1969** (15), 27-54. (in Japanese).
 LANGE-BERTALOT, H. & K. BONIK (1978) - Zur systematisch-taxonomischen Revision des ökologisch interessanten Formenkreises um *Navicula mutica* Kützing. *Bot. Mar.* **21**, 31-37.
 MANN, D.G. (1981) - Sieves and flaps: siliceous minutiae in the pores of raphid diatoms. In: R. Ross (ed.), *Proc. 6th Symp. Recent Fossil Diatoms*, Budapest 1980 Koeltz (publ.), 279-300.
 MANN, D.G. (1982) - Structure, life history and systematics of *Rhoicosphenia* (Bacillariophyta). I. The vegetative cell of *Rh. curvata*. *J. Phycol.* **18**, 162-176.
 MAYAMA, S. & H. KOBAYASI (1982) - Diatoms from the Aono-gawa River. *Bull. Tokyo Gakugei Univ. Sect. 4.* **34**, 77-107. (in Japanese).
 PATRICK, R. (1959) - New species and nomenclatural changes in the genus *Navicula* (Bacillariophyceae). *Proc. Acad. Nat. Sci. Philadelphia* **111**, 91-111.
 PHIPPS, Jr. D.W. & J.R. ROSOWSKI (1983) - The morphology and integration of valves and bands in *Navicula mutica* var. *mutica* (Bacillariophyceae). *J. Phycol.* **19**, 320-323.
 ROSS, R., E.J. COX, N.I. KARAYEVA, D.G. MANN, T.B.B. PADDOCK, R. SIMONSEN & P.A.

SIMS (1979) - An amended terminology for the siliceous components of the diatom cell. *Nova Hedwigia*, Beih. 64, 513-533.

SMITH, H.L. (1874-1879) - *Species diatomacearum typicae studiis* H.L. Smith. Geneva, New York.

Explanation of Plates

Black scale bar = 10 μ m; white bar = 1 μ m; white bar with a dot = 0.1 μ m.

Plate 1

Figs 3-13. *Navicula mobiliensis* var. *minor* Patr. - Figs 3-5. Specimens from Sohrohseken. - Fig. 6. Valve center showing outer opening of the stigma and depressions (arrowhead) on the opposite side. - Fig. 7. Central raphe-ending showing pleat-like structure. - Fig. 8. Internal view of valve apex showing the continuous rica cover and the helictoglossa (arrowhead). - Fig. 9. Valve interior showing transapically expanded central nodule. - Fig. 10. Valve apex showing the Voigt fault (arrowhead). - Fig. 11. Internal view of fractured eroded valve showing the long struts supporting marginal row of ricae. - Fig. 12. Interior of fractured eroded valve showing the plicate raphe. - Fig. 13. Internal view of fractured valve near axial area showing gap between ricae and interstitial rib (arrowhead).

Plate 2

Figs 14-23. *N. mobiliensis* var. *minor*. - Fig. 14. Internal view of fractured valve near central area. - Fig. 15. Section near valve margin showing long struts supporting marginal rica and the step on the inside surface of the valve mantle (arrowhead). - Fig. 16. Internal view near valve margin showing marginal longitudinal row of pores and large ricae covering it. - Fig. 17. Side view of broken mantle showing long struts. - Fig. 18, 19. Internal stigma covered by thin siliceous cover. - Fig. 20. Internal stigma showing broken stalk of the cover and circular inner opening of the stigma and elevated marginal ring of the depression. - Fig. 21. Epi- and hypo-cingulum, composed of four bands (B3 etc.) and three bands respectively. - Fig. 22. Epi-cingulum composed of six bands showing valvocopula (B1) and bands 2 to 6. - Fig. 23. Pore occlusions with perforations of regular scatter type (Mann 1981) (TEM).

Plate 3

Figs 24-39. *N. goeppertiana*. - Figs 24, 25. (Specimens from a moat of Matsumoto Castle). - Figs 26, 27. (Chikugo-gawa). - Figs 28, 29. (Kinu-gawa). - Figs 30, 31. (Naka-gawa). - Figs 32, 33. (Karabori-gawa). - Fig. 34. Central raphe ending. - Fig. 35. Exterior valve center. - Fig. 36. Valve apex showing the Voigt fault (arrowhead). - Fig. 37. Internal view of central area. - Fig. 38. Internal valve apex showing marginal longitudinal rica band. - Fig. 39. Internal eroded valve. Note the two marginal struts on both valve margin and mantle (white arrows), and minute struts locating on both sides of the interstitial surface in pairs (black arrow).

Plate 4

Figs 40-48. *Navicula goeppertiana*. - Fig. 40. Internal view of valve margin neighbouring the central area showing longitudinal canal-like structure. - Fig. 41. Fractured valve margin showing section of the longitudinal canal-like structure. - Fig. 42. Internal view of valve fractured along the marginal pore row showing struts supporting ricae (arrowhead), and the trace of the struts on the broken fragment of the mantle (arrow). - Fig. 43. Longitudinally broken central nodule showing side view of pleat-like structure in the central raphe ending. - Fig. 44. Internal view of fractured stigma showing thin siliceous covering. - Fig. 45. Internal stigma with broken stalk of the covering. - Fig. 46. Fractured valve showing plicate raphe system. - Fig. 47. Epi-theca with five bands. Band 1 (valvocopula) bears double row of poroids and bands 2 to 4 with a single row of poroids on each advalval edge. Band 5 (pleura) without poroids. - Fig. 48. Pore occlusions with perforations of the regular scatter (Mann 1981) (TEM).

