

Miocene to Pliocene Paleoceanography of the Western Equatorial Pacific Ocean Based on Calcareous Nannofossils, ODP Hole 805B

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ABSTRACT

We describe in detail the Miocene to Quaternary paleoceanography of the western equatorial Pacific Ocean based on calcareous nannofossils of Hole 805B. The relative abundance of *Discoaster* which lived in the lower photic zone under the stable sea with nutricline and thermocline, decreased step by step at NN5/NN6 and NN10/NN11 boundaries. Although the size of *Reticulofenestra* which is strongly influenced by nutrient, increased five times throughout the section, it drastically decreased in NN4-5 zone, NN10, NN12, and in NN15/NN16 boundary. On the basis of the relationship between *Discoaster* abundance and *Reticulofenestra* size change, collapse of the stability of the sea surface in the western equatorial Pacific Ocean progressed step by step throughout the Miocene to Quaternary.

Keywords: Paleoceanography; Calcareous Nannofossils; *Discoaster*; *Reticulofenestra*; Nutricline; Thermocline

1. Introduction

Calcareous *nannofossils*, which have been widely distributed in the world's oceans since the Mesozoic, are well known as a useful tool for paleoenvironmental analysis as well as for age determination. A living nannofossil species, *Florisphaera profunda*, which is presently found in lower photic zone [1], is a proxy to reconstruct the stability of the Quaternary sea surface condition with nutricline and thermocline. However, as *F. profunda* is not found in the Pliocene or older sections, it was difficult to reconstruct the sea surface conditions during the Neogene Period.

Recently, it became gradually clear that the size changes of coccolith and productivity of nannoplankton are strongly influenced by sea surface conditions such as the presence of nutricline, thermocline or upwellings [2, 3]. Furthermore, as *Discoaster* which last appeared in 2.0 Ma [4], is indicated as a lower photic zone species same as *F. profunda*, abundant occurrence of *Discoaster* indicates the sea surface stratification and the oligotrophic condition. On the basis of these phenomena, firstly we describe in detail the calcareous nannofossil assemblages of Ocean Drilling Program (ODP), Hole 805B located in the western equatorial Pacific Ocean, and then we discuss the sea surface stability of the ocean from the Miocene to the Pleistocene, focusing on both the cocco-

lith size and *Discoaster* abundance changes.

2. Oceanographic Setting

Hole 805B is situated in 3188 m of water on the northwestern margin of the Ontong Java Plateau, close to the equator of the western equatorial Pacific Ocean, (latitude 1°13.68'N, longitude 160°31.76'E).

This site is influenced under variable world ocean circulation systems (**Figure 1**), such as, North Equatorial Current (NEC), North Equatorial Countercurrent (NECC), and Indonesian Throughflow (IT), in association with the New Guinea Coastal Undercurrent (NGCUC), the South Equatorial Current (SEC), and Equatorial Undercurrent (EUC), respectively. The western equatorial Pacific Ocean is dominated by the Western Pacific Water Pool (WPWP), which is characterized by a thick mixed layer, a deep, well-developed thermocline, and a deep maximum chlorophyll [5].

3. Samples and Methods

The sedimentary section at Site 805 is stratigraphically complete, covering the Pleistocene to the upper Oligocene. The sedimentary sequence was divided into two subunits (IA and IB) based on the degree of consolidation. The subunit IA from 805B-1H to 805B-30X is composed of nannofossil ooze to foraminifer nannofossil

