Cenozoic diatom genus *Bogorovia* Jousé: An emended description

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Abstract. An emended definition of the fossil diatom genus *Bogorovia* Jousé is presented along with a detailed description of eight species. The stratigraphic range and geographic distribution of each species are provided based on analysis of deep-sea cores and literature survey. The genus is closely related to the genus *Ressiella* Desikachary et Maheshwari, but is distinguished from the latter mainly by the presence of transapical costae. It also shows a close resemblance to *Koizumia* Yanagisawa, but differs mainly by the structure of the marginal ridge. On the basis of certain characteristic features, the genus *Bogorovia* can be placed in the family Cylatosiraceae Hasle, von Stosch et Syvertsen. Four new species are described and two new combinations are established; *Bogorovia barronii* Yanagisawa sp. nov., *B. curvata* Yanagisawa sp. nov., *B. puncticulata* Yanagisawa sp. nov., *B. rostrata* Yanagisawa sp. nov., *B. gombosii* (Desikachary) Yanagisawa comb. nov. and *B. lancettula* (Schrad) Yanagisawa comb. nov.

Key words: Taxonomy, diatom, *Bogorovia*, fossil, biostratigraphy

Introduction

*Bogorovia* is a diatom genus erected by Jousé (1973) for a Late Oligocene marine diatom, *B. veniamini* Jousé, which is of great importance in Late Oligocene to Early Miocene diatom marine biostratigraphy (e.g. Fenner, 1985; Barron, 1985b). A detailed morphologic and biostratigraphic examination of the genus *Bogorovia* and its related genus *Ressiella* Desikachary et Maheshwari has revealed the need for taxonomic revision of this diatom group, showing that there are three distinct subgroups that merit separate generic recognition; *Bogorovia* emended, *Ressiella* emended and *Koizumia* gen. nov. The latter two genera are dealt with elsewhere (Yanagisawa, 1994, 1995).

In this paper, an emended definition of the genus *Bogorovia* is presented along with detailed descriptions of its eight members. Furthermore, the stratigraphic range and geographic distribution of each species are established on the basis of analysis of deep-sea cores and literature survey.

Material and methods

For biostratigraphic study, samples from the Upper Oligocene to Upper Miocene sections of DSDP Holes 71, 77B and 70A in the eastern equatorial Pacific were used (Table 1). Slides of some selected samples studied by

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<th>No.</th>
<th>Cores &amp; samples</th>
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<th>References and remarks</th>
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<tr>
<td>1</td>
<td>DSDP Hole 70A</td>
<td>Eastern equatorial Pacific</td>
<td>6°20'08&quot; N, 140°21'72&quot; W</td>
<td>DSDP core</td>
<td>Tracey et al. (1971)</td>
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<td>2</td>
<td>DSDP Hole 71</td>
<td>Eastern equatorial Pacific</td>
<td>4°28'28&quot; N, 140°18'91&quot; W</td>
<td>DSDP core</td>
<td>Tracey et al. (1971), Barron (1983)</td>
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<td>3</td>
<td>DSDP Hole 77B</td>
<td>Eastern equatorial Pacific</td>
<td>0°28'90&quot; N, 133°13'70&quot; W</td>
<td>DSDP core</td>
<td>Hays et al. (1972), Barron (1981b, 1983)</td>
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<td>4</td>
<td>DSDP Hole 438A</td>
<td>Northwest Pacific</td>
<td>40°37'79&quot; N, 143°14'15&quot; E</td>
<td>DSDP core</td>
<td>Scientific Party (1980), Barron (1980b)</td>
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<td>5</td>
<td>225</td>
<td>Central equatorial Pacific</td>
<td>3°13'32&quot; N, 169°41'65&quot; W</td>
<td>Piston core</td>
<td>Nishimura (1986)</td>
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<td>6</td>
<td>P 3</td>
<td>Indian Ocean off Java</td>
<td>11°59'04&quot; S, 113°31'37&quot; E</td>
<td>Piston core</td>
<td>Yanagisawa (1987), Honza et al. (1987)</td>
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<td>8</td>
<td>A-1</td>
<td>Tomioka, Fukushima, Japan</td>
<td>37°20'26&quot; N, 140°59'31&quot; E</td>
<td>Drill core</td>
<td>Yanagisawa et al. (1989)</td>
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Barron (1983, 1985a) and the slides deposited in the DSDP Reference Center in the National Science Museum (Tokyo) were examined in this study. Samples from the Lower Miocene through Quaternary section of DSDP Hole 438A in the northwestern Pacific were also analyzed. Slides analyzed by Akiba et al. (1982), Manuyama (1984) and Akiba (1986), together with those deposited in the DSDP Reference Center in the National Science Museum (Tokyo) were re-examined with special attention to the genus Bogorovia. For taxonomic study and SEM observations, several selected samples were used to supplement the DSDP samples (Table 1).

Preparation methods for light and scanning electron microscopy (SEM) were described in Yanagisawa (1994).

Results and discussion

As a result of taxonomic study, eight species are recognized, including four new species and two new combinations as follows: Bogorovia baronii Yanagisawa sp. nov., B. curvata Yanagisawa sp. nov., B. gombosii (Desikachary) Yanagisawa comb. nov., B. lancettula (Schrader) Yanagisawa comb. nov., B. praepaleacea (Schrader) Jousé, B. puncticulata Yanagisawa sp. nov., B. rostrata Yanagisawa sp. nov., B. veniamini Jousé ex Yanagisawa.

