10. CALCAREOUS NANNOFOSSIL BIOSTRATIGRAPHY, LEG 55 OF THE DEEP SEA DRILLING PROJECT

Toshiaki Takayama, Department of Geology, College of Liberal Arts, Kanazawa University, Kanazawa, Japan

INTRODUCTION

Leg 55 of the Deep Sea Drilling Project began at Honolulu, Hawaii, on 23 July 1977. Eleven holes were drilled at 4 sites in the Emperor Seamount chain in the North Pacific Ocean Basin, including a multiple re-entry hole on Suiko Seamount. The cruise ended at Yokohama, Japan on 6 September 1977 (Figure 1). The principal biostratigraphic objectives of Leg 55 were (1) to determine by paleontological methods the minimum time since cessation of volcanism at seamounts of the Emperor Seamount chain; (2) to determine whether the Emperor Seamounts ever rose above sea level as islands and whether coral reefs once grew atop the seamounts before submergence, and if so, to determine the time and cause of extinction of those reefs; (3) to investigate the Neogene–Paleogene environmental history; and (4) to establish the Neogene–Paleogene biostratigraphic zonation on seamounts of the Emperor Seamount chain. Unfortunately, these objectives were not entirely achieved, because of difficulties in recovery caused by mechanical failure of the bottom hole assemblies at most of the sites. To further complicate matters, only a few poorly preserved coccolith specimens were found in the samples taken from the reef sediments lying just above the top of the seamounts. Nevertheless, a continuous sedimentary sequence was recovered at Site 433 (Suiko Seamount) which allowed quantitative biofacies analyses to be conducted that provided information about the subsidence history of the Emperor Seamount chain.

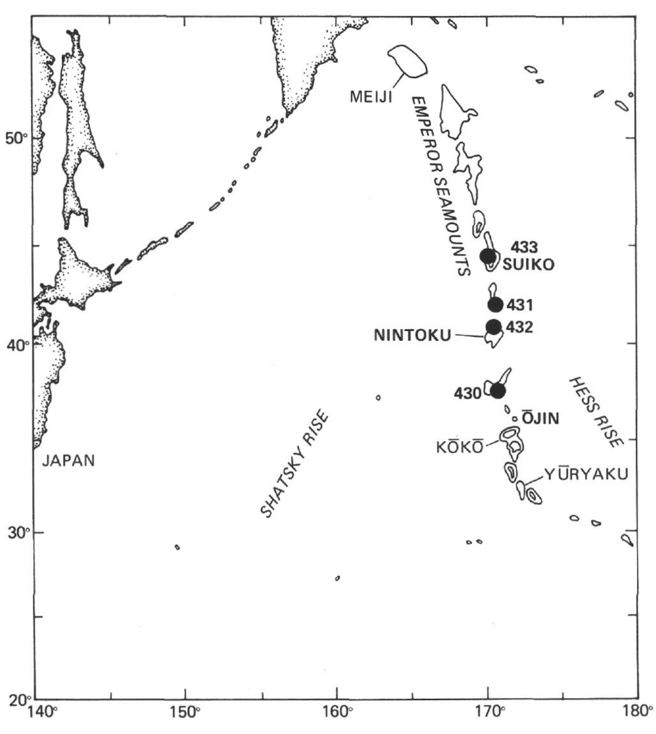

Figure 1. *Locations of sites cored during Leg 55.*

This report deals with the study of the calcareous nannofossils recovered at the four Emperor Seamount chain sites drilled during Leg 55 (Sites 430 through 433). Its main purpose is to describe the calcareous nannofossil assemblages and their stratigraphic changes, and to discuss the basis for biostratigraphic age assignments.

NANNOFOSSIL ZONATION

Various Cenozoic calcareous nannofossil zonation schemes, based primarily on land or epicontinental sections, have been established by numerous investigators (Bramlette and Sullivan, 1961; Bramlette and Wilcoxon, 1967; Hay and Mohler, 1967; Hay et al., 1967; Gartner, 1969: Edwards, 1971, and Martini, 1971). Among them, the "Standard Calcareous Nannofossil Zonation" established by Martini (1971) is most applicable and widely used. These land-based zonation schemes, however, are not always the most useful when dealing with deep-sea sediments. Because of this, the comprehensive zonation proposed by Bukry (1971, 1973a, 1973b, 1975) for low-latitude deep-sea sections proved to be a more practical approach to deep-sea calcareous nannofossil biostratigraphy.

As with planktonic foraminifers, calcareous nannoplankton attain their maximum diversity in tropical areas. Many tropical forms used as guide fossils are not found in the higher latitudes, and therefore the number of usable coccolith index species decreases with increasing latitude; thus, zonal intervals must be expanded poleward, with consequent loss of biostratigraphic resolution. This creates a serious problem for interpreting the Neogene calcareous nannofossil biostratigraphy in the present investigation.

Throughout this report, I attempt to use the two zonal schemes established by Martini (1971) and Bukry (1971, 1973a, 1973b, 1975) for age determinations. But because of the low-diversity nannofossil assemblages, consisting mainly of long-ranging species, and the absence of almost all index fossils used for zonation in low latitudes, these zonations are not applicable for most of the Paleogene sedimentary sequences recovered during Leg 55. Consequently, only those stratigraphic intervals characterized by the presence of selected species are discussed.

METHOD OF STUDY

I collected all samples examined from suitable levels in the core sections while aboard the *Glomar Challenger.* The sample spacing in critical intervals was sufficiently close that stratigraphic first and last appearances of selected species were determined with reasonable accuracy.

The outermost portion of each sample was removed to avoid floral contamination caused by the drag of the sediment against the tube. A total of 286 samples was processed and examined according to the following methods, which were originally outlined by Stradner and Papp (1961). A very small quantity of the sample was placed in a small glass vial and about 20 cm^3 of water was added. The vial was placed in an ultrasonic cleaner at a moderate vibration setting. After five seconds, the vial was removed from the ultrasonic cleaner, and after the heavier particles had settled, a few drops were withdrawn from the upper layer of the suspension with a pipette and placed on a square microscopic cover glass (18 mm × 18 mm) and carefully allowed to dry on an electric hot plate set at low heat. Caedax (n = 1.55) was then spread over it and a large glass slide pressed on it. The slide was examined under an Olympus Binocular Polarizing Microscope (BHA-P) with phase contrast equipment (BH-PC). A magnification of 1,500× with oil-immersion objective lens was necessary. Several thousand specimens were identified in those samples that were found to contain abundant coccoliths and discoasters. In addition, where possible, 200 specimens were counted at random and listed in order to determine the relative frequencies of occurrence of the species and their stratigraphic changes. If calcareous nannofossils were extremely rare in a sample, only the presence of the species was shown. The state of preservation of the calcareous nannofossils was also estimated for all samples studied.

Sample material and microslides used during the present investigation will be placed permanently in the Micropaleontology Collection of the Department of Geology, College of Liberal Arts, Kanazawa University.

SUMMARY OF NANNOFOSSIL BIOSTRATIGRAPHY

The nannofossil assemblages recovered from Leg 55 are discussed in detail in what follows. Each site is considered separately, and the basis for biostratigraphic age assignment is discussed. Occurrence tables have been prepared for all the holes containing calcareous nannofossil assemblages. The tables show the numbers of coccoliths counted at random in each sample during the 200-specimen count; + indicates the presence of a species in a sample. The state of preservation is designated as follows: G = good, little or no etching or overgrowth; M = moderate, some etching or overgrowth and some destruction or fragmentation that obscures delicate structures and ornamentation; P = poor, strong overgrowth and/or fragmentation, so that sometimes the species is difficult to recognize.

The nannofossil zones identified in the core samples recovered during Leg 55 are listed in Tables 1 and 2.

Site 430: Ōjin Seamount

The first site sampled during Leg 55 is located at the top of Ōjin Seamount in the Emperor Seamount chain. Three holes were drilled in what appeared to be a lagoonal sediment pond.

Hole 430
(lat. 37°58.88′N, long. 170°35.45′E; water depth 1445 m)

Hole 430 was abandoned because of caving after recovering three cores (14 m) of sediments. Only three samples were available for examination.

The nannofossil assemblages recovered from the samples of this hole are fairly diversified, but the nannofossil content is very low and the state of preservation is generally very poor (Table 3). The assemblages are predominantly asteroliths consisting of *Discoaster barbadiensis, D. deflandrei, D. nodifer, D. saipanensis,* and *D. tani. Cyclicargolithus floridanus* is also very common, but most of the specimens are broken and fragmented. The presence of the discoasters mentioned above, together with other age-diagnostic species such as *Cyclococcolithus formosus, Dictyococcites scrippsae, D. bisectus, Reticulofenestra hillae, R. umbilica,* and *Isthmolithus recurvus,* indicates that sediments from this hole are upper Eocene. More specifically, the uppermost Eocene *Isthmolithus recurvus* Subzone proposed by Bukry (1975), the NP 19 *Isthmolithus recurvus* Zone, and the NP 20 *Sphenolithus pseudoradians* Zone of Martini (1971) can be recognized by the presence of *Discoaster saipanensis* in Sample 2-4, 5–10 cm and the nominate zone fossil *I. recurvus* in Sample 2,CC. Judging from the state of preservation, the Paleocene species *Toweius craticulus,* which occurs in the lowest sample of this hole (Sample 2,CC), is considered to be reworked from the underlying sediments. Deeper penetration at Hole 430A indicates that Paleocene sediments are present at this site.