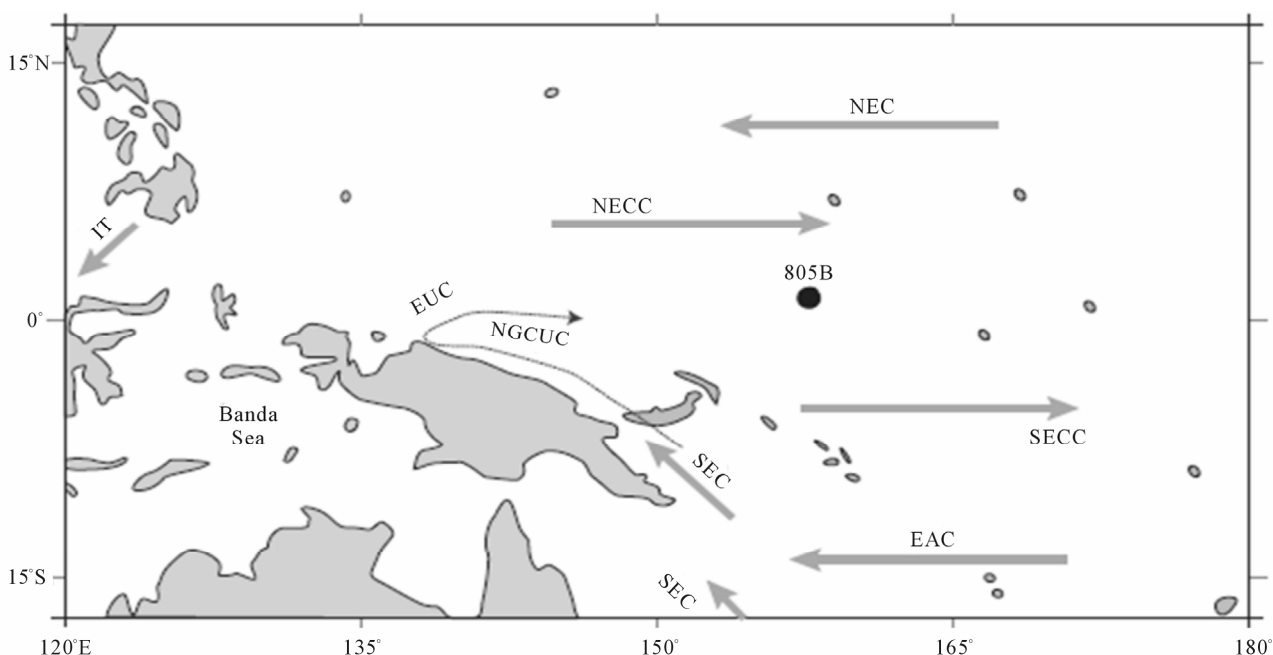


Figure 1. Location of Hole 805B and the major current systems of SE Asia. NEC (North Equatorial Current), NECC (North Equatorial Countercurrent), SEC (South Equatorial Current), SECC (South Equatorial Countercurrent), EAC (East Australian Current), IT (Indonesian Throughflow), EUC (Equatorial Undercurrent), NGCUC (New Guinea Coastal Undercurrent).

ooze, and subunit IB 805B-31X to 50X is characterized by nanofossil chalk to foraminifer nanofossil chalk [6]. We examined Hole 805B of this site.

A total of 317 samples from ODP Hole 805B were made samples preparation. The sample of 0.0400 g (after pounded to be powder) was placed in a breaker, and then 50 ml of water was added. After suspension, 0.5 ml of suspension was pipetting to be evenly distributed on a cover glass (18 mm × 18 mm). The cover glass was carefully dried on an electric hot plate set at 40°C, and placed on a slide glass with embedded medium to make slides. The slide was examined under a binocular polarizing microscope with an oil-immersion objective at lens at 1.500× magnification.

Several thousands coccolith and *Discoaster* were observed to recognized both their last and first occurrence horizons. After that, to obtain their floral change through the examined geological time, 200 specimens were counted at random. In addition, number of coccolith and *Discoaster* were counted in the area of one survey line (18 mm × 10 μm) to be estimated the quantitative amount of accumulation in a unit of sample weight (the number/gram). The size distribution of *Reticulofenestra* spp. was also measured to the 50 to 100 *Reticulofenestra* specimens in each sample.

4. Biostratigraphy

The zonal scheme by Martini [7], is applied for in this

study. Calcareous nanofossil flora are characterized by abundant occurrence of *Reticulofenestra* spp. throughout the section (**Figure 2**). *Coccolithus pelagicus*, which is commonly distributed in the high latitude regions near Greenland [8,9], occurs abundantly below 220 m. *Calcidiscus leptoporus* are found commonly in the middle to upper section of Hole 805B, whereas the samples in the lower part are characterized by the Miocene marker species such as *Cyclicargolithus floridanus*, *Sphenolithus moriformis* and *Sphenolithus heteromorphus*.

