Quantitative Analysis of Quaternary Nannoplankton in the Subtropical Northwestern Pacific Ocean

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(Revised and accepted June 11, 1988)

Abstract


Time-progressive changes of nannoflora and biometry of coccoliths for the last 1.3 m.y. were investigated for a piston core recovered from the West Mariana Ridge. The species compositions were quantitatively investigated under an electron microscope, and six assemblages (Assemblages A through F) were identified. Significant changes in relative abundances of various types of genus *Gephyrocapsa* are the main cause for the stratigraphic change of the flora. A dominant occurrence of *Gephyrocapsa protohuxleyi* var. A, which can be identified only under an electron microscope, was observed for the first time in a thin sequence which corresponds to the lowest part of the Brunhes Epoch (0.75-0.62 Ma). Because of this characteristic occurrence, Assemblage D was further subdivided into three sub-assemblages. The dominant occurrence of small *Gephyrocapsa* which is well known in the “small *Gephyrocapsa* Zone” of the equatorial Pacific Ocean was not observed, but the almost complete absence of medium to large *Gephyrocapsa* during approximately 200K years of the middle Pleistocene was confirmed. A stratigraphically restricted occurrence of a large form of *Reticulofenestra* was also confirmed by the biostratigraphic study under a light microscope, and the last and first occurrences of the largest form (*Reticulofenestra* sp. A, > 6.5 \(\mu\)m) were identified at 0.81 and 0.98 Ma respectively. In addition to these four events, precise ages for another five well known evolutionary events were also calibrated. These ages are generally in good agreement with previously reported ages from other world oceans, and diachronism was not evident for most of these evolutionary events.

Introduction

Calcareous nannoplankton is well utilized for biostratigraphy, and standard zones established for the Mesozoic (e.g. Perch-Nielsen, 1985) and Cenozoic (e.g. Martini, 1971; Bukry, 1973a, 1975; Okada and Bukry, 1980; Martini and Müller, 1986) marine sediments are proved to be powerful tools for world-wide correlation.

Cenozoic nannoplankton zonations developed by Martini (1971) and Bukry (1973a, 1975) divide the Quaternary period only into three zones or subzones. The currently most popular Quaternary zonation proposed by Gartner (1977) after studying cores recovered from three DSDP (Deep Sea Drilling Project) sites in the Caribbean and Pacific basins recognizes seven zones for the Quaternary. Pujos (1985a, b) who had studied IPOD (International Phase of Ocean Drilling) cores, taken from the northeast Atlantic and equatorial Pacific Oceans, identified approximately 30 evolutionary events within the Quaternary, but some of the employed taxonomic concepts are difficult to follow. Takayama and Sato (1987) recognized 12 evolutionary events within the Qua-
ternary sequence recovered from the North Atlantic during IPOD Leg 94. All of these recent studies strongly indicate the possibility of developing a detailed biostratigraphic scheme applicable to the Quaternary marine sediments.

These recent studies for Quaternary evolutionary events, as well as the standard zones, utilize the first and last occurrences of key species or beginning and end of acme of some characteristic taxa. Quantitative studies have proved a global synchronism for some of the Pliocene and Pleistocene events (e.g. Thierstein et al., 1977; Backman and Shackleton, 1983). Diachronism for some of evolutionary events, meanwhile, are documented for Cenozoic era (e.g. Haq et al., 1979), and a detailed examination of Quaternary nannoflora have also revealed a time-transgressive nature between world oceans for some evolutionary events (Pujos, 1985b).

To establish a precise biostratigraphic standard which is applicable in global scale, the trend and magnitude of diachronism have to be carefully monitored between world oceans as well as for latitudinal differences. Moreover, sizes and morphology of calcareous nannoplankton changes time-progressively and these characters can also be utilized for age-diagnostic purpose. For precise application of nannoplankton biostratigraphy, especially for the late Neogene and Quaternary periods where time resolution is most crucial, the time progressive changes in biometrical features as well as the evolution of taxa have to be studied quantitatively. The time progressive change in floral composition is also a result of biotic response to environmental change. Quantitative analysis of nannoflora, therefore, can be a useful tool for paleoceanography. All of these discussions indicate the importance of quantitative investigations for a detailed biostratigraphy and paleoceanography, and the studies have to be conducted in each different environmental setting.

Recently we were asked to identify the age of a piston-core KH84-1, St. 21 which was recovered from the West Mariana Ridge area, and our preliminary investigation revealed a continuous record of the middle to late Pleistocene nannoflora. This core also contains well preserved magnetic record and the bottom age was calculated as approximately 1.3 Ma. The purpose of the present study is to quantitatively investigate the stratigraphic changes in species composition and biometry of major species and to identify significant evolutionary events preserved in this core. We expect to provide standard data for the paleoceanography and nannobiostratigraphy in the subtropical Western Pacific.

**Samples and method**

The 916 cm long piston-core KH84-1, St. 21 was recovered from the western flank of northern West Mariana Ridge (19° 55.8'N 142° 22.3'E) in May 20, 1984 from the water depth of 3,512 m during KH84-1 cruise of R/V Hakuho-Maru of Ocean Research Institute, University of Tokyo (Fig. 1). The entire core consists of olive colored calcareous ooze.
intercalated with thin layers of volcanic ash and sandy silt (Kobayashi, 1985).

The paleo-magnetic record was measured for all samples collected at 2 cm intervals. The base of Brunhes Epoch and the top and base of Jar-amillo Event were identified at 489 cm, 620 cm and 670 cm sub-bottom depths respectively (Kobayashi, K. et al., unpublished data). Using these three levels and core top as reference points, the depth-age relationship was plotted (Fig. 2). The two nannoplankton evolutionary events, which are believed to be globally synchronous (Thierstein et al., 1977), the extinction of *Pseudoemiliania lacunosa* (0.46 Ma) and the first occurrence of *Emiliania huxleyi*, (0.27 Ma), fit nicely with this magneto-stratigraphically calculated age. The calculated sedimentation rates are 0.67 cm/kyr and 0.72 cm/kyr for the upper half (above 489 cm level) and the lower half of the core respectively. At the short interval between 744 to 756 cm, a normal magnetic event (Cobb Mountain Event?) was observed (Fig. 2). Although the identical event was also recorded at various DSDP sites (e.g. Takayama and Sato, 1987), the precise age was not determined for this event.