One of the most reliable age indicators for the late Eocene, *Isthmolithus recurvus,* has been considered previously to occur only in sediments deposited in cold water. Bukry (1975) showed the geographical distribution of *Isthmolithus recurvus* at DSDP sites in the Pacific, Indian, and Atlantic Oceans, and indicated that this species is typically absent at tropical sites and is best considered a restricted subzonal marker. For example, of 43 sites between 30°S and 30°N, *I. recurvus* occurs in only 7, where the tropical coccolith zonation is most effectively employed. The present study yields new information on the distribution of *I. recurvus* and also indicates that Site 430 was already situated at a comparatively high latitude in latest Eocene time.

Hole 430A
(lat. 37°59.29′N, long. 170°35.86′E; water depth 1479 m)

At this hole, the drill penetrated 47.5 meters of calcareous ooze and sand which directly overlie basaltic rocks on Ōjin Seamount. Because of the bottom-hole

TABLE 1
Chronostratigraphy and Zonal Assignments, Leg 55

Chronostratigraphy		Calcareous Nannofossil Zones		Hole 430	Hole 430A	Hole 430B	Hole 431	Hole 431A	Hole 432	Hole 432A	Hole 433	Hole 433A		Hole 433B	Hole 433C
				Core-Section, Interval (cm)							Core-Section, Interval (cm)				
Quaternary		NN 21	*Emiliania huxleyi* Zone			PUNCH CORE	1-1, 40 2,CC		1-1, 8 1,CC		1-1, 1 1-1, 121	1-1, 0 1-1, 1			
Quaternary		NN 20	*Gephyrocapsa oceanica* Zone										2-1, 1 2-1, 21		
Quaternary		NN 19	*Pseudoemiliania lacunosa* Zone					1-1, 4 1,CC			1-1, 140 1-2, 101	1-1, 4 1-1, 81	2-1, 43 2-1, 123		
Pliocene	Upper	NN 18	*Discoaster brouweri* Zone												
Pliocene	Upper	NN 17	*Discoaster pentaradiatus* Zone								1-2, 120 1-3, 121		2-2, 1 2-2, 22		
Pliocene	Upper	NN 16	*Discoaster surculus* Zone									1-1, 100 1,CC	2-2, 43 3-6, 6		
Pliocene	Lower	NN 15	*Reticulofenestra pseudoumbilica* Zone								1-3, 140 1,CC		3-6, 25 3,CC		
Pliocene	Lower	NN 14	*Discoaster asymmetricus* Zone												
Pliocene	Lower	NN 13	*Ceratolithus rugosus* Zone												
Pliocene	Lower	NN 12	*Ceratolithus tricorniculatus* Zone												
Miocene	Upper	NN 11	*Discoaster quinqueramus* Zone										4-1, 5 6-5, 7		
Miocene	Upper	NN 10	*Discoaster calcaris* Zone										6-5, 53 6-6, 4		
Miocene	Middle	NN 9	*Discoaster hamatus* Zone												
Miocene	Middle	NN 8	*Catinaster coalitus* Zone												
Miocene	Middle	NN 7	*Discoaster kugleri* Zone												
Miocene	Middle	NN 6	*Discoaster exilis* Zone												
Miocene	Lower	NN 5	*Sphenolithus heteromorphus* Zone										6-6, 53 7-6, 51		
Miocene	Lower	NN 4	*Helicopontosphaera ampliaperta* Zone												
Miocene	Lower	NN 3	*Sphenolithus belemnos* Zone												
Miocene	Lower	NN 2	*Discoaster druggi* Zone												
Miocene	Lower	NN 1	*Triquetrorhabdulus carinatus* Zone												
Oligocene	b	NP 25	*Sphenolithus ciperoensis* Zone												
Oligocene	a	NP 24	*Sphenolithus distentus* Zone												
Oligocene	a	NP 23	*Sphenolithus predistentus* Zone												
Oligocene	Lower	NP 22	*Helicopontosphaera reticulata* Zone												
Oligocene	Lower	NP 21	*Ericsonia? subdisticha* Zone												
Eocene	Upper	NP 20	*Sphenolithus pseudoradians* Zone	2-4, 5											
Eocene	Upper	NP 19	*Isthmolithus recurvus* Zone	2,CC											
Eocene	Upper	NP 18	*Chiasmolithus oamaruensis* Zone												
Eocene	Upper	NP 17	*Discoaster saipanensis* Zone												
Eocene	Middle	NP 16	*Discoaster tani nodifer* Zone												
Eocene	Middle	NP 15	*Chiphragmalithus alatus* Zone												
Eocene	Middle	NP 14	*Discoaster sublodoensis* Zone												
Eocene	Lower	NP 13	*Discoaster lodoensis* Zone												
Eocene	Lower	NP 12	*Marthasterites tribrachiatus* Zone												
Eocene	Lower	NP 11	*Discoaster binodosus* Zone												
Eocene	Lower	NP 10	*Marthasterites contortus* Zone												
Paleocene	Upper	NP 9	*Discoaster multiradiatus* Zone		1-1, 0 3,CC								7, CC	1-3, 2	3-1, 15
Paleocene	Upper	NP 8	*Heliolithus riedeli* Zone												
Paleocene	Middle	NP 7	*Discoaster gemmeus* Zone										10-1, 5	1-5, 81	3,CC
Paleocene	Middle	NP 6	*Heliolithus kleinpelli* Zone										10-1, 120	1-6, 85	
Paleocene	Middle	NP 5	*Fasciculithus tympaniformis* Zone										19,CC	3,CC	
Paleocene	Lower	NP 4	*Ellipsolithus macellus* Zone												
Paleocene	Lower	NP 3	*Chiasmolithus danicus* Zone												
Paleocene	Lower	NP 2	*Cruciplacolithus tenuis* Zone												
Paleocene	Lower	NP 1	*Markalius inversus* Zone												

[a] Middle, [b] Upper

TABLE 2
Chronostratigraphy and Zonal Assignments, Leg 55

Chronostratigraphy		Zone	Subzone	Hole 430	Hole 430A	Hole 430B	Hole 431	Hole 431A	Hole 432	Hole 432A	Hole 433	Hole 433A		Hole 433B	Hole 433C
				Core-Section, Interval (cm)											
Pleistocene		*Emiliania huxleyi*				PUNCH CORE	1-1, 40 2,CC		1-1, 8 1,CC		1-1, 1 1-1, 121	1-1, 0 1-1, 1			
		Gephyrocapsa oceanica	*Ceratolithus cristatus*										2-1, 1 2-1, 21		
			Emiliania ovata					1-1, 4 1,CC			1-1, 140 1-2, 101	1-1, 4 1-1, 21	2-1, 43 2-1, 101		
		Crenalithus doronicoides	*Gephyrocapsa caribbeanica*												
			Emiliania annula									1-1, 40 1-1, 81	2-1, 122 2-1, 123		
Pliocene	Upper	*Discoaster brouweri*	*Cyclococcolithina macintyrei*												
			Discoaster pentaradiatus								1-2, 120 1-3, 121		2-2, 1 2-2, 22		
			Discoaster surculus									1-1, 100 1,CC	2-2, 43 3-3, 3		
			Discoaster tamalis										3-3, 21 3-6, 6		
	Lower	*Reticulofenestra pseudoumbilica*	*Discoaster asymmetricus*								1-3, 140 1,CC		3-6, 25 3,CC		
			Sphenolithus neoabies												
		Ceratolithus tricorniculatus	*Ceratolithus rugosus*												
			Ceratolithus acutus												
Miocene	Upper		*Triquetrorhabdulus rugosus*												
		Discoaster quinqueramus	*Ceratolithus primus*										4-1, 5 6-5, 7		
			Discoaster berggrenii										6-5, 53 6-6, 4		
		Discoaster neohamatus	*Discoaster neorectus*												
			Discoaster bellus												
		Discoaster hamatus	*Catinaster calyculus*												
			Helicopontosphaera kamptneri												
	Middle	*Catinaster coalitus*													
		Discoaster exilis	*Discoaster kugleri*												
			Coccolithus miopelagicus												
		Sphenolithus heteromorphus											6-6, 53 7-6, 51		
	Lower	*Helicopontosphaera ampliaperta*													
		Sphenolithus belemnos													
		Triquetrorhabdulus carinatus	*Discoaster druggii*												
			Discoaster deflandrei												
Oligocene	Upper		*Cyclicargolithus abisectus*												
		Sphenolithus ciperoensis	*Dictyococcites bisectus*												
			Cyclicargolithus floridanus												
	Middle	*Sphenolithus distentus*													
		Sphenolithus predistentus													
	Lower	*Helicopontosphaera reticulata*	*Reticulofenestra hillae*												
			Coccolithus formosus												
			Coccolithus subdistichus												
Eocene	Upper	*Discoaster barbadiensis*	*Isthmolithus recurvus*	2-4, 5 2,CC											
			Chiasmolithus oamaruensis												
		Reticulofenestra umbilica	*Discoaster saipanensis*												
	Middle		*Discoaster bifax*												
		Nannotetrina quadrata	*Coccolithus staurion*												
			Chiasmolithus gigas												
			Discoaster strictus												
		Discoaster sublodoensis	*Rhabdosphaera inflata*												
			Discoasteroides kuepperi												
		Discoaster lodoensis													
	Lower	*Tribrachiatus orthostylus*													
		Discoaster diastypus	*Discoaster binodosus*												
			Tribrachiatus contortus												
Paleocene	Upper	*Discoaster multiradiatus*	*Campylosphaera eodela*		1-1, 0							7,CC		1-3, 2	3-1, 15
			Chiasmolithus bidens		3,CC										
		Discoaster nobilis													
		Discoaster mohleri											10-1, 5	1-5, 81	3,CC
		Heliolithus kleinpellii										10-1, 120		1-6, 85	
		Fasciculithus tympaniformis											19,CC	3,CC	
	a	*Cruciplacolithus tenuis*													

[a]Lower

TABLE 3
Nannofossil Occurrences in Hole 430

Sample (Interval in cm)	Preservation	*Coccolithus eopelagicus*	*Coccolithus pelagicus*	*Cyclicargolithus floridanus*	*Cyclococcolithus formosus*	*Dictyococcites bisectus*	*Dictyococcites scrippsae*	*Discoaster barbadiensis*	*Discoaster deflandrei*	*Discoaster nodifer*	*Discoaster saipanensis*	*Discoaster tani*	*Discoaster* spp.	*Isthmolithus recurvus*	*Reticulofenestra hillae*	*Reticulofenestra umbilica*	*Sphenolithus moriformis*	*Toweius craticulus*	Total	Zone: Bukry (1975)	Zone: Martini (1971)	Chronostratigraphy
2-4, 5–10	P	1	8	13					12		1	1	12		1		1		50	*I. recurvus*	NP 19–NP 20	Upper Eocene
2-5, 25–30	P	3	11	28	1	3		4	29	6	1	2	12						100			
2,CC	P	5	8	22		1	1	5	25	9	3	1	17	1		1		1	100			

conditions, however, recovery of sediments was very poor.

