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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

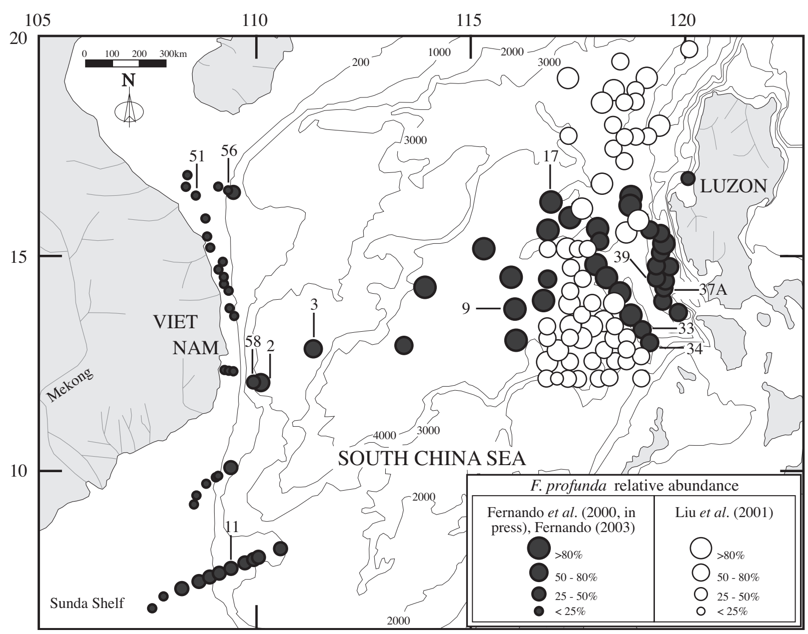

Figure 1: Map of the SCS and abundance values of *F. profunda* in the surface sediments, using data from Fernando *et al.* (2000, in press), Fernando (2003) and Liu *et al.* (2001). Samples included in the *F. profunda* experiment are indicated by arrows and are labeled accordingly

sample number	water depth (m)	*Emiliania huxleyi*			*Florisphaera profunda*			*Gephyrocapsa oceanica*		
		0%	0.50%	1.00%	0%	0.50%	1.00%	0%	0.50%	1.00%
140-51	96.5	45.8	31.9	28.7	3.6	8.9	9.3	29.4	35.4	48.1
140-56	196.6	36.4	27.9	21	19.2	17.9	23	21.5	29.8	45
140-11	710.7	35.5	17.3	26.8	41.9	46.7	49.3	14.4	19.2	15.9
140-58	1906	28.9	17	14.9	41.3	57.7	61.1	17.6	16.5	22.2
132-2	2094	26.6	10.1	17.4	52.9	63.4	57.6	12.9	19.4	18.6
132-34	2364	9.5	6.7	0	54	68.6	0	23.4	18.7	0
132-3	2435	23.3	6.9	6.8	51.9	72.4	75.9	18	15.6	15.6
132-39	2486	10.7	0	0	64	0	0	15.7	0	0
132-37A	2603	10.5	0	0	68.6	0	0	13	0	0
132-33	3392	9.6	0	0	68.6	0	0	17.9	0	0
132-17	4121	10	0	0	82.2	0	0	6.3	0	0
132-9	4345	0.7	0	0	91.7	0	0	7.3	0	0

Table 1: Comparison of % relative abundance values of the three major species in samples prepared with 0%, 0.5% and 1.0% HCl

