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54. *DATA REPORT:* PALEOGENE CALCAREOUS NANNOFOSSIL BIOSTRATIGRAPHY OF DSDP SITE 210 OFFSHORE NORTHEASTERN AUSTRALIA[1]

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INTRODUCTION

The major objectives of Leg 133 were (1) to define the evolution of the carbonate platforms on the northeastern Australian margin, including their relationship to adjoining basins; and (2) to understand the effects of climate and sea level on their development in space and time (Davies, McKenzie, Palmer-Julson, et al., 1991). Sixteen sites were drilled (Fig. 1), and more than 5.5 km of Neogene core was recovered during Leg 133. However, recovery of Paleogene sediments was unexpectedly poor (a total of a few meters), and the sediments were poorly dated because of strong diagenesis. On the other hand, Site 210 drilled in this region during Leg 21 yielded an expanded Paleogene section, which contains abundant calcareous microfossils. Biostratigraphic information for this section given in Burns, Andrews, et al. (1973) was based primarily on shipboard results. Detailed calcareous nannofossil and planktonic foraminifer biostratigraphies have not been published. Here we provide a detailed documentation of the calcareous nannofossil distribution in the section, biostratigraphically date the section using the modern nannofossil zonation of Okada and Bukry (1980), and construct an age-depth curve based on current knowledge of nannofossil magnetobiochronology. This should provide a useful Paleogene biostratigraphic reference in the northeastern Australian sea, as Site 210 has apparently yielded the most complete Paleogene record in the region. The detailed biostratigraphy should provide a better age constraint for the regional Eocene-Oligocene hiatus recognized previously (e.g., Jenkins and Srinivasan, 1986) and should be useful for future studies on various aspects of Paleogene history of the northeastern Australian sea.

MATERIAL AND METHODS

Site 210 is located at 13°45.99′S, 152°53.78′E, roughly in the center of the Coral Sea Basin (Fig. 1), and at a water depth of 4643 m. About 711 m of sediment was penetrated at this site. The cored sequence consists of five lithologic units:

1. Unit 1 (0–470 m) is Pleistocene to Miocene graded cycles of silt and clay with interbeds of nannofossil ooze.
2. Unit 2 (470–521.6 m) is Miocene clay.
3. Unit 3 (521.6–540 m) is lower Oligocene clay-bearing to clay-rich nannofossil chalk.
4. Unit 4 (540–554.4 m) is upper Eocene–middle Eocene clay-bearing to clay-rich nannofossil chalk with minor chert nodules.
5. Unit 5 (554.4–711 m) is middle Eocene–lower Eocene clay nannofossil chalk.

The interval examined in this study ranges from 516 to 710 m (lower part of Unit 2 through Unit 5). One sample per core section was taken from the sequence. Smear slides were made directly from unprocessed samples and examined with a light microscope at a magnification of about 1250×. The abundance of calcareous nannofossils on each slide was estimated using the following criteria: A = abundant, 1–10 specimens per field of view; C = common, 1 specimen per 2–10 fields of view; F = few, 1 specimen per 11–50 fields of view; R = rare, 1 specimen per 51–200 fields of view; B = barren, no specimen was found in 200 fields of view. Abundances of reworked specimens have been recorded in lowercase letters. For preservation of nannofossil assemblages: M = moderate, etching or overgrowth is apparent; P = poor, there is significant etching or overgrowth; VP = very poor, strong etching or overgrowth is apparent on most specimens and identification of a large number of specimens is impaired.

Selected nannofossil species are illustrated in Plate 1. Bibliographic references for the species used here can be found in Perch-Nielsen (1985). Biostratigraphic zones are given in the zonation of Okada and Bukry (1980). Numerical ages for the nannofossil datums used to construct age-depth curves were taken from Berggren et al. (1985), with a few updated ages from Backman (1986), Wei and Wise (1989), and Backman et al. (1990).

