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## Calcareous Nannofossils from Cape Roberts Project Drillhole CRP-3, Victoria Land Basin, Antarctica

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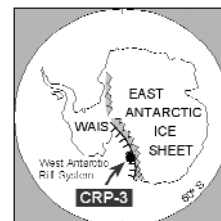
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**Abstract** - Fossil specimens of the exclusively oceanic calcareous nannoplankton were found only in the upper 200 m of the Cape Roberts Project 3 (CRP-3) cores. These assemblages are depauperate and sporadic in occurrence. The majority of the assemblages contain fewer than 4 species, indicating a severe palaeoecological restriction. The clear domination of these assemblages by reticulofenestrid species, coupled with the almost total exclusion of *Coccolithus pelagicus*, indicates cold surface water conditions in the Victoria Land Basin during the lives of these poor algae. These cold surface water conditions, perhaps coupled with abnormal surface water chemistry, excluded almost all of the age-diagnostic species from the area. The occurrence of *Transversopontis pulcheroides*, however, suggests a biostratigraphic assignment of lower Oligocene for this part of the core. The CRP-3 assemblages occur within fine-grained clastic sedimentary rocks, but only those that are in close stratigraphical proximity with coarser-grained lithologies.



### INTRODUCTION

Scientific drilling at Cape Roberts, Antarctica (Fig. 1) has yielded three overlapping records spanning the Oligocene through Quaternary history of sedimentation in the rifted Victoria Land Basin. By taking advantage of dipping strata and only minimally buried subcrops of older material, the Cape Roberts Project (CRP) has been able to core over 1600 metres of Cenozoic sediment. CRP-1, drilled in 1997, recovered a thin sequence of Neogene and Quaternary glaciogenic sediment. Drilling in the 1998 season yielded CRP-2 and CRP-2A, containing Miocene to Quaternary and Oligocene to Miocene sections, respectively. Results from both CRP-1 and CRP-2 indicate that the Pliocene and most of the Miocene are absent or relatively thin in the study area. During 1999, the last field season of the project, CRP-3 (located at 77.0106°S, 163.6404°E) penetrated through a thick section of glaciogenic clastics of Oligocene age, unconformably overlying intruded Beacon Supergroup sedimentary rocks of probable Late Palaeozoic age.

Calcareous nannofossils occur in parts of the sections recovered from all three years of Cape Roberts drilling. Results from CRP-1 (Villa & Wise, 1998) suggest that calcareous nannoplankton were absent from the Victoria Land Basin during the Quaternary. Villa & Wise (1998) observed only rare specimens of *Thoracosphaera* (a calcareous

dinoflagellate) in the CRP-1 Quaternary. Results from both CRP-1 and CRP-2 (Watkins & Villa, 2000) suggest that calcareous nannoplankton did not inhabit this part of the Ross Sea during the early Miocene, as nannofossils do not occur in rocks of this age. The stratigraphically-highest calcareous nannofossils include *Dictyococcites bisectus*, indicating a minimum age of latest Oligocene. Late Oligocene nannoplankton in the Ross Sea of the Cape Roberts region consisted of sparse, depauperate assemblages dominated by small *Reticulofenestra* and *Dictyococcites* species that only occasionally invaded the study area. The early Oligocene record of nannoplankton in the area is complicated by reworking (Watkins & Villa, 2000), making it difficult to determine if and when nannoplankton actually inhabited the study area.

### METHODS

The entire section from CRP-3 above the contact with the Beacon Supergroup was sampled and examined for calcareous nannofossils. Samples were chosen preferentially from fine-grained lithologies or at least from sedimentary rocks with fine-grained matrix material. All samples were examined initially by using smear slides of raw sediment. In most cases, no additional sample preparation was done. A few coarser-grained sediments were processed by a