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 *Florosphaera 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 CO_2 released from the reaction of the sediments with HCl is recorded by the pressure gauge. The values obtained were compared to the standard (100% $CaCO_3$) 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

$$FDX = \Sigma [(pi)(Ri)] / \Sigma pi$$

where pi = % of species i, and Ri = 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* in the water-column (*i.e.* a deep nutricline is favourable for *F. profunda* growth). In the central SCS, Conductivity Temperature Depth data (Wiesner *et al*., 1999) and low chlorophyll concentration (<0.1-0.3mg/m^3: 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 $CaCO_3$-undersaturated, resulting

western South China Sea						
station	latitude	longitude	water depth (m)	% carbonate	% *F. profunda*	Shannon-Weaver Diversity Index
SO132-02	11°56.03'	110°06.04'	2094.0	17.45	52.931	1.309
SO132-03	12°40.75'	111°24.14'	2435.0	18.10	51.897	1.326
SO132-04	12°48.04'	113°33.43'	4327.0	1.94	61.538	0.925
SO140A-01	6°43.56'	107°38.99'	73.5	21.98	8.940	1.340
SO140A-03	7°00.20'	107°54.87'	86.2	12.28	22.364	1.473
SO140A-05	7°10.71'	108°20.28'	98.8	4.52	26.282	1.511
SO140A-07	7°20.39'	108°44.16'	119.4	14.22	33.127	1.425
SO140A-08	7°26.54'	108°59.32'	149.7	9.70	35.572	1.325
SO140A-10	7°31.91'	109°12.75'	283.9	34.26	39.754	1.651
SO140A-11	7°38.52'	109°29.17'	710.7	14.61	41.935	1.392
SO140A-12	7°46.33'	109°48.68'	829.1	26.50	41.326	1.464
SO140A-13	7°51.43'	110°00.98'	73.8	76.27	39.935	1.345
SO140A-14	7°54.09'	110°07.85'	380.4	107.29	44.124	1.491
SO140A-15	8°06.18'	110°38.33'	381.6	77.56	47.241	1.407
SO140A-16	9°08.55'	108°37.39'	108.8	6.46	18.533	1.377
SO140A-18	9°20.52'	108°40.53'	101.4	9.70	20.667	1.418
SO140A-20	9°37.08'	108°54.36'	116.1	23.92	18.736	1.292
SO140A-21	9°45.69'	109°07.96'	155.9	35.55	19.328	1.734
SO140A-22	9°47.67'	109°10.88'	183.0	17.45	18.768	1.382
SO140A-23	9°59.22'	109°28.73'	280.1	24.56	35.556	1.466
SO140A-25	12°14.71'	109°19.91'	45.5	7.11	8.895	1.268
SO140A-26	12°14.21'	109°22.83'	59.3	6.02	7.667	1.466
SO140A-28	12°13.67'	109°25.96'	103.6	7.76	10.855	1.711
SO140A-29	12°12.89'	109°32.09'	134.2	10.99	18.750	1.560
SO140A-32	13°30.12'	109°33.67'	169.1	29.23	18.636	1.830
SO140A-33	13°41.11'	109°27.02'	129.3	16.81	17.188	1.522
SO140A-35	14°05.08'	109°25.53'	134.7	none	19.107	1.723
SO140A-36	14°14.90'	109°20.20'	116.5	14.22	12.325	1.242
SO140A-39	15°20.03'	108°55.41'	56.8	6.88	2.417	1.149
SO140A-43	15°05.00'	109°00.01'	34.6	none	1.807	1.080
SO140A-45	14°44.81'	109°17.61'	97.9	16.81	9.565	1.151
SO140A-46	14°24.10'	109°18.57'	100.0	18.10	6.704	1.509
SO140A-48	14°34.13'	109°11.36'	61.5	none	3.618	1.378
SO140A-49	15°44.94'	108°53.33'	82.5	31.02	12.060	1.281
SO140A-51	16°16.62'	108°39.59'	96.5	23.27	3.611	1.496
SO140A-52	16°28.61'	108°26.15'	91.1	14.22	3.762	1.337
SO140A-54	16°44.40'	108°27.77'	92.9	18.10	12.766	1.262
SO140A-55	16°28.55'	109°11.47'	114.8	13.57	19.777	1.603
western South China Sea (continued)						
SO140A-56	16°23.59'	109°25.04'	196.6	10.34	19.205	1.674
SO140A-57	16°20.98'	109°32.34'	756.3	14.87	32.338	1.441
SO140A-58	11°55.23'	110°01.03'	1906.0	14.22	41.333	1.532