BIOSTRATIGRAPHY

The highest sample examined is Sample 21-210-33-1, 100 cm. This sample contains *Sphenolithus heteromorphus* and a few other lower Miocene taxa, but no *Calcidiscus macintyrei* (Fig. 2). Rare specimens of *Reticulofenestra bisecta* in the sample are considered as reworked. Because the first occurrence (FO) of *S. heteromorphus* defines the lower boundary of Zone CN3 and the FO of *C. macintyrei* is widely used to mark the upper boundary of Zone CN3, the sample has thus been dated as Zone CN3 (18.0–18.4 Ma). The next three samples (21-210-33-2, 100 cm, through -33-4, 100 cm) are barren of calcareous nannofossils.

Abundant *Sphenolithus predistentus* are present in Sample 21-210-33-5, 120 cm. Upper Oligocene index fossils, such as *Sphenolithus distentus, S. ciperoensis,* and *Helicosphaera recta,* are absent. This suggests that the sample is in the lower Oligocene, with an age older than 34.2 Ma (the age for the FO of *S. distentus*). Common *Reticulofenestra umbilicus* were first encountered in Sample 21-210-34-2, 100 cm. The CP16/CP17 zonal boundary is thus located between Samples 21-210-34-2, 100 cm, and -34-3, 100 cm.

The last occurrences (LOs) of both *Coccolithus formosus* and *Discoaster saipanensis* are found in Sample 21-210-35-1, 100 cm, where the two species are common. This means that Subzones CP16a and CP16b are missing as a result of a major hiatus. The next lower datum identified is the LO of *Chiasmolithus grandis* in Sample 21-210-35-2, 100 cm. This datum defines the CP14/CP15 zonal boundary and coincides with the middle Eocene/upper Eocene boundary. The upper Eocene-lower Oligocene index fossil, *Isthmolithus recurvus,* is not present at Site 210. The exclusion of this cool-water species is indicative of a warm-water condition at the site by the late Eocene.

The FO of *Reticulofenestra umbilicus,* which defines the CP13/CP14 zonal boundary, is located between Samples 21-210-36-1, 100 cm, and -36-2, 100 cm. Only questionable specimens of *Discoaster bifax* were recorded in Sample 21-210-36-1, 100 cm, and the range of this species could not be used here to subdivide Zone CP14. On

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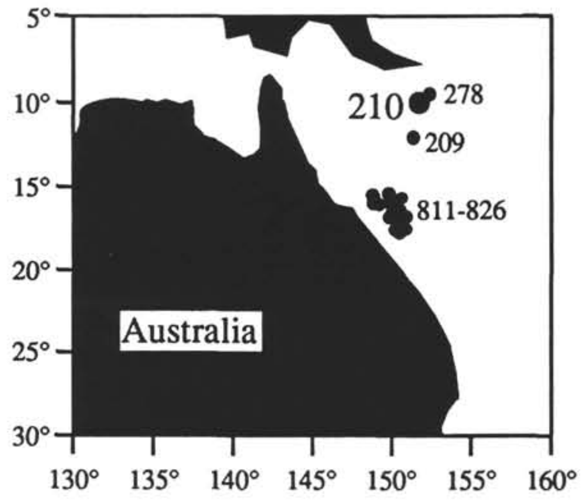

Figure 1. Locations of Site 210 and other DSDP/ODP sites offshore northeastern Australia.

the other hand, *Chiasmolithus gigas* occurs consistently from Samples 21-210-36-3, 100 cm, through -37-1, 100 cm, and its range can be used to subdivide Zone CP13. The lower boundary of Zone CP13 has been placed between Samples 21-210-38-2, 100 cm, and -38-3, 100 cm, based on the FO of *Nannotetrina fulgens* in Sample 21-210-38-2, 100 cm. *Rhabdosphaera inflata,* the FO of which subdivides Zone CP12, is absent at Site 210, as in most deep-sea sites. The lower boundary of Zone CP12 is defined by the FO of *Discoaster sublodoensis*, which is located between Samples 21-210-46-3, 100 cm, and -46-4, 100 cm. As the occurrence of *D. sublodoensis* in its lower range is rare and sporadic, the placement of this datum is less reliable.

