

Distribution of Calcareous Nannoplankton near the Subtropical Convergence, South of Tasmania, Australia

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Abstract. The floral composition of living calcareous nannoplankton collected from surface waters near the Subtropical Convergence (STC), offshore south-eastern Tasmania, in January 1994 is presented. *Emiliania huxleyi* represented more than 90% of all coccolithophorids. Scanning electron microscopy showed a substantial increase in intraspecific variation of *E. huxleyi*, and in variation in coccolith size of *Calcidiscus leptoporus*, *E. huxleyi* type A and *C. leptoporus* (small), north of the STC.

It is postulated that the percentage abundance of these taxa may be used to determine the position and/or shift of the STC zone through time, and therefore may be of use for palaeoceanographic studies.

Extra keywords: Tasman Sea, palaeoceanography.

Introduction

Calcareous nannoplankters belong to a group of organisms that readily pass through the mesh of a plankton net. These microorganisms consist mainly of coccolithophorids, which are unicellular marine phytoplankton and produce coccoliths composed of minute calcite plates on their cell surface. Calcareous nannoplankters are significant primary producers in the food chain in the oceans, because of their abundant production and world-wide distribution. Coccolithophorids also play a major role in the uptake of carbonate ions in a portion of the ocean (viz. near the surface) which is directly interacting with the atmosphere, and therefore have the potential to significantly affect the uptake of CO₂ and eventually transfer some of it for storage on the sea floor as calcium carbonate (Westbroek *et al.* 1993). Thus, coccoliths form one of the principal components of calcareous ooze, together with calcareous foraminiferans, found on the sea floor of most oceans down to substantial depths. Moreover, calcareous nannoplankton is useful for biostratigraphic studies such as the determination of geological age and the world-wide correlation of Mesozoic and Cenozoic marine sediments (Perch-Nielsen 1985).

Although knowledge of calcareous nannoplankton is critical for obtaining an understanding of the floral distribution and palaeoceanographic reconstructions in the Southern Hemisphere, few reports on calcareous nannoplankton from the southern Pacific and Southern Oceans have been published (e.g. Burns 1972; Hallegraeff 1984; Nishida 1986). The purpose of this study was therefore to (1) investigate the floral composition in the surface water

collected from near the Subtropical Convergence (STC), off Tasmania, (2) understand the relationship between this composition and environmental factors (e.g. sea-surface temperature and salinity), and (3) apply this knowledge to late-Quaternary palaeoceanographic studies.

Materials and Methods

As part of the Australian Marine Quaternary Program initiated in the Geology Department at the Australian National University, 21 5-L water samples [labelled 1P to 20P, with an additional one taken at a depth of 50 m (Station 8P taken during a conductivity-temperature-depth, CTD, profile)] were collected along two north-south transects (Fig. 1) from the RV *Franklin* during 10–18 January 1994. Sea-surface temperature (SST) and salinity were recorded directly into the ship's log-book at the time of each sampling.

The water samples were filtered immediately in the laboratory on board ship over Millipore filters with a 0.2- μ m pore size with the use of a peristaltic pump. The calcareous nannoplankters collected on the filters were transferred into aseptic sample bags (Whirlpak) in 100% alcohol and carefully stored to avoid contamination.

After several days, thus allowing for sufficient time for all specimens to settle on the bottom of the sample bags, 30 drops of alcohol including the nannoplankton sample were pipetted out onto a glass slide (40 mm \times 22 mm). The alcohol solution was then allowed to evaporate from the glass slides at room temperature before use of an Entellan-Neu mounting medium to prepare slides according to standard procedures for the study of nannoplankton. All specimens were observed under a polarizing microscope at \times 1600 magnification.

One coccusphere was counted as representing a single individual and ten coccoliths were also tentatively regarded as belonging to one individual. A species represented by fewer than ten coccoliths in each sample was only recorded as being present (+) in the occurrence chart (Table 1).