eastern South China Sea						
station	latitude	longitude	water depth (m)	% carbonate	% *F. profunda*	Shannon-Weaver Diversity Index
SO132-05	14°10.03'	113°59.99'	4323.0	1.29	88.710	0.399
SO132-07	15°06.33'	115°23.10'	4269.0	1.29	86.932	0.500
SO132-08	14°22.99'	116°03.99'	4320.0	1.29	83.750	0.544
SO132-09	13°40.62'	116°07.01'	4345.0	3.23	91.694	0.323
SO132-10	12°58.27'	116°09.90'	4345.0	1.29	91.667	0.340
SO132-11	13°50.02'	116°48.35'	4249.0	1.29	90.909	0.394
SO132-12A	14°18.96'	116°52.03'	4320.0	1.94	79.056	0.735
SO132-16	15°29.99'	116°55.01'	4233.0	none	89.552	0.476
SO132-17	16°06.08'	116°59.63'	4121.0	1.29	82.188	0.645
SO132-20	15°42.60'	117°25.50'	4192.0	1.29	93.729	0.282
SO132-23	15°15.24'	118°07.11'	3714.0	none	79.294	0.802
SO132-24	15°32.69'	118°05.59'	4014.0	1.29	80.000	0.745
SO132-27	14°39.96'	118°05.15'	4254.0	2.00	92.570	0.303
SO132-28	14°19.64'	118°18.93'	4060.0	1.29	90.062	0.459
SO132-30	14°02.43'	118°41.03'	3937.0	0.65	90.000	0.419
SO132-32	13°31.68'	118°53.94'	3513.0	3.88	87.187	0.529
SO132-33	13°12.06'	119°04.47'	3392.0	3.44	68.642	0.995
SO132-34	12°53.58'	119°18.39'	2364.0	6.02	54.006	1.459
SO132-35	13°37.02'	119°58.40'	3322.0	3.88	50.809	0.899
SO132-37	13°54.33'	119°36.77'	2762.0	1.29	57.311	1.336
SO132-37A	14°06.19'	119°37.48'	2603.0	3.23	68.642	1.147
SO132-38	14°15.07'	119°38.11'	2496.0	2.26	59.103	1.408
SO132-39	14°18.74'	119°25.52'	2486.0	4.52	64.028	1.263
SO132-40	14°35.06'	119°45.12'	2510.0	3.44	68.421	1.086
SO132-41	14°38.40'	119°28.85'	2605.0	1.94	53.293	1.333
SO132-42	14°54.67'	119°32.29'	2514.0	1.94	59.672	1.353
SO132-43	15°12.50'	119°37.50'	2286.0	0.97	83.621	0.631
SO132-46	16°37.69'	120°11.56'	349.0	8.40	48.787	1.369
SO132-47	16°14.18'	118°55.57'	3980.0	1.29	95.238	0.191
SO132-48	16°01.70'	118°53.75'	3799.0	0.00	85.867	0.568
SO132-49	15°27.84'	119°19.37'	3010.0	2.59	68.241	1.149
SO132-50	15°24.99'	119°35.21'	2459.0	1.29	66.565	1.172

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

in corrosion/partial dissolution of any calcareous matter. As a consequence, when smear-slides of samples are prepared with an acidic solution, dissolution is easier because of the coccoliths' weakened structure due to partial dissolution (double dissolution effect: Fernando, 2003).