No in-situ *Tribrachiatus orthostylus* was found at Site 210. This indicates that the oldest sediment is in Zone CP11 (lower Eocene). This age is also suggested by the consistent presence of *Coccolithus crassus* to the bottom of the hole. The expanded lower Eocene sequence at Site 210 is in contrast to a major lower Eocene disconformity (with three nannofossil zones missing; Bukry, 1975) at Site 287 in the Coral Sea.

AGE-DEPTH PLOT

Biostratigraphic datum levels from Figure 2 are summarized in Table 1. The sources of the age estimates for the datums also are given. The age-depth plot (Fig. 3) shows that the sedimentation rate was high during the early Eocene (>50 m/m.y.) and that it decreased through time as the basin subsided, which may have been accompanied by a rise of carbonate compensation depth in the Coral Sea.

A hiatus has been identified around the Eocene/Oligocene boundary. This is a regional hiatus that was recognized in previous studies, such as Jenkins and Srinivasan (1986), who indicated an age span of 43.0 to 35.0 Ma. However, here we show that the hiatus is about 36.4 to 35.1 Ma old, and is certainly younger than 40.0 Ma (the LO of *Chiasmolithus grandis*) and older than 34.6 Ma (the LO of *Reticulofenestra umbilicus*). Consequently, the age of the regional Eocene/Oligocene hiatus has been best constrained at Site 210 because more than several million years of sediments are missing at other sites offshore eastern Australia (see, for example, Jenkins and Srinivasan, 1986).

Although the FOs of *Sphenolithus heteromorphus* and *S. distentus* cannot be precisely located because of a barren interval from 517 to 521 mbsf (Fig. 3), one can see from Figure 3 that much of the lower Oligocene through middle Miocene sediment is missing. A major disconformity here is also suggested by an abrupt change from clay-rich nannofossil chalk below 521 mbsf to clay above 521 mbsf (see "Material and Methods" section, this chapter).

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* Abbreviations for names of organizations and publications in ODP reference lists follow the style given in *Chemical Abstracts Service Source Index* (published by American Chemical Society).

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Table 1. Age vs. depth data, Site 210.

Nannofossil datum	Depth (mbsf)	Age (Ma)	Age reference
FO *Sphenolithus heteromorphus*	>516.0	18.4	Backman et al. (1990)
FO *Sphenolithus distentus*	<520.5	34.2	Berggren et al. (1985)
LO *Reticulofenestra umbilicus*	535.5/537.0	34.6	Berggren et al. (1985)
LO *Coccolithus formosus*	538.5/543.0	35.1	Berggren et al. (1985)
LO *Discoaster saipanensis*	538.5/543.0	36.4	Wei and Wise (1989)
LO *Chiasmolithus grandis*	543.0/544.5	40.0	Berggren et al. (1985)
FO *Reticulofenestra umbilicus*	552.0/553.5	44.6	Wei and Wise (1989)
LO *Chiasmolithus gigas*	553.5/555.0	47.0	Berggren et al. (1985)
FO *Chiasmolithus gigas*	561.0/562.5	47.4	Wei and Wise (1989)
FO *Nannotetrina fulgens*	571.5/573.0	49.8	Backman (1986)
FO *Discoaster sublodoensis*	652.0/653.5	52.6	Berggren et al. (1985)
LO *Tribrachiatus orthostylus*	>710.5	53.7	Berggren et al. (1985)

Notes: FO = first occurrence. LO = last occurrence.