The last occurrence of *Pseudoemiliana lacunosa*, defined the Zone NN20/NN19 boundary, was observed in samples between 130-805B-1H-CC (6.7 mbsf) and 130-805B-2H-CC (16.2 mbsf).

The zonal boundary of NN19/NN18 was defined by the last occurrence of *Discoaster brouweri*, was identified in samples between 3H-CC (25.7 mbsf) and 4H-CC (35.2 mbsf). The last occurrences of *Discoaster pentaradiatus* and *Discoaster surculus* which mark the NN17/NN18 and NN17/NN16 boundaries respectively, are found between samples 4H-CC (35.2 mbsf)/5H-CC (44.7 mbsf), and 6H-CC (54.2 mbsf)/8H-2 23 - 24 cm (65.43 mbsf), respectively. The NN15/NN16 boundary which is defined by the last occurrence of *Reticulofenestra pseudoumbilicus* is traceable in the horizon between samples 8H-CC (73.2 mbsf)/9H-1, 23 - 24cm (73.43 mbsf). *Ceratolithus rugosus* which defines NN12/NN13 boundary is found between samples 11H-3, 23 - 24 cm (95.43 mbsf) and 11H-5, 23 - 24 cm (98.43 mbsf). Both the last occur-

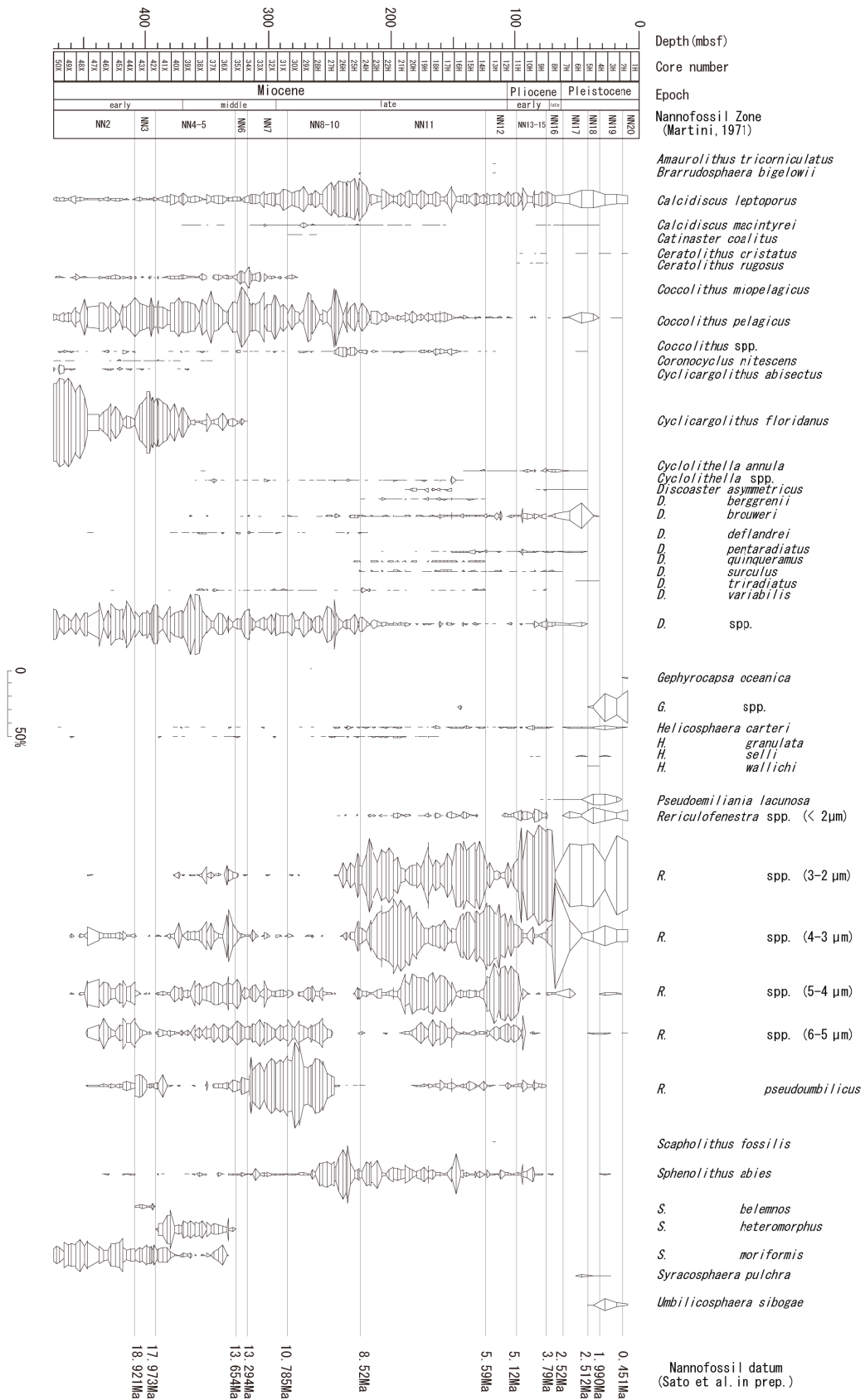


Figure 2. Distribution of nannofossils in Hole 805B.

rence of *Discoaster quinquerramus* and the first occurrence of *D. berggrenii* which indicate top and bottom of NN11 zone are found in samples between 14H-1, 23 - 24 cm (120.93 mbsf)/14H-3, 23 - 24 cm (123.93 mbsf) and between 24H-5, 23 - 24 cm (221.93 mbsf)/24H-7, 23 - 24 cm (224.93 mbsf).