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-

sample number	water depth (m)	*Globigerina bulloides*	*G. calida*	*Globigerinella aequilateralis*	*Globigerinoides conglobatus*	*G.* cf. *G. fistula*	*G. ruber*	*G. sacculifer*	*Globorotalia hirsuta*	*G. menardii*	*G. scitula*	*G. truncatulinoides*	*Neogloboquadrina dutertrei*	*N. pachyderma*	*Orbulina universa*	*Pulleniatina obliquiloculata*	*Sphaeroidinella dehiscens*	total	FDX (Berger, 1979)	FDX (Hemleben & Auras, 1984)	*F. profunda* abundance
SO132-37A	2603.00	2.94	0.00	11.76	4.90	0.00	3.92	51.96	0.00	6.86	0.98	0.00	5.88	3.92	1.96	4.90	0.00	100.00	4.66	4.34	68.64
SO132-34	2364.00	4.82	8.43	13.25	3.61	0.00	8.43	42.17	0.00	2.41	1.20	0.00	6.02	3.61	1.20	4.82	0.00	100.00	4.42	4.14	54.01
SO140-55	114.80	5.62	0.00	6.74	1.69	0.00	22.47	37.08	0.00	6.74	0.00	0.00	10.67	1.69	1.12	6.18	0.00	100.00	4.28	4.09	19.78
SO132-3	2435.00	5.00	0.00	5.00	10.00	0.00	7.50	17.50	0.00	7.50	0.00	0.00	15.00	5.00	0.00	15.00	12.50	100.00	5.53	5.37	51.90
SO132-39	2486.00	4.65	2.33	17.44	0.00	0.00	5.81	46.51	0.00	2.33	0.00	0.00	3.49	3.49	5.81	8.14	0.00	100.00	4.52	4.25	64.03
SO132-49	3010.00	2.50	0.00	7.50	0.00	0.00	5.00	50.00	0.00	12.50	0.00	0.00	15.00	2.50	2.50	2.50	0.00	100.00	4.95	4.46	68.24
SO140-57	756.30	16.35	0.00	7.60	3.42	0.00	20.91	27.38	0.38	2.66	0.00	0.00	3.42	7.98	1.52	8.37	0.00	100.00	4.12	3.74	32.34
SO140-58	1906.00	1.72	0.00	6.55	2.07	0.34	5.86	47.59	0.00	6.55	0.00	0.00	10.00	5.17	7.24	6.90	0.00	100.00	4.86	4.56	41.33
SO140-56	196.60	0.00	0.00	13.75	3.75	0.00	20.00	26.25	0.00	10.00	0.00	1.25	16.25	1.25	6.25	0.00	1.25	100.00	4.65	4.43	19.21
SO140-52	91.10	14.49	0.00	0.00	1.45	0.00	49.28	21.74	0.00	1.45	0.00	0.00	2.90	5.80	0.00	2.90	0.00	100.00	3.26	3.28	3.76

Table 3: Planktonic foraminifera occurrence and relative abundance in selected stations in the SCS (refer to Table 2 for coordinates). FDX values were computed using the dissolution ranking scales of Berger (1979) and Hemleben & Auras (1984)

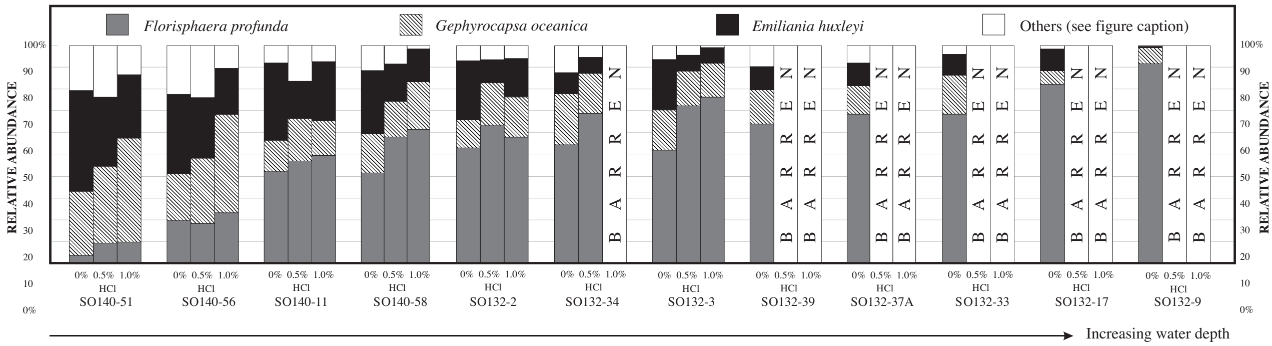

Figure 2: Graphical comparison of the % relative abundance values of the three major species in the smear-slide analysis of the 0%, 0.5% and 1.0% HCl experiment. The category 'Other taxa' includes *C. leptoporus*, *C. murrayi*, *D. tubifera*, *G. ericsonii*, *Helicosphaera* spp., *Reticulofenestra* spp., *Syracosphaera* spp., *Umbellosphaera* spp. and *Umbilicosphaera* spp. (see discussion)