Age	Nannofossil zones of Okada and Bukry (1980)	Sample (Core-section, depth)	Depth (mbsf)	Abundance	Preservation	*Bicolomnus ovatus*	*Blackites* spp.	*Braarudosphaera bigelowii*	*Bramletteius serraculoides*	*Campylosphaera dela*	*Chiasmolithus eograndis*	*Chiasmolithus expansus*	*Chiasmolithus gigas*	*Chiasmolithus grandis*	*Chiasmolithus solitus*	*Chiasmolithus* spp.	*Chiphragmalithus calathus*	*Coccolithus crassus*	*Clausicoccus fenestratus*	*Coccolithus eopelagicus*	*Coccolithus formosus*	*Coccolithus pelagicus*	*Coccolithus staurion*	*Cyclicargolithus abisectus*	*Cyclicargolithus floridanus*	*Discoaster barbadiensis*	*Discoaster bifax*	*Discoaster cruciformis*	*Discoaster deflandrei*	*Discoaster elegans*	*Discoaster kuepperi*	*Discoaster lodoensis*	*Discoaster mirus*	*Discoaster saipanensis*	*Discoaster sublodoensis*
e. Miocene	CN3	33-1, 100	516.00	C	VP																	F		C	F				F						
(?)	(?)	33-2, 100	517.50	B																															
		33-3, 100	519.00	B																															
		33-4, 100	520.50	B																															
early Oligocene	CP17	33-5, 120	522.20	A	P	F																C		C	C				A						
		33-6, 130	523.80	A	P																	C		C	A										
		34-1, 100	534.00	A	P	F														F		C		C	A				F						
		34-2, 100	535.50	A	P	F													R	C	r	C			A				C						
	CP16c	34-3, 100	537.00	A	P														R	C		C			A										
		34-4, 100	538.50	A	P				R										R	F		A			A				F						
late Eocene	CP15	35-1, 100	543.00	A	P																C	C			C	F								C	
middle Eocene	CP14	35-2, 100	544.50	A	P									F						A	C	A				C			F					?	
		35-3, 100	546.00	A	VP									R						C	C	C				C								F	
		35-4, 100	547.50	C	VP									R						C	C	C				F									
		36-1, 100	552.00	A	VP									F							C	A				F	?								
	CP13c	36-2, 100	553.50	A	P									C	R						C	A	F												
	CP13b	36-3, 100	555.00	A	P			F					F	C							C	C				F									
		36-4, 100	556.50	A	P		F						F	C							C	A				F									
		36-5, 100	558.00	A	P			F					F	C							C	A				F									
		37-1, 100	561.00	A	P								R	F							C	A	?			C								C	
	CP13a	37-2, 100	562.50	A	VP									R	F						F	C				F						R		R	R
		37-3, 100	564.00	A	VP									C	C					C	C	C				C			C					C	F
		37-4, 100	565.50	A	P									C			R				C	A	?			F									R
		38-1, 100	570.00	C	VP							F		C	F							C				C									C
		38-2, 100	571.50	C	VP																	C				C				F				F	F
	CP12	38-3, 100	573.00	A	VP							F		C	F		R					C				C					R				F
		39-1, 120	579.20	A	VP		F					F		F	F					C	F	A				F						F		F	F
