26. CALCAREOUS NANNOPLANKTON BIOSTRATIGRAPHY—DEEP SEA DRILLING PROJECT LEG 60[1]

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ABSTRACT

During Leg 60 of the Deep Sea Drilling Project, 17 holes were drilled at 10 sites in the Mariana Trench and Trough region of the western Pacific from March to May 1978. Samples recovered from these holes range in age from late middle or late Eocene to late Pleistocene, as determined by calcareous nannoplankton. Late Cretaceous specimens, together with mixed Cenozoic assemblages (Eocene through Pleistocene), were recorded for the first time in samples recovered from the west wall of the Mariana Trench. Detailed biostratigraphic studies reveal several hiatuses in the Oligocene and Miocene intervals at two sites in the fore-arc basin east of the Mariana Ridge (Sites 458 and 459). The greatest of these shows 4 m.y. to be missing between late Miocene and late Pliocene at Site 458, while a time span of about 7 m.y. is absent at the same horizon at Site 459.

A nannoplankton zonation, which is largely an emendation of that proposed by Bukry (1973b, 1975) for low latitudes and by Ellis (1979), is described and compared with the zonation used by Martini (in press) on Leg 59.

INTRODUCTION

On Leg 60 of the Deep Sea Drilling Project, we occupied 10 sites and drilled 17 holes across the Mariana Trench, island arc, and Trough in the western Pacific from March to May 1978 (Figure 1). A total of 560 samples was examined by light microscope, and from these 17 critical samples were selected for detailed study by scanning electron microscopy. The samples range in age from late middle or late Eocene to late Pleistocene. Several reworked Late Cretaceous nannoplankton specimens, together with mixed Cenozoic assemblages, were observed in samples recovered from the west (arc-side) wall of the Mariana Trench (Site 460). This is the first occurrence of Mesozoic fossils from the western margin of the Mariana Trench.

NANNOPLANKTON ZONATION

The zonation used for nannoplankton age determinations during Leg 60 is emended from that proposed by Bukry (1973b, 1975) for low latitudes and by Ellis (1979) (Figure 2). The absolute age estimates and epoch boundary placement are also after Bukry (1973b, 1975), except for the Miocene/Pliocene boundary and the ages of the adjacent subzones. These conform to the position proposed by Ellis and Lohman (1979).

The nannoplankton zonation utilized on Leg 60 is different from that used on Leg 59 (Martini, in press). A conference between Martini and Ellis resulted in a graphic comparison of the two zonation schemes (Figure 3). Although a different absolute time framework was employed by Martini (in press) than is used here, the relationship of zone-defining species to one another remains the same in both schemes.

The following zonation description presents a brief definition or emendation of each zone or subzone, lists the nannoplankton species used to recognize the zonal limits, and compares the zone definition with that of Martini (1971, in press) and Bukry (1973b, 1975) where appropriate.

Many of the emendations are necessary because of local influences affecting species occurrence relationships. Consequently, a coded zonation scheme is presented for application of Leg 60 biostratigraphic results and possibly other western Pacific nannoplankton data. A comparison of the WPN zones and subzones proposed here with those of Bukry (1973b, 1975) is shown in Figure 2. Those zones that have been emended are designated with an asterisk.

WPN-12b Subzone

Definition. Top—*Chiasmolithus grandis*, last occurrence. Base—*Dictyococcites bisectus*, first occurrence.

Remarks. This subzone has a different, older base than Bukry's (1973b, 1975) *Discoaster saipanensis* Subzone.

WPN-13a Subzone

Definition. Top—*Isthmolithus recurvus*, first occurrence. Base—*Chiasmolithus grandis*, last occurrence.

WPN-13b Subzone

Definition. Top—*Discoaster barbadiensis* and *D. saipanensis*, last occurrence. Base—*Isthmolithus recurvus*, first occurrence.

Remarks. This subzone is equal to the *I. recurvus* Subzone of Bukry (1975).

WPN-14a Subzone

Definition. Top—*Coccolithus subdistichus* acme, last occurrence. Base—*Discoaster barbadiensis* and *D. saipanensis*, last occurrence.

WPN-14b Subzone

Definition. Top—*Coccolithus formosus*, last occurrence. Base—*Coccolithus subdistichus* acme, last occurrence.

Remarks. This subzone is equal to the *C. formosus* Subzone of Bukry (1973b), and together with the *Coccolithus subdistichus* Subzone it is equal to the *Ericsonia*? *subdistichus* Zone (NP 21) of Martini (1971, in press).

WPN-14c Subzone

Definition. Top—*Reticulofenestra hillae* and *R. umbilica*, last occurrence. Base—*Coccolithus formosus*, last occurrence.

Remarks. This subzone is equal to the *Helicosphaera reticulata* Zone (NP 22) of Martini (1971, in press) and the *R. hillae* Subzone of Bukry (1973b).

WPN-15 Zone

Definition. Top—*Sphenolithus distentus*, *Cyclicargolithus abisectus*, and *Triquetrorhabdulus carinatus*, first occurrence. Base—*Reticulofenestra hillae* and *R. umbilica*, last occurrence.

Remarks. The last occurrence of *Bramletteius serraculoides* also occurs at the top of this zone at Site 458. This zone is equal to the lower part of the *Sphenolithus predistentus* Zone (NP 23) of Martini

[1] *Initial Reports of the Deep Sea Drilling Project*, Volume 60.

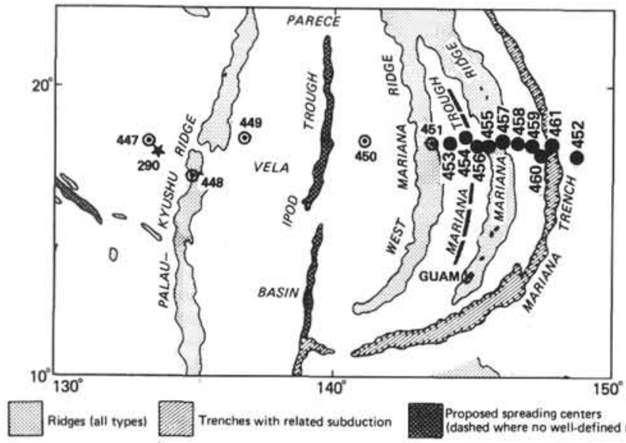

Figure 1. Location of sites cored in the northern Philippine Sea during DSDP Leg 60, (●).

(1971, in press). It differs from Bukry's (1975) *Sphenolithus predistentus* Zone by the use of *C. abisectus* and *T. carinatus* as zonal indices, making the top of the zone younger at some sites.

WPN-16 Zone

Definition. Top—*Sphenolithus ciperoensis*, first occurrence. Base—*Sphenolithus distentus, Cyclicargolithus abisectus*, and *Triquetrorhabdulus carinatus*, first occurrence.

Remarks. The last appearance of *Sphenolithus predistentus* and *Discoaster tanii* also occurs at the top of this zone at Site 458. This zone is equal to the upper part of the *Sphenolithus predistentus* Zone (NP 23) of Martini (1971, in press). It is slightly shorter than Bukry's (1975) *S. distentus* Zone when *C. abisectus* and *T. carinatus* are used as zonal indices.

WPN-17a Subzone

Definition. Top—*Sphenolithus distentus*, last occurrence. Base—*Sphenolithus ciperoensis*, first occurrence.

Remarks. This subzone is equal to the *Sphenolithus distentus* Zone (NP 24) of Martini (1971, in press) and the *Cyclicargolithus floridanus* Subzone of Bukry (1975).

WPN-17b Subzone

Definition. Top—*Dictyococcites bisectus* and *Sphenolithus ciperoensis*, last occurrence. Base—*Sphenolithus distentus*, last occurrence.

Remarks. This subzone is equal to the *Sphenolithus ciperoensis* Zone (NP 25) of Martini (1971, in press) and the *D. bisectus* Subzone of Bukry (1975).

WPN-18a Subzone

Definition. Top—*Cyclicargolithus abisectus* acme, last occurrence. Base—*Dictyococcites bisectus* and *Sphenolithus ciperoensis*, last occurrence.

Remarks. The top of this subzone is considered to be the Oligocene/Miocene boundary. This subzone is equal to the *C. abisectus* Subzone of Bukry (1973b) and, together with the *Discoaster deflandrei* Subzone, it is equal to the *Triquetrorhabdulus carinatus* Zone (NN 1) of Martini (1971, in press).

Age		Zone		Subzone		Duration (m.y.)	Boundary (m.y.)
Holocene		WPN-32	*Emiliania huxleyi*			0.2	0.2
Pleistocene	Late	WPN-31	*Gephyrocapsa oceanica*	WPN-31b	*Ceratolithus cristatus*	0.1	0.3
				WPN-31a	*Emiliania ovata*	0.6	0.9
	Early	WPN-30	*Crenalithus doronicoides*	WPN-30b	*Gephyrocapsa caribbeanica*	0.7	1.6
				WPN-30a	*Emiliania annula*	0.2	1.8
Pliocene	Late	WPN-39	*Discoaster brouweri*	WPN-29d	*Calcidiscus macintyrei*	0.2	2.0
				WPN-29c	*Discoaster pentaradiatus*	0.1	2.1
				WPN-29b*	*Discoaster surculus*	0.4	2.5
				WPN-29a*	*Discoaster tamalis*	0.5	3.0
	Early	WPN-28	*Reticulofenestra pseudoumbilica*	WPN-28b*	*Discoaster asymmetricus*	0.5	3.5
				WPN-28a*	*Sphenolithus neoabies*	0.5	4.0
		WPN-27	*Amaurolithus tricorniculatus*	WPN-27c*	*Ceratolithus rugosus*	0.3	4.3
				WPN-27b	*Ceratolithus acutus*	0.4	4.7
				WPN-27a	*Triquetrorhabdulus rugosus*	0.3	5.0
Miocene	Late	WPN-26	*Discoaster quinqueramus*	WPN-26b	*Amaurolithus primus*	1.4	6.4
				WPN-26a*	*Discoaster berggrenii*	0.6	7.0
		WPN-25	*Discoaster neohamatus*	WPN-25b*	*Discoaster neorectus*	0.5	7.5
				WPN-25a*	*Discoaster bellus*	3.5	11.0
	Middle	WPN-24	*Discoaster hamatus*	WPN-24b*	*Catinaster calyculus*	1.0	12.0
				WPN-24a*	*Helicosphaera carteria*	1.0	13.0
		WPN-23*	*Catinaster coalitus*			0.2	13.2
		WPN-22	*Discoaster exilis*	WPN-22b*	*Discoaster kugleri*	0.2	13.4
				WPN-22a*	*Coccolithus miopelagicus*	0.6	14.0
		WPN-21*	*Sphenolithus heteromorphus*			1.0	15.0
	Early	WPN-20*	*Helicosphaera ampliaperta*			2.0	17.0
		WPN-19	*Sphenolithus belemnos*			1.0	18.0
		WPN-18	*Triquetrorhabdulus carinatus*	WPN-18c	*Discoaster druggii*	3.0	21.0
				WPN-18b	*Discoaster deflandrei*	2.0	23.0
Oligocene	Late			WPN-18a	*Cyclicargolithus abisectus*	1.0	24.0
		WPN-17	*Sphenolithus ciperoensis*	WPN-17b	*Dictyococcites bisectus*	1.0	25.0
				WPN-17a	*Cyclicargolithus floridanus*	1.5	26.5
		WPN-16*	*Sphenolithus distentus*			3.5	30.0
	Early	WPN-15*	*Sphenolithus predistentus*			4.0	34.0
		WPN-14	*Helicosphaera reticulata*	WPN-14c	*Reticulfenestra hillae*	0.5	34.5
				WPN-14b	*Calcidiscus formosus*	2.5	37.0
				WPN-14a	*Coccolithus subdistichus*	1.0	38.0
Eocene (part)	Late	WPN-13	*Discoaster barbadiensis*	WPN-13b	*Isthmolithus recurvus*	3.0	41.0
				WPN-13a	*Chiasmolithus oamaruensis*	1.0	42.0
	Middle	WPN-12	*Reticulofenestra umbilica*	WPN-12b*	*Discoaster saipanensis*	2.0	44.0
				WPN-12a	*Discoaster bifax*	1.0	45.0

Figure 2. Calcareous nannoplankton zonation scheme used for Leg 60; modified after Bukry (1973b, 1975) and Ellis (1979).

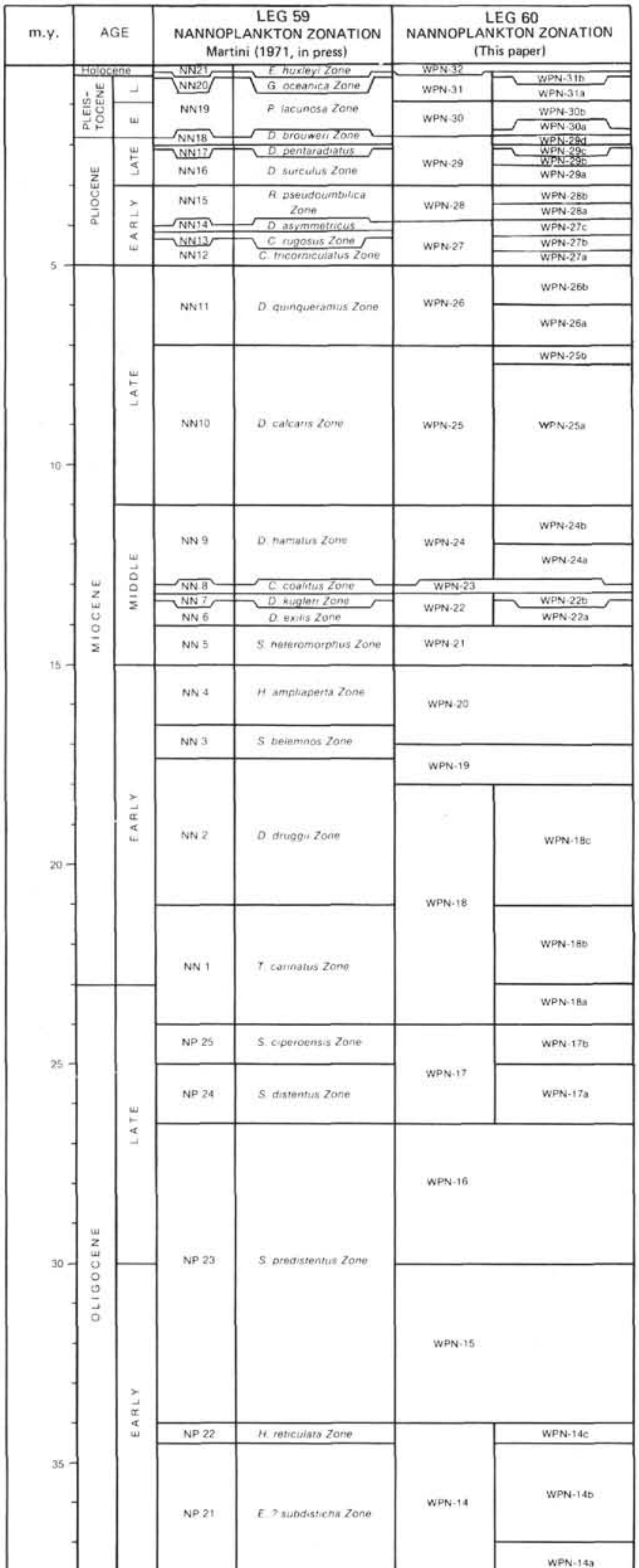

Figure 3. Comparison of calcareous nannoplankton zonation schemes used on Legs 59 and 60.

WPN-18b Subzone

Definition. Top—*Discoaster druggii*, first occurrence. Base—*Cyclicargolithus abisectus* acme, last occurrence.

Remarks. The first appearance of *Discoaster* sp. cf. *D. variabilis* and the last appearance of *Sphenolithus conicus* occurs at the top of this subzone at Sites 458 and 459. This subzone is equal to the *D. deflandrei* Subzone of Bukry (1973b).

WPN-18c Subzone

Definition. Top—*Sphenolithus belemnos*, first occurrence. Base—*Discoaster druggii*, first occurrence.

Remarks. The last occurrence of *Orthorhabdus serratus* also occurs at the top of this subzone at Site 459. The base of this subzone coincides with the base of the *Discoaster druggii* Zone (NN 2) of Martini (1971, in press); however, the top differs in that the Martini *D. druggii* Zone upper limit is defined on the last occurrence of *Triquetrorhabdulus carinatus*. This subzone is equal to the *D. druggii* Subzone of Bukry (1973b).

WPN-19 Zone

Definition. Top—*Sphenolithus heteromorphus*, first occurrence. Base—*Sphenolithus belemnos*, first occurrence.

Remarks. The last appearance of *Discoaster druggii* and *Triquetrorhabdulus carinatus* also occurs near the top of this zone at Site 459 and at the top of the zone in the truncated section at Site 458. The top of this zone differs from the top of the *Sphenolithus belemnos* Zone (NN 3) of Martini (1971, in press). The top of the Martini zone is described as the last occurrence of *S. belemnos*. This zone is equal to the *S. belemnos* Zone of Bukry (1973b).

WPN-20 Zone

Definition. Top—*Discoaster exilis*, first occurrence; *D. deflandrei* acme, last occurrence. Base—*Sphenolithus heteromorphus*, first occurrence.

Remarks. *Sphenolithus belemnos* and *Triquetrorhabdulus milowii* both have their last occurrence together in the basal part of this zone. *Discoaster signus, D. variabilis*, and *Calcidiscus macintyrei* have their first appearance in the upper part of this zone. *Helicosphaera ampliaperta* was not observed in any of the samples recovered during Leg 60. This zone includes all of the *Helicosphaera ampliaperta* Zone (NN 4) and the upper part of the *Sphenolithus belemnos* Zone (NN 3) of Martini (1971, in press). The top of this zone is slightly younger than Bukry's (1973b) *H. ampliaperta* Zone when *D. exilis* is used instead of *D. deflandrei* and *C. macintyrei.*

WPN-21 Zone

Definition. Top—*Sphenolithus heteromorphus*, last occurrence. Base—*Discoaster exilis*, first occurrence; *D. deflandrei* acme, last occurrence.

Remarks. *Calcidiscus leptoporus, Sphenolithus abies*, and *Triquetrorhabdulus rugosus* have their first appearances in the upper part of this zone. This zone is equal to the *S. heteromorphus* Zone (NN 5) of Martini (1971, in press). It is shorter than the *S. heteromorphus* Zone of Bukry (1973b) when the *D. exilis* zonal index is used. Bukry (written communication, 1979) prefers not to use *D. exilis*, because overgrowth on discoasters makes the distinction of *D. variabilis* from *D. exilis* difficult.

WPN-22a Subzone

Definition. Top—*Discoaster kugleri* and *D. bollii*, first occurrence. Base—*Sphenolithus heteromorphus*, last occurrence.