For the present study, a small piece of sediment (less than 1 cm thick) was collected from the entire length of the core at an interval of 5 cm. A sub-set of samples representing 10 cm intervals were prepared for the quantitative study under a transmission electron microscope. The preparation technique to make carbon replicas for the electron microscopy is the same as used by Okada and Honjo (1973). Nannofloras were recorded by identifying and counting 350 specimens of reasonably well preserved coccoliths. While observing 350 individuals of these specimens, poorly preserved specimens which are difficult to identify at species level, were separately counted. The occurrence of a dominant nannofossil species which is usually ignored by many specialists, *Florisphaera profunda*, was also counted separately, and its abundance against 100 moderately well preserved coccoliths was recorded.

For the study of datum events, the complete set of samples (5 cm interval samples) was prepared for smear slides and was observed under a polarizing light microscope. The first and last occurrences as well as significant changes in relative abundances of taxa were semi-quantitatively recorded. Taxonomy and identification of species are slightly different between the electron and light microscopic studies since resolutions for morphological features are greatly different between these two microscopies.

**Taxonomic remarks**

Classification schemes are not in good agreement among specialists for some of the Pliocene and Pleistocene nannoplankton. In this study, we have quantitatively measured biometric features for some of the disputed taxa, and tried to establish a simple criterion which is useful for the detailed biostratigraphy and pa-

![Fig. 2. Depth-age relationship for Core KH84-1, St. 21.](image-url)
leoceanographic analysis of the Quaternary Period.

_Gephyrocapsa_ group

Classification of _Gephyrocapsa_ is certainly one of the most controversial topics among the specialists. The overall size, proportion of central area and shape and angle of the central bridge are important factors for species identification under a light microscope. Many species have been described under this genus by utilizing these criteria (e.g., Bukry, 1973b; Hay and Beaudry, 1973). Living specimens of _Gephyrocapsa_, however, show considerable variations in overall size and in shapes of the central bridge among a set of coccoliths constructing single coccospheres (e.g., Okada and McIntyre, 1977).

We have employed a size criteria which is applicable to the entire stock of _Gephyrocapsa_; large forms (maximum diameter >5.0 μm), medium forms (between 5.0 μm and 2.5 μm), and small forms (<2.5 μm). Characteristic ornamentations such as distal projections around the central opening or slits on the distal shield which are observable for some small _Gephyrocapsa_ are often unrecognizable under a light microscope. Presence of some characteristic species such as _Gephyrocapsa ornata_ or _Gephyrocapsa protohuxleyi_ therefore can be correctly identified only under an electron microscope.

Throughout the present investigation under an electron microscope, we could not observe _G. ornata_ though _G. protohuxleyi_ was abundant in certain sections. Most of the specimens identified as _G. protohuxleyi_ in our samples, especially in the short interval where they dominate the flora, are actually a type which McIntyre (1970) identified as "a transitional type between _Gephyrocapsa protohuxleyi_ and _Gephyrocapsa ericsonii_", and we will call this type _G. protohuxleyi_ var. A. Although rare, typical _G. protohuxleyi_ were encountered only in the upper sequence. This species with size variations ranging between the small to medium categories was identified as a single entity, and all other small _Gephyrocapsa_ having no slits on the distal shield are lumped together under the name of _Gephyrocapsa_ spp. (small). Besides the possible inclusion of the small forms of _G. car-

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**PLATE I**

Electron and optical micrographs of selected species and morphologic varieties observed in Core KH84-1, St. 21. Figs. 1 through 10 and 20 through 26 are electron micrographs enlarged to the same scale, and the scale bar in Fig. 26 indicates 5 μm. Figs. 11 through 19 and 27 through 32 are cross-polarized light micrographs enlarged to the same scale, and the scale bar in Fig. 32 indicates 5 μm.

1. _Gephyrocapsa oceanica_ (L. diagonal), 860 cm.
2. _Gephyrocapsa oceanica_ (L. vertical), 400 cm.
3. _Gephyrocapsa oceanica_ (L), 780 cm.
4. _Dictyococites perplexa_, 910 cm.
5. _Gephyrocapsa oceanica_ (M. diagonal), 290 cm.
6. _Gephyrocapsa oceanica_ (M. vertical), 560 cm.
7. _Gephyrocapsa caribbeanica_ (M), 290 cm.
8. _Dictyococites productus_, 290 cm.
9. _Gephyrocapsa protohuxleyi_ var. A, 460 cm.
10, 11. _Gephyrocapsa_ sp. (small), 740 cm.
12. _Gephyrocapsa oceanica_ (L. diagonal), 770 cm.
13. _Gephyrocapsa oceanica_ (L. vertical), 560 cm.
14. _Gephyrocapsa caribbeanica_ (L), 770 cm.
15. _Dictyococites perplexa_, 770 cm.
16. _Gephyrocapsa oceanica_ (M. diagonal), 290 cm.
17. _Gephyrocapsa oceanica_ (M. vertical), 460 cm.
18. _Gephyrocapsa caribbeanica_ (M), 290 cm.
19. _Dictyococites productus_, 290 cm.
20. _Reticulofenestra_ sp. A (small elliptical form), 690 cm.
21. _Pseudoemiliania lacunosa_ (elliptical var. A: a variety having a small number of slits), 690 cm.
22. _Pseudoemiliania lacunosa_ (elliptical var. B: a variety having a moderate number of slits), 690 cm.
23. _Pseudoemiliania lacunosa_ (elliptical var. C: a variety having a large number of slits), 690 cm.
24. _Reticulofenestra_ sp. A (large elliptical form), 590 cm.
25. _Reticulofenestra_ sp. A (large round form), 590 cm.
26. _Pseudoemiliania lacunosa_ (round var. C), 760 cm.
27. _Reticulofenestra_ sp. A (large elliptical form), 590 cm.
28. _Reticulofenestra_ sp. A (large round form), 590 cm.
29. _Pseudoemiliania lacunosa_ (elliptical form), 380 cm.
30. _Pseudoemiliania lacunosa_ (round form), 380 cm.
31. _Helicosphaera inversa_, 460 cm.
32. _Helicosphaera sellii_, 915 cm.
ibbeanica and G. oceanica, this group contains several species such as G. aperta, G. crassipons and G. ericsonii.

