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BIOGEOGRAPHIC CONTROL OF MODERN NANNOFOSSIL ASSEMBLAGES IN SURFACE SEDIMENTS OF ISE BAY, MIKAWA BAY AND KUMANO-NADA, OFF COAST OF CENTRAL JAPAN

CONTENTS

Key words: ascidian spicule, Atsumi Bay, biogeography, calcareous nannofossils, geographical distribution, Ise Bay, Kumano-nada (Sea of Kumano), paleoenvironmental analysis, provincialism, surface sediments.

ABSTRACT

The floral composition of calcareous nannofossils was investigated in the surface sediments of Kumano-nada and two adjacent bays, and environmental control on species distributions were analyzed. Nannoflora in the shallow and eutrophic Ise and Mikawa Bays is almost monopolized by the single species *Gephyrocapsa oceanica*. Malformation were not observed, but abnormal construction of the bridge is a common phenomenon, and 31-73% of the observed *G. oceanica* had no recognizable bridge structure elements. Six subordinate taxa occur in the two bays, although most of these are probably allochthonous specimens brought from the open sea by incoming tidal currents. Twenty-three taxa were recognized in the Kumano-nada flora, dominated by *Florisphaera profunda, Emiliania huxleyi* and *G. oceanica*. The former two are pelagic species, increasing their abundance in proportion to water depth, whereas *G. oceanica* exhibits its preference for neritic environments by reducing its abundance with depth. Among the subordinate taxa, *Calcidiscus leptoporus, Umbellosphaera irregularis, Umbellosphaera tenuis, Umbilicosphaera hulburtiana*, and *Umbilicosphaera sibogae* were recognized as pelagic species, whereas *Braarudosphaera bigelowii, Gephyrocapsa ericsonii, Helicosphaera carteri* and *Helicosphaera pavimentum* are well adapted to the neritic environment. Although observed results are not conclusive, the genus *Syracosphaera* also seems to prefer neritic waters. Plotting the three main components of the flora into a triangular coordinate diagram clarified their boundaries, representing three different environmental settings; confined bays and marginal seas, neritic open ocean, and bathypelagic ocean. Separation of neritic and bathypelagic flora can be identified by the approximately 20% abundance level of *F. profunda*. Many of the Kumano-nada samples yeld aragonite spicules of the shallow-water dwelling ascidian family Didemni-

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dae. This is proof of universal down-slope redeposition, and this type of spicules may be an excellent marker for monitoring sediment movement and paleoenvironmental changes in relatively shallow marine realms.

RIASSUNTO

È stata studiata la composizione delle associazioni a nannofossili calcarei nei sedimenti superficiali del fondo marino di Kumano-nada e di due baie adiacenti ed è stato analizzato il controllo ambientale sulla distribuzione delle specie. La nannoflora delle baie Ise e Mikawa, poco profonde ed eutrofiche, è composta quasi esclusivamente da *Gephyrocapsa oceanica*. Non si sono osservate malformazioni, ma l'anormale costruzione del ponte è un fenomeno comune e 31-73% degli esemplari osservati di *G. oceanica* sono privi di elementi strutturali del ponte riconoscibili. In subordine nelle due baie si trovano altri sei taxa, per quanto molti di essi siano con probabilità esemplari alloctoni portati dal mare aperto dalle correnti di marea. Ventitrè taxa sono stati riconosciuti nella flora di Kumano-nada dominata da *Florisphaera profunda, Emiliania huxleyi* e *Gephyrocapsa oceanica*. Le prime due sono specie pelagiche, la cui abbondanza aumenta proporzionalmente alla profondità dell'acqua, mentre *G. oceanica* manifesta preferenza per gli ambienti neritici diminuendo in abbondanza con la profondità. Fra i taxa in subordine *Calcidiscus leptoporus, Umbellosphaera irregularis, Umbellosphaera tenuis, Umbilicosphaera hulburtiana* e *Umbilicosphaera sibogae* sono state riconosciute come specie pelagiche, mentre *Braarudosphaera bigelowii, Gephyrocapsa ericsonii, Helicosphaera carteri* e *Helicosphaera pavimentum* sono bene adattate all'ambiente neritico. Per quanto i risultati ottenuti non siano conclusivi, anche il genere *Syracosphaera* sembra preferire acque neritiche. I tre maggiori componenti della nannoflora ordinati in base ad un diagramma triangolare evidenziano chiaramente i loro limiti di distribuzione che rappresentano tre situazioni ambientali differenti: baie ristrette e mari marginali, neritico di oceano aperto e oceano batipelagico. La separazione tra flora neritica e batipelagica può approssimativamente corrispondere al livello di abbondanza del 20% di *Florisphaera profunda*. Molti campioni di Kumano-nada contengono spicule aragonitiche di ascidie di acqua bassa appartenenti alla famiglia Didemnidae. Questa è una prova della generale rideposizione lungo la scarpata e questo tipo di spicule può essere un eccellente *marker* per il monitoraggio del movimento dei sedimenti e dei cambi paleoambientali nei domini marini relativamente poco profondi.

INTRODUCTION

The living flora of calcareous nannoplankton in the marginal and inland seas of the North-western Pacific Ocean is mostly dominated by *Gephyrocapsa oceanica* (Okada *et al.*, 1975), the flora of calcareous nannofossils in the surface sediments of two shallow bays and an inland sea of the Japanese islands are monopolized by *G. oceanica* (Okada, 1983). The nannofossil flora in the surface sediments of Asian marginal seas is also dominated by *G. oceanica*, but its degree of dominance is significantly less than the level of monopolization observed in the coastal waters of the Japanese islands (Chen *et al.*, 1982; Wang *et al.*, 1983; Okada, 1983). These observations indicate that environmental stresses occur in calcareous nannoplanktons in restricted coastal waters and in certain marginal seas.

G. oceanica may also dominate the flora in neritic open-sea environment, if living conditions are similar to those of stressed marginal seas. This species, for example, constitutes 68-96% of the flora in the upper continental shelf off the north-western subcontinent of India (Guptha, 1985). Floras of neritic or marginal seas should become much closer to that of open oceans, if the influence of ocean currents is pronounced. A preliminary study of nannofossil flora in the shallow part of the Kumano-nada (Sea of Kumano), a neritic open sea strongly influenced by the warm ocean current Kuroshio, revealed a flora similar to that of the neighboring bathypelagic samples, except for the significant sparseness of *Florisphaera profunda* (Okada, 1983). Actually, the percentage abundance of *F. profunda* increases proportionally to water depth, particularly at the upper continental shelf, and this species becomes a dominant element of nannoflora in pelagic situations. Subsequent use of these data, in paleoenvironmental analysis of a core drilled off north-east Japan, yielded consistent results with paleodepth changes inferred from benthic foraminifera (Takayanagi *et al.*).

In my previous work (Okada, 1983), the depth-abundance relationship in the Kumano-nada was studied only for *F. profunda*, and similar investigation have not yet been carried out for other species. Although Nishida *et al.* (1974) reported a list of species found in the surface sediments of the Kumano-nada and its adjacent basins, there were no quantitative data to discuss environmental control on nannoflora. Actually, the kind of quantitative data presented here, specifically dealt with provincialism in neritic modern nannoflora, have never been published for any part of world oceans. The purpose of the present investigation was to study geographic control on floral assemblage of calcareous nannofossils in the surface sediments of the Kumano-nada and

adjacent Ise and Mikawa Bays to provide basic data for paleoenvironmental analysis. The Kumanonada is a open sea lying off the east of the Kii Peninsula. Its bottom topography consists of a narrow continental shelf and a continental slope (average gradient 3.8°), surrounding a trough with a fairly flat bottom at a depth of around 2000 m (Fig. 1). The average water depths of Ise and Mikawa Bays are 19.5 m and 9.2 m, respectively. Information on environmental control for distribution of nannoplankton species within such close but completely different environments are essential for a reconstruction of the Quaternary neritic paleoenvironment.