Remarks. *Cyclicargolithus floridanus* and *Discoaster deflandrei* also have their last occurrence at the top of this subzone at Site 458. This subzone is equal to the *Discoaster exilis* Zone (NN 6) of Martini (1971, in press). It is younger than Bukry's (1973b) *Coccolithus miopelagicus* Subzone when the *D. bollii* index is used. Bukry also uses *C. floridanus* to identify the top of the subzone.

WPN-22b Subzone

Definition. Top—*Discoaster kugleri*, last occurrence; *Catinaster coalitus*, first occurrence. Base—*Discoaster kugleri* and *D. bollii*, first occurrence.

Remarks. This zone is equal to the *D. kugleri* Zone (NN 7) of Martini (1971, in press). The *D. kugleri* Subzone of Bukry (1973b) has *C. coalitus* as the primary index at the top and does not employ *D. bollii* for the base.

WPN-23 Zone

Definition. Top—*Discoaster calcaris, D. hamatus*, and *D. neohamatus*, first occurrence. Base—*Discoaster kugleri*, last occurrence; *Catinaster coalitus*, first occurrence.

Remarks. This zone is equal to the *Catinaster coalitus* Zone (NN 8) of Martini (1971, in press). Use of *D. kugleri* or *D. neohamatus* as indices would alter Bukry's (1973b) definition for the *C. coalitus* Zone.

WPN-24a Subzone

Definition. Top—*Catinaster calyculus*, first occurrence. Base—*Discoaster calcaris, D. hamatus*, and *D. neohamatus*, first occurrence.

Remarks. This subzone is equal to the lower part of the *Discoaster hamatus* Zone (NN 9) of Martini (1971, in press). Use of *D. neohamatus* as an index for the base would alter the original definition of Bukry (1975) for the *Helicosphaera carteri* Subzone.

WPN-24b Subzone

Definition. Top—*Discoaster hamatus*, last occurrence; *D. pentaradiatus*, first occurrence. Base—*Catinaster calyculus*, first occurrence.

Remarks. This subzone is equal to the upper part of the *Discoaster hamatus* Zone (NN 9) of Martini (1971, in press). Use of *D. pentaradiatus* as an index for the top would extend the *C. calyculus* Subzone defined by Bukry (1975).

WPN-25a Subzone

Definition. Top—*Catinaster calyculus* and *C. coalitus*, last occurrence. Base—*Discoaster hamatus*, last occurrence; *D. pentaradiatus*, first occurrence.

Remarks. *Discoaster bollii* also has it last occurrence at the top of this subzone at Site 458. This subzone is equal to the lower part and much of the upper part of the *Discoaster calcaris* Zone (NN 10) of Martini (1971, in press). Three of the four index species for the subzone boundaries differ from those used by Bukry (1973b, 1975) to define the *D. bellus* Subzone.

WPN-25b Subzone

Definition. Top—*Discoaster bellus, D. loeblichii*, and *D. neohamatus*, last occurrence; *D. surculus*, first occurrence. Base—*Catinaster calyculus* and *C. coalitus*, last occurrence.

Remarks. The top of this subzone is identical to the top of the *D. neohamatus* Zone, which was formerly identified by five species events, including the first occurrence of *D. quinqueramus* (Ellis, 1979). The first occurrence of *D. quinqueramus* is discounted here, because the species occurs too rarely and sporadically to be of use. *Discoaster* sp. cf. *D. quinqueramus* also has its last occurrence at the top of this subzone at Site 458. This species is described by Bukry (1973b) as being transitional between *Discoaster bellus* and *D. quinqueramus* and has been reported as occurring in the *D. bellus* Subzone by Ellis and Lohman (1979) and Ellis (1979). This occurrence extends its range to include all of the WPN-25 Zone (Figure 2). The top of this subzone is equal to the top of the *Discoaster calcaris* Zone (NN 10) of Martini (1971, in press). All four of the subzone boundary species are different from those used to define the original *D. neorectus* Subzone (Bukry, 1973b, 1975). The new markers lower the base and raise the top of the original subzone.

WPN-26a Subzone

Definition. Top—*Amaurolithus primus*, first occurrence; *Discoaster berggrenii* acme, last occurrence. Base—*Discoaster bellus, D. loeblichii*, and *D. neohamatus*, last occurrence; *D. surculus*, first occurrence.

Remarks. Since the interval represented by the WPN-26 Zone is not present in any of the Leg 60 samples, this subzone and the WPN-26b Subzone were not recognized. Consequently, its definition is based on other nearby western Pacific observations (Ellis, 1975) and Bukry's (1973b, 1975) zonation. This subzone is equal to the lower part of the *Discoaster quinqueramus* Zone (NN 11) of Martini (1971, in press). The alteration of the basal boundary criteria from the *D. berggrenii* Subzone of Bukry (1973b) makes the base of this subzone younger.

WPN-26b Subzone

Definition. Top—*Discoaster quinqueramus* and *D. berggrenii*, last occurrence. Base—*Amaurolithus primus*, first occurrence; *Discoaster berggrenii* acme, last occurrence.

Remarks. This subzone, which is equal to the upper part of the *Discoaster quinqueramus* Zone (NN 11) of Martini (1971, in press), was not recognized in the Leg 60 samples. The subzone definition has been established on the same basis as that noted for the WPN-26a Subzone. It is equal to the *Amaurolithus primus* Subzone of Bukry (1973b).

WPN-27a Subzone

Definition. Top—*Ceratolithus acutus*, first occcurrence. Base—*Discoaster quinqueramus* and *D. berggrenii*, last occurrence.

Remarks. *Amaurolithus amplificus* also has its last occurrence at the top of this subzone at Site 453. The base of this subzone is considered to approximate the Miocene/Pliocene boundary (Ellis and Lohman, 1979). This subzone is equal to the lower part of the *Amaurolithus tricorniculatus* Zone (NN 12) of Martini (1971, in press) and the *Triquetrorhabdulus rugosus* Subzone of Bukry (1973b).

WPN—27b Subzone

Definition. Top—*Ceratolithus acutus*, last occurrence; *C. rugosus*, first occurrence. Base—*Ceratolithus acutus*, first occurrence.

Remarks. *Amaurolithus delicatus* has its last occurrence at the top of this subzone at Site 453, which is earlier than usual relative to *C. rugosus*. This subzone, together with the *Triquetrorhabdulus rugosus* Subzone, is equal to the *Amaurolithus tricorniculatus* Zone (NN 12) of Martini (1971, in press) and the *C. acutus* Subzone of Bukry (1973b).

WPN-27c Subzone

Definition. Top—*Sphenolithus neoabies* acme, first occurrence. Base—*Ceratolithus acutus*, last occurrence; *C. rugosus*, first occurrence.

Remarks. *Ceratolithus armatus* has its last occurrence within this subzone. This subzone is approximately equal to the *C. rugosus* Zone (NN 13) and the *Discoaster asymmetricus* Zone (NN 14) of Martini (1971, in press). The top of this subzone is a local abundance effect, making its relation to the *C. rugosus* Subzone of Bukry (1973b) uncertain. The indices that define the top of Bukry's subzone are not present in Leg 60 samples.

WPN-28a Subzone

Definition. Top—*Discoaster tamalis*, first occurrence. Base—*Sphenolithus neoabies* acme, first occurrence.

Remarks. *Sphenolithus neoabies* also has the last occurrence of its acme near the top of this subzone at Site 453. The subzone is equal to the lower part of the *Reticulofenestra pseudoumbilica* Zone (NN 15) of Martini (1971, in press). Both the base and top of this subzone are defined by different species from the *S. neoabies* Subzone of Bukry (1973b). It has not been applied sufficiently to establish correlation with the original subzone.

WPN-28b Subzone

Definition. Top—*Sphenolithus abies*, last occurrence. Base—*Discoaster tamalis*, first occurrence.

Remarks. *Reticulofenestra pseudoumbilica*, whose last occurrence also normally defines the top of this subzone, has its last appearance just before that of *Sphenolithus abies* at Site 453. This subzone is equal to the upper half of the *Reticulofenestra pseudoumbilica* Zone (NN 15) of Martini (1971, in press). It differs from the *Discoaster asymmetricus* Subzone of Bukry (1973b) by using the first occurrence of *D. tamalis* for the base instead of the first occurrence of the *D. asymmetricus* acme.

WPN-29a Subzone

Definition. Top—*Discoaster tamalis, D. decorus*, and *D. variabilis*, last occurrence. Base—*Sphenolithus abies*, last occurrence.

Remarks. This subzone is equal to the lower part of the *Discoaster surculus* Zone (NN 16) of Martini (1971, in press). This subzone may be shorter (if *D. decorus* is used) or longer (if *D. variabilis* is used) than the *D. tamalis* Subzone of Bukry (1973b).

WPN-29b Subzone

Definition. Top—*Discoaster surculus*, last occurrence. Base—*Discoaster tamalis, D. decorus, D. variabilis*, last occurrence.

Remarks. This subzone is equal to the upper part of the *Discoaster surculus* Zone (NN 16) of Martini (1971, in press). The base of the subzone is different from the *D. surculus* Subzone of Bukry (1975).

WPN-29c Subzone

Definition. Top—*Discoaster pentaradiatus*, last occurrence. Base—*Discoaster surculus*, last occurrence.

Remarks. This subzone is equal to the *Discoaster pentaradiatus* Zone (NN 17) of Martini (1971, in press) and the *D. pentaradiatus* Subzone of Bukry (1973b).

WPN-29d Subzone

Definition. Top—*Discoaster brouweri* and *D. triradiatus*, last occurrence. Base—*Discoaster pentaradiatus*, last occurrence.

Remarks. This subzone is equal to the *Discoaster brouweri* Zone (NN 18) of Martini (1971, in press), and its upper limit is considered to be the Pliocene/Pleistocene boundary. The addition of *D. triradiatus* as a guide species has virtually no effect on correlation of this subzone to the *Calcidiscus macintyrei* Subzone of Bukry (1973b).

WPN-30a Subzone

Definition. Top—*Gephyrocapsa caribbeanica*, first occurrence; *Calcidiscus macintyrei*, last occurrence. Base—*Discoaster brouweri* and *D. triradiatus*, last occurrence.

Remarks. This subzone is equal to the basal part of the *Pseudoemiliania lacunosa* Zone (NN 19) of Martini (1971, in press). Use of dual criteria may slightly alter correlation to the *Emiliania annula* Subzone of Bukry (1973b).

WPN-30b Subzone

Definition. Top—*Gephyrocapsa oceanica*, first occurrence; *Discolithina japonica*, last occurrence. Base—*Gephyrocapsa caribbeanica*, first occurrence; *Calcidiscus macintyrei*, last occurrence.

Remarks. Locally, *Gephyrocapsa aperta* and *Ceratolithus telesmus* also have their first occurrence at the top of this subzone at Sites 453, 454, 456, and 459. This subzone is equal to the middle part of the *Pseudoemiliania lacunosa* Zone (NN 19) of Martini (1971, in press). It may differ from the *G. caribbeanica* Zone of Boudreaux and Hay (1967) by use of dual indices such as *D. japonica*.

WPN-31a Subzone

Definition. Top—*Emiliania ovata*, last occurrence. Base— *Gephyrocapsa oceanica*, first occurrence; *Discolithina japonica*, last occurrence.

Remarks. *Emiliania annula* becomes extinct slightly before *E. ovata* at Sites 454, 455, and 456, but the two species have the same extinction point at Sites 458 and 459. This subzone is equal to the upper part of the *Pseudoemiliania lacunosa* Zone (NN 19) of Martini (1971, in press) and the *E. ovata* Subzone of Bukry (1975).

WPN-31b Subzone

Definition. Top—*Emiliania huxleyi*, first occurrence. Base—*Emiliania ovata*, last occurrence.

Remarks. *Helicosphaera hyalina* also has its first appearance at the top of this subzone at Site 454. This subzone is equal to the *Geophyrocapsa oceanica* Zone (NN 20) of Martini (1971, in press) and the *Ceratolithus cristatus* Subzone of Bukry (1975).

WPN-32 Zone

Definition. The range of *Emiliania huxleyi*.

Remarks. This zone is equal to the *Emiliania huxleyi* Zone (NN 21) of Martini (1971, in press) and the *E. huxleyi* Zone of Bukry (1973b).

BIOSTRATIGRAPHY

The nannoplankton zones represented in the core samples recovered from the sites cored during Leg 60 are listed in Table 1. Nearly complete zonal representation is present in samples from Sites 458 and 459, except for an hiatus between late Miocene and late Pliocene. The oldest sediments cored at Site 458 contain both nannoplankton and radiolarians of early Oligocene age. At Site 459 late Eocene radiolarians occur in Core 59, while the oldest sediments that contain nannoplankton were recovered from Core 58 and are of early Oligocene age.

Calcareous nannoplankton recovery from the two deep-water sites (Sites 460 and 461) occupied along the west wall of the Mariana Trench is very meager at best, since sample recovery was from well below the carbonate compensation depth (CCD). Sediment transport and/or slumping has permitted material from above the CCD to be moved to great depths and to be buried immediately, so that the carbonate constituents have not been totally dissolved. The nannoplankton assemblages recovered from these sites (Plates 1 and 2) contain a complete mixture of Mesozoic and Cenozoic species.

SYSTEMATIC PALEONTOLOGY

Forty genera and 133 species of calcareous nannoplankton were recognized during the study of the core samples from Leg 60 holes. The genera are listed in alphabetic sequence for convenient reference. No attempt has been made to provide complete synonomies, but significant references are listed and remarks are made where clarification may be needed.

Cenozoic Species

Genus AMAUROLITHUS Gartner and Bukry, 1975

Amaurolithus amplificus **(Bukry and Percival)**

Ceratolithus amplificus Bukry and Percival, 1971, p. 125, pl. 1, figs. 9–11.

Amaurolithus amplificus (Bukry and Percival). Gartner and Bukry, 1975, p. 455–56, figs. 6g–l.

Amaurolithus delicatus **Gartner and Bukry**

Amaurolithus delicatus Gartner and Bukry, 1975, p. 456, figs. 7a–f.

Amaurolithus primus **(Bukry and Percival)**

Ceratolithus primus Bukry and Percival, 1971, p. 126, pl. 1, figs. 12–14.

Amaurolithus primus (Bukry and Percival). Gartner and Bukry, 1975, p. 457, figs. 7g–l.

Amaurolithus tricorniculatus **(Gartner)**

Ceratolithus tricorniculatus Gartner, 1967, p. 5, pl. 10, figs. 4–6.

Amaurolithus tricorniculatus (Gartner). Gartner and Bukry, 1975, p. 457–58. figs. 8c–h.

Genus ASPIDORHABDUS Hay and Towe, 1962

Aspidorhabdus stylifer **(Lohmann)**

Rhabdosphaera stylifer Lohmann, 1902, p. 143, pl. 5, fig. 65.

Aspidorhabdus stylifer (Lohmann). Boudreaux and Hay, 1969, p. 269, pl. 5, figs. 11–15.

Genus BRAARUDOSPHAERA Deflandre, 1947

Braarudosphaera discula **Bramlette and Riedel**

Braarudosphaera discula Bramlette and Riedel, 1954, p. 394, pl. 38, fig. 7.

Genus BRAMLETTEIUS Gartner, 1969

Bramletteius serraculoides **Gartner**

Bramletteius serraculoides Gartner, 1969a, p. 31, pl. 1, figs. 1–3.

Genus CALCIDISCUS Kamptner, 1950

The argument of Loeblich and Tappan (1978) that the name *Calcidiscus* Kamptner has priority for this genus after the names *Cyclococcolithus* and *Cyclococcolithina* have been suppressed as being invalid, is adopted here.

Calcidiscus leptoporus **(Murray and Blackman)**

Coccosphaera leptopora Murray and Blackman, 1898, p. 430, pl. 15, figs. 1-7.
Cyclococcolithus leptoporus (Murray and Blackman). Kamptner, 1954, p. 23, fig. 23. Boudreaux and Hay, 1969, p. 263, 264, pl. 2, figs. 13, 14; pl. 3, figs. 1-6.
Cyclococcolithina leptopora (Murray and Blackman). Wilcoxon, 1970 p. 82.
Calcidiscus leptoporus (Murray and Blackman). Loeblich and Tappan, 1978, p. 1391.

Calcidiscus macintyrei **(Bukry and Bramlette)**

Cyclococcolithus macintyrei Bukry and Bramlette, 1969, p. 132, pl. 1, figs. 1-3.
Cyclococcolithina macintyrei (Bukry and Bramlette). Bukry, 1973c, p. 392. Ellis and Lohman, 1979, p. 75, pl. 1, fig. 9.
Calcidiscus macintyrei (Bukry and Bramlette). Loeblich and Tappan, 1978. p. 1392.

Genus CATINASTER Martini and Bramlette, 1963

Catinaster calyculus **Martini and Bramlette**

Catinaster calyculus Martini and Bramlette, 1963, p. 850, pl. 103, figs. 1-6.

Catinaster coalitus **Martini and Bramlette**

Catinaster coalitus Martini and Bramlette, 1963, p. 851, pl. 103, figs. 7-10.

Genus CERATOLITHUS Kamptner, 1950

Ceratolithus acutus **Gartner and Bukry**

Ceratolithus acutus Gartner and Bukry, 1974, p. 115, pl. 1, figs. 1-4.

Ceratolithus armatus **Müller**

Ceratolithus armatus Müller, 1974, p. 591, pl. 11, figs. 4-6; pl. 19, figs. 3, 4.

Ceratolithus cristatus **Kamptner**

Ceratolithus cristatus Kamptner, 1954, p. 43, figs. 44, 45.

Ceratolithus rugosus **Bukry and Bramlette**

Ceratolithus rugosus Bukry and Bramlette, 1968, p. 152, pl. 1, figs. 5-9.

Ceratolithus telesmus **Norris**

Ceratolithus telesmus Norris, 1965, p. 21, pl. 11, figs. 5-7; pl. 13, figs. 1-3.

Genus COCCOLITHUS Schwarz, 1894

Coccolithus eopelagicus **(Bramlette and Riedel)**

Tremalithus eopelagicus Bramlette and Riedel, 1954, p. 392, pl. 38, figs. 2a, b.
Coccolithus eopelagicus (Bramlette and Riedel). Bramlette and Sullivan, 1961, p. 141.

Coccolithus formosus **(Kamptner)**

Cyclococcolithus formosus Kamptner, 1963, p. 163, pl. 2, fig. 8.
Coccolithus lusitanicus Black, 1964, p. 308, pl. 50, figs. 1, 2.
Cyclococcolithus orbis Gartner and Smith, 1967, p. 4, pl. 4, figs. 1-3.
Cyclococcolithina formosa (Kamptner). Wilcoxon, 1970, p. 82.
Coccolithus formosus (Kamptner). Wise, 1973, p. 593, pl. 4, figs. 1-6.
Calcidiscus formosus (Kamptner). Loeblich and Tappan, 1978, p. 1391.

Coccolithus miopelagicus **Bukry**

Coccolithus miopelagicus Bukry, 1971a, p. 310, pl. 2, figs. 6-9.

Coccolithus pelagicus **(Wallich)**

Coccosphaera pelagica Wallich, 1877, p. 348, pl. 17, figs. 1, 2, 5, 11, 12.
Coccolithus pelagicus (Wallich). Schiller, 1930, p. 246, figs. 123, 124.