Morphology

Morphologic terminology for the genus was introduced in Yanagisawa (1994), and general terminology for description of frustule follows Anonymous (1975), Ross et al. (1973), Simonsen (1979) and Round et al. (1990).

The valve outline of this genus is linear-lanceolate and isopolar (Figure 1). The apical axis is generally straight except for B. curvata which has a curved apical axis. The apex is rostrate with an apical pore field consisting of fine puncta. All species have transapical costae (ribs) which extend from both valve margins. The costae are generally continuous, but some of them are interrupted at the middle. For description, the spacing of transapical costae is classified into two categories: narrowly spaced type (9-14 costae in 10 \( \mu \)m) and broadly spaced type (6-8.5 costae in 10 \( \mu \)m).

All members of this genus have marginal ridges of the fused type wherein the marginal ridges of sibling valves are completely fused so that a set of fused sibling valves seems as if it were a frustule (Figure 1). The marginal ridge is either of type 3 or type 2 (See Yanagisawa, 1994).

![Figure 1. Structure of a chain of frustule of Bogorovia puncticulata Yanagisawa sp. nov.](image_url)
Figure 2. Stratigraphic distribution of *Rossiella* and *Bogorovia* species in DSDP Holes 77B, 71 and 70A. Narrow horizontal lines show samples examined. Each dot indicates the presence of each species. Original data are presented in Appendix table and appendix table in Yanagisawa (1995).
The type 3 is a fused-type marginal ridge with three longitudinal rows of pores. The type 2 marginal ridges have two longitudinal rows of pores. *Bogorovia* species may form a long chain colony by the fusion of their marginal ridges (Figure 1). In some species, valves with the separate-type marginal ridge are observed. These may be separation valves that may have a role to separate an otherwise interminably long chain into shorter chains.

A rimoportula (labiate process) is present generally in "one per cell pattern"; a funstule consists of a process valve and a non-process valve, and thus this genus is heterovalvate. In the non-process valve, a small structureless area is present where a rimoportula might be located if it were present. The non-process valve of *Bogorovia puncticulata* has a small knob which may be a reduced rimoportula (Figures 13-1, 13-2), suggesting that the rimoportula of the non-process valve may be secondarily reduced. All species have a subcentral rimoportula without exception.

The valve face is convex. In some species, the valve face is perforated with areolae, but others lack areolae, in which case the valve face is hyaline. The areolae of this genus are classified into four types for description: medium (ca. 0.8 \( \mu \)m in diameter), fine (ca. 0.4-0.5 \( \mu \)m in diameter), very fine areolae (less than 0.1 \( \mu \)m in diameter) and the absence of areolae (hyaline). The areolae are circular in shape and distributed sparsely and randomly on the valve face.

The cingulum is composed of a few bands with a row of small puncta, but its detailed composition is not known at present.

### Stratigraphic distribution

The stratigraphic occurrences of *Bogorovia* species are presented in Figure 2 and Appendix table for DSDP Holes 77B, 71 and 70A. The stratigraphic ranges of each species are shown in Figure 3, which is mainly based on Figure 2 as well as on some other important biostratigraphic studies such as Baldauf (1985), Baldauf and Barron (1991), Barron (1981a, 1981b, 1983, 1985a, 1985b, 1992), Fenner (1984a, 1984b, 1985), Fourtanier (1987, 1991), Geronde and Burckle (1990), Harwood and Maruyama (1982), Sancetta (1982) and Schrader (1973, 1974a, 1974b, 1976). Correlation to the time scale of Berggren et al. (1985) is adjusted through Barron et al. (1985) and Oda (1986).

### Geographic distribution

The geographic distribution of each species was surveyed from literature. The results are shown in Figures 7, 10, 11, 15, 17 and 18. All species of the genus are distributed mainly at low latitudes in the Pacific, Atlantic and Indian Oceans with rare occurrences at middle latitudes, indicating that they are essentially oceanic warm-water species

### Systematics

In this paper, the classification system of Round et al. (1990) is adopted for the description of the genus *Bogorovia* because the system appears to be the most natural system at present.
Diatom genus *Bogorovia*

Class Coscinodiscophyceae Round et Crawford, 1990
Subclass Cymatosiophycidae Round et Crawford, 1990
Order Cymatosirales Round et Crawford, 1990
Family Cymatosiraceae Hasle, von Stoch et Syvertsen, 1983
Subfamily Cymatosiroideae Hasle, von Stoch et Syvertsen, 1983


Generic type.—*Bogorovia veniamini* Jousé ex Yanagisawa

*Original description.*—Valves lanceolate or linear-lanceolate with slightly rostrate ends. No axial area present. Valve surface with closely packed areolae, in transverse rows near the margin of the valve, elsewhere randomly arranged. No intercalary bands or pseudosepta present (Jousé, 1973).

*Emended description.*—Cell heterovalvate, rectangular or lanceolate in girdle view, forming inseparable chain colonies. Separation valve or end valve separates chain colonies. Cingula with several bands with or without fine puncta. Valve slightly convex, linear-lanceolate. Apices with small apical pore field, mostly rostrate. Marginal ridge always present, completely fused with sibbling valve. Rimoportulae one per cell; a frustule consisting of a process valve and a non-process valve. Rimoportula located at subcentral position near the margin. Transapical costae developed.

