Silver, E. A., Rangin, C., von Breymann, M. T., et al., 1991
Proceedings of the Ocean Drilling Program, Scientific Results, Vol. 124

10. CALCAREOUS NANNOFOSSIL BIOSTRATIGRAPHY OF THE CELEBES AND SULU SEAS[1]

Jih-Ping Shyu[2] and Carla M. Müller[3]

ABSTRACT

Five sites were drilled in the Celebes Sea and Sulu Sea During ODP Leg 124. Sites 767 and 771 in the Celebes Sea are below the regional carbonate compensation depth (CCD) and all calcareous nannofossils recovered in post-Oligocene sediments were recovered from turbidites. From the late middle Eocene to the late Oligocene, Site 771 was above the CCD and accumulated pelagic nannofossil clay. The highest occurrence of *Chiasmolithus grandis* is just above basement and indicates a late middle Eocene age for the Celebes Basin. In the southeast Sulu Basin, calcareous nannofossils are preserved only in post early middle Miocene sediments and are not useful for estimating the age of the basin. A late Pliocene change in calcareous nannofossil preservation and lithology at Sites 768 and 769 indicate deepening of the CCD. This corresponds to the progressive isolation of the southeast Sulu Basin, which is a consequence of global lowering of sea level and local tectonic adjustment of sill depth. The calcareous nannofossils at all five sites provide a good biostratigraphic framework for the sedimentary histories of the two basins even though some of the fossils were deposited by turbidity currents below the regional CCD, or have been mixed with redeposited specimens. The biostratigraphy record of Sites 767, 768, and 769 show that the lowest occurrence of *Gephyrocapsa oceanica* s.l. is consistently the nearest datum to the top of the Olduvai paleomagnetic event and, therefore, is the most suitable biohorizon for approximating the Pliocene/Pleistocene Boundary in the Celebes and Sulu Seas.

INTRODUCTION

Five sites were drilled in the Celebes and Sulu Seas, two small marginal basins off Southeast Asia, during Ocean Drilling Program Leg 124 (Fig. 1, Table 1). One of the major problems of the Celebes and Sulu Seas is that their origins and ages are uncertain. Murauchi et al. (1973) suggested that the Celebes Sea has an oceanic crust. Lee and McCabe (1986) proposed that the Celebes Basin is a trapped piece of an originally continuous ocean basin that also includes the Banda Sea and the Sulu Sea. The age of the Celebes Sea was interpreted as 42–47 m.y. by Weissel (1980) and 65–72 m.y. by Lee and McCabe (1986). Both interpretations are based on magnetic anomalies. Heat-flow data (Murauchi et al., 1973) permit either interpretation, but the crustal depth implies an age of approximately 65 m.y. (Sclater et al., 1976).

It was proposed that the Sulu Sea formed by entrapment of a piece of a larger ocean basin (Lee and McCabe, 1986) or by back-arc spreading (Mitchell et al., 1986; Holloway, 1981; Hamilton, 1979). The age of the Sulu Basin is also controversial; Lee and McCabe (1986) interpreted magnetic anomalies in the southeast Sulu Basins as seafloor spreading anomalies and assigned the basin an age of 41–45 m.y., but Mitchell et al. (1986) thought the southeast Sulu Basin opened by back-arc spreading in the early Oligocene (30–37 m.y.). Leg 124 was designed to resolve these problems, and one of its major scientific objectives was to determine the ages and stratigraphic histories of the Celebes and Sulu seas.

Calcareous nannofossils are the most abundant fossils and the best-preserved age markers at all five sites. The sediments in the Celebes Sea and Sulu Sea record the development of both basins. Turbidites are common in both basins and they produce significant bias in the fossil records. Site 767 in the Celebes Basin is located in deep water (4905 m below the sea level) below the local CCD, and all nannofossils found in the sediments are essentially displaced and redeposited in carbonate turbidites. Site 770, also in the deep Celebes Basin, was deposited in a shallower depth above and/or around the local CCD prior to late Oligocene time, and subsided below the CCD thereafter. Southeast Sulu Basin Sites 768 and 769 are located in much shallower water, but reworked specimens are still found throughout the sediments. Most of the important nannofossil biohorizons recognized in all five sites are in the correct order of succession, although some of the markers may have been redeposited and may not represent the real event. Because several sites are located in deep water, dissolution is also an important factor controlling nannofossil preservation. The age suggested for the Celebes Sea by the calcareous nannofossils recovered at Site 770 in the northern Celebes Basin is in good agreement with the late middle Eocene age estimated from radiolarians at Site 767 (Scherer and Lazarus, this volume) and from magnetic anomaly data (Weissel, 1980). In the Southeast Sulu Basin, calcareous nannofossils recovered at Sites 768, 769, and 771 indicate a late middle Miocene age in the deepest carbonate-bearing sediments but because calcareous nannofossils are not preserved in sediments close to basement, they do not give a good estimate of the age of the basin.

Rio et al. (in press) studied the calcareous nannofossils in the Pliocene/Pleistocene Boundary stratotype-Vrica section. They concluded that the Pliocene/Pleistocene Boundary exactly coincides with the top of the Olduvai Subchron (1.66 m.y.) and can be best approximated by the *Gephyrocapsa oceanica* s.l. lowest occurrence datum. In this study we have carefully examined the nannofossil biohorizons in the latest Pliocene to early Pleistocene sediments in the Celebes and Sulu Seas and correlated them with the magnetic polarity data (magnetostratigraphy of Leg 124 is discussed in Shyu et al., this volume). Our result shows that these nannofossil datums are in the same order as in the Vrica section, with only one exception in Hole 768B. The lowest occurrence of *Gephyro-*

[1] Silver, E. A., Rangin, C., von Breymann, M. T., et al., 1991. *Proc. ODP, Sci. Results,* 124: College Station, Tx (Ocean Drilling Program).
[2] Department of Oceanography, Texas A&M University, College Station, Tx 77843, U.S.A.
[3] Geologisch-Palöntologisches Institut, Universiät Frankfurt, Senckenberg-Anlage 32-34, D-6000 Frankfurt/Main, Federal Republic of Germany.

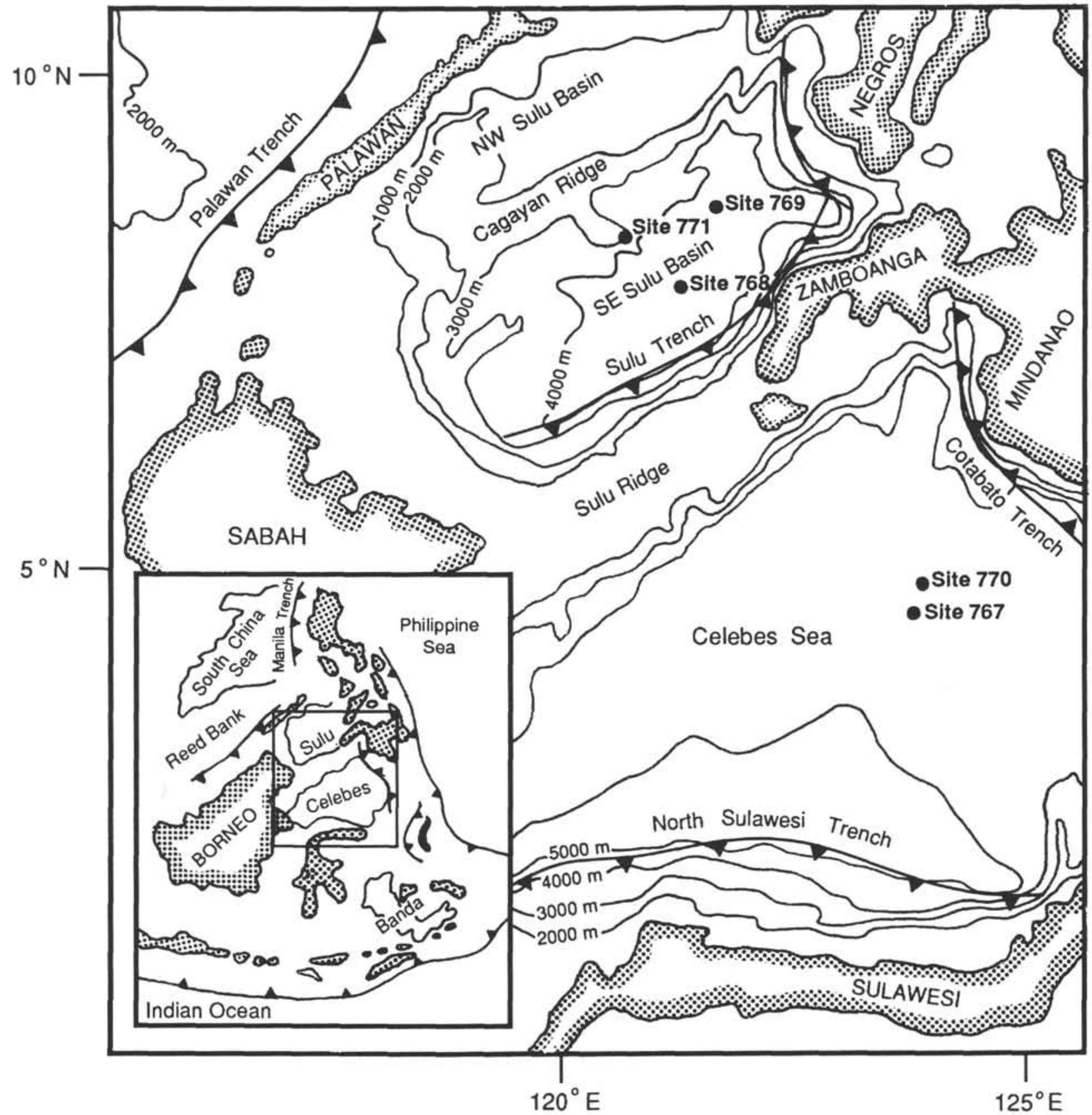


Figure 1. Locations of ODP Leg 124 sites in the Celebes Sea and Sulu Sea.

capsa oceanica s.l. is consistently the closest biohorizon to the top of Olduvai Subchron in this area (Shyu et al., this volume) and, therefore, has been used to approximate the Pliocene/Pleistocene Boundary.

CALCAREOUS NANNOFOSSIL BIOSTRATIGRAPHY AND GEOCHRONOLOGY

A summary of the biostratigraphic schemes and geochronologic framework used in this study and calcareous nannofossil biohorizons recognized at all five sites are shown in Figure 2. The "Standard Calcareous Nannoplankton Zonation" of Martini (1971; also see Martini and Müller, 1986) is based primarily on hemipelagic nannofossil records and is widely used in Cenozoic nannofossil biostratigraphy. In this study, we have mainly followed Martini's scheme; we have also recognized some nannofossil biohorizons not used as zonal markers by Martini but which proved useful for age determination. Bukry (1973; Okada and Bukry, 1980) also proposed a comprehensive zonation, based largely on deep-sea nannofossil data. That zonation is most useful for nannofossil biostratigraphy in low latitude, deep-sea sediments. Okada and Bukry's zones are also shown in Figure 2 for comparison.

The Cenozoic geochronology in this study follows mainly the compilation of Berggren, Kent, Flynn, and van Couvering (1985). The ages of the calcareous nannofossil biohorizons mainly refer to the compilations of Berggren, Kent, and Flynn (1985) for the Neogene, and Berggren, Kent and van Couvering (1985) for the Paleogene. Some ages are revised based on the biostratigraphic and magnetostratigraphic studies of North Atlantic deep-sea sediments (Baldauf et al., 1987; Takayama and Sato, 1987). The most significant departures are in the

Table 1. Locations of ODP Leg 124 sites.

Hole	Latitude(°N)	Longitude(°E)	Water depth (m)
767A	04°47.47′	123°30.21′	4905
767B	04°47.47′	123°30.20′	4905
767C	04°47.50′	123°30.21′	4905
768A	08°00.05′	121°13.16′	4385
768B	08°00.05′	121°13.19′	4385
768C	08°00.04′	121°13.18′	4385
769A	08°47.14′	121°17.65′	3644
769B	08°47.12′	121°17.68′	3644
769C	08°47.12′	121°17.69′	3644
770A	05°08.70′	123°40.24′	4505
770B	05°08.69′	123°40.10′	4505
770C	05°08.69′	123°40.11′	4505
771A	08°40.69′	120°40.78′	2859

early and middle Miocene (see discussion in Gartner, 1990). Some of these new age assignment seem to fit well in our data; they are also listed in Figure 2.

METHODS

Smear slides were prepared from unprocessed samples for biostratigraphic study. A very small amount of sample was evenly spread onto a glass slide with a drop of water and filming agent (Polyvinyl Alcohol). When dried, the cover-glass was mounted on the glass slide to cover the sample. For most of the samples this technique provided adequate data, but at some critical levels (e.g., near zonal boundaries) slides were prepared from processed samples to ensure reliability of the data.

Relative abundances of calcareous nannofossil species were determined by a semiquantitative method modified from Gartner (1972). All slides were checked with a light microscope at a magnification of 1500X. Each slide was scanned 20 to 30 min, but this time may vary depending on the abundance and preservation of nannofossils. Relative abundances of individual species were recorded in six categories: a species representing more than 70% of a rich assemblage is "very abundant"; an average of more than 10 specimens in each field is "abundant"; one to ten specimens in each field is "common"; more than seven specimens in the entire scanning area but averaging less than one specimen in each field is "few"; three to six specimens encountered in the entire scanning area is "rare"; one or two specimens encountered in the entire scanning area is "very rare".

SUMMARY OF CALCAREOUS NANNOFOSSIL BIOSTRATIGRAPHY

Celebes Sea

Site 767

Site 767 is located in the northeast part of the Celebes Sea, in a water depth of 4905 m (Fig. 1, Table 1). The 768 m of sediments overlying the basaltic basement contain the entire depositional history of the basin from the late middle Eocene to the Holocene. Carbonate content is low throughout the sediment section, indicating that deposition at this site was below the regional CCD. Four distinct lithologic units are recognized (Rangin, Silver, von Breymann, et al., 1990). Unit I is a 56.8-m-thick Pleistocene-Holocene hemipelagic volcanogenic clayey silt with rare calcareous turbidite layers and sparsely interbedded volcanic ashes. Unit II is 349.7 m in thickness and was deposited from the late Miocene to the Pleistocene. This unit consists of volcanogenic siltstone and claystone, with interbeds of volcanic ashes and carbonate turbidites. Unit III is a 292.4-m-thick, lower to upper Miocene terrigenous turbidite sequence with carbonate turbidite layers in the upper and middle parts, and volcanogenic turbidites near the base. Unit IV is a 87.7-m-thick homogenized middle Eocene to lower Miocene grayish to reddish brown pelagic clay with extremely low carbonate content (0.2%). Rare laminated volcaniclastic siltstones occur in the upper part of this unit. Agglutinated foraminifers, radiolarians, and fish teeth are found throughout this unit. Generally well-preserved calcareous nannofossils are found only in the upper Miocene to Holocene carbonate turbidites where the carbonate was preserved because of the fast deposition of the turbidites. Calcareous nannofossils are very rare in the interbedded clastic sediments.

Three holes were drilled at Site 767. Only 4.2 m of upper Pleistocene sediments were retrieved from Hole 767A. This section is assigned to Zone NN21 by the occurrence of *Emiliania huxleyi* in Sample 124-767A-1H, CC.

Hole 767B yielded 78 cores above basement. The oldest marker species recovered is *Catinaster coalitus* in Core 124-767B-62X, which indicates a late middle Miocene age. Nannofossil biohorizons identified in this hole are shown in Figure 2 and the nannofossil check list is shown in Table 2 (back pocket). The youngest biohorizon recognized is the lowest occurrence of *Emiliania huxleyi,* which marks the beginning of Zone NN21 in Sample 124-767B-2H, CC. Nannofossils are not abundant in the top two cores probably because of dissolution. The highest occurrence of *Pseudoemiliania lacunosa,* used to mark the top of Zone NN19, is not easy to determine in this hole because of mixing and redeposition. *Pseudoemiliania lacunosa* occurs consistently from Sample 124-767B-4H-1, 25–26 cm and downward, and the two isolated higher occurrences (in Samples 124-767B-2H-4, 80 cm and -3H-5, 97 cm) probably should be disregarded. Several biohorizons can be used to subdivide the lower Pleistocene. The top of the acme of small *Gephyrocapsa* spp. with an estimated age of 0.92 m.y. (Gartner, 1977) should be found in the lower part of Core 124-767B-7H just below the top of the Jaramillo magnetic event (magnetostratigraphic and biostratigraphic correlation is discussed in Shyu et al., this volume) but that interval is almost barren of nannofossils. The only three samples that contain very abundant small *Gephyrocapsa* specimens are 124-767B-8H-2, 64–65 cm, -8H-3, 20-21 cm, and -11X, CC. The next lower biohorizon, the highest occurrence of *Helicosphaera sellii* (Pl. 2), is distinct and in Sample 124-767B-11X, CC. The highest occurrence of *Calcidiscus tropicus* is identified in Sample 124-767B-14X-1, 13–14 cm. Some sporadic higher occurrences of this species can be identified as redeposited by comparing them with other biohorizons. The above three biohorizons are useful markers in the early Pleistocene and the last event has been incorporated into Martini's zonation to separate Zone NN19 into Subzones a and b (Martini and Jenkins, 1986). The lowest occurrence of *Gephyrocapsa oceanica* s.l. is found next below in Sample 124-767B-15X-3, 14–15 cm. In a turbidite section this lowest occurrence datum is probably more reliable than nearby highest occurrence datums.

