11. PACIFIC COAST COCCOLITH STRATIGRAPHY BETWEEN POINT CONCEPTION AND CABO CORRIENTES, DEEP SEA DRILLING PROJECT LEG 63[1]

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ABSTRACT

DSDP Leg 63 recovered Neogene coccoliths from south of Point Conception, California (Site 467), to north of Cabo Corrientes, Mexico (Site 473), as part of a traverse exploring the sedimentary record of the California Current along the Pacific Coast. A combination of temperate and tropical zonations were used to date Leg 63 coccolith assemblages because of intergradations of warm and cool species along the transect. Variations in the abundance and the presence and absence of *Discoaster* species are useful in recognizing warm–cool intergradations. New taxa described in this report include *Discoaster okadai* n. sp., *D. sanmiguelensis* n. sp., *Helicosphaera californiana* n. sp., *H. crouchii* n. sp., *H. gertae* n. sp., and *H. vedderi* n. sp.

INTRODUCTION

Leg 63 of the Deep Sea Drilling Project recovered 398 cores at seven drilling sites, 467 through 473 (Fig. 1, A). These sites all lie south of DSDP Site 173 (Fig. 1, B), which is a standard reference for middle-latitude biostratigraphy along the Pacific Coast. Light-microscope techniques were used to study a set of 1100 coccolith smear slides. At most sites coccoliths provided the most continuous biostratigraphic record for correlation, however, gaps are indicated in the summary of coccolith zonal sequences (Figs. 2 and 3). Different sections in this chapter discuss zonation, site summaries, variation of assemblages along the traverse of sites, systematic paleontology, and species cited.

ZONATION

Low-latitude coccolith zonation (Bukry, 1971a, 1973a, 1975) can be applied to the lower middle Miocene at all of the Leg 63 sites. A significant change in assemblages at northern Sites 467 to 469 occurred in the middle Miocene *Discoaster exilis* Zone (Crouch and Bukry, 1979); low-diversity temperate assemblages became established and low-latitude guide taxon became sparse and sporadic. Temperate zones developed from Leg 18 (Bukry, 1973b), which span broader time intervals than do low-latitude zones, are used for the upper middle Miocene to lower Pliocene for Sites 467 and 468, with a minor change. The modification is that the earliest *D. mendomobensis* occurs in the *D. neorectus* Subzone correlative (in Leg 63 sites) instead of at the upper boundary of the *D. neorectus* Zone. The zone and subzone codes (CN12a . . .) are from Okada and Bukry (1980) (Fig. 4).

In the lower Pliocene of Holes 467, 468, 468A, and 469, a new local or limited middle-latitude subzone is recognized. The new *Amaurolithus delicatus* Subzone CN10d is bounded by the first consistent *Discoaster*

asymmetricus Gartner at the base and by the last *Amaurolithus* spp. at the top. It is assigned to the top of the *Amaurolithus tricorniculatus* Zone CN10, above the *Ceratolithus rugosus* Subzone CN10c. This unit is not part of the regular low-latitude zonation, because the *Amaurolithus* extinction typically precedes the first consistent *D. asymmetricus* populations; however, this unit has been identified previously as a *Discoaster asymmetricus* Zone by Gartner (1969) and Martini (1971). The sporadic occurrence of *D. asymmetricus* in the upper Miocene (Bukry, 1973a; Shafik, 1975) can cause problems with this subzone. The occurrence of this unit in tropical areas is questionable, because my slides from DSDP Hole 62.1, Core 10 (01°52.2′N), identified as *D. asymmetricus* Zone (Martini, 1971), show *Ceratolithus rugosus* Bukry and Bramlette and *D. asymmetricus*, but no *Amaurolithus*, which should signify the low-latitude *Reticulofenestra pseudoumbilica* Zone CN11a and b (compare Martini, 1971). The Leg 63 occurrences of the overlap between *Amaurolithus* and *D. asymmetricus* are in single samples or very short intervals of 1 or 1.5 meters at California Continental Borderland Sites 467 to 469. The brevity of this unit, which is also indicated by Gartner (1969) for Atlantic cores, may be a function of the sporadic occurrence of *D. asymmetricus* in the lower lower Pliocene and local variations in gradually increasing productivity near the extinction of *Amaurolithus*. This could account for the brevity or apparent nonoverlapping relation between these taxa in various regions. Detailed study of subsection intervals through the lower Pliocene in additional tropical and temperate cores should resolve this subzone correlation.

The upper Miocene zonal boundary between the middle-latitude *Discoaster mendomobensis* Zone and *D. variabilis* Zone, when first described, was correlated with the boundary between the low-latitude *D. quinqueramus* Zone and *D. neohamatus* Zone (Bukry, 1973b). Studies of borderland dart cores and DSDP Site 469, Core 14, however, show that specimens of *Discoaster mendomobensis* Wise may occur earlier, in upper *D. neohamatus* Zone assemblages identified by the

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[1] *Initial Reports of the Deep Sea Drilling Project*, Volume 63.
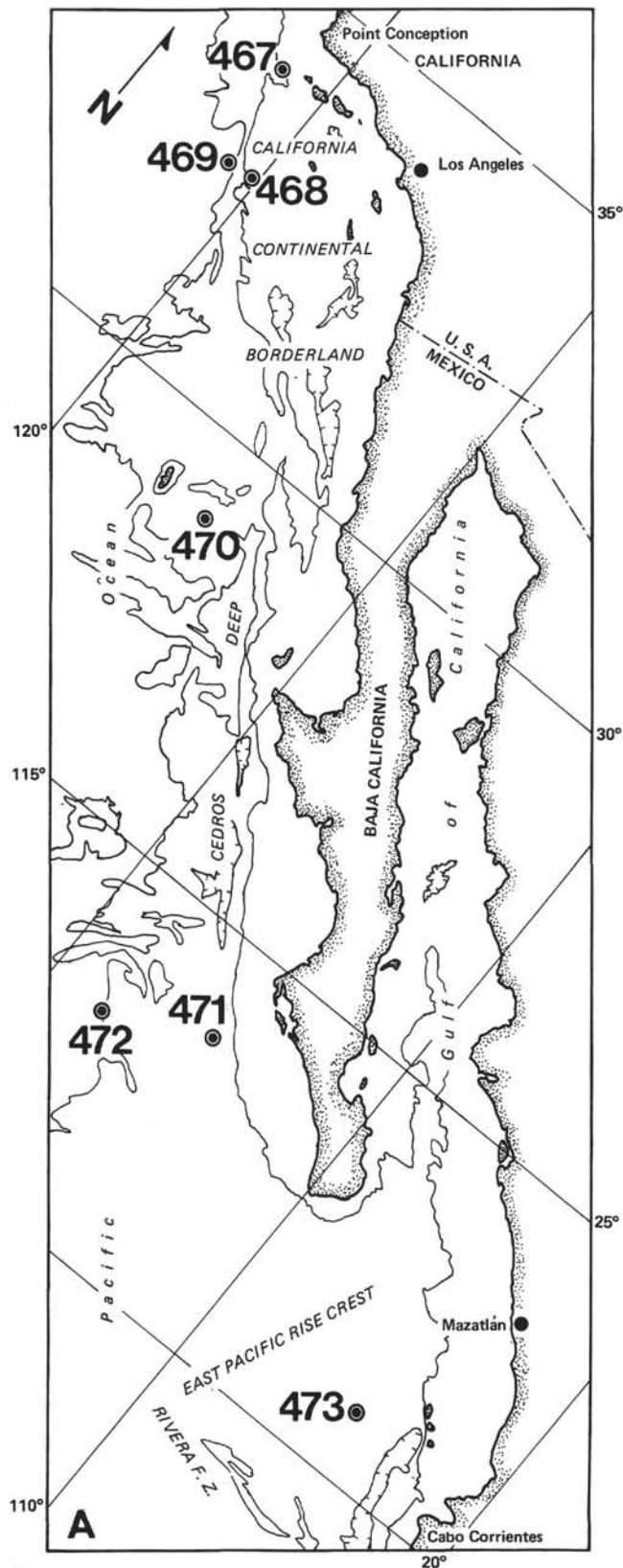
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Figure 1. A. Location of DSDP Leg 63 sites along the Pacific Coast from Point Conception to Cabo Corrientes. (The Experimental Mohole Site is 8 km north of DSDP 470.) B. Locations of Site 173 and Leg 63 sites used for coccolith ratios along the Pacific Coast traverse.
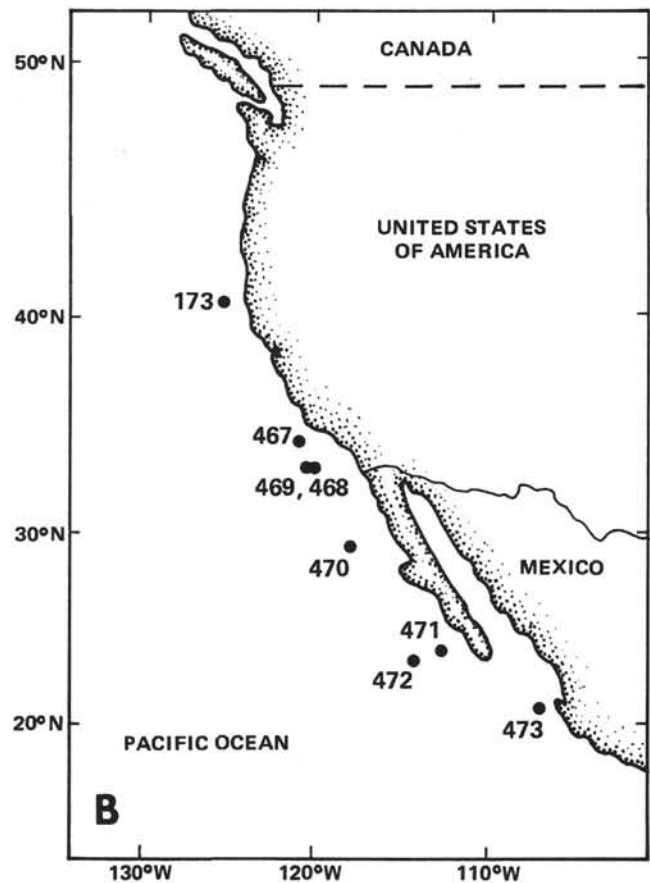
occurrence of *D. bellus* Bukry and Percival, *D. loeblichii* Bukry, and *Minylitha convallis* Bukry, without *D. berggrenii* Bukry, *D. quinqueramus* Gartner, or *D. surculus* Martini and Bramlette. Therefore, the bottom of the *D. mendomobensis* Zone appears to be slightly below the top of the *D. neohamatus* Zone in the borderland where species characterizing both of these latitudinal zones occur together.