The sediments of Cores 1 through 3 contain a very limited number of poorly preserved calcareous nannofossils. Below Core 4, no calcareous nannofossils occur. The stratigraphic distribution and additional data on the state of preservation of the fossiliferous samples are shown in Table 4. The assemblages are characteristic of a Paleocene flora mixed with a few Eocene, Oligocene, Miocene, Pliocene, and even Pleistocene specimens, such as *Cyclococcolithus formosus, Dictyococcites dictyodus, Discoaster nodifer, Reticulofenestra umbilica, Catinaster coalitus, Discoaster exilis,* and *Gephyrocapsa oceanica.* The indigenous species diversity, however, is low, and the assemblage consists mainly of *Coccolithus pelagicus* and *Toweius craticulus.* The presence of *Discoaster multiradiatus* in nearly one third of the samples, including Samples 1-1, 0–2 cm and 3,CC (the shallowest and deepest), and the absence of age-diagnostic Eocene species throughout the studied section suggest that these samples are probably upper Paleocene and belong to the *Discoaster multiradiatus* Zone (Bukry, 1975) or the NP 9 *Discoaster multiradiatus* Zone (Martini, 1971). Such an interpretation is also supported

TABLE 4
Nannofossil Occurrences in Hole 430A

Sample (Interval in cm)	Preservation	*Catinaster coalitus*	*Chiasmolithus californicus*	*Chiasmolithus consuetus*	*Coccolithus eopelagicus*	*Coccolithus pelagicus*	*Cyclicargolithus abisectus*	*Cyclicargolithus floridanus*	*Cyclococcolithus formosus*	*Cyclococcolithus leptoporus*	*Cyclococcolithus macintyrei*	*Dictyococcites bisectus*	*Dictyococcites dictyodus*	*Dictyococcites scrippsae*	*Discoaster brouweri*	*Discoaster deflandrei*	*Discoaster druggii*	*Discoaster exilis*	*Discoaster intercalaris*	*Discoaster multiradiatus*	*Discoaster nobilis*	*Discoaster nodifer*	*Discoaster pansus*	*Discoaster tani*	*Discoaster variabilis*	*Ellipsodiscoaster lidzi*	*Gephyrocapsa caribbeanica*	*Gephyrocapsa doronicoides*	*Gephyrocapsa oceanica*	*Helicopontosphaera kamptneri*	*Neochiastozygus chiastus*	*Neochiastozygus distentus*	*Pontosphaera* spp.	*Reticulofenestra hillae*	*Reticulofenestra pseudoumbilica*	*Reticulofenestra umbilica*	*Sphenolithus abies*	*Sphenolithus moriformis*	*Toweius craticulus*	*Toweius eminens*	Zone: Bukry (1975)	Zone: Martini (1971)	Chronostratigraphy
1-1, 0–2	P					+			+											+																			+	+	*D. multiradiatus*	NP 9	Upper Paleocene
1-1, 10–12	P					+			+	+																			+										+	+			
1-1, 20–22	P				+	+					+									+						+	+	+	+														
1-1, 30–32	P					+					+					+			+																				+	+			
1-1, 38–40	P				+	+		+												+								+		+									+				
1-1, 40–42	P				+							+																															
1-1, 50–52	P					+		+																											+				+				
1-1, 60–62	P					+	+																																				
1-1, 70–72	P				+	+		+				+								+															+				+				
1-1, 80–82	P				+	+	+					+								+																			+	+			
1-1, 90–92	P				+	+		+														+						+							+			+	+				
1,CC	M				+	+		+				+	+				+				+																		+	+			
2-1, 90–92	P					+		+						+				+	+				+		+						+				+	+			+				
2-1, 100–102	P	+				+			+		+	+			+			+							+						+				+		+	+	+	+			
2-1, 110–112	P					+	+				+	+			+			+							+										+		+	+	+				
2-1, 120–122	P				+	+												+						+	+							+		+	+				+				
2-1, 123–124	P				+	+		+						+	+			+	+						+						+				+	+			+				
2-1, 130–132	P				+	+					+							+							+										+		+		+	+			
2-1, 140–142	P					+					+							+		+					+									+				+	+	+			
2-1, 148–150	P					+					+				+																			+	+				+	+			
2,CC	P		+		+	+																													+				+				
3,CC	P			+	+	+														+													+					+	+	+			
4-1, 40–42		Barren																																									
10,CC		Barren																																									

by the persistent distribution of *Toweius craticulus* and sporadic occurrences of *Discoaster nobilis, Chiasmolithus californicus, C. consuetus, Neochiastozygus chiastus, N. distentus,* and *Toweius eminens* throughout the cores. Therefore, the Eocene to Recent specimens present in this assemblage are interpreted as up-hole contamination.

The preceding evidence indicates that upper Paleocene sediments are present in Hole 430A. This demonstrates that Ojin Seamount is older than Koko Seamount to the south. Typical shallow-water genera such as *Braarudosphaera* reported from Koko Guyot (Sites 308, 309; Bukry, 1975) were not observed in samples from Hole 430A. However, low species diversity as well as the paucity of nannofossils may be the results of deposition in a shallow-water environment.

Hole 430B
(lat. 37°59.52′ N, long. 170°36.12′ E; water depth 1471 m)

To compare the Quaternary flora along the Emperor Seamount chain, a punch core was attempted as Hole 430B before departure from this site; but only a very small quantity of loose watery sand was obtained, owing to what later proved to be a plugged bit.

A comparatively abundant and moderately well preserved Pleistocene to Holocene nannofossil assemblage of thirteen species has been observed. A few reworked specimens of Paleocene, Miocene and Pliocene dates, such as *Toweius craticulus, Cyclicargolithus floridanus, Discoaster quinqueramus, Helicopontosphaera sellii, Reticulofenestra pseudoumbilica,* and *Sphenolithus moriformis* are also recognized. The presence of *Emiliania huxleyi* suggests that this sample is upper Pleistocene to Holocene and belongs to the *Emiliania huxleyi* Zone (Bukry, 1975) or the NN 21 *Emiliania huxleyi* Zone (Martini, 1971). The calcareous nannofossils and the state of preservation of the assemblages are shown in Table 5.

Site 431: North of Nintoku Seamount

Site 431 is on a small seamount north of Nintoku Seamount in the Emperor Seamount chain. Two holes were drilled in what appeared to be a faulted terrace at the top of this small seamount. Recovery of sediments at this site was disappointingly low because of drilling equipment failure at both Hole 431 and Hole 431A. The following data are therefore based on the limited number of samples available.

Hole 431
(lat. 42°25.44′ N, long. 170°32.68′ E; water depth 1704 m)

A total of 3.33 meters of sand and unconsolidated gravel was recovered from Hole 431. This material contains subarctic upper Pleistocene to Holocene nannofossils.

Seven samples from Cores 1 and 2 were studied. Calcareous nannofossil abundance ranges from barren (Sample 1-1, 104–106 cm) to common, and the assemblages are marked by low species diversity, which may be a result of low water temperature. The microflora generally consists of *Coccolithus pelagicus, Cyclococcolithus leptoporus, Emiliania huxleyi, Gephyrocapsa caribbeanica, G. doronicoides,* and *G. oceanica.* This assemblage may belong to the subarctic zone of the modern coccolithophorid biogeography according to McIntyre and Bé (1967). Sample 2,CC, however, contains a slightly more diversified nannofossil assemblage consisting of *Helicopontosphaera wallichi, Scapholithus fossilis, Syracosphaera pulchra,* and *Umbilicosphaera mirabilis,* in addition to the typical cold-water species noted above. The occurrence of *Emiliania huxleyi* throughout the cores places all these samples in the upper Pleistocene to Holocene *Emiliania huxleyi* Zone or NN 21 *Emiliania huxleyi* Zone. The stratigraphic distribution of the calcareous nannofossils and the preservation of the assemblages are shown in Table 6.

Hole 431A
(lat. 42°25.39′ N, long. 170°32.60′ E; water depth 1704 m)

Hole 431A penetrated 17.0 meters of sediment, of which only 4.35 meters was recovered. Sediment recovered from this hole is similar to that of Hole 431, and consists chiefly of fine to medium-grained sand. Eight samples were available for investigation.