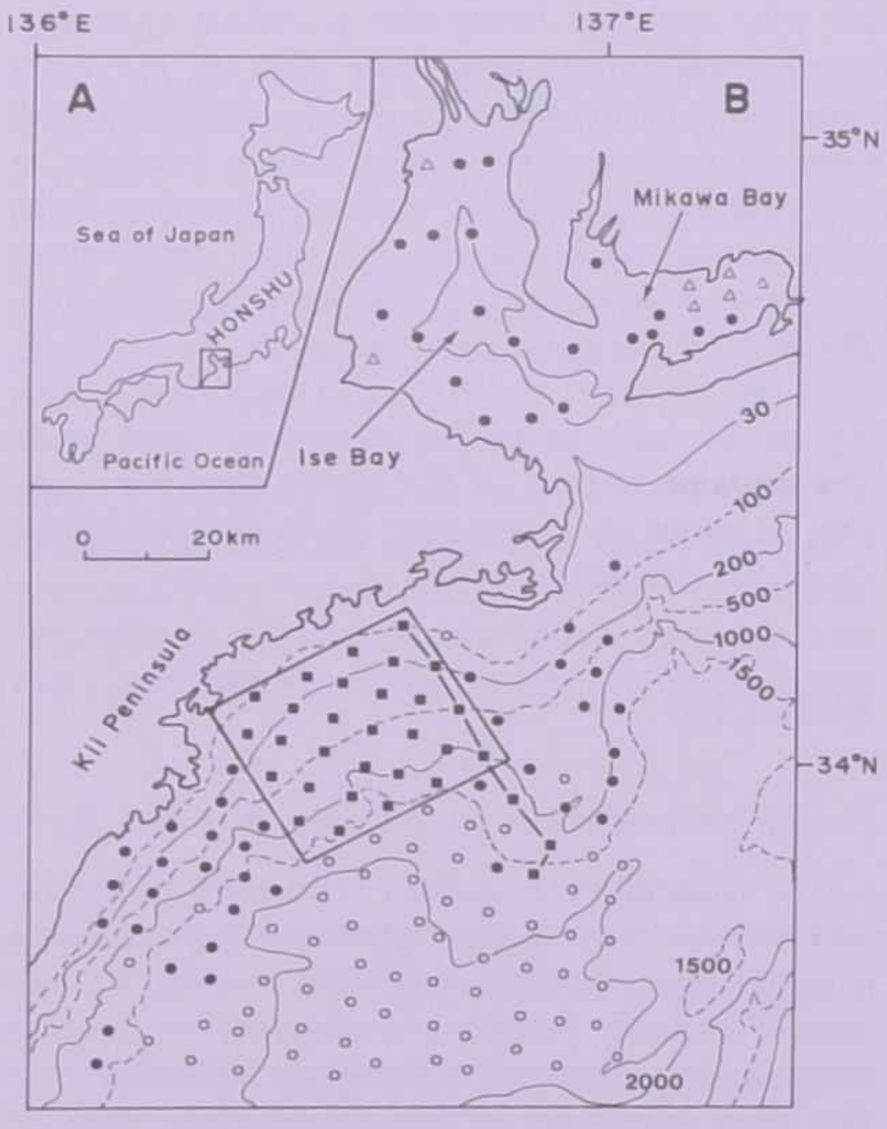

FIG. 1 - General location of the studied area (A), and sampling localities in the Ise Bay, Mikawa Bay, and Kumano-nada (B). Water depth is in meters. Solid circles and solid squares represent studied samples, and the latter identifies selected samples collected from Area A (enclosed by the square) and along the traverse, which were studied for geographical distribution of the minor species. Open triangles indicate samples which were not studied due to the very scarce occurrence of nannofossils, whereas open circles represent samples excluded from the prevent investigation because of frequent occurrence of reworked fossils.

SAMPLES AND METHODS

SAMPLES

Ise and Mikawa Bays - A total of 27 surface sediment samples were collected on board the "Seisui-maru" of Mie University from Ise and Mikawa Bays (Fig. 1). These samples were obtained using a Smith-McIntyre sampler, from water depths between 8 and 51 m. A shore-based study revealed that seven of these samples, collected from shallower depths (8-17 m), yielded no or very rare nannofossils. Consequently, the nannoflora of the remaining 20 samples was investigated (Fig. 1).

Kumano-nada - 129 surface sediment samples from the Kumano-nada were collected by the Geological Survey of Japan on board the "Hakurei-Maru" using a Smith-MacIntyre sampler (Fig. 1). The depth-abundance relationship of *Florisphaera profunda* reported in my previous work (OKADA, 1983) was based upon the entire set of 129 samples. A subsequent investigation, however, revealed that many of these samples contain extinct nannofossils such as *Pseudoemiliania lacunosa* or the early Pleistocene forms of *Gephyrocapsa oceanica*. Local erosion or downward movement of shallower sediments may be causes. Extinct coccoliths are abundant, particularly in the deep samples collected from the trough floor. As will be discussed later, ascidian spicules of shallow-water origin were also detected in many of the studied samples. These observations support the redeposition of shallower materials as the true cause for the presence of extinct species.

Due to the exposure of a hard basement, no samples were obtained from the ridge of a spur extending south-east of the north-eastern corner of the trough (Fig. 1). For the two samples collected from the side slope of this spur, local erosion is probably more significant for the occurrence of old fossils. Coccoliths found in these two samples are moderately overgrown, a feature not observed in other samples. Of the 129 samples examined, 68 contain no or a significantly small number of extinct fossils; the nannoflora composition was investigated exclusively for these samples. Since most of the remaining 61 contaminated samples were collected from the deep portion of the sea-floor, with an average water depth of 2000 m, this exclusion does not significantly change the depth-abundance relationship of *F. profunda*, previously reported in OKADA (1983).

Preparation and observation

Samples were prepared to make smear slides, and the flora of calcareous nannofossils were observed under a high-power polarizing microscope equipped for phase contrast. Several samples selected from the two bays and various portions of the Kumano-nada were also examined under a transmission electron miscroscope to check the reliability of taxonomic identification.

Counting procedures

As the Quaternary flora of calcareous nannofossils are dominated by few species, especially in the shallow bays or marginal seas of the Pacific and Indian Oceans (*e.g.* Winter, 1982; Okada, 1983; Gupta, 1985), a stepwise counting method is more suitable than single counting of total flora (*e.g.* Chen *et al.*, 1982; Biekart, 1989). The flora of the studied samples is actually dominated by three species, and four different procedures of counting were employed for this investigation. Most of the specimens counted here were identified to a species level. However, for members of *Acanthoica* and *Syracosphaera*, the limited resolution of the light miscroscope prevents detailed taxonomic diagnosis. Although taxonomic identification was possible at a variety level for several species, separate plots of data did not produce significant results; consequently, no taxa are treated at an intraspecific level in this report.

Except for special counting of *Gephyrocapsa ericsonii* (see later), nannofossils smaller than 2.5 μm length were disregarded. The only exception to this general rule was the inclusion of small *F. profunda*, smaller than 2.5 μm but easily identifiable under light microscopy.

Redeposited specimens of old taxa, generally constituting less than a few percent of the total flora, were also excluded from counting. Besides the two already mentioned Pleistocene taxa, rare specimens of Pliocene Discoasters such as *Discoaster brouweri* and *Discoaster pentaradiatus* were recognized in some samples.

Procedure 1) - The 300 specimens first encountered for each sample were identified, and their numbers were recorded to calculate the percent abundance for each taxa. This counting, which aimed at identifying the floral characters in the triangular coordinate diagram proposed by Okada (1983), was conducted for all samples examined throughout this investigation.

Procedure 2) - Because *F. profunda* is so abundant in the deeper samples from the Kumano-nada, it was excluded in the second counting. A total of 1000 specimens exclusive of *F. profunda* were identified and tallied to calculate percent abundances. This procedure was performed for all samples from the Kumano-nada.

Procedure 3) - Besides *F. profunda*, the nannoflora of the Kumano-nada is also dominated by two other species; *Emiliania huxleyi* and *Gephyrocapsa oceanica*, and even procedure 2 was not sufficient to study the detailed biogeographic trend for the minor species. A third counting procedure was therefore conducted for a subset of 28 samples collected from a small area with a relatively smooth bottom topography (Area A), to investigate the detailed distributional trends for the subordinate species (Fig. 1). In this procedure, a total of 200 specimens exclusive of *E. huxleyi, F. profunda* and *G. oceanica* were recorded.

Procedure 4) - Another subset of seven samples lining a depth transect was selected to investigate the depth-abundance relationship for the subordinate species (Fig. 1). Small coccoliths (< 2.5 μm) excluded from the previous counting, generally constitute less than 10% of the total nannoflora, except for *F. profunda*. Although very small in overall size, *Gephyrocapsa ericsonii* is relatively easy to identify under high-power light microscopy, and its depth-controlled distribution had been noticed during the previous counting. The special counting rule employed here, therefore, was to count the first 200 coccoliths, inclusive of *G. ericsonii* but exclusive of other small coccoliths as well as of the three dominant species, in order to investigate flora changes along the depth transect.

RESULTS

Floral distribution in Ise and Mikawa Bays

The nannoflora in surface sediments of the Ise and Mikawa Bays is dominated by *Gephyrocapsa oceanica* and elliptical coccoliths having a large central opening. Subsequent observation under a transmission electron microscope revealed that the latter forms are in fact *G. oceanica* with no bridge structure. Some *G. oceanica* with bridge elements also reveal abnormal bridge construction; *e.g.*, bridge elements are very short, one is missing, more than two elements are placed separately or fused together, and/or they project in unusual ways. This type of abnormal *G. oceanica* occupies 10-20% of the *G. oceanica* population with any form of bridge. Abnormal *G. oceanica* with no bridge elements constitute 31-73% of the total flora, and the combined count of all *G. oceanica* monopolizes the flora in most of the exam-

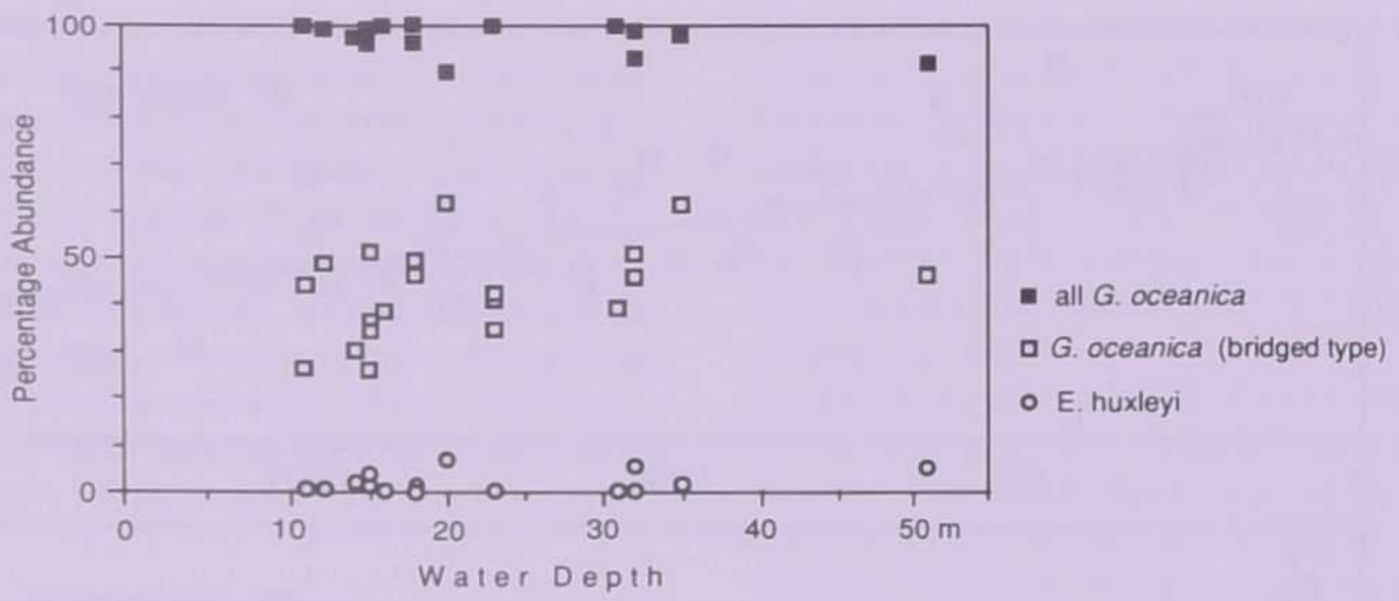

FIG. 2 - Relations between percent abundances of the two most abundant species and water depth in Ise and Mikawa Bays. Open squares indicate abundance of *Gephyrocaspa oceanica* that has any forms of bridges, and solid squares represent total abundances of the species including specimens without bridge. The data was obtained by the counting procedure 1.