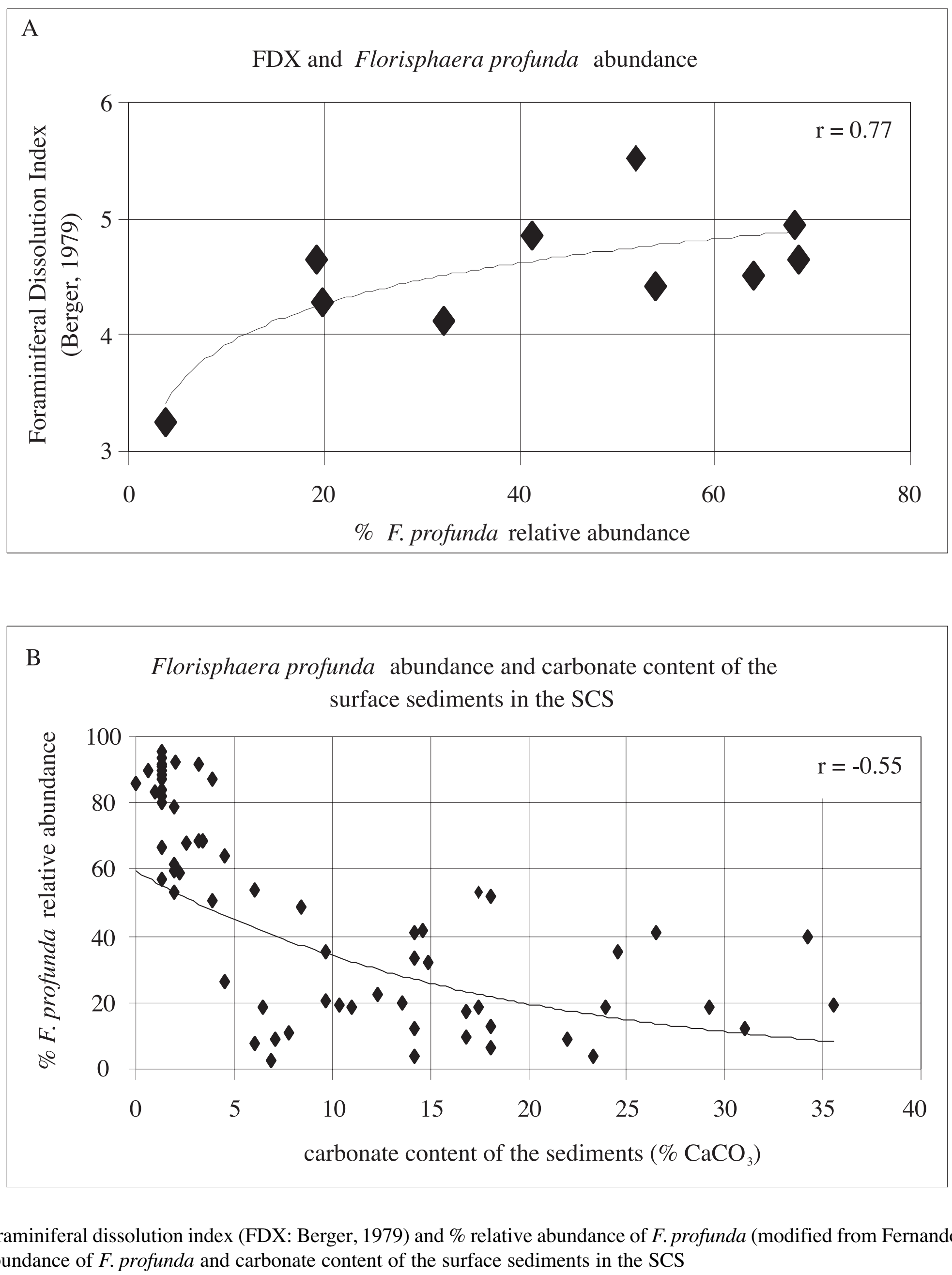

Figure 3: **A**) Foraminiferal dissolution index (FDX: Berger, 1979) and % relative abundance of *F. profunda* (modified from Fernando *et al*., in press). **B**) % relative abundance of *F. profunda* and carbonate content of the surface sediments in the SCS

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, *Calcidiscus 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% $MgCO_3$: 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 ($CaCO_3$ content of the sediments and FDX), however, *F. profunda* could be a dissolution-resistant species and is a significant contributor of $CaCO_3$ 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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References

Ahagon N., Tanaka, Y. & Ujie, H. 1993. *Florisphaera profunda*, a possible nannoplankton indicator of late Quaternary changes in sea-water turbidity at the northwestern margin of the Pacific. *Marine Micropaleontology*, **22**: 255-273.

Andruleit, H. & Rogalla, U. 2002. Coccolithophores in surface sediments of the Arabian Sea in relation to environmental gradients in surface waters. *Marine Geology*, **186**(3-4): 505-526.

Berger, W.H. 1979. Preservation of Foraminifera. *In*: *Foraminiferal Ecology and Paleoecology. SEPM Short Course*, **6**: 105-155.

Fernando, A.G.S. 2003. *Calcareous nannoplankton distribution in surface sediments from the eastern and western portions of the South China Sea*. Unpublished MSc thesis, National Institute of Geological Sciences, University of the Philippines, Diliman, Quezon City, Philippines: 171pp.

