

UTRECHT MICROPALEONTOLOGICAL BULLETINS

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RECONSTRUCTION OF MARINE PALEOENVIRONMENTS

30

MODERN NANNOFOSSIL ASSEMBLAGES IN SEDIMENTS OF COASTAL AND MARGINAL SEAS ALONG THE WESTERN PACIFIC OCEAN

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ABSTRACT

The ecology and biogeography of Recent calcareous nannoplankton are briefly reviewed, and the results are presented of a study of the composition of nannofossil associations collected in various environments ranging from marginal to open seas along the western Pacific Ocean.

Florisphaera profunda has become a major component of the flora since the Late Miocene. Its abundance shows a positive correlation with depth; the species is absent in shallow water, whereas it constitutes more than half of the total associations recovered from deep, pelagic sediments. *Gephyrocapsa oceanica*, on the other hand, dominates the flora in shallow, marginal seas and in inland seas.

A triangular coordinate diagram is constructed by using *F. profunda* and *G. oceanica* as environmental markers, while a third category represents all other species. The diagram clearly illustrates provincialism in the composition of the nannoflora associations; a discussion is given on the applicability of this analytical method.

INTRODUCTION

The ecology and distribution patterns of living calcareous nannoplankton have been studied in various marine environments. Their ocean-wide distribution is controlled by the geography of water masses (McIntyre and Bé, 1967; Okada and Honjo, 1973; Honjo and Okada, 1974); seasonal fluctuations in the composition of nannoplankton communities were documented by Okada and McIntyre (1979) for the northern Atlantic. Okada and Honjo (1975) reported conspicuous differences in the community structure between marginal seas and their pelagic counterparts along the western Pacific.

The ocean-wide distribution of calcareous nannofossils in surface sediments of the Atlantic was studied by McIntyre (1967) and McIntyre and Bé (1967); similar studies were performed for the Pacific by Geitzenauer et al. (1976), McIntyre et al. (1970), Roth and Berger (1975), Roth and Coulbourn (1982) and Ushakova (1970), while Geitzenauer et al. (1977) reported on both the Atlantic and Pacific Oceans. The results of these studies clearly demonstrate a good correspondance between the species distribution patterns in sediments and the nannoplankton in the water column. The cause of such a good correspondance has to be looked for in the rapid transfer of coccoliths through the water column by faecal pellets. This mode of transport is now a well-known fact (Roth et al., 1975; Honjo, 1976) and quanti-

tatively the most important mechanism of coccolith deposition (Honjo and Roman, 1978). Selective dissolution of coccoliths in the deep sea water column and in deep sea sediments was subject to studies by Honjo (1975), and by McIntyre and McIntyre (1971), Roth and Berger (1975), and Schneidermann (1973), respectively.

Until now there have been only a few studies dealing with nannofossils recovered from surface sediments of neritic and marginal seas. Scholle and Kling (1972) investigated the flora from lagoonal sediments in British Honduras; Bukry (1974) reported the predominance of *Emiliania huxleyi* in the flora from the top layer of the Black Sea floor. There are several reports on nannofossils from various parts of the coastal floor of the Indian Ocean, but these reports lack a quantitative analysis of data (Guptha, 1976, 1979, 1981; Shafik, 1978). Such quantitative studies have been made for sediments in marginal seas along the western Pacific, e.g., for the Sendai Bay (Takayama, 1972), the Okinawa Trough (Chen, 1979), and the South China Sea (Chen and Shieh, 1982). The fossil association from the continental shelf of the South China Sea is dominated by *Gephyrocapsa oceanica*; the same applies to the living communities, studied by Okada and Honjo (1975).

Okada and Honjo (1973) first described *Florisphaera profunda* from the Pacific Ocean and observed its depth-sensitiveness. The species was only found in the lower part of the euphotic layer, usually below 100 m, of the Equatorial to Transitional zones. A large form of the species was described by Okada and McIntyre (1977, 1980) as *F. profunda* var. *elongata*. Since coccoliths of *F. profunda* are abundant in deeper waters of the Pacific Ocean (Honjo, 1975) they may be expected to be a good depth indicator in basin analysis. Because of the unique (perhaps too simple) shapes of these coccoliths, however, not many paleontologists recognized them as such, and in none of the papers listed above has *F. profunda* been counted as a member of the nannoplankton community. The coccoliths of another "deep layer species", *Thorosphaera flabellata*, are less frequent in the aphotic water column than those of *F. profunda* (Honjo, 1975), and they can hardly be recognized under a normal light microscope.

This paper mainly deals with the frequency distribution and ecological interpretation of *Florisphaera profunda* in sediments, and with general environmental aspects of nannoflora associations, in particular from neritic and marginal seas. Coccospheres and nannofossils of *F. profunda* from various localities are illustrated on Plate 1.

SAMPLES AND TECHNIQUES

Twenty-seven core samples which cover the Upper Miocene to Holocene

sequences of DSDP sites 289 and 445, and 97 surface sediment samples recovered from the Sea of Kumano were studied for the analysis of the frequency distribution patterns of *Florisphaera profunda* (figs. 1, 3, 4). Ten surface samples were obtained from the Tokyo Bay, the Inland Sea of Seto, the Ohmura Bay and some nearshore and further offshore localities of Japan for the study of nannofloras in the Transitional zone (fig. 5). Surface sediment samples were also collected from the Taiwan Strait and from a locality of bathyal depth at the same latitude (fig. 2). Surface sediments from 18 stations in the Gulf of Thailand (fig. 6) and from 23 stations in the Arafura Sea and in the Gulf of Carpentaria (fig. 7) were sampled for the investigation of associations in tropical, marginal seas.

All determinations and countings were performed with a light microscope; supplementary SEM observations were made for some selected samples. The diversities of the communities are expressed by the Yule Simpson Index (D_p) and by the Shannon-Weaver Function (D_H), which were calculated following the method reported by Berger and Parker (1970).