The highest occurrence of *Discoaster brouweri,* the marker of the top of Zone NN18, is not easy to determine in this hole because of reworking and the scarcity of *Discoaster brouweri* toward its extinction. This datum is placed in Sample 124-767B-17X-3, 140–141 cm, based on consistent occurrences and higher abundances of *Discoaster brouweri* below this level. This approach was also used on most other highest occurrences in the Pliocene because they are also affected by

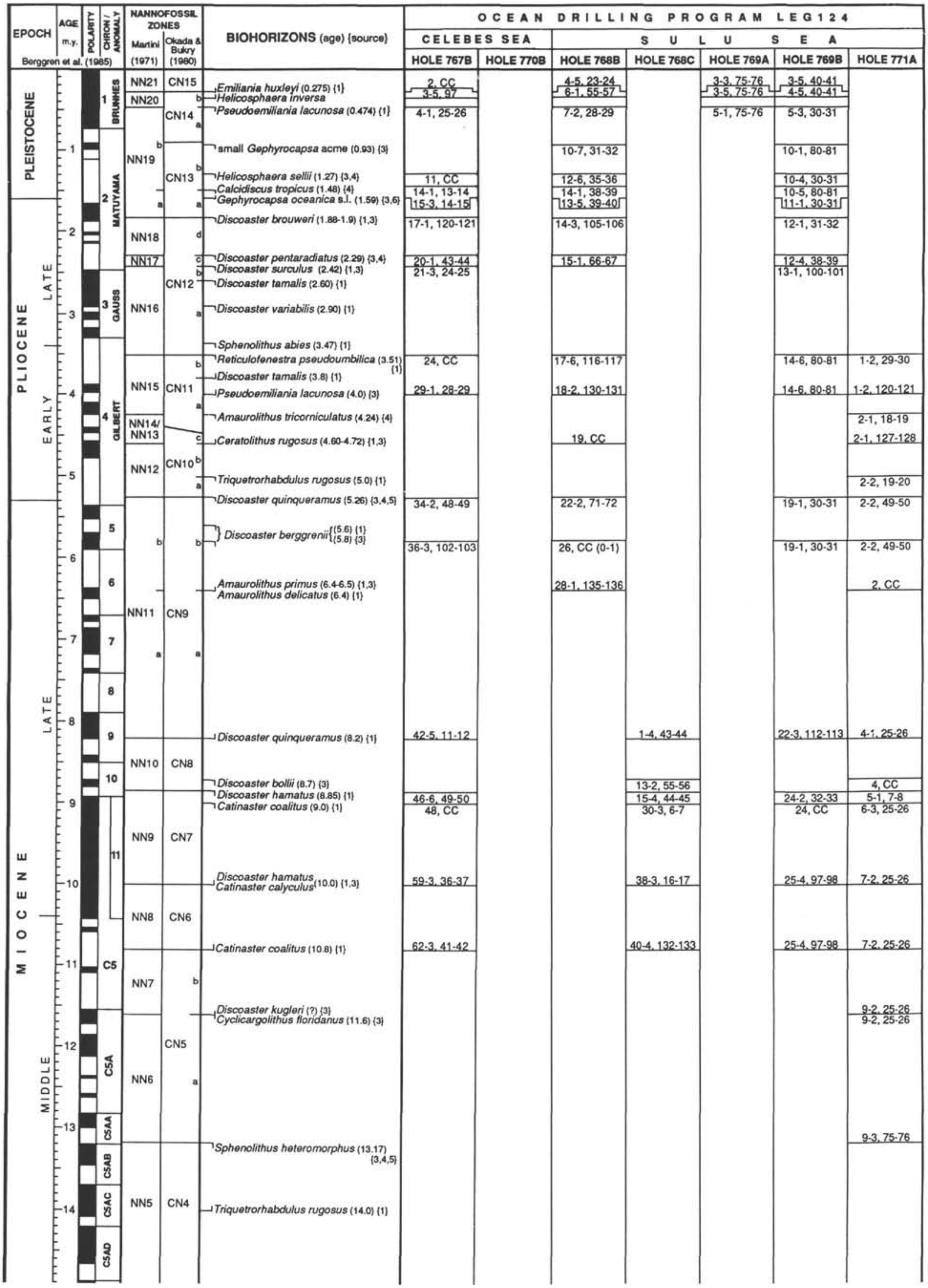


Figure 2. Nannofossil chronostratigraphic framework and summary of ODP Leg 124 calcareous nannofossil biostratigraphy. Geochronology follows Berggren, Kent, Flynn, and van Couvering (1985). Sources of the reference ages of biohorizons are: 1. Berggren, Kent, and van Couvering (1985), 2. Berggren, Kent, and Flynn (1985), 3. Gartner (1990), 4. Takayama and Sato (1987), 5. Baldauf et al., (1987), 6. Rio et al., (in press).

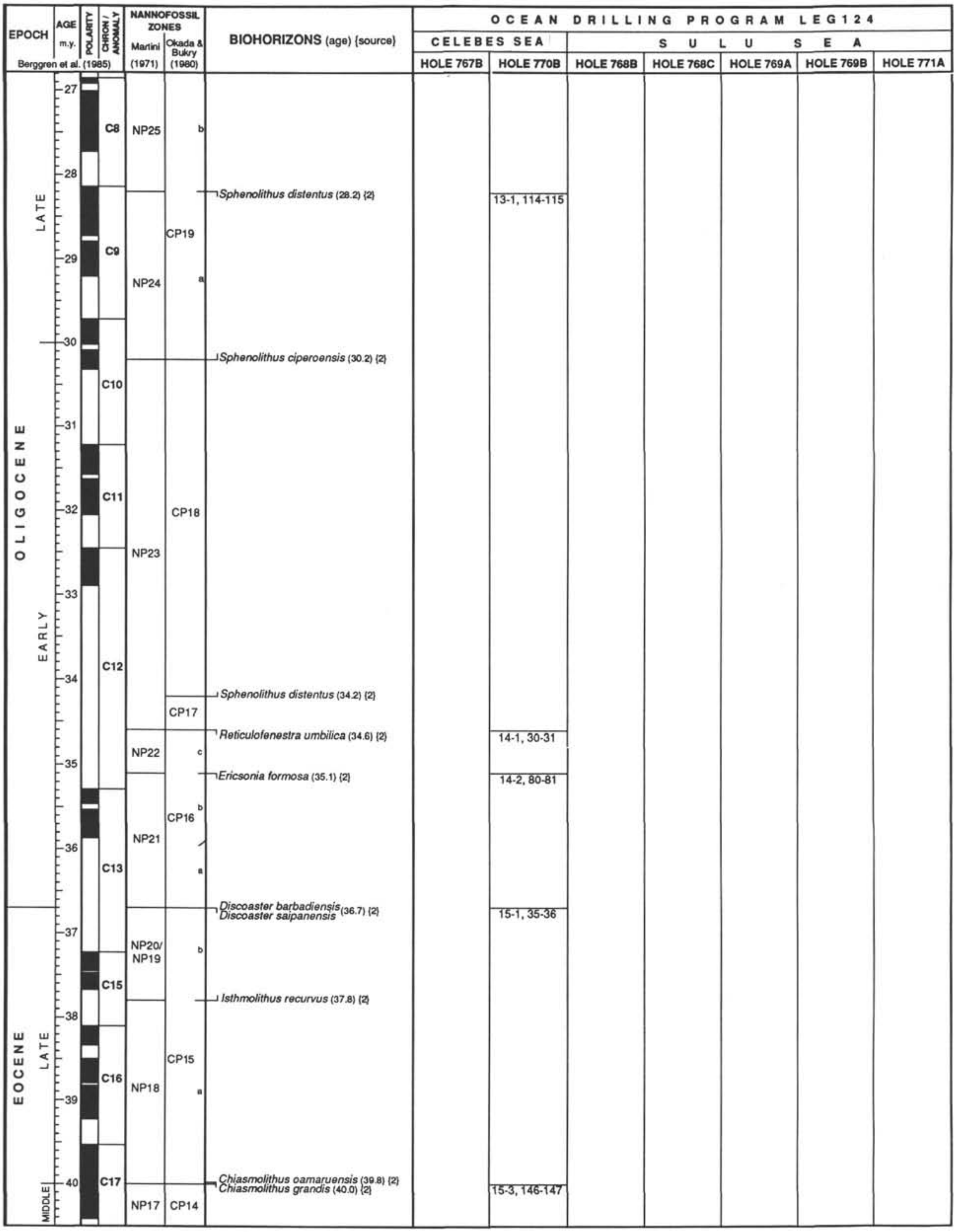


Figure 2 (continued).

reworking. The following biohorizons were found in the correct order of succession in Hole 767B, but it is impossible to evaluate whether they represent the real events or have been displaced by reworking. The highest occurrences of *Discoaster pentaradiatus* (Pl. 5), *Discoaster surculus,* and *Reticulofenestra pseudoumbilica* (Pl. 3), which mark the top of Zones NN17, NN16, and NN15, respectively, are placed successively in Samples 124-767B-20X-1, 43–44 cm, -21X-3, 24–25 cm, and -24X, CC. The highest occurrence of *Sphenolithus abies,* which should be slightly above the highest occurrence of *Reticulofenestra pseudoumbilica,* can not be identified in this hole because its range is obscured by reworked specimens. The lower Pliocene is difficult to subdivide because nearly all of the useful markers are either absent or are poorly preserved. *Amaurolithus tricorniculatus* only has a few scattered, very rare occurrences and is insufficiently represented to clearly mark a zonal boundary. However, the lowest occurrence of *Pseudoemiliania lacunosa* in Sample 124-767B-29X-1, 28–29 cm is less likely to be influenced by reworking and is considered reliable.

The highest occurrence of *Discoaster quinqueramus,* which marks the top of Zone NN11 and is traditionally used as the marker of the Miocene/Pliocene Boundary, occurs in Sample 124-767B-34X-2, 48–49 cm. It is followed by the highest occurrence of *Discoaster berggrenii* in Sample 124-767B-36X-3, 102–103 cm. The age of this datum was interpolated at 5.6 m.y. by Berggren, Kent, and van Couvering (1985), which is the same as that of the highest occurrence of *Discoaster quinqueramus,* but Gartner (1990) has suggested that the age of the highest occurrence of *Discoaster berggrenii* should be slightly older, *i.e.,* approximately 5.8 m.y. The lowest occurrence of *Discoaster quinqueramus,* the marker of the bottom of Zone NN11, is in Samples 124-767B-42X-5, 11–12 cm. The highest and lowest occurrences of *Discoaster hamatus* in Samples 124-767B-46X-6; 49–50 cm and -59X, CC, respectively, are also the markers of the top and the bottom of Zone NN9. *Catinaster coalitus* occurs from Sample 124-767B-56X-2, 76–77 cm, just below the top of Zone NN9, to the bottom of Zone NN8 in Sample 124-767B-62X-3, 41–42 cm. No diagnostic species were found below this level and nannofossils are absent below Core 124-767B-63X.

Site 770

Site 770 is located on a raised fault block 45 km north of Site 767 and is presently 400 m shallower than Site 767 (Fig. 1, Table 1). The main purpose of drilling this site was to test the age of the basement determined at Site 767 (based on radiolarians) and to collect basement samples. The upper 349.6 m of sediment section were spot cored. The recovered sediments are almost devoid of calcareous nannofossils, indicating that the sediment was deposited below the CCD and its higher elevation prevents it from receiving reworked nannofossils carried by turbidity currents. Only a few nannofossils were found in Core 124-770B-4R: *Discoaster asymmetricus, Discoaster brouweri, Discoaster pentaradiatus, Discoaster surculus, Sphenolithus abies, Pseudoemiliania lacunosa, Ceratolithus rugosus* (Pl. 1), and *Reticulofenestra minutula,* indicate a possible mid-Pliocene age.

Thick brown claystone beds recovered in Core 124-770B-11R and from Cores 124-770B-13R to -16R, consist predominantly of nannofossils and clays with carbonate content varying from 10% to 38%. The fluctuation of carbonate contents and nannofossil preservation indicate that this section was deposited above the CCD but at some periods it was close to or below the CCD. The nannofossil check list for this section is given in Table 3. *Sphenolithus ciperoensis,* found in Sample 124-770B-11R-1, 70 cm, indicates a late Oligocene age (Zone NP25). Nannofossils are absent in Core 124-770B-12R, but are present again in Core 124-770B-13R. The absence of *Sphenolithus distentus* in sediments above Sample 124-770B-13R-1, 114–115 cm indicates that the NP24/NP25 boundary is between Samples 124-770B-11R-1, 80–81 cm and -13R-1, 114–115 cm in an unfossiliferous interval. Rare *Dictyococcites bisectus* occur in Sample 124-770B-13R-1; 114–115 cm. This species has been used as a zonal marker in southern high latitudes (Perch-Nielsen, 1985) but it seems to disappear from the record earlier in low-latitude sections and is not useful in the subtropical hemipelagic environment. Some Eocene and early Oligocene species, apparently reworked from older strata, were found in Core 124-770B-13R. *Sphenolithus ciperoensis,* an important marker for the late Oligocene, is very rare at this site; therefore, the lowest occurrence of *Cyclicargolithus abisectus* in Sample 124-770B-13R-4, 78–79 cm was used to approximate NP23/NP24 zonal boundary. The highest occurrence of *Reticulofenestra umbilica,* the marker for the top of early Oligocene Zone NP22, is in Sample 124-770B-14R-1, 30–31 cm. The highest occurrence of *Ericsonia formosa,* the marker of the top of Zone NP21, is in Sample 124-770B-14R-2, 120–121 cm. *Dictyococcites scrippsae* is common and occurs consistently throughout the Oligocene. The lowest occurrence of *Sphenolithus distentus* in Sample 124-770B-14R-3, 16–17 cm is lower than it is normally cited (Bukry, 1973; Bramlette and Wilcoxon, 1967); however, this species has been found down to the upper Eocene (Gartner, unpublished data), and its lowest occurrence is not always a reliable marker.

The next two lower biohorizons, the highest occurrences of *Discoaster saipanensis* and *Discoaster barbadiensis,* are found together in Sample 124-770B-15R-1, 35–36 cm. They mark the top of Zone NP20 and are traditionally used as markers of the Eocene/Oligocene Boundary in calcareous nannofossil biostratigraphy. A noncalcareous brown clay layer separates this datum from the Oligocene nannofossil claystone, indicating that deposition was below the CCD at the beginning of the Oligocene. In general, the CCD was descending in the early Oligocene; therefore, this transition could have been caused by an accelerating subsidence of the Celebes Basin that exceeded the dropping of the CCD. Zones NP19 and NP20 cannot be separated because the Eocene marker species *Sphenolithus pseudoradians* is lacking. Zones NP18 and NP19 also cannot be differentiated because the marker species *Isthmolithus recurvus* prefers extratropical environments and is not present at this low-latitude site. The top of Zone NP17 is marked by the highest occurrence of *Chiasmolithus grandis* in Sample 124-770B-15R-4; 131–132 cm. *Sphenolithus obtusus* was also found at this level and down to the top of Core 124-770B-16R. Dissolution is more severe in the Eocene interval, and even the most dissolution-resistant species are poorly preserved. Sample 124-770B-16R-3, 29–30 cm (390.9 mbsf) was taken at 30 cm above the basement and contains only rare *Discoaster binodosus.* No nannofossils were found in sediments below this level. Nannofossils are too rare in Sections 124-770B-16R-2 and -16R-3 to identify a reliable biohorizon; however, the occurrences of *Dictyococcites bisectus* and *Reticulofenestra umbilica* suggest a late middle Eocene age (Zone NP17) immediately above the basement.

Sulu Sea

Site 768

Three holes were drilled at Site 768 in the center of the southeast Sulu Basin in water depth of 4395.3 m (Fig. 1, Table 1). The recovered sediment section is divided into five distinct lithologic units (Rangin, Silver, von Breymann, et al., 1990). Unit I is late Pliocene to Holocene in age and consists of

Table 3. Calcareous nannofossil check list of Hole 770B. Relative abundance as defined in Table 2.