TABLE 5
Nannofossil Occurrences in Hole 430B

Sample	Preservation	*Ceratolithus cristatus*	*Coccolithus pelagicus*	*Cyclicargolithus floridanus*	*Cyclococcolithus leptoporus*	*Cyclococcolithus macintyrei*	*Discoaster quinqueramus*	*Discoaster* spp.	*Discolithina japonica*	*Ellipsodiscoaster lidzi*	*Emiliania huxleyi*	*Gephyrocapsa caribbeanica*	*Gephyrocapsa doronicoides*	*Gephyrocapsa oceanica*	*Helicopontosphaera kamptneri*	*Helicopontosphaera sellii*	*Reticulofenestra pseudoumbilica*	*Reticulofenestra?* sp.	*Sphenolithus moriformis*	*Syracosphaera pulchra*	*Thoracosphaera heimi*	*Toweius craticulus*	*Umbilicosphaera mirabilis*	Total	Zone Bukry (1975)	Zone Martini (1971)	Chronostratigraphy
Punch core	P	+	33	1	54	6	+	1	2	2	8	1	11	43	13	1	4	12	1	3	+	2	2	200	*E. huxleyi*	NN 21	Pleist./Holo.

TABLE 6
Nannofossil Occurrences in Hole 431

Sample (Interval in cm)	Preservation	*Coccolithus pelagicus*	*Cyclococcolithus leptoporus*	*Cyclococcolithus macintyrei*	*Ellipsodiscoaster lidzi*	*Emiliania huxleyi*	*Gephyrocapsa caribbeanica*	*Gephyrocapsa doronicoides*	*Gephyrocapsa oceanica*	*Helicopontosphaera kamptneri*	*Helicopontosphaera wallichi*	*Reticulofenestra?* sp.	*Scapholithus fossilis*	*Syracosphaera pulchra*	*Umbilicosphaera mirabilis*	Miscellaneous	Total	Zone: Bukry (1975)	Zone: Martini (1971)	Chronostratigraphy
1-1, 40–42	M	37	22	1	1	1	10	17	8		1	2					100	*E. huxleyi*	NN 21	Pleistocene/Holocene
1-1, 104–106		Barren																		
1,CC	G	47	40	3		8	14	69	10	2		3				4	200			
2-1, 7–9	P	23	56	5		10	7	82	8	1		3			1	4	200			
2-1, 25–27	P	26	86	3		3	1	62	11	1		4				3	200			
2-1, 119–121	M	25	68	4		6	5	72	11	2	+	4		2		1	200			
2,CC	P	23	63			3	1	1	5		1		1	1	1		100			

Only the samples from Core 1 contain calcareous nannofossils in any abundance (Table 7). The first two samples of Core 1 (1-1, 4–6 cm and 1-1, 40–42 cm) contain common but poorly preserved coccolith assemblages. The species diversity is low; *Coccolithus pelagicus, Cyclococcolithus leptoporus, Gephyrocapsa caribbeanica,* and *G. doronicoides* are dominant, and a few species, such as *Cyclococcolithus macintyrei, Gephyrocapsa aperta, G. oceanica, Helicopontosphaera kamptneri, Pseudoemiliania lacunosa* (= *Emiliania annula*), and *Umbilicosphaera mirabilis* occur rarely. It is worth noting that these samples contain comparatively abundant *Pseudoemiliania lacunosa* and *Gephyrocapsa oceanica.* These samples may thus represent the Pleistocene (*Emiliania ovata* Subzone or NN 19 *Pseudoemiliania lacunosa* Zone). In the remaining samples of Core 1 (Sample 1-2, 36–38 cm to Sample 1,CC), coccoliths are rare and the preservation is very poor. *Coccolithus pelagicus* and *Cyclococcolithus leptoporus* are dominant, and a few additional species, such as *Ellipsodiscoaster lidzi, Gephyrocapsa* spp., and *Helicopontosphaera sellii* occur. On the basis of the coexistence of *Gephyrocapsa oceanica, Cyclococcolithus macintyrei,* and *Helicopontosphaera sellii,* Sample 1,CC is also

TABLE 7
Nannofossil Occurrences in Hole 431A

Sample (Interval in cm)	Preservation	*Coccolithus pelagicus*	*Cyclococcolithus leptoporus*	*Cyclococcolithus macintyrei*	*Ellipsodiscoaster lidzi*	*Gephyrocapsa aperta*	*Gephyrocapsa caribbeanica*	*Gephyrocapsa doronicoides*	*Gephyrocapsa oceanica*	*Helicopontosphaera kamptneri*	*Helicopontosphaera sellii*	*Pseudoemiliania lacunosa*	*Reticulofenestra pseudoumbilica*	*Syracosphaera pulchra*	*Umbilicosphaera mirabilis*	Miscellaneous	Total	Zone: Bukry (1975)	Zone: Martini (1971)	Chronostratigraphy
1-1, 4–6	P	56	46	4		3	24	44	15	2		2			1	3	200	*E. ovata*	NN 19	Pleistocene
1-1, 40–42	P	61	43	4		3	23	40	17	1		1	1	+		6	200			
1-2, 36–38	P	15	5	1	1			3									25			
1,CC	P	44	49	1				3	2		1						100			
2-1, 30–31		Barren																		
2-1, 98–99		Barren																		
2-2, 6–7		Barren																		
2,CC	P	+	+																	

Pleistocene and referred to the basal part of NN 19 *Pseudoemiliania lacunosa* Zone (*Emiliania ovata* Subzone).

Nannofossils in Sample 2,CC are extremely rare, and only poorly preserved *Coccolithus pelagicus* and *Cyclococcolithus leptoporus* are present. Because of the absence of age-diagnostic species in this sample, no biostratigraphic assignment can be made.

Site 432: Nintoku Seamount

Site 432 is on the top of Nintoku Seamount. Two holes were drilled in what appeared to be perched terrace deposits atop this seamount, but unfortunately both holes had to be abandoned prematurely because of mechanical failure in the bottom hole assemblies.

Hole 432
(lat. 41°20.03′ N, long. 170°22.74′ E; water depth 1310 m)

About three meters of light green unconsolidated pelagic sediments was recovered from the first hole at this site. All the samples from this hole except the lowest one (Sample 1,CC) are characterized by fairly abundant calcareous nannofossils. The species diversity, however, is comparatively low and the state of preservation is generally moderate (Table 8). Assemblages are dominated by placoliths, particularly *Coccolithus pelagicus, Cyclococcolithus leptoporus, Emiliania huxleyi, and Gephyrocapsa* spp. Among them, *C. pelagicus* is fairly abundant between Samples 1-1, 10–11 cm and 1-3, 10–11 cm, which suggests that the sediments at these levels were deposited beneath a comparatively cold water mass. The presence of *Emiliania huxleyi* places these samples in the *Emiliania huxleyi* Zone or NN 21 *Emiliania huxleyi* Zone. In addition to the presence of *Emiliania huxleyi,* moreover, the occurrence of *Helicopontosphaera wallichi,* considered to be a typical Recent species (Haq, 1973), indicates that the assemblage is Pleistocene to Holocene. In the lowest sample obtained, Sample 1,CC, species diversity and population density are very low. In this sample, *Coccolithus pelagicus, Gephyrocapsa doronicoides,* and small undiagnostic placoliths are dominant. The presence of *Emiliania huxleyi,* however, indicates that this sample is also upper Pleistocene to Holocene. Throughout the core, sporadic occurrences of Cyclicargolithus floridanus, Cyclococcolithus macintyrei, Pseudoemiliania lacunosa, Reticulofenestra hillae, R. pseudoumbilica, Sphenolithus moriformis, Toweius craticulus, and *T. eminens* were recognized. These species are interpreted as being reworked from Paleogene and Neogene sediments. Among them, *Toweius craticulus* and *T. eminens* are dominant in Sample 1,CC. A single specimen of *Braarudosphaera bigelowi* was also recovered from this sample. This is a typical shallow-water species (Martini, 1967; Takayama, 1972). Judging from the state of the preservation, it is also considered to be reworked from Paleogene formations.

Hole 432A
(lat. 41°20.03′ N, long. 170°22.74′ E; water depth 1310 m)

Only conglomeratic basalt and red clay material from the core catcher of Core 2 were recovered from this hole. Calcareous nannofossils were completely absent in this sample.

Site 433: Suiko Seamount

Site 433 is on the top of Suiko Seamount, where seismic profiles show a blanket of sediment about 160 meters thick in a sedimentary pond. This was the only proposed primary target for a multiple re-entry hole, and the finale for Leg 55.

TABLE 8
Nannofossil Occurrences in Hole 432

Sample (Interval in cm)	Preservation	*Braarudosphaera bigelowi*	*Ceratolithus cristatus*	*Coccolithus pelagicus*	*Cyclicargolithus floridanus*	*Cyclococcolithus leptoporus*	*Cyclococcolithus macintyrei*	*Discolithina japonica*	*Ellipsodiscoaster lidzi*	*Emiliania huxleyi*	*Gephyrocapsa aperta*	*Gephyrocapsa caribbeanica*	*Gephyrocapsa doronicoides*	*Gephyrocapsa oceanica*	*Helicopontosphaera kamptneri*	*Helicopontosphaera wallichi*	*Oolithotus antillarum*	*Pseudoemiliania lacunosa* (oval)	*Reticulofenestra hillae*	*Reticulofenestra pseudoumbilica*	*Rhabdosphaera clavigera*	*Scapholithus fossils*	*Sphenolithus moriformis*	*Syracosphaera pulchra*	*Toweius craticulus*	*Toweius eminens*	*Umbilicosphaera mirabilis*	Miscellaneous	Total	Zone Bukry (1975)	Zone Martini (1971)	Chronostratigraphy
1-1, 8–9	G			31		8				38	1	25	67	23	2		+							2				3	200	*E. huxleyi*	NN 21	Pleistocene/Holocene
1-1, 10–11	M			33		4		+		65	1	44	16	22	6		1			1	1			2			2	2	200			
1-1, 27–28	M			50		15		2		25		22	44	25	6									1			2	8	200			
1-1, 60–61	M			49		13				50	1	29	26	23	4									2			2	1	200			
1-2, 41–42	G		+	43		11				60		25	33	24	2						+			1			+	1	200			
1-2, 81–82	M			54		11				57		31	22	16	7												1	1	200			
1-3, 10–11	G			38		14	3			67		26	17	24	4	+					1			3			2	1	200			
1-3, 40–41	M			27		6				38	2	31	61	26				1						1				7	200			
1-3, 60–61	G			38		7				60	1	23	32	33	1		1							2				2	200			
1-3, 80–81	G			30		11		+		79		24	30	16	1					1				4				4	200			
1-3, 100–101	M			21		7				68	1	19	31	44	2							1		1			1	4	200			
1-3, 148–149	G			29		8		+		54		27	46	27	2	+	2				+	+		2	+		+	3	200			
1-4, 15–16	G			26		4		+	1	42		16	64	35	2	+	1	+			+			1			2	6	200			
1-4, 47–48	G			22	1	8				57		17	66	25	1									1	1		+	1	200			
1-4, 108–109	G			66		9				27		25	40	11	1				+	1			1	1	13			5	200			
1,CC	M	+		20		1				7		3	26	7	1										22	2		11	100			

Hole 433
(lat. 44°46.60′N, long. 170°01.26′E; water depth 1862 m)

The first hole at this site was drilled as a washdown test hole for a possible multiple re-entry hole. A 5.0-meter core of pelagic ooze was obtained.