The low-latitude zonation for the upper Pliocene and Quaternary is generally recognizable through the Leg 63 area. Site 467 presents the most difficulty, with etched assemblages containing reworked specimens but few discoasters. The brief *Discoaster pentaradiatus* Subzone CN12c occurs only at Site 470. Quaternary assemblages contain fairly representative numbers of *Ceratolithus, Emiliania,* and *Gephyrocapsa,* but dilution by terrigenous or opal biogenic sediment hinders zonal assignments.

SITE SUMMARIES

Site 467
(33°50.97′N, 120°45.47′W, depth 2128 m)

The Miocene to Quaternary coccoliths at Site 467 in the San Miguel Gap constitute much of the micropaleontologic record of the California Current in the outer California Continental Borderland. Coccoliths occur in most of the 110 cores recovered. Middle Miocene to

Age	Zone or Subzone	467	468	468A	468B	469
Quaternary	CN15	1,CC/2,CC		1-1		1-1/2-2
Quaternary	CN14b	3-2/5-1			2,CC	1-1/2-2
Quaternary	CN14a	5-3/5,CC				3-3/4,CC
Quaternary	CN13b	6,CC/8-3 — 8-5		1-2	2-1/2-2	
Quaternary	CN13a	8,CC/9-3		1-4/1,CC		5-1/5-5
Pliocene	CN12d	9,CC/10,CC, ?17-3				5,CC/7-5 — 6-3
Pliocene	CN12c	11,CC/24,CC				
Pliocene	CN12b	?25-1/?26-1		2-3/2-5	1-1	7,CC/8-1
Pliocene	CN12a	25-3/25-7	1-1, 2-1	3-1/3-4	1-2/1-5	8-2/9-2
Pliocene	CN11b	26,CC/27-1			1,CC	9,CC
Pliocene	CN11a					
Pliocene	CN10d	?26-3	1-2	?4-1/4-2		10-1/10-2
Pliocene	CN10c				2-1/2,CC	10,CC/12-3
Pliocene	CN10b	27-2/52-1				
Pliocene	CN10a					
Miocene	CN9b					12-5/13,CC
Miocene	CN9a					
Miocene	CN8b	56,CC/90-1			3-1	14-2 — ?14-1/16,CC
Miocene	CN8a					17,CC/18-3
Miocene	CN7b				3-3/4-2	
Miocene	CN7a					
Miocene	CN6					
Miocene	CN5b	90-2/?90-4				?19-1
Miocene	CN5a	92,CC/?100-1	2-2/?10-3		5,CC/10-1 — ?12-2	19,CC/24-3
Miocene	CN4	100,CC/110-1	?11-2/19,CC		13-3/15,CC	24,CC/35,CC — 38,CC/43-3
Miocene	CN3					36-1/38-2

Figure 2. Coccolith zonation of core samples from northern Sites 467 to 469 of DSDP Pacific Coast Leg 63. (The numbers assigned to zonal intervals are core and section numbers of samples examined. Where a zone or subzone is represented in samples from two or more core sections, the highest and lowest are given. CC = core-catcher sample from the bottom of the core.)

lowest Pliocene coccoliths are generally few to common and are moderately to poorly preserved. Dissolution and fragmentation of both placolith and asterolith specimens are typical in Cores 37 to 110. Coccoliths are abundant and moderately well preserved in Quaternary and Pliocene Cores 1 to 36. Reworked coccoliths from the Eocene occur sparsely through Quaternary Cores 1 to 9 and in Cores 32 and 42 but are essentially absent in Miocene Cores 47 to 110.

Biostratigraphically, few of the 24 low-latitude coccolith units (zones and subzones) for the middle Miocene to Quaternary could be specifically identified because of the paucity of low-latitude marker species in the low-diversity (2–10 species) assemblages. The most frequently recurring species are relatively cosmopolitan species such as *Amaurolithus primus* (Bukry and Percival), *Calcidiscus leptoporus* (Murray and Blackman), *C. macintyrei* (Bukry and Bramlette), *Coccolithus pelagicus* (Wallich), *Crenalithus taganus* (Fonseca) s. ampl., *Discoaster brouweri* Tan s. ampl., *D. intercalaris* Bukry, *D. variabilis* Martini and Bramlette, and *Reticulofenestra pseudoumbilica* (Gartner) s. ampl. The cool-water *Discoaster variabilis* Zone (Milow, 1970; Bukry, 1973b) had to be used for most of the upper Miocene

and part of the middle Miocene (Cores 56–90). The *Amaurolithus tricorniculatus* Zone (Bukry, 1973a) that includes the Miocene/Pliocene boundary could not be divided effectively into subzones because of the scarcity or absence of *Ceratolithus acutus* Gartner and Bukry, *C. rugosus* Bukry and Bramlette, and *Triquetrorhabdulus rugosus* Bramlette and Wilcoxon. The Miocene/Pliocene boundary is provisionally drawn between Cores 45 and 47, because the silicoflagellate *Dictyocha aspera clinata* Bukry is present in Core 47.