Medium and large Gephyrocapsa that has no characteristic ornamentation are classified as Gephyrocapsa caribbeanica or Gephyrocapsa oceanica. G. caribbeanica has a small irregularly shaped central area spanned by a robust bridge, whereas Gephyrocapsa oceanica encompasses all other forms with a relatively large central opening. In addition to distinguishing three size variations for G. oceanica, we have recognized three morphologic varieties for the medium and large G. oceanica; a variety having a vertically oriented bridge against the long axis of the coccolith, a variety with a diagonally oriented bridge, and a variety with an almost horizontal bridge. To avoid cumbersome repetitions, these varieties hereafter will be referred to in abbreviated form; G. oceanica (vertical), G. oceanica (diagonal) and G. oceanica (horizontal), respectively. The large G. oceanica (diagonal) is very close to Gephyrocapsa lumina Bukry (1973) but, unlike G. lumina which is a species exclusive to the lower Pleistocene, this variety occurs also in the latest Pleistocene and Holocene samples. The large G. oceanica (vertical) is similar to Gephyrocapsa omega Bukry, 1973 except that the lower size limit for the former variety is larger (5.0 μm vs. 4.0 μm).

Dictyococcites group

Pujos (1985a, b) included small to medium placoliths with closed central areas into the Gephyrocapsa complex. We are also aware of a kinship between Gephyrocapsa (especially G. caribbeanica) and Dictyococcites of Pliocene and Pleistocene Epochs. To avoid further confusion until more solid evidence becomes available, we followed the presently common practice and have classified the small to medium placoliths which have a closed central opening and no recognizable bridge under the genus Dictyococcites. Backman (1980) identified two species of late Neogene Dictyococcites which are differentiated by size (coccolith length larger or smaller than 4.0 μm), and we will follow his scheme. He had identified the larger form as Dictyococcites antarcticus Haq (1976) but later realized (pers. commun., 1987) that this species is actually a junior synonym of Dictyococcites perplexa Burns (1975). We, therefore, recognized two species of Dictyococcites in our studied material; D. productus (smaller than 4.0 μm) and D. perplexa (equal to or larger than 4.0 μm).

Pseudoemiliania lacunosa, Emiliana ovata and Emiliana annula

Kamptner (1963) originally introduced Ellipsoplacolithus lacunosus for a placolith which has slits on the distal shield. Although E. lacunosus was invalidated by Loeblich and Tappan (1966), Gartner (1969) introduced a genus Pseudoemiliania and designated this species as its type species. Pseudoemiliania lacunosa, however, was again stated as invalid by Loeblich and Tappan (1970) because the basionym was originally invalid. Bukry (1971) who took Loeblich and Tappan’s judgment seriously introduced a new combination Emiliana annula for this species, and he later introduced another name Emiliana ovata for the elliptical form (Bukry, 1973b). According to Gartner (1977), however, Pseudoemiliania lacunosa is a valid name and these two species of Emiliana are junior synonyms of Pseudoemiliania lacunosa. Meanwhile, Nishida (1979) introduced a new species Reticulofenestra pacifica for an elliptical form which has less than 10 slits on the distal shield.

As will be mentioned later, we have examined stratigraphic occurrences for various morphologic variations of this taxon and have concluded that it is not appropriate to establish a separate species solely by number of slits or by the roundness of coccoliths. Although there are
two contradicting opinions on the validity of *P. lacunosa*, the majority of nannoplankton specialists use this name in their recent publications. We, therefore, will call elliptical to round placoliths, which have any number of slits on their distal shields: *Pseudoemiliania lacunosa*.

Reticulofenestra group

Genus *Reticulofenestra* appeared in the early Eocene and the relatively large Neogene species *Reticulofenestra pseudoumbilica* (maximum length more than 14 μm) disappeared at the early/late Pliocene boundary. Small forms of this genus were also thought to disappear at about this time (e.g. Haq and Berggren, 1978), but some workers classified small placoliths of the late Pliocene to Pleistocene under this genus (e.g. Nishida, 1979).

Roth (1973) introduced genus *Crenalithus* for the small elliptical placolith species which was originally described as *Coccolithus doronicoides* Black and Barns (1961). This species, however, is practically impossible to distinguish from the small forms of genus *Reticulofenestra*. The common practice among nannofossil workers has been to call this small form small *Reticulofenestra* in the lower Pliocene and the older sequence where *R. pseudoumbilica* occurs, and call it *Crenalithus doronicoides* in the upper Pliocene and Pleistocene sequences.

Backman (1980) gave a thorough reexamination of *Crenalithus* and *Reticulofenestra* and found *Crenalithus* to be a junior synonym of the genus *Reticulofenestra*. He also rejected the specific epithet *doronicoides* and identified three species of small *Reticulofenestra* in the lower Pliocene and the older sequence where *R. pseudoumbilica* occurs, and call it *Crenalithus doronicoides* in the upper Pliocene and Pleistocene sequences.

Backman (1980) gave a thorough reexamination of *Crenalithus* and *Reticulofenestra* and found *Crenalithus* to be a junior synonym of the genus *Reticulofenestra*. He also rejected the specific epithet *doronicoides* and identified three species of small *Reticulofenestra* for the late Neogene; *R. minuta* for very small forms smaller than 3.0 μm, *R. minutula* (3.0-5.0 μm) which has a relatively large central opening and *R. haquii* (3.0-5.0 μm) with a small central opening. He also defined *R. pseudoumbilica* as larger than 5.0 μm, but, as previous workers, he did not notice the recurrence of *Reticulofenestra* which is larger than 5.0 μm in the upper Pliocene and Pleistocene sequences.

Pujos (1985a, b) was probably the first person to document the occurrence of large *Reticulofenestra* (greatest length: 8 to 9 μm) in the middle Pleistocene of the northern Atlantic Ocean and equatorial Pacific Ocean. She considered it as a member of the genus *Gephyrocapsa* with no crossbar present and called it *Gephyrocapsa doronicoides* var. 3. Takayama and Sato (1987) identified this form as *Reticulofenestra* sp. A and have utilized its top of acme as a good marker of the middle Pleistocene in the northern Atlantic Ocean.

D. Bukry (pers. commun., 1987) questioned the legitimacy of classifying this large form under the genus *Reticulofenestra*, because *Reticulofenestra* should possess a reticulated grid spanning the proximal side of the central opening. In the material of our present investigation, the central grids are not preserved due to the relatively advanced dissolution. The same forms observed from the middle Pleistocene Kazusa Group which outcrops on the Boso Peninsula, Central Japan, however, possess both fenestrated and latticed grids. Actually, the majority of larger specimens seems to have a fenestrated grid whereas the smaller ones tend to possess a latticed grid. Some specimens even have a grid showing a combination of both types; a fenestrated central grid surrounded by lattice structure. These are only tentative results, however, and the subject needs further investigation. Accepting both classifications of Backman (1980) and Takayama and Sato (1986), we will call the large Pleistocene form of *Reticulofenestra* which is larger than 5.0 μm *Reticulofenestra* sp. A for the time being.