Genus CORONOCYCLUS Hay, Mohler, and Wade, 1966

Coronocyclus nitescens **(Kamptner)**

Umbilicosphaera nitescens Kamptner, 1963, p. 187-188, pl. 1, fig. 5.
Coronocyclus nitescens (Kamptner). Bramlette and Wilcoxon, 1967a, p. 103, pl. 1, fig. 4; pl. 5, figs. 7-8.

Coronocyclus serratus **Hay, Mohler, and Wade**

Coronocyclus serratus Hay, Mohler, and Wade, 1966, p. 394, pl. 11, figs. 1-5.

Genus CRENALITHUS Roth, 1973

Crenalithus doronicoides **(Black and Barnes)**

Coccolithus doronicoides Black and Barnes, 1961, p. 142, pl. 25, fig. 3.
Gephyrocapsa doronicoides (Black and Barnes). Bukry, 1973a, p. 678.
Crenalithus doronicoides (Black and Barnes). Roth, 1973, p. 731, pl. 3, fig. 3.
Cyclicargolithus doronicoides (Black and Barnes). Wise, 1973, p. 594.

Crenalithus productellus **Bukry**

Crenalithus productellus Bukry, 1975, p. 688.

Genus CRICOLITHUS Kamptner, 1958

Cricolithus jonesii **Cohen**

Cricolithus jonesii Cohen, 1965, p. 16, pl. 2, figs. j, k; ? pl. 16, figs. a–c.

Genus CYCLICARGOLITHUS Bukry, 1971

Cyclicargolithus abisectus **(Müller)**

Coccolithus? *abisectus* Müller, 1970, p. 92, pl. 9, figs. 9, 10; pl. 12, fig. 1.
Dictyococcites abisectus (Müller). Bukry and Percival, 1971, p. 127, pl. 2, figs. 9-11.
Cyclicargolithus abisectus (Müller). Bukry, 1973b, p. 703. Wise, 1973, p. 594.
Reticulofenestra abisecta (Müller). Roth, 1973, p. 731, pl. 6, fig. 5; pl. 7, fig. 2.

Cyclicargolithus floridanus **(Roth and Hay)**

Coccolithus floridanus Roth and Hay, *in* Hay, Mohler, Roth, Schmidt, and Boudreaux, 1967, p. 445, pl. 6, figs. 1-4.
Cyclococcolithus neogammation Bramlette and Wilcoxon, 1967a, p. 104, pl. 3, figs. 1-3; pl. 4, figs. 3-5.
Cyclicargolithus floridanus (Roth and Hay). Bukry, 1971a, p. 312-313.

Genus DICTYOCOCCITES Black, 1967

Dictyococcites bisectus **(Hay, Mohler, and Wade)**

Syracosphaera bisecta Hay, Mohler, and Wade, 1966, p. 393, pl. 10, figs. 1-6.
Coccolithus bisectus (Hay, Mohler, and Wade). Bramlette and Wilcoxon, 1967a, p. 102, pl. 4, figs. 11-13.
Dictyococcites bisectus (Hay, Mohler, and Wade). Bukry and Percival, 1971, p. 127, pl. 2, figs. 12, 13.
Reticulofenestra bisecta (Hay, Mohler, and Wade). Roth, 1973, p. 732, pl. 4, fig. 1; pl. 7, figs. 4, 5; pl. 9, figs. 1, 2; pl. 10, fig. 2.

Table 1. Geologic age and nannoplankton zone assignment of cores from Leg 60.

SERIES OR SUBSERIES	ZONE OR SUBZONE	DSDP HOLES														
		452A	453	454	454A	455	456	456A	457	458	459	459B	460	460A	461	461A
HOLOCENE	WPN-32			1cc?		1-1/1-3	1cc/2-3	1-1		1-1/1-2	1-1/1-2					
LATE PLEISTOCENE	WPN-31b	4cc	1cc/2cc		1-1	1-5/2-4			2-3/4-1& 5-1/5cc	1-3/1-5		1-1/1-4				
	WPN-31a			3-1/5cc	1-2/3cc	2-6/9cc	2-4/7cc	1-3/4cc	4cc&6cc	1cc/2-6	1cc	1-5/4cc				
EARLY PLEISTOCENE	WPN-30b		3-2/6cc		4-2/13-1	10-2		5-1/5-3		2cc		5cc				
	WPN-30a		8cc/10cc			11cc	8cc/16-1	5cc/10cc								
LATE PLIOCENE	WPN-29d									3-1						
	WPN-29c		13cc							3-2/3cc						
	WPN-29b		14-1/14-2													
	WPN-29a		15-2/17cc							4-1/4cc		6cc				
EARLY PLIOCENE	WPN-28b		19-1/22-2													
	WPN-28a		22cc/27-1													
	WPN-27c		27-2/29-3?													
	WPN-27b		29cc/38-2													
	WPN-27a		38cc/47cc													
LATE MIOCENE	WPN-26b															
	WPN-26a															
	WPN-25b									5-1/6-1						
	WPN-25a									6-3/6cc						
MIDDLE MIOCENE	WPN-24b									7-2/7-4		8-1/15-1				
	WPN-24a											17-1/19-1		4-3/4cc	BARREN	
	WPN-23											19cc				
	WPN-22b									7cc		20-1/20cc				
	WPN-22a									8cc/9cc						
	WPN-21									10cc/11cc		21-1/21cc				
EARLY MIOCENE	WPN-20									12cc/14cc		22-1/28-1				
	WPN-19									15cc		28-2/35cc				
	WPN-18c									16-1/16cc or 19-1		36-1/46cc				
	WPN-18b															
LATE OLIGOCENE	WPN-18a									17cc or 19cc/21cc		47-1/48cc				
	WPN-17b									22cc/23cc		49-1/53cc				
	WPN-17a											54-1/54-2	4-1			
	WPN-16									24-1/24cc		54-3/57cc				
EARLY OLIGOCENE	WPN-15									25-1/27-2						
	WPN-14c												5cc			1-3/1cc
	WPN-14b											58-1				
	WPN-14a															
EOCENE	WPN-13b												7-1			
	WPN-13a												7cc			

Dictyococcites scrippsae **Bukry and Percival**

Dictyococcites scrippsae Bukry and Percival, 1971, p. 128, pl. 2, figs. 7, 8.

Genus DISCOASTER Tan, 1927

Discoaster asymmetricus **Gartner**

Discoaster asymmetricus Gartner, 1969b, p. 598, pl. 1, figs. 1-3.

Discoaster barbadiensis **Tan**

Discoaster barbadiensis Tan, 1927, p. 119. Bramlette and Riedel, 1954, p. 398, pl. 39, fig. 5.

Discoaster bellus **Bukry and Percival**

Discoaster bellus Bukry and Percival, 1971, p. 128, pl. 3, figs. 1, 2.

Discoaster blackstockae **Bukry**

Discoaster blackstockae Bukry, 1973d, p. 307, pl. 1, figs. 1-4.

Discoaster bollii **Martini and Bramlette**

Discoaster bollii Martini and Bramlette, 1963, p. 851, pl. 105, figs. 1-4, 7.

Discoaster braarudii **Bukry**

Discoaster braarudii Bukry, 1971b, p. 45, pl. 2, fig. 10.

Discoaster brouweri **Tan**

Discoaster brouweri Tan, 1927, p. 120, figs. 8a-b. Bramlette and Riedel, 1954, p. 402, pl. 39, fig. 12; text-figs., 3a-b.

Discoaster calcaris **Gartner**

Discoaster calcaris Gartner, 1967, p. 2, pl. 2, figs. 1-3.

Discoaster challengeri **Bramlette and Riedel**

Discoaster challeñgeri Bramlette and Riedel, 1954, p. 401, pl. 39, fig. 10.

Discoaster decorus **(Bukry)**

Discoaster variabilis decorus Bukry, 1971b, p. 48, pl. 3, figs. 5, 6.
Discoaster decorus (Bukry). Bukry, 1973a, p. 677, pl. 2, figs. 8, 9; pl. 4, fig. 11.

Discoaster deflandrei **Bramlette and Riedel**

Discoaster deflandrei Bramlette and Riedel, 1954, p. 399, pl. 39, fig. 6; text-figs. 1 a-c.

Discoaster divaricatus **Hay**

Discoaster divaricatus Hay, *in* Hay et al., 1967, p. 451, pl. 3, figs. 7-9.
Discoaster aulakos Gartner, 1967, p. 2, pl. 4, figs. 4, 5.

Discoaster druggii **Bramlette and Wilcoxon**

Discoaster extensus Bramlette and Wilcoxon, 1967a, p. 110, pl. 8, figs. 2-8.
Discoaster druggii Bramlette and Wilcoxon, 1967b, p. 220 (nom. subst. pro *D. extensus* Bramlette and Wilcoxon, 1967, *non* Hay, 1967).

Discoaster exilis **Martini and Bramlette**

Discoaster exilis, Martini and Bramlette, 1963, p. 852, pl. 104, figs. 1-3.

Discoaster hamatus **Martini and Bramlette**

Discoaster hamatus Martini and Bramlette, 1963, p. 852, pl. 105, figs. 8, 10, 11.

Discoaster intercalaris **Bukry**

Discoaster intercalaris Bukry, 1971a, p. 315, pl. 3, fig. 12; pl. 4, figs. 1, 2.

Discoaster kugleri **Martini and Bramlette**

Discoaster kugleri Martini and Bramlette, 1963, p. 853, pl. 102, figs. 11-13.

Discoaster loeblichii **Bukry**

Discoaster loeblichii Bukry, 1971a, p. 315-316, pl. 4, figs. 3-5.

Discoaster moorei **Bukry**

Discoaster moorei Bukry, 1971b, p. 46, pl. 2, figs. 11, 12; pl. 3, figs. 1, 2.

Discoaster neohamatus **Bukry and Bramlette**

Discoaster neohamatus Bukry and Bramlette, 1969, p. 133, pl. 1, figs. 4-6.

Discoaster neorectus **Bukry**

Discoaster neorectus Bukry, 1971a, p. 316-318, pl. 4, figs. 6, 7.

Discoaster nodifer **(Bramlette and Riedel)**

Discoaster tani nodifer Bramlette and Riedel, 1954, p. 397, pl. 38, fig. 2.
Discoaster nodifer (Bramlette and Riedel). Bukry, 1973a, p. 678, pl. 4, fig. 24.

Discoaster pentaradiatus **Tan**

Discoaster pentaradiatus Tan, 1927, p. 120, fig. 2.

Discoaster pseudovariabilis **Martini and Worsley**

Discoaster pseudovariabilis Martini and Worsley, 1971, p. 1500, pl. 3, figs. 2-8.

Discoaster quadramus **Bukry**

Discoaster quadramus Bukry, 1973d, p. 307, pl. 1, figs. 5, 6.

Discoaster quinqueramus **Gartner**

Discoaster quinqueramus Gartner, 1969b, p. 598, pl. 1, figs. 6, 7.
Discoaster quintatus Bukry and Bramlette, 1969, p. 133, pl. 1, figs. 6-8.

Discoaster **sp. cf.** *D. quinqueramus* **Gartner**

Discoaster quinqueramus Gartner, 1969b, p. 598, pl. 1, figs. 6, 7.

Discoaster saipanensis **Bramlette and Riedel**

Discoaster saipanensis Bramlette and Riedel, 1954, p. 398, pl. 39, fig. 4.

Discoaster signus **Bukry**

Discoaster signus Bukry, 1971b, p. 48, pl. 3, figs. 3, 4.

Discoaster stellulus **Gartner**

Discoaster stellulus Gartner, 1967, p. 3, pl. 4, figs. 1-3.

Discoaster sublodoensis **Bramlette and Sullivan**

Discoaster sublodoensis Bramlette and Sullivan, 1961, p. 162, pl. 12, figs. 6a, b.

Discoaster surculus **Martini and Bramlette**

Discoaster surculus Martini and Bramlette, 1963, p. 854, pl. 104, figs. 10-12.

Discoaster tamalis **Kamptner**

Discoaster tamalis Kamptner, 1967, p. 166, pl. 24, fig. 131; text-fig. 28.

Discoaster tanii **Bramlette and Riedel**

Discoaster tanii Bramlette and Riedel, 1954, p. 397, pl. 39, fig. 1.

Discoaster triradiatus Tan

Discoaster triradiatus Tan, 1927, p. 417.

Discoaster variabilis Martini and Bramlette

Discoaster variabilis Martini and Bramlette, 1963, p. 854, pl. 104, figs. 4-8.

Discoaster sp. cf. _D. variabilis_ Martini and Bramlette

Discoaster variabilis Martini and Bramlette, 1963, p. 854, pl. 104, figs. 4-8.

Genus DISCOLITHINA Loeblich and Tappan, 1963

Discolithina japonica Takayama

Discolithina japonica Takayama, 1967, p. 177, 181, 189, pl. 2, fig. 11; pl. 9; pl. 10, text-figs. 6, 7.

Discolithinia multipora (Kamptner)

Discolithus multiporus Kamptner, 1948, p. 5, pl. 1, fig. 9.
Discolithina multipora (Kamptner). Martini, 1965, p. 400.

Genus EMILIANIA Hay and Mohler, 1967

Emiliania annula (Cohen)

Coccolithites annulus Cohen, 1964, p. 237, pl. 3, figs. 1a-c.
Pseudoemiliania lacunosa (Kamptner). Gartner, 1969b, p. 598, pl. 2, figs. 9, 10.
Emiliania annula (Cohen). Bukry, 1973a, p. 678.

Remarks. The genus and species *Pseudoemiliania lacunosa* have been judged invalid (Loeblich and Tappan, 1970). Taxonomic assignments of these taxa in this report to *Emiliania annula* follow the suggestion of Bukry (1973a, p. 678).

Emiliania huxleyi (Lohmann)

Pontosphaera huxleyi Lohmann, 1902, p. 130, pl. 4, figs. 1-6; pl. 6, fig. 69.
Coccolithus huxleyi (Lohmann). Kamptner, 1943, p. 44.
Emiliania huxleyi (Lohmann). Hay and Mohler, *in* Hay, Mohler, Roth, Schmidt, and Boudreaux, 1967, p. 447, pl. 10, 11, figs. 1, 2.

Emiliania ovata Bukry

Emiliania ovata Bukry, 1973a, p. 678, pl. 2, figs. 10-12.

Genus GEPHYROCAPSA Kamptner, 1943

Gephyrocapsa aperta Kamptner

Gephyrocapsa aperta Kamptner, 1963, p. 173, pl. 6, figs. 32, 35.

Gephyrocapsa caribbeanica Boudreaux and Hay

Gephyrocapsa caribbeanica Boudreaux and Hay, *in* Hay, Mohler, Roth, Schmidt, and Boudreaux, 1967, p. 447, pl. 12, 13, figs. 1-4.

Geophyrocapsa oceanica Kamptner

Gephyrocapsa oceanica Kamptner, 1943, p. 43-49.

Gephyrocapsa omega Bukry

Gephyrocapsa omega Bukry, 1973a, p. 679, pl. 3, figs. 5-11.

Genus HAYASTER Bukry, 1973

Hayaster perplexus (Bramlette and Riedel)

Discoaster perplexus Bramlette and Riedel, 1954, p. 400, pl. 39, fig. 9.
Hayaster perplexus (Bramlette and Riedel). Bukry, 1973d, p. 308.

Genus HELICOSPHAERA Kamptner, 1954

Helicosphaera carteri (Wallich)

"Coccosphaera" Carterii (Wallich). Wallich, 1877, p. 347-48, pl. 17, figs. 3-4, ?6, 7, 7a, 12S, 17.
Helicosphaera carteri (Wallich). Kamptner, 1954, p. 21-23, 73-74, text-figs. 17a-c, 18, 19. Jafar and Martini, 1975, p. 381-97, pl. 1, figs. 1, 4, 5.
Helicopontosphaera kamptneri Hay and Mohler, *in* Hay et al., 1967, p. 448, pl. 10, fig. 5; pl. 11, fig. 5.

Helicosphaera euphratis Haq

Helicosphaera euphratis Haq, 1966, p. 33, pl. 2, figs. 1, 3.
Helicopontosphaera euphratis (Haq). Martini, 1969, p. 136.

Helicosphaera granulata (Bukry and Percival)

Helicopontosphaera granulata Bukry and Percival, 1971, p. 132, pl. 5, figs. 1, 2.
Helicosphaera granulata (Bukry and Percival). Jafar and Martini, 1975, p. 390.

Helicosphaera hyalina Gaarder

Helicosphaera hyalina Gaarder, 1970, p. 113-114, text-figs. 1-3.
Helicopontosphaera hyalina (Gaarder). Haq, 1973, p. 37.

Helicosphaera intermedia Martini

Helicosphaera intermedia Martini, 1965, p. 404, pl. 35, figs. 1, 2.
Helicopontosphaera intermedia (Martini). Hay and Mohler, *in* Hay, Mohler, Roth, Schmidt, and Boudreaux, 1967, p. 448.

Helicosphaera recta (Haq)

Helicosphaera siminulum recta Haq, 1966, p. 34, pl. 2, fig. 6; pl. 3, fig. 4.
Helicopontosphaera recta (Haq). Martini, 1969, p. 136.
Helicosphaera recta (Haq). Jafar and Martini, 1975, p. 391.

Helicosphaera reticulata Bramlette and Wilcoxon

Helicosphaera reticulata Bramlette and Wilcoxon, 1967a, p. 106, pl. 6, fig. 15.
Helicopontosphaera reticulata (Bramlette and Wilcoxon). Roth, 1970, p. 863, pl. 10, fig. 5.

Helicosphaera sellii (Bukry and Bramlette)

Helicopontosphaera sellii Bukry and Bramlette, 1969, p. 134, pl. 2, figs. 3-7.
Helicosphaera sellii (Bukry and Bramlette). Jafar and Martini, 1975, p. 391. Ellis and Lohman, 1979, p. 76.
Helicosphaera inversa Gartner, 1977, p. 23, pl. 1, figs. 4a, b, 5a-c.

Genus OOLITHOTUS Reinhardt, in Cohen and Reinhardt, 1968

Oolithotus fragilis (Lohmann)

Coccolithophora fragilis Lohmann, 1912, p. 49, 54, text-fig. 11.
Coccolithus fragilis (Lohmann). Schiller, 1930, p. 243-45, text-figs. 43, 120.
Cyclococcolithus fragilis (Lohmann). Deflandre, *in* Deflandre and Fert, 1954, p. 37, pl. 6, figs. 1-3.
Discolithus antillarum Cohen, 1964, p. 236, pl. 1, figs. 3a-e.
Oolithotus fragilis (Lohmann). Okada and McIntyre, 1977, p. 11, pl. 4, fig. 3.

Genus ORTHORHABDUS Bramlette and Wilcoxon, 1967

Orthorhabdus serratus Bramlette and Wilcoxon

Orthorhabdus serratus Bramlette and Wilcoxon, 1967, p. 114-16, pl. 9, figs. 5-10.