The oldest zone identified at Site 467 is the *Sphenolithus heteromorphus* Zone, which is part of the early middle Miocene (approximately 14.0–15.5 Ma). R. Z. Poore (personal communication, 1978) has identified this zone in the type Luisian Stage onshore in California. The zonal assemblages at Site 467 include sparse *Sphenolithus heteromorphus* Deflandre, *Helicosphaera carteri* (Wallich), and *Calcidiscus macintyrei* (Bukry and Bramlette); few *Coccolithus miopelagicus* Bukry, *Discoaster deflandrei* Bramlette and Riedel, *D. exilis* Martini and Bramlette, and *D. variabilis* Martini and Bramlette; and common *Cyclicargolithus floridanus* (Roth and Hay). Assemblages of the upper *Coccolithus miopelagicus* Subzone are characterized by *C. mio-*

Age	Zone or Subzone	470	470A	471	472	473
Quaternary	CN15			?1-1		
	CN14b			1-4		1,CC/3,CC
	CN14a	1,CC/2,CC		3-1/3,CC		
	CN13b			4-0		4,CC/9,CC, ?10,CC
	CN13a	?3-3				
Pliocene	CN12d	?3-3, 4-1/4-2				11,CC
	CN12c	4-3/4,CC				
	CN12b	5-1/5-2		4-2/4-4		12,CC/14,CC, ?15,CC
	CN12a	5-3		4-5/5-7		
	CN11b	6-2		5,CC/6-3		
	CN11a					16,CC/18,CC
	CN10d	6,CC/7-3	1-3			19,CC/22,CC
	CN10c					
	CN10b		1-1			
Miocene	CN10a					
	CN9b	8-1	2-1/3-2			23,CC/27,CC
	CN9a	?8,CC	3-5/4-1	4-3		
	CN8b	9-2/10-2		4-5		
	CN8a	11-2/11-5	5-1/?5,CC			
	CN7b	11-6/12-5				
	CN7a	12-6/12-7			?10-2	
	CN6				10,CC	
	CN5b	14-1/14-1				
	CN5a	14-2/17,CC	6-1/6-2	39-4/78-4	11-1/12-1	
	CN4	18-1/18-2	6-2/12-1	78-5/79-1	12-2/13,CC	?15-1
	CN3					

Figure 3. Coccolith zonation of core samples from southern Sites 467 to 473 of DSDP Pacific Coast Leg 63. (The numbers assigned to zonal intervals are core and section numbers of samples examined. Where a zone or subzone is represented in samples from two or more core sections, the highest and lowest are given. CC = core-catcher sample from the bottom of the core.)

pelagicus, Crenalithus taganus (Fonseca) s. ampl., Cyclicargolithus floridanus, D. exilis, and Reticulofenestra pseudoumbilica (Gartner). In the lower part of the subzone, R. pseudoumbilica is less common and Sphenolithus neoabies is more common, suggesting some decrease in paleotemperature upward through the interval. However, the more common occurrence of discoasters in the Discoaster kugleri Subzone, just below a long sequence of cool–temperature assemblages, indicates that the environment was rather warm.

Above, in Cores 56 to 90, cooler, temperate, low-diversity coccolith assemblages, dominated by species of Reticulofenestra and D. variabilis, are present. The long Discoaster variabilis Zone interval can be divided into lower and upper parts by the appearances of Discoaster brouweri Tan s. ampl. in the lower part and Minylitha convallis Bukry in the upper part, which corresponds with the low-latitude upper Miocene Discoaster neohamatus Zone. Warm-water Discoaster neohamatus Bukry and Bramlette is absent, emphasizing the nontropical character of the assemblages. However, no specimens of cool-water Discoaster mendomobensis

Wise were detected; this species flourished to the north at DSDP Site 173 at the northern end of the California Current for a short interval at the top of the D. variabilis Zone and has rare occurrences in the California Continental Borderland (D. Bukry, unpublished data, 1978).

Sporadic occurrences of guide species Amaurolithus delicatus Gartner and Bukry, A. primus (Bukry and Percival), and Discoaster quinqueramus Gartner in the upper Miocene to lower Pliocene interval of Cores 27 to 55 make zonal assignments of individual samples difficult. Cores 27 to 55 are assigned to an undifferentiated A. primus Subzone or A. tricorniculatus Zone because of the absence of warm-water ceratolith guide species.

The overlap of Discoaster tamalis Kamptner and D. asymmetricus Gartner in Section 467-26-1 indicates the Discoaster tamalis Subzone or D. asymmetricus Subzone. Therefore this level correlates to the type Repettian Stage onshore (R. Arnal and D. Bukry, unpublished data, 1978).

Division of the upper Pliocene into subzones is doubtful at Site 467 because of the scarcity or absence

AGE	ZONE		SUBZONE		Martini (1971) Zone
Quaternary	CN15	*Emiliania huxleyi*			NN21
Quaternary	CN14	*Gephyrocapsa oceanica*	CN14b	*Ceratolithus cristatus*	NN20
Quaternary	CN14	*Gephyrocapsa oceanica*	CN14a	*Emiliania ovata*	NN19
Quaternary	CN13	*Crenalithus doronicoides*	CN13b	*Gephyrocapsa caribbeanica*	NN19
Quaternary	CN13	*Crenalithus doronicoides*	CN13a	*Emiliania annula*	NN19
Pliocene	CN12	*Discoaster brouweri*	CN12d	*Calcidiscus macintyrei*	NN18
Pliocene	CN12	*Discoaster brouweri*	CN12c	*Discoaster pentaradiatus*	NN17
Pliocene	CN12	*Discoaster brouweri*	CN12b	*Discoaster surculus*	NN16
Pliocene	CN12	*Discoaster brouweri*	CN12a	*Discoaster tamalis*	NN16
Pliocene	CN11	*Reticulofenestra pseudoumbilica*	CN11b	*Discoaster asymmetricus*	NN15
Pliocene	CN11	*Reticulofenestra pseudoumbilica*	CN11a	*Sphenolithus neoabies*	NN15
Pliocene	CN10	*Amaurolithus tricorniculatus*	CN10d	*Amaurolithus delicatus*	NN14
Pliocene	CN10	*Amaurolithus tricorniculatus*	CN10c	*Ceratolithus rugosus*	NN13
Pliocene	CN10	*Amaurolithus tricorniculatus*	CN10b	*Ceratolithus acutus*	NN12
Pliocene	CN10	*Amaurolithus tricorniculatus*	CN10a	*Triquetrorhabdulus rugosus*	NN12
Miocene	CN9	*Discoaster quinqueramus*	CN9b	*Amaurolithus primus*	NN11
Miocene	CN9	*Discoaster quinqueramus*	CN9a	*Discoaster berggrenii*	NN11
Miocene	CN8	*Discoaster neohamatus*	CN8b	*Discoaster neorectus*	NN10
Miocene	CN8	*Discoaster neohamatus*	CN8a	*Discoaster bellus*	NN10
Miocene	CN7	*Discoaster hamatus*	CN7b	*Catinaster calyculus*	NN9
Miocene	CN7	*Discoaster hamatus*	CN7a	*Helicosphaera carteri*	NN9
Miocene	CN6	*Catinaster coalitus*			NN8
Miocene	CN5	*Discoaster exilis*	CN5b	*Discoaster kugleri*	NN7
Miocene	CN5	*Discoaster exilis*	CN5a	*Coccolithus miopelagicus*	NN6
Miocene	CN4	*Sphenolithus heteromorphus*			NN2/NN5
Miocene	CN3	*Helicosphaera ampliaperta*			NN2/NN5
Miocene	CN2	*Sphenolithus belemnos*			NN2/NN5
Miocene	CN1	*Triquetrorhabdulus carinatus*	CN1c	*Discoaster druggii*	NP25/NN1
Miocene	CN1	*Triquetrorhabdulus carinatus*	CN1b	*Discoaster deflandrei*	NP25/NN1
Miocene	CN1	*Triquetrorhabdulus carinatus*	CN1a	*Cyclicargolithus abisectus*	NP25/NN1
Oligocene	CP19	*Sphenolithus ciperoensis*	CP19b	*Dictyococcites bisectus*	NP25/NN1
Oligocene	CP19	*Sphenolithus ciperoensis*	CP19a	*Cyclicargolithus floridanus*	NP24
Oligocene	CP18	*Sphenolithus distentus*			NP23
Oligocene	CP17	*Sphenolithus predistentus*			NP23
Oligocene	CP16	*Helicosphaera reticulata*	CP16c	*Reticulofenestra hillae*	NP22
Oligocene	CP16	*Helicosphaera reticulata*	CP16b	*Coccolithus formosus*	NP21
Oligocene	CP16	*Helicosphaera reticulata*	CP16a	*Coccolithus subdistichus*	NP21
Eocene	CP15	*Discoaster barbadiensis*	CP15b	*Isthmolithus recurvus*	NP19/NP20
Eocene	CP15	*Discoaster barbadiensis*	CP15a	*Chiasmolithus oamaruensis*	NP18
Eocene	CP14	*Reticulofenestra umbilica*	CP14b	*Discoaster saipanensis*	NP17
Eocene	CP14	*Reticulofenestra umbilica*	CP14a	*Discoaster bifax*	NP15/NP16
Eocene	CP13	*Nannotetrina quadrata*	CP13c	*Coccolithus staurion*	NP15/NP16
Eocene	CP13	*Nannotetrina quadrata*	CP13b	*Chiasmolithus gigas*	NP15/NP16
Eocene	CP13	*Nannotetrina quadrata*	CP13a	*Discoaster strictus*	NP15/NP16
Eocene	CP12	*Discoaster sublodoensis*	CP12b	*Rhabdosphaera inflata*	NP14
Eocene	CP12	*Discoaster sublodoensis*	CP12a	*Discoasteroides kuepperi*	NP14
Eocene	CP11	*Discoaster lodoensis*			NP12/NP13
Eocene	CP10	*Tribrachiatus orthostylus*			NP12/NP13
Eocene	CP9	*Discoaster diastypus*	CP9b	*Discoaster binodosus*	NP11
Eocene	CP9	*Discoaster diastypus*	CP9a	*Tribrachiatus contortus*	NP10
Paleocene	CP8	*Discoaster multiradiatus*	CP8b	*Campylosphaera eodela*	NP9
Paleocene	CP8	*Discoaster multiradiatus*	CP8a	*Chiasmolithus bidens*	NP9
Paleocene	CP7	*Discoaster nobilis*			NP7/NP8
Paleocene	CP6	*Discoaster mohleri*			NP7/NP8
Paleocene	CP5	*Heliolithus kleinpellii*			NP6
Paleocene	CP4	*Fasciculithus tympaniformis*			NP5
Paleocene	CP3	*Ellipsolithus macellus*			NP4
Paleocene	CP2	*Chiasmolithus danicus*			NP3
Paleocene	CP1	*Zygodiscus sigmoides*	CP1b	*Cruciplacolithus tenuis*	NP2
Paleocene	CP1	*Zygodiscus sigmoides*	CP1a	*Cruciplacolithus primus*	NP1