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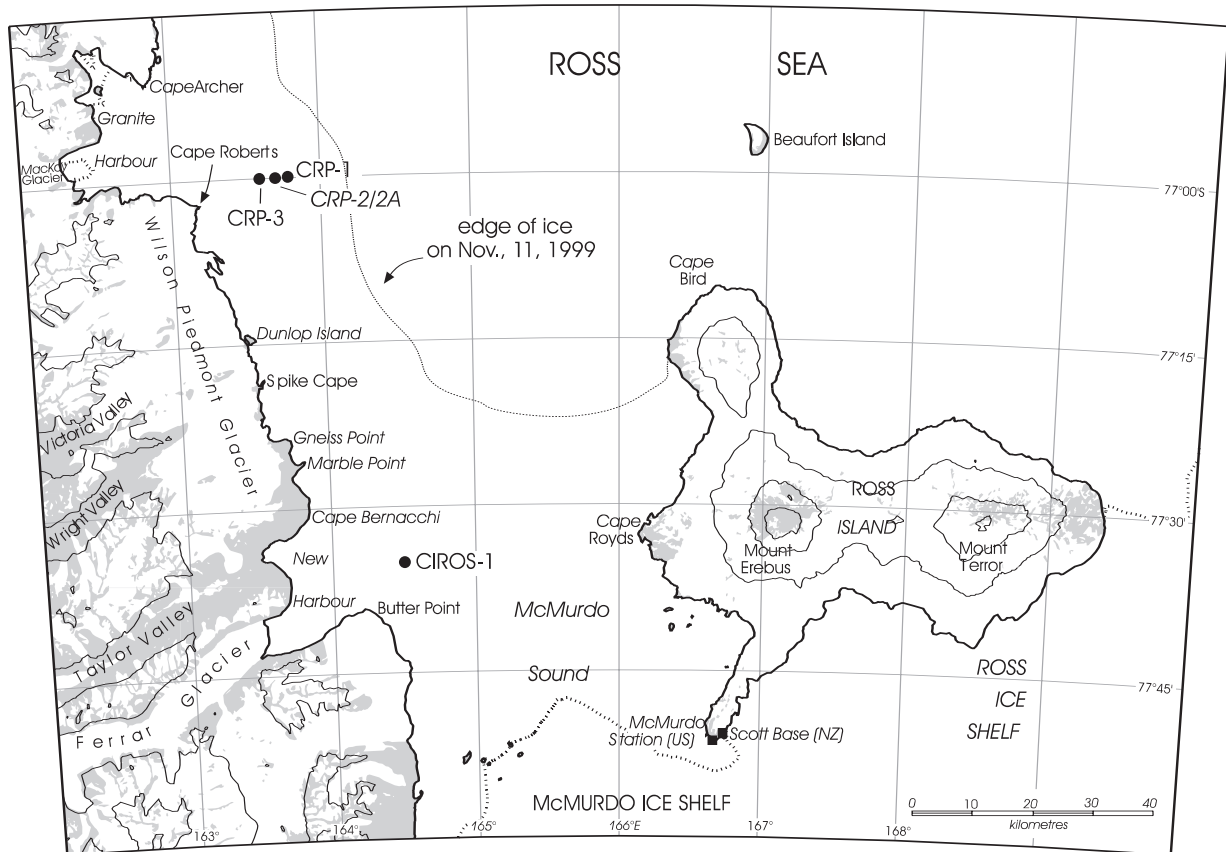


Fig. 1 - Location of Cape Roberts Project drill sites and environs.

gravitational settling technique in which approximately  $0.1 \text{ cm}^3$  of sediment was disaggregated and suspended in sufficient purified water to constitute a column of approximately 2 cm height in a small closed vial. This suspension was allowed to settle undisturbed for 60 seconds, at which point an aliquot of the supernatant was withdrawn with a pipette and mounted on a cover glass. This procedure removed grains larger than approximately 20 micrometres from the supernatant, and thus concentrated the finer, nanofossil-bearing size fraction. Many of these slides were prepared originally to concentrate siliceous microphytoplankton fossils, and use of these existing preparations greatly expedited our work.

Nanofossils occur in only some samples in the CRP-3 section. Even in these samples, nanofossils are an extremely rare sedimentary component (much less than 1%). As such, the traditional estimators of calcareous nanofossil abundance as a sedimentary component yield little information, as they all would be either B (Barren) or V (Very rare). Conventions for reporting the semi-quantitative relative abundance of different calcareous nanofossil species are also difficult to apply to these extremely sparse assemblages. As a result, we have reported the raw number of each different species counted in two longitudinal transects of the cover slip at 1250x.