*Comparison.*—The genus resembles the genus *Rossiella* Desikachary et Maheshwari, but clearly differs from the latter genus mainly by having transapical costae, relatively small areolae or missing areolae. The genus *Bogorovia* is similar to the genus *Koizumia*, but the two genera are distinguished by the type of marginal ridge; *Bogorovia* has marginal ridges of type 3 or type 2, whereas *Koizumia* is characterized by a type 4 marginal ridge (Yanagisawa, 1994). *Bogorovia* is also discriminated from *Koizumia* in having randomly distributed areolae on the valve face, in contrast to the regularly arranged areolae of *Koizumia* forming transapical and longitudinal rows.

*Bogorovia* closely resembles genera in the Cymatosiraceae such as *Cymatosira* Grunow and *Campyllosira* Grunow in Van Heurck in that they commonly possess a generally dipolar outline, chain colonies connected by marginal ridge or linking spines, rimoportula in the pattern of one per cell, and an ocellus or apical pore field at each apex; the genus *Bogorovia* therefore can be included in the family Cymatosiraceae Hasle, von Stoch et Syvertsen. Jousé (1973) has already suggested that the genus *Bogorovia* has some relationship to *Campyllosira* and *Cymatosira*.

*Stratigraphic occurrence.*—Late Oligocene to Middle Pleistocene. The first species of this genus is *B. gombosii* which appeared in the uppermost part of the b Subzone of the *Rocella vigilans* Zone of Fenner (1984a, 1985). The last species *R. curvata* is found in the *Pseudoeunotia doliolus* Zone (NTD 17).

*Habitat.*—Because of its dominant occurrence in oceanic sediments, most species of the genus are probably holoplanktonic, making a long chain formed by fused

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**Table 2. Key to species based on light microscopy.**

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<td>1a. Areolae present</td>
<td>2</td>
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<tr>
<td>1b. Areolae absent</td>
<td>6</td>
</tr>
<tr>
<td>2a. Areolae medium or fine</td>
<td>3</td>
</tr>
<tr>
<td>2b. Areolae very fine</td>
<td>5</td>
</tr>
<tr>
<td>3a. Areolae medium and transapical costae partially developed</td>
<td><em>B. gombosii</em></td>
</tr>
<tr>
<td>3b. Areolae fine and transapical costae well developed</td>
<td>4</td>
</tr>
<tr>
<td>4a. Transapical costae broadly spaced and valve relatively large</td>
<td><em>B. veniamini</em></td>
</tr>
<tr>
<td>4b. Transapical costae narrowly spaced and valve relatively small</td>
<td><em>B. barronii</em></td>
</tr>
<tr>
<td>5a. Valve with slightly rostrate apices</td>
<td><em>B. puncticulata</em></td>
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<tr>
<td>5b. Valve with strongly rostrate apices</td>
<td><em>B. rostrata</em></td>
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<tr>
<td>6a. Transapical costae narrowly spaced</td>
<td>7</td>
</tr>
<tr>
<td>6b. Transapical costae broadly spaced</td>
<td><em>B. praeapaleacea</em></td>
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<tr>
<td>7a. Valve not curved</td>
<td><em>B. lancettula</em></td>
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<td>7b. Valve curved</td>
<td><em>B. curvata</em></td>
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Figure 5. Scanning electron photomicrographs of *Bogorovia gombosi* (Desikachary) Yanagisawa comb. nov. and *B. barronii* Yanagisawa sp. nov. Scale bars equal 5 μm. 1, 2. *Bogorovia gombosi* (Desikachary) Yanagisawa comb. nov. DSDP Hole 71, 36-2, 125-129 cm. (1) Inner view of valve. (2) Oblique view of a set of sibling valves. 3-5. *Bogorovia barronii* Yanagisawa sp. nov. Sample P 225 VII 20, equatorial Pacific. (3, 4) Outer view of a separation valve. (5) Enlarged view of a valve apex with an apical pore field.

marginal ridges.

**Geographic distribution.**—All species are distributed mainly in the low–latitude areas of the Pacific, Atlantic and Indian Oceans, and rarely and sporadically occur also in the middle- to high-latitude areas.

Key to species based on light microscopy is presented in Table 2.

**Bogorovia gombosi** (Desikachary) Yanagisawa comb. nov.

Figures 4-1, 4-2, 5-1, 5-2


Synonymy. *Bogorovia veniamini* Jousé, Schrader, 1976, p. 630, pl. 5, figs. 22-23; Gombos, 1976, p. 593, pl. 1, figs. 6, 7, pl. 12, figs. 2, 4 (non pl. 12, fig. 1); Genus et species indet., Schrader, 1976, pl. 5, fig. 16; *Rossiella* sp., Gombos and Ciesielski, 1983, p. 604, pl. 24, figs. 1-2; *Rossiella* aff. *R. symmetrifica* Fenner, Fourtanier, 1991, pl. 4, fig. 2.

**Additional description.**—Valve lanceolate with slightly rostrate rounded apices, 30-64 μm long, 7-10.5 μm wide (Figure 6). Valve face slightly convex, covered with rounded medium areolae distributed randomly and sparsely, 6-7 in 10 μm. On both valve sides, numerous transapical costae present, 7-8.5 in 10 μm, incomplete, not reaching valve center (Figure 5-1). Marginal ridge, fused-type with three longitudinal rows of rounded pores (type 3), 7-8.5 pores in 10 μm (Figure 5-2). A small pore field present at each apex. A subcentral rimoportula, one per cell, located near edge of valve face.