ined samples (Fig. 2). The type of malformations seen in the living community of the East China Sea and in the tropical marginal seas of Southeast Asia (OKADA *et al.*, 1975) were not observed in a few samples examined under the electron miscroscope, and the construction of both shields were normal, even for the abnormal specimens with no or abnormal bridges.

The second most frequent species, *Emiliania huxleyi*, occupies several percent of the flora at maximum, and the other five subordinate taxa observed here, *Calcidiscus leptoporus, Florisphaera profunda, Helicosphaera carteri, Syracosphaera* spp., and *Umbilicosphaera sibogae*, each represent less than 1% of the flora. Occurrences of *E. huxleyi* and these subordinate species show no relationship with water depth (see Fig. 2 for the case of *E. huxleyi*). *E. huxleyi* and *F. profunda* are more common in entrance areas than in the inner parts of the bays (Fig. 3). Due to their great scarcity, distributional trends are not clear for the other four subordinate species. This observation suggests that the five subordinate species are not remnants of indigenous living nannoplanktons but allochthonous coccoliths brought from the Kumano-nada by incoming tidal currents. The same may also be true of *E. huxleyi*, although some of them may be autochthonous.

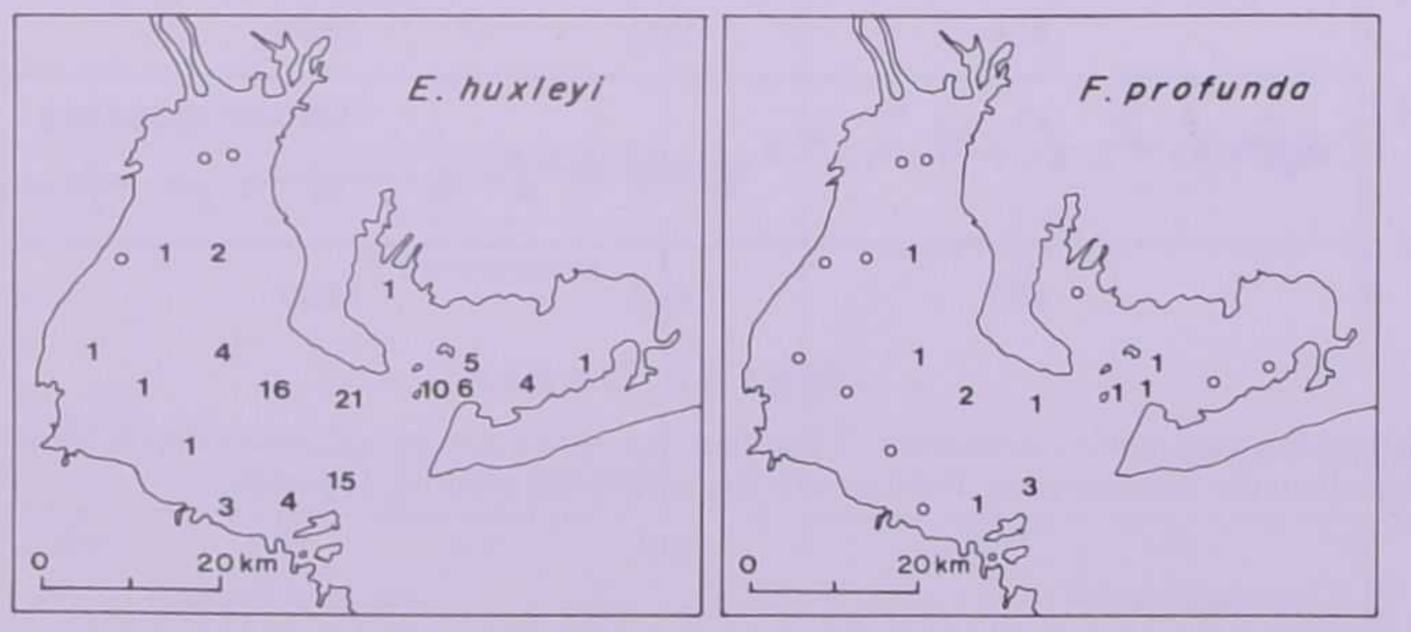

FIG. 3 - Distributions of *Emiliania huxleyi* and *Florisphaera profunda* in Ise and Mikawa Bays. Numbers indicate individual abundances of the specimens observed during the countings of 300 nannofossils.

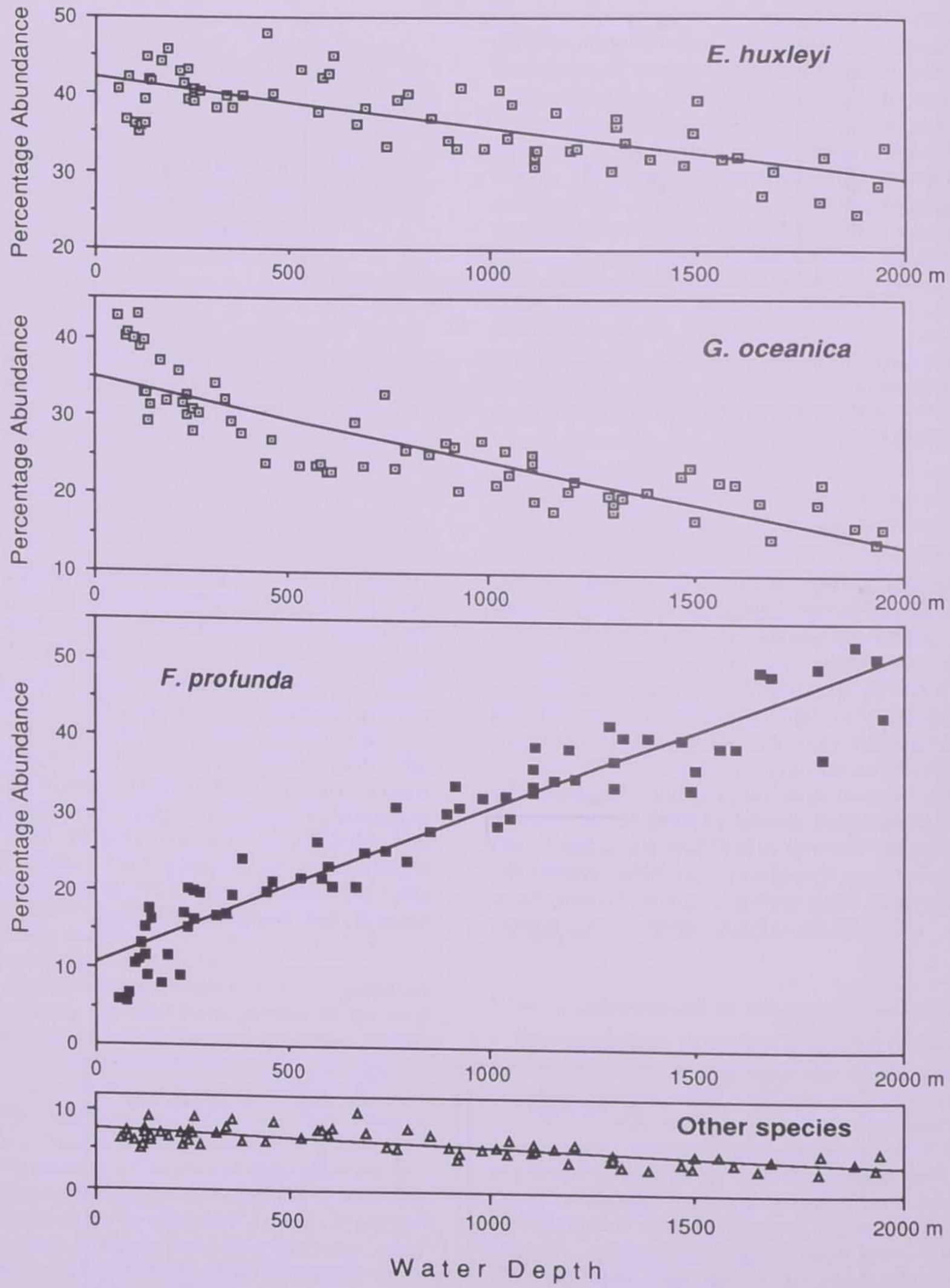

FIG. 4 - Relations between percent abundances of the four taxonomic groups and water depth observed in all the studied samples from the Kumano-nada. The data was obtained by the counting procedure 1.