## RESULTS

A total of 248 samples were examined for nanofossil occurrence and biostratigraphy in the CRP-3 sequence above 782 metres below sea floor (mbsf). Fast-track samples and prepared (non-acidified) diatom settled slides were used to locate promising horizons for further examination. Additional smear slides were then prepared and examined to further define the nanofossil-bearing intervals. Calcareous nanofossils were observed only from the upper 194 m of CRP-3 core. The nanofossil assemblages are not ubiquitous in this upper 194 m, but occur restricted to certain stratigraphic intervals that are separated by rock that is barren of calcareous nanofossils (Fig. 2). The characteristics of the nanofossils in these intervals are discussed below.

Calcareous nanofossils occur in the upper two samples examined from CRP-3. Two specimens (one each of *Dictyococcites daviesii* and *Dictyococcites productus*) were observed in a sample from 2.85 mbsf. The sample at 5.01 mbsf contains a few more specimens of these taxa and also several specimens of *Reticulofenestra hampdenensis*. This assemblage is similar to the *in situ* assemblages from the upper Oligocene documented by Watkins & Villa (2000), so they may be assumed to be in place. However, the CRP-3 assemblages occur in sediments that are very

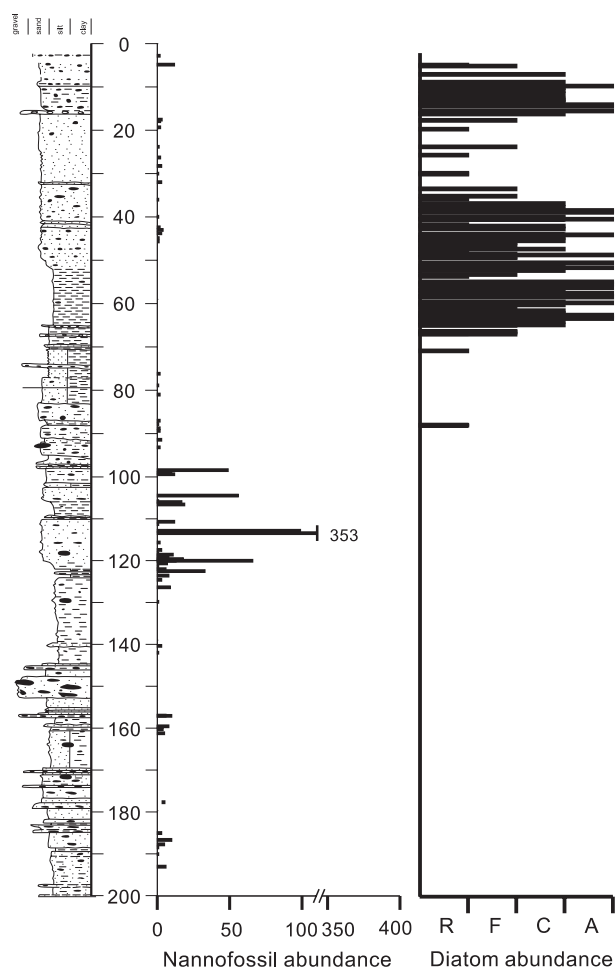


Fig. 2 - Numerical abundance of calcareous nannofossil assemblages from CRP-3 (center column) compared to diatom abundance (right column). Nannofossil abundance is the number of specimens encountered in two random traverses of the slide at 1250x. Diatom abundance is expressed as follows: R = rare; F = few; C = common; and A = abundant. Note that the distribution of nannofossil-bearing samples is non-random (see text), also that diatom abundance and calcareous nannofossil abundance trends are not coincident.

close to a seafloor that has been actively eroded during the Neogene and Quaternary (as demonstrated by the lack of overlying sedimentary cover). In addition, this upper part of the cored section is highly drilling-disturbed. Thus, it is impossible to ascertain whether these are *in situ* lower Oligocene assemblages, or have been transported in either time or space.

Calcareous nannofossil assemblages occur in the fine-grained matrix of several sandy rocks from 17.82 through 46.42 mbsf. These assemblages consist almost exclusively of *Dictyococcites daviesii*, with only a few fragmentary specimens of *Thoracosphaera heimii* and *Thoracosphaera saxea* in sample 44.98 mbsf. These calcareous dinoflagellate cysts are often produced at times of abnormal surface water conditions (e.g., eutrophication events, high fluvial discharge), and are reminiscent of the Quaternary assemblage in CRP-1 documented by Villa & Wise

(1998).