Genus RETICULOFENESTRA Hay, Mohler, and Wade, 1966

Reticulofenestra gartneri Roth and Hay

Reticulofenestra gartneri Roth and Hay, *in* Hay et al., 1967, p. 449, pl. 7, fig. 1.

***Reticulofenestra hillae* Bukry and Percival**

Reticulofenestra hillae Bukry and Percival, 1971, p. 136, pl. 6, figs. 1-3.

***Reticulofenestra pseudoumbilica* (Gartner)**

Coccolithus pseudoumbilicus Gartner, 1967, p. 4, pl. 6, fig. 3.
Reticulofenestra pseudoumbilica (Gartner). Gartner, 1969, p. 587-589.

***Reticulofenestra umbilica* (Levin)**

Coccolithus umbilicus Levin, 1965, p. 265, pl. 41, fig. 2.
Reticulofenestra caucasica Hay, Mohler, and Wade, 1966, p. 386, p. 3, figs. 1, 2; pl. 4, figs. 1, 2.
Reticulofenestra umbilica (Levin). Martini and Ritzkowski, 1968, p. 245, pl. 1, figs. 11, 12.

Genus RHABDOSPHAERA Haeckel, 1894

***Rhabdosphaera clavigera* Murray and Blackman**

Rhabdosphaera clavigera Murray and Blackman, 1898, p. 438, pl. 15, figs. 13-15.

***Rhabdosphaera tenuis* Bramlette and Sullivan**

Rhabdosphaera tenuis Bramlette and Sullivan, 1961, p. 147, pl. 5, figs. 14a, b.

Genus SCYPHOSPHAERA Lohmann, 1902

***Scyphosphaera apsteinii* Lohmann**

Scyphosphaera apsteinii Lohmann, 1902, p. 132, pl. 4, figs. 26-30.

***Scyphosphaera globulata* Bukry and Percival**

Scyphosphaera globulata Bukry and Percival, 1971, p. 138-40, pl. 7, figs. 1-6. Ellis and Lohman, 1979, p. 76, pl. 4, fig. 5.

***Scyphosphaera pulcherrima* Deflandre**

Scyphosphaera pulcherrima Deflandre, 1942, p. 133, figs. 28-31.

Genus SPHENOLITHUS Deflandre, 1952

***Sphenolithus abies* Deflandre**

Sphenolithus abies Deflandre, *in* Deflandre and Fert, 1954, p. 164, pl. 10, figs. 1-4.

***Sphenolithus belemnos* Bramlette and Wilcoxon**

Sphenolithus belemnos Bramlette and Wilcoxon, 1967a, p. 118, pl. 2, figs. 1-3.

***Sphenolithus ciperoensis* Bramlette and Wilcoxon**

Sphenolithus ciperoensis Bramlette and Wilcoxon, 1967a, p. 120, pl. 2, figs. 15-18.

***Sphenolithus conicus* Bukry**

Sphenolithus conicus Bukry, 1971a, p. 320, pl. 5, figs. 10-12.

***Sphenolithus delphix* Bukry**

Sphenolithus delphix Bukry, 1973a, p. 679, pl. 3, figs. 19-22.

***Sphenolithus dissimilis* Bukry and Percival**

Sphenolithus dissimils Bukry and Percival, 1971, p. 140, pl. 6, figs. 7-9.

***Sphenolithus distentus* (Martini)**

Furcatolithus distentus Martini, 1965, p. 407, pl. 35, figs. 7-9.
Sphenolithus distentus (Martini). Bramlette and Wilcoxon, 1967a, p. 122, pl. 1, fig. 5; pl. 2, figs. 4, 5.

***Sphenolithus heteromorphus* Deflandre**

Sphenolithus heteromorphus Deflandre, 1953, p. 1785-86, figs. 1, 2.

***Sphenolithus moriformis* (Brönnimann and Stradner)**

Nannoturbella moriformis Brönnimann and Stradner, 1960, p. 368, figs. 11-16.
Sphenolithus pacificus Martini, 1965, p. 407, pl. 36, figs. 7-10.
Sphenolithus moriformis (Brönnimann and Stradner). Bramlette and Wilcoxon, 1967a, p. 124-126, pl. 3, figs. 1-6.

***Sphenolithus neoabies* Bukry and Bramlette**

Sphenolithus neoabies Bukry and Bramlette, 1969, p. 140, pl. 3, figs. 9-11.

***Sphenolithus obtusus* Bukry**

Sphenolithus obtusus Bukry, 1971a, p. 321, pl. 6, figs. 1-9.

***Sphenolithus predistentus* Bramlette and Wilcoxon**

Sphenolithus predistentus Bramlette and Wilcoxon, 1967a, p. 126, pl. 1, fig. 6; pl. 2, figs. 10, 11.

Genus SYRACOSPHAERA Lohmann, 1902

***Syracosphaera pulchra* Lohmann**

Syracosphaera pulchra Lohmann, 1902, p. 134, pl. 4, figs. 33, 36, 37.

Genus THORACOSPHAERA Kamptner, 1927

***Thoracosphaera heimii* (Lohmann)**

Syracosphaera heimii Lohmann, 1919, p. 117, fig. 29.
Thoracosphaera heimii (Lohmann). Kamptner, 1954, p. 40-42, figs. 41, 42.

***Thoracosphaera saxea* Stradner**

Thoracosphaera saxea Stradner, 1961, p. 84, fig. 71.

Genus TRIQUETRORHABDULUS Martini, 1965

***Triquetrorhabdulus carinatus* Martini**

Triquetrorhabdulus carinatus Martini, 1965, p. 408, pl. 36, figs. 1-3.

***Triquetrorhabdulus milowii* Bukry**

Triquetrorhabdulus milowii Bukry, 1971a, p. 325, pl. 7, figs. 9-12.

***Triquetrorhabdulus rugosus* Bramlette and Wilcoxon**

Triquetrorhabdulus rugosus Bramlette and Wilcoxon, 1967a, p. 128-129, pl. 9, figs. 17, 18.

Genus UMBELLOSPHAERA Paasche, 1955

***Umbellosphaera irregularis* Paasche**

Umbellosphaera irregularis Paasche, *in* Markali and Paasche, 1955, p. 97, pls. 3-6.

Genus UMBILICOSPHAERA Lohmann, 1902

***Umbilicosphaera cricota* (Gartner)**

Cyclococcolithus cricotus Gartner, 1967, p. 5, pl. 7, figs. 5-7.
Umbilicosphaera cricota (Gartner). Cohen and Reinhardt, 1968, p. 296, pl. 19, figs. 1, 5; pl. 21, fig. 3; text-fig. 6.

***Umbilicosphaera sibogae* (Weber van Bosse)**

Coccosphaera sibogae Weber van Bosse, 1901, p. 137, 140, pl. 17, figs. 1, 2.
Umbilicosphaera mirabilis Lohmann, 1902, p. 139, pl. 5, figs. 66, 66a.
Umbilicosphaera sibogae (Weber van Bosse). Gaarder, 1970, p. 126.

Genus ZYGRHABLITHUS Deflandre, 1959

***Zygrhablithus bijugatus* (Deflandre)**

Zygolithus bijugatus Deflandre, *in* Deflandre and Fert, 1954, p. 148, pl. 11, figs. 20, 21.
Zygrhablithus bijugatus (Deflandre). Deflandre, 1959, p. 135.

Mesozoic Species

Genus ARKHANGELSKIELLA Vekshina, 1959

***Arkhangelskiella cymbiformis* Vekshina**

Arkhangelskiella cymbiformis Vekshina, 1959, p. 66, pl. 1, fig. 1; pl. 2, figs. 3a-c.

Genus CRETARHABDUS Bramlette and Martini, 1964

***Cretarhabdus crenulatus* Bramlette and Martini**

Cretarhabdus crenulatus Bramlette and Martini, 1964, p. 300, pl. 2, figs. 21-24.

Genus LUCIANORHABDUS Deflandre, 1959

***Lucianorhabdus cayeuxii* Deflandre**

Lucianorhabdus cayeuxii Deflandre, 1959, p. 142, pl. 4, figs. 11-25.

Genus MICULA Vekshina, 1959

***Micula staurophora* (Gardet)**

Discoaster staurophorus Gardet, 1955, p. 534, pl. 10, fig. 96.
Micula decussata Vekshina, 1959, p. 71, pl. 1, fig. 6; pl. 2, fig. 11.
Micula staurophora (Gardet). Stradner, 1963, p. 8.

Genus PARHABDOLITHUS Deflandre, 1952

***Parhabdolithus embergeri* (Noel)**

Discolithus embergeri Nöel, 1959, p. 164, pl. 1, figs. 5-8.
Parhabdolithus embergeri (Nöel). Stradner, 1963, p. 13, pl. 4, figs. 1, 1b.

Genus PREDISCOSPHAERA Vekshina, 1959

***Prediscosphaera cretacea* (Arkhangelsky)**

Coccolithophora cretacea Arkhangelsky, 1912, p. 410, pl. 6, fig. 12, ?fig. 13.
Prediscosphaera cretacea Gartner, 1968, p. 19, pl. 2, figs. 10-14; pl. 3, fig. 8; pl. 4, figs. 19-24; pl. 6, figs. 14, 15; pl. 9, figs. 1-4; pl. 12, fig. 1; pl. 14, figs. 20-22; pl. 18, fig. 8; pl. 22, figs. 1-3; pl 23, figs. 4-6; pl. 25, figs. 12-14; pl. 26, fig. 2.

Genus TETRALITHUS Gardet, 1955

***Tetralithus aculeus* (Stradner)**

Zygrhablithus aculeus Stradner, 1961, p. 81, figs. 53-57.
Tetralithus sp. aff. *Tetralithus aculeus* (Stradner) Gartner, 1968, p. 43, pl. 9, fig. 5; pl 13, figs. 5a-c.

***Tetralithus obscurus* Deflandre**

Tetralithus obscurus Deflandre, 1959, p. 138, pl. 3, figs. 26-29.

***Tetralithus quadratus* Stradner**

Tetralithus quadratus Stradner, 1961, p. 86, fig. 92.

Genus WATZNAUERIA Reinhardt, 1964

***Watznaueria barnesae* (Black)**

Tremalithus barnesae Black, *in* Black and Barnes, 1959, p. 325, pl. 9, figs. 1, 2.
Watznaueria barnesae (Black) Perch-Nielsen, 1968, p. 69-70, pl. 22, figs. 1-7; pl. 23, figs. 1, 4, 5, 16; text-fig. 32.

SUMMARY OF NANNOPLANKTON STRATIGRAPHY

Tables of nannoplankton occurrences have been prepared for all sites except Site 452, where only four fossiliferous samples were recovered. The state of preservation is designated as: G = good, little or no etching or overgrowth; M = moderate, some etching or overgrowth which has destroyed or obscures delicate structures and ornamentation; P = poor, strong solution or overgrowth which has destroyed many species or made the original species difficult to be recognized. The abundance of specimens in smear slides of unprocessed sediment is noted as: VA = very abundant (flood); A = abundant; C = common; F = few; R = rare; VR = very rare (one or two specimens per slide); and B = barren.

Holes 452 and 452A

A total of 20 samples from Hole 452 and 22 samples from Hole 452A was examined for calcareous nannoplankton. (See the core description charts in the Site Report for the stratigraphic location of these samples.) The following samples were found to contain one moderately preserved nannoplankton specimen each of the species noted:

Sample 452-2,CC: *Cricolithus jonesii*
Sample 452A-1,CC: *Calcidiscus leptoporus*
Sample 452A-2,CC: *Crenalithus doronicoides*
Sample 452A-4,CC: *Gephyrocapsa oceanica*

This site is located in water well below the CCD. However, if these specimens are indigenous, then the pelagic clay at this site must belong to the late Pleistocene WPN-31 Zone based on the occurrence range of *Gephyrocapsa oceanica*.

Hole 453

Table 2 lists all of the samples examined from this hole noting the abundance of nannoplankton species observed. Nannoplankton occur sparsely and are poorly preserved in the Pleistocene, late Pliocene, and latest early Pliocene (Cores 1 through 21). However, most of the nannoplankton zones or subzones can be recognized, although the boundaries between them cannot always be precisely located because of the many barren samples.

The first appearance of *Gephyrocapsa oceanica* and *G. aperta* in Sample 2,CC and the absence of these species in the next fossiliferous specimen (Sample 3-1, 90-91 cm) places Cores 1 and 2 in the WPN-31 Zone. The last occurrence of *Discoaster brouweri* and *D. pentaradiatus* in Sample 13,CC places Cores 3 through 10 (and possibly 12) in the WPN-30 Zone. The high proportion of barren samples and the very poor recovery from productive samples in this interval make the determination of subzones very hazardous. However, the first appearance of *Gephyrocapsa caribbeanica* in Sample 6,CC may indicate that the boundary between the WPN-30b and WPN-30a subzones occurs at, or below, this horizon.

The presence of *Discoaster brouweri* and *D. pentaradiatus* together in Sample 13,CC places that sample in the WPN-29c Subzone. The apparently missing WPN-29d Subzone at the top of the Pliocene may be present in the barren interval represented by Cores 11 and 12.

The last occurrence of *Discoaster surculus* in Sample 14-1, 20-21 cm permits all of Core 14 to be assigned to the WPN-29b Subzone. Cores 15 through 18 can be placed in the WPN-29a Subzone based on the last occurrence of *D. tamalis* in Samples 15-2, 90-91 cm and the

Table 2. Nannoplankton occurrences, Site 453.

SITE 453 AGE		NANNOPLANKTON ZONE OR SUBZONE	CORE SECTION, INTERVAL (cm)	ABUNDANCE AND PRESERVATION	*Amaurolithus amplificus*	*A. delicatus*	*A. primus*	*A. tricorniculatus*	*Calcidiscus leptoporus*	*C. macintyrei*	*Ceratolithus acutus*	*C. armatus*	*C. cristatus*	*C. rugosus*	*Coccolithus pelagicus*	*Coronocyclus serratus*	*Crenalithus doronicoides*	*C. productellus*	*Cyclicargolithus abisectus*	*Dictyococcites bisectus*	*Discoaster asymmetricus*	*D. brouweri*	*D. challengeri*	*D. decorus*	*D. deflandrei*	*D. pentaradiatus*	*D. quadramus*	*D. surculus*	*D. tamalis*	*D. triradiatus*	*D. variabilis*	*Emiliania annula*	*E. ovata*	*Gephyrocapsa aperta*	*G. caribbeanica*	*G. oceanica*	*Helicosphaera carteri*	*H. sellii*	*Reticulofenestra pseudoumbilica*	*Scyphosphaera pulcherrima*	*Sphenolithus abies*	*S. neoabies*
PLEISTOCENE	LATE	WPN-31	1-1, 90-91	B																																						
			1-2, 90-91	B																																						
			1-3, 90-91	B																																						
			1-4, 90-91	B																																						
			1-5, 90-91	B																																						
			1cc	Rm					R				R				R																	R	R	R		R				
			2-4, 90-91	B																																						
			2cc	Fm					F	R			F				F					F		R		F						C		R	C	R		R				
	EARLY	WPN-30b	3-1, 90-91	B																																						
			3-2, 90-91	Cm						R			F		R		C	F				R										F			C		F	F				
			3cc	Rp					R																							R			R							
			4-1, 90-91	B																																						
			4-3, 90-91	B																																						
			4-6, 90-91	B																																						
			4cc	Rp						R							R																									
			5-1, 90-91	B																																						
			5cc	Rp									R																													
			6-1, 90-91	B																																						
			6cc	Rp						R																					R	R			R							
		WPN-30a	7cc	B																																						
			8-1, 90-91	B																																						
			8-3, 90-91	B																																						
			8cc	Rp														R																								
			9-1	Rp									R																													
			10-2, 90-91	B																																						
			10cc	Rm																																				R		
			11-1, 90-91	B																																						
			11-3, 90-91	B																																						
			11-6, 90-91	B																																						
			11cc	B																																						
			12cc	B																																						
PLIOCENE	LATE	WPN-29c	13cc	Rm						R			R				R					C		R		R																
		WPN-29b	14-1, 20-21	Ag					F	R			R	R		R	F				A	A				C		C		R			R									
			14-2, 90-91	Fm																		F				F		F														
			14cc	B																																						
		WPN-29a	15-2, 90-91	Cm					R					R							F	F		C		C		C	C													
			15cc	Rp									R									R																				
			17-1, 53-54	B																																						
			17cc	Rp																	R	F		R		R																
			18-1, 90-91	B																																						
			18-3, 90-91	B																																						
			18-6, 90-91	B																																						
			18cc	B																																						
	EARLY	WPN-28b	19-1, 60-61	Rp						R											F	F																			R	
			19cc	Rp						F				R								F																			R	
			20-1, 101-102	B																																						
			20-2, 101-102	B																																						
			20cc	Rm																																		R			
			21-2, 19-20	B																																						
			21cc	B																																						
			22-2, 90-91	Cp					R				R								R			C		C		F	R		C								F		R	
		WPN-28a	22cc	Cm						R			R									C	F	F		C		C			C						R		R		F	
			23cc	Am						R				R	R						F	A	F	R		A		F		R	C								C		C	C
			24-1, 120-121	Rp																	R										R											
			24cc	Cm					R	R				R								C				C		F			C						R		F		C	F
			25-1, 64-65	Cp					F													F	F	R		F		F			C								C		C	
			25cc	Fm						R												C	R			F					F								F		F	F
			26-3, 95-96	B																																						
			26cc	Rp																		R				R					R											
			27-1, 90-91	Am					F				R	R							F	C	R	C		A		C		R	C						R		C		F	C

Table 2. (Continued).