As the living flora of calcareous nannoplankton collected during the cruise was dominated by one species, *Emiliania huxleyi*, a stepwise counting method (Okada 1992) had to be used. This method is useful when an assemblage is dominated by very few species, such as is often the case

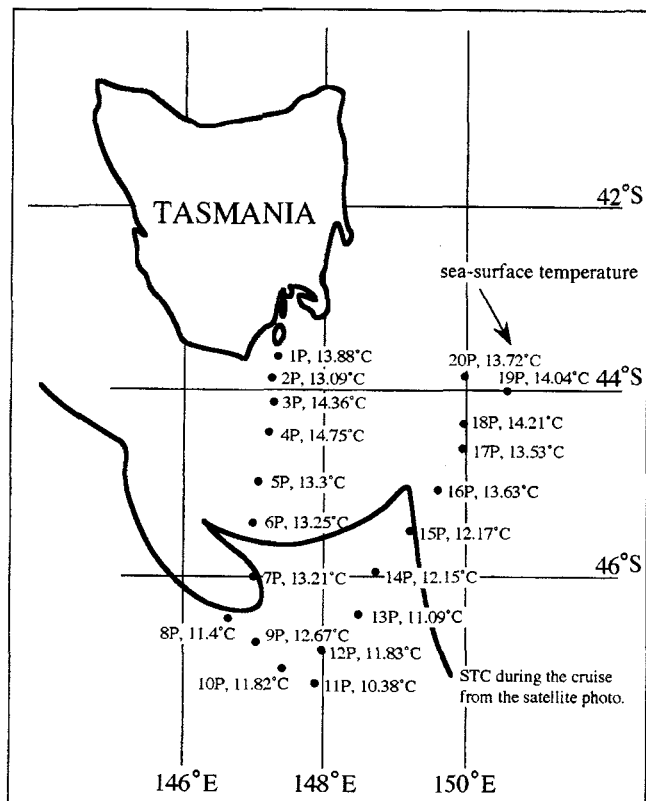


Fig. 1. Sample locality map (Stations 1P–20P) showing the position of the Subtropical Convergence (STC) as recognized by significant temperature contrasts from NOAA satellite data during 7–26 January 1994, by courtesy of the CSIRO Marine Laboratories in Hobart.

for late-Quaternary calcareous nannoplankton assemblages. This method consists of two consecutive counting procedures: (*Procedure 1*) the first 200 individuals encountered for each sample were identified; and (*Procedure 2*) as *E. huxleyi* was so abundant in all samples, it was excluded from the second counting, and the first 100 individuals exclusive of *E. huxleyi* were identified in order to study the characteristics of subdominant taxa.

Additional caution is required because one coccosphere is regarded here as representing one specimen only in the water sample, whereas one coccolith is counted as one single specimen in the sediment sample. In addition, the number of coccoliths forming a single coccosphere differs among species and sometimes even within a single species. Consequently, the percentage abundance of one species in a water sample has to be given a weight different from that of the same species recorded from a sediment sample. Thus, for example, if species A has twice the number of coccoliths in comparison with species B, the percentage abundance of species A is twice that of species B in the sediment sample, although their abundance may be equal in a water sample. However, it is difficult to count precisely the number of coccoliths on a coccosphere, especially for species forming multi-layers, such as *E. huxleyi*. The relative abundance of *E. huxleyi* type A in the sediment sample is considered to decrease in comparison with that of the water sample, because its number of coccoliths forming a single coccosphere is obviously lower than that of other types of *E. huxleyi*.

Taxonomic Notes

The polarizing light microscope at $\times 1600$ magnification permits rapid study of samples but the superior image resolution of scanning electron microscopy (SEM) or transmission electron microscopy (TEM) proved necessary for a detailed examination of small ($< 3 \mu\text{m}$) coccoliths, such as for the genus *Syracosphaera* which has fragile coccoliths. Two main forms of *E. huxleyi* were recognized in the samples; these are labelled *E. huxleyi* type A and *E. huxleyi* type K. Their description is warranted because of their potential use in dealing with similar fossil material in attempts to link specific nannoplankton morphologies with water characteristics. Specimens were observed under SEM.