Fernando, A.G.S., Peleo-Alampay, A.M. & Wiesner, M.G. 2000. Calcareous nannoplankton from surface sediments of the eastern and western portions of the South China Sea. *Journal of Nannoplankton Research*, **22**(2): 97.

Fernando, A.G.S., Peleo-Alampay, A.M. & Wiesner, M.G. In press. Calcareous Nannofossils in Surface Sediments of the Eastern and Western South China Sea. *Marine Micropaleontology*.

Gibbs, S.J., Shackleton, N.J. & Young, J.R. 2004. Identification of dissolution patterns in nannofossil assemblages: A high-resolution comparison of synchronous records from Ceara Rise, ODP Leg 154. *Paleoceanography*, **19**: PA1029.

Hemleben, C. & Auras, A. 1984. Variations in the calcite dissolution pattern on the Barbados Ridge Complex at Site 541 and 543, Leg 78A. *In*: B. Biju-Duval & C.J. Moore *et al.* (Eds). *Initial Reports of the Deep Sea Drilling Project*, **78A**:

471-497.

Isenberg, H.D., Lavine, L.S., Moss, M.L., Kupferstein, D. & Lear, P.E. 1963. Calcification in a marine coccolithophorid. *Annals of the New York Academy of Sciences*, **109**: 49-64.

Liu, C.-L., Shao, L., Chen, R.-H., Cheng, X.-R. & Zhang, F.-Y. 2001. Distribution of calcareous nannoplankton in surface sediments of the northeastern parts of the South China Sea. *Marine Geology and Quaternary Geology*, **21**(3): 23-28. (In Chinese, with English Abstract)

Liu, K.-K., Chao, S.-Y., Shaw, P.-T., Gong, G.-C., Chen, C.-C. & Tang, T.Y. 2002. Monsoon-forced chlorophyll distribution and primary production in the South China Sea: Observations and a numerical study. *Deep-Sea Research I: Oceanographic Research Papers*, **49**(8): 1387-1412.

Molfino, B. & McIntyre, A. 1990. Precessional forcing of nutricline dynamics in the equatorial Atlantic. *Science*, **249**: 766-769.

