Surface sediment distribution of *Florisphaera profunda* in the South China Sea: an effect of dissolution?

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**Abstract** Calcareous nannofossil assemblages in the surface sediments of the South China Sea (SCS), at depths >200m, are dominated by *Florisphaera profunda*, with abundance values ranging from 32-95%. Towards the central (abyssal) portion of the SCS, at depths below the inferred lysocline and the calcite compensation depth, *F. profunda* abundance values in the surface sediments reach >80%. An experiment, involving the use of an acidic solution in the preparation of smear-slides, showed an apparent increase in *F. profunda* abundance relative to the other taxa present in the original sample. *F. profunda*, therefore, is herein proposed as a dissolution-resistant species.

**Keywords** South China Sea, surface sediments, calcareous nannofossils, *Florisphaera profunda*, dissolution, preservation

1. Introduction
The preference of *Florisphaera profunda* for the lower euphotic zone of the water-column makes it very unusual among the living coccolithophores. First described by Okada & Honjo (1973) from the Pacific Ocean, coccospheres of *F. profunda* are composed of polygonal, tooth-like coccoliths comprising a single calcite crystal and are distinguished under the light-microscope by their low birefringence. This nannoplankton species has been present since the Middle Miocene (NN5; Young, 1998). *F. profunda* is considered to be an important component of Recent surface sediments in the world’s oceans and seas, and has been known to dominate nannofossil assemblages in the sediments of deep basins, increasing in relative abundance offshore, with increasing water-depth and distance from the coast (e.g. Okada & Honjo, 1975; Okada, 1983, 1992; Takahashi & Okada, 2000; Andruleit & Rogalla, 2002). In the South China Sea (SCS), *F. profunda* dominates both surface-water and surface-sediment nannoplankton/nannofossil assemblages (Fernando et al., 2000, in press; Peleo-Alampay et al., 2000; Liu et al., 2001; Fernando, 2003; Figure 1). Below the inferred lysocline and calcite compensation depth (CCD) in the SCS (i.e. 3000m and 3500m, respectively: Wang et al., 1995), *F. profunda* abundance values are >80%, dominating the deep basin (abyssal) nannofossil assemblage (Fernando et al., in press).

The present study investigates the possible reasons causing such patterns of *F. profunda* distribution in the SCS. In particular, the possible effect of the resistance of the species to dissolution, compared to other taxa, is investigated through an experiment, herein referred to as...
the F. profunda experiment. The experiment is a modified smear-slide sample preparation technique, using solutions of varying HCl concentration.

2. Materials and methods

A total of 12 samples, from the eastern and western portions of the SCS, collected during R/V Sonne cruises SO-132 in 1998 (Wiesner et al., 1998) and SO-140A in 1999 (Wiesner et al., 1999), were used for the experiment (Figure 1). The samples were taken at water-depths ranging from 97-4345m (Table 1). The topmost portion (0-0.25cm) of the samples, representing the most recent sediments, was used for this study. Relative abundance data of Florisphaera profunda in the surface sediments of the SCS were taken from Fernando et al. (2000), Liu et al. (2001) and Fernando (2003). Slides were examined under a polarising light-microscope (Carl Zeiss Axiophot) at 1000x and 1250x magnifications. For species relative abundance analysis, 300 specimens were counted per sample on randomly selected fields of view.

In determining the possible resistance of F. profunda to dissolution, two sets of smear-slides were prepared using a modified sample preparation technique: instead of distilled water, a small quantity of sediment was mixed with 0.5% and 1.0% HCl solution, respectively.

The carbonate content of the samples was determined using the carbonate bomb method of Muller (1967). A small amount of sediment (0.5-1.0g) is placed inside the carbonate bomb, along with 10ml of 5% HCl in a small container. The lid of the container is closed tightly and the contents are mixed. The CO₂ released from the reaction of the sediments with HCl is recorded by the pressure gauge. The values obtained were compared to the standard (100% CaCO₃) to get the carbonate percentage of the sediments (Table 2). The foraminiferal dissolution index (FDX) of Berger (1979) was used to check dissolution intensity in the investigated samples. The FDX measures dissolution intensity in samples using the equation

\[
FDX = \Sigma (\pi_i R_i) / \Sigma \pi_i
\]

where \(\pi_i\) = % of species \(i\), and \(R_i\) = dissolution ranking of species \(i\). The higher the values obtained in the computed FDX, the stronger the dissolution effect (i.e. the more dissolution-resistant planktonic foraminifera species in the sample). Hemleben & Auras (1984) used the same equation in the calculation of the FDX, although the planktonic foraminifera dissolution rankings slightly differ from those of Berger (1979). The FDX values of the investigated samples are shown in Table 3.