LITHOLOGIC UNIT	AGE	NANNOFOSSIL ZONE	SAMPLE Core-section, interval (cm)	*Bramletteius serraculoides*	*Chiasmolithus grandis*	*Coccolithus eopelagicus*	*Coccolithus pelagicus*	*Coronocyclus nitescens*	*Cyclicargolithus abisectus*	*Cyclicargolithus floridanus*	*Dictyococcites bisectus*	*Dictyococcites scrippsae*	*Discoaster barbadiensis*	*Discoaster binodosus*	*Discoaster deflandrei*	*Discoaster saipanensis*	*Discoaster tani*	*Discoaster tani nodifer*	*Ericsonia formosa*	*Ericsonia obruta*	*Ericsonia subdisticha*	*Helicosphaera compacta*	*Helicosphaera euphratis*	*Helicosphaera recta*	*Helicosphaera reticulata*	*Lanternithus minutus*	*Pedinocyclus larvalis*	*Reticulofenestra* spp.	*Reticulofenestra umbilica*	*Sphenolithus ciperoensis*	*Sphenolithus distentus*	*Sphenolithus moriformis*	*Sphenolithus obtusus*	*Sphenolithus predistentus*	*Sphenolithus pseudoradians*	*Sphenolithus radians*	*Thoracosphaera* spp.	*Triquetrorhabdulus carinatus*
IIA	OLIGOCENE	NP25	11-1; 30–31																																			
			11-1; 70			F			F	C	R				F									R						R		F		R				
			11-1; 80–81			R			F	R	F	R			R	X	R	R								R						R						R
			11-1; 130–131																																			
			11CC																																			
			12CC																																			
IIB		NP23/ NP24	13-1; 114–115			F	R		X	A	X	R			R		F	R													R	F		C	R			X
			13-2; 40–41	X		F	R		X	A	X	F			R		R	R										X			R	F		C	X			
			13-3; 29–30	X		F	F		F	A	R	C			F		R	R		R								R			F	C		C	X		R	
			13-4; 78–79			F	F	X	R	A	F	F	X		F	X	R	F										X			R	F		C				
			13CC	R		F	C	F		A	C	F					F			F		F		F	R		R	F			C	C		F			R	
		NP22	14-1; 30–31	F		F	C	R		A	C	F	X		X			F		F		F	R	R	R		F	R	R		C	C		F			F	
			14-1; 80–81	F		F	C	R		C	C	F			F			F		F	R	F		R			R		F		C	C		F			R	
			14-1; 130–131	F		F	C	X		C	C	F			R		X	F		R		R			X		X	X	R		C	C		F			X	
			14-2; 30–31	F		F	C	X		C	C	F						F		R	R	F		R	R		R	R	R		C	F		F			R	
		NP21	14-2; 80–81	F		F	C	R		A	C	F			R			F	F			F			F			R	F		F	C		C			F	
			14-2; 120–121	F		F	C			C	F	F	X		X		F	F	F	R	X	F			F		X	R	F		F	F		C		X	F	
			14-3; 16–17	F		F	C	X		C	F	F			F		F	R	F	R	R	R			R		X		F		F	C		F			R	
			14-4; 15–16																																			
			14CC			X	R			F	F							X										X				X						
	EOCENE	NP18/ NP20	15-1; 35–36			F		R			R		C			C			C															R				
			15-2; 39–40			F	R				R	F	C	X		C	X	R	C										F					F		R		
			15-3; 45–46			F	X				F	R	F			C		R	R										X					R		X		
		NP17	15-3; 146–147		X	F	F				C		C	F		C	R	F	R										R							C		
			15-4; 131–132		R	F	F				C	F	C	X		C	R	F	F										X			R	C			F	R	
			15-5; 38–39		F	F	F				C	X	C			C	F	F	F										F			R	C			F	R	
			15CC		R	F	F				C	R	C			C	F	F	F										C				C			F	F	
			16-1; 39–40		R	F	R				C	X	C			C	R	R	R										C				R				X	
			16-1; 79–80		X	F					C	R	C			C													F							F	R	
			16-2; 89–90				X				R					X													R									
			16-3; 29–30											X																								
			16CC																																			

interbedded pelagic carbonate marl, sparse thin volcanic ash layers, and some turbidite beds. Medium to well preserved, common to abundant nannofossils are recorded in this unit but reworked species are also found in most of the samples. From the middle Miocene to the late Pliocene the sediments are mainly composed of alternating claystone, siltstone, and sandstone, and are interpreted as distal turbidites and hemipelagic clays (Unit II). Nannofossils are less abundant and their preservation deteriorates downward until they finally disappear in the middle Miocene. Unit III is early to middle Miocene in age. The upper part of this unit consists of hemipelagic claystone, normally graded interbeds of sandstone, siltstone, and claystone deposited by turbidity currents, a few thick tuff beds, and rare marlstone. The lower part of this unit is mostly claystone with very low carbonate contents (<1%). Sediments below Unit III and overlying basaltic basement are composed of tuff, lapillistone, and claystone.

One core was retrieved from Hole 768A. A late Pleistocene age (Zone NN21) is assigned to this core by the presence of *Emiliania huxleyi* in Sample 124-768B-1H, CC.

Hole 768B has a total recovery of 364.1 m of sediments ranging from Holocene at the top to late Miocene at the bottom. The nannofossil check list of this hole is given in Table 4 (back pocket). Reworked Pliocene and Miocene species are common in Pleistocene and upper Pliocene sediments and cast doubt on the reliability of the highest occurrences. *Emiliania huxleyi* occurs from the top of Core 124-768B-1H down to Sample 124-768B-4H-5, 23–24 cm, and the interval above this sample is assigned to Zone NN21. The lowest occurrence of *Helicosphaera inversa,* the next lower datum, is found in Sample 124-768B-6H-1, 55–57 cm. The highest occurrence of *Pseudoemiliania lacunosa,* used as the marker of the top of Zone NN19, is in Sample 124-768B-7H-2, 28–29 cm. The top of the interval dominated by small *Gephyrocapsa* specimens is found within the Jaramillo magnetic event in Sample 124-768B-10H-7, 31–32 cm, and is followed by the highest occurrences of *Helicosphaera sellii* and *Gephyrocapsa oceanica* s.l. in Samples 124-768B-12H-6, 35–36 cm and 124-768B-13H-5, 39–40 cm, respectively. The highest occurrence of *Calcidiscus tropicus* is in Sample 124-768B-14H-1, 38–39 cm, just above the top of the Olduvai paleomagnetic event.

The highest occurrence of *Discoaster brouweri* is more distinct than in Hole 767B and corresponds to the bottom of the Olduvai magnetic event in Sample 124-768B-14H-3, 105–106 cm. The remaining upper Pliocene is divided by a series of highest occurrences: *Discoaster pentaradiatus* in Sample 124-768B-15H-1, 66–67 cm, *Discoaster surculus* in Sample 124-768B-15H-4, 102–103 cm, and *Reticulofenestra pseudoumbilica* in Sample 124-768B-17H-6, 116–117 cm. These biohorizons are in the right order of succession and mark the tops of Zones NN17, NN16, and NN15, respectively. An additional marker, the lowest occurrence of *Pseudoemiliania lacunosa,* occurs in Sample 124-768B-18H-2, 130–131 cm, suggesting that this level is still within Zone NN15. The early Pliocene biohorizons in this hole are as uncertain as in previous holes. *Discoaster asymmetricus* was found only in two samples and has its lowest occurrence in Sample 124-768B-19H-2, 86–87 cm, just below the top of the Nunivak Subchron. Below this datum, two isolated highest occurrences of *Triquetrorhabdulus rugosus* and *Amaurolithus tricorniculatus* were found together in Sample 124-768B-19H-3, 128–129 cm. These species are too rare to be useful. The next lower biohorizon, the lowest occurrence of *Ceratolithus rugosus,* is in Sample 124-768B-19H, CC; it marks the boundary between Zones NN12 and NN13.

The Miocene/Pliocene Boundary in terms of calcareous nannofossils is traditionally placed at the highest occurrence of *Discoaster quinqueramus*. This datum is recorded in Sample 124-768B-22H-2, 71–72 cm. The highest occurrence of *Discoaster berggrenii* is slightly lower in Sample 124-768B-26X, CC and the lowest occurrence of *Amaurolithus primus,* the datum that separates Subzones NN11a and NN11b (Martini and Müller, 1986), is in Sample 124-768B-28X-1, 135–136 cm. The bottom of this hole is still in Zone NN11, within the range of *Discoaster quinqueramus*.

Hole 768C was washed down to 353 mbsf and then continuously cored into basement. The nannofossil check list of this hole is given in Table 5. Nannofossils occur only in the upper part of the recovered sediment section and are generally few and poorly preserved. The bottom of Zone NN11, marked by the lowest occurrence of *Discoaster quinqueramus,* is in Sample 124-768C-1R-4, 43–44 cm. The highest and lowest occurrences of *Discoaster hamatus* in Samples 124-768C-15R-4, 44–45 cm and -38R-3, 6–7 cm, respectively, mark the top and bottom of Zone NN9. The highest occurrence of *Catinaster coalitus* is in Sample 124-768C-30R-3, 6–7 cm, and its lowest occurrence is in Sample 124-768C-40R-4, 132–133 cm. No nannofossils were found in the underlying greenish gray hemipelagic clay, but two turbidites in Core 124-768C-42R contain mixed early Eocene to middle Miocene nannofossil assemblages.

Site 769

Site 769 is located on a tilted fault block on the southeast flank of Cagayan Ridge in 3643 m water depth (Fig. 1, Table 1). Sediments recovered from this site consist of a thick upper Pliocene to Holocene hemipelagic to pelagic nannofossil and foraminifer marl containing abundant and well-preserved nannofossils; a middle Miocene to upper Pliocene clay with typically very low carbonate content except in the late Miocene; and an upper lower Miocene to middle Miocene brown clay underlain by andesitic pyroclasts.

Three holes were drilled at this site. Hole 769A yielded seven cores but only penetrated into upper Pleistocene. The nannofossil check list of this hole is given in Table 6. *Emiliania huxleyi* occurs from the top down to Sample 124-769A-3H-3, 75–76 cm. The lowest occurrence of *Helicosphaera inversa* is found in Sample 124-769A-3H-5, 75–76 cm. The lowest biohorizon within this hole is the highest occurrence of *Pseudoemiliania lacunosa* in Sample 124-769A-5H-1, 75–76 cm.

Hole 769B penetrated into pyroclasts but nannofossils are not preserved in sediments of pre-late Miocene age. Reworking is common at this site and most pronounced in Pleistocene and upper Pliocene sediments by the occurrences of exclusively early Pliocene species. The nannofossil check list for Hole 769B is given in Table 7 (back pocket). The lowest occurrence of *Emiliania huxleyi* in Sample 124-769B-3H-5, 40–41 cm is the first biohorizon encountered in this hole. The next lower biohorizon is the lowest occurrence of *Helicosphaera inversa* in Sample 124-769B-4H-5, 40–41 cm. This biohorizon occurs in Zone NN20 at Sites 767, 768 and 769, although In the North Atlantic it occurs lower, in Zone NN19 (Takayama and Sato, 1987). This biohorizon may be diachronous. The highest occurrence of *Pseudoemiliania lacunosa* marks the top of Zone NN19 in Sample 124-769B-5H-3, 30–31 cm. The top of the interval of dominantly small *Gephyrocapsa* specimens is in Sample 124-769B-10H-1, 80–81 cm. The next two biohorizons, the highest occurrences of *Helicosphaera sellii* and *Calcidiscus tropicus* are found close together in Samples 124-769B-10H-4, 30–31 cm and -10H-5, 80–81 cm, respectively. The lowest occurrence of *Gephyrocapsa oceanica* s.l. is in Sample 124-769B-11H-1, 30–31 cm and the highest occurrences of *Discoaster brouweri* is in Sample 124-769B-12H-2, 30–31 cm. The upper Pliocene is subdivided by the highest occurrences of *Discoaster pentaradiatus* in Sample 124-769B-12H-4, 38–39 cm, *Discoaster surculus* in

Sample 124-769B-13H-1, 100–101 cm, and *Reticulofenestra pseudoumbilica* in Sample 124-769B-14H-6, 80–81 cm. The gradual downward decrease of nannofossil abundance and increasingly poor preservation starts in the late Pliocene (Zones NN16 to NN18) and grades into almost barren clays in the early Pliocene. This interval records the transit of this site from below CCD to above CCD at approximately 3.5 m.y. ago. No useful nannofossil biohorizon were recognized in the early Pliocene sediments.

Nannofossils are rare but commonly present in most of the late Miocene samples; they are interpreted to be redeposited by turbidity currents. In some beds, nannofossils are sufficiently abundant to be a major constituent of the sediments. These residual assemblages may indicate a fluctuating CCD, with more nannofossils preserved when the CCD becomes deeper. In Sample 124-769B-19H-1, 30–31 cm, the truncated highest occurrences of *Discoaster quinqueramus* and *Discoaster berggrenii* are encountered. *Discoaster quinqueramus* continues occur down to Sample 124-769B-22H-3, 112–113 cm. It disappears in a section containing common nannofossils, and this marks the bottom of Zone NN11. The next lower biohorizon is the highest occurrence of *Discoaster hamatus* in Sample 124-769B-24H-2, 32–33 cm; it marks the top of Zone NN9. The lowest occurrences of *Discoaster hamatus* is in Sample 124-769B-25X-3, 62–63 cm, and marks the bottom of Zone NN9. The lowest occurrence of *Catinaster coalitus* is truncated in Sample 124-769B-25X-4, 97–98 cm and coincides with a sharp decrease in carbonate contents.

Hole 769C consists of unstratified lapillistones. No nannofossils were found in this hole.

Site 771

Site 771 is located on a large plateau on the east flank of Cagayan Ridge 30 km northwest of Site 768 (Fig. 1, Table 1). One hole was drilled at this site to complement Site 769. The recovered sediment column can be divided into two units: an lower upper Pliocene to lower middle Miocene nannofossil clay and marl, and a massive pre-lower middle Miocene lapillistone, tuff, and basalt flow (Rangin, Silver, von Breymann, et al., 1990). This site is only 2856 m below sea level, well above the local CCD. Nannofossils are generally abundant and well preserved, but because of the poor recovery and low sedimentation rate at this site, not all of the biohorizons encountered are reliable. The check list of nannofossils in Hole 771A is given in Table 8.

No cores were taken in the top 100 m of sediments. The youngest biohorizon recorded is the highest occurrence of *Reticulofenestra pseudoumbilica* in Sample 124-771A-1R-2, 29–30 cm, which marks the top of Zone NN15. *Pseudoemiliania lacunosa* has its lowest occurrence in Sample 124-771A-1R-2, 120–121 cm. The highest occurrence of *Amaurolithus tricorniculatus* is in Sample 124-771A-2R-1, 18–19 cm, which separates Zones NN15 and NN14. The next lower biohorizon, the lowest occurrence of *Ceratolithus rugosus* in Sample 124-771A-2R-1, 127–128 cm, marks the boundary between Zones NN12 and NN13. The lowest biohorizon in the Pliocene is the highest occurrence of *Triquetrorabdulus rugosus* in Sample 124-771A-2R-2, 19–20 cm.

The Pliocene/Miocene Boundary, placed at the top of Zone NN11, and defined by the highest occurrence of *Discoaster quinqueramus*, is in Sample 124-771A-2R-2, 49–50 cm. The highest occurrence of *Discoaster berggrenii* is in the same sample, which may be due to the low sedimentation rate. Below this datum, *Amaurolithus primus* and *Amaurolithus delicatus* both have their lowest occurrence in Sample 124-771A-2R, CC, thus dividing Zone NN11 into Subzones a and b. *Discoaster quinqueramus* occur continuously to Sample 124-771A-4R-1, 25–26 cm, which mark the bottom of Zone NN11. The highest occurrence of *Discoaster bollii* is in Sample 124-771A-4R, CC, just above the highest occurrence of *Discoaster hamatus* in Sample 124-771A-5R-1, 7–8 cm; the latter defines the top of Zone NN9. The highest occurrence of *Catinaster coalitus* is in Sample 124-771A-6R-3, 25–26 cm just above the lowest occurrences of *Discoaster hamatus* in Sample 124-771A-6R, CC, 2–3 cm, which marks the bottom of Zone NN9. *Catinaster coalitus* occur continuously down into Sample 124-771A-7R-2, 25–26 cm and marks the bottom of Zone NN8.

The lowest occurrence of *Discoaster kugleri* (Pl. 4), which defines the bottom of Zone NN7, and the highest occurrence of *Cyclicargolithus floridanus* are recorded together in Sample 124-771A-9R-2, 25–26 cm. The latter is 0.1 m.y. older than the former (Fig. 2) and sometimes used as a substitute marker when the lowest occurrence of *Discoaster kugleri* can not be located precisely. The oldest biohorizon recorded in this hole is the highest occurrence of *Sphenolithus heteromorphus* in Sample 124-771A-9R-3, 75–76 cm, which marks the top of Zone NN5 in the early middle Miocene.