Figure 6. Size variation in *Bogorovia gombosii* (Desikachary) Yanagisawa comb. nov. A. Scatter plot of valve width versus length. B. Scatter plot of valve length versus the number of transapical costae in 10 \( \mu \text{m} \). C. Scatter plot of valve width versus the number of transapical costae in 10 \( \mu \text{m} \). Samples from no. 2 in Table 1.

Comparisons.—Bogorovia gombosii bears a close resemblance to Rossella symmertica, but differs from the latter species by the presence of transapical costae and more sparsely distributed smaller areolae on valve face. It is also similar to Bogorovia veniamini, but distinguished by its larger and more sparse areolae and the less developed transapical costae.

The species was first recognized by Gombos and Ciesielski (1983) as Rossella sp., but Fenner (1984a, 1984b) regarded it as synonymous with R. symmertica. Desikachary et al. (1984) erected the species based on Gombos and Ciesielski’s (1983) specimen, but no one else has referred to it to date. Fourtanier (1991) reported it as Rossella aff. R. symmertica.

Stratigraphic range.—At low-latitudes, the first occurrence of this species is in the upper part of the Rocella vigilans Zone. It last occurs near the top of the A. Subzone of the R. paleacea Zone (NTD 1A) (Figures 2, 3).

Geographic distribution.—The species occurs in the equatorial Pacific (Fourtanier, 1987, this study), the equatorial Indian Ocean (Fourtanier, 1991) and the Southern Ocean (Schrader, 1976; Gombos, 1976, 1983; Gombos and Ciesielski, 1983) (Figure 7).

Bogorovia veniamini Jousé ex Yanagisawa

Figures 4–3—10, 8–1—9.

Jousé, 1973, p. 351, pl. 4, figs. 1–3; Jousé, 1976, p. 1233, figs. 1–3; Jousé ed., 1977, pl. 54, figs. 1–5; Barron, 1983, p. 512, pl. V, fig. 3; Barron, 1985a, pl. 8, fig. 12; Fenner, 1985, p. 727; Barron, 1985b, p. 780, fig. 9.5; Kim and Barron, 1986, p. 177, pl. 5, figs. 11–12; Fourtanier, 1991, pl.

Figure 8. Scanning electron photomicrographs of Bogorovia veniamini Jousé ex Yanagisawa. DSDP Hole 71, 36–2, 125–129 cm. Broad and narrow scale bars equal 5 μm and 1 μm, respectively. 1, 2. Two sets of fused sibling valves. Arrows indicate the outer openings of rimoperculie. 3, 4. Inner views of a valve, showing a rimopurtula (arrow heads). 5, 6. Outer views of a separation valve with separated-type marginal ridge. 7. Inner view of a non-process valve (the opposite side of the specimen shown in Figs. 8–3, 8–4). 8, 9. Enlarged views of an apex with an apical pore field.
4, fig. 3; Radionova, 1991, p. 98, pl. 23, fig. 7.

Additional description.—Valve linear-lanceolate with slightly rostrate rounded apices, 18–82 µm long, 6.5–12 µm wide (Figure 9). Valve face convex, densely punctuated by fine areolae distributed randomly, 8–10 areolae in 10 µm. Transapical costae, 5.5–8 in 10 µm, extend from both sides to form a zigzag-longitudinal line in valve center. Marginal ridge, fused type with three longitudinal rows of large round pores (type 3), 5–6 pores in 10 µm (Figure 8–2). A small pore field is present at each apex (Figure 8–8). A subcentral rimoportula, one per cell, located near valve edge with an internal lip-shaped opening (Figures 8–3, 8–4). Non-process valve with a small hyaline area which a rimoportula might occupy if present (Figure 8–7). Cingulum consisting of two or three bands (Figures 8–1, 8–2). Separation valves with a separated type marginal ridge (type I) are sometimes observed (Figures 8–5, 8–6; Fournier, 1987, pl. 14, fig. 5).

Holotype.—Plate 4, fig. 1 in Jousé (1973) designated in this paper (deposited in the collections of the Micropalaeontological Laboratory of the Institute of Oceanology, Academy of Science of Russia).

Type locality and sample.—R/V "Vityaz" Station 5996/8, 630 cm depth in a core, 10°58'N, 153°23'W, central equatorial Pacific (Early Miocene in age).

Comparison.—Bogorovia veniamini resembles B. gombossii but differs by the smaller and denser areolation and the well-developed transapical costae. It is discriminated from B. barronii by the broader and larger valve and wider spacing of transapical costae (Figure 9).

Stratigraphic range.—The first occurrence of this species defines the base of the Bogorovia veniamini Zone (Fenner, 1984b) (Figure 3). Its last occurrence defines the top of the R. paleacea Zone (NDT 1) (Barron, 1983). This species is one of the most abundant constituents of the Late Oligocene to earliest Miocene marine diatom assemblage.

Geographic distribution.—The species is found abundantly at low latitudes in the Atlantic, Pacific, and Indian oceans (e.g. Jousé, 1973, 1976; Barron, 1983; Fenner, 1985; Fournier, 1991; Radionova, 1991) and also in the Southern Ocean (e.g. Baldauf and Barron, 1991; Harwood and Maruyama, 1992) (Figure 10). It also occurs in Baja California (Kim and Barron, 1986), the North Atlantic and northern Italy (Monjanel, 1987), but not in the high-latitude North Pacific (Akiba et al., 1993).