As will be discussed later, *Reticulofenestra* sp. A becomes progressively larger through the early Pleistocene and only the largest variation (maximum diameter larger than 7.0 μm) shows a stratigraphically limited occurrence. A further investigation under a light microscope revealed that no specimens larger than 6.5 μm recur after the sudden disappearance at about 0.8 Ma. We therefore distinguished two varieties of *Reticulofenestra* sp. A for the biostratigraphy
oriented study, which was conducted under a light microscope; the small variety (5.0–6.5 μm) and the large variety (>6.5 μm).

**Time progressive change in nannoflora**

The nannofloras observed under an electron microscope are dominated by various species and varieties of *Gephyrocapsa* species, *Emiliania huxleyi* and *Pseudoemiliania lacunosa*, and time-progressive changes in their relative abundances resulted in major shifts of the flora (Fig. 3). We recognized six major assemblages through the studied core and will call them Assemblages A through F (Fig. 3). Results of actual counts for the selected samples representing each assemblage are shown in Table I, and major characters of these assemblages are listed in Table II. Because these assemblages are defined by combinations of major species, their stratigraphic ranges do not coincide with some of the “biostratigraphic zones” (e.g. Gartner, 1977) which are defined by the first and last appearances of key species that are often minor constituents of the flora.

The youngest Assemblage A which occurs from the top to 80 cm level of the core (younger than ca. 0.12 Ma) is characterized by dominant *E. huxleyi* (Fig. 3). This assemblage is identical to the one observed in the *E. huxleyi* Acme Zone of Gartner (1977) except that its beginning is older than the widely accepted age of 0.085 Ma (Thierstein et al., 1977). This discrepancy can be caused by a change in sedimentation rate, or it can be a reflection of true diachronism. Since oxygen isotope data are not available at this moment, we could not check the accuracy of the age estimation and will not attempt further discussion. *Calcidiscus leptoporus*, *Gephyrocapsa oceanica*, *Rhabdosphaera clavigera* and *Umbilicosphaera sibogae* are other major species observed in this assemblage (Table I). Among *G. oceanica*, the medium *G. oceanica* (diagonal) is the most prominent member of the flora, and the fairly common occurrence of large *G. oceanica* (vertical) is noticeable.

Assemblage B is observed between 90 to 180 cm (ca. 0.13–0.27 Ma), and the dominant occurrences of medium *G. oceanica* (diagonal) and *Umbilicosphaera sibogae* characterize the flora. Besides common *C. leptoporus*, *R. clavigera* and *Syracosphaera pulchra*, the fairly common presence of large *G. oceanica* is notable. *E. huxleyi*, whose first occurrence is well documented at 0.27 Ma (Thierstein et al., 1977), is also a common member, especially in the upper part of the sequence. The stratigraphic range of this assemblage is identical to the *Emiliania huxleyi* Zone of Gartner (1977).

Assemblage C, observable between 200 and 360 cm levels (ca. 0.30–0.54 Ma), is dominated by the medium *G. oceanica* (diagonal). Though the two other varieties of medium *Gephyrocapsa* are noticeably common, large *Gephyrocapsa* are significantly rare in this assemblage (Table I, Fig. 3). This assemblage can be further subdivided into three sub-assemblages by the temporal dominance of *Gephyrocapsa protohuxleyi* var. A (Fig. 3). Sub-assemblage D2 in which *G. protohuxleyi* var. A dominates occurs between 420–500 cm (0.61–0.74 Ma). In sub-assemblages D1 and D3, *Syracosphaera pulchra* and *U. sibogae* are common, and *G. protohuxleyi* var. A greatly reduces their abundances (Table I). Although not so common, the consistent occurrence of large *G. oceanica* (vertical) is notable in the upper part of this assemblage. The stratigraphic range of this assemblage almost coincides with the *Pseudoemiliania lacunosa* Zone of Gartner (1977) as well as with the original *Emiliania ovata* Subzone (CN14a) of Bukry (1975).

The medium and large varieties of *G. oceanica* (vertical) are the taxa which Bukry (1973a) originally identified as *G. oceanica*. He employed its first occurrence as the basal criteria of *Emiliania ovata* Subzone (CN14a). Takay-
TABLE I

Occurrence of nannofossils in selected samples representing typical floras for each assemblage. The numbers of *Florisphaera profunda* shown at the bottom indicate the actual counts encountered during the observation of first 100 coccoliths excluding *F. profunda*

<table>
<thead>
<tr>
<th>Assemblage zone</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
<th>E</th>
<th>F</th>
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</thead>
<tbody>
<tr>
<td>Age (Ma)</td>
<td>0.00</td>
<td>0.07</td>
<td>0.16</td>
<td>0.23</td>
<td>0.35</td>
<td>0.48</td>
<td>0.59</td>
<td>0.70</td>
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<td>Sample (depth in cm)</td>
<td>000</td>
<td>050</td>
<td>110</td>
<td>160</td>
<td>240</td>
<td>290</td>
<td>330</td>
<td>400</td>
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<tr>
<td>Acanthoica spp.</td>
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<tr>
<td>C. leptoporus</td>
<td>22</td>
<td>13</td>
<td>16</td>
<td>9</td>
<td>1</td>
<td>13</td>
<td>18</td>
<td>24</td>
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<tr>
<td>C. murrayi</td>
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<td>3</td>
<td></td>
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<tr>
<td>C. cristatus</td>
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<td></td>
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<tr>
<td>C. quadrilaminata</td>
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<td></td>
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<tr>
<td>Dictyococctes perplexa</td>
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<td></td>
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<tr>
<td>D. productus</td>
<td>17</td>
<td>5</td>
<td>11</td>
<td>4</td>
<td>1</td>
<td>16</td>
<td>12</td>
<td>3</td>
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<tr>
<td>Discoaster sp. (reworked specimen)</td>
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<tr>
<td>Emiliania huxleyi</td>
<td>193</td>
<td>176</td>
<td>19</td>
<td>9</td>
<td></td>
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<td></td>
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<tr>
<td>Gephyrocapsa caribbeanica (M: 2.5-5 μm)</td>
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<tr>
<td>G. caribbeanica (L: &gt;5μm)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Gephyrocapsa oceanica (M: diagonal)</td>
<td>16</td>
<td>23</td>
<td>83</td>
<td>169</td>
<td>240</td>
<td>249</td>
<td>185</td>
<td>13</td>
</tr>
<tr>
<td>G. oceanica (M: vertical)</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>13</td>
<td>3</td>
<td>19</td>
<td>12</td>
<td>18</td>
</tr>
<tr>
<td>G. oceanica (L: diagonal)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>8</td>
<td>1</td>
<td></td>
<td></td>
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<tr>
<td>G. oceanica (L: vertical)</td>
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<td>5</td>
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<tr>
<td>G. oceanica (broken spec.)</td>
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<td>15</td>
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<td>34</td>
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<tr>
<td>Gephyrocapsa protohuxleyi</td>
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<tr>
<td>Gephyrocapsa spp. (small: &lt;2.5 μm)</td>
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<td>11</td>
<td>6</td>
<td>16</td>
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<td>10</td>
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<td>3</td>
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<td>7</td>
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<tr>
<td>Helicosphaera hylinal</td>
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<td>Helicosphaera invetsa</td>
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<td>Helicosphaera wallhii</td>
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<td>Pseudoemiliania lacunosa (elliptical)</td>
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<td>Pseudoemiliania lacunosa (round)</td>
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<tr>
<td>Reticulofenestra minuta (&lt;3 μm)</td>
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<tr>
<td>Reticulofenestra minutula (3-5 μm)</td>
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<tr>
<td>Reticulofenestra sp. A (&gt;5 μm)</td>
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<td>Rhabdosphaera clavigera</td>
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<td>Syracosphaera pulchra</td>
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<td>Umbillosphaera irregularis</td>
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<tr>
<td>Umbillosphaera tenuis</td>
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<td>Umbillosphaera hulburtiana</td>
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<td>2</td>
<td>3</td>
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<tr>
<td>Umbillosphaera sibogae v. sibogae</td>
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<td>33</td>
<td>112</td>
<td>21</td>
<td>7</td>
<td>3</td>
<td>6</td>
<td>41</td>
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<tr>
<td>U. sibogae v. foliosa</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
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<td></td>
<td>4</td>
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<tr>
<td>sp. indet.</td>
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**Total**