SITE 453 AGE	NANNOPLANKTON ZONE OR SUBZONE	CORE SECTION, INTERVAL (cm)	ABUNDANCE AND PRESERVATION	*Amaurolithus amplificus*	*A. delicatus*	*A. primus*	*A. tricorniculatus*	*Calcidiscus leptoporus*	*C. macintyrei*	*Ceratolithus acutus*	*C. armatus*	*C. cristatus*	*C. rugosus*	*Coccolithus pelagicus*	*Coronocyclus serratus*	*Crenalithus doronicoides*	*C. productellus*	*Cyclicargolithus abisectus*	*Dictyococcites bisectus*	*Discoaster asymmetricus*	*D. brouweri*	*D. challengeri*	*D. decorus*	*D. deflandrei*	*D. pentaradiatus*	*D. quadramus*	*D. surculus*	*D. tamalis*	*D. triradiatus*	*D. variabilis*	*Emiliania annula*	*E. ovata*	*Gephyrocapsa aperta*	*G. caribbeanica*	*G. oceanica*	*Helicosphaera carteri*	*H. sellii*	*Reticulofenestra pseudoumbilica*	*Scyphosphaera pulcherrima*	*Sphenolithus abies*	*S. neoabies*
PLIOCENE, EARLY	WPN-27c	27-2, 130-131	Am					F				R	R								C		F		A		F			C						R		F			F
		28-1, 50-51	Cp						R			R	R	R							C				A		C			F								F		F	F
		28cc	Cm						F		R										A				A		A			C								F		R	
		29-1, 92-93	B																																						
		29-2, 97-98	B																																						
		29-3, 40-41	Rp																		R						R														
		29-4, 128-129	B																																						
	WPN-27b	29cc	Am		F		F		F	R											A				A	R	A			C						R		C			
		30-1(cc)	Cm		R				F	R											A				C		F			C								F			
		31cc	Am		F	F	R	F	R	F											A				A		C			C						R		F			
		32-2, 50-52	B																																						
		32cc	B																																						
		33-3, 3-5	B																																						
		33cc	Fm						R												C				C		R			F								R			
		34cc	Cm			F	R	F	F	F											C				C		F													R	
		35-2, 53-54	Rp																		R						R			R											
		35cc	Rp																								R														
		36-3, 28-29	B																																						
		36cc	Rp					R													R				R					R								R		R	
		37-4, 41-42	Fp					R													R						R			R								F		R	
		37cc	Cm		R	R			F	R				F							C	F			C					F								A		A	A
		38-1, 59-60	Rp																		R									R										R	R
		38-2, 59-60	Rp					R		R				R							R									F								R		R	R
	WPN-27a	38cc	Cm	R	F	R			F					F							C	R			C					F						R		C		C	C
		39-3, 46-47	Fp											R							R	R					R			C								R			
		39cc	Am	R	F		R		F					F							C	F			C		F			C								C		C	C
		40-2, 58-59	Fp		R		R							R											R		R			C								F			
		40cc	Rp						R												F				F					F								R			
		41-3, 68-69	B																																						
		41cc	B																																						
		42-2, 32-33	Rp																		R																				
		42cc	B																																						
		43cc	Cm	R	R	R		F	F										R		C	R		R	C		F			F						R		F		C	C
		44-2, 101-102	B																																						
		44cc	B																																						
		45-3, 31-32	Rp	R																	R						R			R											
		45cc	B																																						
		46-1, 134-135	B																																						
		46cc	B																																						
		47-2, 70-71	B																																						
		47cc	Rp					R	R									R			R																	R			
		48-1, 19-20	B																																						
		48cc	Rp																					R																	
		58cc	B																																						
		62cc	B																																						

clearly defined. However, the first occurrence of *Discoaster tamalis* in Sample 22-2, 90–91 cm and the last occurrence of the *Sphenolithus neoabies* acme in Sample 23,CC suggest that the boundary between the two subzones be placed between these two samples.

All three subzones of the early Pliocene WPN-27 Zone can be recognized in Cores 28 through 48. The last occurrence of *Sphenolithus abies* in Sample 19-1, 60–61 cm.

Samples from 19-1, 60–61 cm through 27-1, 90–91 cm are placed in the WPN-28 Zone. The base of this zone is best defined by the first occurrence of the *Sphenolithus neoabies* acme. The two subzones of this zone—Subzone WPN-28b and Subzone WPN-28a—cannot be base of the uppermost subzone, the WPN-27c Subzone, occurs in the interval between Sample 28-1, 50–51 cm and 29,CC. The first occurrence of *Ceratolithus rugosus*, an indicator of the base of this subzone, is in Sample 28-1, 50–51 cm. The last occurrence of *C. acutus*, also an indicator of the base of this subzone, is in Sample 29,CC. The occurrence of *C. armatus*, which has its last occurrence within the WPN-27c Subzone, in Sample 28,CC provides further evidence that the lower boundary of this subzone is in this sample interval. The middle subzone, the WPN-27b Subzone, ranges downward through Sample 38-2, 59–60 cm and is defined by the presence of *C. acutus* in these samples. The last occurrence of *Amaurolithus amplificus* in Sample 38,CC lends additional support to this determination. Samples 38,CC through 48,CC are assigned to the lowest subzone, the WPN-27a Subzone. Samples below 43,CC do not contain species restricted in their occurrence to the Pliocene, but they do not contain any species used to define Miocene zones either. However, a few rare Oligocene and late Eocene species are seen in Samples 43,CC and 47,CC.

The Pliocene/Miocene boundary is placed at the base of the WPN-27a Subzone. A study by Ellis and Lohman (1979) of the nannoplankton assemblages recovered from the Zanclean (Pliocene) and Messinian (Miocene) stratotype sections in Sicily shows this position to be the most reasonable for the Pliocene/Miocene boundary. No Messinian-age nannoplankton species were observed in samples from Hole 453.

Holes 454 and 454A

A complete section of the late Pleistocene and much of the early Pleistocene was encountered at Site 454. All of the zones and subzones, except the lowest WPN-30a Subzone, can be recognized (Table 3). Each of the sedimentary units recovered from between basaltic layers (in Cores 8, 10, 12, and 13) contains calcareous nannoplankton assemblages with age-diagnostic species. Except for Core 1 in Hole 454A, which duplicates the interval penetrated by Core 1 in Hole 454, cores in Hole 454A continue below the bottom samples in Hole 454.

In Hole 454 the Holocene WPN—32 Zone can probably be identified in Sample 1,CC by the possible presence of *Emiliania huxleyi*. No sediments were recovered in Core 2. Cores 3 through 5 contain *Gephyrocapsa oceanica* together with *E. ovata* and *E. annula*, which place this interval in the late Pleistocene WPN—31a Subzone.

Section 1 of Core 1 in Hole 454A contains nannoplankton indicative of the late Pleistocene WPN-31b Subzone. This subzone was not observed in samples from Hole 454, presumably because of the lack of recovery in Core 2 from that hole.

The late Pleistocene WPN-31a Subzone can be recognized in Samples 454A-1-2, 90–91 cm through 454A-3,CC as defined by the presence of *G. oceanica*, *Ceratolithus telesmus*, and *E. ovata*.

The early Pleistocene WPN-30b Subzone can be recognized in Samples 454A-4-2, 82–83 cm through 454A-13-1, 132–133 cm as determined by the presence of *G. caribbeanica* and *Discolithina japonica* together with the absence of *G. oceanica* and *Ceratolithus telesmus*. Samples from 454A-8,CC through 454A-13-1, 132–133 cm represent fossiliferous sedimentary occurrences between basaltic layers.

Rare occurrences of reworked *Discoaster brouweri* and *Cyclicargolithus abisectus* are seen in a few samples from both holes.

According to the geochronologic time scale for nannoplankton zones (Figure 2), the lowest fossiliferous sediments penetrated at Site 454 can be no younger than 0.9 m.y. and no older than 1.6 m.y.

Hole 455

Table 4 shows that all of the samples examined from Hole 455 contain nannoplankton; however, Samples 3,CC, 5,CC, 6,CC, and 7,CC are coarse-grained sands. Analytical residues of these coarse-grained samples were prepared by washing a portion of the sand in water and examining the resulting wash water. The nannoplankton seen in these preparations may be indigenous or may have originated from softer sediments reworked into the sands or even from the drill-string water column. The samples from Cores 1, 2, 9, 10, and 11 are from muds and presumed to be in place. The presence of *Emiliania huxleyi* identifies the late Pleistocene WPN-32 Zone in Samples 1-1, 90–91 cm and 1-3, 90–91 cm. The late Pleistocene WPN-31b Subzone can be recognized in Samples 1-5, 90–91 cm to 2-4, 94–95 cm. The WPN-31a Subzone is recognized in Samples 2-6, 90–91 cm through 9,CC as defined by the joint occurrence of *G. oceanica* and *E. ovata*. The early Pleistocene WPN-30b Subzone is recognized in Sample 10-2, 136–137 cm by the presence of *G. caribbeanica* together with *Discolithina japonica*. The early Pleistocene WPN-30a Subzone is recognized in Sample 11,CC on the basis of the absence of *G. caribbeanica* and the presence of *Calcidiscus macintyrei*.

Holes 456 and 456A

All of the Pleistocene subzones, except the late Pleistocene WPN-31b Subzone, can be recognized at Site 456 (Table 5). The same sequence of zones and subzones can be recognized in samples from both holes, except for the WPN-30b Subzone which cannot be recognized in Hole 456. This subzone is present in Hole 456A in Sections 1 through 3 of Core 5. These sections are depth-equivalent to Core 8 of Hole 456, an interval that did not have sample recovery.

The presence of *Emiliania huxleyi* in the upper samples of both holes defines the WPN-32 Zone. *Gephyrocapsa oceanica* and *G. aperta* occurring with *Emiliania ovata* define the WPN-31a Subzone in both holes. The presence of *Gephyrocapsa caribbeanica* and the absence of *G. oceanica* and *G. aperta* identify the WPN-30b Subzone in Hole 456A. The presence of *Calcidiscus macintyrei* and the absence of *G. caribbeanica* define the WPN-30a Subzone in both holes.

Hole 457

The nature of the samples recovered from this hole leaves considerable doubt as to the reliability of any age determination that can be made. Six cores were taken before the hole was abandoned because of caving sand. All of the samples consist of coarse unconsolidated sand; however, the fine fraction washed from these sands provided residues containing nannoplankton (Table 6).

The assemblages seen in Samples 2-3, 50–51 cm through 4-1, 30–31 cm and 5-1, 47–48 cm through 5,CC belong to the late Pleistocene WPN-31b Subzone. Samples 4,CC and 6,CC can be assigned to the WPN-31a

Table 3. Nannoplankton occurrences, Site 454.

AGE		NANNOPLANKTON ZONE OR SUBZONE	HOLE, CORE, SECTION, INTERVAL (cm)	ABUNDANCE AND PRESERVATION	*Aspidorhabdus stylifer*	*Calcidiscus leptoporus*	*C. macintyrei*	*Ceratolithus cristatus*	*C. telesmus*	*Coronocyclus serratus*	*Crenalithus doronicoides*	*C. productellus*	*Cricolithus jonesii*	*Cyclicargolithus abisectus*	*Discoaster brouweri*	*Discolithina japonica*	*D. multipora*	*Emiliania annula*	*E. huxleyi*	*E. ovata*	*Gephyrocapsa aperta*	*G. caribbeanica*	*G. oceanica*	*G. omega*	*Helicosphaera carteri*	*H. hyalina*	*H. sellii*	*Rhabdosphaera clavigera*	*Scyphosphaera apsteinii*	*Thoracosphaera saxea*	*Umbilicosphaera cricota*	*U. sibogae*
SITE 454																																
PLEISTOCENE	LATE	WPN-32?	HOLE 454																													
PLEISTOCENE	LATE	WPN-32?	1cc	Cg		F		A	C		F								F?			R	R			R						
PLEISTOCENE	LATE	--?---?---																														
PLEISTOCENE	LATE	WPN-31a	3-1, 90-91	Cm		F		F	R		C									C	F	F	A		F							
PLEISTOCENE	LATE	WPN-31a	3-2, 90-91	Ag		F		R			A	F	R							C		A	A		F		F			R		
PLEISTOCENE	LATE	WPN-31a	3cc	Cm		F		C	F		R									R		A	C		R	R	R					
PLEISTOCENE	LATE	WPN-31a	4-2, 90-91	Ag		F		R	R		C	F	R	R				F		A	F	A	A		F		R			F	R	
PLEISTOCENE	LATE	WPN-31a	4-4, 90-91	Fm		R		R		R	F	R	R					F		F		F	F									R
PLEISTOCENE	LATE	WPN-31a	4cc	Am		A	R	C	F		A			R				F		C		A			R		F					
PLEISTOCENE	LATE	WPN-31a	5-2, 90-91	Cg		F		F			C	R						F		C		C	F	R	R					R	R	R
PLEISTOCENE	LATE	WPN-31a	5-4, 90-91	Cm		C	R	R			C	R						F		C		C	F	R	F					R	R	
PLEISTOCENE	LATE	WPN-31a	5cc	Am	R	C		C	R		C						R	C				C	C		F		C		R			
PLEISTOCENE	LATE	WPN-31b	HOLE 454A																													
PLEISTOCENE	LATE	WPN-31b	1-1, 90-91	Am		F		F	R			C										A	A		C		R	F				
PLEISTOCENE	LATE	WPN-31a	1-2, 90-91	Fg		F		R			F	R								R	R	C	F		R		R					
PLEISTOCENE	LATE	WPN-31a	1-3, 89-90	Am		F		F	R		F		R							R	F	A	A	R	F		R	F				
PLEISTOCENE	LATE	WPN-31a	1-4, 90-91	Am		C		F			C									F	F	A	A		F		C	F				
PLEISTOCENE	LATE	WPN-31a	1cc	Am		A		C	R		A									F		A			F		C					
PLEISTOCENE	LATE	WPN-31a	2-3, 105-106	Fm		F		R			F	R						R		C			F		R		R			R		R
PLEISTOCENE	LATE	WPN-31a	2cc	B																												
PLEISTOCENE	LATE	WPN-31a	3-3, 62-63	Cm		C		F	R						R		R	F		C		F	C		R				R			
PLEISTOCENE	LATE	WPN-31a	3cc	Cm	R	C		C	R		C						R	C		F		A	C		C				R			
PLEISTOCENE	EARLY		4-2, 82-83	Am		F		F			C					R		C		A		C			F			R				
PLEISTOCENE	EARLY		4cc	Cm	F	F		F			C					R		F		C		C			F		F					
PLEISTOCENE	EARLY	*Drilling artifact*	6-1, 12-13	Cm		F		F			C				R	R?		F		C	F	C	C		F		R					
PLEISTOCENE	EARLY	WPN-30a	6cc	B																												
PLEISTOCENE	EARLY	WPN-30a	8cc	Rp		R					R							R		R		R										
PLEISTOCENE	EARLY	WPN-30a	10-1, 10-11	Rp		R								R						F		F			R							
PLEISTOCENE	EARLY	WPN-30a	12-2(cc)	Fp		F		F			F	R				R				C		C			F							
PLEISTOCENE	EARLY	WPN-30a	13-1, 40-44	Fm		R		R			F	F						R		R		F			R							
PLEISTOCENE	EARLY	WPN-30a	13-1, 88-89	Rm				R			R							R		R		R										
PLEISTOCENE	EARLY	WPN-30a	13-1, 132-133	Rp		R														R		R			R							

Subzone on the basis of the presence of *Emiliania ovata*. If the recovered assemblages are indigenous to the samples, then the alternation of zonal occurrence reflects a repetition of sampled intervals due to caving.

Hole 458

In addition to examining a complete suite of samples from the sedimentary sequence overlying the igneous basement, fine-grained rock material intermixed with basalts was examined from Cores 28 through 31, 35, 40, and 48. The nannoplankton assemblages observed throughout the sedimentary interval in Hole 458 show good species diversity and are listed in Tables 7A and 7B.

All of the Pleistocene zones and subzones, except the WPN-30a Subzone, and all of the late Pliocene subzones except the WPN-29b Subzone, can be recognized in samples from Cores 1 through 4.

The presence of *Discoaster loeblichii* and *D. neohamatus* in samples from Core 5 and Section 1 of Core 6 places this interval in the late Miocene WPN-25b Subzone. The absence of all the early Pliocene zones and the late Miocene WPN-26 Zone forms the basis for recog-

Table 4. Nannoplankton occurrences, Site 455.

Age		Nannoplankton Zone or Subzone	Core, Section, Interval (cm)	Abundance and Preservation	*Aspidorhabdus stylifer*	*Calcidiscus leptoporus*	*C. macintyrei*	*Ceratolithus cristatus*	*C. telesmus*	*Coccolithus pelagicus*	*Coronocyclus serratus*	*Crenalithus doronicoides*	*C. productellus*	*Cricolithus jonesii*	*Discolithina japonica*	*D. multipora*	*Emiliania annula*	*E. huxleyi*	*E. ovata*	*Gephyrocapsa caribbeanica*	*G. oceanica*	*Helicosphaera carteri*	*H. sellii*	*Oolithotus fragilis*	*Rhabdosphaera clavigera*	*Scyphosphaera apsteinii*	*S. globulata*	*Thoracosphaera heimii*	*T. saxea*	*Umbilicosphaera cricota*	*U. sibogae*
PLEISTOCENE	LATE	WPN-32	1-1, 90-91	Ag		C		F	R		R	A	R					F		C	C	C	F	R				R			F
			1-3, 90-91	Ag		F		F	R			C						F		A	A	C	F	R	C			R	R	R	F
		WPN-31b	1-5, 90-91	Rg		R		F				F									R	R	R								
			1cc	Ag		C		C	F			C	C			R				A	C	F	C		C						
			2-2, 90-91	Cg		F		R				C								F	F	R	F								R
			2-4, 94-95	Ag	F	F			R			A	F							A	A	R	F					R	R		R
		WPN-31a	2-6, 90-91	Cg		R		R				F	R						F	F	C										
			2cc	Am		F		F				C	C						C	A	A										
			3-1, 85-86	Ag		F		R				C	R						F	A	A	R	R								R
			3-2, 90-91	Am	R			R				F	R						C	A	A										R
			3cc	Cp		R		R				C								C		R									
			5cc	Am		F		F		R		C				R	F		F	C		R	F								
			6cc	Am	R	F		F	R	R		C		R		F	F		C	C	C	F	R		F						
			7cc	Rm		R						F					R		R	F	R	R	R								
			8cc	Cm		C						F							F	C		R									
			9cc	Cm		F		R				C	F				C		C	C	F	F									
	EARLY	WPN-30b	10-2, 136-137	Am	C	A						C	F		R	R	F		A	F					F	R					
		WPN-30a	11cc	Cm	F	A	R	F				C			R		R		C			F				R	R				

nizing an hiatus of 4.0 m.y. (3.0 m.y. B.P. to 7.0 m.y. B. P.) between Samples 4,CC and 5-1, 55–56 cm. The occurrence of *Catinaster calyculus, C. coalitus*, and *Discoaster bollii* together with *D. pentaradiatus* places the remainder of Core 6 in the WPN-25a Subzone.

Cores 7 through 11 are of middle Miocene age with all of the nannoplankton zones and subzones present, except the WPN-24a Subzone and the WPN-23 Zone. This hiatus of 1.2 m.y. (12.0 m.y. B.P. to 13.2 m.y. B.P.) is recognized between Samples 7-4, 90–91 cm and 7,CC.

Samples 12,CC through 14,CC are assigned to the early Miocene WPN-20 Zone. Although the name species is not present, the top of the zone is defined by the top of the *Discoaster deflandrei* acme together with the first occurrence of *D. exilis* and *D. variabilis*. The absence of *Helicosphaera ampliaperta* from this zone was reported by Ellis (1975) at Site 292 (Leg 31) in the western Philippine Sea. Although the WPN-20 Zone was not recognized at that time, re-evaluation of the data now permits identification of the zone at Site 292. It has been suggested that *H. ampliaperta* is a colder water species, thus accounting for its absence at Sites 292 and 458. In support of this theory, the presence of this species was noted by Ellis (1975) at Site 296 at the extreme northern end of the Philippine Sea.

Samples 15,CC is assigned to the WPN-19 Zone. The species *Sphenolithus belemnos* and *Triquetrorhabdulus milowii* have their last occurrence above the first occurrence of *S. heteromorphus* in normal low-latitude, deep-sea sediment sequences. The absence of this occurrence overlap in Hole 458 suggests a period of nondeposition or sediment removal between Samples 14,CC and 15,CC.