Discussion.—As pointed out by Sancetta (1985), no specimen was designated as holotype of this species by Jousé (1973), and as no further action has been taken in this regard, the species has remained invalid according to Article 37 of the International Code of Botanical Nomenclature. It is hereby validated by the above designation of a holotype.

When Desikachary et al. (1984) clarified the taxonomy of the genus Rossella, they did not transfer Bogorovia veniamini Jousé to Rossella because the species is so different from the members of Rossella in having transverse rows of areolae with distinct transverse (transapical) costae. However, this taxonomic treatment of Desikachary et al. (1984) is apparently inconsistent with their admission of Rossella praeapaleacea (Schrader) Gersonde et Schrader and the establishment of Rossella gombossi Desikachary, because the two species have the distinct transapical costae which is one of the important features of the genus Bogorovia. Gersonde and Schrader (1984)
and Barron (1985b) also did not transfer *Bogorovia veniamini* to the genus *Rossiella* without giving any reasons.

**Bogorovia barronii** Yanagisawa sp. nov.

Figures 4-11-14, 5-3-5.

Synonym. *Bogorovia* sp., Akiba, 1980, p. 11, pl. 4, fig. 48.

Description.—Valve linear-lanceolate with slightly rostrate rounded apices, 20-43 μm long, 4.5-6.5 μm wide (Figure 9). Valve face convex, covered with fine areolae, 10-12 in 10 μm. Transapical costae, 10-11.5 in 10 μm. Marginal ridge, fused-type with three longitudinal rows of pores (type 3), 10 pores in 10 μm. A small pore field is present at each apex (Figure 5-5). A subcentral rimportula, one per cell, located near the valve edge. A separation valve with separated-type marginal ridge (type 1) is observed (Figures 5-3, 5-4).

Holotype.—Figure 4-14 (GSJF12755 deposited in the Geological Survey of Japan).

Type locality and sample.—DSDP Hole 71, Core 26, Section 4, Interval 70-72 cm, 4°28.28′N, 140°18.91′W, eastern equatorial Pacific (Early Miocene in age, the Triceratium pileus Zone, NTD 3).

Comparisons.—This species is very similar to *Bogorovia veniamini*, but it differs by its more narrowly spaced transapical costae and narrower valve (Figure 9). It also resembles *B. puncticulata* but is distinguished from the latter species by its larger areolae.

Stratigraphic range.—At low-latitudes, the species occurs from the middle part of the B subzone of the *R. paleacea Zone* (NTD 1B) to the uppermost part of the *T. pileus Zone* (NTD 3) (Figure 3). Reworked specimens are sometimes found in the middle Miocene intervals in DSDP Holes 71 and 77B (Figure 2).

Geographic distribution.—This new species has been found in DSDP Holes 71 and 77B, core P 225 recovered in equatorial Pacific (this study), the Early Miocene Hota Group in the Boso Peninsula, Japan (Akiba, 1980) and DSDP Hole 545 in the North Atlantic off Africa (Monjanel, 1987) (Figure 11).

Etymology.—The species name is dedicated to Dr. John Arthur Barron, who has worked extensively on
marine diatom biostratigraphy and supplied the author the type material of this species.

**Bogorovia puncticulata** Yanagisawa sp. nov.

Figures 4-15-20, 4-33, 4-34, 12-1-5, 13-1-11.

Synonymy. **Bogorovia veniamini** Jousé, Fourtanier and Macharé, 1988, pl. 2, fig. 17; **Rossiella** sp. 1, Fourtanier, 1991, pl. 4, fig. 6; **Rossiella** cf. **lancetula** (Schrader) Gersonde and Schrader, Yanagisawa, 1993, pl. 2, fig. 3.

**Description.**—Valve linear-lanceolate with slightly rostrate rounded apices, 13-51 μm long, 4-7 μm wide (Figure 14). At each apex, an apical pore field is present (Figure 12-5). Valve face convex, punctuated by very fine areolae, densely in the primitive form (10-12 in 10 μm) and sparsely in the advanced form (8-10 in 10 μm). Transapical ribs, 8.5-14 in 10 μm. Marginal ridge, fused-type

**Figure 11.** Geographic distribution of **Bogorovia barronii** Yanagisawa sp. nov. Closed circles: localities reported with figures. 1. DSDP Hole 71, equatorial Pacific (this study). 2. DSDP Hole 77B, equatorial Pacific (this study). 3. Geological Survey of Japan piston core P 225, equatorial Pacific (this study). 4. Hota Group, Boso Peninsula, Japan (Akiba, 1980). 5. DSDP Hole 545, northeast Atlantic off Africa (Monjanel, 1987).

**Figure 12.** Scanning electron photomicrographs of **Bogorovia puncticulata** Yanagisawa sp. nov. (primitive form). Sample P 225, VII 20, equatorial Pacific. Broad and narrow scale bars equal 5 μm and 1 μm, respectively. 1. Inner view of a set of sibling valves. 2, 3. Inner views of a separation valve. Arrow indicates a rimoportula. 4. Enlargement of Fig. 12-1, showing the outer opening of a rimoportula (arrow). 5. Enlarged view of a valve apex with an apical pore field.
Figure 13. Scanning electron photomicrographs of *Bogorovia puncticulata* Yanagisawa sp. nov. (advanced form). Sample M 32, Isozaki Formation, Ajigaura area, Japan. Broad and narrow scale bars equal 5 μm and 1 μm, respectively. 1, 3. Inner views of a non-process valve. Arrows indicate a small knob which may be a "reduced" rimoportula. 2, 4. Inner views of a process valve (the opposite side of the specimen shown in Figs. 13-1, 13-2). Arrows indicate a rimoportula. 5. Girdle view of a set of sibling valves with fused-type marginal ridge (type 3). 6, 7. Outer views of a separation valve with separated-type marginal ridge (type 1). 8. Enlarged view of an apex with an apical pore field. 9. Oblique view of a set of sibling valves. Arrow indicates the outer opening of a rimoportula. 10, 11. Views of valve interior and marginal ridge. Each arrow indicates a rimoportula.