Figure 4. Coccolith zonation and supplementary codes used for this chapter (Bukry, 1973a, 1975; Okada and Bukry, 1980).

of discoasters, especially *D. pentaradiatus* and *D. surculus* Martini and Bramlette. Both taxa, however, occur in the lower Pliocene at Site 467.

The highest occurrence of *Discoaster brouweri* Tan and common *Calcidiscus macintyrei* (Bukry and Bramlette) in Core 9 is used to correlate the top of the Pliocene. Sample 8,CC contains the last *C. macintyrei* without discoasters and is assigned to the lower Pleistocene *Emiliania annula* Subzone. A mixed-temperate environmental aspect of the Quaternary assemblages is shown by the persistence of cool-water *Coccolithus pelagicus* (Wallich) and warm-water *Ceratolithus cristatus* Kamptner through Cores 1 to 5. Cold-water *C. pliopelagicus* Wise is sparser at Site 467 than at Site 173, and *C. pelagicus* is missing from coeval DSDP Leg 54 sites near the southern end of the California Current. Therefore the Quaternary coccolith assemblages from the Site 467 region of the California Current suggest a gradational change in assemblages southward along the current.

The coccolith record at Site 467 shows climatic changes from warm in early middle Miocene (*Coccolithus miopelagicus* Bukry, emended, Wise; *Cyclicargolithus floridanus* [Roth and Hay]; *Discoaster deflandrei* Bramlette and Riedel; *D. exilis* Martini and Bramlette; *Sphenolithus heteromorphus* Deflandre; *S. neoabies* Bukry and Bramlette), to cool in late middle Miocene to early Pliocene (low diversity with *Discoaster variabilis* Martini and Bramlette and *Reticulofenestra pseudoumbilica* [Gartner] and essentially no *Ceratolithus*, *Discoaster loeblichii* Bukry, *D. pentaradiatus* Tan, *D. quinqueramus* Gartner, *D. surculus* Martini and Bramlette, or *Triquetrorhabdulus*), to warm in middle Pliocene (*Ceratolithus*, *Discoaster asymmetricus* Gartner, *D. pentaradiatus* Tan, and *D. tamalis* Kamptner), to mixed cool and warm in the Pleistocene (by fluctuations in *Ceratolithus*, *Coccolithus*, and *Gephyrocapsa*). The lower 55 cores (representing most of the Miocene) lack diatoms, radiolarians, and even planktonic foraminifers, suggesting deposition from a sluggish or distal portion of any eastern boundary current. Changes in submarine topography or current circulation patterns in the late Miocene apparently brought the San Miguel Gap area under the active part of the California Current, because the low-fertility coccolith claystones and siltstones pass upward into diatom-, silicoflagellate-, radiolarian-, ebridian-, and dinoflagellate-bearing biogenic ooze. This change indicates the higher fertility of upwelled waters, in contrast to the deeper cores where coccolith predominance indicates low to moderate fertility.

Site 468
(32°37.03′N, 120°07.07′W, depth 1849 m)
Holes 468A and B
(32°37.41′N, 120°06.55′W, depth 1737 m)

Warm-water coccoliths characterize the short Pliocene and Quaternary interval at Holes 468, 468A, and 468B. Most of the cores from Site 468 are barren or contain middle Miocene *Discoaster exilis* Zone or *Sphenolithus heteromorphus* Zone coccoliths. The upper Mio-

cene occurs in only a few cores, suggesting one or more major hiatuses. The upper Miocene to lower Pliocene at Hole 468A, Core 4, is notable for the presence of a cool-water facies with discoasters dominated by *Discoaster variabilis* Martini and Bramlette and for a warm-water facies with discoasters dominated by *D. brouweri* Tan, *D. pentaradiatus* Tan, and *D. surculus* Martini and Bramlette. Site 468 assemblages appear warmer than those of Site 467 on the basis of *Ceratolithus* in the Pliocene and more common *Discoaster*, *Discolithina*, *Helicosphaera*, and *Sphenolithus* in the middle Miocene. Preservation is generally moderate throughout Site 468; solution is less severe than at Site 467. Overgrowth occurs only in the middle Miocene and is minor.

Many Leg 63 Miocene discoasters have exceptionally large central stems, the most prominent being *Discoaster sanmiguelensis* n. sp., which is common in Sample 468-7-3, 50–51 cm (55 m). Warm-water *D. signus* Bukry occurs sparsely in the thick *Coccolithus miopelagicus* Subzone of Site 468, being noteworthy in Sample 468-7-3, 50–51 cm, where warm-water *Sphenolithus* is abundant.

Site 469
(32°37.00′N, 120°32.90′W, depth 3790 m)

Lower Miocene to upper Quaternary coccolith assemblages are typically abundant, diverse, and moderately well preserved at Site 469. Lower upper Miocene warm-water discoasters—*Discoaster bellus* Bukry and Percival, *D. loeblichii* Bukry, *D. neohamatus* Bukry and Bramlette, and *D. pentaradiatus* Tan—in Cores 13 to 18 distinguish the Site 469 assemblages from cooler-water, less diverse assemblages of the upper Miocene at Site 467. Although the upper Miocene record is less complete at nearby Site 468, the correlative assemblages are similar to those at Site 469 for the upper Miocene, suggesting a similar oceanographic environment.

Reworked Eocene or Oligocene coccoliths give some evidence for the amount and duration of erosion in the vicinity of Site 469. Displaced Eocene and Oligocene species are sparse in middle and lower Miocene Cores 27, 32 to 39, and 43, common in middle Miocene Cores 28 to 31, and absent in Quaternary to middle Miocene Cores 1 to 26. This distribution is in contrast to Site 467, where reworked Eocene and Oligocene specimens are recorded only from the Pliocene and Quaternary.

The oldest coccoliths from Site 469 are sparse, moderately preserved specimens from a baked, reddish, metalliferous sediment intercalated with basalt in Core 45. A smear slide of Sample 469-45-1, 90–93 cm contains *Helicosphaera carteri*, which indicates deposition in the early Miocene or later. The oldest sediment above basalt, in Core 43, probably belongs to the lower part of the *Helicosphaera ampliaperta* Zone, considered to be of late early Miocene age (Bukry, 1979). An overlap between *Sphenolithus heteromorphus* Deflandre and *Triquetrorhabdulus milowii* Bukry suggests the lower part of the *H. ampliaperta* Zone (Bukry, 1971a) comprises Core 43. *Helicosphaera ampliaperta* Bramlette and Wil-

coxon ranges from Sections 469-36-1 to 469-38-2; deeper samples contain *S. heteromorphus* without *H. ampliaperta*.