3. Results and interpretations

3.1 Florisphaera profunda distribution in the surface sediments of the SCS

The relative abundance values of Florisphaera profunda in the SCS range from 2-61% in the western portion and 49-95% in the eastern portion (Fernando, 2003; Fernando et al., in press). At depths below 200m, F. profunda abundance values range from 32-95%. Farther offshore, with increasing water-depth and distance from the coast, towards the central (abyssal) part of the SCS, F. profunda increases in abundance, comprising >80% of the assemblage below the inferred CCD. Fernando et al. (in press) referred to this assemblage as the ‘deep-basin’ or ‘abyssal’ assemblage. The deep-basin assemblage is believed to be the result of the combined effects of the taxon’s preference for increased water-depth and distance from the coast, a deep nutricline, and the possible effect of carbonate dissolution (i.e. F. profunda is resistant to dissolution). Ahagon et al. (1993) suggested an inverse relationship between water turbidity and F. profunda abundance. Molfino & McIntyre (1990), on the other hand, suggested the control of nutricline depth on F. profunda growth. In the central SCS, Conductivity Temperature Depth data (Wiesner et al., 1999) and low chlorophyll concentration (<0.1-0.3mg/m³: Liu et al., 2002) are consistent with higher F. profunda abundance.

3.2 Florisphaera profunda experiment

Of the 12 samples included in this experiment, only seven contained calcareous nannofossils after preparation with 0.5% and 1.0% HCl solutions (Table 1, Figure 2). Interestingly, smear-slides of samples obtained at depths approaching >2500m (below the lysocline) are barren of nannofossils when prepared with HCl. This phenomenon could be attributed to the partial dissolution of nannofossils during deposition. With increasing water-depth, the bottom-water becomes CaCO₃-undersaturated, resulting

<table>
<thead>
<tr>
<th>sample number</th>
<th>water depth (m)</th>
<th>Emiliania huxleyi</th>
<th>Florisphaera profunda</th>
<th>Gephyrocapsa oceanica</th>
</tr>
</thead>
<tbody>
<tr>
<td>132-3</td>
<td>2435</td>
<td>23.3</td>
<td>6.9</td>
<td>6.8</td>
</tr>
<tr>
<td>132-39</td>
<td>2486</td>
<td>10.7</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>132-37A</td>
<td>2603</td>
<td>10.5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>132-33</td>
<td>3392</td>
<td>9.6</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>132-17</td>
<td>4121</td>
<td>10</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>132-9</td>
<td>4345</td>
<td>0.7</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 1: Comparison of % relative abundance values of the three major species in samples prepared with 0%, 0.5% and 1.0% HCl.
Table 2: Carbonate content, % relative abundance of *F. profunda*, and Shannon-Weaver diversity values of the samples from the eastern and western portions of the SCS

<table>
<thead>
<tr>
<th>Station</th>
<th>% carbonate</th>
<th>% <em>F. profunda</em></th>
<th>Shannon-Diversity Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO12-02</td>
<td>95.1 0.00</td>
<td>0.00 0.00</td>
<td>4.68 3.45 88.84</td>
</tr>
<tr>
<td>SO12-03</td>
<td>95.5 0.00</td>
<td>0.00 0.00</td>
<td>4.48 3.45 88.84</td>
</tr>
<tr>
<td>SO12-04</td>
<td>95.8 0.00</td>
<td>0.00 0.00</td>
<td>4.68 3.45 88.84</td>
</tr>
<tr>
<td>SO12-05</td>
<td>96.0 0.00</td>
<td>0.00 0.00</td>
<td>4.68 3.45 88.84</td>
</tr>
</tbody>
</table>