LATEST PLIOCENE–EARLY PLEISTOCENE CALCAREOUS NANNOFOSSIL BIOHORIZON AND THE PLIOCENE/PLEISTOCENE BOUNDARY

The Pliocene/Pleistocene Boundary continues to be a controversial chronostratigraphic horizon in the geologic time scale. Arguments about this boundary are mainly the consequences of interpretations based on different stratigraphic philosophies and began shortly after Lyell first introduced the name "Pleistocene" in 1839 (Pelosio et al., 1980). According to the International Stratigraphic Guide (Hedberg, 1976), a chronostratigraphic boundary must be defined in a designated stratotype (lithostratigraphic unit) and should be chosen at or near markers that allow long-distance correlation. It is also important that this boundary must follow the original concepts. For the Pliocene/Pleistocene Boundary this means that at least 70% of the mollusk species immediately above this boundary are still living (Lyell's original concept of Pleistocene), which roughly corresponds to the level where Suess' "northern immigrants" (marine faunas that are presently restricted to the boreal region) begin to occur in the Mediterranean (Pelosio et al., 1980; Rio et al., in press). Three stratotypes have been proposed to define the Pliocene/Pleistocene Boundary: Le Castella (Emiliani et al., 1961), Santa Maria di Catanzaro (Selli, 1971), and Vrica (Selli et al., 1977). It has been argued that the Vrica section is the most suitable stratotype, and the other two are inadequate to define this boundary (Haq et al., 1977; Rio, 1982; Rio et al., in press).

A proposed Pliocene/Pleistocene Boundary at the top of a sapropelic layer "e" in the Vrica section exactly coincides with the top of the Olduvai Subchron and its age is estimated to be approximately 1.66 m.y. (Rio, 1982; Rio et al., in press; Backman et al., 1983; Berggren, Kent, and van Couvering, 1985; Tauxe et al,, 1983). Calcareous nannofossil biostratigraphy of the Vrica section has been studied by many investigators (see review by Rio et al., in press). Rio's results indicated that no nannofossil biohorizon coincides precisely with the proposed Pliocene/Pleistocene Boundary and the nearest datum to the boundary is the lowest occurrence of *Gephyrocapsa oceanica* s.l., which is just above the designated boundary level.

Holes 767B, 768B, and 769B drilled in the Celebes and Sulu seas during ODP Leg 124 recovered complete sediment sections of latest Pliocene to early Pleistocene age. Three important nannofossil biohorizons that have been described in the Vrica section around the Pliocene/Pleistocene Boundary are also found in these holes. The correlation of these biohorizons

Table 5. Calcareous nannofossil check list of Hole 768C. Relative abundance as defined in Table 2.

LITHOLOGIC UNIT	Age	NANNOFOSSIL ZONE	Sample Core-Section, interval (cm)	*Calcidiscus leptoporus*	*Calcidiscus tropicus*	*Catinaster calyculus*	*Catinaster coalitus*	*Coccolithus pelagicus*	*Cyclicargolithus abisectus*	*Cyclicargolithus floridanus*	*Dictyococcites productellus*	*Discoaster barbadiensis*	*Discoaster berggrenii*	*Discoaster bollii*	*Discoaster brouweri*	*Discoaster calcaris*	*Discoaster deflandrei*	*Discoaster hamatus*	*Discoaster intercalaris*	*Discoaster moorei*	*Discoaster neohamatus*	*Discoaster neorectus*	*Discoaster pansus*	*Discoaster pentaradiatus*	*Discoaster prepentaradiatus*	*Discoaster quinqueramus*	*Discoaster signus*	*Discoaster surculus*	*Discoaster tamalis*	*Discoaster variabilis*	*Discolithina discopora*	*Discolithina japonica*	*Discolithina multipora*	*Hayaster perplexus*	*Helicosphaera carteri*	*Helicosphaera euphratis*	*Reticulofenestra minuta*	*Reticulofenestra minutula*	*Reticulofenestra pseudoumbilica*	*Rhabdosphaera claviger*	*Scapholithus fossilis*	*Sphenolithus abies*	*Sphenolithus grandis*	*Sphenolithus heteromorphus*	*Sphenolithus moriformis*	*Syracosphaera pulchra*	*Thoracosphaera* spp.	*Umbilicosphaera sibogae*
II	LATE MIOCENE		1-1; 143–144	R				X			C					X										R						X			F					X		F	R		C	X		
		NN11	1-4; 43–44	F	R			R			C		R		F	F					R			F		F		X		F					F					F		F			C			
			1CC																																													
			2-3; 50–51	F	R			F			C		X		F	F							X	F	X	F				R					C					R		C			F			
			2CC																																													
			3CC																																													
			4CC																																														
			5-1; 33												R			R			R			R						R					R				R			R			F			
			5-1; 131–132	R				X			F																								X							F	X				R	
			5CC																																													
			6CC	X																															X													
			7-1; 106–107												X	X								X											X										F			
			7-2; 74–75																																													
			7-4; 15–16																																													
			7-4; 91–92	X				X																																					X			
			7-5; 130–131	X																				X																					R			
			7CC	X							X					X								X						R					R					X		R			F		X	
			8CC																																													
		NN10	9CC																																													
			10-1; 67–68	X				R		X	R				X	X								X											R										F			
			10-2; 147–148																																													
			10CC																																													
			11-1; 125–126	X																																												
			11-5; 37–38																																													
			11CC																					X																					X			
			12-1; 85–86					X																																								
			12CC																																													
			13-2; 55–56	R	X			X						R		X				X	X		X	R	R					R					F				R	R					F		X	X
			13-3; 84–86																																										X			
			13CC																																													
			14-2; 58–59																																													
			14-3; 84–86					X						X	X								X	R																X					F	X	X	
			14CC																																													
			15-2; 90–91																																													
			15-4; 44–45	R				X						X	R	R		X	X				X	F	X					R					R			R	R	R					F			X
			15CC	X												X								R						R					X		X	R		X					X		X	
			16CC					X							X									X																		X						
			17-2; 44–45																X		X			R														X	X			F						
			17CC																																													
			18-1; 14B–149	F	X						F			X	R	R		X	X				X	F									X		F		X	R	F	F		F			F			
			18-3; 37–38																																													
			18CC					X																R						X					X			X	X			X			R			
			19-1; 79–80																					R						X										X					R			
			19-2; 92–93																																				X	X			X		F			
			19CC																																													

Table 5 (continued).

LITHOLOGIC UNIT	Age	NANNOFOSSIL ZONE	Sample Core-Section, interval (cm)	*Calcidiscus leptoporus*	*Calcidiscus tropicus*	*Catinaster calyculus*	*Catinaster coalitus*	*Coccolithus pelagicus*	*Cyclicargolithus abisectus*	*Cyclicargolithus floridanus*	*Dictyococcites productellus*	*Discoaster barbadiensis*	*Discoaster berggrenii*	*Discoaster bollii*	*Discoaster brouweri*	*Discoaster calcaris*	*Discoaster deflandrei*	*Discoaster hamatus*	*Discoaster intercalaris*	*Discoaster moorei*	*Discoaster neohamatus*	*Discoaster neorectus*	*Discoaster pansus*	*Discoaster pentaradiatus*	*Discoaster prepentaradiatus*	*Discoaster quinqueramus*	*Discoaster signus*	*Discoaster surculus*	*Discoaster tamalis*	*Discoaster variabilis*	*Discolithina discopora*	*Discolithina japonica*	*Discolithina multipora*	*Hayaster perplexus*	*Helicosphaera carteri*	*Helicosphaera euphratis*	*Reticulofenestra minuta*	*Reticulofenestra minutula*	*Reticulofenestra pseudoumbilica*	*Rhabdosphaera claviger*	*Scapholithus fossilis*	*Sphenolithus abies*	*Sphenolithus grandis*	*Sphenolithus heteromorphus*	*Sphenolithus moriformis*	*Syracosphaera pulchra*	*Thoracosphaera* spp.	*Umbilicosphaera sibogae*
			20CC																					X											X				X			X						
			22-2; 68–69	R				X							R	R							R	F					X	R					F			R	F	F	X	F	R		F		X	
			22CC	X			X								X									R						X					X				X						R			
			23-1; 102–103	R				F			X					X		X					X	R						X					F			X	R			F	F		F			
			23CC																																													
			26-3; 32–33																																													
			26CC; 5–6	F				F						F		F					R			C	X					C					F				C			C			F		X	
			26CC																																													
			27-1; 66–67																																													
			27-2; 43–44																																													
			27-6; 70–71																																													
II			27CC	X										X	X							R		R														R				X			X			
			28-4; 11–12																																										R			
			28-6; 51–52											X	R	X		X					X	R						X					X				R			X			R			
			29-2; 23–24	R	X										X			X		R			X	F											F				R			X			F		X	X
			29-3; 83–84																																													
			29-4; 53–54																																													
			30-2; 70–71	X				X						X	X	X					X			F						X					X			X	X	X		X						
			30-3; 6–7	R			X								R	R					R			F			X			X					R			F	F			R					X	
			30-5; 113–114	X											X	X					X		X	X														X				X						
	LATE MIOCENE		30-6; 49–50	C			X	X						X	X	R								R														R	R			X						
			30CC											X	X																								X						X			
		NN9	31-1; 146–148																																													
			31CC	X			X	R		X	X			R	F	R		R			R			F						F	X				R			R	F			F			R		X	X
			32-5; 27–28																																													
			32CC											X	R	X		X						X						R									X									
			33CC																																													
			34-4; 112–113																																													
			34-5; 89–90																																													
			34-6; 36–37																																													
			34CC	R		X	R	R						F	R	X		R						R						R	X		X		F			X	F		X	F			X		X	R
			35-2; 25–26	X										F				X						X						X									X			X			X			
			35-5; 7–8																																													
			35CC				X	X						R			X																						R									
III			36-1; 126–127	R	R		F	R						F	X	X		R																	F		F	X	F			F	X		R		X	
			36-2; 33–34	R			F	X						F		X		R																	F			F	F			F			R			
			36-2; 109–110	R			F	R						F	X	R		X			X													F				F	F			F			X		X	
			36-6; 37–38																																													
			36CC	X			X	X																											X							X			X			
			37-1; 40–41																																													
			37-2; 45–46	X			F	X						F				R																	R				R						R			
			37-2; 125–126	R			R							R				X						X											R			R	F						X			
			37-3; 124–125	X			R	C						F				?												R					R			X	R			X			F			
			37-4; 103–104	X			X							R				X																					R						X			
			37-6; 14–15	R			F							R		R		?																	R			X	F									

Table 5 (continued).

LITHOLOGIC UNIT	Age	NANNOFOSSIL ZONE	Sample Core-Section, interval (cm)	*Calcidiscus leptoporus*	*Calcidiscus tropicus*	*Catinaster calyculus*	*Catinaster coalitus*	*Coccolithus pelagicus*	*Cyclicargolithus abisectus*	*Cyclicargolithus floridanus*	*Dictyococcites productellus*	*Discoaster barbadiensis*	*Discoaster berggrenii*	*Discoaster bollii*	*Discoaster brouweri*	*Discoaster calcaris*	*Discoaster deflandrei*	*Discoaster hamatus*	*Discoaster intercalaris*	*Discoaster moorei*	*Discoaster neohamatus*	*Discoaster neorectus*	*Discoaster pansus*	*Discoaster pentaradiatus*	*Discoaster prepentaradiatus*	*Discoaster quinqueramus*	*Discoaster signus*	*Discoaster surculus*	*Discoaster tamalis*	*Discoaster variabilis*	*Discolithina discopora*	*Discolithina japonica*	*Discolithina multipora*	*Hayaster perplexus*	*Helicosphaera carteri*	*Helicosphaera euphratis*	*Reticulofenestra minuta*	*Reticulofenestra minutula*	*Reticulofenestra pseudoumbilica*	*Rhabdosphaera claviger*	*Scapholithus fossilis*	*Sphenolithus abies*	*Sphenolithus grandis*	*Sphenolithus heteromorphus*	*Sphenolithus moriformis*	*Syracosphaera pulchra*	*Thoracosphaera* spp.	*Umbilicosphaera sibogae*
III	LATE MIOCENE	NN9	38-1; 19–20	X			R	X						X																					X				F						R		X	
			38-2; 19–20					X																															X									
			38-3; 16–17	R			F	X						F	X	R		X												X		X			F		X	R	F			X			R		X	
		NN8	38-3; 70–71																																													
			38-3; 138–139																																													
			38-4; 19–20					X						X																R																		
			39-2; 20–21																																													
	---		39-3; 32–33		X		R								X	X																			X			X	F			X			X			
	MIDDLE MIOCENE		39-4; 85–86				X							X																							X	X							X			
			40-2; 91–92																																													
			40-3; 76–77																																													
			40-4; 132–133	X			X								X	X							X							X					X		X		F			X		X			X	
		NN7	41-1; 86–87																																													
			41-1; 112–113																																													
			42-1; 102–104																																													
			42-1; 113	R					X	R		X		X	X		R													X									R			X		X	R			
			42-1; 123–124																																													
			42-3; 149–150	X				X	X	R					X		X													R			X		X	X	X	X	R					F	R			
			43-2; 53–54																																													
			43CC																																													
			44CC																																													
			45CC																																													
			46CC																																													

Table 6. Calcareous nannofossil check list of Hole 769A. Relative abundance as defined in Table 2.

LITHOLOGIC UNIT	AGE	NANNOFOSSIL ZONE	SAMPLE Core-section, interval (cm)	*Calcidiscus leptoporus*	*Ceratolithus cristatus*	*Ceratolithus telesmus*	*Coccolithus pelagicus*	*Cyclolithella annula*	*Dictyococcites productellus*	*Discolithina discopora*	*Discolithina japonica*	*Discosphaera tubifer*	*Emiliania huxleyi*	*Gephyrocapsa caribbeanica*	*Gephyrocapsa margerelii*	*Gephyrocapsa oceanica* (>5 µm)	*Gephyrocapsa oceanica* s.l.	*Gephyrocapsa* spp. (small)	*Helicosphaera carteri*	*Helicosphaera hyalina*	*Helicosphaera inversa*	*Helicosphaera wallichii*	*Oolithotus antillarum*	*Pseudoemiliania lacunosa*	*Reticulofenestra minuta*	*Reticulofenestra minutula*	*Rhabdosphaera claviger*	*Scapholithus fossilis*	*Syracosphaera lamina*	*Syracosphaera nodosa*	*Syracosphaera pulchra*	*Thoracosphaera* sp.	*Umbilicosphaera sibogae*	*Umbellosphaera irregularis*	*Umbellosphaera tenuis*
I	PLEISTOCENE	NN21	1CC	F				X	C			X	F			F	C	C	F	X		X	R		X		R	F	X		F	X	F	F	X
			2-3; 75–76	F				X	F	X		X	R			R	A	A	F			X	F				R	F	F		F	R	F	R	
			2-5; 75–76	F	X			X	C	X	X	X	X				C	A	F				R				F	R	X		F	R	F	X	
			2-7; 75–76	F	X			R	C			X	R				A	A	F	X			F				F	F	F		F	R	F		
			2CC	F				R	F		R	R	R				A	A	F	X	R	X	F				F	F	R	X	F	F	F	R	X
			3-3; 75–76	F				R	F			X	R				A	C	F		F		F		X		F	F	F		F	X	F	R	
		NN20	3-4; 75–76	F			X	F	F					X	R		C	A	F		R	R	R				F	F	X		R	X	F	F	
			3-5; 75–76	F	X	X		R	C	R	R	X			F		A	A	F		X	F	R				R	F	R	R	F	R	F	R	
			3CC	F					C					R	F		A	A	F				F					R	R		R	R	F	X	
			4CC	F			R		C	R		X		R	C		A	A	F				F				R	F	R	X	F	R	C	X	
		NN19	5-1; 75–76	F					C	R				R	F		A	A	F			X	F	R			F	F	R		F	R	C	X	
			5-3; 75–76	C	X				C						F	R	A	C	F			X	R	R							X	X	R		
			5-5; 75–76	C	X	X			C						F	F	C	C	F			R	R	R							R	X	F		
			5CC	F					C			R		X	F	R	A	C	F				F	R			X	F	R	R	R	X	F		
			6CC	C					C	R	R				F	F	A	A	F			X	F	X	R	X	X	F	X	X	F	R	F		
			7CC	F	X			X	C						F	R	A	C	F			X	F	X		X	R	F			F	R	F		

Table 8. Calcareous nannofossil check list of Hole 771A. Relative abundance as defined in Table 2.