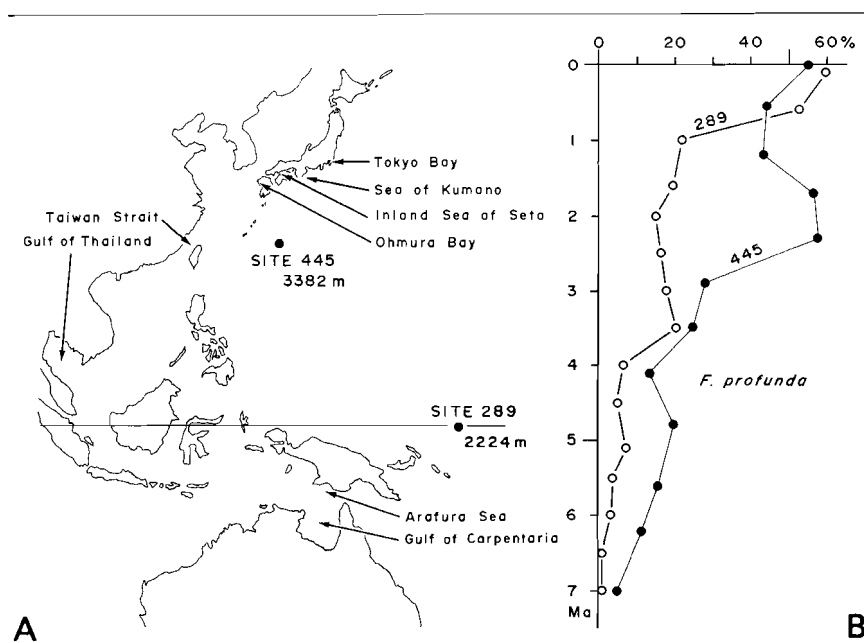


Fig. 1 A) Position of coastal and marginal seas and of DSDP sites 445 and 289; B) Relation between relative frequency of *Florisphaera profunda* and time for Late Miocene to Holocene sediments of DSDP sites 445 and 289. The frequency of *F. profunda* is expressed by percentage values of the total associations.

Geological record of *Florisphaera profunda* in deep sea cores

The lowest occurrence of *F. profunda* in both DSDP sites 289 and 445 (fig. 1) is in the Upper Miocene. Its presence in sediments older than 7 m.y. is uncertain, due to the rather poor state of preservation. In both DSDP profiles a time-transgressive change in frequency of coccoliths of *F. profunda* can be observed. In site 445 they become abundant from the Upper Miocene upward (more than 10% of the association) and they constitute more than 40%, i.e., they become predominant, in the Upper Pliocene and Quaternary. In the equatorial site 289, however, coccoliths of *F. profunda* are not common until the Lower Pliocene, while they become abundant in the Upper Pleistocene (fig. 1).

Abundance of *Florisphaera profunda* in relation to depth

In order to investigate the use of relative numbers of *F. profunda* as a depth indication in basin analysis, counts were performed on associations recovered from sediments in the vicinity of Taiwan and in the Sea of Kuman. The two samples from the Taiwan area (fig. 2) come from the continental shelf below the Taiwan Strait (water depth 70 m) and from the continental slope off the east coast of Taiwan (approximate water depth 1,000 m). The individual counts for 300 specimens excluding *F. profunda* are fairly similar in the two samples, except for slightly higher relative numbers of *Gephyrocapsa oceanica* and lower relative numbers of *Emiliana huxleyi* in the sample from the shelf (CSK-36). Similar results were obtained by Chen and Shieh (1982) from the South China Sea. If coccoliths of *F. profunda* are counted, the diversity indices are still almost identical in the two samples, but conspicuous differences can be observed in the percentage values of the species between the two samples: almost 70% in the deep sample, less than 3% in the shallow sample.

More data could be obtained from surface sediments in the Sea of Kuman, Japan (figs. 3 and 4). The relative numbers of *F. profunda* show an obvious correlation with depth and with distance from the shore. The percentage values display a strong increase from the sublittoral to the upper bathyal zones (from 60 to 300 m), which is followed by a less strong increase from lower bathyal to abyssal depths (fig. 4A). A comparable trend of increasing percentage values was found concerning the distance from the shore (fig. 4B), but the data display a more scattered picture. Data from deeper and more pelagic sediments in other areas (figs. 1, 2, 5) suggest that the high