Although they were not counted, a small number of typical *Gephyrocapsa ericsonii* were observed in the three samples collected from the entrance of bays. Unlike the flora of open oceans, in which the size ranges of *G. oceanica* and *G. ericsonii* are clearly separated, some specimens of *G. oceanica* were very small, and identification of *G. ericsonii* from *G. oceanica* became difficult in the samples from the two bays. Other small nannofossils (< 2.5 μm) not counted here, are scarce in these bays.

Floral distribution in the Kumano-nada

Distribution of Major Species

The nannoflora in the surface sediments of the Kumano-nada is dominated by three species, *Florisphaera profunda, Gephyrocapsa oceanica* and *Emiliania huxleyi*; all other species combined represent less than 10% of total flora (Fig. 4). The new depth-abundance plot of *F. profunda* studied for the selected 68 samples (Fig. 4) shows much less scattered distribution than that reported previously, in which data from 61 contaminated samples were also included (Okada, 1983, Fig. 4). In the new plot, *F. profunda* increases proportionally with water depth, and the positive gradient is much steeper at the continental shelf (Fig. 4). Although the trend is not so proportional to water depth, the two other major species, *E. huxleyi* and *G. oceanica*, show the opposite pattern; the steep negative gradient at the shelf is especially notable for *G. oceanica*. (Fig. 4).

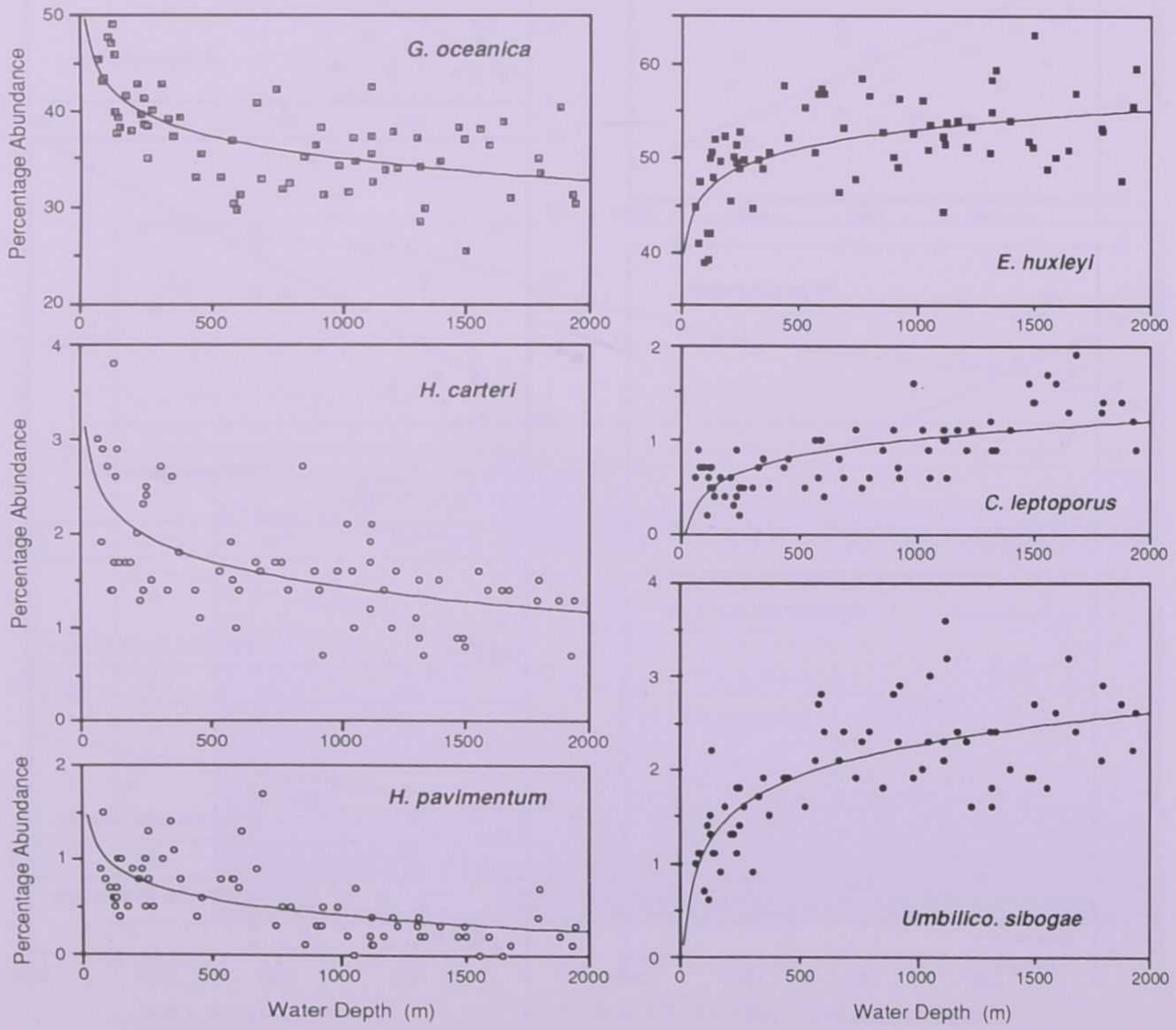

Fig. 5 - Relations between percent abundances of the six most abundant species and water depth observed in all the studied samples from the Kumano-nada. The data was obtained by the counting procedure 2.

Plots of the data obtained during the second counting procedure reveal depth-controlled distribution for six species (Fig. 5). As observed in the first counting, *G. oceanica* is generally less abundant in deeper samples, although some of the plotted points are quite far from the coordinate curve. Two subordinate species, *Helicosphaera carteri* and *Helicosphaera pavimentum*, also show similar trends to that of *G. oceanica* (Fig. 5). *E. huxleyi*, which had shown a decreasing trend in the first counting, exhibits the opposite tendency in this second counting. The discrepancy is obviously due to the very high abundance of *F. profunda,* which is strongly related to water depth, in the first counting. *Calcidiscus leptoporus* and *Umbilicosphaera sibogae* also show similar increasing trends (Fig. 5).

Distribution of Subordinate Species in the Selected Area

Counting of the selected 28 samples by proce-

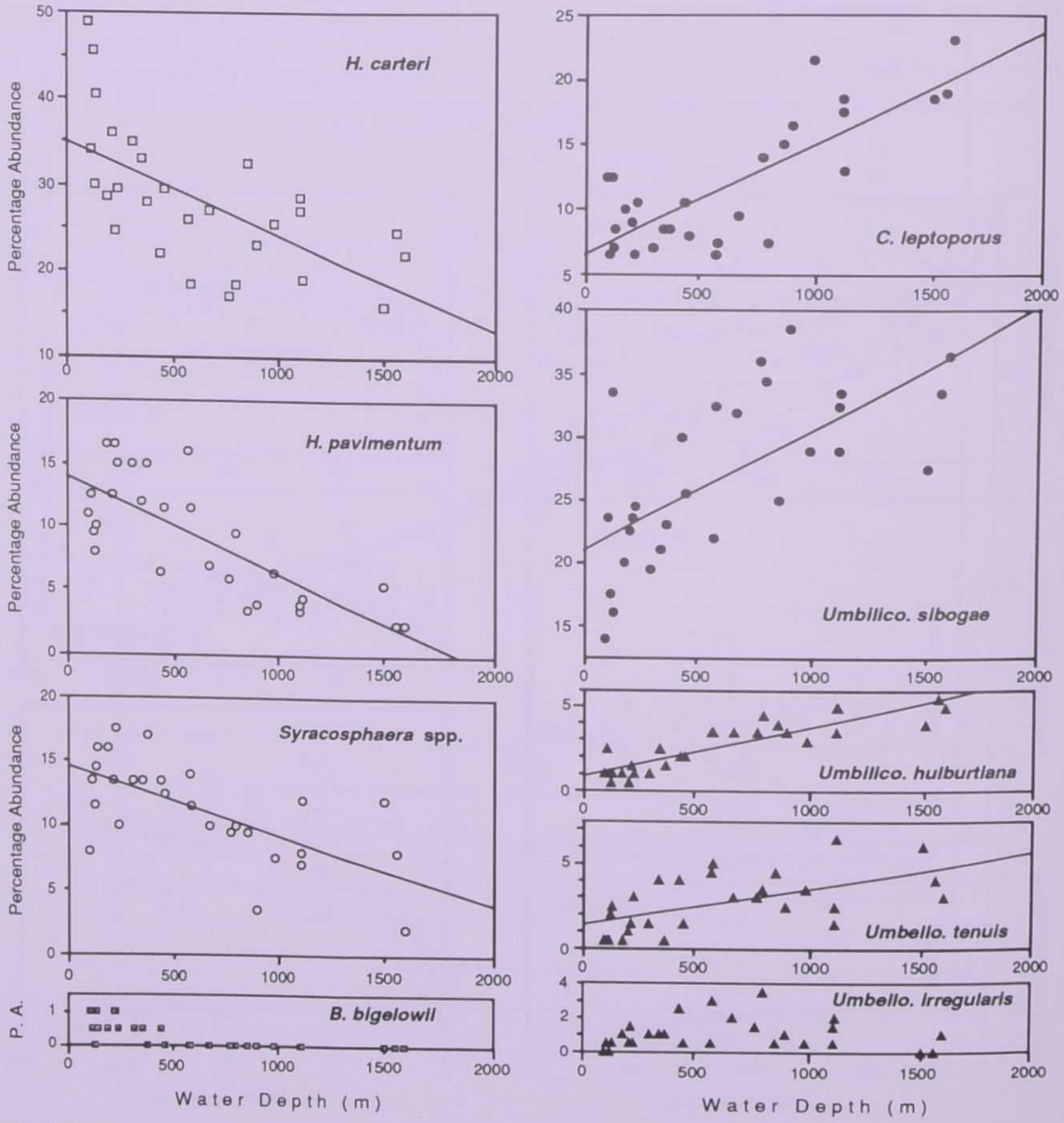

FIG. 6 - Relations between percent abundances of nine subordinate taxa and water depth observed in the Area A. The data was obtained by the counting procedure 3.

dure 3 revealed depth-controlled distributions for nine subordinate species (Fig. 6). In addition to the two *Helicosphaera* species, *Syracosphaera* spp. also exhibits a reducing trend in the deeper samples. The rare specimens of *Braarudosphaera bigelowii* occur exclusively in the shallower samples. Although the plots are scattered, *C. leptoporus* and *U. sibogae* show positive increases with water depth, and the trends are the same for *Umbilicosphaera hulburtiana* and *Umbellosphaera tenuis* (Fig. 6). *Umbellosphaera irregularis*, being less common than the related *U. tenuis*, also increases its abundance in upper slope samples, but becomes less abundant in lower slope samples. The coccolith of this species is very fragile, and the observed reduction in deeper samples is probably due to disintegration caused by advanced dissolution.