with three longitudinal rows of pores (type 3), 8-10 pores in 10 μm (Figure 13-1). Separation valve exceptionally has separated-type marginal ridge with one row of pores (type 1) (Figures 12-2, 13-6). A subcentral rimoportula, one per cell, located near valve edge with its internal lip-shaped opening oriented diagonal to apical axis, and with a small external pore at the marginal ridge (Figures 13-4, 13-11). Non-process valve with a small knob at the position which a rimoportula might occupy if present (Figure 13-2).

Holotype.—Figure 4-15 (GSJF15593 deposited in the Geological Survey of Japan).

Type locality and sample.—Piston core sample P225, VII 20 cm (570 cm from the core top); 31°33.32'N, 169°41.65'W, 5,427 m in water depth, central Pacific. The core was recovered by GH81-4 Cruise of the Geologic Survey of Japan (Nishimura, 1986). Core P225, 768 cm in thickness, is composed of the upper Pleistocene unit and the lowermost Miocene unit, which are bounded by a hiatus 268 cm from the top. The type sample is taken from the lower unit of dark brown siliceous ooze. The radiolarian fauna indicates Early Miocene age, ranging from 20.7 to 23.2 Ma (Nishimura, 1986). The diatom assemblage from the sample is correlative with the *Triceratium pileus* Zone (NTD 3) of Barron (1985b).

Comparisons.—This species differs from *Bogorovia lancetula* and *B. praepalaeaceae* by the presence of areolae on the valve face. It is distinguished from *B. barronii* by finer areolation. The species is similar to *B. rostrata*, but differs by its more slender valve outline and not so strongly rostrate apices (Figure 14).

Stratigraphic range.—This species occurs from the
upper part of the C Subzone of the R. paleacea Zone (NTD 1C) to the top of the B Subzone of the Coscinodiscus yabei Zone (NPD 10B) in the equatorial Pacific (Figures 2, 3). It was found from the upper part of the Denticulopsis predimensiona Zone (NPD 5B) to the lower part of the Thalassiosira yabei Zone (NPD 5C) in DSDP Hole 438A (Yanagisawa, 1994, fig. 6), but this range is much shorter than that in the low-latitude.

Geographic distribution.—This new species is found commonly in the equatorial Pacific (this study) (Figure 15). The species also has been figured from the equatorial Indian Ocean (Fourtanier, 1991) and the Cabellas Formation in Peru (Fourtanier, 1987, Fourtanier and Macharé, 1988). It occurs in DSDP Hole 438A and several Japanese on-land sections (this study; Yanagisawa, 1993).

Discussion.—The species shows a typical phylectic change with gradual reduction of areolae through time. The older primitive form has densely perforated puncta (Figures 4-15, 12-1-5), whereas the younger advanced form is characterized by sparsely distributed areolae on the valve face (Figures 4-16-20, 13-1-11). The youngest form carries only a few puncta (Figure 4-19), showing very close resemblance to B. lancettula.

Etymology.—The species name is derived from its minutely punctate valve face.

**Bogorovia rostrata** Yanagisawa sp. nov.

Figure 4-21.

Description.—Valve broadly lanceolate with strongly rostrate rounded apices, 29-43 μm long, 8.5-9.5 μm wide (Figure 14). Valve face convex, sparsely punctated by very fine areolae, 8-10 in 10 μm. Transapical ribs, 9.5-10 in 10 μm. Marginal ridge, fused—type with three longitudi-

Figure 14. Size variation in *Bogorovia puncticulata* Yanagisawa sp. nov. and *B. rostrata* Yanagisawa sp. nov. A. Scatter plot of valve width versus length. B. Scatter plot of valve length versus the number of transapical costae in 10 μm. C. Scatter plot of valve width versus the number of transapical costae in 10 μm. Samples from nos. 2-5, 7, 8 in Table 1.

Figure 16. Size variation in *Bogorovia lancettula* (Schrader) Yanagisawa comb. nov. and *B. praepaleacea* (Schrader) Jousé. A. Scatter plot of valve width versus length. B. Scatter plot of valve length versus the number of transapical costae in 10 μm. C. Scatter plot of valve width versus the number of transapical costae in 10 μm. Samples from no. 2, 3 in Table 1.

Slightly rostrate and acutely rounded apices, 17–45 μm long, 3.5–5 μm wide (Figure 16). Valve face convex, hyaline without areolae. Transapical costae, 10–13 in 10 μm. Marginal ridge, fused-type with two rows of pores (type 2), 9–10 pores in 10 μm. A subcentral rimoportula, one per cell, located near valve edge. A separation valve with separated-type marginal ridge (type 1) has been observed (Fournier, 1987, pl. 15, figs. 6, 7).

Comparisons.—The species differs from *B. puncticulata* by the absence of areolae on valve face and the two rows of marginal ridge (type 2). It is distinguished from *B. praepaleacea* by the narrower interval of transapical costae and smaller valve size (Figure 16). This species differs from *B. curvata* by its transapically symmetric valve outline.