From the graph showing the results of the experiment (Figure 2), it can be observed that there is an apparent increase in the relative abundance of *F. profunda*, with respect to other coccoliths, in samples prepared with 0.5% and 1.0% HCl, compared to samples prepared with 0% HCl. Although Gephyrocapsa oceanica also increases in relative abundance in the experiment, this is only appar-
Figure 2: Graphical comparison of the % relative abundance values of the three major species in the smear-slide analysis of the 0%, 0.5% and 1.0% HCl experiment. The category ‘Other taxa’ includes C. leptoporus, C. murrayi, D. tubifera, G. ericsonii, Helicosphaera spp., Reticulofenestra spp., Syracospaera spp., Umbellosphaera spp. and Umbilicosphaera spp. (see discussion)

Figure 3: A) Foraminiferal dissolution index (FDX: Berger, 1979) and % relative abundance of F. profunda (modified from Fernando et al., in press). B) % relative abundance of F. profunda and carbonate content of the surface sediments in the SCS
ent in Samples SO140-51 and SO140-56, collected on the Vietnam shelf at water-depths <200m. G. oceanica is one of the most abundant species in these locations, along with *Emiliania huxleyi*, which may explain its abundance even after acidification. *E. huxleyi*, however, appears to be more susceptible to dissolution than *F. profunda* and, to a lesser extent, *G. oceanica*, thus its low abundance after the experiment.

Although there is a consistent decline in the values of the total 'minor' taxa after the experiment, *Calcisidiscus leptoporus*, *Ceratolithus* spp. and *Helicosphaera* spp. (mainly *H. carteri*) were observed to become slightly more common. This is attributed to the dissolution of more susceptible forms, such as *Calciosolenia murrayi*, *Discosphaera tubifera*, *Gephyrocapsa ericsonii*, *Reticulofenestra* spp., *Syracosphaera* spp., *Umbellosphaera* spp. and *Umbilicosphaera* spp.

### 3.3 Dissolution Indices

Although few samples were subjected to FDX analysis, the result was favourable. FDX values increase with increasing water-depth and show direct correlation with *F. profunda* abundance (r = 0.77: Figure 3a). The carbonate content of the sediments, on the other hand, shows an inverse relationship with *F. profunda* abundance (r = -0.55: Figure 3b). Both parameters, therefore, support the inference that high abundances of *F. profunda* are related to dissolution.

### 4. Discussion and conclusions

Early petrographic works suggested calcite to be the main component of coccoliths, which was supported by succeeding studies using chemical and X-ray diffraction analyses (e.g. Isenberg *et al.*, 1963 in Siesser & Winter, 1994). Further studies revealed that the calcite produced by coccolithophores is the low-Mg variety (i.e. <4% MgCO3); Siesser, 1971 in Siesser & Winter, 1994).

A non-reviewed, informal discussion regarding the composition of *Florisphaera profunda* coccoliths was compiled in the *Journal of Nannoplankton Research* (2000, 22(1): 10). Evidence presented to favour calcite over aragonite included: (1) high *F. profunda* abundance in samples that do not contain aragonite (i.e. below the aragonite compensation zone); and (2) its occurrence and preservation patterns in deep-sea sediments. The distribution pattern of *F. profunda* in recent studies in the SCS confirms these observations, wherein the species dominates the deep-basin (abyssal) assemblage (Fernando *et al.*, in press).

The present study is one of very few to report increased abundance of *F. profunda* in the abyssal portion of the SCS, and one of the few to propose the taxon’s possible resistance to dissolution (e.g. Gibbs *et al.*, 2004). The abundance of *F. profunda* in the surface sediments of the deep portions of the SCS is probably a combined result of its high abundance in the water-column and its resistance to dissolution. Abundance in the water-column is evident in the sediment-trap data of Peleo-Alampay *et al.* (2000) and is supported by oligotrophic conditions in the eastern and central portions of the SCS, as indicated by the deep nutricline level and low chlorophyll data (Wiesner *et al.*, 1999; Liu *et al.*, 2002). Based on the high abundance values of the species at depths below the lysocline and CCD, and the dissolution parameters investigated (CaCO3 content of the sediments and FDX), however, *F. profunda* could be a dissolution-resistant species and is a significant contributor of CaCO3 at greater depths. A likely explanation could be the fact that *F. profunda* coccoliths are made up of single calcite crystals, as opposed to the coccoliths of other taxa in the investigated samples in the SCS, which have smaller constituent crystal elements (Gibbs *et al.*, 2004; J. Young and H. Andruleit, pers. comms, 2007).

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