		39-2, 120	580.70	A	VP									F	F							A				F						F			R
		39-3, 120	582.20	A	P		C			R				F	F						C	A	R			C					F	C			F
		40-1, 100	588.00	C	P									F								C				C				F		C			
		40-2, 100	589.50	A	P		C					C			C	C		R			C	A	?			C				F		C		F	
		40-3, 100	591.00	A	P		F			F				C	C			R			C	A				C				F		C		C	R
		40-4, 100	592.50	C	P									F				R				A	R			C				F		C			?
		40-5, 100	594.00	A	P		F					F		C	F						C	C				C						C			
		41-1, 70	596.70	C	VP									F		F		R			C	A				F						F			
		41-2, 30	597.80	C	VP									C				R			F	C				F						F			
		42-1, 30	605.30	C	P					F				C				F			C	A				C						F		F	R
		42-2, 80	607.30	C	P										C			F			C	C				C						C		F	
		43-2, 100	616.50	A	M					F				C	C			R		C	C	A				C						A			
		43-3, 100	618.00	A	VP					F				C	C			F			C	A				C				F	R	C		F	
		43-4, 100	619.50	A	VP											C		R				C				F						C			
		44-1, 40	623.40	A	P		R			F				F	C			R			F	A				C						C			?
		44-2, 40	624.90	A	P									C		C					C	A				C						C			R
		44-3, 70	626.70	A	VP					F				C	C			R			F	A				F				F		C			
		45-2, 70	634.20	A	P									F				R			C	A				C				F	F	C		C	
		45-3, 70	635.70	A	P									C	F						C	A				F				F		F		F	?
		46-1, 100	649.00	A	P									F	C			R			C	A				C						C		C	
		46-2, 100	650.50	A	VP							C		C	C			R			C	A				F				R		C		C	R
		46-3, 100	652.00	A	P									C	C			R		F	C	C				C					F	C		C	R
early Eocene	CP11	46-4, 100	653.50	A	P									C	F			F		C	C	A				C				F	R	C		C	
		46-5, 100	655.00	A	P									C	C			F			C	A				F				F		C		C	
		46-6, 100	656.50	A	P									C	C			R			C	A				C					F	C		C	
		47-1, 100	666.00	A	P									F	C			R			F	A				F						C		F	
		47-3, 100	669.00	A	M					F				C	C			R			C	C				C						C	F	C	
		48-1, 100	679.00	A	P					F		F		C	C	C		R			A	A									R	C		F	
		48-2, 100	680.50	A	P					F		F		C	C	C		R			A	A				C					R	C	F	F	
		48-3, 100	682.00	A	VP						F			F	C	C		R			C	A				C						C	F		
		48-4, 70	683.20	A	P									F	C			R			C	A				C						C			
		49-1, 100	693.00	A	P									C	C			R			C	A				C						C		C	
		49-2, 100	694.50	A	P					F				R	C			R		C	C	A				C						C			
		49-3, 100	696.00	A	P									C	R	C		F		C	C	A				C					F	C			
		50-1, 100	703.00	A	P									C	C			R			C	A									F	A		F	
		50-2, 100	704.50	A	P			F			F			C	C			R			C	A				F		F			R	C			
		50-3, 100	706.00	A	P									C	C			R			C	A				F					F	C			
		50-4, 100	707.50	A	VP									C	F			R			F	A				F					R	C			
		50-5, 100	709.00	A	VP									C	F			R			C	A				C						C			
		50-6, 100	710.50	C	P									C	C	C		F			C	A				C					C	A			