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<tbody>
<tr>
<td><em>F. profunda</em> (N: 100 coccoliths)</td>
<td>451</td>
<td>327</td>
<td>235</td>
<td>664</td>
<td>111</td>
<td>125</td>
<td>414</td>
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TABLE II

Summary of the characteristic occurrence of species in each assemblage

<table>
<thead>
<tr>
<th>Assemblage</th>
<th>Characteristic occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>dominant <em>E. huxleyi</em></td>
</tr>
<tr>
<td>B</td>
<td>abundant medium <em>G. oceanica</em> (2.5-5.0 μm, diagonal bridge)</td>
</tr>
<tr>
<td></td>
<td>abundant <em>U. sibogae</em></td>
</tr>
<tr>
<td></td>
<td>common <em>E. huxleyi</em></td>
</tr>
<tr>
<td></td>
<td>fairly common large <em>G. oceanica</em> (&gt; 5.0 μm, vertical bridge)</td>
</tr>
<tr>
<td>C</td>
<td>dominant medium <em>G. oceanica</em> (diagonal)</td>
</tr>
<tr>
<td>D1</td>
<td>abundant <em>P. lacunosa</em></td>
</tr>
<tr>
<td></td>
<td>common medium and large <em>G. oceanica</em> (vertical)</td>
</tr>
<tr>
<td>D2</td>
<td>dominant <em>G. protohuxleyi</em> var. A</td>
</tr>
<tr>
<td>D3</td>
<td>abundant medium <em>G. oceanica</em> (vertical)</td>
</tr>
<tr>
<td></td>
<td>abundant <em>P. lacunosa</em></td>
</tr>
<tr>
<td></td>
<td>common <em>Reticulofenestra</em> sp. A in lower part</td>
</tr>
<tr>
<td>E</td>
<td>almost complete absence of medium and large <em>Gephyrocapsa</em></td>
</tr>
<tr>
<td></td>
<td>dominant <em>P. lacunosa</em></td>
</tr>
<tr>
<td></td>
<td>common <em>Reticulofenestra</em> sp. A in upper part</td>
</tr>
<tr>
<td></td>
<td>abundant small <em>Gephyrocapsa</em> (&lt;2.5 μm) in lower part</td>
</tr>
<tr>
<td>F</td>
<td>abundant to common large <em>G. oceanica</em> (diagonal)</td>
</tr>
<tr>
<td></td>
<td>common large <em>G. caribbeana</em> (&gt;5.0 μm)</td>
</tr>
<tr>
<td></td>
<td>abundant <em>P. lacunosa</em></td>
</tr>
</tbody>
</table>

ama and Sato (1987) also recognized the biostratigraphic importance of *G. oceanica* (vertical). They have identified this variety as *Gephyrocapsa parallela* and have reported its first appearance at 0.89 Ma in the northern Atlantic Ocean. Because there is much confusion and disagreement over classification of *G. oceanica* among specialists, the base of Subzone CN14a was lowered to approximate the base of the Pleistocene where the first occurrence of medium *Gephyrocapsa* with relatively large central opening is recognized (Haq, 1984; Berggren et al., 1985).

Assemblage E (between 630 and 760 cm: 0.92–1.10 Ma) is characterized by the almost complete absence of medium and large *Gephyrocapsa*, and *C. leptoporus*, *P. lacunosa* and *U. sibogae* are the prominent members of the flora (Table I). This assemblage corresponds to the flora in the upper portion of the small *Gephyrocapsa* Zone of Gartner (1977). Small *Gephyrocapsa*, although abundant in the lower part of this sequence, is not an abundant constituent of the flora in our studied material (Fig. 3). They are probably opportunistic elements of the flora, and their dominance during the middle Pleistocene, which is observable in the equatorial Pacific and other oceans (e.g. Gartner, 1977), is probably not a global event. Their abundance may actually reflect a certain oceanographic phenomenon such as an intensified upwelling, and therefore, their abundance alone should not be regarded as a globally correlatable event. On the other hand, small *Gephyrocapsa* observed in their concentrated interval possess a vertically oriented bridge, whereas the majority of small *Gephyrocapsa* in the upper sequences exhibit diagonal to hori-
horizontal bridge orientations. A quantitative analysis of small *Gephyrocapsa* may provide useful information for biostratigraphy as well as for paleoceanography.