Distribution of Subordinate Species along the Depth Transect

Investigation of subordinate species by the fourth counting procedure along the depth transect confirms the trends observed in the previous counting (Fig. 7). In addition to *H. carteri* and *H. pavimentum*, *Gephyrocapsa ericsonii*, counted for the first time here, shows a clear decreasing trend with water depth. The pattern for *Syracosphaera* spp., which showed a decreasing trend in the previous counting (Fig. 6), is not so clear along this transect (Fig. 7). *C. leptoporus*, *Umbilicosphaera hulburtiana* and *Umbilicosphaera sibogae* are more abundant in deeper samples. Two species of *Umbellosphaera*, *U. irregularis* and *U. tenuis*, also exhibit increasing trends. Due to their relatively few occurrences, the abundance distributions for these two species are combined in figure 7.

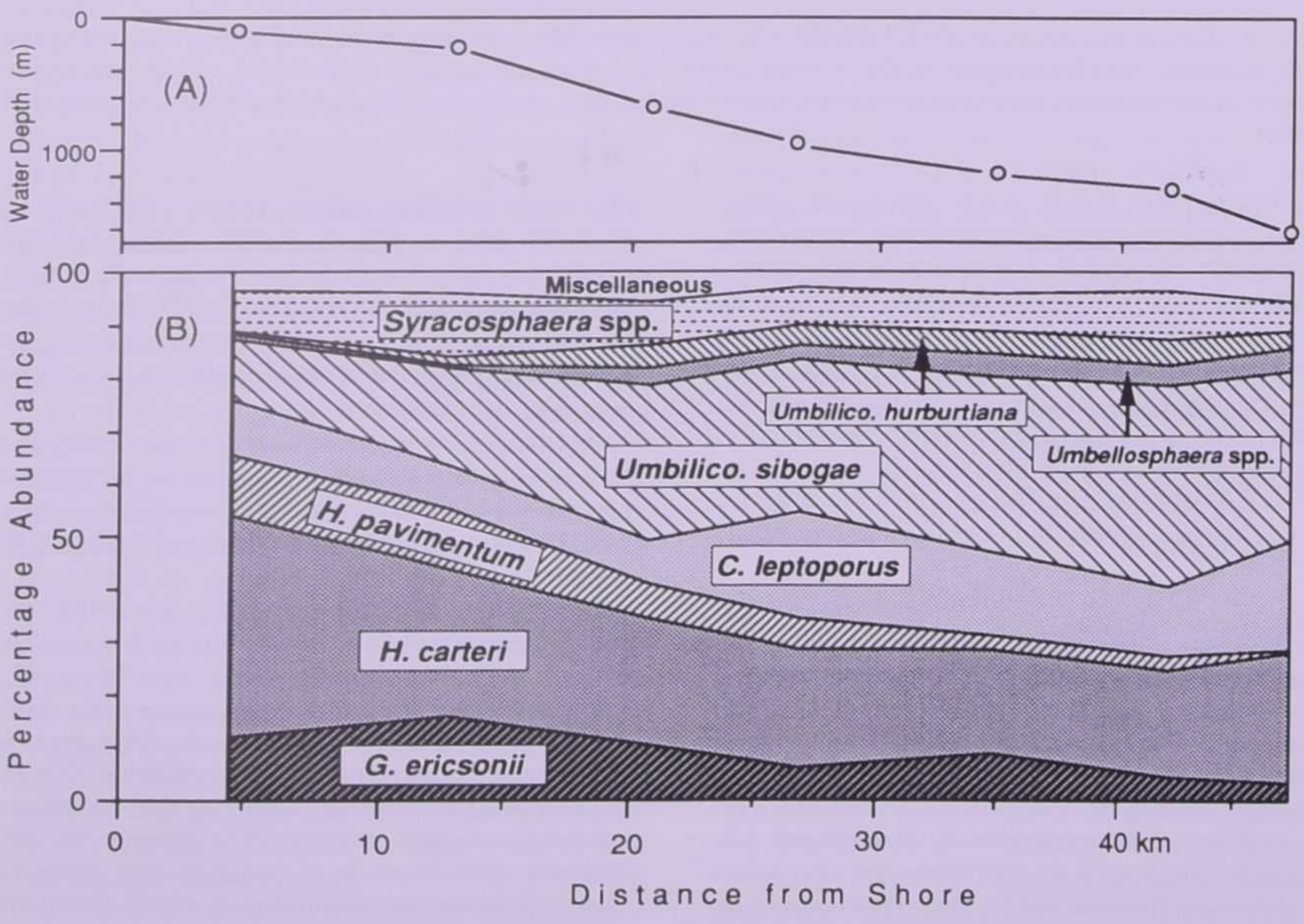

FIG. 7 - Bottom profile (A), and floral distribution of the subordinate taxa (B) along the depth transect. The data was obtained by the counting procedure 4.

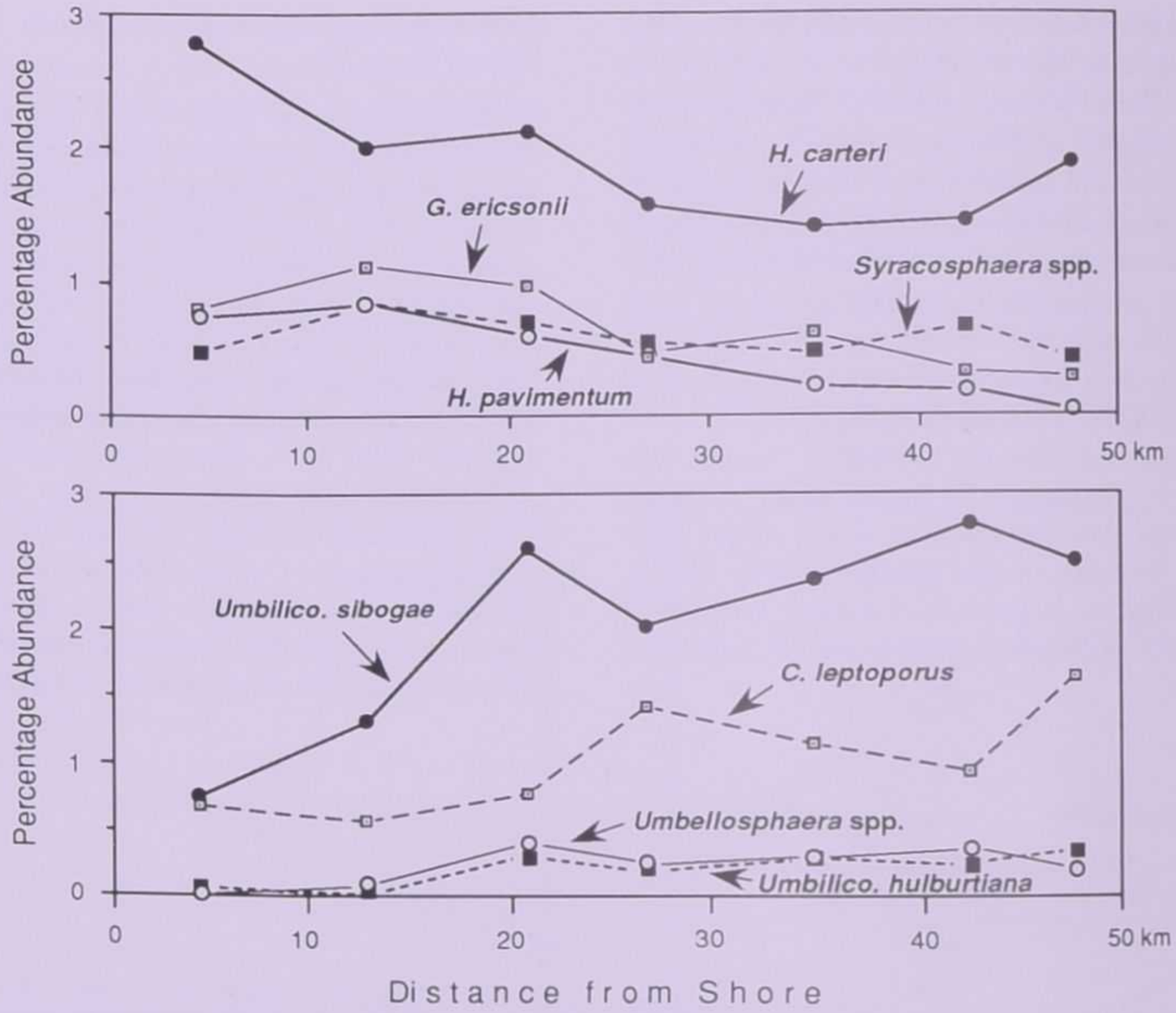

FIG. 8 - Percent abundances of the subordinate taxa within total flora excluding *Florisphaera profunda* along the depth transect. Results obtained by the counting procedure 4 were incorporated to the total abundances of the subordinate taxa which were obtained by the counting procedure 2, to calculate the percent abundances presented here.