Although the first occurrence of *Catinaster coalitus*, which marks the NN7/NN8 boundary, is situated between 30X-CC (282.5 mbsf)/31X-1, 23 - 24 m (282.73 mbsf), *Discoaster hamatus* which defines both top and bottom of NN9 zone is not found throughout the section. Based on the last occurrences of *Cyclicargolithus floridanus* and *Sphenolithus heteromorphus*, the NN6/NN7 and NN5/NN6 boundaries are traceable to between 34X-3, 23 - 24 cm (314.23mbsf)/34X-5, 23 - 24 cm (317.23 mbsf) and between 35X-3, 23 - 24 cm (323.73 mbsf)/35X-5, 23 - 24 cm (326.73 mbsf). As *Helicoshaera ampliapertura* which defines the top of NN4 zone, is not found in the section, NN4/NN5 boundary is not detected. The first and last occurrences of *Sphenolithus belemnos* which mark NN3 Zone, are traceable to between 42X-2,

25 - 26 cm (389.75 mbsf)/42X-3, 23 - 24 cm (391.23 mbsf) and between 43X-CC (407.30 mbsf)/44X-1, 23 - 24 cm (407.53 mbsf). *Discoaster druggi* the marker species of NN1 Zone is not found throughout the section.

On the basis of distributions of marker species mentioned above, the sequence in this study is correlated to NN2 to NN20 Zone from the early Miocene to Pleistocene.

5. Productivity and Size Variation

Coccolith and *Discoaster* are phytoplankton that the amount of these microfossils are roughly reflected to the primary productivity. The size variation of *Reticulofenestra* through time is also well known worldwide, but there are a few quantitative data.

5.1. Coccolith and Discoaster Productivity

We examined the coccolith and *Discoaster* productivity as shown in **Figure 3**.