Assemblage F (770–910 cm: 1.12–1.31 Ma) is characterized by the common to abundant occurrence of large *Gephyrocapsa* and *Dictyococcites* such as the large *Gephyrocapsa caribbeana*, large *G. oceanica* (diagonal) and *D. perplexa* (Fig. 3). These taxa are either absent or rare in the upper assemblages. Conversely, the large *G. oceanica* (vertical) which is consistently a common member of the upper assemblages, is almost absent in this assemblage (Table I). The significant difference in the occurrences of large *Gephyrocapsa* varieties below and above the Assemblage E is easy to recognize even under a light microscope. Besides the three taxa mentioned above, *C. leptoporus*, medium *G. oceanica* (diagonal), *P. lacunosa* and *R. clavigera* are the abundant members of Assemblage F. Due to the lack of core penetration, we can not see the base of this assemblage. Since Rio et al., (in press) reported the first appearance of large *Gephyrocapsa* (defined as larger than 5.5 μm) at 1.31–1.32 Ma in the western equatorial Pacific, however, the lower boundary of Assemblage F should be close to the base of this core.

The species diversity measured by the Shannon–Wiener Function ($D_H$) well reflects the time-progressive changes in floral composition (Fig. 4). The diversity generally corresponds to the floral change and is alternatively high and low in the successive assemblages. It is relatively low in Assemblages A, C and E and is high in Assemblages B, D and F. The average value is particularly low in Assemblage C, in which the medium *G. oceanica* (diagonal) alone occupies more than two thirds of the flora (Fig. 3). A similar trend is also evident in Assemblage A, particularly at the 30 cm level (ca. 0.05 Ma), in which *E. huxleyi* dominates the flora. The low values in Assemblage E is the result of the almost complete absence of medium and large *Gephyrocapsa* coupled with the dominance of *P. lacunosa*. Reflecting the gradual rejuvenation of larger *Gephyrocapsa* and *Dictyococcites productus*, the diversity progressively increases through Assemblage D. The temporal but sharp increase of *G. protohuxleyi* var. A in Sub-assemblage D2 is not apparent in the diversity measurement (Figs. 3 and 4). This stability can be explained by the fact that the increase of *G. protohuxleyi* is mostly compensated by a reduction in a single species *P. lacunosa*, and other major species do not significantly reduce their abundances (Fig. 3).

*Florisphaera profunda* is a unique species among calcareous nannoplanktons because it dwells only in the deeper part of euphotic layers and in subphotic waters (Okada and Honjo, 1973). Its relative abundance is known to increase concordantly with water depth of sedi-
mentary basin in the realms of neritic and bathypelagic oceans (Okada, 1983). The water depth at this site is approximately 3,500 m and is much greater than the lower limit of the bathypelagic realm even during the period of maximum sea level lowering caused by Pleistocene glaciation. This species is relatively solution resistant and is easy to recognize under an electron microscope even in fairly dissolved samples. The temporal increases of *F. profunda* observed here, therefore, can be interpretable as an indication of either a decrease of coccolith production in euphotic waters or as a deterioration of coccolith preservation (Fig. 4). Their consistently depressed appearance within Assemblage C may reflect an increased coccolith production, particularly that of medium *G. oceanica* (Fig. 3).

**Stratigraphic occurrence of various morphological types**

Some nannoplankton species have changed their morphological character through the Pleistocene, and evolution of certain morphologic types are useful for the Pleistocene biostratigraphy. To examine the biostratigraphic value of medium and large *Gephyrocapsa oceanica*, the three morphologic varieties (vertical, diagonal and horizontal varieties) were further subdivided into 5 classes by overall sizes and the stratigraphic occurrences were investigated for each class (Fig. 5). *G. oceanica* (horizontal) is rather small (generally less than 4.0 μm) and none was observed as larger than 5.0 μm. Because of this size limitation and their generally rare occurrence, all specimens of this variety are lumped together, and their occurrence was expressed as a single entity in Fig. 5. *G. oceanica* (diagonal) is the most abundant among the three varieties, and a time-transgressive trend seems to exist for the common appearance of each size category; the larger classes showing up successively later than the adjacent smaller classes. The medium to large classes with size ranges between 3.0 and 6.0 μm occur abun-
dantly within two separate intervals, while the small (2.5–3.0 μm) class occurs rather consistently and becomes common only during the middle part of the Late Pleistocene (Fig. 5). On the other hand, the largest (>6.0 μm) classes appear only in the lower sequence of the core. This restricted occurrence coincides with that of the large *Gephyrocapsa caribbeana*, and it can be a useful criterion for the biostratigraphy. A time-transgressive trend is not clear for *G. oceanica* (vertical) and *G. oceanica* (horizontal) and their occurrence is very much subdued in the lower sequence of the studied core.

The high potential of *Gephyrocapsa protohuxleyi* as a stratigraphic marker of the Pleistocene biostratigraphy is a new finding to come out of this study (Fig. 3). The short-lasting dominance during the earliest part of the Brunhes Epoch is totally accountable by the appearance of *G. protohuxleyi* var. A, and the same occurrence was also observed in the Deep Sea Drilling Project site 289 located on the Ontong-Java Plateau in the equatorial western Pacific Ocean (Matsuoka and Okada, unpublished data). The common occurrence of *G. protohuxleyi* var. A was observed in the lower sections of Core 289-2 directly above the "highest occurrence of abundant small specimens of *Gephyrocapsa*" which was observed at the 125 cm level of Section 289-2-6 (Gartner, 1977). In Samples 289-2-4, 90–91 cm, this variety occupies approximately 16% of the flora while other small *Gephyrocapsa* share only 8%.

This variety may be an ecophenotype of certain small *Gephyrocapsa* taxon, and such a peaked occurrence observed here may not be a global phenomenon. Alternatively, this variety may be a transitional form between *Gephyrocapsa ericsonii* and *G. protohuxleyi*, and their acme can be globally correlatable. In any case, their stratigraphic occurrence as well as the morphologic change should be carefully monitored in different ocean basins. The fact that this taxon can correctly be identified only under an electron microscope is certainly a draw-
Fig. 5. Stratigraphic occurrence for various morphologic varieties and size classes of Gephyrocapsa oceanica. Because of the generally rare occurrence, all specimens belonging to the variety with a horizontal bridge are combined.

back, but its high potential for biostratigraphy, paleoceanography and possibly for the study of evolution is certainly worth further consideration.