Figure 2. Distribution of calcareous nannofossils in the lower Eocene through lower Miocene at Site 210. For abundance of nannofossils, A = abundant, C = common, F = few, R = rare, r = rare specimens that are considered reworked, B = barren, and ? = questionable presence. For preservation, M = moderate, P = poor, and VP = very poor. Wavy line indicates hiatus.

Age	Nannofossil zones of Okada and Bukry (1980)	Sample (Core-section, depth)	Depth (mbsf)	*Discoaster* spp.	*Helicosphaera lophota*	*Helicosphaera seminulum*	*Markalius inversus*	*Nannotetrina cristata*	*Nannotetrina fulgens*	*Neococcolithes dubius*	*Pontosphaera plana*	*Pseudotriquetrorhabdulus inversus*	*Reticulofenestra bisecta*	*Reticulofenestra daviesii*	*Reticulofenestra dictyoda*	*Reticulofenestra samodurovii*	*Reticulofenestra umbilicus*	*Reticulofenestra* spp.	*Sphenolithus furcatolithoides*	*Sphenolithus heteromorphus*	*Sphenolithus moriformis*	*Sphenolithus predistentus*	*Sphenolithus pseudoradians*	*Sphenolithus radians*	*Sphenolithus spiniger*	*Toweius gammation*	*Toweius magnicrassus*	*Tribrachiatus orthostylus*	*Triquetrorhabdulus carinatus*	*Thoracosphaera* spp.	*Zigrablithus bijugatus*
e. Miocene	CN3	33-1, 100	516.00										r							F	R										
(?)	(?)	33-2, 100	517.50																												
		33-3, 100	519.00																												
		33-4, 100	520.50																												
early Oligocene	CP17	33-5, 120	522.20										F	F				C				A							A		
		33-6, 130	523.80										C								A	C	F						R		F
		34-1, 100	534.00	C									C					C			A	F			C						F
		34-2, 100	535.50	C									C					C			A	F			C				?		
	CP16c	34-3, 100	537.00														C				A	F									
		34-4, 100	538.50										C				F					F									
late Eocene	CP15	35-1, 100	543.00	C									A				C				C			F	C						
middle Eocene	CP14	35-2, 100	544.50										C			C	C				A			C	F						
		35-3, 100	546.00	C									A			C	C				C			C						F	
		35-4, 100	547.50	F									C			C	C				C										
		36-1, 100	552.00	C												C	C		F		C										
	CP13c	36-2, 100	553.50									A				A			C					C							
	CP13b	36-3, 100	555.00	C					F			A			F	C			F		C			F	F						
		36-4, 100	556.50	F					F			C				C					C			F	F						
		36-5, 100	558.00	C					R			A				C			C		C			F	F						
		37-1, 100	561.00						R			A			C	C			C		C			C	C						
	CP13a	37-2, 100	562.50	C					R			F				F					F				F						R
		37-3, 100	564.00						R			C			C	C					C			C							
		37-4, 100	565.50					R		R		C				C														F	
		38-1, 100	570.00										C		C	C								F							
		38-2, 100	571.50					R	R	C																					
	CP12	38-3, 100	573.00	C		F				C						C								C							
		39-1, 120	579.20																		C			C		F					
		39-2, 120	580.70																												
		39-3, 120	582.20				R								C	C							F	C		F				F	C
		40-1, 100	588.00	C											C						C			C			F				
		40-2, 100	589.50							F					C	C					C			C	C	F	F				
		40-3, 100	591.00		F										C	C								C		F		r		F	
		40-4, 100	592.50													C								C		F	C	r			
		40-5, 100	594.00		F					F					C						C			C		F	F				F
		41-1, 70	596.70	C						F					C	C								C		C	R				
		41-2, 30	597.80							C					C	C										C					C
		42-1, 30	605.30		C					R						C								C		R		r			
		42-2, 80	607.30		F					R					C	C					C			C		F					
		43-2, 100	616.50		F																					F					
		43-3, 100	618.00							F					C									C		F		r			
		43-4, 100	619.50	C																											C
		44-1, 40	623.40		F	F				F					F	F					A			C	C	F					F
		44-2, 40	624.90		F										C									C							
		44-3, 70	626.70												C						A			C	F			r			C
		45-2, 70	634.20							C					C											F					
		45-3, 70	635.70		R					F					C						F			A		F					
		46-1, 100	649.00		R	F				F														C	F		F				F
		46-2, 100	650.50		F		F			C	R				C						A			C		F					
		46-3, 100	652.00	C		R				F					C						C			C							C
early Eocene	CP11	46-4, 100	653.50	C		F									C						C			C			C				
		46-5, 100	655.00							C					A						A			C			F				
		46-6, 100	656.50							F					C						C			A			F			F	C
		47-1, 100	666.00		F																C			C	C	R					C
		47-3, 100	669.00	A	F	F				F	F				C						C			C	F		F				F
		48-1, 100	679.00		F		F								C						A			C	F		F			C	F
		48-2, 100	680.50	C	F	F				F					C						A			C	C		C	r		F	
		48-3, 100	682.00								R				C						A			C		R	F			F	
		48-4, 70	683.20	C		F				F					C						A			C			C			F	
		49-1, 100	693.00	A		F				C					C						A			A	?						
		49-2, 100	694.50	A		F									C						A			A			F				
		49-3, 100	696.00	A						F											A			A			F				
		50-1, 100	703.00	A		F				F											F			C				r			
		50-2, 100	704.50	A			F			A											A			A		F	F				
		50-3, 100	706.00	A		F				C					F						C			C							
		50-4, 100	707.50	A																	F			C			F	r			
		50-5, 100	709.00	C		R				F											F			A							
		50-6, 100	710.50	A																	A			A						F	

Figure 2 (continued).