Lithologic unit	Age	Nannofossil zone	Sample Core-Section, interval (cm)	*Amaurolithus bizzarus*	*Amaurolithus delicatus*	*Amaurolithus primus*	*Amaurolithus tricorniculatus*	*Calcidiscus leptoporus*	*Calcidiscus tropicus*	*Catinaster calyculus*	*Catinaster coalitus*	*Ceratolithus armatus*	*Ceratolithus cristatus*	*Ceratolithus rugosus*	*Ceratolithus telesmus*	*Coccolithus miopelagicus*	*Coccolithus pelagicus*	*Coronocyclus nitescens*	*Cricosphaera quadrilaminata*	*Cyclicargolithus floridanus*	*Cyclolithella annula*	*Dictyococcites antarcticus*	*Dictyococcites productellus*	*Discoaster asymmetricus*	*Discoaster berggrenii*	*Discoaster blackstockae*	*Discoaster bollii*	*Discoaster brouweri*	*Discoaster calcaris*	*Discoaster* cf. *asymmetricus*	*Discoaster challengeri*	*Discoaster deflandrei*	*Discoaster druggii*	*Discoaster exilis*	*Discoaster formosus*	*Discoaster hamatus*	*Discoaster kugleri*	*Discoaster moorei*	*Discoaster musicus*
I	PLIOCENE	NN16	1-1; 3–4					F	F				F		X		F						C					C											
			1-1; 46–47					F	F				R	R			R						C					C											
		NN15	1-2; 29–30					F	F				R										F					F											
			1-2; 120–121					F	F				X	X	X		R				R		R			X		C											
			1CC			X		R	R				X		X		R									X		F											
		NN13/NN14	2-1; 18–19	X	X		R	F	R			F	R											X				C											
			2-1; 71–72					R					R															F											
			2-1; 127–128				R	F	F			F	F	X			X							R		X		C			R								
		NN12	2-2; 19–20		X			F																				F			R								
	LATE MIOCENE	NN11	2-2; 49–50			R		F	R								F						C		X			R											
			2CC		R	X		F	F								F						C					F											
			3-1; 25–26					F									R						F		R			R											
			3-3; 25–26					F	F								F						X		C			C	F										
			3CC					F	R								F								C	R		C	F		X								
			4-1; 25–26					F	F								R							X	F	R		F	F		X								
			4-1; 75–76					F	F								F						C	R				C	F		X								
		NN10	4CC					F	F							F	F							R			F	F	F		X								
			5-1; 2–3																					X															
		NN9	5-1; 7–8					C	F								F							X		X	F	F	F							F			
			5CC					C	F								F							X			F	F	F							X			
			6-1; 9–10					C	F								F									X	R	F	F							R			
			6-3; 25–26					F	F	R	C					X	F							X			R	F	F	R						F			
			6-5; 25–26					F	F	R	F						F											R	C	R	X					R			
			6-7; 25–26					F	F	X	C					X	F							R				F	F	X						F		X	
			6CC; 2–3					R	F	X	C						F							X				R	C	R						F			
		NN8	6CC					F	F		C					X	F										X	X	F		X								
			7-1; 25–26					F	F		C						F											R	C	X									
	MIDDLE MIOCENE		7-2; 25–26					F	R		F																	X	F	R									
		NN7	7-2; 73–74					F	F								F		X					X			R	X										R	
			7CC					F	F							X	F										X							R	X			F	
			8-1; 25–26					F	F								F						R									R		C			F	R	
			8-3; 25–26					R	F								F	R					X									F		F			X	X	
			8-4; 25–26					R	X								F																	F			X	X	
			8CC					F	F							X	F	R		R											X	R		R				F	
			9-1; 25–26					F	F							X	F	X																					
			9-1; 75–76					F	F								F	F		X				X						X		X		F			X	R	X
			9-2; 25–26					F	F								F	F		R												F	R	R			X	F	
		NN6	9-2; 69–70					F	F								F	F		C													X	R				F	
			9-3; 12–13					F	F							X	F	R		F												X		F				F	
		NN5	9-3; 75–76					R	F								F	R	X	C		C	C											F				R	
			9-5; 25–26					F	X								R	F	X	C		X	F									C		C				F	
			9CC					F									F	F	X	C		R	F							X		F	R	C				F	X
			10-1; 22–23					F	X								R	F		F		X										C		C				F	X
			10-3; 23–24					R	R							R	F	R		C												C	R	F				F	X
			10-5; 24–25					R								R		R		C			X									C	R		R			F	
			10CC						F							R	F	F		C												C		F	F			F	
			11-1; 23–24					F	X							X	X	F		A												C	X		X			F	
			11-1; 136–137					R	R								F	F		C												C	R					R	

Table 8 (continued).

Discoaster neohamatus	Discoaster neorectus	Discoaster pansus	Discoaster pentaradiatus	Discoaster prepentaradiatus	Discoaster pseudovariabilis	Discoaster quadramus	Discoaster quinqueramus	Discoaster signus	Discoaster subsurculus	Discoaster surculus	Discoaster tamalis	Discoaster variabilis	Discolithina discopora	Discolithina japonica	Discolithina multipora	Discolithina syracusana	Discosphaera tubifer	Gephyrocapsa spp. (small)	Hayaster perplexus	Helicosphaera burkei	Helicosphaera carteri	Helicosphaera euphratis	Helicosphaera granulata	Helicosphaera intermedia	Helicosphaera mediterranea	Helicosphaera rhomba	Helicosphaera sellii	Holodiscolithus macroporus	Oolithotus antillarum	Pseudoemiliania lacunosa	Reticulofenestra ampliumbilica	Reticulofenestra minuta	Reticulofenestra minutula	Reticulofenestra pseudoumbilica	Rhabdosphaera claviger	Scapholithus fossilis	Scyphosphaera pulcherrima	Scyphosphaera spp.	Sphenolithus abies	Sphenolithus compactus	Sphenolithus grandis	Sphenolithus heteromorphus	Sphenolithus moriformis	Sphenolithus verensis	Syracosphaera nodosa	Syracosphaera pulchra	Thoracosphaera spp.	Triquetrorhabdulus rugosus
			C							R			X	R				R			F									C		R	R		F	X	R								X	C	X	
			C							R				X		R		F	R		C									C		R	F		F	X	R								X	F	R	
			C										X	X				X			F									F		F	C	R	X		R									F	X	
			C							R				R				F			F						X			F		C	C	R	X		R									F	R	
			C							R				X							F									F			C	R					X							R		
			C							F								F	R		F									R		C	F	C					C							X		
			F							X																						X	F	X					F									
		F	C							F	X	F							X		R												F	C					C									
		R	C							F		C									X										R		F	F					C									R
			F				C			F		R									F										C		C	F					C									F
			F				C			F		R									F								X		F	F	C	F					A									R
			R				F			R		X									R										X	R	F	R					F				X					
F			F				C			R		R			R						F											R	C	R					A							X	X	R
F		X	F				F					R									F											R	C						A									F
F		R	F				C					R							X		C											C	A		F	X			A		R		X					
F		X	C									F	X		X						C											C		R	R				C	F	X			R			X	X
C		R				X				R		F									F													C					C								X	R
																																																R
C		R	C		X					R		F									C												C	C					C									R
C		X	C			X				F		R									C												F	C					C				R					R
C		F	C		R							R									F												C	C					C				R					R
R		X	R									F									F												R	C					C				X				X	R
					F							F	X	X			X				C												F	C	R	X			C		R		F					F
X					F							F					R				C												R	C	R	R			F		R		C				R	F
					F	?						F					R				C												R	C	F	R			F				C			X	X	R
		X	R		F							F	X	F	R		X		X		C							X					F	C	F	R			F		R		C			X	X	R
					F							F			X						F												F	C	F						F		C					R
					R	X						C		X							X												F	C									C					R
	R		R	X								C					X				F												F	C					C				F					F
												C	X	F	F		F		X		C												C	C	F	F			R		F		F		X	R		F
		X				R		R				C			R						F	X											C	C						F			F					F
												C									R												F	F							F		F					R
								C				C									R											X	F	F						R	R		F					
						R		F	R			C	R		F		R		R		C											X	F	C	R	X					C		F	R		X	X	R
																					C												F	C	X					C	F		C					F
						R		F				C									F	X	X									X	F	C						F	F		C					X
						X		F				C									F	R	R									R	C	C						F	F		F	R				
					R	X		F				C									F	X											C	F						F	R		C					
						X		R				C			X					F	R		F	X								F	C	C		X				F	R		F			X		
								X				C								R	F	R										F	F	F	X					X		F	F					
								F				C								X	F	R	F	X									F							F		C	F					
						X		X	X										X		X	R	F										F									C	F					
								F				F								X	F	X	R			X							C							R	R	C	F					
									X			C									F	X											F								R	C	R					
												F			F						F	X	X		X								R									A	R					
						X		F	F			R			X				R		F				R								C							R		C	F					
								R				F			X				X		X	X	R										C									C					X	
												R							X														X								X	F						

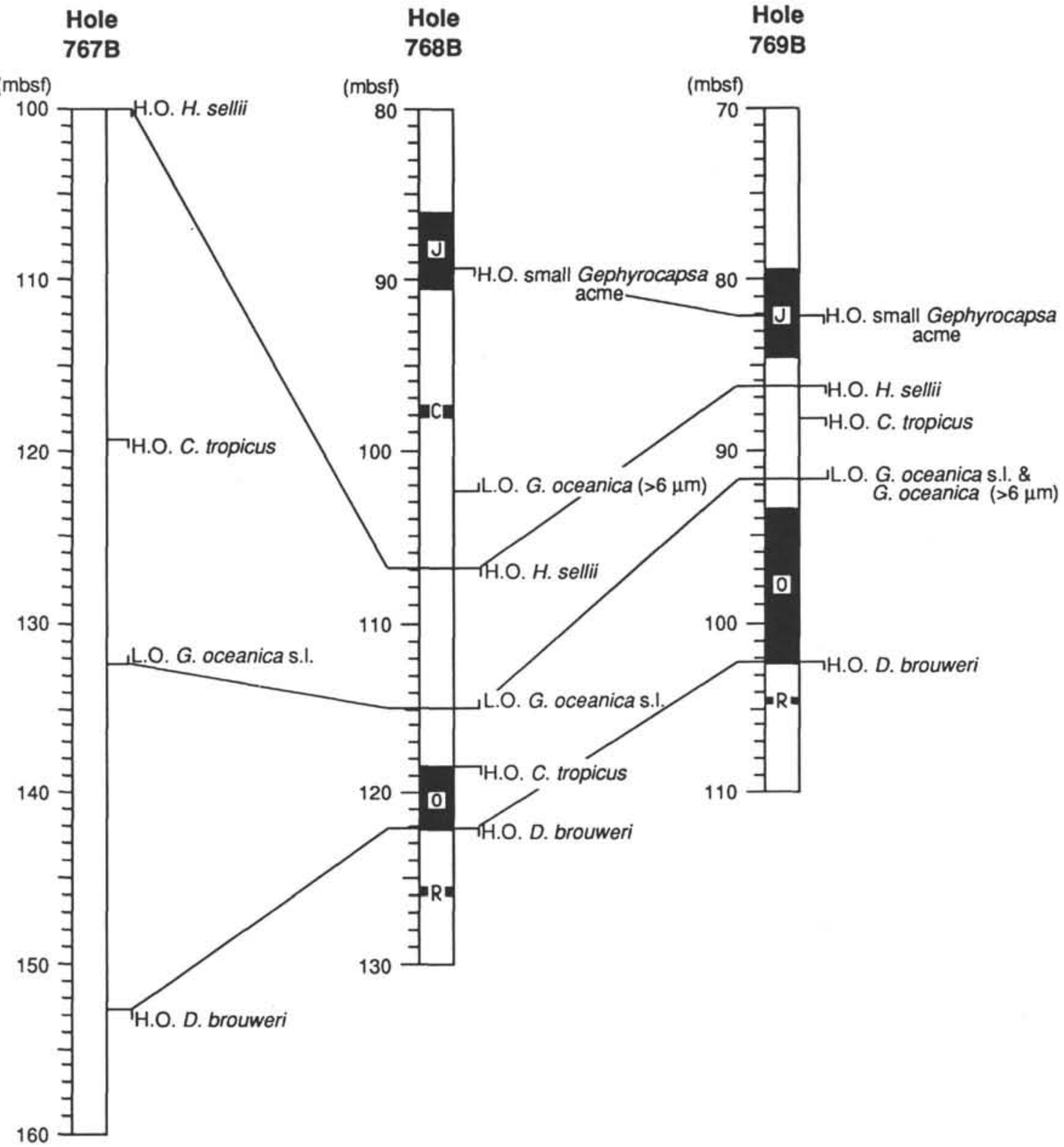


Figure 3. Latest Pliocene to early Pleistocene calcareous nannofossil biohorizons and their correlations with magnetic reversals in Holes 767B, 768B and 769B. H.O. = highest occurrence; L.O. = lowest occurrence. Abbreviations for magnetic polarity events: J = Jaramillo; C = Cobb Mountain; O = Olduvai; R = Reunion.

among Holes 767B, 768B, and 769B are shown in Figure 3. Excellent paleomagnetic polarity data were recorded in this interval in Holes 768B and 769B but not in Hole 767B. Reworked specimens, including exclusively Pliocene species, were found throughout the section (Tables 2, 4, and 7).

The oldest biohorizon found in the three holes is the highest occurrence of *Discoaster brouweri*. *Discoaster brouweri* becomes very rare as it approaches its extinction and its highest occurrence is difficult to identify. The problem becomes even more complex when reworked specimens are present; unfortunately, this is exactly what we find in Holes 767B, 768B, and 769B. Backman et al. (1983) and Backman and Shackleton (1983) found that a distinct increase of the abundance of *Discoaster brouweri* var. *triradiatus* relative to the common *Discoaster brouweri* and their simultaneous extinction can help identify the highest occurrence of *Discoaster brouweri*. *Discoaster brouweri* var. *triradiatus* appears only sporadically in our samples, in very low abundances, and no distinct increase of relative abundance is found. Apparently the criteria proposed by Backman and Shackleton (1983) are not useful in this area. In this study the highest occurrence of *Discoaster brouweri* is determined by consistent occurrence and/or increased abundance of the species. This datum is found at 152.7 mbsf in Hole 767B. In Hole 768B and 769B, this datum is at 122.05 mbsf and 102.2 mbsf, respectively, both at the bottom of the Olduvai event (Table 9 and Fig. 3). Although the highest occurrence of *Discoaster brouweri* is about 0.22 m.y. older than the Pliocene/Pleistocene Boundary as designated in Vrica section (Pelosio et al., 1980; Cati and Borsetti, 1982; Rio, 1982;

Table 9. Calcareous nannofossil biohorizons, ages and depths at Sites 767, 768, 769, 770, and 771. H.O. = highest occurrence; L.O. = lowest occurrence.

Biohorizons	Age (Ma)	Sub-bottom Depth (m) Hole 767B	770B	768B	768C	769A	769B	771A
L.O. *Emiliania huxleyi*	0.274	18.5	—	29.23	—	—	21.65	21.30
L.O. *Helicosphaera inversa*		25.47	—	42.55	—	24.65	—	—
H.O. *Pseudoemiliania lacunosa*	0.474	28.25	—	53.28	—	37.65	49.70	—
H.O. small *Gephyrocapsa* Acme	0.93	—	—	89.31	—	—	82.20	—
H.O. *Helicosphaera sellii*	1.27	100.00	—	106.85	—	—	86.20	—
H.O. *Calcidiscus tropicus*	1.48	119.43	—	118.38	—	—	88.20	—
L.O. *Gephyrocapsa oceanica* s.l.	1.59	132.04	—	114.89	—	—	91.60	—
H.O. *Discoaster brouweri*	1.88	152.70	—	124.40	—	—	102.20	—
H.O. *Discoaster pentaradiatus*	2.29	171.49	—	128.66	—	—	105.28	—
H.O. *Discoaster surculus*	2.42	187.04	—	133.52	—	—	110.90	—
H.O. *Reticulofenestra pseudoumbilica*	3.51	222.90	—	155.16	—	—	127.70	101.79
L.O. *Pseudoemiliania lacunosa*	4.0	261.68	—	158.80	—	—	127.70	102.70
H.O. *Amaurolithus tricorniculatus* and *Amaurolithus delicatus*	4.24	—	—	—	—	—	—	144.88
L.O. *Ceratolithus rugosus*	4.60–4.72	—	—	—	—	—	—	145.97
H.O. *Discoaster quinqueramus*	5.26	311.78	—	195.01	—	—	167.2	146.09
H.O. *Discoaster berggrenii*	5.8	333.12	—	228.40	—	—	167.2	146.09
L.O. *Discoaster quinqueramus*	8.2	393.21	—	—	158.13	—	196.42	164.45
H.O. *Discoaster bollii*	8.7	—	—	—	470.95	—	—	164.95
H.O. *Discoaster hamatus*	8.85	433.97	—	—	493.16	—	213.12	173.97
H.O. *Catinaster coalitus*	9.0	—	—	—	636.16	—	—	186.85
L.O. *Discoaster hamatus* and *Catinaster calyculus*	10.0	553.56	—	—	713.66	—	224.42	192.72
L.O. *Catinaster coalitus*	10.8	582.51	—	—	735.50	—	226.27	194.95
L.O. *Discoaster kugleri*	11.2	—	—	—	—	—	—	214.35
H.O. *Cyclicargolithus floridanus*	11.3	—	—	—	—	—	—	214.35
H.O. *Sphenolithus heteromorphus*	13.17	—	—	—	—	—	—	216.35
H.O. *Sphenolithus distentus*	28.2	—	388.31	—	—	—	—	—
H.O. *Reticulofenestra umbilica*	34.6	—	398.20	—	—	—	—	—
H.O. *Ericsonia formosa*	35.1	—	400.20	—	—	—	—	—
H.O. *Discoaster barbadiensis* and *Discoaster saipanensis*	36.7	—	407.95	—	—	—	—	—
H.O. *Chiasmolithus grandis*	40.0	—	412.06	—	—	—	—	—

Backman et al., 1983; Rio et al., in press), it is still widely used to represent the boundary in calcareous nannofossil biostratigraphy by the majority of biostratigraphers.