No calcareous nannofossils were observed from samples in the interval 44.6 to 77.11 mbsf. This absence is notable, as considerable efforts were made to locate calcareous nannofossils within the fine-grained sedimentary rocks of this diatom-rich interval.

Sparse, depauperate calcareous nannofossil assemblages occur in some of the samples in the interval from 77.46 through 95 mbsf. Only one to three specimens per double transect were observed, reflecting low abundances of nannofossils. *Dictyococcites daviesii* was present in all of these assemblages, and often was the only species observed. Other species observed in this interval included *Dictyococcites productus*, *Reticulofenestra hampdenensis*, and a single specimen of *Transversopontis*. The single *Transversopontis* specimen is partially obscured in the smear slide (Sample 94.72 mbsf), preventing definitive species attribution. It has features common to both *T. obliquipons* and *T. pulcheroides*, but the poor preservation and presentation on the slide make it impossible to see the surface ornamentation that would differentiate the exact species. It has been denoted on the range chart (Tab. 1) as *T. pulcheroides*, but may actually be *T. obliquipons*.

The interval from 100 to 131 mbsf contains the most abundant nannofossil assemblages in the entire sedimentary section recovered by Cape Roberts drilling (Fig. 2). The relatively high number of specimens in this interval allows some meaningful quantitative analysis of these assemblages. *Dictyococcites daviesii* occurs in all of these samples and comprises the majority of specimens in these assemblages. There is a sizable variation in the percentage of *D. daviesii*. This is exemplified by considering the two most populous samples (114.31 and 114.89 mbsf), which contain 60% and 88% *D. daviesii* (respectively). *Reticulofenestra hampdenensis* and *D. productus*, together comprise 10-20% of these assemblages, although the contribution of each of these two species varies widely amongst the samples in this interval. *Dictyococcites bisectus* and *Dictyococcites scrippsae* are common accessory species. A single specimen of *Chiasmolithus altus* occurs in the richest sample in the sequence (114.89 mbsf; Fig. 2). In addition, three samples (114.31, 114.89, and 121.36 mbsf) contain *Transversopontis pulcheroides*.

The nannofossil-rich interval from 100 to 131 mbsf is underlain by about 10 m of largely barren sedimentary rock comprised of coarse-grained clastic sediments. Samples at 141.32 and 142.93 mbsf contain isolated specimens of *D. daviesii* and *R. hampdenensis*, respectively. The interval from 157.7 to 161.9 mbsf records another episode of relatively high nannofossil abundance accompanied by good preservation. These assemblages reflect the same basic population structure as those from 100 to 131

Tab. 1 - Range chart of calcareous nannofossils identified in samples from CRP-3. The "Abundance" column denotes the abundance of calcareous nannofossils as a sedimentary component, where B = barren, V = very rare (1-2 specimens per longitudinal traverse of the 40-mm smear slide), R = rare (3-10 specimens per traverse), and F = few (10-100 specimens per traverse). The "Preservation" column denotes the average preservation of the fossils, with P = poor (severely dissolved so that species identification is frequently impaired), M = moderate (species identification only occasionally impaired by diagenesis), and G = good (mild or no diagenesis, species identification not impaired).