Emiliana huxleyi type A (Figs 2A, 2B)

Spherical to subspherical coccosphere consisting of approximately 10 to 30 partly interlocked placoliths. Size ranges from 4 to 10 μm , but mostly between 5 and 7 μm . Oval placolith has a narrower and irregular-shaped central area, and the distal shield is formed by robust I-shaped elements. Length of coccolith ranges from 2.5 to 4.0 μm .

E. huxleyi type A is characterized by having a very narrow and irregular-shaped central area as a result of over-calcification. The distal shield slitting is narrower because of robustly developed I-shaped elements. The proximal shield is either solid or with a few slits between some of the elements. The placoliths are so thick that high birefringence is obvious under a cross-nicol in the microscope. This form is easily identified, even under a polarized light microscope, if observed as a coccosphere. However, SEM observations are necessary for accurate identification of isolated coccoliths.

E. huxleyi type A in this study coincides with the 'warm water form' of Nishida (1986), and possibly with the heavily calcified form of the warm-water type of Hallegraeff (1984) and *E. huxleyi* type A of Young and Westbroek (1991).

Emiliana huxleyi type K (Figs 2C, 2D)

The other type of *E. huxleyi* recognized in the studied area is characterized by a relatively larger coccosphere, many more coccoliths forming a single coccosphere, and a relatively 'darker image' (i.e. showing less birefringence) under polarized light; this last phenomenon very likely results from the specimens being less strongly calcified than the characteristically thicker *E. huxleyi* type A.

E. huxleyi type K corresponds to the 'cold water form' of Nishida (1986), the cold-water type of Hallegraeff (1984) and *E. huxleyi* type C of Young and Westbroek (1991). An intermediate type that fits between the two extremes, and which is considered to be the overcalcified form of the latter type, was rarely observed.

Results

The total species assemblage of calcareous nannoplankton collected from surface water near the STC was characterized by the dominant occurrence of *Emiliana huxleyi*. *E. huxleyi* occupied more than 90% of the total assemblage in almost all samples collected (Table 1) within a SST range of 10° to 15°C (Fig. 3). The percentage abundance of *E. huxleyi* type A in the total of all *E. huxleyi* specimens increased with SST ($r^2 = 0.742$) in the study area (Fig. 4); abundance was high to the north of the STC and significantly lower to the south.

Fig. 5 displays the relationship between the composition of subdominant taxa and SST; data from samples 2P, 5P and 20P are excluded because they represent relatively few