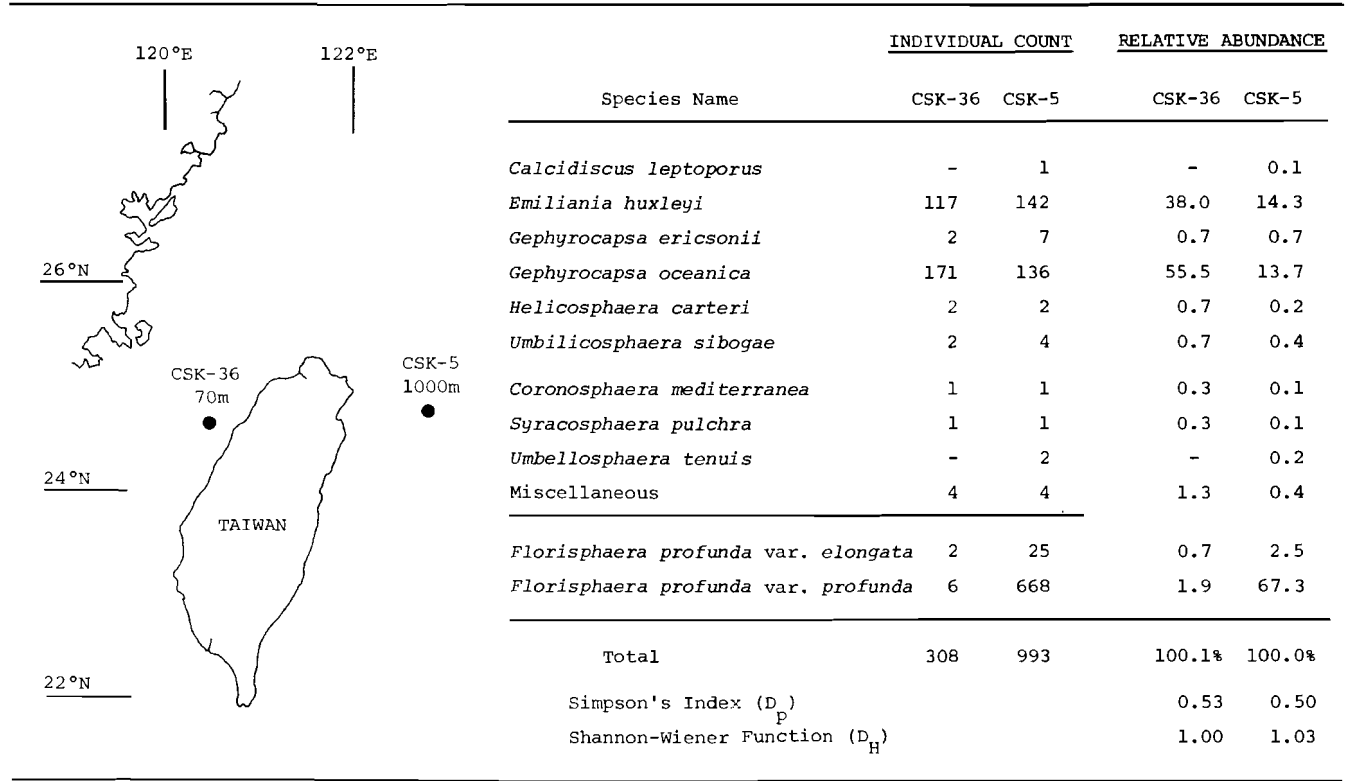


Fig. 2 Location, water depth, and species composition of nannofossil associations for two samples recovered from stations off Taiwan.

percentage values observed in the Kumano set of samples may be rather close to the "maximum" values that can be reached.

Separate counts of *Florisphaera profunda* var. *elongata* do not show any clear correlation between relative numbers and either depth or distance from the shore in the Kumano samples (figs. 4A and B). This may indicate that the variety *elongata* is less sensitive to water depth than the nominate type of *F. profunda*.

Samples from four western stations (figs. 3A and 4A, open circles) display abnormally low percentage values in the depth – frequency diagram, whereas the percentage values fall within the cluster in the frequency - distance from shore diagram. The latter four samples were collected in an area where sedimentation is disturbed by a prevailing bottom current. Due to the exposure of consolidated rocks, attempts to obtain sediment samples failed at several points in this area. The explanation of the aberrant values needs further investigation; a complete analysis of the floral composition of these samples will be published separately.

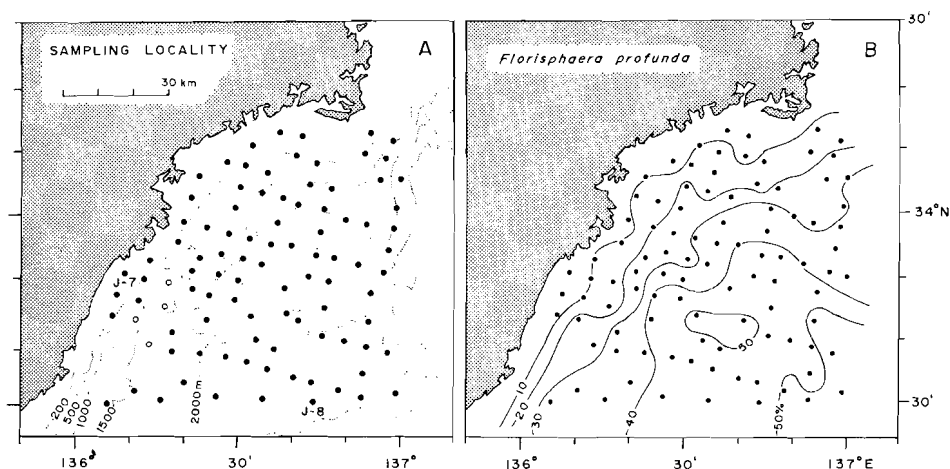


Fig. 3 Sampling localities and water depth (A), and frequency pattern of *Florisphaera profunda* (B) in the Sea of Kumano. The frequencies are expressed by percentage values of the total associations.

Species composition in surface sediments of semi-confined and open sea environments around Japan.

A set of ten surface sediment samples was collected from nearshore and further offshore localities around Japan in order to investigate the compo-