Sample depth	Abundance	Preservation	<i>Braarudosphaera bigelowii</i> (coccosphere)	<i>Chiasmolithus altus</i>	<i>Chiasmolithus oamaruensis</i>	<i>Coccolithus pelagicus</i>	<i>Dicryococites birectus</i>	<i>Dicryococites daviesii</i>	<i>Dicryococites heslandii</i>	<i>Dicryococites productus</i>	<i>Dicryococites scrippsae</i>	<i>Reticulofenestra hamdensis</i>	<i>Thoracosphaera</i> sp. cf. <i>T. heimi</i>	<i>Thoracosphaera</i> sp. cf. <i>T. saxeae</i>	<i>Transverseponis putcheroides</i>	" <i>Coccosphaera pachyderma</i> "	# Specimens	Species richness
2.85	D	V	M					1									2	2
5.01	D	V	M					8		1		3					12	3
6.87	D	B															0	0
15.99	D	B															0	0
17.82	D	V	M					3									3	1
18.02	D	V	G					2									2	1
18.19	D	V	M					2									2	1
19.10	D	B															0	0
19.62	D	V	M					1									2	2
22.12	D	B													1		0	0
22.26	D	V	P					1?									0	0
22.75	D	B															0	0
23.34	D	B															0	0
24.20	D	V	P					1									1	1
25.08	D	B															0	0
26.72	D	V	M					2									2	1
28.44	D	B															0	0
28.70	D	V	M					3									3	1
30.50	D	V	M					1									1	1
32.20	D	B															0	0
32.51	D	V	M					3									3	1
33.21	D	B															0	0
35.70	D	B															0	0
36.61	D	V	P										1				1	1
37.29	D	B															0	0
39.35	D	B															0	0
40.63	D	V	M					1									1	1
41.00	D	B															0	0
41.75	D	B															0	0
43.09	D	V	M					2									2	1
43.72	D	V	M					4									4	1
44.18	D	B															0	0
44.50	D	V	M					1					1	1			3	3
44.98	D	B															0	0
45.63	D	V	P					1									1	1
46.04	D	B															0	0
46.42	D	V	M					1									1	1
47.60	D	B															0	0
77.11	D	B															0	0
77.45	S	V	M					1				1					2	2
77.80	D	B															0	0
80.19	D	V	M					1									1	1
80.33	D	B															0	0
81.98	D	B															0	0
82.34	D	V	P					2?		2							2	1
83.04	D	B															0	0
88.18	D	B															0	0
88.46	S	V	M					1				1					2	2
89.25	D	V	M					1									1	1
90.24	S	V	M					1				1					2	2
90.86	D	V	M					2									2	1
91.91	D	B															0	0
92.94	S	V	M					2				1					3	2
93.52	D	B															0	0
94.72	S	V	M					1							1		2	2
96.06	D	B															0	0
98.13	D	B															0	0
100.07	S	F	M				6	21		8	3	11					49	5
100.75	S	R	G			1		5		1		3					10	4
101.03	D	F	G					11				1					12	2
104.62	D	B															0	0
106.07	S	F	G				2	28		9		17					56	4
107.37	D	V	P					1									1	1
107.58	S	F	M					14		1		2					17	3
108.16	D	F	M					15		2						2	19	3
110.98	D	B															0	0
112.21	S	F	M					8				4					12	2
112.77	D	V	P										1				1	1
114.31	S	F	G				5	60		10	3	20			1		99	6

Tab. 1 - Continued.

Sample depth	Abundance	Preservation	<i>Braarudosphaera bigelowii</i> (coccosphere)	<i>Chiasmolithus altus</i>	<i>Chiasmolithus oamaruensis</i>	<i>Coccolithus pelagicus</i>	<i>Dictyococites bisectus</i>	<i>Dictyococites daviesii</i>	<i>Dictyococites hesslandii</i>	<i>Dictyococites productus</i>	<i>Dictyococites scrippsae</i>	<i>Reticulofenestra hampdenensis</i>	<i>Thoracosphaera</i> sp. cf. <i>T. heimii</i>	<i>Thoracosphaera</i> sp. cf. <i>T. sazea</i>	<i>Transversopontis pulcheroides</i>	" <i>Coccosphaera pachyderma</i> "	# Specimens	Species richness
114.89	D	F	G					311	1	27	3	6					353	8
117.07	D	V	M		1			1				1					2	2
118.84	D	V	M					2				1					3	2
119.60	D	V	M					1									1	1
119.93	S	V	M					8				3					11	2
120.33	D	V	M					2									4	2
120.56	D	R	P					4		1		3					8	3
120.97	S	R	G				2	10		1	1	4					18	5
121.07	D	V	G					5									5	1
121.36	D	F	G				4	36		5	3	15			2	1	66	7
121.36	D	F	G					11			1	1					13	3
121.98	D	V	M					6			1						7	2
122.81	D	V	M					1									1	1
123.33	D	V	M					3		3							6	2
123.78	S	F	G				1	23		2		7					33	4
124.84	D	V	M					8									8	1
125.83	S	V	M					2				1					3	2
127.58	S	R	M					6		1		2					9	3
128.91	D	B															0	0
130.20	D	B															0	0
131.00	D	V	M	1													1	1
132.26	D	B															0	0
140.66	D	B															0	0
141.32	S	V	M					3									3	1
142.41	D	B															0	0
142.93	S	V	M									1					1	1
144.61	D	B															0	0
155.87	D	B															0	0
157.70	D	V	M					6									6	1
157.75	S	R	M					5		1	2	2					10	4
159.05	D	B															0	0
160.19	S	V	M					4		1		3					8	3
160.36	D	V	M					4									4	1
160.87	S	V	M					2		1					1		4	3
161.84	D	V	M					3				2					5	2
162.10	D	B															0	0
177.35	S	B															0	0
178.01	D	V	M					2									2	1
179.13	S	B															0	0
183.95	D	B															0	0
185.25	S	V	M		1			1		1							3	3
185.79	D	B															0	0
186.85	S	R	M					7		1	1	1					10	4
187.89	D	V	M					5									5	1
188.61	S	V	M					1									1	1
190.18	D	V	M					1									1	1
191.30	S	B															0	0
191.93	D	B															0	0
193.14	S	V	M					2		2		2					6	3
194.41	D	B															0	0
257.16	S	B															0	0
266.27	S	V	M					1									1	1
278.54	S	B															0	0