Percent occurrences of the subordinate species in the total nannoflora, exclusive of *Florisphaera profunda*, also agree with the results observed for the relative abundances of subordinate species (Figs. 7 and 8). Thus, the exclusive count of subordinate species proves to be a reliable time-saving method for biogeographic studies and paleoenvironmental analysis.

DISCUSSION

TAXONOMIC REMARKS

The principal aim of this investigation was to obtain basic data for future analysis of the Quaternary paleoenvironment; emphasis was placed on relatively large species easily identifiable under a light microscope. Except for *Gephyrocapsa ericsonii* and small specimens of *Florisphaera profunda*, small nannofossils were not counted in this study. BIEKART (1989) reported common occurrences of small placoliths such as *Reticulofenestra minuta* and *Reticulofenestra parvula* from the south-east Indonesian basins. Although it generally occupies less than 10% of the total flora, the percent abundance of small nannofossils, disregarded in this study, reaches 30% in some samples. An attempt to identify these small neglected specimens will no doubt increase the length of the taxonomic list.

A total of twenty-three taxa were identified during this investigation. The actual method of species identification for some confusing cases, and the taxonomic concept employed here, are as follows:

1) Elliptical placoliths showing the typical extinction pattern of *G. oceanica* but with no visible bridges were counted separately, and were only later included in the counting of *G. oceanica*. This type of abnormal *G. oceanica* is very abundant in the Ise and Atsumi Bays (maximum value 73% of *G. oceanica* population), whereas the maximum abundance is less than a few percent in the Kumano-nada flora. It is possible that some of these specimens are normal ones which lost their bridges during post-mortem transportation and /or the preparation of smear slides.

2) For *Calcidiscus leptoporus* and *Umbilicosphaera sibogae*, only the proximal shields, which are brighter than the distal shields and show characteristic extinction patterns, were counted.

3) Because of the difficulty of species identification, all caneoliths were grouped together as *Syracosphaera* spp. Although some characteristic species such as *Syracosphaera pulchra* or *Syracosphaera lamina* were identifiable by light microscopy, the relatively rare occurrences of these species discouraged separate counting.

4) For *Rhabdosphaera clavigera* and *Acanthoica* spp., ordinary coccoliths are not identifiable by light microscopy, and consequently only those with a central process were counted.

5) In the workshop held during the Florence meeting of INA, the exclusive use of variety was proposed for the intraspecific level of ranking, and some former species were reclassified to varieties. (JORDAN *et al.*, 1990). Thus, the living members of the genus *Helicosphaera* now count only two species, *Helicosphaera carteri* and *Helicosphaera pavimentum*, and the former contains three varieties, var. *carteri*, var. *hyalina* and var. *wallichii*. *H. pavimentum* is easy to identify under a polarizing light microscope, because it is much smaller and appears much darker than the three varieties of *H. carteri*. The separate count of the three varieties of *H. carteri* did not exhibit significantly different tendencies from those presented as *H. carteri* alone (Figs. 5-8).

6) Very rare *Coccolithus pelagicus* observed in some Kumano-nada samples may be allochthonous. However, because of the current lack of convincing data indicating its presence in the living community of the studied area, these specimens were considered as reworked fossils.

7) *Dictyococcites productus* and an extant taxa *Reticulofenestra parvula* var. *tecticentrum* are morphologically very similar to each other. The maximum coccolith size of *D. productus* is defined as 4 μm, and the smallest size for Pliocene specimens is approximately 2.6 μm (BACKMAN, 1980). Instead, the size of *R. parvula* var. *tecticentrum* ranges between 1.6 and 2.0 μm (OKADA *et al.*, 1977). These two taxa should be treated as the same species if there is no possible separation in coccolith size. However, the living specimens of *D. productus*, have never been reported. Because of the present lack of convincing evidence that *D. productus* is alive in present-day oceans, the fairly common specimens of *D. productus* were excluded from counting. Occasional specimens of *Dictyococcites antarcticus* were regarded as reworked fossils.

ENVIRONMENTAL CONTROL ON NANNOFLORA

Cause of low diversity in neritic waters

Low salinity is probably one of the main reasons for the almost complete monopoly of the flora by *G. oceanica*. Salinity is generally slightly lower in Mikawa Bay than in the oceanic waters, ranging between 28 and 33 per mill (TANAKA *et al.*, 1988). In Ise Bay, into the northern end of which three large rivers flow, the salinity change is more pronounced, dropping to less than one-third of the normal seawater level during the rainy season (AKATSUKA *et al.*, 1960). *G. oceanica* undoubtedly has a close phylogenic relationship to *Emiliania huxleyi*, yet their abilities to withstand the stressed environment of shallow coastal and bay waters differ significantly. Contrary to the fairly common cultural studies on *E. huxleyi* (*e.g.* WILBUR *et al.*, 1963; KLAVENESS, 1972), no published reports deal with the physiology of *G. oceanica*. Future cultural experiments on *G. oceanica* will clarify some of the mystery surrounding the causes of the monopolized flora, abnormal bridge construction, and malformations.

Identification of Flora Characteristic for Each Marine Environment

OKADA (1983) proposed a new analytical method for the environmental characters of recent nannofossil flora by plotting the three floral components into a triangular co-ordinate diagram. Data plots, obtained by the first procedure used here reconfirmed the previous definition of provincialism in nannofossil flora (Fig. 9). While nannofloras observed in the two bays are clustered at the extreme end of the marginal sea zone, the shelf and slope floras of the Kumano-nada are separated by the 20% abundance line of *F. profunda*. (Fig. 9). This result may be directly applicable to nannofossil flora, and plotting Quaternary flora into this diagram will be useful in reconstructing the neritic paleoenvironment.

Provincialism in Distribution of Species

As discussed earlier, *G. oceanica* is well-known for its hardiness in shallow bays and coastal waters, and *Florisphaera profunda* is known to increase its abundance proportionally to water depth in bathypelagic realms. The preferential occurrence of *Braarudosphaera bigelowii* in shallow bays and continental shelves is also well documented (MARTINI, 1967; BUKRY *et al.*, 1971; TAKAYAMA, 1972). The present investigation reconfirmed provincialism for distribution of these three species and revealed the geographic prefer-

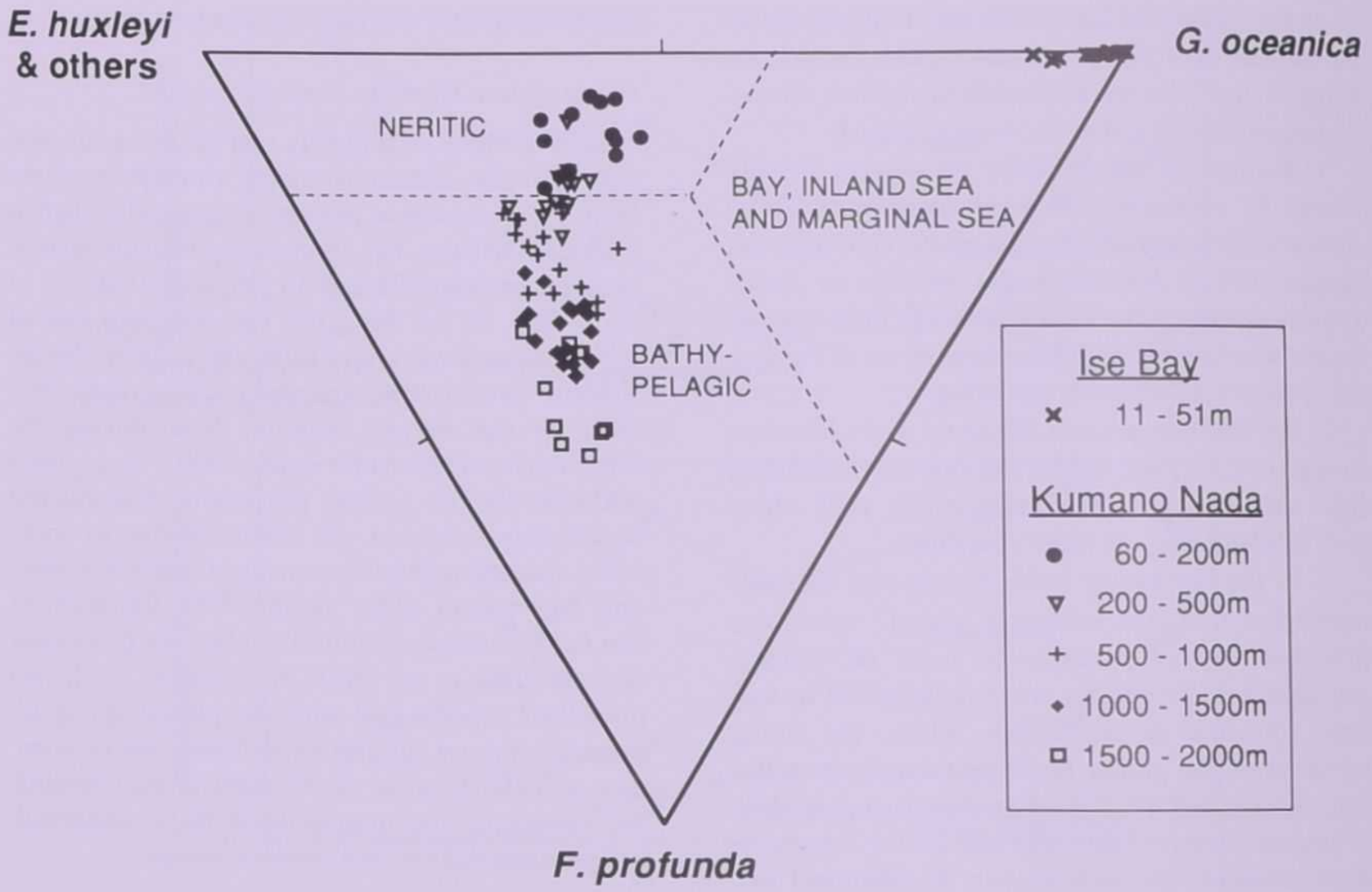

FIG. 9 - Triangular co-ordinate diagram showing the relations between species composition of nannofossil associations in surface sediment samples and depositional environments. Samples are plotted by using percent values of the total association for each component which were obtained by the counting procedure 1.

ences for ten other taxa (Tab. 1). *Syracosphaera* spp. showed its preference for a neritic environment within Area A (Fig. 6), but the trend is ambiguous along the depth transect (Figs. 7 and 8). The inclusion of all caneoliths into a single taxonomic group is probably the main reason for this ambiguity. Separate counting of *Syracosphaera* at species level may provide useful data for paleoenvironmental analysis, but the counting procedure that has to be performed under the electron microscope is impractical for most future investigations.