A diabase sill cored in Cores 40 to 42 (368.5–387 m) is within the *H. ampliaperta* Zone (approximately 15.5–17.5 m.y. old). *S. heteromorphus* Zone (approximately 14–15.5 m.y. old) assemblages from Core 24 to Core 35, providing evidence for a high rate of sedimentation for the middle Miocene. Four cores from the interval, however, contain sandy sediments with reworked Eocene or Oligocene coccoliths, such as *Chiasmolithus grandis* (Bramlette and Riedel), *Dictyococcites bisectus* (Hay, Mohler, and Wade), *Discoaster barbadiensis* Tan, and *Reticulofenestra umbilica* (Levin).

The middle Miocene *Discoaster exilis* Zone of Core 19 is separated from the upper Miocene *Discoaster neohamatus* Zone in Core 17 by a probable unconformity. After encountering a "sand" during the cutting of Core 18, there was difficulty in retrieving the core barrel. It is apparent from the mixed colors and late Miocene ages of the pea-sized drill cuttings constituting Core 18 that flow-in occurred. *Discoaster* sp. cf. *D. kugleri* Martini and Bramlette occurs in Core 19 in the upper part of the *D. exilis* Zone, which suggests correlation to Core 90 at Site 467.

Discoaster neohamatus Bukry and Bramlette s. str. is present in Core 15 and represents the northernmost record of this tropical and subtropical species in the eastern Pacific. The *D. neohamatus* Zone, also identified by the use of *D. bellus* Bukry and Percival, *D. brouweri* Tan, *D. loeblichii* Bukry, *D. prepentaradiatus* Bukry and Percival, and *Minylitha convallis* Bukry, ranges from Core 14 to Core 17 (121.5–159.5 m). Silicoflagellates are especially common and diverse in this interval, suggesting fertile and variable oceanographic conditions. *Minylitha convallis* appears relatively late at Site 469, within the *Discoaster neohamatus* Zone in Section 469-15-1, just below the first *Discoaster loeblichii* Bukry in Section 469-14-2. The Section 469-14-2 assemblage also contains the Pacific Coast middle-latitude species *Discoaster mendomobensis* Wise. On the basis of its occurrence in Section 469-14-2 and in another borderland dart core, *D. mendomobensis* appears to range slightly below *D. quinqueramus*, creating a possible offset between the *Discoaster variabilis* Zone/*Discoaster mendomobensis* Zone boundary of middle latitudes and the *Discoaster neohamatus* Zone/*Discoaster quinqueramus* Zone boundary of low latitudes (Bukry, 1973b) along the Pacific Coast.

The paucity of *Ceratolithus*, *Discoaster quinqueramus* Gartner, and *Triquetrorhabdulus rugosus* Bramlette and Wilcoxon precludes precise placement of the Miocene/Pliocene boundary. *Amaurolithus primus* (Bukry and Percival) ranges through the interval in Cores 10 and 13 and indicates the *Amaurolithus primus* Subzone or *Amaurolithus tricorniculatus* Zone. A brief mid-latitude overlap between *Amaurolithus delicatus* Gartner and Bukry and *Discoaster asymmetricus* Gartner occurs in Core 10 and is recorded as the local *Amaurolithus delicatus* Subzone (CN10d). Other taxa present in the Core include *Ceratolithus* sp. aff. *C. acutus* Gartner and Bukry, *C. rugosus* Bukry and Bram-

lette, and *A. primus* (Bukry and Percival), which helps to confirm a lower Pliocene correlation.

The upper nine cores contain a seemingly incomplete upper Pliocene and Quaternary coccolith succession, although the recovered sediment commonly is disturbed by drilling operations. *Discoaster* and *Gephyrocapsa* are sufficiently diverse to permit recognition of low-latitude subzones. However, cool-water *Coccolithus pelagicus* (Wallich) is present throughout the Quaternary and Pliocene, and warm-water *Ceratolithus* occurs only at the top of the interval, in the upper *Emiliania ovata* Subzone of Core 3 and in Pliocene Cores 6 and 9. This contrasts with the prominent occurrences of these taxa at the southern end of the California Current in the coring area of DSDP Leg 54 (Bukry, 1980).

Site 470
(28°54.46′N, 117°31.11′W, depth 3549 m)

Lower middle Miocene to Quaternary coccoliths are abundant and moderately well preserved in 25 sediment cores above basalt at Holes 470 and 470A, east of Guadalupe Island. A limestone within the basalt section (Hole 470A, Core 12) contains common but poorly preserved coccoliths of the lower middle Miocene *Sphenolithus heteromorphus* Zone (14–15.5 m.y. old). The same zone is present directly above basalt.

The deepest coccolith assemblages above basalt at both holes belong to the *Sphenolithus heteromorphus* Zone. At Hole 470A the boundary with the overlying *Coccolithus miopelagicus* Subzone (approximately 14 m.y.) is within Core 6. The sediment in lower Core 6 and in Core 7 contains dolomite rhombs, which are most abundant just above basalt (all coccoliths are missing due to diagenesis) and diminish in size and number upward. Thus within 4.4 meters above basalt the sediment of Sample 470A-6-1, 1 cm (161.5 m) is a nearly pure coccolith ooze with no clumped coccoliths or rhombs.

The sequence of coccolith zones at Holes 470 and 470A corresponds closely with the ranges and zones reported from the nearby Experimental Mohole (EM) drillsite (Martini and Bramlette, 1963; Martini, 1971; not Martini, fide Schrader, 1974, who erroneously references Martini, 1971, who never recognized NN5 or NN11 in EM samples and reported NN7 and NN10 only from single samples). Correlation of coccolith zones from the EM site (Martini, 1971) and Site 470 is illustrated in Figure 5. The close correspondence in the depth reported for key coccolith events by Martini and Bramlette (1963) and by this study is shown in the following coccolith correlations:

Coccolith Event	EM-8		DSDP 470	
	Core	Depth (m)	Core	Depth (m)
Highest				
Discoaster hamatus	11	95–105	11	95–105
Lowest				
Catinaster calyculus	13	113–122	12	105–114
Lowest				
Discoaster kugleri	14	122–131	14	123.5–133.0

Age	Zone or Subzone	EM	470	470A
Quaternary	E. ovata	WASHED	1,CC to 2,CC	WASHED
Quaternary	E. annula	WASHED	?3-3	WASHED
Pliocene	C. macintyrei	—	?3-3 to 4-2	WASHED
Pliocene	D. pentaradiatus	—	4-3 to 4,CC	WASHED
Pliocene	D. surculus	—	5-1 to 5-2	WASHED
Pliocene	D. tamalis	—	5-3	WASHED
Pliocene	D. asymmetricus	—	6-2	WASHED
Late Miocene	A. primus to A. tricorniculatus	—	6,CC to 7-3	1-1 to 1,CC (?)
Late Miocene	A. primus	—	8-1	2-1 to 3-2
Late Miocene	D. berggrenii	—	8,CC (?)	3-5 to 4-1
Late Miocene	D. neorectus	8-10 (383–384)	9-2 to 11-5	4-5
Late Miocene	D. bellus	8-10 (383–384)	9-2 to 11-5	5-1 to 5,CC (?)
Middle Miocene	C. calyculus	8-11 (286) to 8-12 (226–229) & 8-11 (70–72) ?	11-6 to 12-5	WASHED
Middle Miocene	H. carteri	8-11 (286) to 8-12 (226–229) & 8-11 (70–72) ?	—	WASHED
Middle Miocene	D. kugleri	8-14 (384–387)	14-1	WASHED
Middle Miocene	C. miopelagicus	8-15 (34–37) to 7-5 (5)	14-2 to 17,CC	6-1 to 6-2
Middle Miocene	S. heteromorphus	—	18-1 to 18-2	6-2 to 12-1*

Figure 5. Coccolith zonation for Guadalupe Island oceanic cores . (* indicates brackets basalt recovered in Cores 7 to 11 of Hole 470A. The Experimental Mohole Site [EM] was cored in 1961; the coccolith stratigraphy was reported in Martini and Bramlette [1963] and Martini [1971].)