The calcareous nannofossil assemblages from this hole are characterized by being very abundant and well preserved, but of comparatively low species diversity. The cored sediments range from Recent to lower Pliocene. The calcareous nannofossil species and their relative abundances observed in samples recovered from Hole 433, together with the state of preservation, are shown in Table 9.

Interval from Sample 1-1, 1–2 cm to Sample 1-1, 120–121 cm

This interval is represented by seven samples. In these samples, the nannofossil assemblages are predominantly placoliths consisting of *Coccolithus pelagicus* and *Cyclococcolithus leptoporus,* though they fluctuate considerably in species composition. The gephyrocapsid species *G. caribbeanica, G. doronicoides,* and *G. oceanica* are also abundant. This interval is also marked by numerous occurrences of *Emiliania huxleyi,* which, however, becomes drastically less abundant in Samples 1-1, 79–80 cm and 1-1, 120–121 cm. Occasional specimens of *Ellipsodiscoaster lidzi, Oolithotus antillarum,* and *Ceratolithus cristatus* occur in this interval. On the basis of the presence of *Emiliania huxleyi,* this interval is considered to be upper Pleistocene to Holocene (*Emiliania huxleyi* Zone or NN 21 *Emiliania huxleyi* Zone). The occurrences of *Cyclococcolithus macintyrei, Pseudoemiliania lacunosa* and *Reticulofenestra pseudoumbilica* in this interval are therefore considered to result from reworking.

Interval from Sample 1-1, 140–141 cm to Sample 1-2, 100–101 cm

This interval is also represented by seven samples in which lower Pleistocene nannofossil assemblages are present. They are also characterized by abundant *Coccolithus pelagicus* and *Cyclococcolithus leptoporus.* In addition, *Cyclococcolithus macintyrei* occurs abundantly and *Emiliania huxleyi* is absent in all samples in this interval. The interval also contains fairly abundant *Pseudoemiliania lacunosa.* Many specimens of a small placolith which may be referred to *Reticulofenestra* (*Reticulofenestra*? sp.) are also present. Specimens of *Helicopontosphaera* occur occasionally in small numbers. Among them, the occurrence of *H. sellii* in Sample 1-2, 80–81 cm is significant. Judging by the coexistence of *Pseudoemiliania lacunosa, Gephyrocapsa oceanica,* and *Helicopontosphaera sellii,* and the absence of discoasters, this interval is Pleistocene, and assigned to the *Emiliania ovata* Subzone or NN 19 *Pseudoemiliania lacunosa* Zone. Gartner (1977) points out that the following three extinction horizons can be recognized above the *Discoaster brouweri* extinction datum which occurs

TABLE 9
Nannofossil Occurrences in Hole 433

Sample (Interval in cm)	Preservation	*Ceratolithus cristatus*	*Coccolithus pelagicus*	*Cyclococcolithus leptoporus*	*Cyclococcolithus macintyrei*	*Discoaster asymmetricus*	*Discoaster brouweri*	*Discoaster pentaradiatus*	*Discoaster surculus*	*Discoaster tamalis*	*Discolithina japonica*	*Ellipsodiscoaster lidzi*	*Emiliania huxleyi*	*Gephyrocapsa aperta*	*Gephyrocapsa caribbeanica*	*Gephyrocapsa doronicoides*	*Gephyrocapsa oceanica*	*Helicopontosphaera kamptneri*	*Helicopontosphaera sellii*	*Helicopontosphaera wallichi*	*Oolithotus antillarum*	*Pontosphaera* spp.	*Pseudoemiliania lacunosa*	*Pseudoemiliania lacunosa* (oval)	*Reticulofenestra pseudoumbilica*	*Reticulofenestra*? sp.	*Rhabdosphaera clavigera*	*Syracosphaera pulchra*	*Umbilicosphaera mirabilis*	Miscellaneous	Total	Zone: Bukry (1975)	Zone: Martini (1971)	Chronostratigraphy
1-1, 1–2	M		81	37							1		27		4	38	6	2			1							+	1	2	200	*E. huxleyi*	NN 21	Pleistocene/Holocene
1-1, 20–21	M		66	35									38		2	42	11	3									1		2		200			
1-1, 38–39	G		74	38								1	50		5	13	11	3										1	3	1	200			
1-1, 60–61	G		107	30									33	1	2	9	9	2								2		1		4	200			
1-1, 79–80	G	1	103	17	2							1	4	2	27	10	21	2								1				9	200			
1-1, 100–101	G		135	3									25		8	10	9	3						1	1			1	1	3	200			
1-1, 120–121	G		134	13									1	3	12	8	16						1							12	200			
1-1, 140–141	G		76	15	4									2	12	56	10					1	9	3	1	4			1	6	200	*E. ovata*	NN 19	
1-2, 4–5	G		64	25	25										4	20	19	2					7	3	1	19		2	1	8	200			
1-2, 20–21	G		100	19	10									5	12	15	9					1	2	+		20		2		5	200			
1-2, 41–42	G		61	43	37										35	8	9	+					1			4		+		2	200			
1-2, 60–61	G		118	11	14									1	8	12	2						4	+	1	27				2	200			
1-2, 80–81	G		86	9	12											84			2				1	1	1	2				2	200			
1-2, 100–101	G		66	18	1										1	110	1						2		1						200			
1-2, 120–121	G		81	11	6			1								95		+					2	1				+		3	200	*D. pentaradiatus*	NN 17	Pliocene
1-2, 145–146	G		96	18	10											63			1			1	2	1						8	200			
1-3, 0–1	G		82	21	5											86			1	+			3							2	200			
1-3, 20–21	G		100	19	10											56							2					2		11	200			
1-3, 42–43	M		47	24	10			+								115		+				+				2		+		2	200			
1-3, 61–62	M		44	23	18		1	+								107		1				1			1	1	+	1		2	200			
1-3, 80–81	G		69	19	11											96		+				1	1		2	1		+			200			
1-3, 100–101	G		97	5	6											81		+					3	1			1	1		5	200			
1-3, 120–121	G		85	15	7											75						+	7	6						5	200			
1-3, 140–141	G		74	31	11	1			1	1						24		+				2	9	7	8	30				1	200	*D. asymmetricus*	NN 15	
1-4, 4–5	G		96	26	22			2								6						4	5	6	4	29					200			
1-4, 20–21	M		63	37	14	1	1	1								21		1				1	11	4	15	29			1		200			
1,CC	G		80	41	9											32						2	7	5	7	16				1	200			

near the top of the Olduvai magnetic event, dated at about 1.65 m.y.: the *Cyclococcolithus macintyrei* extinction datum at 1.51 m.y., the *Helicopontosphaera sellii* extinction datum at 1.22 m.y., and the *Pseudoemiliania lacunosa* extinction datum at 0.44 m.y. Therefore, the occurrence of *C. macintyrei* in all samples from this interval strongly indicates that these samples are lower Pleistocene, the basal part of NN 19 *Pseudoemiliania lacunosa* Zone between 1.51 m.y. and 1.65 m.y.

Interval from Sample 1-2, 120–121 cm to Sample 1-3, 120–121 cm

This interval is represented by nine samples. As in previous intervals, *Coccolithus pelagicus* is fairly abundant throughout. All samples in this interval also contain fairly abundant *Cyclococcolithus leptoporus* and *C. macintyrei. Gephyrocapsa doronicoides* is dominant, but *G. caribbeanica* and *G. oceanica* are completely absent. *Pseudoemiliania lacunosa* is also present. The rare occurrence of *Discoaster brouweri* and *D. pentaradiatus* in only a few of the samples, together with the absence of *D. surculus,* suggests that this interval is upper Pliocene and can be assigned to the NN 17 *Discoaster pentaradiatus* Zone. This interval is also referred to the *Discoaster pentaradiatus* Subzone proposed by Bukry (1975).

Interval from Sample 1-3, 140–141 cm to Sample 1,CC

This interval is represented by the lowest four samples, and contains fairly abundant *Coccolithus pelagicus*. It is also characterized by the persistent occurrences of *Cyclococcolithus leptoporus, C. macintyrei, Gephyrocapsa doronicoides, Pseudoemiliania lacunosa, Pontosphaera* spp., and *Reticulofenestra pseudoumbilica.* Discoasters become more common in this interval, and consist of *D. asymmetricus, D. brouweri, D. pentaradiatus, D. surculus,* and *D. tamalis*. The interval is considered to be lower Pliocene, *Discoaster asymmetricus* Subzone or NN 15 *Reticulofenestra pseudoumbilica* Zone, on the basis of the presence of *Discoaster asymmetricus* and *Reticulofenestra pseudoumbilica* and the absence of *Amaurolithus tricorniculatus*.