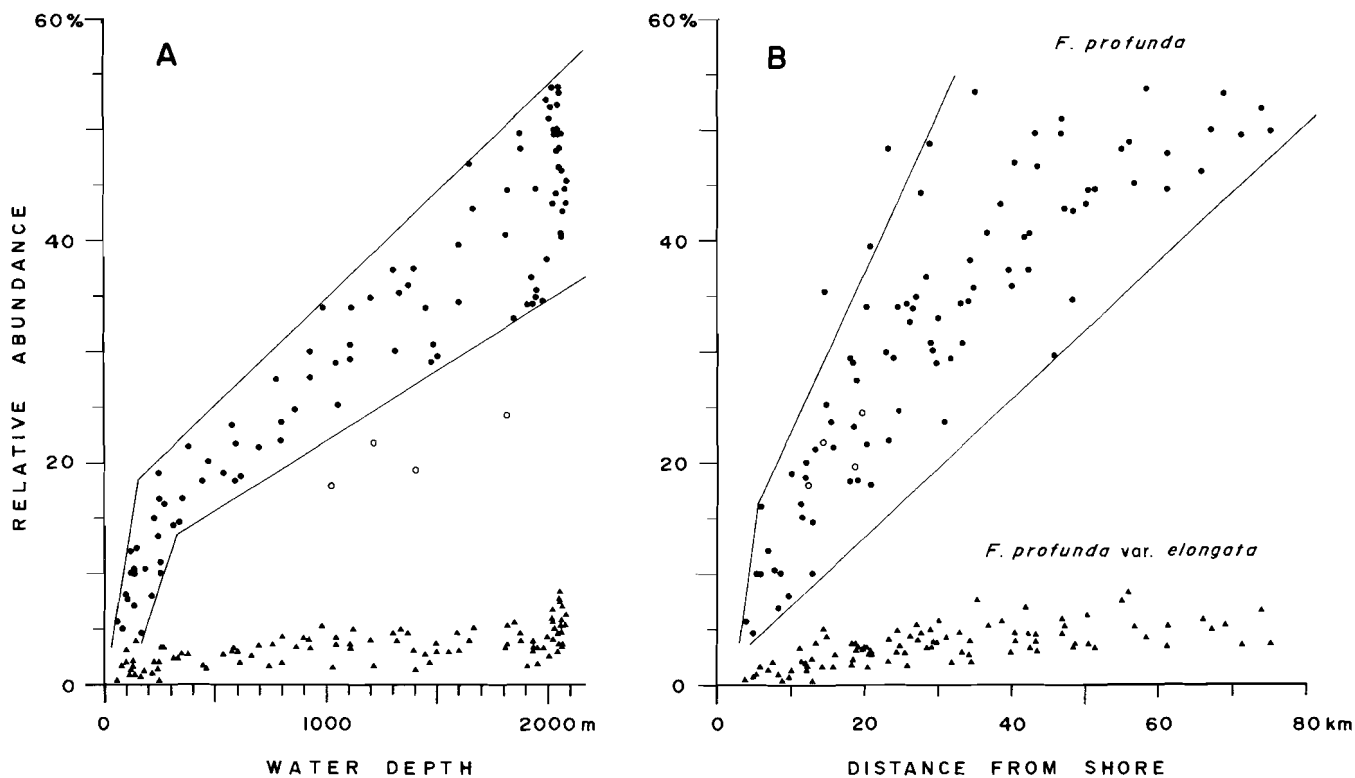


Fig. 4 Relations between relative frequency of *Florisphaera profunda* and water depth (A), and between relative frequency and distance from shore (B) in the Sea of Kumano. The frequencies are expressed by percentage values of the total associations. Closed circles indicate the combined percentage values of the nominate type of *F. profunda* and of *F. profunda elongata*; triangles represent values for *F. profunda elongata* alone; open circles: see text.

sition of the nannofossil association (fig. 5). The collection is meant to represent two different geographical settings. The first group of samples (J1–5) was recovered from semi-confined shallow bay and inland sea environments, whereas the second group (J6–10) was taken in marine open sea, neritic and pelagic environments.

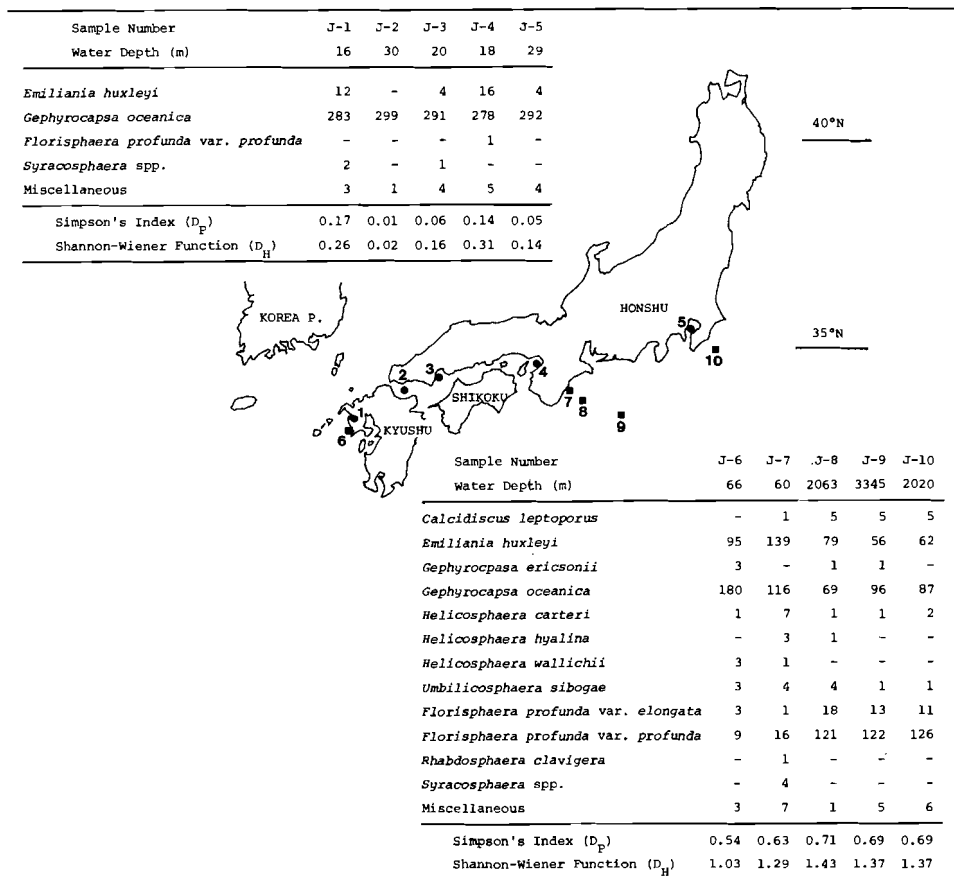


Fig. 5 Location, water depth and species composition of nannofossil associations for ten samples collected nearshore and further offshore Japan.

The nannoflora associations from the Ohmura Bay (J1), from the inland Sea of Seto (J2–4) and from the Tokyo Bay (J5) all display extremely low diversities; in all samples *Gephyrocapsa oceanica* is predominant. The values of the diversity indices calculated for the five samples from the shallow bay and inland sea environments are always less than one third of the values obtained for the samples of the open marine environments (fig. 5). *Flori-*

sphaera profunda is absent or extremely rare in the first group of samples (J1–5), whereas it is common in the open marine, neritic samples J6 and J7, and predominant in the associations from samples J8–J10, derived from pelagic environments. The rare occurrence of *F. profunda* in sample J4 may be explained in terms of transport from the open sea by strong tidal currents through the Naruto Channel.