Middle and lower upper Miocene assemblages of Holes 470 (Cores 11–18) and 470A (Cores 6, 7, 12) are warm temperate (like Site 469), on the basis of common discoasters and sparse *Helicosphaera, Triquetrorhabdulus,* and *Sphenolithus heteromorphus. S. heteromorphus. S. heteromorphus* (with secondary calcite overgrowths) is common only in Sample 470A-7-1, 1 cm

(166.5 m), where its enrichment is considered to be a diagenetic effect at the expense of less durable species. Short-ranged *Discoaster kugleri* of the middle Miocene occurs in Sample 470-14-1, 7 cm (124 m) and permits correlation to Core 90 of Site 467.

The first record of low-latitude guide species *Catinaster calyculus* Martini and Bramlette s. str. and *Dis-*

coaster hamatus Martini and Bramlette s. str. for Leg 63 permits direct identification of part of the *Discoaster hamatus* Zone between Samples 470-12-5, 50–51 cm (110 m) and 470-11-6, 50–51 cm (105 m). The basal *C. calyculus* in Sections 470-12-4 and 470-12-5 conform to the Martini and Bramlette-type suite but have straight rays instead of the more diagnostic curved rays. An occurrence of a curved-ray form in Core 13 is considered to be part of an in-hole slump. The upper Miocene *Discoaster neohamatus* Zone and *Discoaster quinqueramus* Zone also contain more common warm-water species that persist through thicker intervals than at Sites 467 and 469. Cool-water coccolith facies, rich in *Reticulofenestra, Discoaster intercalaris* Bukry, and *D. variabilis* Martini and Bramlette, however, are interspersed throughout these zones. Highlights of the upper Miocene, which was double cored in Hole 470A to fill in core-loss gaps for detailed studies, include the first reports of *Catinaster mexicanus* Bukry from the west coast of Mexico (Sample 470A-3,CC to Section 470A-4-6). This rarely reported species was first described from DSDP Leg 1 cores from the Gulf of Mexico. The presence of large-sized *Discoaster quinqueramus* Gartner is established for the first time from the Guadalupe area in Section 470-8-1.

The difficulty in identifying the Miocene/Pliocene boundary by calcareous microfossils for Leg 63 persists at Site 470. The *Amaurolithus primus* Subzone to *A. tricornicatus* Zone interval that includes the boundary cannot be subdivided because the cool-water coccolith assemblages lack the key guide fossils—persistent *D. quinqueramus* and any *Amaurolithus amplificus* (Bukry and Percival) in the *A. primus* Subzone and any *Triquetrorhabdulus rugosus* Bramlette and Wilcoxon, *Ceratolithus acutus* Gartner and Bukry, or *C. rugosus* Bukry and Bramlette in the *A. tricorniculatus* Zone.

The Pliocene section, according to coccoliths, begins with the *Discoaster asymmetricus* Subzone in Section 470-6-2. The Pliocene assemblages are warm temperate with a few *C. rugosus* Bukry and Bramlette in the *Discoaster tamalis* Subzone, abundant *Discoaster pentaradiatus* Tan in the *Discoaster pentaradiatus* Subzone, but *Coccolithus pelagicus* (Wallich) throughout. The top of the Pliocene is practically in Core 3 on the basis of the last common occurrence of *Discoaster brouweri* Tan and *D. triradiatus* Tan in Sample 470-4-1, 30 cm (29 m) (Haq et al., 1977). *Calcidiscus macintyrei* (Bukry and Bramlette), which marks the top of the Pliocene in the Mediterranean region (Bizon and Müller, 1978) and persists through the *Emiliania annula* Subzone (Bukry, 1973a), is common in Sample 470-3,CC but missing in Sample 470-2,CC.

The Quaternary coccolith assemblages of Cores 1 to 3 in Hole 470 are low-diversity, temperate assemblages characterized by *C. pelagicus* (Wallich), *Calcidiscus leptoporus* (Murray and Blackman), *Emiliania annula* (Cohen) (synonym = circular *Pseudoemiliania lacunosa* Kamptner, invalid fide Loeblich and Tappan, 1970), *E. ovata* Bukry, *Gephyrocapsa caribbeanica* Boudreaux

and Hay, *G. oceanica* Kamptner, and *Helicosphaera carteri* (Wallich).

It is difficult to speculate on the geologic record of the California Current in this region, because there are no DSDP sites on the distal or oceanic side of the zone that was presumably occupied by the current. An observation on the paucity of seabirds and jellyfish at Site 470 suggests that it was not within the active, seasonal, high-fertility zone of the current (R. Wolfart, personal communication, 1978) when drilling took place at this site. The Quaternary and Pliocene sediment of Site 470 show a persistence of coccoliths but only sporadic and rare diatoms and radiolarians. Does this imply that the site has not been under the current for 4 m.y., or that the current was weakened at these latitudes? Both possibilities assume that siliceous microfossils are the keys to identify the current. Coccolithophores persist whether upwelling is present or not.

High biogenic sedimentation rates could also be used to identify earlier tracks of the California Current. But, again, a reference site outside the distal margin of the current would help put into perspective the sedimentation values within the presumed area of the current.

On the basis of coccolith data from Site 470, the current during the middle Miocene was stable and moderately warm, the current during the late Miocene was unstable with alternating warm and cool phases, and during the Pliocene to the Quaternary, the current was unstable and weak and possibly located considerably east or west of Site 470.

Site 471
(23°28.93′N, 112°29.78′W, depth 3101 m)

Coccoliths recovered at Site 471 represent only short intervals of time. The oldest assemblages, just above basalt, in Core 79 belong to the upper *Sphenolithus heteromorphus* Zone (approximately 14 Ma; Bukry, 1975). The overlying *Coccolithus miopelagicus* Subzone (approximately 13.4–14 Ma) extends through a thick interval from Core 39 to Core 78 (368–737 meters), but the short time span involved yields an exceptionally high sedimentation rate (369 m/0.6 m.y. = 615 m/m.y.). In this interval (Lithologic Unit 4 in the Site 471 report), which is characterized by turbid-flow sedimentary structures, reworked Cretaceous and Paleogene coccoliths occur (Fig. 6). Another thick interval from Cores 6 to 39 (55–368 meters) is barren of coccoliths. Pleistocene to lower Pliocene coccoliths are sparse to abundant in the upper cores, Sample 1,CC to Core 6 (9.5–52 m), representing the time interval from approximately 0.5 Ma to 4 Ma. The upper part of Core 1 was not investigated.

All sediment layers intercalated with the igneous rocks of Cores 80 to 88 that were examined for coccoliths are barren. The lower middle Miocene *Sphenolithus heteromorphus* Zone assemblages of Cores 78 and 79 are similar to overlying assemblages, except for the presence of *Sphenolithus heteromorphus* Deflandre, more common *Cyclicargolithus floridanus* (Roth and Hay), and the only observation of overgrowth (+2 to

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Core	Arkhangelskiella cymbiformis	Broinsonia parca	Cribrosphaera ehrenbergii	Eiffellithus eximius	Marthasterites furcatus?	Micula decussata	Prediscosphaera cretacea	Tetralithus trifidus	Watznaueria barnesae	Chiasmolithus consuetus	Discoaster multiradiatus	Heliorthus distentus	Sphenolithus anarrhopus?	Coccolithus crassus	Discoaster barbadiensis	Helicosphaera lophota?	Helicosphaera seminulum	Coccolithus formosus	Dictyococcites bisectus	Discoaster deflandrei?	Reticulofenestra umbilica	Cyclicargolithus abisectus
38																						
39		X		X		X	X	X	X	X	X			X	X			X	X			
40						X			X	X												
43																					X	
44																					X	
45																						
47																				X		
50																						
52	X			X																		
54		X					X			X				X								
56					X	X		X								X						
59																				X		
61	X					X							X					X	X			
65																						
70																						
72						X															X	X
73						X															X	
75						X																
77																		X				
78						X															X	

Figure 6. Upper Cretaceous and Paleogene reworked coccoliths from DSDP Site 471, Cores 38 to 78 (only every fifth core is numbered).

+ 3; Bukry, 1973a) at Site 471 (in Sample 471-79-1, 7 cm [751 m]; this sample also contains some fragments of pyritized centric diatoms).