Gephyrocapsa oceanica is another important marker near the Pliocene/Pleistocene Boundary. This species has some special taxonomic problems because of its considerable morphologic variability in response to the changing environments of the Pleistocene. *Gephyrocapsa oceanica* may include specimens having a wide range of maximum diameter and bridge angle, and a broad species concept has been suggested and used in some previous works (Gartner, 1972; in press; Pelosio et al., 1980; Proto Decima and Masotti, 1981; Rio, 1982; Rio et al., in press). In this study, we follow that broad species concept, and include all *Gephyrocapsa* forms that are larger than 4 μm and have a distinct open center with a relatively flat bridge aligned at 30°–90° relative to the major axis into *Gephyrocapsa oceanica* s.l. The size range of *Gephyrocapsa oceanica* s.l. partially overlaps with that of the early Pleistocene species *Gephyrocapsa margerelii*. The latter is usually smaller than *Gephyrocapsa oceanica* and is characterized by a wider or curved bridge that covers the relatively smaller central opening, and its occurrence can be traced into the early Pliocene Zone NN15 (Breheret, 1978; Samtleben, 1980). Although in other cases this species is probably included with *Gephyrocapsa oceanica* or *Gephyrocapsa caribbeanica*(Proto Decima and Masotti, 1981), we had no problem separating them. Large *Gephyrocapsa oceanica* (> 6 μm) were also recorded in the Vrica section and at other locations and they are thought to have some stratigraphic significance (Proto Decima and Masotti, 1981; Rio, 1982; Rio et al., in press). We record large *Gephyrocapsa oceanica* (> 6 μm) near the top of the Olduvai event in Hole 769B and between the highest occurrence of *Helicosphaera sellii* and the Cobb Mountain event in Hole 768B. We think they may be ecologically controlled in this area and are uncertain of their stratigraphic utility at this time.

The lowest occurrence of *Gephyrocapsa oceanica* s.l. has been recorded at or slightly higher than the top of the Olduvai event and has an interpolated age of 1.59–1.68 m.y. (Berggren, Kent, and van Couvering, 1985; Müller, 1990; Rio, 1982; Rio et al., in press). This datum is found at 20 m above the highest occurrence of *Discoaster brouweri* in Hole 767B, and at 3.5 m and 2 m above the top of the Olduvai event in Holes 768B and 769B (Fig. 3, Table 9). Taking into account the high Pleistocene deposition rate at all three sites (Rangin, Silver, von Breymann, et al., 1990), the lowest occurrence of *Gephyrocapsa oceanica* s.l. must be very close to the Pliocene/Pleistocene Boundary.

The highest occurrence of *Calcidiscus tropicus* is another biohorizon that has been used for the determination of the Pliocene/Pleistocene Boundary (Bizon and Müller, 1977; Müller, 1990). The extinction of this species has been documented close to the top of the Olduvai paleomagnetic event at approximately 1.6 m.y. from the Pacific (Monechi, 1985), Atlantic, and the Mediterranean (Müller, 1979; 1985; 1990) and was thought to be time equivalent or very close to the lowest occurrence of *Gephyrocapsa oceanica* s.l. (Müller, 1990). The age of this biohorizon has been interpolated at 1.45–1.51 m.y. (Backman and Shackleton, 1983; Berggren, Kent, and van Couvering, 1985; Gartner, 1977; 1990; Rio et al., 1990; Takayama and Sato, 1987). The different extinction level of *Calcidiscus tropicus* given in the previous studies is probably due to the different species concept used by different authors. In this study *Calcidiscus tropicus* includes only specimens with more than 38 elements (more than nine elements in one quarter of the shield). The highest occurrence of this species is found at 13.61 m and 3.4 m above the lowest occurrence of *Gephyrocapsa oceanica* s.l. in Holes 767B and 769B, but is found at the top of the Olduvai event in Hole 768B (Fig. 3, Table 9). *Calcidiscus tropicus* is rare in early Pleistocene sediments in all three holes, and the cause of the early disappearance of this species in Hole 768B is unknown.

In the Celebes and Sulu Seas these three nannofossil biohorizons are essentially at the same stratigraphic level as in the Vrica section; however, if we follow the present definition of the Pliocene/Pleistocene Boundary, none of these biohorizons precisely represent the boundary. The highest occurrence of *Discoaster brouweri* is apparently no longer usable to approximate the boundary because two other biohorizons are closer to the boundary than it is. The highest occurrence of *Calcidiscus tropicus* has been used as a marker for the Pliocene/Pleistocene Boundary but the age assigned to it is inconsistent, reflecting different levels of disappearance of the species at different localities (diachrony?). The lowest occurrence of *Gephyrocapsa oceanica* s.l. is a relatively recent addition to the tool kit for identifying the Pliocene/Pleistocene Boundary and not many researchers have documented its range in their studies. It surely deserves more attention. This lowest occurrence datum has already been recorded in all oceans and the Mediterranean Sea (Gartner, 1990; Müller, 1990; Pelosio et al., 1980; Rio et al., in press) and its age is very close to the age of the designated Pliocene/Pleistocene Boundary in the stratotype. The biostratigraphic results in the Celebes and Sulu seas show that no other biohorizons are closer to the top of the Olduvai event than the *Gephyrocapsa oceanica* s.l. lowest occurrence datum and, therefore, it is used to approximate the Pliocene/Pleistocene Boundary in this area.

DISCUSSION AND CONCLUSION

The calcareous nannofossil biostratigraphy of the Celebes and Sulu seas provides important information on the sedimentation history of the two basins and confirms some previous estimates and interpretations on age of formation. Sediments at Site 767 in the Celebes Sea have been deposited below the CCD since late middle Eocene time, and the carbonate content is very low throughout the sediments. Calcareous nannofossils are preserved only in upper middle Miocene to Holocene carbonate turbidites interbedded with hemipelagic clays. The initiation of occurrence of redeposited calcareous nannofossils in the late middle Miocene indicates that the basin was approaching a landmass during that period of time and received remobilized sediments from a much shallower area. Essentially all the calcareous nannofossils recovered at Site 767 are redeposited in the turbidites, although most of the biohorizons are in the right order of succession, which is probably the result of rapid deposition of turbidites. Because the magnetic polarity data are only available for the upper Pleistocene, and other major fossil groups are either absent or poorly preserved, age determination for pre-Pleistocene sediments mainly depends on calcareous nannofossils.

The depositional environment of Site 770 is different from that of Site 767. Deposition at Site 770 was near or above the CCD from late middle Eocene to late Oligocene time, which allowed accumulation of pelagic calcareous nannofossil clay. The lower boundary of this nannofossil clay is only 30 cm above basement and, thereby, gives good control for the age of the Celebes Basin. The occurrence of *Reticulofenestra umbilica* and *Dictyococcites bisectus* at the base of the nannofossil clay indicates a late middle Eocene age (Zone NP17) of the Celebes Sea. This is in good agreement with the age determined from planktonic foraminifers and radiolarians at this site, and with radiolarians at Site 767. Since the late Oligocene, Site 770 has subsided below the CCD and sedimentation has changed to pelagic brown claystone with extremely low carbonate content (Rangin et al., 1990). From the middle Miocene to the Holocene this site was not influenced by turbidites because of its elevation, and almost no calcareous nannofossils are found in the hemipelagic clay.

Calcareous nannofossils are found only in middle Miocene to Holocene sediments in the southeast Sulu Basin. During the Pleistocene, calcareous nannofossil oozes and marls accumulated at Sites 768 and 769, accompanied by sparse ash layers and turbidites. Generally well-preserved calcareous nannofossils provide good age control in this section, although reworked species are still commonly found in most of the samples. A distinct lithologic change occurs at Sites 768 and 769 in the late Pliocene when the lower Pliocene hemipelagic clays and turbidites are replaced by the gradually increasing pelagic nannofossil and foraminifer oozes and marls at approximately 2.5 and 3.5 ma, respectively. The pelagic carbonates become dominant at Site 768 by 1.8 ma, and at Site 769 by 2.0 ma (Rangin et al., 1990). In the calcareous nannofossils this event is marked by the increased abundance and enhanced preservation toward the end of the Pliocene. Very likely the increased pelagic calcareous sediments at both sites result from a gradual deepening of the CCD during late Pliocene, and the difference between the timing of this event at Sites 768 and 769 is due to the differing depths of the sites at that time. The deepening of CCD may have been caused by increasing isolation of the basin and increasing deep water temperature (Linsely, this volume), which may be a consequence of global lowering of sea level and local tectonic adjustment of sill depth in the late Pliocene.

The lower Pliocene sections at Sites 768 and 769 are almost impossible to subdivide because important index fossils such as *Amaurolithus tricorniculatus, Ceratolithus rugosus, Discoaster asymmetricus,* and *Triquetrorhabdulus rugosus* are too rare to be used to identify biohorizons. Although calcareous nannofossils are better preserved at Site 771, the occurrences and abundances of those early Pliocene index fossils are not improved significantly; their occurrences may be environmentally controlled. Several early Pliocene biohorizons recognized in Hole 771A are in the correct order of succession but they may not be entirely reliable. The oldest biohorizon recognized at Site 771 indicates an early middle Miocene age (Zone NN5), but at the other two sites no calcareous nannofossils were found in the hemipelagic clays and volcaniclastic sediments that overlie the basement. Consequently, calcareous nannofossils do not clearly indicate the age of the Sulu Basin.

A new Pliocene/Pleistocene Boundary has recently been proposed by the INQUA Subcommission, but controversy still exists on where it is best to place the boundary. The proposed boundary, the top of sapropelic layer "e" in the Vrica section, coincides with the top of the Olduvai magnetic event, but other than that, no biohorizon occurs at the boundary and different biostratigraphic results from previous studies on the Vrica section create problems in correlation. The lowest occurrence of *Gephyrocapsa oceanica* s.l. is the nearest datum to the designated Pliocene/Pleistocene Boundary in the stratotype (Rio et al., in press). The correlation of calcareous nannofossil biostratigraphy and magnetostratigraphy of Holes 767B, 768B, and 769B shows that the lowest occurrence of *Gephyrocapsa oceanica* s.l. is consistently the nearest biohorizon to the top of the Olduvai Subchron in the three holes and is used to approximate the Pliocene/Pleistocene Boundary in the Celebes and Sulu Seas.

ACKNOWLEDGMENT

We thank Stefan Gartner for his advice and the use of his laboratory and Jan Backman and John Firth for their helpful reviews. This study was supported by the National Science Foundation through JOI-USSAC.

REFERENCES

Backman, J., and Shackleton, N. J., 1983. Quantitative biochronology of Pliocene and early Pleistocene calcareous nannofossils from the Atlantic, Indian and Pacific oceans. *Mar. Micropaleontol.,* 8:141–170.

Backman, J., Shackleton, N. J., and Tauxe, L., 1983. Quantitative nannofossil correlation to open ocean deep-sea sections from Plio-Pleistocene boundary at Vrica, Italy. *Nature,* 304:156–158.

Baldauf, J. G., Thomas, E., Clement, B., Takayama, T., Weaver, P.P.E., Backman, J., Jenkins, G., Mudie, P. J., and Westberg-Smith, M. J., 1987. Magnetostratigraphic and biostratigraphic synthesis, Deep Sea Drilling Project Leg 94. *In* Ruddiman, W. F., Kidd, R. B., et al., *Init. Repts. DSDP,* 94 (Pt. 2): Washington (U.S. Govt. Printing Office), 1159–1205.

Berggren, W. A., Kent, D. V., and Flynn, J. J., 1985. Jurassic to Paleogene: Part 2. Paleogene geochronology and chronostratigraphy. *In* Snelling, N. J. (Ed.), *The Chronology of the Geological Record.* Geol. Soc. London Mem., 10:141–195.

Berggren, W. A., Kent, D. V., Flynn, J. J., and Van Couvering, J. A., 1985. Cenozoic geochronology. *Geol. Soc. Am. Bull.,* 96:1407–1418.

Berggren, W. A., Kent, D. V., and Van Couvering, J. A., 1985. The 2Neogene: Part 2. Neogene geochronology and chronostratigraphy. *In* Snelling, N. J. (Ed.), *The Chronology of the Geological Record.* Geol. Soc. London Mem., 10:211–260.

Bizon, G., and Müller, C., 1977. Remarks on some biostratigraphic problems in the Mediterranean Neogene. *In* Biju-Duval, B., and Montadert, L. (Eds.), *Structural History of the Mediterranean Basins:* Split, Yugoslavia (Tecnoprint), 381–390.

Bramlette, M. N., and Wilcoxon, J. A., 1967. Middle Tertiary calcareous nannoplankton of the Cipero Section, Trinidad, W.I. *Tulane Stud. Geol.,* 5:93–132.

Bréhéret, J. G., 1978. Biostratigraphie du Pléistocéne supérieur et de l'Holocéne de l'Atlantique nord á l'aide des coccolithes. *C. R. Acad. Sci. Paris, Ser. D,* 287:599–601.

Bukry, D., 1973. Low-latitude coccolith biostratigraphic zonation. *In* Edgar, N. T., Saunders, J. B., et al., *Init. Repts. DSDP,* 15: Washington (U.S. Govt. Printing Office), 685–703.

Cati, F., and Borsetti, A. M., 1982. Calcareous nannoplankton biostratigraphy of the Vrica section (Calabria, Southern Italy). *G. Geol.,* 43:365–385.

Emiliani, C., Mayeda, T., and Selli, R., 1961. Paleotemperature analysis of the Plio-Pleistocene section at Le Castella, Calabria, Southern Italy. *Geol. Soc. Am. Bull.,* 72:679–688.

Gartner, S., 1972. Late Pleistocene nannofossils in the Caribbean and their interoceanic correlation. *Paleogeogr., Paleoclimatol., Paleoecool.,* 12:169–191.

Gartner, S., 1973. Absolute chronology of the late Neogene calcareous nannofossil succession in the Equatorial Pacific. *Geol. Soc. Am. Bull.,* 84:2021–2034.

Gartner, S., Jr., 1977. Calcareous nannofossil biostratigraphy and revised zonation of the Pleistocene. *Mar. Micropaleontol.,* 2:1–25.

Gartner, S., 1990. Neogene calcareous nannofossil biostratigraphy, Leg 116 (Central Indian Ocean). *In* Cochran, J. R., Stow, D.A.V., et al., *Proc. ODP, Sci. Results,* 116: College Station, TX (Ocean Drilling Program), 165–187.

Hamilton, W., 1979. Tectonics of the Indonesian region. *Geol. Surv. Prof. Paper U.S.,* 1078.

Haq, B. U., Berggren, W. A., and van Couvering, J. A., 1977. Corrected age of the Pliocene/Pleistocene boundary. *Nature,* 269:483–488.

Hedberg, H. D., 1976. *International Stratigraphic Guide:* New York (Wiley).

Holloway, N. H., 1981. The North Palawan Block, Philippines: its relation to the Asian Mainland and its role in the evolution of the South China Sea. *Bull. Geol. Soc. Malays.,* 14:19–58.

Lee, C. S., and McCabe, R., 1986. The Banda Celebes Sulu Basins: a trapped piece of Cretaceous Eocene oceanic crust? *Nature,* 322:51–54.

Martini, E., 1971. Standard Tertiary and Quaternary calcareous nannoplankton zonation. *In* Farinacci, A. (Ed.), *Proc. 2nd Planktonic Conf. Roma:* Rome (Ed. Technosci.), 2:739–785.

Martini, E., and Jenkins, D. G., 1986. Biostratigraphic synthesis, Deep Sea Drilling Project Leg 90 in the southwest Pacific Ocean. *In* Kennett, J. P., von der Borch, C. C., et al., *Init. Repts. DSDP,* 90 (Pt. 2): Washington (U.S. Govt. Printing Office), 1459–1470.

Martini, E., and Müller, C., 1986. Current Tertiary and Quaternary calcareous nannoplankton stratigraphy and correlations. *Newsl. Stratigr.,* 16:99–112.

Mitchell, A.H.G., Hernandez, F., and Dela Cruz, A. P., 1986. Cenozoic evolution of the Philippine Archipelago. *J. Southeast Asian Earth Sci.,* 1:3–22.

Monechi, S., Bleil, U., and Backman, J., 1985. Magnetobiochronology of Late Cretaceous-Paleogene and late Cenozoic pelagic sedimentary sequences from the northwest Pacific, Deep Sea Drilling Project Leg 86, Site 577. *In* Heath, G. R., Burckle, L. H., et al., *Init. Repts. DSDP,* 86: Washington (U.S. Govt. Printing Office), 787–797.

Müller, C., 1979. Calcareous nannofossils from the North Atlantic (Leg 48). *In* Montadert, L., Roberts, D. G., et al., *Init. Repts. DSDP,* 48: Washington (U.S. Govt. Printing Office), 589–639.