Stratigraphic range.—The first occurrence of the species lies in the middle part of the Coscinodiscus gigas var. diorama Zone (NTD 7) (Figure 3). Its last occurrence, though not precisely known at present, may be near the top of the Nitzschia jouseae Zone (NTD 14) according to Schrader (1974b).

Geographic distribution.—The species is distributed mainly at low latitudes (Figure 17). It was first reported from the Experimental Mohole core off Baja California, Mexico (Schrader, 1974a), but it is rather rare at middle to high latitudes in the Indian and Pacific Oceans, and common in the equatorial Pacific (Barron, 1980a; Kulm *et al.*, 1981; Fournier, 1987; this study), the equatorial Indian Ocean (Schrader, 1974b) and the South Atlantic off Namibia (Schrader, 1978). Monjanel (1987) found this species in the Miocene deposits in Spain.

*Bogorovia praepaleacea* (Schrader) Jousé 1976


*Bogorovia praepaleacea* (Schrader) Jousé, 1976, p. 1233; Barron, 1985a, pl. 4, fig. 14, p. 104.


Synonymy. *Cussia praepaleacea* (Schrader) Schrader, 1974a, p. 543, fig. 1: 9; Schrader, 1974b, p. 914; Koizumi, 1975, p. 876, pl. 4, figs. 36–37; *Cussia lancettula* Schrader, Gombos, 1975, p. 316, pl. 3, figs. 9–12; *Rossiella praepaleacea* (Schrader) Gersonde, Barron, 1985a, pl. 8, fig. 1; *Rossiella praepaleacea* (Schrader) Gersonde and Schrader, 1984, p. 104–105; Yanagisawa *et al.*, 1989, pl. 5, fig. 34; Radionova, 1991, p. 82.

Additional description.—Valve linear-lanceolate with slightly rostrate and acutely rounded apices, 37–64 μm long, 5–7 μm wide (Figure 16). Valve face convex, hyaline without areolae. Transapical costae, 7–8.5 in 10 μm. Marginal ridge, fused-type with two rows of pores (type 2), about 6 pores in 10 μm. A subcentral rimoportula, one per cell, located near valve margin. Fournier (1987, pl. 15, figs. 1, 2) figured a separation valve with separated-type marginal ridge (type 1).
Comparisons.—Bogorovia praepaleacea shares some common features with B. lancetella and B. curvata; e.g., the hyaline valve face and type 2 marginal ridge, but it differs from the latter two species by more widely spaced interval of transapical costae (Figure 16). It is different from B. puncticulata and B. barroni by the absence of valve face areolae. This species has been sometimes confused with "Rossiella" mediopunctata (= Koizumia adaroi (Azpeitia) Yanagisawa) (Barron, 1975; Abbott and Andrews, 1979; Gesner and Schrader, 1984; Powers, 1988) or with K. akibae (Akiba et al., 1982; Akiba, 1986), but it is clearly distinguished from the latter two species in lacking areolae on the valve face. In spite of its specific name, B. praepaleacea is not the ancestor of Rossiella paleacea.

Stratigraphic range.—This species first occurs from the middle part of the Actinocyclus moronensis Zone (NTD 9) in DSDP Hole 77B (Figure 3). In this study, however, the last occurrence of this species could not be determined in DSDP Hole 77B because of the lack of samples.

According to Sancetta (1982) and Baldauf (1985), the last occurrence of B. praepaleacea lies in the middle part of the A Subzone of the Thalassiosira convexa Zone (NTD 13A) in DSDP Holes 503, 572 and 573 in the eastern equatorial Pacific, and was estimated at about 5.9 Ma (Baldauf, 1985) or 6.0 Ma (Barron, 1985a, 1982) (Figure 3). In this study, the estimated age of Barron (1992) is adopted.

In DSDP Hole 173, northeast Pacific off California, Schrader (1973) recognized B. praepaleacea last occurs between the core 20-2 (55-56 cm) and core 20-3 (55-56 cm), a horizon which Barron and Kellar (1983) assigned to the lower part of the C Subzone of the Denticulopsis hustedtii-D. lauta Zone which is equivalent to the Denticulopsis dimorpha Zone (NPD 5D) of Akiba (1986). The horizon is about 8.9 Ma in age and so B. praepaleacea disappeared earlier in the northeast Pacific than in the equatorial Pacific.

Geographic distribution.—The species was first described from the mid-latitude North Pacific (Schrader, 1973) and successively reported from this region (Schrader, 1974a; Koizumi, 1975; Barron, 1981a; Yanagisawa et al., 1989) (Figure 18). However, it appears to be more common in the equatorial Pacific (Gombos, 1975; Sancetta, 1982; Baldauf, 1985; Fourtanier, 1987; this study), and may be a warm-water species.

Discussion.—As pointed out by Fourtanier (1987, p. 107–108), there is some suspicion that the holotype specimen of B. praepaleacea chosen by Schrader (1973) may be a valve of Koizumia adaroi. Despite the original description by Schrader (1973) that B. praepaleacea has a hyaline valve face (absence of areolae), the holotype specimen seems to have circular areolae between the transapical costae on the valve face. However, I cannot assert the presence of areolae with confidence because of the rather poor photograph of the specimen. Another problem is that the holotype of B. praepaleacea is from a sample which is far above the main range of the species in DSDP Hole 173 and interpreted as reworked by Schrader (1973, table 1). Detailed examination of the holotype specimen is required to solve these problems. If the holotype of B. praepaleacea is proved to be K. adaroi, then a new species name needs to be proposed for the taxon.