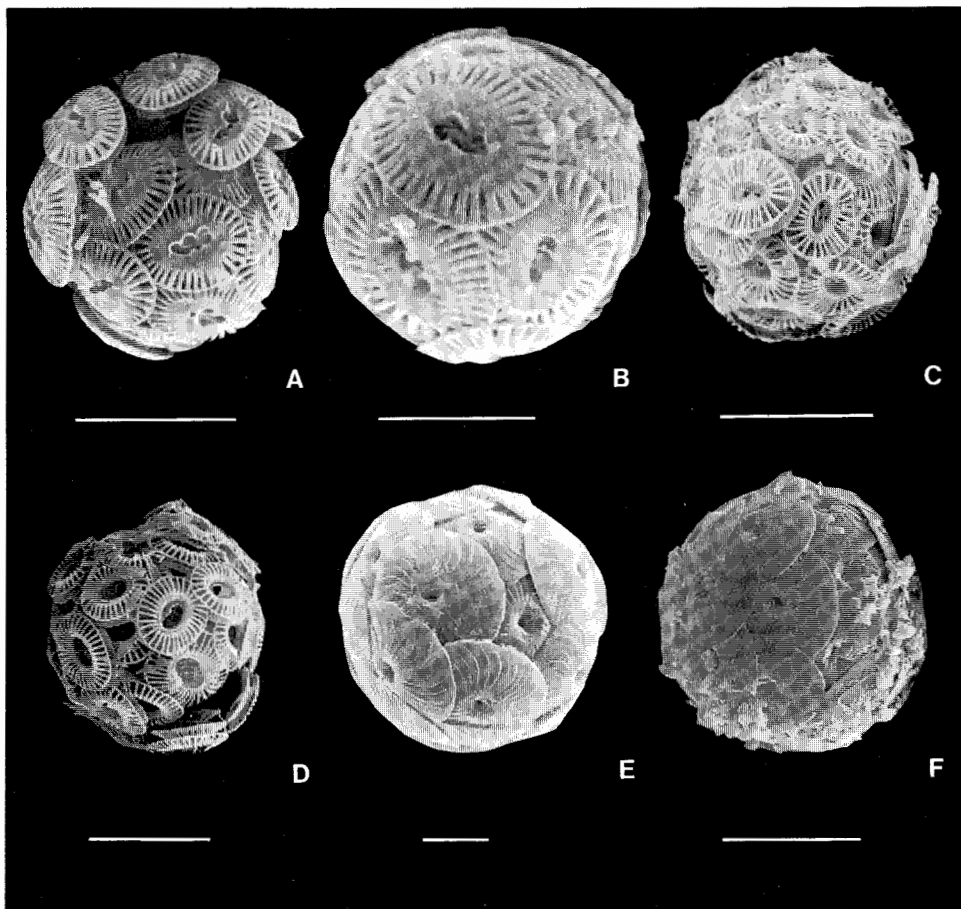


Fig. 2. Scanning electron photomicrographs of living coccolithophores collected during the *Franklin* cruise. (A–B) *Emiliana huxleyi* type A, both from sample 4P; (C–D) *Emiliana huxleyi* type K, both from sample 10P; (E) *Calcidiscus leptoporus*, sample 10P; (F) *Calcidiscus leptoporus*, small variety, sample 4P. All scale bars represent 5 μm , except for specimen B for which the scale represents 3 μm .

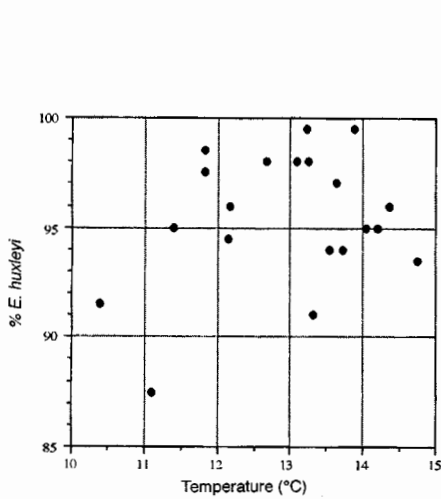


Fig. 3. Relationship between the percentage abundance of *Emiliana huxleyi* among all species and sea-surface temperature.

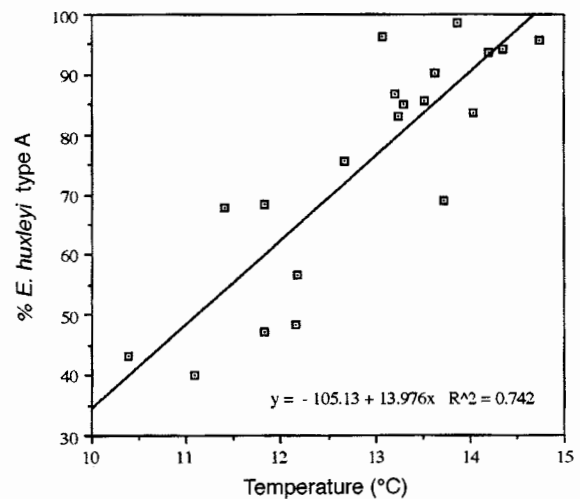


Fig. 4. Relationship between the percentage of *Emiliana huxleyi* type A among all *E. huxleyi* specimens and sea-surface temperature.