Dark olive, clay-rich siltstone directly above basal, blue gray sandstone in the sequence of repeated similar turbidite units of the *Coccolithus miopelagicus* Subzone of Cores 39 to 78 yields the largest, most diverse coccoliths. Lighter-colored claystone from higher in the individual turbidite units yields mostly smaller less diverse coccoliths. Many sediment layers are barren or poor, producing an uneven record of abundance and preservation through the subzone. Reworked Cretaceous coccoliths in Cores 39 to 79 appear to represent Campanian to Maestrichtian horizons. Similar coccoliths occur on-shore at San Diego (Bukry and Kennedy, 1969). Coc-coliths such as *Discoaster multiradiatus* Bramlette and Riedel indicate that upper Paleocene strata were a source of reworking.

Upper Pliocene assemblages are diverse, with up to 19 taxa recorded in some samples. Warm-water discoasters (such as *D. decorus* [Bukry] and *D. black-stockae* Bukry) occur, as do solution-susceptible taxa, such as *Scyphosphaera*, *Syracosphaera*, and even one *Braarudosphaera* in Sample 471-5-3, 50–51 cm (40 m). Lower Pliocene coccoliths of Cores 5 and 6 are common to abundant and etched. The assemblages are assigned to the *Discoaster asymmetricus* Subzone on the basis of *Reticulofenestra pseudoumbilica* (Gartner), *Spheno-lithus abies* Deflandre, *Discoaster tamalis* Kamptner, and *D. asymmetricus* Gartner as deep as Sample 471-

6-2, 50–52 cm (50 m). One reworked *A. delicatus* Gartner and Bukry occurs in Sample 471-5,CC. Coccoliths are missing in the interval from Sections 471-6-4 to 471-39-1, where carbonate occurs as rhombs and granules.

The Pliocene/Pleistocene boundary may be in a condensed section or cut out by a hiatus, because the *Gephyrocapsa caribbeanica* Subzone of Section 471-4-0 (28.5 m) overlies the *Discoaster surculus* Subzone of Sample 471-4-2, 52–53 cm (32 m). Pleistocene assemblages contain *Gephyrocapsa oceanica* Kamptner, having high-angle bars, and *Coccolithus pelagicus* (Wallich), indicating temperate influences.

Site 472
(23°00.35′N, 113°59.71′W, depth 3831 m)

To obtain a comparative pelagic record of the Neogene, Site 472 is located seaward of the terrigenous sedimentary sources that affected the area of Site 471 and, also, beyond the California Current. Unfortunately, no coccolith assemblages younger than middle Miocene are present, although a diverse, upper Miocene, biogenic siliceous record is preserved. Cores 1 to 9 of Hole 472 and Core 1 of Hole 472A are barren of coccoliths. Middle Miocene coccolith assemblages are common to abundant and moderately well preserved; these range from the *Sphenolithus heteromorphus* Zone just above basalt in Core 13 (110–112 m) to the *Catinaster coalitus* Zone in Core 10 (82–91 m). A limestone from Section 471-15-1 is the only coccolith-bearing sediment recovered from the basalt interval at either Hole 472 or Hole 472A. The low-diversity assemblage is dominated by *Cyclicargolithus floridanus* (Roth and Hay) and represents a residuum of durable species that probably belongs to the overlying *S. heteromorphus* Zone. A *S. heteromorphus* Zone assemblage occurs in a black manganese oxide fragment in Sample 472-13,CC. The zone extends as high as Section 2 in Core 12 within the dark brown clay beds.

The overlying *Coccolithus miopelagicus* Subzone ranges from Section 472-12-2 (103 m) to Sample 472-11-1, 10 cm (91 m). *C. floridanus* is common throughout the subzone, suggesting that the top was not sampled. The most consistently occurring discoasters in the subzone are *D. exilis* Martini and Bramlette, *D. sanmiguelensis* n. sp., and *D. variabilis* Martini and Bramlette. *D. deflandrei* Bramlette and Riedel and *D. moorei* Bukry are sparser, and *D. signus* Bukry, a warm-indicating species, is recorded only from the base of the subzone in Sample 472-12-2, 55 cm (103 m). *D. signus* does, however, occur through the underlying *S. heteromorphus* Zone, supporting the early middle Miocene Pacific warming shown by Douglas and Savin (1973) to have occurred in foraminiferal Zone N9, which is equivalent to the *S. heteromorphus* Zone. *Catinaster coalitus* Martini and Bramlette occurs in Sample 472-10,CC with *Coccolithus* sp. aff. *C. miopelagicus* Bukry, indicating the upper middle Miocene *Catinaster coalitus* Zone. Owing to poor recovery in Cores 10 and 11, or to a hiatus, the intervening *Discoaster kugleri* Subzone is missing.

Site 473
(20°57.92′N, 107°03.81′W, depth 3249 m)

Site 473 on the Rivera plate west of Tres Marias Islands contains rare to common, poorly to moderately preserved Quaternary coccoliths in Cores 1 to 10 (0–86 m). Preservation and abundance are worst in Cores 6 to 10 (39–86 m).

Upper Pliocene assemblages of Cores 11 to 15 (86–134 m) are sparse to few, with evident solution effects. No lower upper Pliocene *Discoaster tamalis* Subzone assemblages occur. Because of the presence of *Ceratolithus rugosus* Bukry and Bramlette, *Reticulofenestra pseudoumbilica* (Gartner), and *Sphenolithus abies* Deflandre, Cores 16 to 18 (134–162 m) are assigned to the lower Pliocene. All three cores are tentatively assigned to the *Sphenolithus neoabies* Subzone because of the absence of younger *Discoaster tamalis* Kamptner and older *Amaurolithus* spp. The poor assemblages of Cores 19 to 22 and the lack of any *Amaurolithus* spp. in deeper cores make the duration of the *S. neoabies* Subzone and the placement of the Miocene/Pliocene boundary questionable.

Discoaster quinqueramus Gartner ranges through Cores 23 to 27 (191–238 m) and indicates the upper upper Miocene *Discoaster quinqueramus* Zone (approximately 5.6–7 m.y.) or possibly reworking and redeposition by turbidite flows during earliest Pliocene. Shipboard sedimentologists noted turbidite sequences in Cores 26 to 28. An *in situ* occurrence of the *D. quinqueramus* Zone is favored because of its presence through the overlying claystone of Cores 23 to 25. This would yield an estimated age of 6 to 7 m.y. at the top of the diabase sill in Core 29 (248–252 m). Core 28 is barren. And the sediment that was recovered in diabase Section 473-30-2 is barren.

UPPER CENOZOIC COCCOLITH ASSEMBLAGES FROM A PACIFIC COAST TRAVERSE

The DSDP Pacific Coast Sites 173 and 467 to 473 provide the opportunity to compare assemblages of similar age at various latitudes from about 40°N to 20°N. From the mid-Miocene to the Quaternary, many assemblage differences follow north–south trends, presumably related to temperature gradations along the coast (Addicott, 1970; Lynn, 1967). A group of coccolith genera was selected for survey counts of 100 specimens to assess changing ecologic controls on key stratigraphic taxa off the Pacific Coast. The seven genera selected are the source of the majority of the zonal guide species for the Miocene to Quaternary. The ratio of warm-indicator *Discoaster* to cool-indicator *Coccolithus* was calculated from these surveys. A second survey of 100 specimens counted all of the *Discoaster* species present, because some species like *D. brouweri* and *D. signus* are abundant under warm-water conditions, whereas others like *D. intercalaris* or *D. variabilis* are most numerous under temperate conditions.

Seven biostratigraphic zones or subzones through the Miocene to Quaternary were selected to provide maximum representation of the sites across latitude (Fig. 7).