Okada and Honjo (1975) investigated living nannoplankton from surface waters in the inland Sea of Seto and from the pelagic, warm Kuroshio current. The authors found an almost monospecific community of *Gephyrocapsa oceanica* in the inland Sea of Seto, which result closely resembles that obtained from surface sediment samples (J2–4).

Species composition in surface sediments of the Gulf of Thailand

Altogether 17 species were identified in the 18 samples studied. The distribution patterns of the three most important species, *Emiliania huxleyi*, *Gephyrocapsa oceanica* and *Florisphaera profunda* are illustrated in figure 6, along with the diversity indices values. Numerically less important species, not shown in figure 6 are *Acanthoica* sp., *Calcidiscus leptoporus*, *Calciosolenia murrayi*, *Discosphaera tubifera*, *Gephyrocapsa ericsonii*, *Helicosphaera carteri*, *H. hyalina*, *H. wallichii*, *Neosphaera coccolithomorpha*, *Syracosphaera pulchra*, *S. sp.*, *Umbellosphaera irregularis*, *U. tenuis* and *Umbilicosphaera sibogae*.

Figure 6A shows that *Emiliania huxleyi* has its lowest relative frequencies in samples from stations located close to the coast of the Gulf. *Florisphaera profunda* (fig. 6C) is rare in the coastal stations as well, whereas *Gephyrocapsa oceanica* is abundant (fig. 6B). *F. profunda* reaches its highest percentage values in the central part of the Gulf, where *G. oceanica* is less frequent. These data imply opposite distribution patterns for *G. oceanica* and *F. profunda*.

In an earlier study Okada and Honjo (1975) observed coccolithophores with malformed coccoliths to be abundant in the Gulf of Thailand. Unusually low rates of malformed cells, however, appeared to exist in the surface waters of the central part of the Gulf, which area corresponds to that displaying high relative numbers of *Florisphaera profunda* in the sediments. In contrast to what might be expected, *F. profunda* does not have its highest percentage values in the deepest, southern part of the Gulf (approximately 8°N–102°E, see fig. 6C). This may be due to the effects of local geographical conditions, as appeared to be the case in the living communities, but the exact nature of such local conditions is not yet understood.

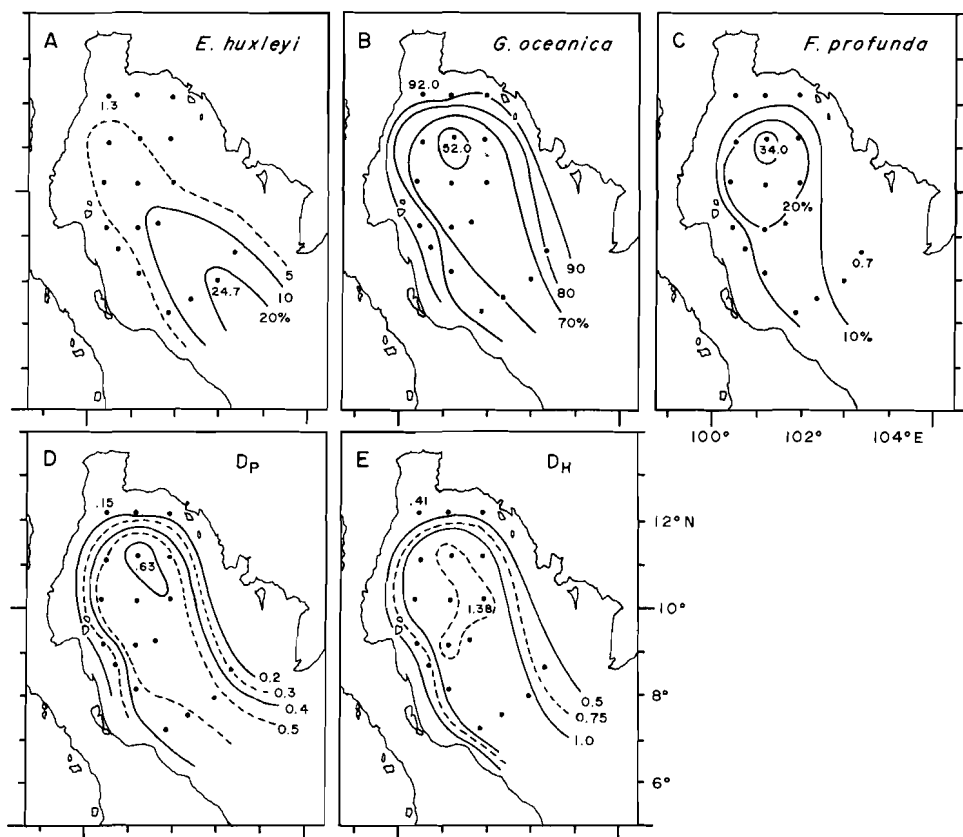


Fig. 6 Distribution patterns of the percentage values of three major species (*Emiliana huxleyi*, *Gephyrocapsa oceanica*, *Florisphaera profunda*) and of the values of the two diversity indices in surface sediment samples from the Gulf of Thailand. Percentage values refer to the total associations. Minimum and maximum values are plotted at the corresponding stations.

The patterns displayed by values of the diversity indices (figs. 6D and E) are similar to the frequency patterns of *Florisphaera profunda*. The values of the diversity indices vary between those calculated for samples from open marine environments and the highest value calculated for samples from the semi-confined seas around Japan (figs. 5 and 6).

Species composition in surface sediments of the Arafura Sea and the Gulf of Carpentaria

Twenty-three surface sediment samples were studied, which contained a total number of fourteen species. The list of species closely resembles that

reported for the Gulf of Thailand; it differs by the absence of four species (*Acanthoica* sp., *Neosphaera coccolithomorpha*, *Umbellosphaera irregularis* and *U. tenuis*), and by the occasional presence of *Braarudosphaera bigelowii*.