Müller, C., 1985. Late Miocene to Recent biostratigraphic and paleoenvironmental results from the Mediterranean based on calcareous nannoplankton. *In* Stanley, D. J., and Wezel, F. C. (Eds.), *Geological 2Evolution of the Mediterranean Basin:* New York (Springer-Verlag), 471–485.

Müller, C., 1990. Nannoplankton biostratigraphy and paleoenvironmental interpretations from the Tyrrhenian Sea, ODP Leg 107 (Western Mediterranean). *In* Kastens, K. A., Mascle, J., et al., *Proc. ODP, Sci. Results,* 107: College Station, TX (Ocean Drilling Program), 495–511.

Murauchi, S., Ludwig, W. J., Den, N., Notta, H., Asanuma, T., Yoshii, T., Kubotera, A., and Hagiwara, K., 1973. Structure of the Sulu Sea and the Celebes Sea. *J. Geophys. Res.,* 78:3437–3447.

Okada, H., and Bukry, D., 1980. Supplementary modification and introduction of code numbers to the low-latitude coccolith biostratigraphic zonation (Bukry, 1973; 1975). *Mar. Micropaleontol.,* 5:321–325.

Pelosio, G., Raffii, S., and Rio, D., 1980. The Plio-Pleistocene boundary controversy. Status in 1979 at the light of International Stratigraphic Guide. *In* Petrucci, F., and Cavazzini, R. (Ed.), *Volume Dedicato a Sergio Venzo:* Parma (Grafiche STEP), 131–140.

Perch-Nielsen, K., 1985. Cenozoic calcareous nannofossils. *In* Bolli, H. M., Saunders, J. B., and Perch-Nielsen, K. (Eds.), *Plankton Stratigraphy:* Cambridge (Cambridge Univ. Press), 427–554.

Proto Decima, F., and Masotti, C., 1981. The genus *Gephyrocapsa (Coccolithophorales)* in the Plio-Pleistocene of the Tlmor Trough. *Mem. Sci. Geol.,* 34:453–464.

Rangin, C., Silver, E. A., von Breymann, M. T., et al., 1990. *Proc. ODP, Init. Repts.,* 124: College Station, TX (Ocean Drilling Program).

Rio, D., 1982. The fossil distribution of coccolithophore genus *Gephyrocapsa* Kamptner and related Plio-Pleistocene chronostratigraphic problems. *In* Prell, W. L., Gardner, J. V., et al., *Init. Repts. DSDP,* 68: Washington (U.S. Govt. Printing Office), 325–343.

Rio, D., Backman, J., Raffi, I., in press. Calcareous nannofossil biochronology and the Pliocene/Pleistocene boundary: the Neogene/Quaternary boundary. *Final Rept. IGCP Project,* No. 41.

Rio, D., Raffi, I., and Villa, G., 1990. Pliocene-Pleistocene calcareous nannofossil distribution patterns in the Western Mediterranean. *In* Kastens, K. A., Mascle, J., et al., *Proc. ODP, Sci. Results,* 107: College Station, TX (Ocean Drilling Program), 513–533.

Samtleben, C., 1980. Die evolution der Coccolithophoriden-Gattung *Gephyrocapsa* nach befunden in Atlantik. *Palaontol. Z.,* 54:91–127.

Sclater, J. G., Karig, D. E., Lawver, L. A., and Louden, K., 1976. Heat flow, depth, and crustal thickness of the marginal basins of the south Philippine Sea. *J. Geophys. Res.,* 81:309–318.

Selli, R., 1971. Calabrian. *G. Geol.*, 37:55–64.

Selli, R., Accorsi, C. A., Bandini Mazzanti, M., et al., 1977. The Vrica section (Calabria, Italy). A potential Neogene/Quaternary boundary stratotype. *G. Geol.*, 42:181–204.

Takayama, T., and Sato, T., 1986. Coccolith biostratigraphy of the North Atlantic Ocean, Deep Sea Drilling Project Leg 94. *In* Ruddiman, W. F., Kidd, R. B., Thomas, E., et al., *Init. Repts. DSDP*, 94 (Pt. 2): Washington (U.S. Govt. Printing Office), 651–702.

Tauxe, L., Opdyke, N. D., Pasini, G., and Elmi, C., 1983. The paleomagnetism of the Vrica section (Calabria, Italy): the proposed Pliocene/Pleistocene Boundary-stratotype section. *Nature*, 304:125–129.

Weissel, J. K., 1980. Evidence for Eocene oceanic crust in the Celebes Basin. *In* Hayes, D. E. (Ed.), *The Tectonic and Geologic Evolution of Southeast Asian Seas and Islands*. Am. Geophys. Union, Geophys. Monogr. Ser., 23:37–47.

Date of initial receipt: 4 June 1990
Date of acceptance: 11 December 1990
Ms 124B-127

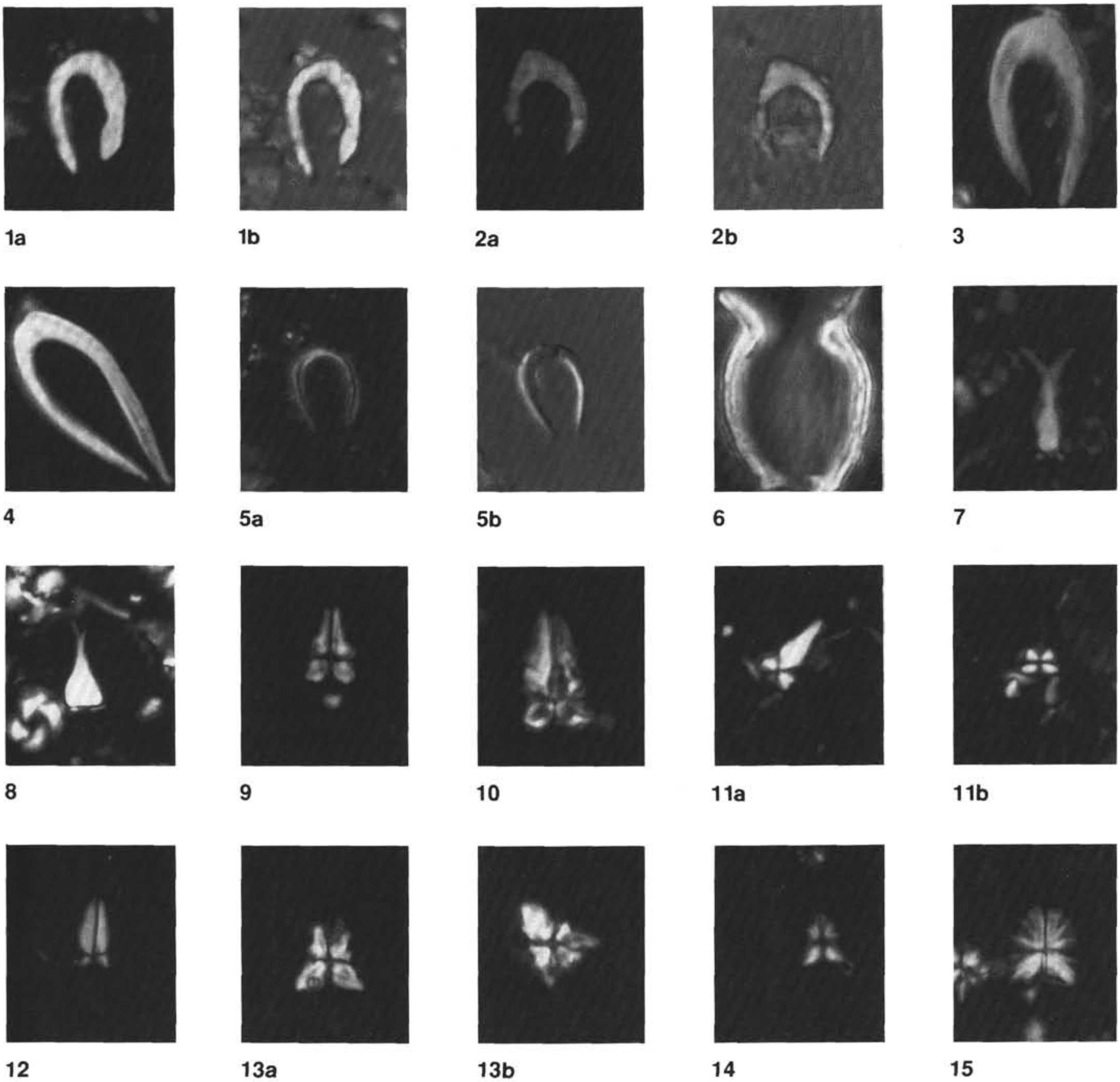


Plate 1. All specimens are magnified by 1920X. **1a, b.** *Ceratolithus rugosus* Bukry and Bramlette, Sample 124-771A-1R-1, 46–47 cm. **2a, b.** *Ceratolithus armatus* Mller, Sample 124-771A-2R-1, 127–128 cm. **3.** *Ceratolithus cristatus* Kamptner, Sample 124-769B-1H-3, 40–41 cm. **4.** *Ceratolithus telesmus* Norris, Sample 124-769A-5H-5, 75–76 cm. **5a, b.** *Amaurolithus delicatus* Gartner and Bukry, Sample 124-771A-2R-1, 127–128 cm. **6.** *Scyphosphaera pulcherrima* Deflandre, Sample 124-771A-1R-1, 3 cm. **7.** *Sphenolithus distentus* (Martini) Bramlette and Wilcoxon, Sample 124-770B-13R, CC. **8.** *Sphenolithus predistentus* Bramlette and Wilcoxon, Sample 124-770B-13R, CC. **9.** *Sphenolithus radians* Deflandre in Grasse, Sample 124-770B-15R-3, 146–147 cm. **10.** *Sphenolithus pseudoradians* Bramlette and Wilcoxon, Sample 124-770B-13R-1, 114–115 cm. **11a, b.** *Sphenolithus heteromorphus* Deflandre, Sample 124-771A-10R, CC. **12.** *Sphenolithus obtusus* Bukry, Sample 124-770B-15R-4, 131–132 cm. **13a, b.** *Sphenolithus conicus* Bukry, Sample 124-770B-15R-3, 146–147 cm. **14.** *Sphenolithus abies* Deflandre, Sample 124-771A-2R-1, 127-128 cm. **15.** *Sphenolithus moriformis* (Bronnimann and Stradner) Bramlette and Wilcoxon, Sample 124-769B-22H-3, 112–113 cm.

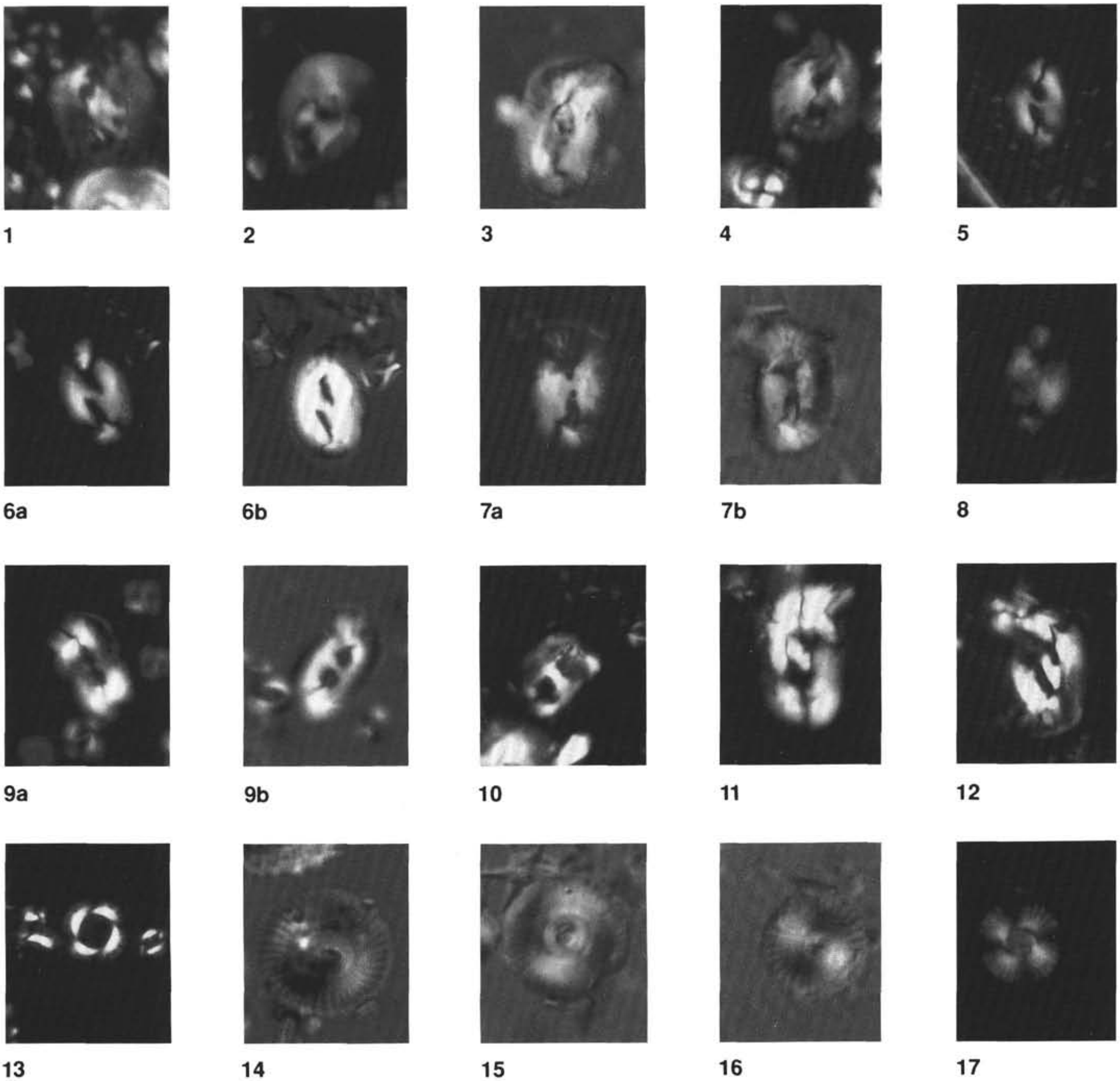


Plate 2. All specimens are magnified by 1920X. **1.** *Helicosphaera reticulata*Bramlette and Wilcoxon, Sample 124-770B-14R-2, 120–121 cm. **2.** *Helicosphaera compacta* Bramlette and Wilcoxon, Sample 124-770B-14R-2, 120–121 cm. **3.** *Helicosphaera granulata* Bukry and Percival, Sample 124-771A-9R-3, 12–13 cm. **4.** *Helicosphaera recta* Haq, Sample 770B-13, CC. **5.** *Helicosphaera sellii* Bukry and Bramlette, Sample 124-769B-11H-1, 30–31 cm. **6a, b.** *Helicosphaera wallichii* (Lohmann) Boudreaux and Hay, Sample 124-771A-1R-1, 46–47 cm. **7a, b.** *Helicosphaera carteri* (Wallich) Kamptner, Sample 124-771A-4R, CC. **8.** *Helicosphaera burkei* Black, Sample 124-771A-9R-3, 12–13 cm. **9a, b.** *Helicosphaera inversa* Gartner, Sample 124-769B-4H-6, 23–24 cm. **10.** *Helicosphaera mediterranea* Mller, Sample 124-771A-10R, CC. **11.** *Helicosphaera rhomba* Bukry, Sample 124-771A-9R-3, 12–13 cm. **12.** *Helicosphaera intermedia* Martini, Sample 124-771A-7R, CC. **13.** *Pseudoemiliania lacunosa* (Kamptner) Gartner, Sample 124-769B-10H-3, 30–31 cm. **14.** *Calcidiscus tropicus* (Kamptner) Gartner, Chow, and Stanton, Sample 124-771A-1R-1, 46–47 cm. **15.** *Calcidiscus tropicus* (Kamptner) Gartner, Chow, and Stanton, Sample 124-771A-4R, CC. **16, 17.** *Calcidiscus leptoporus* (Murray and Blackman) Loeblich and Tappan, Sample 124-771A-2R-1, 127–128 cm.