The species name means that the species is antecedent to Rossiella paleacea, probably because Schrader (1973) regarded the species as the ancestor of R. paleacea. However, B. praepaleacea is not the precursor of R. paleacea nor closely related to R. paleacea.

**Bogorovia curvata** Yanagisawa sp. nov.


Synonymy.—Cussia lancetella Schrader, Schrader, 1974b, pl. 19, ffigs. 14–15 (non pl. 19, fig. 16); Gen. indet., species indet., species indet., Schrader, 1974b, pl. 19, fig. 17; Rossiella cf. lancetella (Schrader) Gesner et Schrader, Yanagisawa, 1987, pl. 5, figs. 3–5.

Description.—Valve delicately silicified, linear–lanceolate, apically curved with less convex ventral side and more convex dorsal side, 16–30 μm long, 4.5–5 μm wide. Apices slightly rostrate and acutely rounded. Valve face hyaline without areolae. Transapical ribs, 12–13 in 10 μm. A subcentral rimoportula located near the valve edge.

Holotype.—Figure 4–39 (GSJF14591 deposited in the Geological Survey of Japan).

Type locality and sample.—Piston core sample P3CC, Indian Ocean off Java Island, 17°59.04', 113°31.37', 4442 m in water depth (Yanagisawa, 1987; Honza et al., 1987). Middle Pleistocene in age. The sample is assigned to the Pseudeunotia doliotus Zone (NTD 17) of Barron's (1985b) low–latitude diatom zonation (Yanagisawa, 1987). According to Nishida (1987), the sample can be placed in the nanofossil CN14b Zone of Okada and Bukry (1980). Buccinoceras invaginata Haeckel (Radiolaria) in this sample suggests a late Middle Pleistocene age younger than 0.2 Ma. In summary, integrating all available age information gives the age of about 0.2 Ma for the sample.

Comparisons.—This new species is typified by its curved valve outline, which is similar to the genus Campylodia. This character distinguished this species from all other Bogorovia species. The species most resembles B. lancetella in having a hyaline valve face and almost the same valve size.

Stratigraphic range.—The stratigraphic range of this species is not well known at present. The oldest known recorded occurrence of this species is in the lower part of the Nitzschia jouseae Zone (NTD 14) (Schrader, 1976) (Figure 3). The youngest occurrence of this species is reported in the type sample which is dated about 0.2 Ma.

Geographic distribution.—This species has been reported only from the equatorial Indian ocean at present (Schrader, 1974b; Yanagisawa, 1987) (Figure 18).

Etymology.—The species name is derived from its curved valve outline.

Note on some species related (?) to *Bogorovia*

*“Bogorovia” sparsipunctata* Hendey

Hendey, 1981, p. 99–100, pl. 4, fig. 22.

Remarks.—The species is characterized by its fusiform valve outline and sparsely punctated valve surface. If it is included in the genera *Bogorovia* or *Rossiella*, the species might be placed in *Rossiella* because the species lacks transapical costae. However, *B. sparsipunctata* has no affinity to any species in *Rossiella*. Until its structure is elucidated by electron microscope examination, the correct taxonomic position of this species cannot be determined nor transferred to the genus *Rossiella*. Therefore the species is referred to under its original generic name.

*Cymatosira lorenziana* Grunow


Synonymy. *Cussia* species 1, Schrader, 1974a, p. 543, figs. 1–18, 19; *Bogorovia cypriata* Gardette, 1978, p. 762–763, p. 1, figs. 1–12; *Cussia paleacea* (Grunow) Schrader, Abbott and Andrews, 1979, p. 241, pl. 3, fig. 14; *Cymatosira* sp., Abbott, 1980, pl. 1, fig. 13; *Bogorovia* (?) *cypriata* Gardette, Desikachary et al., 1984, p. 338, pl. 1, fig. 6; *Cussia* (?) *lancettula* Schrader, Desikachary et al., 1984, p. 338, pl. 1, fig. 12

Remarks.—The species found in fossil material have been sometimes reported as species of *Bogorovia* or *Cussia*. *Bogorovia cypriata* Gardette is a fossil species described from the Upper Miocene deposits of Cyprus (Gardette, 1978). However, its valve outline, size and distribution of areolae and valve architecture are just the same as those of *Cymatosira lorenziana* Grunow (Hasle et al., 1983), and therefore *B. cypriata* is a synonym of *C. lorenziana*.

*Cymatosira* sp. A

*Cussia* sp. 1, Schrader, 1974b, p. 914, pl. 18, fig. 12; *Cymatosira* aff. *lorenziana* Grunow, Akiba, 1980, p. 11, pl. 4, fig. 47.

Remarks.—*Cussia* sp. 1 of Schrader (1974a) closely resembles *C. lorenziana* and therefore can be included in the genus *Cymatosira*. However, *Cymatosira* sp. A is
distinct from the latter species in having a transapical hyaline zone along the transapical axis. This species is found commonly from the Early to Middle Miocene sediments of Japan (e.g. Akiba, 1980). It will be described as a distinct species elsewhere.

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### Appendix table. Occurrence of Bogorovia species in DSDP Holes 70A, 71 and 77B. Diatom zones after Barron (1986b) and Fenner (1985). Abundance of each species: A = abundant (>8%), C = common (5-7%), F = few (2-4%), R = rare (<1%).