Gephyrocapsa oceanica and *Emiliana huxleyi* are the most important taxa in the Arafura Sea/Gulf of Carpentaria (figs. 7A and B). The distribution patterns of these two species and the diversity indices (figs. 7C and D) indicate the presence of more open sea type environments in the western part of the area studied. In contrast to the tendency in the Gulf of Thailand the

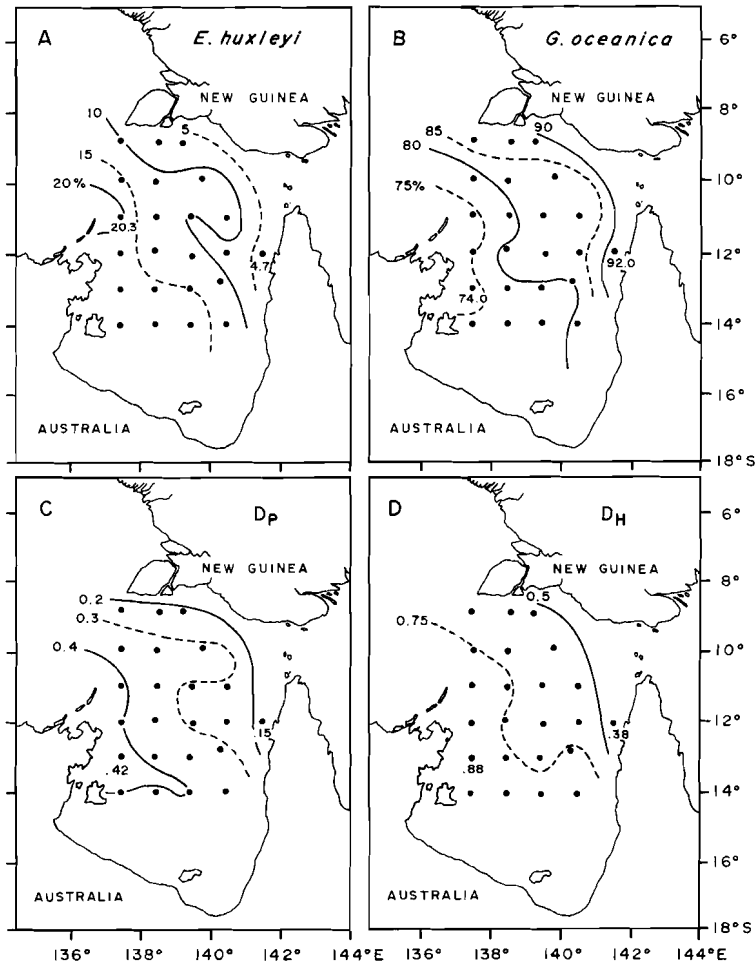


Fig. 7 Distribution patterns of two major species (*Emiliana huxleyi*, *Gephyrocapsa oceanica*) and of the values of two diversity indices in surface sediment samples from the Arafura Sea/Gulf of Carpentaria. Values are presented in the same way as in fig. 6.

contour lines of percentage values and of diversity indices do not run roughly parallel to the coast lines. This difference may be due to the limited fresh-water input into the Gulf of Carpentaria.

Florisphaera profunda is rare in the samples of all stations. In associations from 11 stations in the Gulf of Thailand covering about the same depth-range (49–74 m) as the stations in the Arafura Sea/Gulf of Carpentaria (40–68 m), however, *F. profunda* may reach values of more than 10% of the total associations. This suggests that depth alone does not account for the differences in relative numbers of *F. profunda* between the Gulf of Thailand and the Arafura Sea/Gulf of Carpentaria.

DISCUSSION

Combining all data discussed in the preceding paragraphs, the following conclusions may be drawn concerning the distribution of calcareous nannofossils in surface sediments from low and mid-latitude areas of the western Pacific Ocean:

1. The relative abundance of *Florisphaera profunda* shows a positive correlation with depth in open marine environments ranging from the lower continental shelf to abyssal depths. *F. profunda* dominates the associations in the deep basins.

2. *Gephyrocapsa oceanica* predominates in associations from shallow marginal seas; the species may even monopolize the associations in samples from very shallow and semi-confined seas.

It is attempted to illustrate the relations between species abundances and environmental settings in a triangular co-ordinate diagram. In this diagram *Florisphaera profunda*, *Gephyrocapsa oceanica* and the group of all other species together were chosen as the end members (fig. 8). The diagram illustrates the provincialism of calcareous nannofossils; the composition of the associations in the groups of samples studied reflects the effects of different environmental settings, i.e., marginal sea, open sea, neritic, and open sea bathypelagic to abyssopelagic. Since the numbers of data are limited, however, the "phase boundaries" in figure 8 can only be tentative and need to be reexamined by plotting more data.

The distribution patterns of both *Florisphaera profunda* and *Gephyrocapsa oceanica* are geographically controlled: these species are found in high relative numbers in low to mid-latitude waters and they are not common at high latitudes. Therefore, the diagram can be useful only for warm regions, and the limits of its applicability have to be checked by incorporating data from other seas and oceans.

The values of the two diversity indices calculated for the associations discussed in this paper are independent of the relative frequencies of any particular species. The utilization of these indices as one or two component members of the diagram may widen the applicability of this method for paleoenvironmental analysis.