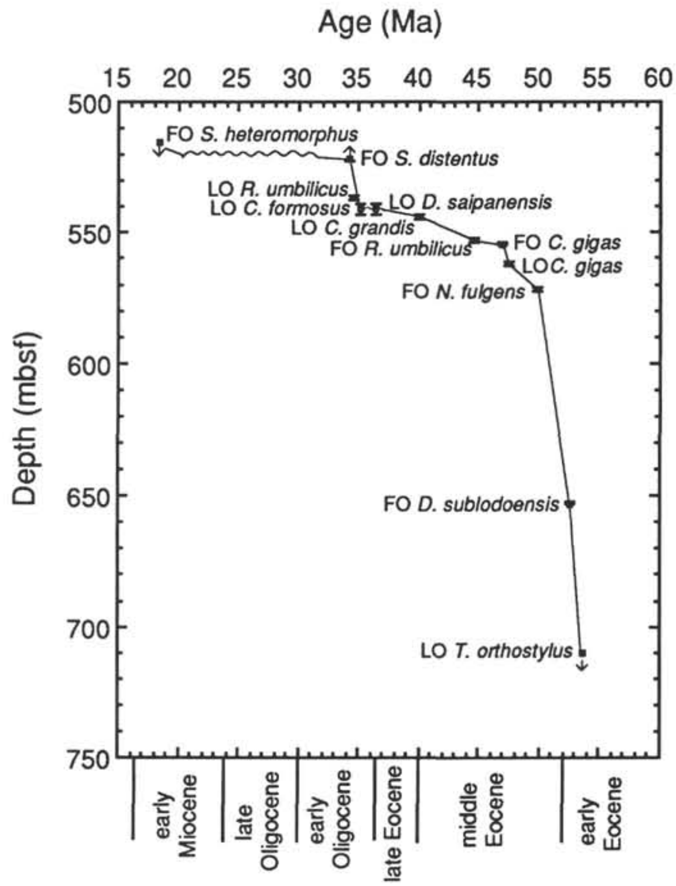

Figure 3. Plot of age vs. depth, Site 210. Wavy line indicates hiatus. FO = first occurrence. LO = last occurrence.