Table 1. Species occurrence chart for all samples

Sample No.	1P	2P	3P	4P	5P	6P	7P	8P	8P	9P
Latitude (S)	43.30	43.45	44.1	44.3	45	45.3	46	46.13	46.14	46.45
Longitude (E)	147.2	147.2	147.2	147.1	146.6	146.5	146.4	146.3	146.3	147
Temperature (°C)	13.88	13.09	14.36	14.75	13.3	13.25	13.21	11.4	12.31	12.67
Salinity (‰)	35	35.14	35.5	35.64	35.36	35.22	35.21	34.83	34.79	35.31
Water depth	Surface	Surface	Surface	Surface	Surface	Surface	Surface	Surface	50 m	Surface
Step 1										
<i>Emiliana huxleyi</i>	199	196	192	187	182	196	199	190	197	196
<i>Emiliana huxleyi</i> type A(%)	98.5	96.4	94.4	95.7	85.2	83.2	86.9	67.9	84.8	75.5
Subdominant taxa		1	4	8	13	3	4	1	10	3
Total	200	200	200	200	185	200	200	200	200	200
Step 2										
<i>Acanthoica quatorospina</i>	2	4	5	13		2	2	7		1
<i>Braarudosphaera bigelowii</i>		+					+			
<i>Calcidiscus leptoporus</i>	+	+	85	66	3	54	58	49	14	40
<i>Calcidiscus</i> aff. <i>leptoporus</i>										
<i>Calciosolenia murrayi</i>	+	+		+						
<i>Coccolithus pelagicus</i>		+	+	+		+	+	1	+	1
<i>Coccolithus streckerii</i>										+
<i>Gephyrocapsa ericsonii</i>										+
<i>Gephyrocapsa muelleriae</i>	4	2	+	5	+	2	6	1		1
<i>Gephyrocapsa oceanica</i>	+	1	+	+	+	+	2	+	+	1
<i>Helicosphaera carteri</i>	+	+	+			1	5	1	2	+
<i>Pontosphaera japonica</i>						+	+			
<i>Pontosphaera multipora</i>			+			+	+			
<i>Reticulofenestra productus</i>		+								
<i>Rhabdosphaera clavigera</i>										
<i>Scyphosphaera</i> spp.								+		
<i>Syracosphaera</i> spp.	94	30	10	16		41	27	39	28	51
<i>Thoracosphaera saxea</i>										
<i>Umbellosphaera irregularis</i>							+	2	1	5
<i>Umbellosphaera tenuis</i>		+								
<i>Umbilicosphaera sibogae</i>	+	+					+			+
Undetermined species										
Subdominant taxa total	100	37	100	100	3	100	100	100	45	100

specimens. The subdominant taxa are mainly *Calcidiscus leptoporus* (Fig. 2E) in combination with *Syracosphaera* spp. The absence of *C. leptoporus* from the samples collected adjacent to the Tasmanian coast (1P at 13.88°C and possibly 2P) suggests that this species is restricted to the open ocean. *Syracosphaera* specimens were not identified to species level under the polarized light microscope used for this study and electron microscopy may prove necessary for more detailed study of the genus.

The overall size variation of the coccoliths of *C. leptoporus* was remarkable. *C. leptoporus* with coccoliths smaller than 5 µm (Fig. 2F) is tentatively referred to here as *C. leptoporus* (small). Percentage abundance data for *C. leptoporus* (small) versus the total number of

C. leptoporus specimens are plotted against SST in Fig. 6. *C. leptoporus* (small) was abundant north of the STC but numbers were low south of the STC, presumably affected by the temperature contour of 13°C in the area in January 1994, possibly as a result of a change in water density or nutrient concentrations.