Occurrence of malformations and other abnormalities

Besides the almost complete monopolization of flora by *G. oceanica*, frequent malformations are also commonly found in the living community of nannoplanktons in the marginal seas of Southeast Asia at subtropical and tropical latitudes (OKADA *et al.*, 1975; HONJO, 1977). However, malformations are not significant features in the surface sediment flora of the East China Sea, and the sparseness of malformed coccoliths has been attributed to either 1) seasonal and/or local occurrence of malformations, or 2) rapid postmortem dissolution of malformed coccoliths (WANG *et al.*, 1983). These are reasonable assumptions, and I am in perfect agreement with their conclusion. The main malformation discussed here involves the construction of the basic structure of coccoliths such as discs or central tubes, and malformed coccoliths probably disintegrate quickly on the sea floor. The cause of malformation is probably a deficiency of certain nutrients (OKADA *et al.*, 1975), and occurs only in a particular oligotrophic condition which seems to appear seasonally in certain parts of the marginal seas of South-east Asia.

The cause of malformation is not related to the neritic character which inhibits the growth of nannoplankton species other than *G. oceanica*. The living flora of the Inland Sea of Seto, for example, is dominated by *G. oceanica*, yet malformed specimens are scarce (OKADA *et al.*, 1975). Therefore, the observed absence of malformation in the Ise and Mikawa Bay specimens is no surprise. These bays are highly eutrophic, and the

TABLE 1 - Nannofossil taxa identified to exhibit provincialism, and a complete list of observed rare taxa whose preferences of environment are not clear

Species fitted for shallow embayment	Species preferring neritic environment	Species preferring pelagic environment
	Braarudosphaera bigelowii	*Calcidiscus leptoporus*
	Gephyrocapsa oceanica	*Emiliania huxleyi*
	Gephyrocapsa ericsonii	*Florisphaera profunda*
Gephyrocapsa oceanica	*Helicosphaera carteri*	*Umbellosphaera irregularis*
	Helicosphaera pavimentum	*Umbellosphaera tenuis*
	Syracosphaera spp.	*Umbilicosphaera hulburtiana*
		Umbilicosphaera sibogae
Rare Species whose environmental preferences are not clear		
Acanthoica spp.	*Discosphaera tubifera*	*Pontosphaera japonica*
Calciosolenia murrayi	*Hayaster perplexus*	*Pontosphaera* sp.
Ceratolithus cristatus	*Neosphaera coccolithomorpha*	*Rhabdospaera clavigera*
Cricosphaera quadrilaminata	*Oolithotus fragilis*	

deficiency of certain nutrients which triggers the onset of malformation simply does not exist in these Japanese embayments.

Unlike the malformation discussed above, the bridge abnormality which occurs in many coccoliths of *G. oceanica* in the two bays is also a fairly common feature in the living communities of pelagic oceans (OKADA *et al.*, 1977). The direct cause of abnormality is not known. However, because of its prevailing occurrence in these shallow eutrophic embayments, an extreme nutrient condition (excess or deficiency of certain nutrients) is suspected to be the cause. Although both may be related to abnormal nutrient levels, the malformation and the abnormality may be the result of different direct causes.

ASCIDIAN SPICULES AS A USEFUL INDICATOR OF REDEPOSITED SEDIMENT

Ascidians are important members of shallow benthic communities, and attention was called recently for paleontologists to examine their fossil record (BROOKFIELD, 1988). Many species of Didemnidae and some of Polycitoridae secrete star-shaped spicules, and their fossil occurrences are known from various Mesozoic and Cenozoic sediments (*e.g.* MONNIOT *et al.*, 1971; EDWARDS, 1973).

Disintegrated elements of star-shaped spicules are commonly found in the sediment in some of the studied samples. Although the spicule element is absent in samples taken from the inner parts of Ise and Mikawa Bays, it is fairly common in those from the entrance part of the two bays. Within the Kumano-nada, spicules are abundant in shallow shelf samples and decrease drastically in the upper part of the continental shelf (Fig. 10). The shelf samples contain complete spicules and their disintegrated elements, whereas the slope samples yield only elements. The observed spicules and their elements are referable to the family *Didemnidae* and most probably belong to *Didemnum moseleyi*. Although some Didemnidae have recorded from an abyssal depth (MONNIOT *et al.*, 1975), *D. moseleyi* has been collected mostly from very shallow sea bottoms. No quantitative data are currently available, but colonies are usually found at above ca. 20 m water depth (T. NISHIKAWA, pers. comm.). Most of the spicules and their elements in the studied samples are therefore very likely reworked, and their abundance may be a good indicator of sediment contamination. As mentioned earlier, the 68 Kumano-nada samples selected for the present study are relatively free of reworked nannofossils, but the presence of spicule elements in them is proof of universal redeposition in the studied area. Since this consists exclusively of aragonite, the ascidian

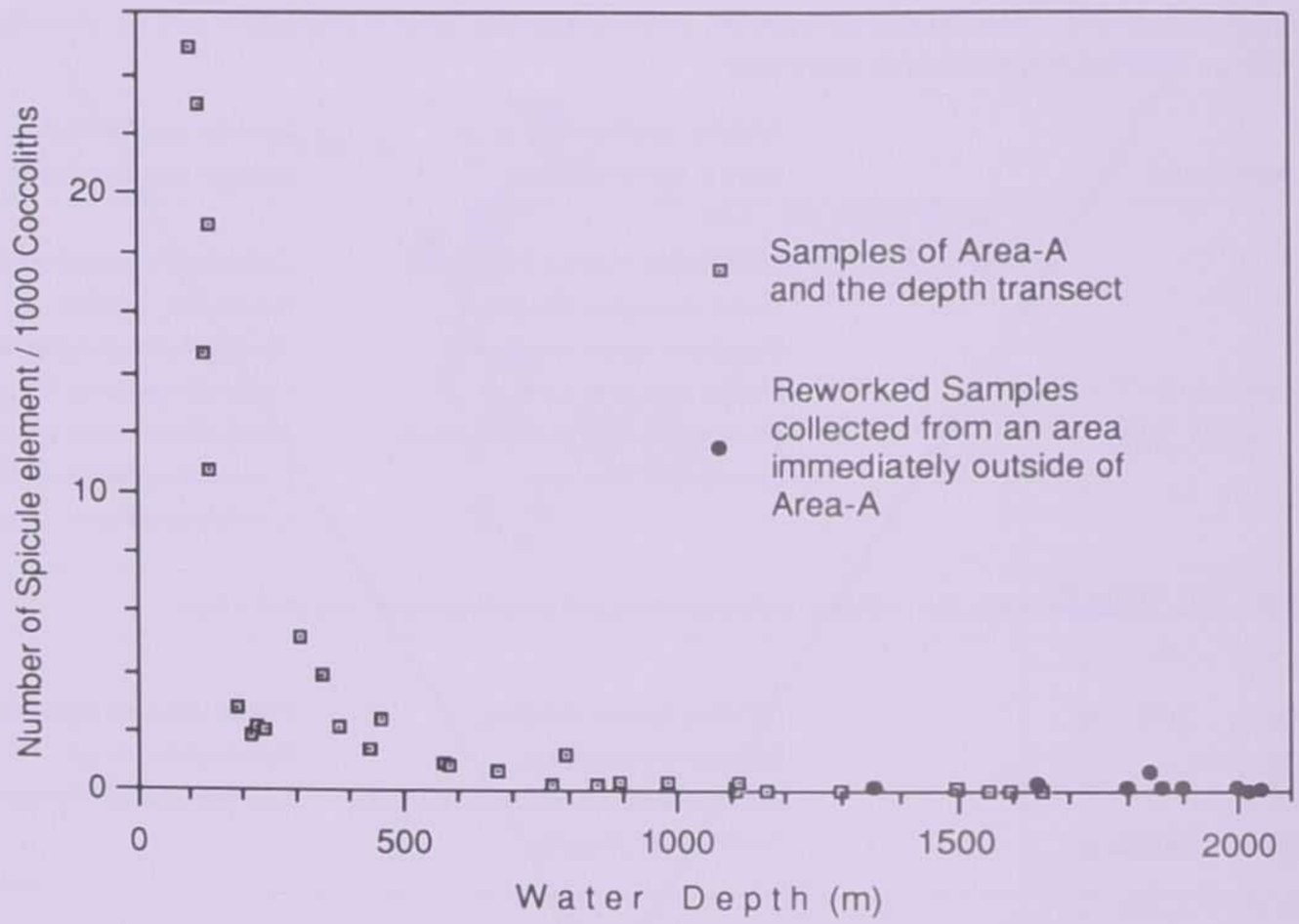

FIG. 10 - Depth-abundance relationship observed for the spicule elements of ascidian in the surface sediment samples from the Kumano-nada. Values are the number of disintegrated spicule elements encountered during the observation of first 1000 coccoliths exclusive of *Florisphaera profunda*. Complete spicules are converted to the numbers of elements estimated to construct respective spicules.

spicules and their elements probably dissolved quickly at depths below the lysocline. The rare elements of spicules found in deeper parts are therefore likely to be recent arrivals. Although rare, spicule elements are slightly more common in rejected samples containing common reworked coccoliths than in the studied samples of corresponding water depth (Fig. 10). These preliminary results suggest that: 1) ascidian spicules may be excellent monitors of down-slope contamination; 2) they may also be good indicators of paleoenvironmental changes in shelf and beach environments, especially if combined with the abundance data of *Florisphaera profunda*.