The WPN-18c Subzone is determined for Samples 16-1, 42–43 cm through 19-1, 67–68 cm by the occurrence of *Discoaster druggii* and the absence of *Sphenolithus belemnos*. The other two subzones of the WPN-18 Zone cannot be identified with any confidence; however, the last occurrence of an abundance acme of *Cyclicargolithus abisectus*, which defines the top of the WPN-18a Subzone, is seen in Sample 17,CC. Interpretation of the significance of this unexpected overlap of defining criteria, together with the apparent absence of the intervening WPN-18b Subzone, is complicated by the reduced number of samples (there was no recovery in Core 18) through the interval. As a result of this conflicting evidence, the Miocene/Oligocene boundary (23 m.y. B.P.), which is drawn at the top of the WPN-18a Subzone, is placed between Samples 16,CC and 19,CC. Samples 22,CC and 23,CC, which contain *Dictyococcites bisectus* and *Sphenolithus ciperoensis*, are clearly in the late Oligocene WPN-17 Zone.

The lower subzone of the WPN-17 Zone, the WPN-17a Subzone, is defined as that interval where *S. ciperoensis* and *S. distentus* occur together. Since these two

Table 5. Nannoplankton occurrences, Site 456.

SITE 456

Age	Nanno-plankton zone or subzone	Hole, core, section, interval (cm)	Abundance and preservation	Aspidorhabdus stylifer	Calcidiscus leptoporus	C. macintyrei	Ceratolithus cristatus	C. telesmus	Coccolithus neogammation	C. pelagicus	Coronocyclus serratus	Crenalithus doronicoides	C. productellus	Cricolithus jonesii	Cyclicargolithus floridanus	Dictyococcites bisectus	Discoaster brouweri	D. surculus	Discolithina japonica	D. multipora	Emiliania annula	E. huxleyi	E. ovata	Gephyrocapsa aperta	G. caribbeanica	G. oceanica	G. omega	Hayaster perplexus	Helicosphaera carteri	H. sellii	Oolithotus fragilis	Reticulofenestra pseudoumbilica	Rhabdosphaera clavigera	Scyphosphaera apsteinii	S. pulcherrima	Syracosphaera pulchra	Thoracosphaera heimii	T. saxea	Umbellosphaera irregularis	Umbilicosphaera cricota	U. sibogae
		HOLE 456																																							
Pleistocene, late	WPN-32	1cc	Rm		R		R															F			F	F			F	R							R		R		R
		2-1, 65-66	Ag	F	C		C	R												R		F			A	C			C	C			C				C	C			
		2-2, 65-66	Ag	R	C		F	R			R		F									F			A	C			C	F			R				F				R
		2-3, 65-66	Am	F	F		F	R		R	R									R		F			C	F			F	F			C				F	F			
	WPN-31a	2-4, 65-66	Fm		F		R					F											R		F	F			F	R			F				F	R		R	
		2cc	Cm	R	F		F					F	F							R			R	R	C	C			F									R	R		R
		3cc	Cm	R	F		R	R				F	R										F		C	A			R	R			R				R				R
		4-2, 50-51	Am		F		R					A	R											R	C	C			R								R				
		4cc	Cm		R		R					C	F										C	R	A	A			R												
		6-2, 90-91	Am	R	F		F			R		A	F						F		C		F			R			C	F			R				R				R
		6cc	Am	C	F		F					C		R									A		F	R			F	R			C	R							F
		7-2, 90-91	Rm	R	R		R					F		R							F		R		R	F			R									R			
		7cc	Rm		R							F	R								R		R	R	C	C			R												R
Pleistocene, early	WPN-30a	8cc	Cp		F	R	R			R		C		R							C		C						F			F		R							
		9-1, 89-90	Rp		R		R					R									R		R						R												
		9cc	Fp		F	R						F									F		C						F												
		10-2, 89-90	Fp			F						R									F		R															R			
		10-3, 27-28	Am	R	F	F						C		R					R		A		A						C		R					R		F			R
		10cc	Rp		R							F									F		F						R		R										
		11cc	Rp																										R												
		12-2, 33-34	B																																						
		12cc	Rp		R	R															R		R						R												
		13cc	Rp		R							R	R								R								R												
		14-1, 80-81	B																																						
		14-1, 92-94	Rp		R				R						R	R																									
		14cc	B																																						
		15cc	Rp		R	VR																																			
		16-1, 0.1-0.2	Rp			R																																			
		17-1, 50	B																																						
		HOLE 456A																																							
Pleistocene, late	WPN-32	1-1, 90-91	Ag		R		R	R				C		R			VR			R		F	C		C	C			C	R			C					F			
	WPN-31a	1-3, 90-91	Ag	F	C		F	R				C		R									R		A	A	R		C	R			R				R	R			R
		1-5, 90-91	Ag		F		F	R		R													R		A	A			C	F							F	F			F
		1cc	Fm		F		R					R		R							R		R		R	F												R			R
		2cc	B																																						
		3-1, 90-91	B																																						
		3-2, 90-91	B																																						
		3cc	Rm																				VR																		
		4cc	Cm		F		R					F	F								C		C	R	C	C		R	C	R			R					R			
Pleistocene, early	WPN-30b	5-1, 86-87	Fp		R							R									F		F		F				R		R										R
		5-2, 80-81	Rp									R									R																				
		5-3, 34-35	Cm		F					R		F								R	C		C		R				F									R			
	WPN-30a	5cc	Cm	R	C	R	R					F		R							A		A					R	F	R					R						
		6-2, 42-43	Rp																		R																				
		6cc	Fp		F	R						F									F		R						R												
		7-2, 42-43	B																																						
		7cc	Rp		R	R						R											R						R												
		8-2, 62-64	Fp		F	R				R			R				VR						F					R	R	R											
		8cc	Rp		F	F	R					F	R							R	R		R																		
		9-1, 16-17	B																																						
		9-2, 23-24	Rp		VR																																				
		9cc	B																																						
		10-1, 68-69	Rp		R	F				R																			R												
		10-2, 60-61	Rp		R	R				R																															
		10-3, 44-45	Rp		R																																				
		10-4, 31-32	B																																						
		10cc	Rp			VR																																			

Table 6. Nannoplankton occurrences, Site 457.

SITE 457 AGE		NANNOPLANKTON ZONE OR SUBZONE	CORE, SECTION, INTERVAL (cm)	ABUNDANCE AND PRESERVATION	*Aspidorhabdus stylifer*	*Calcidiscus leptoporus*	*Ceratolithus cristatus*	*C. telesmus*	*Crenalithus doronicoides*	*C. productellus*	*Cricolithus jonesii*	*Discolithina multipora*	*D. sp.*	*Emiliania ovata*	*Gephyrocapsa aperta*	*G. caribbeanica*	*G. oceanica*	*Hayaster perplexus*	*Helicosphaera carteri*	*H. sellii*	*Rhabdosphaera clavigera*	*Thoracosphaera heimi*	*T. saxea*	*Umbellosphaera irregularis*	*Umbilicosphaera sibogae*
PLEISTOCENE	LATE	WPN-31b	2-3, 50-51	Fg	R	R			F	R	R		R			R	R		F	R		F			
			2cc	Fm		F	R	F				R				R	R		F	R					
			4-1, 30-31	Cg	F	F	R		C		R		R			C	C		F	F	R	F	F		R
		WPN-31a	4cc	Fm		F		R	F	F				F		R	R			R				F	
		WPN-31b	5-1, 47-48	Cg	F	F	R		C		R					C	F	R	F	R			F		R
			5cc	Fm		R		R							R	F	F		R	R				R	R
		WPN-31a	6cc	Fm		F				F	R			F		C	C		R						

species have this occurrence relationship in the western and northern Philippine Sea at Sites 292 and 296 (Ellis, 1975), the absence of the WPN-17a Subzone in these samples may indicate an hiatus of about 1.5 m.y. in Hole 458 between Samples 23,CC and 24-1, 45–46 cm.

The late Oligocene WPN-16 Zone is recognized in samples of Core 24. Cores 25, 26, and 27 contain an assemblage that is referred to the WPN-15 Zone, since it occurs beneath the first appearance of *S. distentus* and above the WPN-14 Zone assemblage.

The few occurrences of the early Oligocene or late Eocene species *Reticulofenestra hillae, R. umbilica*, and *Coccolithus formosus*, are considered to be due to reworking because of their sporadic occurrence and because they appear in the reverse order from what they should. A single reworked specimen of the early or middle Eocene species *Discoaster sublodoensis* is present in Sample 27-1, 50–51 cm.

Several bits of fine-grained rock material occurring in conjunction with the basalts were examined from Cores 28 through 48 in an attempt to date the various pillow lavas. Two sparse occurrences [Samples 29-1 (No. 1) and 40-1] are interpreted as contamination from uphole.

Holes 459 and 459B

Nannoplankton assemblages observed throughout the sedimentary interval at Site 459 range from good to poor in preservation and display wide species diversity. They also contain sufficient age-diagnostic forms to indicate that the biostratigraphic sequence is discontinuous. Nannoplankton occurrences at this site are listed in Tables 8A and 8B.

Only one core was recovered from Hole 459. Sections 1 and 2 can be assigned to the Holocene-late Pleistocene WPN-32 Zone on the basis of the presence of *Emiliania huxleyi*.

Cores 1 through 5 of Hole 459B contain abundant nannoplankton that place these intervals in the early and late Pleistocene WPN-31b, WPN-31a, and WPN-30b Subzones. Samples from Cores 6 and 7 are barren, except for Sample 6,CC which contains three rarely occurring species of *Discoaster—D. brouweri, D. triradiatus*, and *D. variabilis*. If these are indigenous, then the sample can be assigned an age no younger than the late Pliocene WPN-29a Subzone. The intervening subzones are either missing or represented by the barren interval.

Samples from Cores 8 to 19 are assigned to the late middle Miocene WPN-24 Zone because of the presence of the nominate species, *D. hamatus*. The presence of *D.* sp. cf. *D. quinqueramus* in Samples 8-1, 90–91 cm; 9,CC; 11-2, 18–19 cm; 11,CC; and 12,CC suggests that these samples might possibly belong in the early late Miocene. (This species is discussed by Bukry, 1973b; Howe and Ellis, 1977; Ellis and Lohman, 1979). However, the total absence of other late Miocene key species indicates that these samples more probably belong in the middle Miocene. If that is the case, a considerable section is missing. Nannoplankton zones from early Pliocene (3.0 m.y. B.P.) to the top of the middle Miocene (11.0 m.y. B.P.) are absent. However, late Miocene radiolarians are noted in Sample 7,CC. Consequently, an hiatus representing about 7.0 m.y. (3.0–10.0 m.y. B.P.) exists between Samples 6,CC and 7,CC.

The two subzones of the WPN-24 Zone—Subzone WPN-24b and Subzone WPN-24a—can also be identified. The boundary between them occurs between Samples 15-1, 52–53 cm, and 17,CC. A series of barren samples in Core 15 and no recovery from Core 16 prevent defining the boundary more precisely.

The WPN-23 Zone is determined for Samples 19-1, CC top and bottom by the occurrence of *C. coalitus* minus the WPN-24 Zone assemblage. Samples from

Table 7a. Nannoplankton occurrences, Site 458.

SITE 458

AGE	NANNOPLANKTON ZONE OR SUBZONE	CORE, SECTION, INTERVAL (cm)	ABUNDANCE AND PRESERVATION	*Aspidorhabdus stylifer*	*Calcidiscus leptoporus*	*C. macintyrei*	*Catinaster calyculus*	*C. coalitus*	*Ceratolithus cristatus*	*C. telesmus*	*Coccolithus pelagicus*	*Coronocyclus nitescens*	*C. serratus*	*Crenalithus doronicoides*	*C. productellus*	*Cricolithus jonesii*	*Cyclicargolithus floridanus*	*Discoaster asymmetricus*	*D. bellus*	*D. blackstockae*	*D. bollii*	*D. braarudii*
PLEISTOCENE LATE	WPN-32	1-1, 90-91	Ag		C				F	R			F	C	R	R						
		1-2, 80-81	Ag	R	F				F	R	R			F	R	R						
	WPN-31b	1-3, 90-91	Am	F					R		R		R	C	F							
		1-4, 90-91	Am	R	R				R	R				C								
		1-5, 90-91	Am	R	R				R					C		R						
	WPN-31a	1cc	Ag	F	R				F	R	R			C	F	R						
		2-1, 90-91	Cm		F				R		R			C	F							
		2-2, 90-91	Cm	F	F				R						F							
		2-3, 90-91	Cm		C				R				F	C								
		2-4, 46-47	Fp		F				R				F	R	R							
		2-4, 92-93	Fp		F						R			F	R							
		2-5, 90-91	Fp		F				R		R		F	R								
		2-6, 90-91	Fp		F				R				F	F	R							
PLEISTOCENE E	WPN-30b	2cc	Rm		R									R								
PLIOCENE LATE	WPN-29d	3-1, 110-111	Fm			VR																
	WPN-29c	3-2, 90-91	Am		C	C			C		R											
		3cc	Am		F	F			R		R			C	F							
	WPN-29a	4-1, 90-91	Ag		F	F			R		R			F						R		
		4cc	Am																			
MIOCENE LATE	WPN-25b	5-1, 55-56	Ag		R	F					R			R				A				
		5-2, 55-56	Am		F	C					R							A	R	R		
		5-3, 55-56	Am		F	R					F							C	F	R		
		5-4, 55-56	Am		F	F					F							F	VR?			C
		5cc	Am		R	F					R			R						R		
		6-1, 115-116	Cm															F	F	R		
	WPN-25a	6-3, 83-84	Am			R	A	F											F	R	F	C
		6cc	Ap																			
MIOCENE MIDDLE	WPN-24b	7-2, 90-91	Ag				A	C			F								R		F	F
		7-4, 90-91	Ag			F	C	A			C											
	WPN-22b	7cc	Ap		R	R					F											C
	WPN-22a	8cc	Ap			R					C						R					F
		9-1, 90-91	Ap		R	R					C						R					F
		9-2, 90-91	Ap		R	R											R					R
		9cc	Ap		R						R	R										R

CORE, SECTION, INTERVAL (cm)	*D. brouweri*	*D. calcaris*	*D. challengeri*	*D. decorus*	*D. deflandrei*	*D. exilis*	*D. hamatus*	*D. intercalaris*	*D. loeblichii*	*D. moorei*	*D. neohamatus*	*D. pentaradiatus*	*D. pentaradiatus (3 rayed)*	*D. quadramus*	*D. sp. cf. D. quinqueramus*	*D. signus*	*D. surculus*	*D. tamalis*	*D. triradiatus*	*D. variabilis*	*D. sp.*
1-1, 90-91																					
1-2, 80-81																					
1-3, 90-91																					
1-4, 90-91																					
1-5, 90-91																					
1cc	R																				
2-1, 90-91					R																
2-2, 90-91																					
2-3, 90-91																					
2-4, 46-47	R																				
2-4, 92-93																					
2-5, 90-91												R									F
2-6, 90-91																					
2cc																					
3-1, 110-111	C																		F		
3-2, 90-91	A											F							A		
3cc	A											A									
4-1, 90-91	A			C								A					A	R	R		
4cc	A			C								A					R	R	R		
5-1, 55-56	A		R						F		C	C			F			R?	R	C	
5-2, 55-56	A								R		C	C			F			R?	F	F	
5-3, 55-56	A		R						R		F	A	C		F			R?	F	C	
5-4, 55-56	A		R						R		C	A			F			R?	F	F	
5cc	A		F		R				F		F	A	A	R	F				C	A	
6-1, 115-116	A		R						R		C	A	R	R	R				B	C	
6-3, 83-84	A	F									R	C								A	
6cc	C											C	R							C	
7-2, 90-91		F					C													A	
7-4, 90-91		C									F									A	
7cc						C		R												A	
8cc					C	C														A	
9-1, 90-91					A	C				F										A	
9-2, 90-91					A	C				R						R				A	
9cc					A	F										F				A	

CORE, SECTION, INTERVAL (cm)	*Discolithina multipora*	*Emiliania annula*	*E. huxleyi*	*E. ovata*	*Gephyrocapsa caribbeanica*	*G. oceanica*	*Helicosphaera carteri*	*H. sellii*	*Reticulofenestra pseudoumbilica*	*Sphenolithus abies*	*S. neoabies*	*S. predistentus*	*Thoracosphaera heimii*	*T. saxea*	*Triquetrorhabdulus rugosus*	*Umbilicosphaera cricota*	*U. sibogae*
1-1, 90-91			F		A	A	R	R					R	R		F	F
1-2, 80-81			F		A	A	C	F					R	F		F	R
1-3, 90-91					A	C	F	R						F			
1-4, 90-91					A	C	R	R						F			
1-5, 90-91					A	C	F	F						F			
1cc	R	F		F	A	A	F	R						R			R
2-1, 90-91		F		F		R	R	F									R
2-2, 90-91		C		F			F	R						R			
2-3, 90-91				A	R	R	F							R			
2-4, 46-47		F			F	R	R							R			
2-4, 92-93		R		F	F	R	R	R				R					
2-5, 90-91				R		R											
2-6, 90-91		R		R	R	R											
2cc		R		R	R												
3-1, 110-111																	
3-2, 90-91																	
3cc		R		C				R						R			
4-1, 90-91																	
4cc																	
5-1, 55-56								R		F					F		
5-2, 55-56										R	R				F		
5-3, 55-56									R						F		
5-4, 55-56							R		F	C	C				F		
5cc									F								
6-1, 115-116																	
6-3, 83-84															F		
6cc																	
7-2, 90-91																	
7-4, 90-91									F						F		
7cc									F								
8cc									F						F		
9-1, 90-91									C	R					C		
9-2, 90-91									C	R					F		
9cc									C	R							

Table 7b. Nannoplankton occurrences, Site 458.