Muller, G. 1967. *Methods in Sedimentary Petrology, Part I*. Hafner Publishing Company: 283pp.

Okada, H. 1983. Modern nannofossil assemblages in sediments of coastal and marginal sea along the Western Pacific Ocean. *Utrecht Micropaleontology Bulletins*, **30**: 171-187.

Okada, H. 1992. Biogeographic control of modern nannofossil assemblages in surface sediments of Ise Bay, Mikawa Bay and Kumano-Nada, off coast of Central Japan. *Memorie di Scienze Geologiche, Padova, **XLIII***: 431-449.

Okada, H. & Honjo, S. 1973. The distribution of oceanic coccolithophorids in the Pacific. *Deep-Sea Research*, **20**: 355-374.

Okada, H. & Honjo, S. 1975. Distribution of coccolithophores in marginal seas along the Western Pacific Ocean and in the Red Sea. *Marine Biology*, **31**: 271-285.

Peleo-Alampay, A.M., Lucero, E.S., Wiesner, M. & Gerbich, C. 2000. Coccolith flux from sediment traps in the South China Sea. *Journal of Nannoplankton Research*, **22**(2): 132.

Siesser, W.G. 1971. Mineralogy and diagenesis of some South African coastal and marine sediments. *Marine Geology*, **10**: 15-38.

Siesser, W.G. & Winter, A. 1994. Composition and morphology of the coccolithophore skeleton. *In*: A. Winter & W.G. Siesser (Eds). *Coccolithophores*. Cambridge University Press: 51-62.

Takahashi, K. & Okada, H. 2000. Environmental control on the biogeography of modern coccolithophores in the southeastern Indian Ocean offshore of Western Australia. *Marine Micropaleontology*, **39**: 73-86.

Wang, P., Wang, L., Yunhua, B. & Zhimi, J. 1995. Late Quaternary paleoceanography of the South China Sea: surface circulation and carbonate cycles. *Marine Geology*, **127**: 145-165.

Wiesner, M.G., Kuhnt, W., de Leon, M., Duffel, R., Funke, L., Gerbich, C., Glos, M., Haeckel, M., Hess, S., Hill, S., Holbourn, A., Nguyen, H.P., Kaminski, M., Mirabueno, H., Peleo-Alampay, A., Salomon, B., Seemann, B., Steen, E., Nguyen, T.H., von Wersch, V., Wang, Y., Wetzel, A. & Witzki, D. 1998. *SO-132 SUDMEER II Cruise Report*. Institute of Biogeochemistry and Marine Chemistry, University of Hamburg, Germany, Reference no. SCS-98-CR-01: 19pp.

Wiesner, M.G., Stattegger, K., Kuhnt, W., Arpa, C., Bracker, E., Catane, S., de Leon, M., Duyanen, J., Faber, U., Gerbich, C., Hess, S., Holbourn, A., Jagodzinski, R., Kaminski, M., Kawamura, H., Kruger, O., Lorenc, S., Nguyen, H.S., Nguyen, H.P., Nguyen, T.T, Nguyen V.B., Paulsen, H., Peleo-Alampay, A., Richter, A., Rimek, R., Schimanski, A., Seemann, B., Sharma, C., Siringan, F., Steen, E., Steinke, S., Szarek, R., Szczucinski, W., Vo Duy Son, von Wersch, V., Wetzel, A. & Witzki, D. 1999. *Cruise Report Sonne 140. Leg A: Late Pleistocene-Holocene sea level fluctuations and high resolution stratigraphy of the post-Pleistocene transgression of the Vietnam Shelf. Leg B: Particle fluxes and recolonisation of the 1991 Mount Pinatubo tephra layer in the South China Sea*. Institut für Geowissenschaften, Universität Kiel, **7**: 157pp.

Young, J.R. 1998. Neogene. *In*: P.R. Bown (Ed.). *Calcareous Nannofossil Biostratigraphy*. British Micropalaeontological Society Series, Chapman & Hall/Kluwer Academic Press, London: 225-265.