From NN2 Zone to the upper part of NN4-5 Zone, the

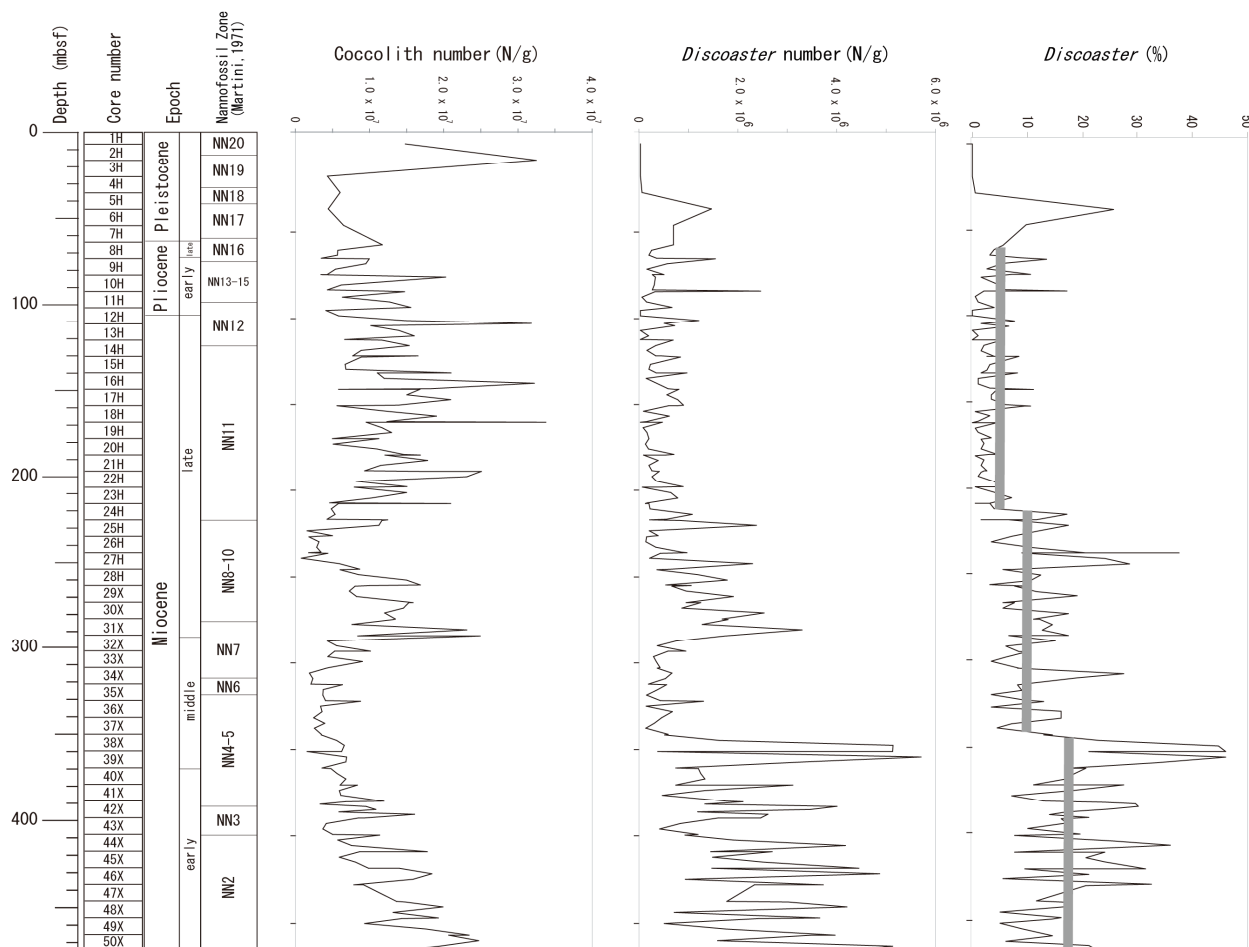


Figure 3. Comparison between Coccolith and *Discoaster* number (N/g), and relative abundance of *Discoaster* (%). Grey solid line indicates the mean of *Discoaster* percentage.

number of coccolith productivity decreased around 3.0×10^7 N/g through less than 1.0×10^7 N/g. Otherwise *Discoaster* productivity was recognized at a maximum in this period, reaching approximately 6.0×10^6 N/g (~50%). From the upper part of NN4-5 Zone through the upper part of NN8-10 Zone, the coccolith is likely to increase in number. On the other hand, *Discoaster* in the sequence of the upper part of NN4-5 to NN7 Zones decreased abruptly. The section above the NN7/NN8 boundary is marked by increasing *Discoaster* again until approximately 4.0×10^6 N/g, and then its number gradually decreased towards the upper Pliocene.