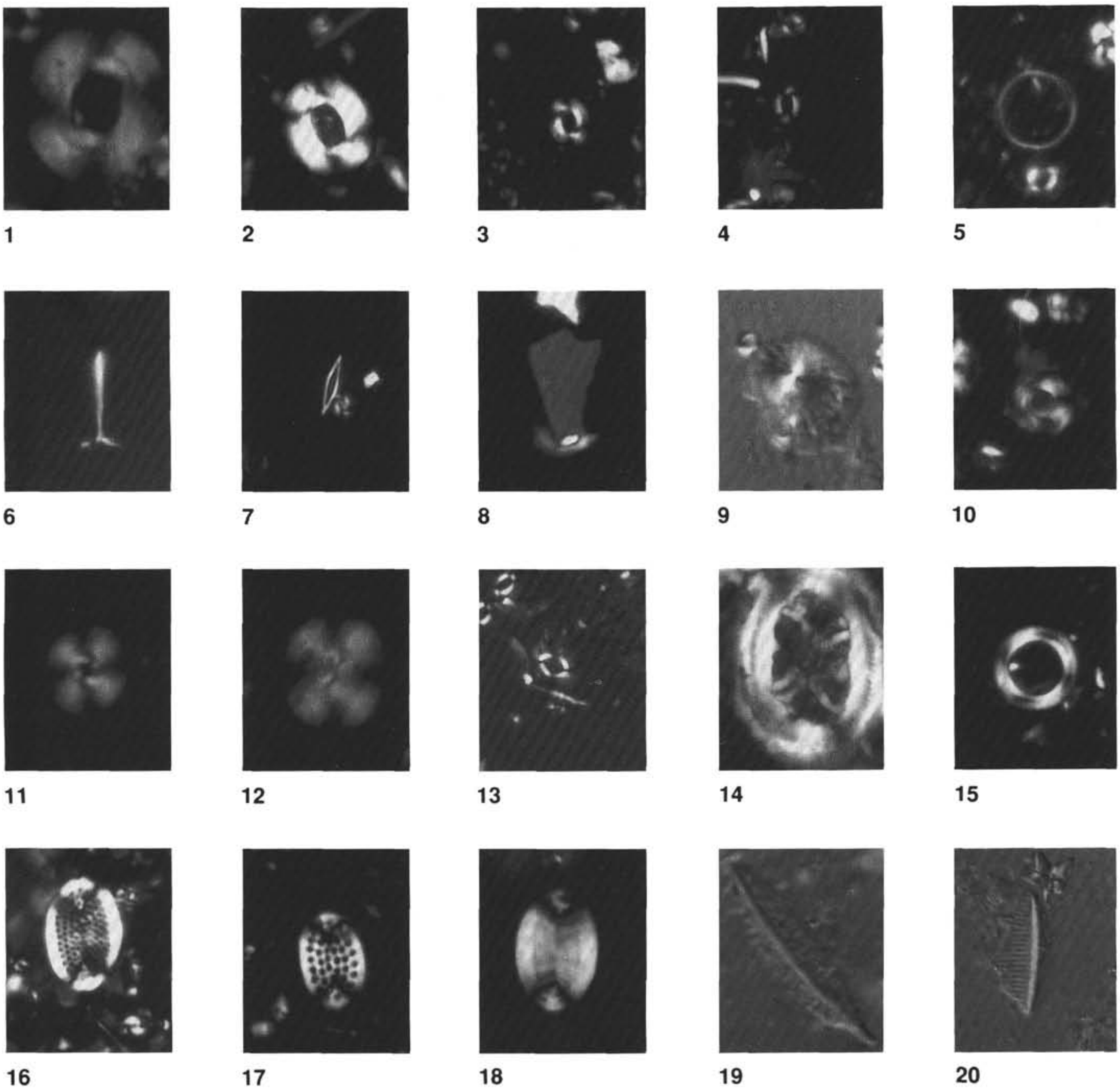
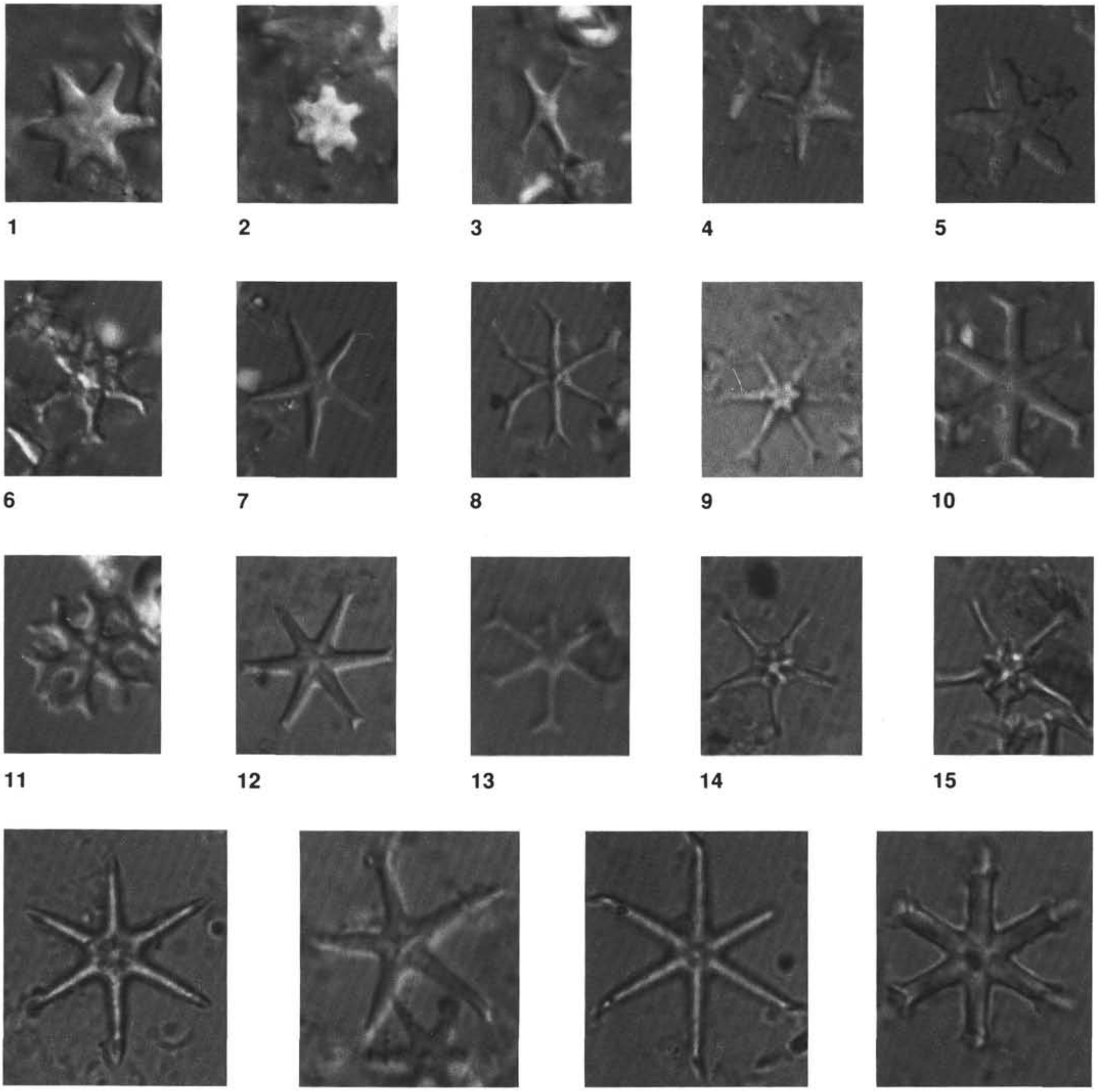


Plate 3. All specimens are magnified by 1920X. **1.** *Reticulofenestra umbilica* (Levin) Martini and Ritzkowski, Sample 124-770B-14R-2, 120–121 cm. **2.** *Reticulofenestra pseodoumbilica* (Gartner) Gartner, Sample 124-771A-6R-3, 25–26 cm. **3.** *Reticulofenestra minutula* (Gartner) Haq and Berggren, Sample 124-771A-1R-1, 46–47 cm. **4.** *Reticulofenestra minuta* Roth, Sample 124-771A-1R-1, 46-47 cm. **5.** *Cyclolithella annula* (Cohen) Boudreaux and Hay, Sample 124-769B-1H-3, 40–41 cm. **6.** *Rhabdosphaera claviger* Murray and Blackman, Sample 124-769B-2H, CC. **7.** *Scapholithus fossilis* Deflandre in Deflandre and Fert, Sample 124-769B-2H, CC. **8.** *Bramletteius serraculoides* Gartner, Sample 124-770B-14R-3, 16–17 cm. **9.** *Oolithotus antillarum* (Cohen) Reinhardt, Sample 124-769B-10H-3, 30–31 cm. **10.** *Umbilicosphaera sibogae* Weber-van Bosse, Sample 124-769B-10H-3, 30–31. **11.** *Cyclicargolithus floridanus* (Roth and Hay) Bukry, Sample 124-771A-10R-5, 24–25 cm. **12.** *Dictyococcites bisectus* (Hay, Mohler and Wade) Bukry and Percival, Sample 124-770B-14R-3, 16–17 cm. **13.** *Emiliania huxleyi* (Lohmann) Hay and Mohler, Sample 769B-1-3, 40–41 cm. **14.** *Chiasmolithus grandis* (Bramlette and Riedel) Radomski, Sample 124-770B-15R-5, 38–39 cm. **15.** *Coronocyclus nitescens* (Kamptner) Bramlette and Wilcoxon, Sample 124-771A-10, CC. **16.** *Discolithina discopora* (Schiller) Chen, Sample 124-768B-10H-7, 31–32 cm. **17.** *Discolithina multipora* (kamptner) Chen, Sample 124-771A-7R, CC. **18.** *Discolithina japonica* Takayama, Sample 124-768B-11H-1, 30–31 cm. **19, 20.** *Triquetrorhabdulus rugosus* Bramlette and Wilcoxon, Sample 124-771A-2R-2, 49–50 cm.



1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19

Plate 4. All speciemens are magnified by 1920X. **1.** *Discoaster druggii* Bramlette and Wilcoxon, Sample 124-771A-8R-1, 25–26 cm. **2.** *Discoaster kugleri* Martini and Bramlette, Sample 124-771A-8R-1, 25–26 cm. **3.** *Discoaster quadramus* Bukry, Sample 124-771A-8R-1, 25–26 cm. **4.** *Discoaster tamalis* Kamptner, Sample 124-769B-22H-1, 88–89 cm. **5.** *Discoaster tanii nodifer* Bramlette and Wilcoxon, Sample 124-770B-15R-3, 146–147 cm. **6.** *Discoaster bollii* Martini and Bramlette, Sample 124-769B-24H-2, 122–123 cm. **7.** *Discoaster asymmetricus* Gartner, Sample 124-769B-22H-3, 112–113 cm. **8.** *Discoaster signus* Bukry, Sample 124-771A-8R, CC. **9.** *Discoaster exilis* Martini and Bramlette, Sample 124-771A-10R-3, 24–25 cm. **10.** *Discoaster variabilis* Martini and Bramlette, Sample 124-771A-2R-1, 127–128 cm. **11.** *Discoaster pansus* (Bukry and Percival) Bukry, Sample 124-771A-10R-3, 24–25 cm. **12.** *Discoaster calcaris* Gartner, Sample 124-771A-6R-3, 25–26 cm. **13.** *Discoaster challengeri* Bramlette and Riedel, Sample 124-771A-1R-1, 46–47 cm. **14.** *Discoaster quinqueramus* Gartner, Sample 124-771A-3R-3, 25–26 cm. **15.** *Discoaster berggrenii* Bukry, Sample 124-771A-3R-3, 25–26 cm. **16.** *Discoaster brouweri* Tan, Sample 124-771A-2R-1, 18–19 cm. **17.** *Discoaster hamatus* Martini and Bramlette, Sample 124-771A-6R-3, 25–26 cm. **18.** *Discoaster neohamatus* Bukry and Bramlette, Sample 124-771A-2R-1, 18–19 cm. **19.** *Discoaster surculus* Martini and Bramlette, Sample 124-771A-2R-1, 18–19 cm.

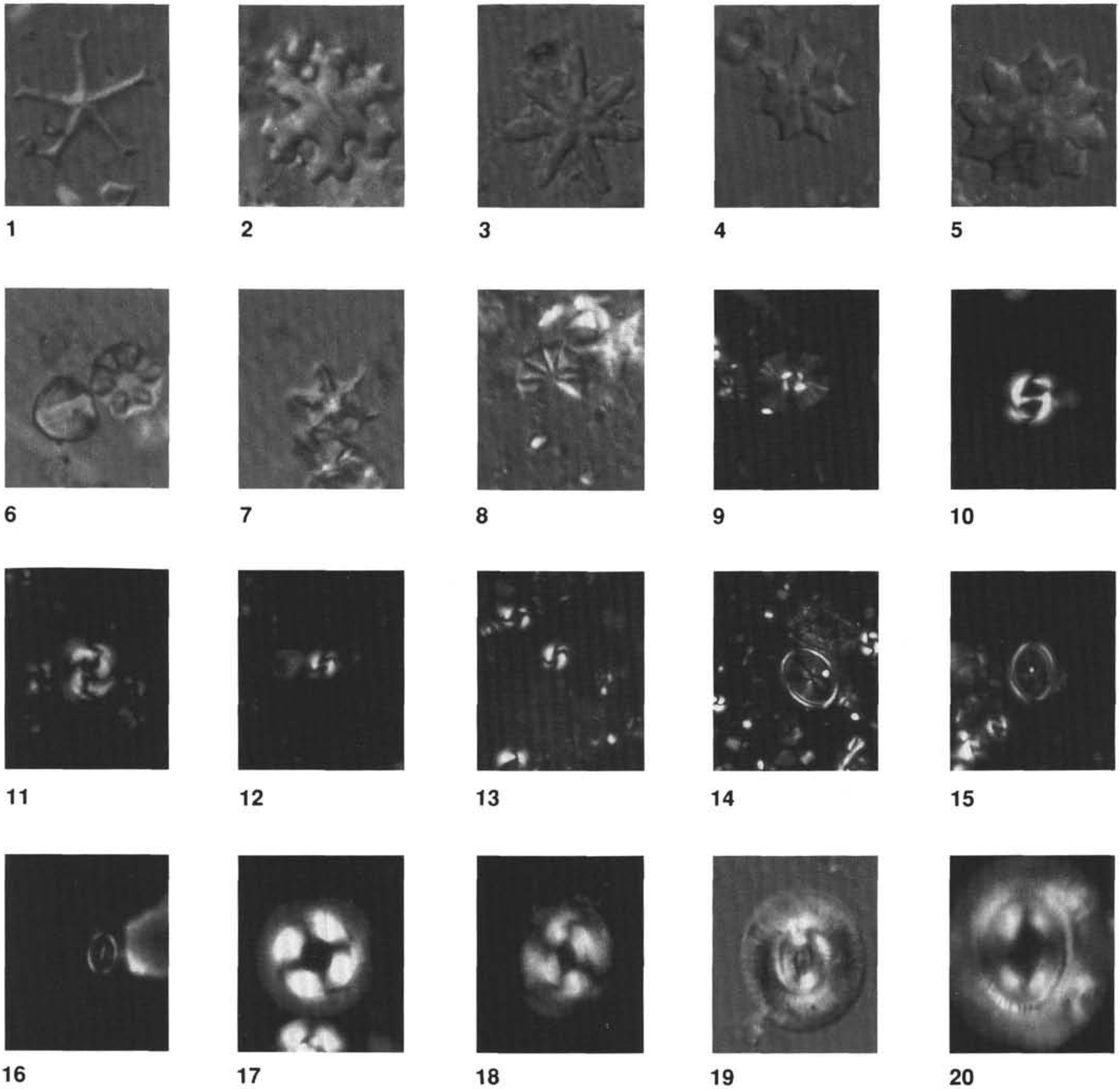


Plate 5. All specimens are magnified by 1920X. **1.** *Discoaster pentaradiatus* Tan emend. Bramlette and Riedel, Sample 124-771A-1R-1, 3–4 cm. **2.** *Discoaster deflandrei* Bramlette and Riedel, Sample 124-771A-10R, CC. **3.** *Discoaster binodosus* Martini, Sample 124-770B-15R-3, 146–147 cm. **4.** *Discoaster saipanensis* Bramlette and Riedel, Sample 124-770B-15R-3, 146–147 cm. **5.** *Discoaster barbadiensis* Tan, Sample 124-770B-15R-3, 146–147 cm. **6.** *Catinaster coalitus* Martini and Bramlette, Sample 124-771A-6R-3, 25–26 cm. **7.** *Catinaster calyculus* Martini and Bramlette, Sample 124-771A-6R-3, 25–26 cm. **8.** *Hayaster perplexus* (Bramlette and Riedel) Bukry, Sample 124-771A-1R-1, 46–47 cm. **9.** *Umbellosphaera irregularis* Paasche, Sample 124-769B-1H-3, 40–41 cm. **10.** *Gephyrocapsa oceanica* Kamptner, Sample 124-769B-2H, CC. **11.** *Gephyrocapsa oceanica* Kamptner, Sample 124-769B-6H, CC. **12, 13.** *Gephyrocapsa margarelii* Breheret, Sample 124-769B-12H-4, 38–39 cm. **14.** *Syracosphaera pulchra* Lohmann, Sample 124-771A-1R-1, 3–4 cm. **15.** *Syracosphaera nodosa* Kamptner, Sample 124-769B-4H-3, 40–41 cm. **16.** *Syracosphaera lamina* Lecal-Schlander, Sample 124-769B-4H-6, 23–24 cm. **17.** *Ericsonia formosa* (Kamptner) Haq, Sample 124-770B-14R-3, 16–17 cm. **18, 19.** *Coccolithus pelagicus* (Wallich) Schiller, Sample 124-771A-10R-3, 23–24 cm. **20.** *Coccolithus eopelagicus* (Bramlette and Riedel) Bramlette and Sullivan, Sample 124-770B-13R, CC.