SITE 458 AGE		NANNOPLANKTON ZONE OR SUBZONE	CORE, SECTION, INTERVAL (cm)	ABUNDANCE AND PRESERVATION	*Bramletteius serraculoides*	*Coccolithus formosus*	*Calcidiscus leptoporus*	*C. macintyrei*	*Coccolithus eopelagicus*	*C. miopelagicus*	*C. pelagicus*	*Coronocyclus nitescens*	*Cyclicargolithus abisectus*	*C. floridanus*	*Dictyococcites bisectus*	*Discoaster bollii*	*D. deflandrei*	*D. divaricatus*	*D. druggii*	*D. exilis*	*D. loeblichii*	*D. moorei*	*D. neorectus*	*D. nodifer*	*D. signus*	*D. sublodoensis*	*D. surculus*	*D. tanii*	*D. variabilis*	*D. sp. cf. D. variabilis*	*Hayaster perplexus*	*Helicosphaera carteri*	*H. recta*	*Reticulofenestra hillae*	*R. pseudoumbilica*	*R. umbilica*	*Sphenolithus abies*	*S. belemnos*	*S. ciperoensis*	*S. distentus*	*S. heteromorphus*	*S. moriformis*	*S. predistentus*	*Triquetrorhabdulus carinatus*	*T. milowii*	*T. rugosus*
MIOCENE	MID.	WPN-21	10cc	Ap			R	R			R	R		C		R	A	R		C	R	R	R		C		VR		A		VR	R			C		F				R	R				R
			11-1, 90-91	Am				R						A			F								F				A			R			C		F				C	R				
			11-2, 90-91	Am				R						A			F					R							A								R				C	R				
			11cc	Am						R		R		A			C	R		F		F			F				A												C	C				
	EARLY	WPN-20	12cc	Ap				R		R	R			A			VA	F	R?			R			F																C	F				
			13cc	Ap										A			A	R				F																			C	R				
			14cc	Ap									R	A			A					R							R?						R						C	F				
		~?~?~ WPN-19	15cc	Am				R	R			C	R	A			C	F	C											F					R			C				F		F	R	
		WPN-18c	16-1, 42-43	Rp										VR																																
			16-2, 23-24	Rp																										VR																
			16cc	Cp										C			F		R																		R					F				
			17cc	Ap							F		C	C			A		F					R						R												F		R		
OLIGOCENE	LATE	WPN-18a	19-1, 67-68	Am					R			F	C	A					R											F												R		F		
			19cc	Ap						F	R	R	C	A	R?		A																									F		R		
			21cc	Ap						F		F	C	A	R?		C																									C		C		
		WPN-17b	22cc	Ap					F			F	C	A	C		C																						C			C		C		
			23cc	Ap					R		R			C	F		C							R															A							
		WPN-16	24-1, 45-46	Ap									F	A	F		F											R												R		F	A			
			24cc	Ap		R			F		F		R	A	F													R												F		C	A			
	EARLY	WPN-15	25-1, 90-91	Ap	C				F		R			A	F													R														F	C			
			25cc	Ap	C	R			F		R			A	F		C							R									R			R						F	C			
			26-1, 1-2	Ap	C				R		F			A	C		F											R														R	C			
			26cc	Ap	C				F		F			A	C		C											R						F		R							C			
			27-1, 10-11	Rp													R																													
			27-1, 24-25	Rp							VR																																			
			27-1, 50-51	Fp	F	R?			R					C	F		F									R?																R	R			
			27-2, 47-48	Rp										R																																
?	?	*BASALT*	28-1, #14	B																																										
			28-1, #17	B																																										
			29-1, #1	Rp										R	R																											R				
			30-2, #15	B																																										
			31-1, #2	B																																										
			35cc	B																																										
			40-1	Rp													VR																													
			48cc	B																																										

Table 8a. Nannoplankton occurrences, Site 459.

AGE	NANNO-PLANKTON ZONE OR SUBZONE	CORE, SECTION, INTERVAL (cm)	ABUNDANCE AND PRESERVATION	Aspidorhabdus stylifer	Calcidiscus leptoporus	C. macintyrei	Catinaster calyculus	C. coalitus	Ceratolithus cristatus	C. telesmus	Coccolithus miopelagicus	C. pelagicus	Coronocyclus nitescens	Crenalithus doronicoides	C. productellus	Cricolithus jonesii	Cyclicargolithus abisectus	C. floridanus	Discoaster bollii	D. braarudii	D. brouweri	D. calcaris	D. deflandrei	D. divaricatus	D. druggii	D. exilis	D. hamatus	D. intercalaris	D. kugleri	D. moorei	D. pseudovariabilis	D. sp. cf. D. quinqueramus	D. signus	D. triradiatus	D. variabilis	D. sp. cf. D. variabilis	Discolithina japonica	D. multipora	Emiliania annula	E. ovata	Gephyrocapsa aperta	G. caribbeanica	G. oceanica	G. omega	Helicosphaera carteri	H. granulata	H. intermedia	H. sellii	Oolithotus fragilis	Reticulofenestra pseudoumbilica	Scyphosphaera globulata	S. pulcherrima	Sphenolithus abies	S. belemnos	S. heteromorphus	S. moriformis	S. neoabies	Thoracosphaera heimii	T. saxea	Triquetrorhabdulus carinatus	T. milowii	Umbilicosphaera sibogae
PLEISTOCENE, LATE	WPN-31b	1-1, 90-91	Ag		C				C	F		R		A		R							VR																			A	C	R	F			F										F				R
		1-2, 90-91	Ag		C				C	F		R		A				R																	R							C	C		R			F										F	C			
		1-3, 90-91	B																																																											
		1-4, 90-91	B																																																											
	WPN-31a	1-5, 90-91	Am		F				C					A	F																								R	F		A	F		R														F			
		1cc	Am		F				C	R				C							R																		F	C		A	C		R														R			R
		2-2, 93-94	Am	R	C				F	R?				A	C			R			VR		VR												VR				F	C		A	C		F			F			R	R							F			
		2cc	Rp		VR									R	R																									VR																						
		3cc	Am		F				F	R				C							R																	R	C	C		A	A		R				R										R			
		4cc	Cm		F				F	R		R		C	C	R					VR		VR												VR				C	C	R	A	F		R														F			
PLEISTOCENE, EAR.	WPN-30b	5cc	Fm		R									F	R																						R		F	F		R			R			R														R
		6-1, 58-59	B																																																											
?	?	6-2, 58-59	B																																																											
		6-3, 58-59	B																																																											
		6-4, 58-59	B																																																											
PLIO.	WPN-29a or older ?	6cc	Rp																		R													R	R																											
		7cc	B																																																											
MIOCENE, MIDDLE	WPN-24b	8-1, 90-91	Am			R	C	F											R		R						R					VR			A															R												
		8cc	Am				C												F		F							R							A															R												
		9-1, 90-91	Ap			R	C	R				R									R						C								A											R				R			R									
		9cc	Ap		R	R	C	R				R							F		F						R					R			A															R			R									
		11-2, 18-19	Am				C	F				C										F	F				A					F			A										R					R			R				R					
		11cc	Am			F	F	F				F								R	F							R				F			A										F					F			C									
		12cc	Am		R		C	F				F							F	F	F	R					R	R				R			A											R				R												
		13cc	Am		R		F	F				F										R					C	R							A															R			R									
		14-1, 90-91	B																																																											
		14cc	B																																																											
		15-1, 50	Am			R	F	C				C															C								A										F	R				F			C									
		15-1, 52-53	Am			R	F	A				C	R														C						R		A										R					C			F			R	F					
		15-2, 92-93	B																																																											
		15cc	B																																																											
	WPN-24a	17-1, 40-41	Rp																																R																											
		17cc	Am		R			C				F							F	R		F					R								A															F												
		19-1, 30-31	Cm			R		R				F							R			R?					R?				R				A			R															R									
	WPN-23	19-1,cc Top	Cm		R	R		R?				C																							A			R								R				R			R			R						
		19-1,cc Bottom	Fp			R		F				F																							F															R												
	WPN-22b	20-1, 44-45	Am		R								R							F						A			R						A															R												
		20-1cc	Am		R							R							R	C						F									A															R												
	WPN-21	21-1, 35-36	Am			F												A					R			F				F					A																		R		C							
		21cc	Ap			R												C					F			F				F					A																				F							
MIOCENE, EARLY	WPN-20	22-1, 4-5	Ap			R						C						A					A	R											F																		R		C	F						
		22cc	Ap									R						A					A												F																				C							
		24-1, 49-50	Cp										R					A					A							F			F		F																				C							
		24-2, 90-91	Am			F						R						A					A												C															R					C							
		24cc	Rp																				R																																							
		25-1, 20-21	Ap								R							A					A	R						R					F																				R							
		25-1, 101-102	B																																																											
		25-2, 101-102	Fp															C					C	R											R																											
		25-3, 3-5	B																																																											
		25-3, 88-89	B																																																											
		25cc	Fp			R												C		R			F												R																											
		26-1, 29-30	B																																																											
		26cc	B																																																											
		27-1, 24-25	Am														VR	A					C							F					C											R									C							
		27-2, 38-39	Fp															R					F	R											R																				R?						R	
		27-3, 39-40	Rp															R					VR																																							
		27-4, 98-99	Fp									R					F	F					F												R										R					F					R	R						
		27-5, 17-18	Rp			R												R																																					R							
		27cc	Cp															C					F												C																		R									
		28-1, 42-43	Fp			R						R						C					C												R																				R							
	WPN-19	28-2, 102-103	Rp															VR																																												
		28-3, 77-78	B																																																											
		28cc	Cp			R							R					C					C	F						R						F									R	F							R			R						
		29-1, 41-42	B																																																											
		29-2, 40-41	B																																																											
		29cc	Ap										F				VR	A					C	F														R								F								R		R						
		30-1, 70	Cp										R					A					F	F	R																													R		F						
		30-2, 90-91	Cp															A					C	F	R																						VR						VR	R		R				R		
		30-4, 90-91	B																																																											
		30cc	B																																																											
		31-2, 90-91	B																																																											
		31cc	B																																																											
		32cc	B																																																											

Table 8b. Nannoplankton occurrences, Site 459.

SITE 459 AGE		NANNOPLANKTON ZONE OR SUBZONE	CORE, SECTION, INTERVAL (cm)	ABUNDANCE AND PRESERVATION	*Braarudosphaera discula*	*Bramletteius serraculoides*	*Coccolithus formosus*	*Coccolithus eopelagicus*	*C. miopelagicus*	*C. pelagicus*	*Coronocyclus nitescens*	*Cyclicargolithus abisectus*	*C. floridanus*	*Dictyococcites bisectus*	*D. scrippsae*	*Discoaster barbadiensis*	*D. deflandrei*	*D. divaricatus*	*D. druggii*	*D. moorei*	*D. nodifer*	*D. tanii*	*D. sp. cf. D. variabilis*	*Helicosphaera euphratis*	*H. granulata*	*H. reticulata*	*Orthorhabdus serratus*	*Reticulofenestra gartneri*	*R. hillae*	*R. umbilica*	*R. sp.*	*Sphenolithus ciperoensis*	*S. conicus*	*S. delphix*	*S. dissimilis*	*S. distentus*	*S. moriformis*	*S. obtusus*	*S. predistentus*	*Triquetrorhabdus carinatus*
MIOCENE	EARLY	WPN-19	33cc	Am								F	A	R			F	F										R?									C			
			34-2,cc	Cp							R		A				F	F																						
			35-1, 36-37	Ap							F		A				C			R			R																	R
			35-2, 33-34	Ap								C	A				A						R					C?									C			F
			35cc	Cp			R					C	C	R		VR	F				R					R											F	R	VR	
		WPN-18c	36-1, 86-87	Cp									C				C		R				F				R	R?					R				F			R
			36-2, 32-33	Ap					R	R	F		A				C		R				F	R			R	C?					R				C			R
			36cc	Cp						R			C				F	F							R												F			
			37-1, 69-71	Cm					R	F	R	F	C	R		VR	C										R	R?						R	F				F	R
			37cc	Cp		R						R	C	R			F										F							R		R	F		R	R
			38-1, 26-27	Cp					R			R	C				C		R				F				R										F			F
			38cc	Rp								VR					VR																							
			39cc	Cp								R	A				F						F				R	F?									C			
			40cc	Fp									C				F						R														F			
			41cc	Rp									R				R						R														R			
			42cc	Fp							R		R				F		R				R												R		R			
			43-1, 54-55	B																																				
			43cc	Rp									VP				VR																				VR			
			44-1, 59-60	B																																				
			44cc	B																																				
			45-1, 28-29	B																																				
			45-1cc	B																																				
			46-1, 99-100	Cp					R				A				C		C																					C
			46cc	Ap					R		R	VR	A				A		F				F												F		F			C
		WPN-18b	47-1, 57-58	Cm					R	R	R	R	C	F			C										VR						F	R	F		F			F
			47-1cc	Am					F	R		R	A				A																F		F		F			C
		WPN-18a	48-1, 22-23	Cp					R	R		R	C				C																F	R	F		C			F
			48cc	Cp					R			R	C				F																	R			F			C
OLIGOCENE	LATE	WPN-17b	49-1, 8-9	Am								F	A	R			C															F					C			F
			49-1cc	Am						R		R	C				F																F				F			C
			50-1, 44-45	Cm						R		F	C	R	F		C																R		R					F
			50-2, 2-3	B																																				
			50-3, 63-64	Am						F		C	C	F			A																R							A
			50cc	Ap								F	C	R			F																							C
			51-2, 27-28	Ap						F	R	C	A	R	F		C															F	R				C		VR	R
			51cc	Ap						F		R	A	R			F															R					C			F
			52-1, 96-97	Ap					R	C			A				C														F	F					C		VR	F
			52-2, 83-84	Ap					R	C		C	C	F			C														F	F					C			C
			52-3, 58-59	Ap						F		R	C	R			F															F					F			F
			52cc	B																																				
			53-1, 102-103	Ap		VR				F		R	C	F			C														F	R					C		R	F
			53cc	Ap						F		F	A	F			F															F	R				A			F
		WPN-17a	54-1, 78-79	Ap					R	C		A	A	F			C															F				R	C		F	F
			54-2, 66-67	Ap					R	F		A	C	F			C															F				R	C		F	F
		WPN-16	54-3, 83-84	Cp					R	R		F	F	F	R		R																			R	F		R	R
			54-5,cc	B																																				
			55-3, 9-10	Ap								C	C	F																						F	C		C	
			55cc	Cp	VR							C	C	C			F																							
			56-3, 12-13	Cp					R			C	C	F			F																			F	C		C	F
			56cc	Rp								VR																												
			57-1, 27-28	Ap				R	R			F	A	C		R	F																				F		A	R
			57-3, 35-36	Ap						R		F	C	C			C																				C		C	
			57cc	Ap					R	R		C	C	C			R																			F	F		A	
			58-1, 28-29	Ap			F			R	R		R	C			R					R							F	C							R			
	E.	WPN-14b	58-2, 70-71	Rp																										VR										
			58-3, 123-124	B																																				
			58cc	Rp								VR																												
			59-1, 112-113	B																																				
			59-2, 45-46	B																																				
			59cc	Rp						VR		R	R		R		VR														VR									
			60-1, 9-10	Rp								VR																												
			60-1, 30-31	B																																				
			64-1 Top (pebble)			F				R		F	F																								F		F	
			65cc	B																																				
			70cc	B																																				

Core 20 can be assigned to the WPN-22b Subzone based on joint occurrences of *D. kugleri* and *D. bollii*.

The presence of the early middle Miocene WPN-21 Zone assemblage in the two samples of Core 21 (Samples 21-1, 35–36 cm, and 21,CC) suggests that the lower subzone of the overlying WPN-22 Zone—the WPN-22a Subzone—is missing. This would represent an interval spanning 0.6 m.y. (13.4 to 14.0 m.y. B.P.).

The early Miocene/middle Miocene boundary, which corresponds with the boundary between the WPN-21 Zone and the WPN-20 Zone, is placed between Cores 21 and 22 on the basis of the top of the *Discoaster deflandrei* acme together with the first occurrence of *D. exilis*. The first appearance of *Calicidiscus macintyrei* and *Reticulofenestra pseudoumbilica*, which aid in defining this boundary, are found somewhat lower in Sample 24-2, 90–91 cm.

The top of the early Miocene WPN-19 Zone is drawn between Samples 28-1, 42–43 cm, and 28-2, 102–103 cm at the first occurrence of *Sphenolithus heteromorphus*. A few reworked species of several early Oligocene and/or Eocene species occur in Sample 35,CC at the base of the zone.

The early Miocene WPN-18c Subzone can be recognized in Samples 36-1, 86–87 cm through 46,CC by the last occurrences of *Discoaster* sp. cf. *D. variabilis* and *Orthorhabdus serratus* at the top and the first appearances of *D. druggii* and *D.* sp. cf. *D. variabilis* at the bottom.

The remaining two lower subzones of the WPN-18 Zone cannot be differentiated. Consequently, the Miocene/ Oligocene boundary, which coincides with the boundary between these two subzones, cannot be precisely defined. This undifferentiated interval of the WPN-18 Zone is present in samples of Cores 47 and 48.

The late Oligocene WPN-17b Subzone can be recognized in Samples 49-1, 8–9 cm through 53,CC by the last occurrence of *Sphenolithus ciperoensis* and *Dictyococcites bisectus* at the top and by the last occurrence of *S. distentus* at the base. The WPN-17a Subzone can be recognized in Samples 54-1, 78–79 cm and 54-2, 66–67 cm by the joint occurrence of *S. ciperoensis* and *S. distentus*. Normally *S. predistentus* does not occur above the base of the WPN-17 Zone; however, it does occur rarely above this horizon in samples from this hole.

The early late Oligocene WPN-16 Zone is determined for Samples 54-3, 83–84 cm through 57,CC and is defined at its base by the first appearances of *S. distentus* and *Cyclicargolithus abisectus*.

Sample 58-1, 28–29 cm can be placed in the early Oligocene WPN-14b Subzone. This would indicate an hiatus of at least 4.5 m.y. (30.0 to 34.5 m.y. B.P.) between Cores 57 and 58. Although the occurrence range of key age-determining species extends into the Eocene, an Eocene age is not considered for this sample because nannofossil species limited in their occurrence to the Eocene are not found in association.

A few nannoplankton species occur sporadically lower in the hole; however, these are considered to be contaminants from uphole.

Holes 460 and 460A

The comparison of sporadic occurrences of nannoplankton in samples from each of these holes indicates poor correlation between these two deep-water locations that are only 500 meters apart. Paleontologically productive levels present in one hole are apparently absent or at least different from those in the second hole. Nannoplankton occurrences observed in samples from Hole 460 are listed in Table 9, those from Hole 460A in Table 10.

In Hole 460, four samples contain poorly preserved nannoplankton assemblages indicating an age of late Oligocene or older, early Oligocene, late Eocene, and late or late middle Eocene.

In Hole 460A, nine samples contain nannoplankton. The highly diverse assemblage in samples from Core 4 contain elements diagnostic of all Cenozoic epochs from Eocene through Pleistocene as well as late Cretaceous. Preservation ranges from moderate to very poor. Specimens representative of these assemblages showing varying degrees of overgrowth and solution are illustrated in Plates 1 and 2.

Table 9. Nannoplankton occurrences, Hole 460.