From the upper part of NN8-10 to NN16, the amount of coccolith increased in NN11, indicating the highest peak around 3.5×10^7 N/g. The relative abundance of *Discoasters* is also shown in Figure 3 as an indicator the surface water stability. The relative abundance of *Discoaster* specimens steps down throughout the sequence. Although the average of the relative abundance is scored at about 15% in the interval from NN2 to the upper part

of NN4-5 Zone, the average decreased step-wise from 10% in the upper part of NN4-5 to lower part of NN11 Zone, to 3% in NN11 to NN16 Zone.

5.2. Size Variation

We measured the coccolith size of *Reticulofenestra* specimens in each samples to clarify the size distributions of them, throughout the sequence (Figure 4).

The increase trend of the maximum size is recognized in the following four intervals, NN2 to NN4-5 Zone, NN4-5 to NN8-10 Zone, NN11 to NN12 Zone, and NN13 to 15 Zone. As shown in Figure 4, the statistical modal size of them shows the repetition of apparent gradual increasing period and abrupt size decreasing. The left column of Figure 4 shows that the majority of *Reticulofenestra* showed change in size in associated with change in modal size, suggesting the flora kept the statistical Gauss distribution in size throughout time. It is noteworthy that the change in the maximum size of

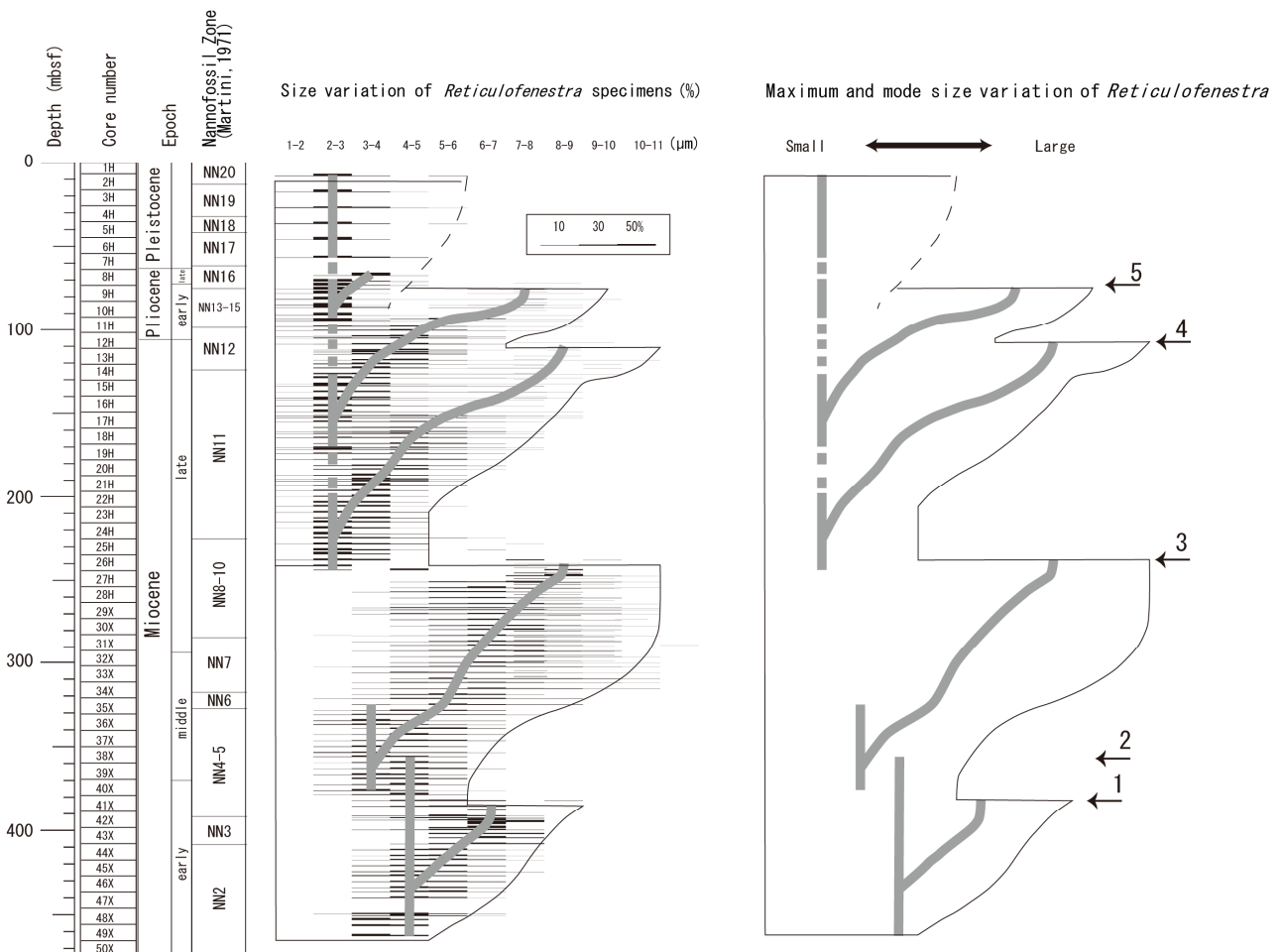


Figure 4. Comparison between distribution of size variation of *Reticulofenestra* specimens (%) and the maximum and mode size of *Reticulofenestra*.

Reticulofenestra is well recognized rather than the minimum size of them as shown in **Figure 4**. This looks as like that the mode of the *Reticulofenestra* size is characterized by positive correlation with maximum size. Not only does **Figure 4** show the size change in the mode, but also the bimodal distributions are marked every interval before and after the termination of maximization (**Figure 4**). The bimodal patterns are composed of both unchanged small groups and maximized large groups. Although the smaller size mode is not distinct in the early to middle Miocene sequence, 2 - 3 micron *Reticulofenestra* specimens mark a clear mode in the interval of NN11 to NN20 Zone. However, these two small and large groups are not always concurrently present throughout the time. The small size mode is not detected in the intervals in NN2 to NN10 Zone of the early to middle Miocene, while the maximized phenomena have been unextinguished since the late NN16.

6. Discussion

6.1. Background of Ecology and Paleocology Nannoplankton