SUMMARY

(1) Nannofossil floras in the surface sediments of Ise and Mikawa Bays are almost completely monopolized by *Gephyrocapsa oceanica*, and many specimens of this species suffer various degrees of abnormality in bridge construction, ranging from displacement to total absence of bridge elements. No malformation, however, was observed in a few selected samples observed under the electron microscope. The malformation and abnormality observed here were probably caused by different kinds of abnormal nutrient levels.

(2) Six taxa occur as subordinate members of the flora within the two bays and, except for one possible case of their most abundant member, *Emiliania huxleyi*, specimens of these subordinate taxa are suspected to be allochthonous, brought from the Kumano-nada by incoming tidal currents.

(3) Twenty-three taxa were identified within the surface sediments of the Kumano-nada, and three species dominate the flora. One of these, *Florisphaera profunda*, increases proportionally with water depth, and the positive gradient is particularly steep within the upper few hundred meters. Although trends are not truly proportional to water depth, the other major species, *E. huxleyi*, is more abundant in the deeper samples than in the shelf samples, and the remaining *G. oceanica* exhibits an inverted relationship.

(4) Among the subordinate taxa, *Helicosphaera carteri, Helicosphaera pavimentum, Syracosphaera* spp. and *Braarudosphaera bigelowii* are more abundant in neritic samples, whereas the five species, *Calcidiscus leptoporus, Umbilicosphae-*

ra sibogae, Umbilicosphaera hulburtiana, Umbellosphaera tenuis and *Umbellosphaera irregularis*, become more abundant in deeper samples.

(5) Plotting the observed data into the triangular co-ordinate diagram proposed by OKADA (1983) reconfirmed the provincialism of nannofossil flora in the two bays and the Kumano-nada, and boundaries were defined for the three environmental settings. Approximately 20% abundance of *F. profunda* may be assumed as the criterion for distinguishing neritic from pelagic flora.

(6) Ascidian spicule of the shallow-water family Didemnidae may be a good indicator of sediment contamination in shelves and upper continental slopes. Stratigraphic variations in spicule abundance will provide useful information for paleodepth analysis, especially together with similar data for *F. profunda*.

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PLATE I

EXPLANATION OF PLATE I

Optical micrographs of calcareous nannofossils and ascidian spicules observed in the studied samples. All of the nannofossil taxa identified as autochthonous are illustrated here except the extremely rare *Hayaster perplexus* (Bramlette and Riedel) Bukry, Magnifications are the same for all figures and the scale bar in figure 35 indicates 5 µm. All figures are cross-polarized light images.

Fig. 1 - *Calcidiscus leptoporus* (Murray and Blackman) Loeblich and Tappan.

Figs. 2 - *Emiliania huxleyi* (Lohmann) Hay and Mohler.

Fig. 3 - *Gephyrocapsa ericsonii* McIntyre and Bé.

Figs. 4-5 - *Gephyrocapsa oceanica* Kamptner, 4, a normal specimen observed in a Kumano-nada sample. 5, an abnormal specimen observed in the Ise Bay that has a pair of short bridge-elements.

Fig. 6 - *Helicosphaera carteri* var. *carteri* (Wallich) Kamptner.

Fig. 7 - *Helicosphaera carteri* var. *hyalina* (Gaarder) Jordan and Young.

Fig. 8 - *Helicosphaera carteri* var. *wallichii* Theodoridis.

Figs. 9-10 - *Helicosphaera pavimentum* Okada and McIntyre.

Fig. 11 - *Oolithotus fragilis* (Lohmann) Martini and Müller.

Fig. 12 - *Umbilicosphaera hulburtiana* Gaarder.

Fig. 13 - *Umbilicosphaera sibogae* (Weber-Van Bosse) Gaarder var. *foliosa* Okada and McIntyre.

Fig. 14 - *Acanthoica* sp.

Fig. 15 - *Calciosolenia murrayi* Gran.

Fig. 16 - *Cricosphaera quadrilaminata* Okada and McIntyre.

Fig. 17 - *Discosphaera tubifera* (Murray and Blackman) Ostenfeld.

Fig. 18 - *Florisphaera profunda* Okada and Honjo. The larger specimen shown at the left side of the figure is *F. profunda* var. *elongata* Okada and McIntyre, whereas the smaller specimen at the right side is *F. profunda* var. *profunda* Okada and Honjo.

Fig. 19 - *Neosphaera coccolithomorpha* Lecal-Schlauder

Figs. 20-21 - *Pontosphaera japonica* (Takayama) Nishida.

Fig. 22 - *Pontosphaera* sp.

Figs. 23-24 - *Syracosphaera* spp.

Fig. 25 - *Rhabdosphaera clavigera* Murray and Blackman.

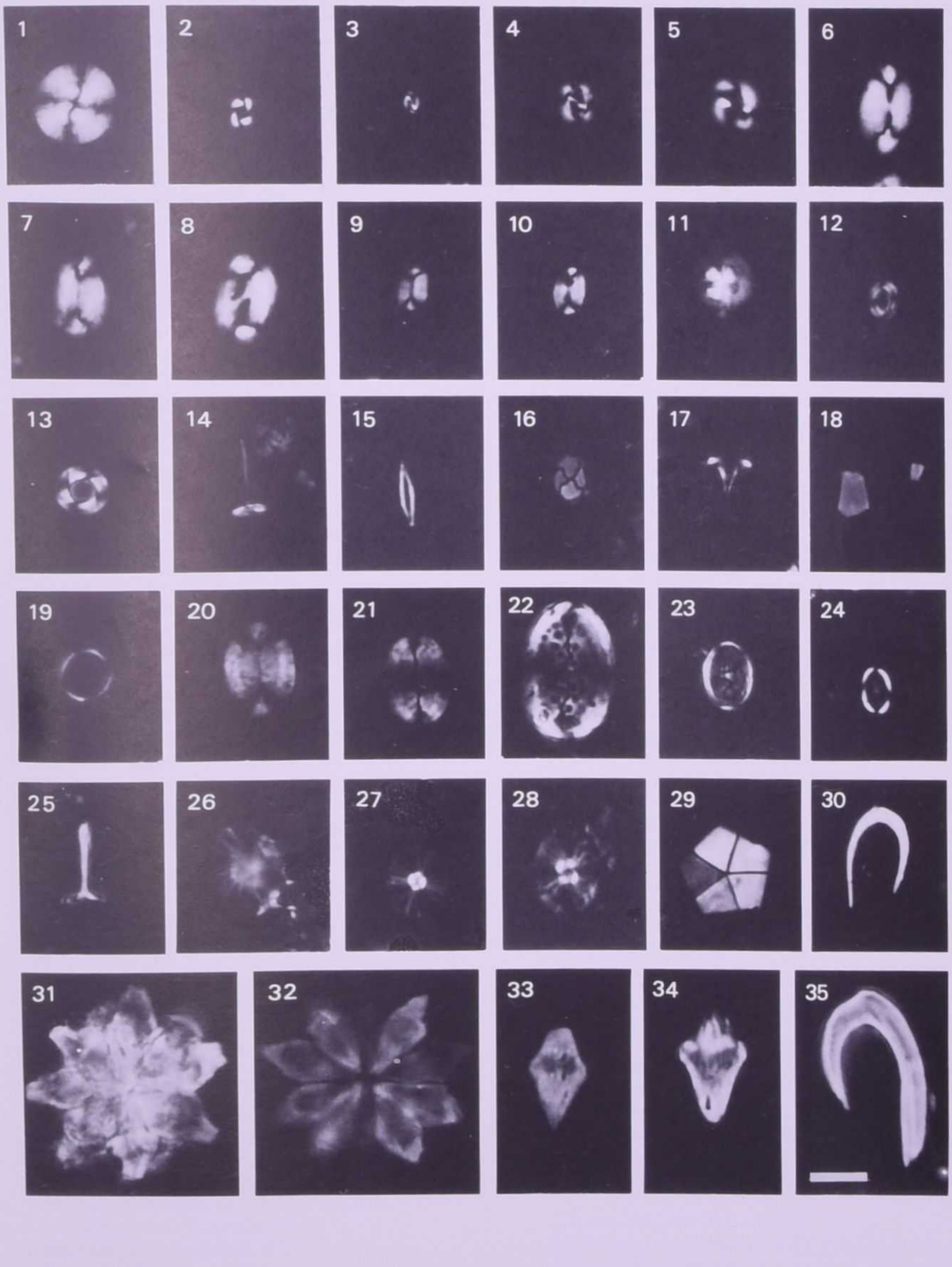
Figs. 26-27 - *Umbellosphaera irregularis* Paasche.

Fig. 28 - *Umbellosphaera tenuis* (Kamptner) Paasche.

Fig. 29 - *Braarudosphaera bigelowii* (Gran and Braarud) Deflandre.

Figs. 30, 35 - *Ceratolithus cristatus* Kamptner.

Figs. 31-34 - Ascidian spicule of family Dideminidae. 31 and 32, complete spicule. 33, a well preserved disintegrated element. 34, a partly dissolved disintegrated element.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