mbsf, with *D. daviesii* being the dominant species and other reticulofenestrads comprising the secondary taxa. *Transversopontis pulcheroides* is also present in at least one of the samples in this interval, indicating the persistent nature of this taxon below its occurrences near 114 mbsf.

An interval barren of calcareous nannofossils extends from 162 to 185 mbsf, interrupted only by the occurrence of *D. daviesii* in sample 178.01 mbsf. The lowest interval of nannofossil presence occurs between 185 and 193.2 mbsf. *Dictyococites daviesii* was observed in all nannofossil-bearing samples in

this interval. A few samples also contained *R. hampdenensis* and *D. productus*. A single specimen of *Chiasmolithus oamaruensis* was observed in a sample from 185.25 mbsf. This relatively large nannofossil is characteristic of upper Eocene and lowest Oligocene sediments throughout the oceanic system, but is more common in higher latitudes. The youngest documented occurrence of this species is within the *Blackites spinosus* Zone of earliest Oligocene age at Site 511 on the Falkland Plateau (Wise, 1983).

A single specimen of *D. daviesii* was found in a sample from 266.27 mbsf. Additional slides from this

sample do not contain any nannofossils, suggesting that this single occurrence might be a laboratory contaminant. No other nannofossils have been observed in samples from 195 to 781.4 mbsf. This is not unexpected, given the coarse-grained nature of sediment that dominates this interval, the suspected depositional environment, and high sedimentation rate for this material. In addition, some of the samples between 600 and 780 mbsf yield clay-sized authigenic smectite precipitated interstitially within the sandstone host rock (Wise et al., this volume). These indicate fluid movements and diagenetic processes that may have affected nannofossil preservation in the lower part of the Cenozoic section.

#### CALCAREOUS NANNOFOSSIL BIOSTRATIGRAPHY

In general, the sparse assemblages in the upper 200 m of CRP-3 are not age diagnostic. The absence of many important groups of Palaeogene calcareous nannoplankton, including the discoasters, sphenoliths, helicosphaerids, and even coccolithids, was due undoubtedly to ecological exclusion rather than biostratigraphical constraints. In this light, biostratigraphical arguments that are based on the absence of taxa must be viewed with caution. Given this caveat, there is evidence that suggests a lower to mid-Oligocene placement for the upper 200 m of CRP-3, based on the lack of other taxa known to occur in the sedimentary sequence of the Victoria Land Basin (*i.e.* CIROS-1 and CRP-2A). The absence of several species of the genus *Reticulofenestra*, including *R. minuta*, *R. haqii*, and *R. minutula*, in CRP-3 is probably biostratigraphical in nature (*i.e.*, not the result of environmental exclusion). These small diameter (<5 micrometres) reticulofenestrids first occur at *c.* 340 mbsf in CRP-2A, at a level that is no older than early late Oligocene (Wilson et al., 2000). Thus, their absence in CRP-3 suggests that this section is stratigraphically below the lower upper Oligocene. In a similar way, the absence of *Reticulofenestra oamaruensis* indicates that this assemblage is not latest Eocene in age. *Reticulofenestra oamaruensis* has a well-calibrated upper Eocene range in the Southern Ocean. More importantly, it is known to occur in CIROS-1 (Edwards & Waghorn, 1989; Wei, 1992; Monechi & Reale, 1997) and (as a reworked component) in CRP-2 (Watkins & Villa, 2000). Therefore, its absence from CRP-3 is most probably biostratigraphical.