The relation between the structure of the sea surface and the ecology of coccolithophorids have been clarified in previous studies [1,2,10]. Molfino and McIntyre [1] described that *Florisphaera profunda* lives in lower photic zone in recent ocean, so that its relative abundance decreases in upwelling environment, because of the upward moving the nutricline. Hagino *et al.* [2] studied the ecology of the coccolithophorids in the western equatorial Pacific Ocean and clarified that the lower photic zone species disappear in unstable surface conditions such as upwelling environment. Takahashi and Okada [3] reconstructed the paleoenvironment of the Quaternary southeastern Indian Ocean based on the abundance of *F. profunda*. Although the abundance of *F. profunda* is a good proxy for reconstruction of sea surface stability, the species does not occur in the Miocene sequence. Instead, *Discoaster* species is useful to similar purpose.

Discoaster species occur abundantly in the Paleogene to Neogene intervals and had been interpreted as a typical warm water species [11]. Recently, Aubry [12], Flores *et al.* [13], Stoll *et al.* [14] and Sato and Chiyonobu [15] summarized that the *Discoaster* species are a typical lower photic zone species same as *F. profunda*. Sato and Chiyonobu [15] studied the relationship between the size changes of coccolith and *Discoaster* abundance in the Paleogene to Neogene sequences, and described the changes of stability of the sea surface conditions briefly.

Coccolith size changes in the Neogene sequence were discussed by Young [16] and Kameo and Bralower [17] and indicated as a proxy of stratigraphic utility. Recently, the size changes and productivity of coccolith are dis-

cussed as the characteristics of coccolith K-r selection [15,18]. It means that oligotrophic and eutrophic conditions are related to the development of both thermocline and nutricline, since they strongly influence to the productivity and size of coccolith.

6.2. Paleooceanography of the Western Equatorial Pacific Ocean

Our results indicate that lower photic zone species *Discoaster* decreased step by step (**Figure 5**). This means that thermo- and nutri-cline developed in NN2 to the upper part of NN4-5 Zone. However the thermo- and nutri-cline collapsed step by step from the upper part of NN4-5 zone to the NN10/NN11 boundary. The change in relative abundance is also closely related with the stepwise change in the modal size of *Reticulofenestra* (**Figure 5**). The termination 2 shown in **Figure 5** is characterized by discontinuity in size changes, which is situated roughly in the same horizons of significant changes in *Discoaster* abundance. This spontaneous event can be explained by the stepwise collapse of the thermo- and nutri-cline collapsed step by step at NN4-5 Zone and NN10/NN11 boundary. As a result, the sea surface of the western equatorial Pacific Ocean changed from oligotrophic mode to eutrophic condition.