Discussion

The data presented above, which indicate a markedly higher percentage of *E. huxleyi* type A and *C. leptoporus* (small) north of the STC, suggest that it should be possible to reconstruct the position, and therefore migration, of the STC zone through time, on the basis of fossil material recovered from sediment cores judiciously located on either

collected during the RV *Franklin* cruise in January 1994

10P	11P	12P	13P	14P	15P	16	P17P	18P	19P	20P
46.57	47	46.36	46.13	45.49	45.25	45.01	44.38	44.15	44.01	43.31
147.2	147.33	137.58	148.2	148.45	149.09	149.37	149.53	150	150.27	149.47
11.82	10.38	11.83	11.09	12.15	12.17	13.63	13.53	114.21	14.04	13.27
35.17	34.2	34.74	34.49	34.63	34.62	35.03	35.04	35.08	35.01	35.04
Surface	Surface	Surface	Surface	Surface	Surface	Surface	Surface	Surface	Surface	Surface
197	183	195	175	189	192	194	188	190	190	188
68.5	43.2	47.2	40	48.3	56.8	90.2	85.6	93.7	83.7	69.1
4	17	5	25	11	8	6	12	10	10	12
200	200	200	200	200	200	200	200	200	200	200
3		4	7	9	4	17	3	19	26	
		+				+				
58	91	72	61	49	51	51	61	76	53	1
					2	1				
			1							
1			+	+	+	1	8	+	+	+
+	+	1	1	1	+	4	3	+	8	+
+			4		+	2	+		+	
2	1	1	2	1	2	4	6	+	+	+
							+			
							+			
30	+									
	7	20	27	34	37	21	17	5	13	18
		1		+		1				
4	1	1	1	2	4					
							+			
2										
100	100	100	100	100	100	100	100	100	100	19

side of the present STC. However, there are problems when observations of living nannoplankton are applied to palaeoceanographic studies based on sediment samples recovered from the sea floor.

Firstly, the floral composition of the water samples represents collections made only once (i.e. a fraction of time in comparison with a fossil sample that may represent the deposition of several years or decades of floral productivity at the sea surface). With a sedimentation rate of approximately 1000 years cm^{-1} in this area (ANU Geology Department, unpublished data), postulation of past oceanic events by extrapolating from our present collection results to fossil material is ambitious. Moreover, it is necessary to consider seasonal changes in floral composition. So far,

information dealing with seasonal change is scant except for a study of stations in the Atlantic Ocean (Okada and McIntyre 1979) in which *Coccolithus pelagicus* almost monopolized the flora during spring and summer in the Northern Hemisphere, whereas *E. huxleyi* dominated during the rest of the year at high latitudes (Stations Bravo and Charlie) in the Atlantic Ocean. The composition of the top sample taken from a core collected at Station 18P off Tasmania (core GC-3), where *E. huxleyi* dominates the floral counts (~80%), similar to counts from the water samples at the same site in the present study, suggests that there is no marked seasonal change in floral composition in the area but probably only a seasonal change in productivity.

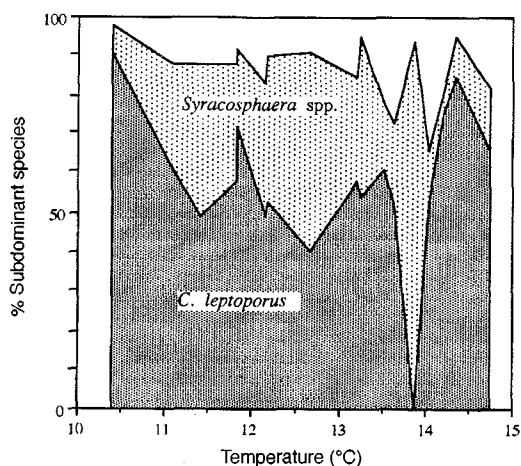


Fig. 5. Relationship between the composition of the subdominant taxa and sea-surface temperature. The absence of *C. leptoporus* at 13.8°C is due to the sample location, which is the nearest point to the Tasmanian coast.