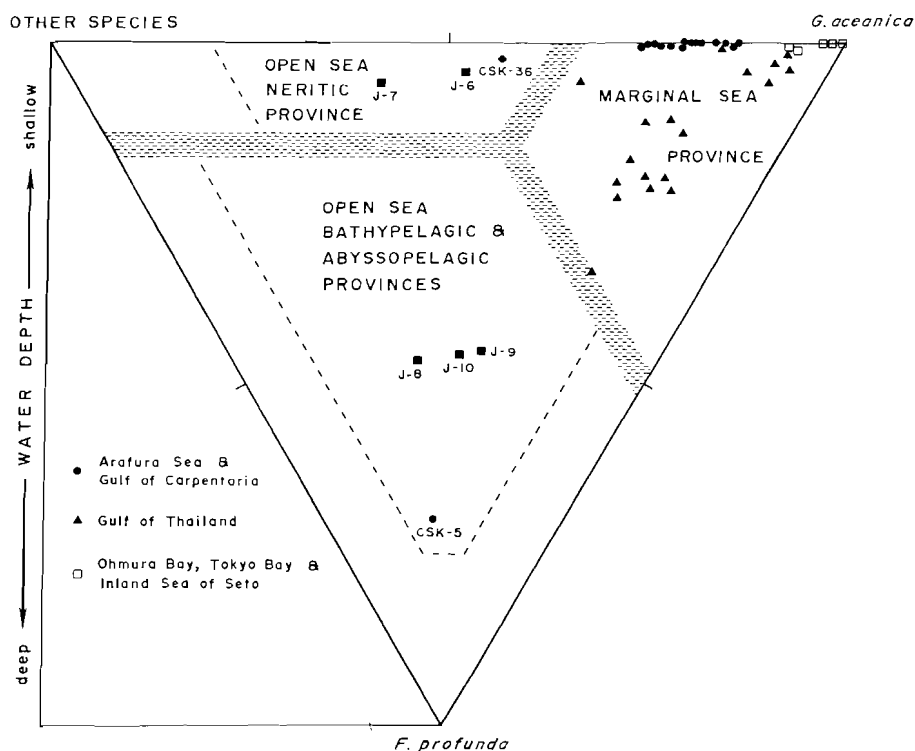


Fig. 8 Triangular co-ordinate diagram showing the relations between species composition of nannoplankton associations in surface sediment samples and depositional environments. Samples are plotted by using percentage values of the total associations for each component.

ACKNOWLEDGEMENTS

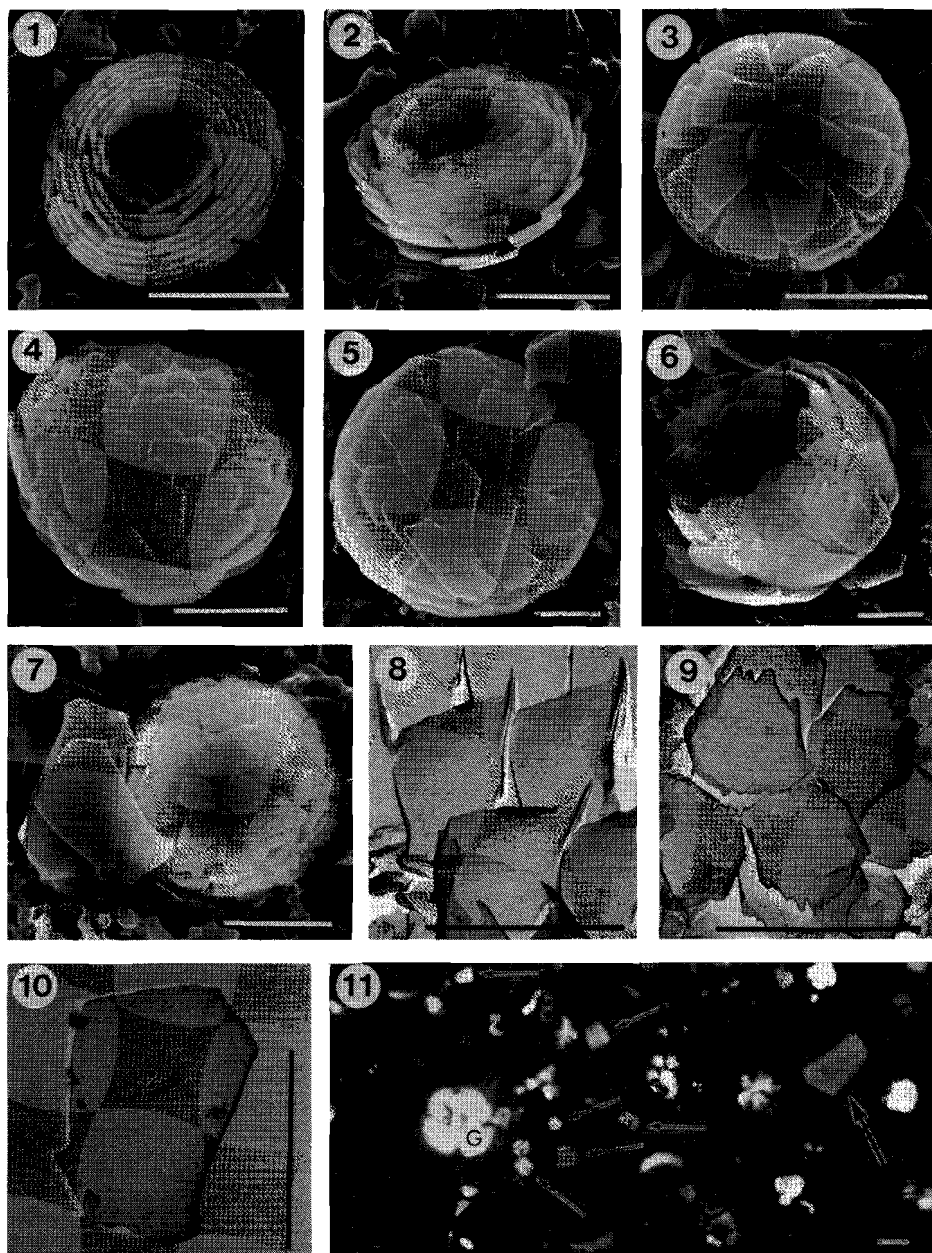
Dr. K. Matsuoka, Nagasaki University, Dr. M. Anraku, Nansei Regional Fisheries Research Laboratory, Dr. M. Okamura, Khochi University and Dr. E. Matsumoto, Geological Survey of Japan, collected samples from the Ohmura Bay and a nearby coastal station (J1 and 6), from the western part of the Inland Sea of Seto (J2 and 3), from the eastern station of the Inland Sea (J4) and from the Tokyo Bay (J5), respectively. Mr. Y. Kinoshita and