The maximum size of coccolith (*Reticulifera*) changed four times at the termination 1, 3, 4, and 5 (**Figure 5**). Differing from termination 2, it is unlikely to be positively compared with the changes in *Discoaster* abundance. This will be interpreted that minor paleoceanographic changes occurred across the termination 1, 4, and 5, respectively.

7. Conclusions

We describe in detail the nannofossil biostratigraphy of the Hole 805B is located in the western equatorial Pacific Ocean. The sequence is correlated to NN2 to NN20 Zones of early Miocene to Quaternary based on 13 nannofossil datums.

Collapse of the changes of *Discoaster* relative abundance and the coccolith size indicates that the thermo- and nutri-cline progressed step by step at NN4-5 Zone and NN10/NN11 boundaries. As a result, sea surface of the western equatorial Pacific Ocean has been changed from oligotrophic to eutrophic conditions during the Miocene to Quaternary.

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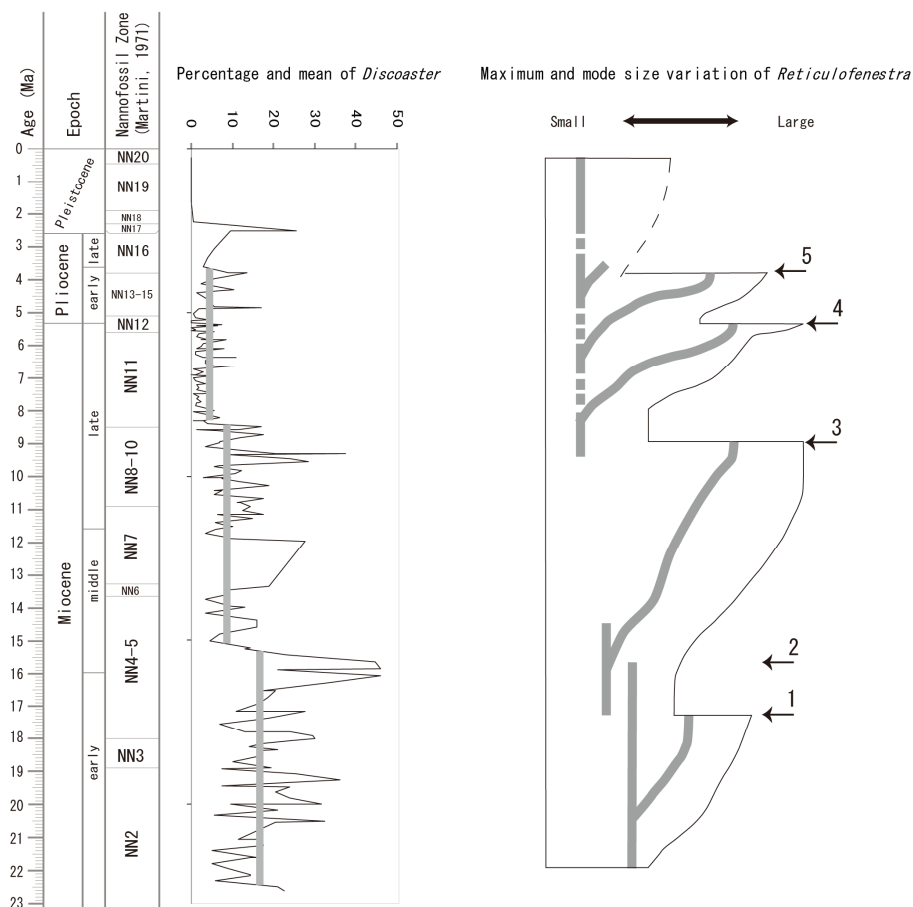


Figure 5. Simplified illustrations of percentage and mean of *Discoaster*, and also shown in left figure both maximum size and mode of *Reticulofenestra*.

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