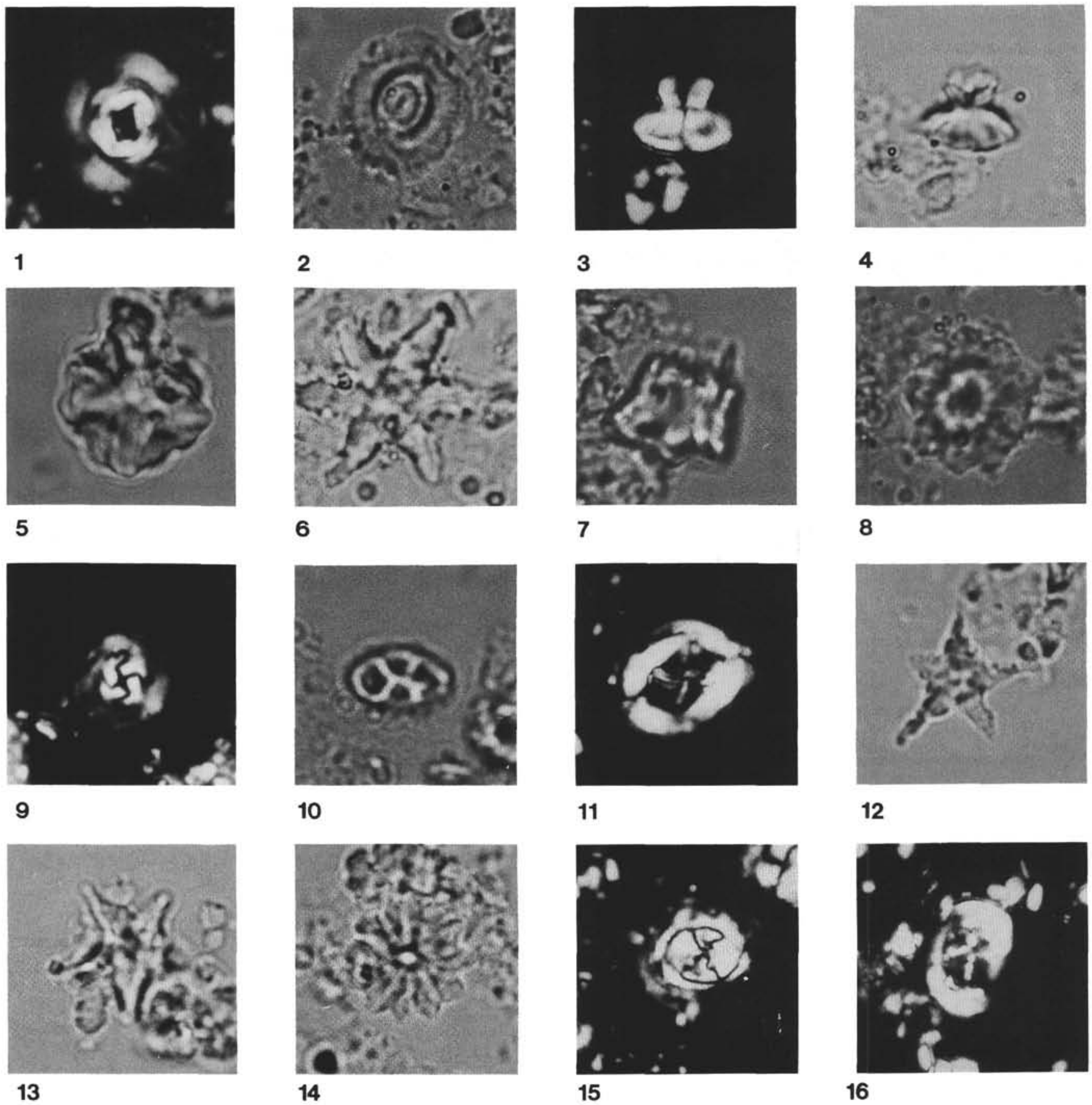

Plate 1. Paleogene calcareous nannofossils from Site 210 (magnification is 2400× for all specimens). **1, 2.** *Toweius magnicrassus* (Bukry) Romein, Sample 210-41-1, 70–71 cm. **3, 4, 8.** *Discoaster keupperi* Stradner, (3) Sample 210-50-4, 100–101 cm, (4, 8) Sample 210-50-2, 100–101 cm. **5.** *Nannotetrina fulgens* (Stradner) Achuthan and Stradner, Sample 210-37-1, 100–101 cm. **6.** *Discoaster lodoensis* Bramlette and Riedel, Sample 210-50-2, 100–101 cm. **7.** *Chiphragmalithus calathus* Bramlette and Sullivan, Sample 210-38-3, 100–101 cm. **9.** *Toweius gamation* (Bramlette and Sullivan) Perch-Nielsen, Sample 210-47-1, 100–101 cm. **10.** *Neococcolithes dubius* (Deflandre) Black, Sample 210-50-2, 100–101 cm. **11.** *Chiasmolithus solitus* (Bramlette and Sullivan) Locker, Sample 210-50-1, 100–101 cm. **12, 13.** *Discoaster sublodoensis* Bramlette and Sullivan, (12) Sample 210-46-2, 100–101 cm, (13) Sample 210-39-2, 100–101 cm. **14.** *Discoaster bardadiensis* Tan, Sample 210-47-1, 100–101 cm. **15.** *Cruciplacolithus cribellus* (Bramlette and Sullivan) Romein, Sample 210-49-2, 100–101 cm. **16.** *Campylosphaera dela* (Bramlette and Sullivan) Hay and Mohler, Sample 210-48-1, 100–101 cm.