HOLE 460 AGE		Nannoplankton zone or subzone	Core, section, interval (cm)	Abundance and preservation	*Coccolithus formosus*	*Coccolithus pelagicus*	*Cyclicargolithus abisectus*	*C. floridanus*	*Dictyococcites bisectus*	*Discoaster barbadiensis*	*D. deflandrei*	*D. saipanensis*	*Reticulofenestra umbilica*	*Zygrhabilithus bijugatus*
OLIGOCENE	LATE		1-1, 100-101	B										
			1-2, 80-81	B										
			1-3, 90-91	B										
			1-4, 100-101	B										
			1-5, Bottom	B										
			2cc	B										
			3-1, 90-91	B										
			3-2, 90-91	B										
			3-3, 90-91	B										
			3-4, 90-91	B										
			3-5, 90-91	B										
			3-5, Bottom	B										
		WPN-17 or older	4-1, 20	Fp		R	R	F	R		R			
			4-1, 123-124	B										
			4-2, 95-96	B										
			4-3, 90-91	B										
			4-4, 90-91	B										
	EARLY		4-5, 90-91	B										
			4-6, 31-32	B										
			4cc	B										
			5-1, 20-21	B										
		WPN-14c or older	5cc	Rp				F	VR				VR	
			6cc	B										
EOCENE	MID./LATE	WPN-13 or older	7-1, 7-8	Rp				VR	VR	F?				
			7cc, Top	B										
		WPN-13 or WPN-12	7cc, Bottom	Cp	C	C		C	F	C	R	R	C	R
			8-1, 61-62	B										
			8cc	B										

Table 10. Nannoplankton occurrences, Hole 460A.

HOLE 460A				CENOZOIC SPECIES																				
AGE	NANNO-PLANKTON ZONE OR SUBZONE	CORE, SECTION, INTERVAL (cm)	ABUNDANCE AND PRESERVATION	Aspidorhabdus stylifer	Coccolithus formosus	Calcidiscus leptoporus	C. macintyrei	Ceratolithus cristatus	C. rugosus	Coccolithus eopelagicus	C. miopelagicus	C. pelagicus	Coronocyclus nitescens	Crenalithus doronicoides	C. productellus	Cricolithus jonesii	Cyclicargolithus abisectus	C. floridanus	Dictyococcites bisectus	Discoaster bellus	D. bollii	D. braarudii	D. brouweri	D. challengeri
PLEISTOCENE, LATE		1-1, 91-92	B																					
		1-2, 90-91	B																					
		1-3, 90-91	B																					
		1-4, 90-91	B																					
		1-5, 90-91	B																					
		1-6, 44-45	B																					
		2-1, 90-91	B																					
		2-2, 42-43	B																					
		2-3, 42-43	B																					
		2-4, 75-76	B																					
		2cc	B																					
		3-1, 90-91	B																					
		3-2, 90-91	B																					
		3-3, 90-91	B																					
		3cc	B																					
		4-1, 90-91	B																					
		4-2, 90-91	B																					
	Mixed Cenozoic and Mesozoic assemblages	4-3, 71	Cm			C	F	R			R			A	F		R	F		R			F	
		4-3, 90-91	Cm		R	R	R				R	R	R	F	F	R	F	F	R					
		4-3, 124	Cm			C	F	R			R			A	F		R	F		R			F	
		4-4, 90-91	B																					
		4-5, 90-91	Cp		F	F	R		R		R	R	R	F	R	R	R	R	R				R	
		4-6, 90-91	Cm	R	F	C	F	R	R	X	R	R		C	F	R	R	F	F	X		R	R	F
		4cc	Cm			C	F	R			R	R		A	F		R	F	R	R	R	R	F	
		5-1, 90-91	B																					
		5-2, 90-91	B																					
		5-3, 93-94	B																					
		5cc	B																					
	Pleistocene?	6-1, 20	Rp			R								R										
		6-1, 38-39	B																					
		6-1, 90-91	B																					
		6cc	B																					
		7-1, 78-79	B																					
		7-2, 24-25	B																					
		7cc	B																					
	Cenozoic?	8cc, 35	Rp														VR	VR						
		8cc	Rp																					
		9cc	B																					
		10cc	B																					

CORE, SECTION, INTERVAL (cm)	D. decorus	D. deflandrei	D. exilis	D. hamatus	D. loeblichii	D. moorei	D. neohamatus	D. quinqueramus	D. saipanensis	D. signus	D. stellulus	D. surculus	D. tanii	D. variabilis	Emiliania annula	E. ovata	Gephyrocapsa caribbeanica	G. oceanica	G. omega	Helicosphaera carteri	H. sellii
1-1, 91-92																					
1-2, 90-91																					
1-3, 90-91																					
1-4, 90-91																					
1-5, 90-91																					
1-6, 44-45																					
2-1, 90-91																					
2-2, 42-43																					
2-3, 42-43																					
2-4, 75-76																					
2cc																					
3-1, 90-91																					
3-2, 90-91																					
3-3, 90-91																					
3cc																					
4-1, 90-91																					
4-2, 90-91																					
4-3, 71		A							R					C	F	C	F	R		F	
4-3, 90-91		F			R	R		R			R			R	R	F	F	F		F	R
4-3, 124		A							R					C	F	C	F	R		F	
4-4, 90-91																					
4-5, 90-91		F			R		R			R				F	R	R	F	R		F	
4-6, 90-91	R	C						R				R	R	C	F	C	F	F		C	R
4cc		A	R	R	R	R	R	R	R			R		C	F	C	F	R	R	F	R
5-1, 90-91																					
5-2, 90-91																					
5-3, 93-94																					
5cc																					
6-1, 20														R			R				
6-1, 38-39																					
6-1, 90-91																					
6cc																					
7-1, 78-79																					
7-2, 24-25																					
7cc																					
8cc, 35																					
8cc																					
9cc																					
10cc																					

	CENOZOIC SPECIES											MESOZOIC SPECIES								
CORE, SECTION, INTERVAL (cm)	Tribrachiatus orthostylus	Reticulofenestra hillae	R. pseudoumbilica	Rhabdosphaera tenuis	Sphenolithus heteromorphus	S. moriformis	Syracosphaera pulchra	Thoracosphaera heimii	Triquetrorhabdulus carinatus	Umbilicosphaera cricota	U. sibogae	Arkhangelskiella cymbiformis	Cretarhabdus crenulatus	Lucianorhabdus cayeuxii	Micula staurophora	Parhabdolithus embergeri	Tetralithus aculeus	T. obscurus	T. quadratus	Watznaueria barnesae
1-1, 91-92																				
1-2, 90-91																				
1-3, 90-91																				
1-4, 90-91																				
1-5, 90-91																				
1-6, 44-45																				
2-1, 90-91																				
2-2, 42-43																				
2-3, 42-43																				
2-4, 75-76																				
2cc																				
3-1, 90-91																				
3-2, 90-91																				
3-3, 90-91																				
3cc																				
4-1, 90-91																				
4-2, 90-91																				
4-3, 71			F			R		R												
4-3, 90-91			R		F	F			R				R			R			R	C
4-3, 124			F			R		R												
4-4, 90-91																				
4-5, 90-91			F			R	R		F					R		R		R		C
4-6, 90-91	R		F		F	F	F	X	X	R							R			R
4cc		R	F	R	F	R		R			R	R			R				R	R
5-1, 90-91																				
5-2, 90-91																				
5-3, 93-94																				
5cc																				
6-1, 20																				
6-1, 38-39																				
6-1, 90-91																				
6cc																				
7-1, 78-79																				
7-2, 24-25																				
7cc																				
8cc, 35																				
8cc			VR																	
9cc																				
10cc																				

The presence of calcareous microfossils in deposits well below the present CCD suggests rapid burial of material redeposited from shallower depths. This secondarily derived sediment in Hole 460A was deposited at its present location no earlier than Pleistocene. The fossiliferous section in Hole 460 may represent an entire block that has slid or been faulted down the west side of the Mariana Trench.

The Cretaceous radiolarians and nannoplankton at this site represent the first Mesozoic occurrence recorded on the western margin of the Mariana Trench.

Holes 461 and 461A

The samples examined from these holes and the nannoplankton they contain are listed in Table 11. All samples from Hole 461 are barren. Three samples from Core 1 of Hole 461A contain rare specimens of late Oligocene, early Oligocene–late Eocene, and also from the Late Cretaceous age.

A sample of the muddy water found in association with the sample from the bottom of Section 461A-2-1, bottom, was also found to contain a few specimens of Oligocene or late Eocene nannoplankton. Since the sediments recovered from these holes are presently well below the CCD, the calcareous nannoplankton had to have originated in much shallower water. Only redeposition with very rapid burial can explain their present occurrence at this depth below sea level (7040 m).

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Table 11. Nannoplankton occurrences, Site 461.

SITE 461				CENOZOIC SPECIES							MESOZOIC SPECIES				
AGE	NANNO-PLANKTON ZONE OR SUBZONE	HOLE, CORE, SECTION, INTERVAL (cm)	ABUNDANCE AND PRESERVATION	*Coccolithus pelagicus*	*Cyclicargolithus abisectus*	*C. floridanus*	*Dictyococcites bisectus*	*Discoaster deflandrei*	*D. sp.*	*Reticulofenestra umbilica*	*Cretarhabdus crenulatus*	*Micula staurophora*	*Parhabdolithus embergeri*	*Prediscosphaera cretacea*	*Watznaueria barnesae*
? ?	?	HOLE 461													
		1-1, 12-13	B												
		1-1, Bottom	B												
		2-1, 90-92	B												
		2-2, 90-91	B												
		2-3, 90-91	B												
		2-4, 90-92	B												
		2cc	B												
		3cc	B												
? ?	*Mixed Oligocene, late Eocene, and Cretaceous assemblages*	HOLE 461A													
		1-1, 90-91	B												
		1-2, 90-91	B												
		1-3, 90-91	Rp			VR									
		1-4, 90-91	Rp						VR						
		1cc	Rp	R	F	F	R	R		R	F	R	R	R	F
		2-1, Bottom	B												
		2-1, Fluid	Rp	VR			R								

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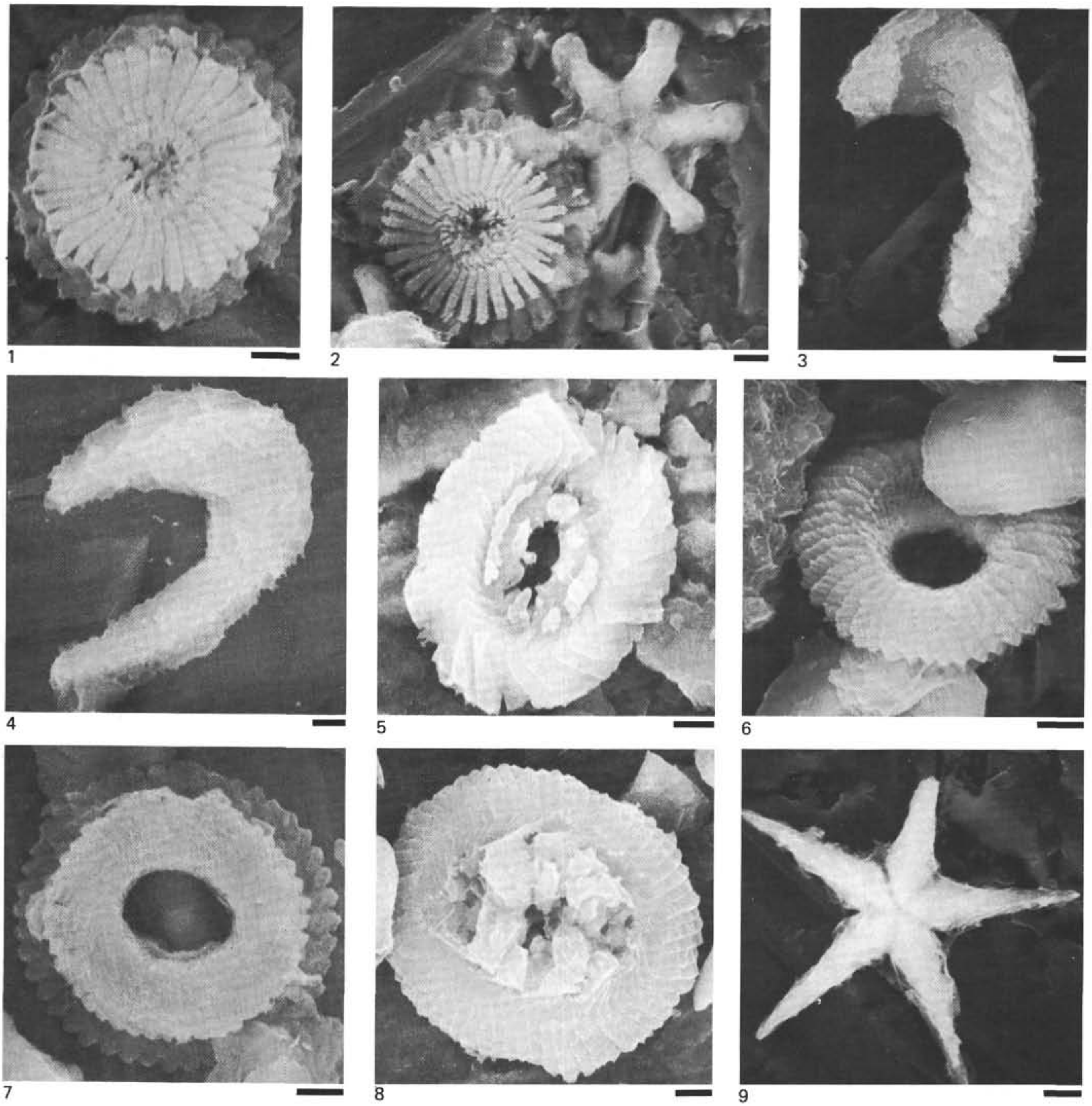

Plate 1. Mixed nannoplankton assemblages observed in samples recovered from the west (arc-side) wall of the Mariana Trench at Site 460. Solid bar in each figure represents 1.0 μm.

Figures 1, 2. *Calcidiscus leptoporus* (Murray and Blackman). Sample 460A-4-6, 90–91 cm. Fig. 1. Proximal surface. Fig. 2. Proximal surface showing concentric ridges due to solution. *Discoaster* sp. also displays effects of solution.

Figure 3. *Ceratolithus cristatus* Kamptner? Sample 460A-4-6, 90–91 cm.

Figure 4. *Ceratolithus rugosus* Bukry and Bramlette? Sample 460A-4-5, 90–91 cm.

Figure 5. *Coccolithus sarsiae* Black? Sample 460A-4-5, 90–91 cm.

Figure 6, 7. *Cyclicargolithus floridanus* (Roth and Hay). Fig. 6. Distal side. Sample 460A-4-6, 90–91 cm. Fig. 7. Proximal side. Sample 460A-4-5, 90–91 cm.

Figure 8. *Dictyococcites bisectus* (Hay, Mohler, and Wade). Sample 460A-4-5, 90–91 cm.

Figure 9. *Discoaster bellus* Bukry and Percival? Sample 460A-4-6, 90–91 cm.

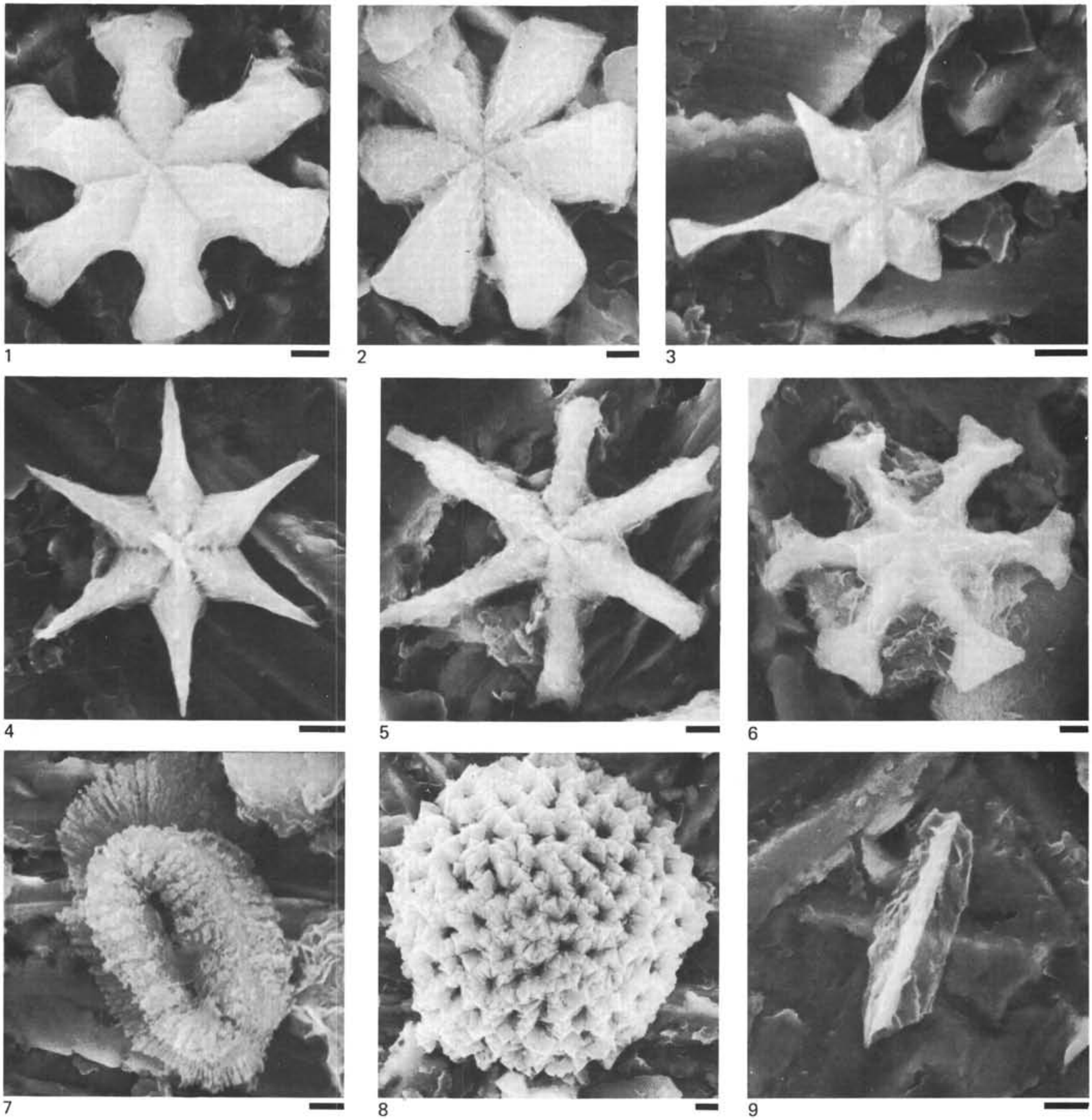

Plate 2. Mixed nannoplankton assemblage observed in Sample 460A-4-6, 90–91 cm recovered from the west (arc-side) wall of the Mariana Trench at Site 460. Solid bar in each figure represents 1.0 μm.

Figure 1–3. *Discoaster deflandrei* Bramlette and Riedel. Varying degrees of solution shown on normal and overgrown specimens.

Figure 4. *Discoaster deflandrei* Bramlette and Riedel? Specimen may have been subjected to greater solution than suffered by specimen illustrated in Figure 3, thus accounting for the absence of all bifurcations at the ends of the rays.

Figure 5. *Discoaster surculus* Martini and Bramlette.

Figure 6. *Discoaster variabilis* Martini and Bramlette.

Figure 7. *Helicosphaera carteri* (Wallich).

Figure 8. *Thoracosphaera heimii* (Lohmann).

Figure 9. *Triquetrorhabdulus carinatus* Martini.