Two additional lines of evidence suggest an earliest Oligocene age for the upper 200 mbsf of CRP-3. The last appearance datum (LAD) of *Transversopontis pulcheroides*, in sample 114.13 mbsf, is a useful biostratigraphical indicator. The highest stratigraphical occurrence for this species has been documented from near the midpoint of the lowest Oligocene *Blackites spinosus* Zone on the Falkland Plateau (Wise, 1983). This last occurrence

datum is best expressed in the relatively shallow Deep Sea Drilling Project (DSDP) Site 511, although it is evident even in the deeper water DSDP Site 513. Although *T. pulcheroides* has not been observed in all (nannofossil-bearing) samples from CRP-3, its occurrence in the three richest samples of the interval from 100 to 131 mbsf imply that this interval of CRP-3 is below the lowest Oligocene LAD of this species. Secondly, *Chiasmolithus oamaruensis* is a relatively large nannofossil that is characteristic of upper Eocene and lowest Oligocene sediments throughout the oceanic system. Although cosmopolitan in distribution, it tends to be much more abundant in sediments deposited at higher latitudes. The youngest documented occurrence of this species is within the *Blackites spinosus* Zone of earliest Oligocene age at Site 511 on the Falkland Plateau (Wise, 1983). The significance of the occurrence of the single specimen of *C. oamaruensis* (sample 185.25 mbsf) is questionable. The fact that this species occurs only as an isolated individual specimen is possibly a result of reworking.

The available biostratigraphical evidence from calcareous nannofossils consistently suggest an assignment of an earliest Oligocene age for the upper 200 mbsf of CRP-3. None of the lines of evidence is particularly strong, given the depauperate and sparse nature of the calcareous nannofossil assemblages. This age determination is corroborated by diatom biostratigraphy (Harwood & Bohaty, this volume), and is an internally-consistent part of the geochronological age model for this locality (Hannah et al., this volume).

#### THE SIGNIFICANCE OF NANNOFOSSIL OCCURRENCE

Calcareous nannofossils are extremely rare in the CRP-3 samples. None of the samples examined contain calcareous nannofossils in rock-forming quantities. Concentrations of nannofossils in many samples are so low that the possibility of their being derived from reworking is significant. Indeed, at least some, similarly sparse assemblages from CRP-2 were shown to be reworked (Watkins & Villa, 2000). Although extreme sparsity is suggestive of reworking, it is by no means a definitive criterion. Reworking can only be demonstrated where there is a clear biostratigraphical incongruity. For example, very sparse but well-preserved specimens of *Reticulofenestra oamaruensis* in CRP-2 (449.35 to 474.63 mbsf) indicate a latest Eocene age, whereas diatom biostratigraphy, strontium isotope stratigraphy, and palaeomagnetic geochronology indicate a middle early Oligocene age for this interval (Scherer et al., 2000; Lavelle, 2000; Wilson et al., 2000). In the case of the CRP-2 material, more than one line of evidence indicates the biostratigraphical incongruity that betrays the reworked nature of *R. oamaruensis*.

There is no compelling evidence for reworking of

calcareous nannofossils in the CRP-3 section. As stated above, the little biostratigraphical evidence derived from the calcareous nannofossil assemblages is consistent with the siliceous microfossil biostratigraphy and the geochronological age model. Thus, if there was any reworking of nannofossils, it occurred so briefly after initial deposition as to be biostratigraphically undetectable. Given this (internal) consistency, the assemblages from CRP-3 are assumed to be autochthonous representations of the calcareous nannoplankton that sporadically inhabited the surface waters of the Victoria Land Basin during the earliest Oligocene.