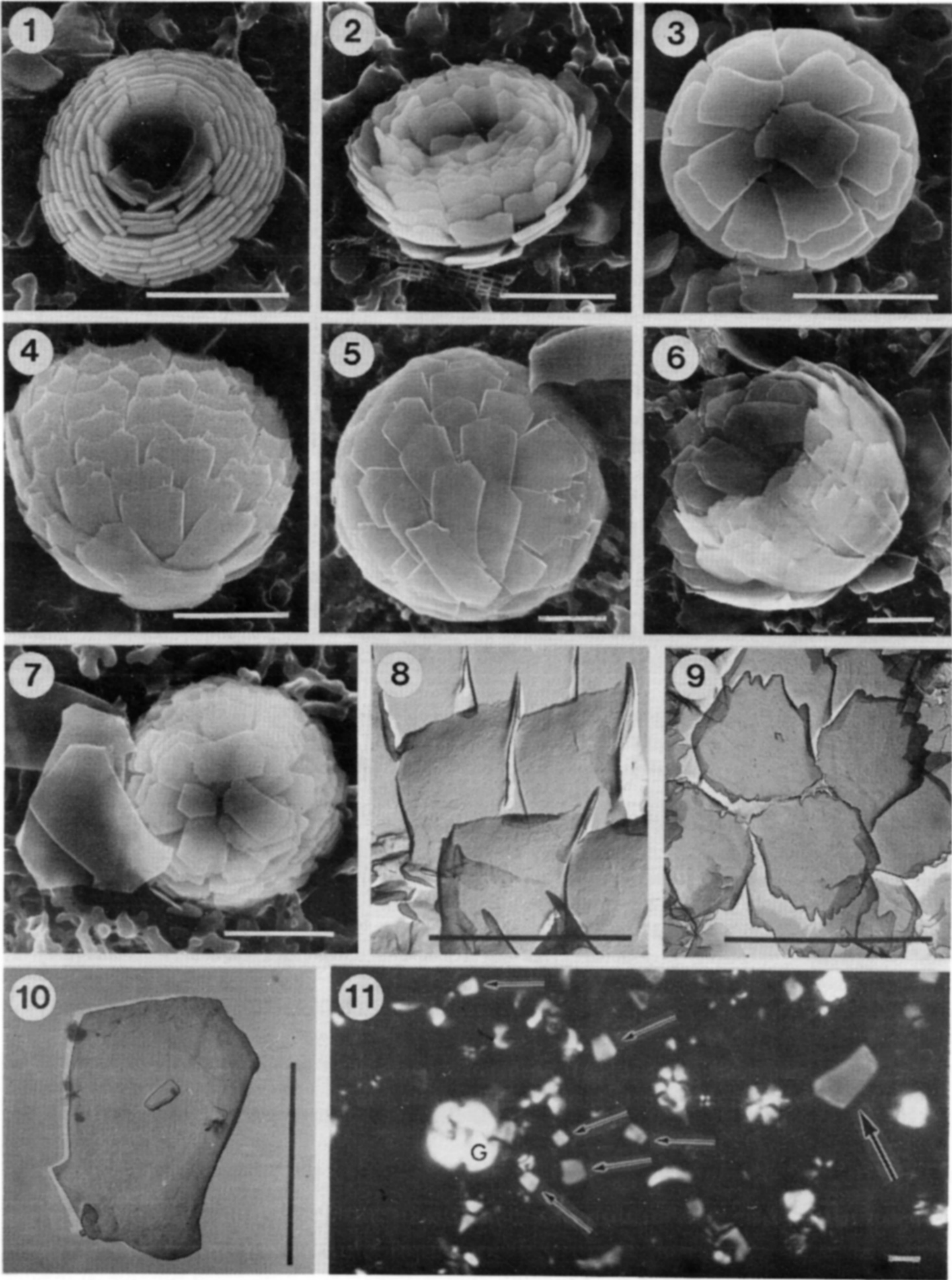
Plate 1

Florisphaera profunda as living coccospheres in plankton samples (figs. 1–9) and as nannofossils in marine sediments (figs. 10, 11). Scale bars = 3 μ m.

- Figs. 1–4 Scanning electron micrographs of *F. profunda* var. *profunda*. 1, top view, 2, oblique top view, 3, bottom view, 4, oblique bottom view. All specimens recovered from the 150 m level of the Equatorial Central Pacific.
- Figs. 5, 6 Scanning electron micrographs of *F. profunda* var. *elongata*. 5, bottom view, 6, oblique top view, Specimens recovered from the 175 m level of the Equatorial Central Pacific.
- Fig. 7 Scanning electron micrograph showing *F. profunda* var. *profunda* (coccosphere) and desintegrated coccoliths of *F. profunda* var. *elongata*. Specimens derived from the same level as those illustrated in figures 1–4.
- Fig. 8 Transmission electron micrograph of unnamed variety of *F. profunda*. Specimen recovered from the 125 m level of the Equatorial Central Pacific.
- Fig. 9 Transmission electron micrograph of unusual *F. profunda* showing zig-zag patterns in its configuration of coccoliths. Specimen recovered from the 125 m level of the Central Red Sea.
- Fig. 10 Transmission electron micrograph showing a small form of *F. profunda* var. *elongata* from the Western North Atlantic (DSDP 386-1-1-130 cm).
- Fig. 11 Light micrograph showing Pleistocene nannofossil association from the Philippine Sea (DSDP 445-1-6-75 cm). Large arrow: *F. profunda* var. *elongata*; small arrows: *F. profunda* var. *elongata*, a coccolith marked "G", and *Gephyrocapsa oceanica*.

Plate 1





Dr. M. Arita of the Geological Survey of Japan, Dr. T. Huang, Kuroshio Research Group, and Dr. S. Yamamoto, Ryukyu University, provided samples from the Sea of Kumano, from offshore Taiwan and from the Gulf of Thailand, respectively. I am truly grateful for their efforts in sampling and for their permission to study the material and to publish the results in this paper.

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