In this hole, four calcareous nannofossil zones, ranging from lower Pliocene to Recent, can be recognized. According to the calcareous nannofossil zonation established by Martini (1971), they are the NN 15 *Reticulofenestra pseudoumbilica* Zone, the NN 17 *Discoaster pentaradiatus* Zone, the lower part of the NN 19 *Pseudoemiliania lacunosa* Zone, and the NN 21 *Emiliania huxleyi* Zone. The NN 16 *Discoaster surculus* Zone, NN 18 *Discoaster brouweri* Zone, and the upper part of the NN 19 *Pseudoemiliania lacunosa* Zone and NN 20 *Gephyrocapsa oceanica* Zone are not represented in this hole. These zones may be absent either because the sediments of these ages are too thin and consequently were not sampled or because that erosion by bottom currents removed them.

Hole 433A

(lat. 44°46.60′N, long. 170°01.26′E; water depth 1862 m)

After offsetting slightly, Hole 433A was drilled as a pilot hole for re-entry at this site. This hole was continuously cored, and penetrated 163.5 meters of sedimentary rocks, from Quaternary ooze at the surface to Paleogene consolidated reef limestone at the base. The recovery of sediments ranged from excellent in the pelagic oozes in the upper part of the hole to very poor in the unconsolidated reef sands and silts in the interval between 81 and 157 meters below mudline.

On the basis of the calcareous nannofossil assemblages, the sedimentary sequences recovered from Hole 433A can be divided into four microfloral units; unit 1 (Sample 1-1, 0–1 cm through Sample 3,CC), unit 2 (Sample 4-1, 5–6 cm through Sample 6-6, 3–4 cm), unit 3 (Sample 6-6, 53–54 cm through Sample 7-6, 50–51 cm) and unit 4 (Sample 7, CC through Sample 19,CC), in descending order. Sizeable biostratigraphic gaps occur between these microfloral units, as well as marked changes in the abundance, species composition, and state of preservation of the calcareous nannofossils. The stratigraphic distribution of the nannofossils and information regarding abundance and preservation of the assemblages are shown in Table 10 (back pocket, this volume).

Unit 1 (Sample 1-1, 0–1 cm to Sample 3, CC)

Nannofossil assemblages ranging from Quaternary to lower Pliocene occur in this unit, which is represented by a total of 47 samples. Calcareous nannofossils are very abundant throughout, except in Sample 2-1, 20–21 cm, where coccoliths are rather sparse. The assemblages are characterized by good preservation, but species diversity is comparatively low. Throughout the unit, assemblages show considerable fluctuation in species composition; but *Coccolithus pelagicus, Cyclococcolithus leptoporus*, and *Gephyrocapsa doronicoides* dominate the assemblage. *Helicopontosphaera kamptneri* is present in most samples of this unit. *Gephyrocapsa aperta, Helicopontosphaera sellii, H. wallichi, Oolithotus antillarum, Pseudoemiliania lacunosa, Rhabdosphaera clavigera, Scapholithus fossilis, Syracosphaera pulchra,* and *Umbilicosphaera mirabilis* are present only in this unit, though their occurrences are sporadic.

The nannofossil assemblage in Sample 1-1, 0–1 cm is quite similar to that observed in the interval ranging from Sample 1-1, 1–2 cm through Sample 1-1, 120–121 cm of Hole 433. The abundant occurrence of *Emiliania huxleyi* suggests that this sample can be correlated with the upper Pleistocene to Holocene *Emiliania huxleyi* Zone or NN 21 *Emiliania huxleyi* Zone. A few specimens of *Cyclococcolithus macintyrei* and *Pseudoemiliania lacunosa* in this sample are considered to be reworked. The next two samples, 1-1, 4–13 cm and Sample 1-1, 20–21 cm, belong to the Pleistocene *Emiliania ovata* Subzone (NN 19 *Pseudoemiliania lacunosa* Zone), according to the occurrence together of *Gephyrocapsa oceanica* and *Pseudoemiliania lacunosa*. The three samples below this (Sample 1-1, 40--41 cm to Sample 1-1, 80–81 cm) are all placed in the basal Pleistocene *Emiliania annula* Subzone (NN 19 *Pseudoemiliania lacunosa* Zone), because of the absence of both *Gephyrocapsa oceanica* and discoasters. In these intervals, a few reworked specimens of *Reticulofenestra pseudoumbilica* are present. The occurrences of *Discoaster pentaradiatus* and *D. surculus,* along with the absence of *D.*

tamalis, indicate a late Pliocene date for the interval ranging from Sample 1-1, 100–101 cm through Sample 1,CC. These samples can be assigned to the *Discoaster surculus* Subzone, which corresponds to the NN 16 *Discoaster surculus* Zone.

The youngest Cenozoic calcareous nannofossil zones recognized in the uppermost part of this hole are unexpectedly thin; besides, the *Ceratolithus cristatus* Subzone, *Gephyrocapsa caribbeanica* Subzone, *Cyclococcolithina macintyrei* Subzone, and the *Discoaster pentaradiatus* Subzone proposed by Bukry (1975) (or the NN 20 *Gephyrocapsa oceanica* Zone, NN 18 *Discoaster brouweri* Zone, and the NN 17 *Discoaster pentaradiatus* Zone of Martini [1971]) are missing. It is therefore considered that the sediments of these missing zones either are too thin to be recognized in the sampled intervals or were removed completely by strong bottom currents.

Below Core 1, samples show a repetition of Pleistocene calcareous nannofossil assemblages. The presence of *Gephyrocapsa oceanica* and the absence of *Emiliania huxleyi, Pseudoemiliania lacunosa,* and *Cyclococcolithus macintyrei* in Sample 2-1, 1–2 cm and Sample 2-1, 20–21 cm strongly indicate that these two samples are upper Pleistocene (*Ceratolithus cristatus* Subzone or NN 20 *Gephyrocapsa oceanica* Zone). The occurrence of *Pseudoemiliania lacunosa* together with *Gephyrocapsa oceanica* allows assignment of the next four samples (Sample 2-1, 43–44 cm to Sample 2-1, 100–101 cm) to the *Emiliania ovata* Subzone (NN 19 *Pseudoemiliania lacunosa* Zone). Sample 2-1, 122–123 cm, situated below the first occurrence of *Gephyrocapsa oceanica* and above the last occurrence of discoasters, is referred to the lowermost Pleistocene *Emiliania annula* Subzone (NN 19 *Pseudoemiliania lacunosa* Zone). Sample 2-2, 1–2 cm and Sample 2-2, 20–22 cm contain an upper Pliocene assemblage of the *Discoaster pentaradiatus* Subzone or NN 17 *Discoaster pentaradiatus* Zone. In this part of the hole, the *Gephyrocapsa caribbeanica* Subzone and the *Cyclococcolithina macintyrei* Subzone or NN 18 *Discoaster brouweri* Zone are lacking.

Specimens of *Reticulofenestra pseudoumbilica* occur sporadically in some intervals of the upper part of this hole. Their abundance, however, drastically increases in Sample 3-6, 25–26 cm, and I interpret this to mean that this species becomes extinct in Sample 3-6, 5–6 cm, and that the occurrences of this species above this sample represent reworking. Therefore, a total of 27 samples (Sample 2-2, 43–44 cm to Sample 3-6, 5–6 cm) is placed in the upper Pliocene NN 16 *Discoaster surculus* Zone. This zone can be referred to two zones of Bukry (1975): upper *Discoaster surculus* Subzone (Sample 2-2, 43–44 cm to Sample 3-3, 2–3 cm) and lower *Discoaster tamalis* Subzone (Sample 3-3, 21–22 cm to Sample 3-6, 5–6 cm). In the upper subzone of this hole, *Helicopontosphaera sellii* is abundant. In the lower subzone, the abundance of *Gephyrocapsa doronicoides* becomes less downsection, whereas small specimens of *Reticulofenestra?* sp. increase in number and become a large part of the assemblage.

The lowest two samples in this unit (Samples 3-6, 25–26 cm and 3,CC) can be placed in the lower Pliocene *Discoaster asymmetricus* Subzone or NN 15 *Reticulofenestra pseudoumbilica* Zone.

As is evident from Tables 1 and 2, the *Emiliania ovata* Subzone, the *Emiliania annula* Subzone, the *Discoaster surculus* Subzone or NN 19 *Pseudoemiliania lacunosa* Zone, and the NN 16 *Discoaster surculus* Zone are repeated in this unit. This could be attributed to faulting at the drilling site on the top of the seamount.

Calcareous nannofossils in unit 1 are represented by abundant Pliocene to Holocene assemblages with relatively low species diversity. This is apparently a result of low water temperature during late Pliocene to Holocene time in this area. This supposition may be supported by the occurrences of cold-water species such as *Coccolithus pelagicus, Cyclococcolithus macintyrei, Discoaster variabilis,* and *Reticulofenestra pseudoumbilica* throughout the unit, and the absence of warm-water species belonging to the genus *Sphenolithus* in the lowest part of this unit.