Except for the slits on its distal disc, Pseudoemiliania lacunosa is almost identical to Reticulofenestra species such as R. minuta, R. minutula and Reticulofenestra sp. A. To examine the legitimacy of claiming a different species within the Pseudoemiliania lacunosa group solely by number of slits or by the outer shape of coccoliths, and to check any difference in mode of occurrence between various morphologic varieties, we have tentatively identified three varieties (Variety A: 1 to 5 slits, Variety B: 6 to 15 slits, and Variety C: more than 16 slits) for the elliptical and round type of P. lacunosa. Each of these six varieties was further subdivided into six size classes by its overall size. In addition, the three species of Reticulofenestra are also subdivided into six size classes in a similar manner, and their stratigraphic occurrences were compared with that of P. lacunosa (Fig. 6). The time-progressive changes in relative abundances are similar between the corresponding size classes of the elliptical Varieties...
Fig. 6. Stratigraphic occurrence of various morphologic varieties and size classes of *Pseudoemiliania lacunosa* and *Reticulofenestra* species. Because of generally rare occurrence, all specimens of the round types are combined. The empty (white) area indicated in the column of the 7-8 μm size fraction in the lower-right figure (*Reticulofenestra* spp.) represents the form, which ranges in size between 6.5 and 7.0 μm.
A and B of *P. lacunosa*. As was observed for *G. oceanica* (diagonal), there seems a successive delay for the beginning of acme for the larger size classes. The temporal depletion observed around 0.7 Ma in the medium size classes obviously caused by the temporal surge of *G. protohuxleyi* (Figs. 3 and 6). The trend is also similar between these two varieties (Varieties A and B) and Variety C except for the very large (> 7.0 μm) elliptical categories. The very large classes of the Varieties A and B show a restricted occurrence centered at 0.9 Ma, and it is identical to the range of the large variety of *Reticulofenestra* sp. A. To the contrary, the very large class of the Variety C occurs only in the higher sequence which corresponds to the terminal phase of *P. lacunosa*’s existence. A separate identification of the large delicate form with a large number of slits, therefore, may have special merit for biostratigraphic purposes.

The stratigraphic occurrence for each size category of *Reticulofenestra* species is also similar to that of *P. lacunosa* (Fig. 6). This similarity is further evidence for genetical kinship between *P. lacunosa* and the three species of *Reticulofenestra*. The presently common practice of recognizing *Pseudoemiliania* as an independent genus may need further evaluation. As was already mentioned in the previous chapter of taxonomic remarks, the restricted occurrence of larger *Pseudoemiliania* sp. A is a useful marker to identify the middle part of the Pleistocene. The round variety, which is usually larger than 5.0 μm, also shows a similar occurrence to the larger elliptical variety. Presence of the round variety, therefore, can confirm the identification of this time period. The stratigraphic occurrence of the Variety C of *P. lacunosa* denies the possibility that the temporal appearances of very large forms observed for the Varieties A and B as well as *Reticulofenestra* sp. A were a response to a certain environmental change.

### Stratigraphic ranges of selected taxa and Pleistocene biostratigraphy

Our study of the time-progressive change in nannoflora confirmed the biostratigraphic usefulness of several events. Many of these evolutionary events were previously known. The biostratigraphic potentials for some of these events, however, were found only recently, and the exact timings have not been examined in many parts of the world ocean. To establish a biostratigraphic standard applicable for the Quaternary sequence of the northwestern Pacific Ocean, and to examine its synchronous or diachronous nature on the global scale, we have semi-quantitatively investigated the occurrences of 16 taxa in the complete set of samples (5 cm interval samples), under a light microscope (Fig. 7). Since a large number of nannofossils (more than 10,000 individuals per sample) were observed for this biostratigraphic study, ages for some events are slightly deviated from the results observed under an electron microscope in which only 350 specimens were identified (Figs. 3, 5 and 6). In the following discussions, our criteria for the expression of species abundance are: abundant (more than 10% of the flora excluding *Florisphaera profunda*), common (between 10% and 1.0%), few (between 1.0% and 0.1%), and rare (less than 0.1%).

Rare specimens of *Helicosphaera sellii* occur in the lowest part of the core, and its last occurrence (LO) is detected at 830 cm (1.20 Ma). This age is similar to those previously reported from various parts of the world ocean; the northern Atlantic (1.22 Ma by Pujos, 1985a; 1.19 Ma by Takayama and Sato, 1987) and in the equatorial Pacific (1.22 Ma by Gartner, 1977; 1.23 Ma by Pujos, 1985b). Due to a generally inconsistent occurrence of *H. sellii*, however, this event was sometimes difficult to pinpoint in our previous experiences.

All varieties of medium to large *Gephyrocapsa caribbeanica* and *Gephyrocapsa oceanica* temporarily disappear or greatly reduce their
abundances during the middle Pleistocene, but the timings of the temporal disappearances are slightly different between the morphologic varieties (Fig. 7). Generally, the medium varieties disappear slightly earlier than the large varieties. The medium *G. caribbeana* and medium *G. oceanica* (vertical) disappear concurrently above 780 cm (1.13 Ma). The medium *G. oceanica* (diagonal) is a relatively common member of the flora up to 770 cm (1.12 Ma). Unlike the other two medium varieties which become completely absent, very rare specimens of this variety sporadically occur in Assemblage E (Fig. 5). The large *G. oceanica* (vertical) is less abundant and disappears earlier than the other two large varieties of *Gephyrocapsa*. Their temporal disappearance is recognized at 760 cm (1.10 Ma). The large *G. caribbeana* and large *G. oceanica* (diagonal) are common to abundant in the lower samples up to the 770 cm (1.12 Ma) level, then they progressively and concurrently become few, rare and absent above the 770, 755 and 745 cm samples respectively. We regarded the 755 cm (1.10 Ma) level as their true disappearance. Takayama and Sato (1987) reported the LO of large *Gephyrocapsa* which
was defined as larger than 6 μm at 1.10 Ma. Some of the large G. oceanica observed in the 755 cm sample and below are actually larger than 6.0 μm (Fig. 5), and their finding fits well with our observation. These events are easy to identify under a light microscope, and the temporal disappearances of large Gephyrocapsa is a good marker to approximate the 1.10 Ma horizon.

Backman (1980) reported evolutional size reduction from Dictyococcites perplexa (> 4.0 μm) to Dictyococcites productus (< 4.0 μm) at the Miocene/Pliocene boundary in the north-east Atlantic Ocean. In our lower Pleistocene samples, however, D. perplexa is a common member of the flora, and its size, though the majority is smaller than 5.0 μm, reaches the maximum value of 5.5 μm. Its stratigraphic range actually overlaps that of the large G. caribbeanica. Since these two species are morphologically close, D. perplexa observed in our samples may be a variant of G. caribbeanica, rather than being the direct survivor of the Miocene D. perplexa. In any case, the LO of our D. perplexa, which was determined by the significant drop in abundance from few to rare categories, occurs at 790 cm (1.15 Ma). It slightly precedes the LO of larger G. caribbeanica and is close to that of medium G. caribbeanica (Fig. 7). Although D. perplexa does not recur in the upper Pleistocene, D. productus which also diminishes temporarily in Assemblage E is a consistent member of the late Pleistocene flora.