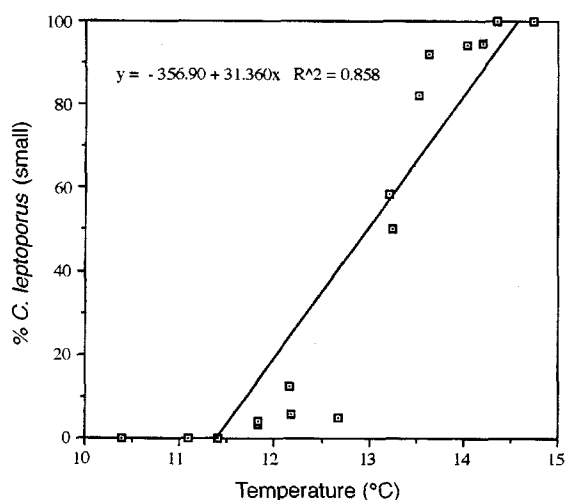


Fig. 6. Relationship between the percentage of *Calcidiscus leptoporus* (small) among the total of *C. leptoporus* and sea-surface temperature. Note the consistently low values of *C. leptoporus* (small) for temperatures lower than 13°C.

Secondly, during the cruise, only surface-water samples were collected except for one sample at 50 m at Station 8P. Thus, the data only permit a description of the floral composition at the sea surface. In contrast, the nanoplankton record in sediment samples represents the accumulation of taxa living within the entire photic zone. At low latitudes, species composition of the upper photic zone is completely different from that of the lower photic zone, where the characteristic species such as *Florisphaera profunda* and *Thorosphaera flabellata* abound (Okada and Honjo 1973). According to Nishida (1986), *E. huxleyi* is dominant in all

water samples collected between 0 and 50 m depth at his Stations 1, STC-1 and 1-1, which are located near the present study area. In the lower photic zone (150 m depth), where productivity decreases, *E. huxleyi* is once again the principal species and the characteristic dwellers in the lower photic zone at low latitudes, such as mentioned above, are not observed at high latitudes. The floral composition at 50 m depth at Station 8P is also dominated by *E. huxleyi*. These data suggest that the marked differences in vertical distribution of calcareous nanoplankton found elsewhere may not be reflected in the present study area.

Thirdly, the fossil floral composition of sediment samples can be affected by dissolution. The species that are resistant to dissolution selectively remain in poorly preserved samples, i.e. those that have undergone dissolution to some extent. In the study area, large numbers belonging to the genus *Syracosphaera*, which have fragile coccoliths and which were represented in the water samples, are not observed in any of the sediment samples. Therefore, abundance of a species may differ substantially between water and sediment samples, and consequently it is necessary to consider species common to both communities when data of water samples are applied to sediment samples.

Finally, the STC migrates seasonally and interannually. Harris *et al.* (1987) described the seasonal and interannual variability of water masses, phytoplankton biomass and primary productivity of the water off eastern Tasmania. Because of this variability, the position of the STC ought to be recorded within the sedimentary pile on the sea floor in the southern portion of the Tasman Sea. The present data on living material will permit us to trace the position of the STC, particularly through examination of the presence and abundance of *E. huxleyi* type A and *C. leptoporus* (small) fossil material.

Hence, there are still many hurdles to be overcome when data from collection of living nanoplankton are applied to palaeoceanographic studies. Nevertheless, it has already been possible to demonstrate substantial changes in the Tasman Sea through time by relying on collections of coccoliths recovered from core-top material from the Coral and Tasman Seas (Hiramatsu and De Deckker, in press *a*) and through examination of the calcareous nanoplankton fossil material extracted from three cores along a north-south transect in the Tasman Sea (Hiramatsu and De Deckker, in press *b*).

Acknowledgments

We thank Japan Petroleum Exploration Co. Ltd for allowing us to publish this paper. We thank the members of the Australian Marine Quaternary Program, and crews of RV *Franklin* for their helpful advice and sampling. We are also grateful for the comments of an anonymous reviewer who helped towards improving our manuscript.

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Manuscript received 27 April 1995; revised and accepted 2 May 1996