Unit 2 (Sample 4-1, 5–6 cm to Sample 6-6, 3–4 cm)

Unit 2 is represented by a total of 66 samples. Its assemblage is also characterized by fairly abundant calcareous nannofossils. The species diversity is also comparatively low, but the preservation is slightly poorer than in the previous unit; many specimens are broken and fragmented. The assemblage consists mainly of *Coccolithus pelagicus, Cyclococcolithus leptoporus, C. macintyrei, Reticulofenestra pseudoumbilica,* and *Reticulofenestra?* sp. Among these, *Reticulofenestra?* sp. constitutes more than 50 per cent of the assemblage in several samples, especially in the lower half of this unit. Sporadic occurrences of ceratoliths in the lower part, and of sphenoliths throughout the unit, are also characteristic. Discoaster species diversity in this unit is greater than in the other three units for this hole. The most important discoaster species is *D. quinqueramus,* which can be used to assign most of this unit (Sample 4-1, 5–6 cm to Sample 6-5, 6–7 cm) to the NN 11 *Discoaster quinqueramus* Zone (upper Miocene). This zone is also referred to *Ceratolithus primus* Subzone of Bukry (1975) based on the simultaneous occurrence in this section of *D. quinqueramus* and *Amaurolithus primus.* The lowest three samples in this unit (Sample 6-5, 53–54 cm to Sample 6-6, 3–4 cm) may belong to the *Discoaster berggrenii* Subzone or the NN 10 *Discoaster calcaris* Zone, on the basis of absent *Amaurolithus primus* and *Discoaster quinqueramus* and the occurrence of *D. surculus.*

The *Sphenolithus neoabies* Subzone, *Ceratolithus rugosus* Subzone, *Ceratolithus acutus* Subzone, and *Triquetrorhabdulus rugosus* Subzone, which range from 3.5 m.y. to 5.6 m.y.B.P. (Bukry, 1975), or the NN 14 *Discoaster asymmetricus* Zone, NN 13 *Ceratolithus rugosus* Zone, and NN 12 *Ceratolithus tricorniculatus* Zone, which range from 3.8 m.y. to 5.0 m.y.B.P. (Martini, 1976) cannot be recognized here. This suggests that there may be a 1.2 to 2.1 m.y. hiatus represented between Samples 3,CC and 4-1, 5–6 cm.

This unit also contains abundant cold-water species. The number of specimens of *Coccolithus pelagicus* and of *Reticulofenestra pseudoumbilica* is slightly less, however, and the species diversity is slightly higher than that of the overlying unit. Moreover, this unit contains a small number of warm-water species such as *Discoaster pentaradiatus* and *D. quinqueramus*. The unit also contains species of the genus *Sphenolithus*, which may reflect somewhat warmer water conditions. On the basis of these observations, sediments in unit 2 seem to have been deposited during cool water conditions but show some influence of warm water currents.

Unit 3 (Sample 6-6, 53–54 cm to Sample 7-6, 50–51 cm)

There are remarkable changes in the abundance, species composition, and the state of preservation of calcareous nannofossils between units 2 and 3. Calcareous nannofossils in 17 samples of this unit are characterized by the common occurrence of middle Miocene species that are poorly to moderately well preserved. The assemblage is composed mainly of *Coccolithus pelagicus, Reticulofenestra?* sp. (abundant), *Cyclococcolithus leptoporus,* and *C. macintyrei* (common). In addition, very abundant *Cyclicargolithus floridanus,* together with common *Coccolithus miopelagicus,* were recovered. An unusual association, with floods of *Discoaster deflandrei,* occurs in Sample 6,CC. Species of the genera *Discoaster, Catinaster,* and *Helicopontosphaera,* which are the most useful for subdivision of the Miocene sequences, are rare or almost absent; those present are not age-diagnostic. However, the presence of *Coccolithus miopelagicus* and *Discoaster deflandrei* throughout the unit, and the occurrence of *Sphenolithus heteromorphus* in Sample 6-7, 6–7 cm, probably suggest the middle Miocene (*Sphenolithus heteromorphus* Zone? or NN 5 *Sphenolithus heteromorphus* Zone?). Occasional occurrences of reworked specimens such as *Cyclicargolithus abisectus, Dictyococcites bisectus, D. dictyodus,* and *Reticulofenestra hillae* are also present in this unit.

Between units 2 and 3, the *Discoaster neohamatus* Zone to *Discoaster exilis* Zone (7.0 m.y. to 14.0 m.y.) (or NN 9 *Discoaster hamatus* Zone to NN 6 *Discoaster exilis* Zone [11.0 m.y. to 14.0 m.y.]) are missing.

This unit contains sphenoliths that may reflect comparatively warm water conditions. This interpretation is supported by a decline in the abundances of *Coccolithus pelagicus* and *Reticulofenestra pseudoumbilica* in this unit. Nannofossils in this unit are again characterized by assemblages with low species diversity, which may be the result of shoaling at the site of deposition, and not to cold water conditions. The occurrence of *Braarudosphaera bigelowi* in Sample 7-2, 50–51 cm may support this conclusion, although this typical shallow-water species is not abundant at this site.

Unit 4 (Sample 7,CC to Sample 19,CC)

The most striking changes in calcareous nannofossil abundance, species composition, and state of preservation in this hole can be recognized between units 3 and 4. In contrast to the previous units, calcareous nannofossils in unit 4 are extremely rare and poorly preserved. The assemblage is marked by a very low species diversity: *Coccolithus pelagicus* occurs sparsely in most samples; *Reticulofenestra?* sp. is present except in the upper part; lower Paleogene species *Toweius craticulus* occurs occasionally throughout, and *Neochiastozygus chiastus, N. distentus,* and *Princius bisulcus* are present mainly in the lower part. Specimens of the genus *Chiasmolithus* occur sporadically, but most of them cannot be identified, because of the very poor state of preservation.

This unit cannot be positioned precisely relative to the zonal scheme proposed by Martini (1971) or Bukry (1975), because it lacks the diagnostic Paleogene species. The species present, however, in their abundances, ranges, and overlaps of ranges when compared with the Paleogene biostratigraphic framework made by several authors — such as Bramlette and Sullivan (1961), Hay and Mohler (1967), Gartner (1971), Martini (1971) and Bukry (1973a, 1973b, 1975) — allow stratigraphic subdivision of this unit.

The upper part (Sample 7,CC to Sample 10-1, 4–5 cm) contains several lower Paleogene nannofossil species, such as *Chiasmolithus consuetus, Neochiastozygus chiastus, Princius bisulcus, Toweius craticulus,* and *T. eminens.* According to Gartner (1971), combined occurrence ranges of *Chiasmolithus consuetus, Toweius craticulus,* and *T. eminens* provide evidence for assignment to the upper Paleocene to lower Eocene (*Discoaster multiradiatus* Zone to the lower part of *Marthasterites contortus* Zone). According to Bukry (1973b), however, *Toweius eminens* is a common species in his *Fasciculithus tympaniformis* Zone (middle Paleocene). It is remarkable that in Sample 10-1, 120–121 cm, a typical Paleocene species, *Cruciplacolithus tenuis,* was found for the first time during this cruise, and it is common in the lower part of this unit. According to Martini (1971), this species occurs commonly in the sequence ranging from the lower Paleocene NP 2 *Cruciplacolithus tenuis* Zone to the upper Paleocene NP 6 *Heliolithus kleinpelli* Zone. The upper part of unit 4 is considered to be middle Paleocene to lower Eocene (probably the NP 7 *Discoaster gemmeus* Zone to lower part of the NP 10 *Marthasterites contortus* Zone, or the *Discoaster mohleri* Zone to the lower part of *Tribrachiatus contortus* Subzone) on the basis of occurrences of the lower Paleogene species mentioned above and the absence of *Cruciplacolithus tenuis.* The presence of *C. tenuis* in samples from the lower part of unit 4 (Sample 10-1, 120–121 cm to Sample 19,CC) together with *Neochiastozygus distentus, Toweius eminens,* and *T. craticulus* indicates that these samples may belong in the middle Paleocene NP 5 *Fasciculithus tympaniformis* Zone to NP 6 *Heliolithus kleinpelli* Zone (*Fasciculithus tympaniformis* Zone to *Heliolithus kleinpellii* Zone). The occurrences of *Chiasmolithus danicus* in Samples 14-1, 43–44 cm and 19-1, 17–18 cm probably support this conclusion. The sediments immediately overlying the basalt can therefore be no younger than middle to upper Paleocene.

Throughout this unit, the following younger coccoliths and discoasters occur sporadically in small numbers: *Coccolithus eopelagicus, C. miopelagicus, Cyclicargolithus floridanus, Cyclococcolithus leptoporus, C. macintyrei, Discoaster brouweri, D. pentaradiatus, D.*

surculus, D. variabilis, Gephyrocapsa doronicoides, Pseudoemiliania lacunosa, and *Reticulofenestra pseudoumbilica.* These species are concentrated especially in the stratigraphic intervals ranging from Sample 9-1, 100–101 cm through Sample 9-5, 3–4 cm. I interpret them as representing up-hole contamination.

As previously mentioned, nannofossils in this unit are extremely rare and poorly preserved. Assemblages are characterized by very low species diversity. Therefore, determination of the Paleocene depositional environment on Suiko Seamount is still uncertain. Judging from the limited information available, however, the assemblages with low species diversity may have resulted from shoaling at the site of deposition and not from cold water conditions. The occurrences of *Braarudosphaera bigelowi,* which is considered to be typical shallow-water species (Martini, 1967; Takayama, 1972), support this conclusion.

Lower Miocene, Oligocene, and Eocene sediments are missing between units 3 and 4. This sizeable stratigraphic gap may have resulted when these sediments were removed completely by bottom currents at a time when Suiko Seamount was uplifted to a point just below sea level.

Hole 433B
(lat. 44°46.63′N, long. 170°01.23′E; water depth 1862 m)

Hole 433B was a single-bit hole. It was washed down to 157.0 meters sub-bottom, and only a short core of the lower section coralline deposits, found just above basalt, was recovered. A total of 10 samples selected from these coralline deposits contain a sparse assemblage of poorly preserved Paleogene calcareous nannofossils.