Rejuvenation of medium Gephyrocapsa is first recognized at 620 cm (0.92 Ma) by the common occurrences of the medium G. oceanica varieties. This is a clear-cut phenomenon, easy to recognize under a light microscope, and probably is the criterion employed as the base of the Gephyrocapsa oceanica Zone (CN14) by Bukry (1973a). Takayama and Sato (1987) identified the FO of Gephyrocapsa parallela at 0.89 Ma in the northern Atlantic Ocean. G. parallela is synonymous with our G. oceanica (vertical), and their finding is again very close to our observation. The recurrence of medium G. caribbeanica is first recognized at 600 cm (0.88 Ma) by the presence of rare specimens. They become common to few above 490 cm (0.7 Ma) and disappear above 100 cm (0.15 Ma).

Among large Gephyrocapsa, the large G. caribbeanica never shows up in the upper Pleistocene samples. The recurrence of large G. oceanica (vertical) is first observed at 530 cm (0.79 Ma), and it becomes a prominent member of the flora during the early Brunhes Epoch. This species again becomes rare or absent for approximately 0.2 million years (ca. 0.5–0.3 Ma) followed by the final rejuvenation above 200 cm (0.3 Ma). The exact ages of recurrences for both varieties of large G. oceanica are difficult to locate, and their frequent occurrences should be utilized for identification of the floral assemblages rather than for the identification of the exact time horizons in the upper Pleistocene sequences.

Dominant occurrence of small Gephyrocapsa within the small Gephyrocapsa Zone of Gartner (1977) was documented from various oceans. Small Gephyrocapsa, however, never dominates the flora in our quantitative study under an electron microscope. Preparation of samples for electron microscopy sometimes causes artificial sorting and results in a deceptive representation of small forms. Our subsequent observation under a light microscope, however, showed no significant difference with the results observed under that microscope. On the other hand, Gephyrocapsa protohuxleyi var. A dominates the flora for a short time period at around 0.7 Ma (Fig. 3). Although it may be difficult to pinpoint the beginning and end of the acme of this variety under a light microscope, these are important time markers to identify in otherwise event-poor intervals of the early late Pleistocene. Utilizing the counting data presented in Fig. 3, we have identified the beginning and end of the acme of G. protohuxleyi at 500 cm (0.75 Ma) and 420 cm (0.62 Ma), respectively.

As was mentioned earlier, the large form of Reticulofenestra sp. A (> 6.5 μm) is a good
biostratigraphic marker (Fig. 6). Its rare occurrence is first noticed at 670 cm (0.98 Ma). Because of its large size, it becomes a prominent member of the flora above 640 cm and disappear suddenly at 545 cm (0.81 Ma). Takayama and Sato (1987) reported its sudden disappearance in the northern Atlantic Ocean at 0.83 Ma, again fitting well with our result. The sudden disappearance of the large Reticulofenestra sp. A, therefore, is a good marker to approximate the middle of the Pleistocene. The small form of Reticulofenestra sp. A (5.0–6.5 μm) occurs continuously from the lowest sample and is a more frequent member of the flora than the larger counterpart (Fig. 6). This small form tentatively disappears during a short period (525–485 cm: 0.78–0.72 Ma), but unlike the large form, it recurs in the upper sequence and disappears finally at 320 cm (0.48 Ma).

Although reworked rare specimens are observed in the upper sequence (up to 290 cm), Pseudoemiliania lacunosa significantly lowers in abundance at 310 cm (0.46 Ma). We have interpreted this evidence as the LO of P. lacunosa, and it is identical to the age of 0.458 Ma which is claimed to be a globally synchronous event (Thierstein et al., 1977). This age, however, is significantly older than the 0.39 Ma observed in the northern Atlantic Ocean by Takayama and Sato (1987). Since Pujos (1985a) has reported 0.475 Ma for this event in the northern Atlantic Ocean in the area very close to where Takayama and Sato studied, their significantly younger age may be a result of reworking.

Takayama and Sato (1987) reported the FO
and LO of *Helicosphaera inversa* at 0.48 and 0.15 Ma, respectively. In our material, their occurrence is continuous between 535 cm (0.80 Ma) and 360 cm (0.54 Ma), but its exact range is difficult to pinpoint. Though *H. inversa* is a good supplementary marker for Assemblage D in the northwest Pacific Ocean, its usefulness for biostratigraphy is somewhat questionable. Its range should be carefully monitored in different world oceans.

The FO and beginning of acme of *E. huxleyi*, which were respectively observed at 180 cm (0.27 Ma) and 80 cm (0.12 Ma) by electron microscopy, are identical to the results observed by light microscopy.

**Summary and conclusions**

(1) Pleistocene nannofossils were quantitatively studied from a piston core collected from the subtropical western Pacific Ocean, to examine the time-progressive change in nannoflora as well as the stratigraphic occurrences of various morphological varieties. The studied core has a continuous sedimentary record for the last 1.3 million years and the magnetostratigraphy is well established.

(2) Various morphological types of genus *Gephyrocapsa* significantly characterize the nannoflora. Based on the abundance or absence of these morphologic types and *Emiliania huxleyi*, six species assemblages (Assemblages A through F) were identified, and one assemblage was further divided into three sub-assemblages (Sub-assemblages D1 to D3).

(3) A variety of *Gephyrocapsa protohuxleyi* (*G. protohuxleyi* var. A) occurs abundantly in a short time period coinciding with the lowest part of the Brunhes Epoch. Since this variety may be a transitional form linking two well known taxa or may be an ecophenotype which became abundant in response to a certain unusual ocean environment, it is important to monitor its stratigraphic range and progressive morphological change for an improved biostratigraphy as well as for the study of paleoceanography.

(4) The biostratigraphic potential for a large form of *Reticulofenestra* sp. A (> 6.5 μm) is confirmed.

(5) A total of 11 evolutional events were recognized, and an age comparison of these events with previously reported results from different world oceans shows generally good agreement. Most of the events identified in this investigation are good markers for global correlation with reasonably good precision.

**Acknowledgements**

We thank Professor K. Kobayashi and Mr. T. Furuta, Ocean Research Institute, University of Tokyo for providing us with the unpublished data for magnetostratigraphy as well as for giving us permission to study the core. Dr. H. Kitazato, Shizuoka University notified us of the availability of the studied core. Dr. D. Bukry of USGS, Menlo Park critically read the manuscript and gave valuable comments. Dr. J. Backman, University of Stockholm and Dr. D. Rio at the University of Parma provided us with helpful suggestions. We are grateful to those people.

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