The distribution of calcareous nannofossil assemblages relative to lithology is not random in the upper 200 mbsf of CRP-3 (Fig. 2). Calcareous nannofossils tend to be present in the fine-grained matrix of sandstones. Nannofossils are absent from conglomerates and the coarsest-grained sandstones. This may indicate the absence of calcareous nannoplankton in the surface waters near the glacial ice margin. Alternatively, the absence of nannofossils may be a mere artifact of removal by current winnowing (in some cases) or diagenesis. The latter alternative is suggested by the calcitic cement that is common in these coarse-grained intervals. More perplexing is the absence of calcareous nannofossils from the finest-grained intervals (Fig. 2). Normally, it is expected that nannofossils should be the most abundant in sediments that are the finest-grained, as these sediments represent depositional environments that are most distal to the glacial ice margin. In addition, such fine-grained sediments are often associated with sea level high stand, when the flooding of oceanic surface waters into the basin should be at its maximum. However, this is not the case with the CRP-3 assemblages. A most notable example of this discrepancy is illustrated by the prominent siltstone interval from 52 to 65 mbsf (Fig. 2), which is characterized by abundant to common diatoms and other siliceous microfossils but contains no nannofossils. This interval, interpreted as a high stand systems tract (Cape Roberts Science Team, 2000), should have the greatest concentration of nannofossils based on its proposed depositional environment and sequence stratigraphic interpretation. Instead, it is barren of calcareous nannofossils. This remains a puzzling feature of the CRP-3 nannofossil record.

Assemblages are species poor in the upper 200 mbsf of CRP-3 (Tab. 1). Many of the assemblages contain only one or two species, while the richest assemblage (114.89 mbsf) contains only seven different taxa. Most of these species are reticulofenestrid placoliths, with *Dictyococcites daviesii* comprising the bulk of the specimens. None of the other (non-reticulofenestrid) taxa make up a numerically significant fraction of the assemblage. These other taxa include *Transversopontis* and

*Chiasmolithus*, two taxa known to have inhabited the Southern Ocean during the Oligocene. Only one single specimen of *Coccolithus pelagicus*, a species that is considered cosmopolitan in the Oligocene, was observed (in sample 100.75 mbsf). This specimen is poorly preserved, with corroded margins, differing markedly from the preservation of other specimens in this sample. This differential preservation, coupled with the singularity of its occurrence, suggests that it may be a reworked specimen. Significantly absent are representatives of "typical" lower Oligocene assemblages including *Discoaster*, *Sphenolithus*, *Ericsonia*, *Helicosphaera*, and *Isthmolithus*. Although the lack of *Discoaster* and *Sphenolithus* is probably a reflection of the cool temperatures of the surface water in the Victoria Land Basin, the other taxa are well known from the Southern Ocean during the early Oligocene. This suggests that the surface water conditions in the Victoria Land Basin were subnormal during the early Oligocene.

## CONCLUSIONS

The extremely rare nannofossils that occur in the CRP-3 section are characterized by low species richness, low diversity, and domination of the assemblages by reticulofenestrid placoliths. These depauperate nannofossil assemblages indicate that marginal conditions for calcareous nannoplankton existed during the Oligocene in McMurdo Sound. The lack of sphenoliths and discoasters indicates very cool surface waters that were near the lower thermal limits for nannoplankton growth. In addition to thermal constraints, the high dominance/low diversity assemblages suggest that subnormal surface water conditions may have existed in the Victoria Land Basin during the early Oligocene. The available biostratigraphical evidence from nannofossils suggests an earliest Oligocene age for the upper 200 mbsf of CRP-3. However, the largely monotaxic nature of these assemblages indicates that conditions for calcareous nannoplankton were very marginal, so that an assignment based on the absence of taxa is tenuous at best.

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Appendix 1 – List of species mentioned in the text.

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- Chiasmolithus altus* Bukry & Percival, 1971  
*Chiasmolithus oamaruensis* (Deflandre) Hay, Mohler & Wade, 1966  
*Coccolithus pelagicus* (Wallich) Schiller, 1930  
*Dictyococcites bisectus* Hay, Mohler & Wade, 1966  
*Dictyococcites productus* (Kamptner) Backman, 1980  
*Dictyococcites scrippsae* Bukry & Percival, 1971  
*Dictyococcites daviesii* (Haq) Perch-Nielsen, 1971  
*Reticulofenestra hampdenensis* Edwards, 1973  
*Reticulofenestra haqii* Bachman, 1978  
*Reticulofenestra minuta* Roth, 1970  
*Reticulofenestra minutula* (Gartner) Haq & Berggren, 1978  
*Reticulofenestra oamaruensis* (Deflandre) Stradner & Edwards, 1968  
*Thoracosphaera heimii* Kamptner, 1941  
*Thoracosphaera saxea* Stradner, 1961  
*Transversopontis obliquipons* (Deflandre) Hay, Mohler & Wade, 1966  
*Transversopontis pulcheroides* (Sullivan) Baldi-Beke, 1971
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