The stratigraphic distribution of the nannofossils and information regarding the state of preservation of the assemblages are shown in Table 11. The difficulties encountered when attempting an accurate age assignment for the calcareous nannofossil assemblages from this hole are the same as for Hole 433A. Lower Paleogene zone fossils occur very rarely in this hole, and the only nannofossil species present in this unit that has been designated as a zonal species is *Cruciplacolithus tenuis.* Using the same criteria as described for Hole 433A, and the stratigraphic distribution of *Cruciplacolithus tenuis,* the boundary between the NP 7 *Discoaster gemmeus* Zone and the NP 6 *Heliolithus kleinpelli* Zone (between *Discoaster mohleri* Zone and *Heliolithus kleinpellii* Zone) in Hole 433B must be placed between Sections 5 and 6 of Core 1. Three samples above this boundary (Sample 1-3, 2–3 cm to Sample 1-5, 80–81 cm) may belong to the NP 7 *Discoaster gemmeus* Zone to the lower part of NP 10 *Marthasterites contortus* Zone (*Discoaster mohleri* Zone to the lower part of *Tribrachiatus contortus* Subzone), on the basis of the presence of *Toweius* and the absence of *Cruciplacolithus tenuis;* seven samples below the boundary (Sample 1-6, 85–86 cm to Sample 3, CC) may belong to the NP 5 *Fasciculithus tympaniformis* to NP 6 *Heliolithus kleinpelli* Zone (*Fasciculithus tympaniformis* Zone to *Heliolithus kleinpellii* Zone), on the basis of the occurrence of *Cruciplacolithus tenuis* together with *Neochiastozygus* and *Toweius.*

TABLE 11
Nannofossil Occurrences in Hole 433B

Sample (Interval in cm)	Preservation	*Chiasmolithus californicus*	*Chiasmolithus consuetus*	*Coccolithus pelagicus*	*Cruciplacolithus tenuis*	*Cyclicargolithus floridanus*	*Cyclococcolithus macintyrei*	*Neochiastozygus chiastus*	*Neochiastozygus distentus*	*Prinsius bisulcus*	*Reticulofenestra pseudoumbilica*	*Toweius craticulus*	*Toweius eminens*	Zone: Bukry (1975)	Zone: Martini (1971)	Chronostratigraphy
1-3, 2–3	P		+					+						a	NP 7–NP 10	Middle Paleocene –Lower Eocene
1-4, 41–42	P			+				+		+		+				
1-5, 80–81	P			+					+	+			+			
1-6, 85–86	P			+	+			+		+		+	+	b	NP 5–NP 6	
1-7, 22–23	P	+		+	+					+						
1,CC	P				+			+		+		+				
2-1, 7–8	P			+						+						
2,CC	P									+						
3-1, 40–41	P		+	+		+				+						
3,CC	P	+		+	+		+		+	+	+	+				

[a]*D. mohleri–T. contortus*
[b]*F. tympaniformis–H. kleinpellii*

Hole 433C
(lat. 44°46.63′N, long. 170°01.23′E; water depth 1862 m)

This is the multiple re-entry hole. After the setting of the re-entry funnel, the hole was washed down to the contact between reef calcarenite and basalt. Then 4.0 meters of sediments lying between the first two flow units of basalt was unexpectedly cored. This interbedded sediment consists of well-sorted, coarse-grained sand composed of about 70 per cent coralline debris and about 30 per cent volcanogenic debris.

Seven samples were selected from this sand layer and examined. They contain assemblages characterized by poorly preserved specimens with low species diversity that are similar to those described for Holes 433A and 433B (Table 12). There are few zone-determining species; but on the basis of the occurrences together of *Chiasmolithus californicus, Prinsius bisulcus, Toweius craticulus,* and *T. eminens,* these samples are most probably Paleocene to lower Eocene. The presence of *Toweius* and absence of *Cruciplacolithus tenuis* may indicate that these samples can be assigned to the NP 7 *Discoaster gemmeus* Zone to the lower part of NP 10 *Marthasterites contortus* Zone (*Discoaster mohleri* Zone to the lower part of *Tribrachiatus contortus* Subzone).

LIST OF SPECIES USED IN THIS REPORT

No new species are described in this report, so no taxonomic discussions and systematic descriptions are included. The species names considered herein are listed alphabetically below. Detailed descriptions of taxa may

TABLE 12
Nannofossil Occurrences in Hole 433C

Sample (Interval in cm)	Preservation	*Chiasmolithus californicus*	*Coccolithus pelagicus*	*Prinsius bisulcus*	*Toweius craticulus*	*Toweius eminens*	Zone: Bukry (1975)	Zone: Martini (1971)	Chronostratigraphy
3-1, 15–16	P		+	+	+		*D. mohleri–T. contortus*	NP 7–NP 10	Middle Paleocene –Lower Eocene
3-1, 75–76	P		+	+	+				
3-2, 15–16	P			+					
3-2, 75–76	P	+	+	+	+				
3-3, 15–16	P			+					
3-3, 75–76	P		+	+	+				
3,CC	P			+	+	+			

be found by consulting Loeblich and Tappan (1966, 1968, 1969, 1970a, 1970b, 1971, 1973), Gartner (1970), Bukry (1973a), Roth (1973), Haq (1973), and Gartner and Bukry (1975).

Amaurolithus delicatus Gartner and Bukry, 1975
Amaurolithus primus (Bukry and Percival) Gartner and Bukry, 1975
Amaurolithus tricorniculatus (Gartner) Gartner and Bukry, 1975
Angulolithina arca Bukry, 1973
Braarudosphaera bigelowi (Gran and Braarud) Deflandre, 1947
Ceratolithus cristatus Kamptner, 1954
Ceratolithus rugosus Bukry and Bramlette, 1968
Chiasmolithus bidens (Bramlette and Sullivan) Hay and Mohler, 1967
Chiasmolithus consuetus (Bramlette and Sullivan) Hay and Mohler, 1967
Chiasmolithus californicus (Sullivan) Hay and Mohler, 1967
Chiasmolithus danicus (Brötzen) Hay and Mohler, 1967
Coccolithus eopelagicus (Bramlette and Riedel) Bramlette and Sullivan, 1961
Coccolithus miopelagicus Bukry, 1971
Coccolithus pelagicus (Wallich) Schiller, 1930
Cruciplacolithus tenuis (Stradner) Hay and Mohler, 1967
Cyclicargolithus abisectus (Müller) Bukry, 1971
Cyclicargolithus floridanus (Roth and Hay) Bukry, 1971
Cyclococcolithus formosus Kamptner, 1963
Cyclococcolithus leptoporus (Murray and Blackman) Kamptner, 1954
Cyclococcolithus macintyrei Bukry and Bramlette, 1969
Dictyococcites bisectus (Hay, Mohler and Wade) Bramlette and Wilcoxon, 1967
Dictyococcites dictyodus (Deflandre and Fert) Martini, 1969
Dictyococcites scrippsae Bukry and Percival, 1971
Discoaster asymmetricus Gartner, 1969
Discoaster aulakos Gartner, 1967
Discoaster barbadiensis Tan Sin Hok, 1927
Discoaster berggrenii Bukry, 1971
Discoaster braarudii Bukry, 1971
Discoaster brouweri Tan Sin Hok, 1927
Discoaster challengeri Bramlette and Riedel, 1954
Discoaster deflandrei Bramlette and Riedel, 1954
Discoaster exilis Martini and Bramlette, 1963
Discoaster intercalaris Bukry, 1971
Discoaster nodifer (Bramlette and Riedel) Bukry, 1973
Discoaster pansus (Bukry and Percival) Bukry, 1973
Discoaster pentaradiatus Tan Sin Hok, 1927
Discoaster quinqueramus Gartner, 1969
Discoaster saipanensis Bramlette and Riedel, 1954
Discoaster surculus Martini and Bramlette, 1963
Discoaster tamalis Kamptner, 1967
Discoaster tani Bramlette and Riedel, 1954
Discoaster triradiatus Tan Sin Hok, 1927
Discoaster variabilis Martini and Bramlette, 1963
Discolithina japonica Takayama, 1967
Emiliania huxleyi (Lohmann) Hay and Mohler, 1967
Gephyrocapsa aperta Kamptner, 1963
Gephyrocapsa caribbeanica Boudreaux and Hay, 1967
Gephyrocapsa doronicoides (Black and Barnes) Bukry, 1973
Gephyrocapsa oceanica Kamptner, 1943
Helicopontosphaera granulata Bukry and Percival, 1971
Helicopontosphaera kamptneri Hay and Mohler, 1967
Helicopontosphaera sellii Bukry and Bramlette, 1969
Helicopontosphaera wallichi (Lohmann) Boudreaux and Hay, 1969
Isthmolithus recurvus Deflandre, 1954
Neochiastozygus chiastus (Bramlette and Sullivan) Perch-Nielsen, 1971
Neochiastozygus distentus (Bramlette and Sullivan) Perch-Nielsen, 1971
Oolithotus antillarum (Cohen) Boudreaux and Hay, 1969
Prinsius bisulcus (Stradner) Hay and Mohler, 1967
Pseudoemiliania lacunosa (Kamptner) Gartner, 1969
Reticulofenestra hillae Bukry and Percival, 1971
Reticulofenestra pseudoumbilica (Gartner) Gartner, 1969
Reticulofenestra umbilica (Levin) Martini and Ritzkowski, 1968
Rhabdosphaera clavigera Murray and Blackman, 1898
Scapholithus fossilis Deflandre, 1954
Sphenolithus abies Deflandre, 1954
Sphenolithus heteromorphus Deflandre, 1953
Sphenolithus moriformis (Brönnimann and Stradner) Bramlette and Wilcoxon, 1967
Syracosphaera pulchra Lohmann, 1902
Thoracosphaera saxea Stradner, 1961
Toweius craticulus Hay and Mohler, 1967
Toweius eminens (Bramlette and Sullivan) Perch-Nielsen, 1971
Umbilicosphaera mirabilis Lohmann, 1902

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