Age	Zone or Subzone	Northern			DSDP Sites			Southern
		173	467	469	470	471	472	473
					Latitude N.			
		39°57.71'	33°50.97'	32°37.00'	28°54.46'	23°28.93'	23°00.35'	20°57.92'
Quaternary	Emiliania ovata CN14a	3-2 (70–71 cm)	5-3 (50–51 cm)	4-2 (50–51 cm)	1,CC	–	–	5,CC
Late Pliocene	Calcidiscus macintyrei CN12d	12-6 (20–21 cm)	17-3 (50–51 cm)	7-1 (50–51 cm)	4-1 (30 cm)	–	–	11,CC
Late Pliocene	Discoaster tamalis CN12a	13-6 (17–18 cm)	25-3 (9–10 cm)	8-3 (100–102 cm)	5-3 (50–51 cm)	4-5 (100–102 cm)	–	–
Late Miocene	Amaurolithus primus CN9b	15-4 (20–21 cm)	52-1 (50–51 cm)	13-1 (50 cm)	8-1 (75 cm)	–	–	27-1 (76 cm)
Late Miocene	Discoaster bellus CN8a	19-4 (20–21 cm)	73-1 (45 cm)	17,CC	5A-1 (22 cm)	–	–	–
Mid-Miocene	Discoaster kugleri CN5b	21-3 (20–21 cm)	90-2 (25 cm)	19-1 (20–21 cm)	14-1 (7 cm)	–	–	–
Mid-Miocene	Sphenolithus heteromorphus CN4	29-2 (20–21 cm)	100,CC	25,CC	18-2 (69–70 cm)	79-1 (34 cm)	12-2 (59–61 cm)	–

Figure 7. Array of samples used to compare changes in coccolith assemblages from DSDP Pacific Coast sites for different zonal time slices. (Water depths from 2927 m at Site 173 to 3249 m at Site 473 are variable [see site summaries] and show no direct correlation between latitude and depth, although the three northern sites are shallowest.)

Calcareous microfossil assemblages of similar age for each zone or subzone are available for comparison at Sites 173 and 467 to 470. Several gaps occur in the stratigraphy of southern Sites 471 to 473 because of dissolution and erosion.

Time slices involving samples in which coccoliths are not zonally diagnostic (e.g., younger intervals of Site 173) are correlated using diatom stratigraphy for the sites (Barron, this volume).

The Quaternary *Emiliania ovata* Subzone (CN14a) is the youngest unit studied. Among the genera selected for counting, *Coccolithus* is considered the cool-indicating taxon because of its Holocene limitation to waters colder than 14°C in the Atlantic (McIntyre et al., 1970). *Helicosphaera* is generally considered a warm-water taxon (20°C–28°C), however, its range does extend as low as 8°C (Roth and Berger, 1975). Its high relative abundance at southern Sites 470 and 473 (Fig. 8) supports warm-water conditions, but the additional presence of numerous *Pontosphaera* and *Thoracosphaera* and reworked Cenozoic coccoliths could also indicate increased coastal turbidity as a factor contributing to its abundance.

A dramatic change in the *Discoaster/Coccolithus* ratio from Site 173 southward to Site 473 in the uppermost Pliocene *Calcidiscus macintyrei* Subzone CN12d (Fig. 9) shows a strong temperature gradient (i.e., warmer to the south), second only to that indicated for lower upper Pliocene CN12a. The large 50% abundance of *Helicosphaera* at northern Site 173 is based on a great

Quaternary *Emiliania ovata* Subzone CN14a							
	Genera						
DSDP Sample (interval in cm)	*Amaurolithus*	*Ceratolithus*	*Coccolithus*	*Discoaster*	*Helicosphaera*	*Sphenolithus*	*Triquetrorhabdulus*
173-3-2, 70–71	–	–	99	–	1	–	–
467-5-3, 50–51	–	2	97	–	1	–	–
469-4-2, 50–51	–	3	88	–	9	–	–
470-1,CC	–	1	26	–	72	–	–
473-5,CC	–	–	–	–	100	–	–

Figure 8. Percentages of selected coccolith genera in Pacific Coast assemblages of Subzone CN14a. (Values for each sample are from a survey of 100 specimens of selected genera. Samples are arrayed according to latitudinal location, with north at the top.)

bloom of the species *H. sellii* at high mid-latitudes. This same nannofacies, with *Coccolithus pelagicus* and *H. sellii* dominant, also occurs in DSDP Leg 12 in the North Atlantic (Bukry, 1972a) near the Pliocene/Pleis-

| Pliocene *Calcidiscus macintyrei* Subzone CN12d | | | | | | | | | | | | | |
DSDP Sample (interval in cm)	*Amaurolithus*	*Ceratolithus*	*Coccolithus*	*Discoaster*	*Helicosphaera*	*Sphenolithus*	*Triquetrorhabdulus*	*Discoaster/Coccolithus* Ratio	*Discoaster brouweri*	*D. triradiatus*	**D. barbadiensis*	**D. deflandrei*	**D. variabilis*
173-12-6, 20–21	–	–	50	–	50	–	–	0.0					
467-17-3, 50–51	–	–	95	4	1	–	–	0.04	90	4	X	2	4
469-7-1, 50–51	–	X	57	23	20	–	–	0.4	83	17			
470-4-1, 30	–	–	29	52	19	–	–	1.8	63	37			
473-11,CC	–	–	7	84	9	–	–	12.0	81	3			

Figure 9. Percentages of selected coccolith genera in Pacific Coast assemblages of Subzone CN12d. (Values for each sample are from a survey of 100 specimens of the selected genera. The *Discoaster/Coccolithus* ratios calculated from these values suggest a north–south paleotemperature trend. All of the *Discoaster* species encountered in a separate 100-specimen count are enumerated. * = Reworked taxon; X = recorded as present after the 100-specimen count was completed.)

tocene boundary. The variance in the proportions of *Discoaster brouweri* and *D. triradiatus* could represent a bracketing of a fairly narrow habitat for *D. triradiatus* by this traverse, a random selection of samples from various levels in the late Pliocene acme of *D. triradiatus*, or, less likely, variations in *D. brouweri* productivity at sites within the traverse.

The reversal in the *Discoaster/Coccolithus* ratio for the *Discoaster tamalis* Subzone CN12a (Fig. 10) occurs between Sites 467 and nearby Site 469. The degree of change in the ratio is large, as are the end-member values for Sites 173 and 471, indicating a strong north to south temperature gradient of warming. The restriction of warm-water species *Discoaster blackstockae, D. pentaradiatus,* and *Hayaster perplexus* to southerly Sites 469, 470, and 471 further emphasizes the temperature trend present in the generic count.

The *Discoaster/Coccolithus* ratio is less discriminating in the upper Miocene *Amaurolithus primus* Subzone CN9b than in shallower levels but suggests that the traverse region was relatively warm. Although discoasters were abundant, the count of species shows that temperate species *D. intercalaris* and *D. variabilis* are dominant in all but the southernmost site (Fig. 11) where *D. quinqueramus* is predominant.

Discoaster, dominated by temperate *D. variabilis*, is abundant throughout the traverse for the lower upper Miocene *Discoaster bellus* Subzone CN8a (Fig. 12). The concentration of warm-water species *Catinaster calyculus, Discoaster bellus, D. blackstockae,* and *D. neo-*

hamatus in southern sites and their absence at northernmost Site 173 suggests a temperature gradient. But the *Discoaster/Coccolithus* ratio gives a cooler value for Site 470 than for Sites 467 or 469. Therefore the generic ratio that was a convenient and consistent measure for the Pliocene is not as useful for the late Miocene of these sites. The change is likely the result of the evolution of different habitat requirements of new biologic species of the genera upsection. Another factor affecting the ratio could be carbonate solution, which may differentially remove somewhat more *Coccolithus* than *Discoaster*. Comparison of carbonate percentages from cored sediments to respective *Discoaster/Coccolithus* ratios is not a straightforward measure of carbonate solution, because of the terrigenous and volcanogenic dilution at many sites. But with this proviso in mind, a paleotemperature significance for the ratio does seem to override any solution effect for Subzone CN8a. The carbonate percentage and *Discoaster/Coccolithus* ratio, respectively, for Sites 173, 467, 469, and 470 are 12% and 2.4, 61% and 14.5, 77% and 17.7, 41% and 6.3. This relation shows the higher proportion of *Discoaster* with the higher carbonate percentages. The results for other zones are mixed or show the opposite trend. For example Subzone CN12d has the following values for Sites 173, 467, 469, 470, and 473: 14% and 0.0, 40% and 0.04, 38% and 0.4, 16% and 1.8, and 8% and 12.0. The last three sets match higher proportions of *Discoaster* with lower carbonate percentages, which could be caused by paleotemperature and/or solution. The

| Pliocene *Discoaster tamalis* Subzone CN12a | | | | | | | | | | | | | | | | | | | |
| DSDP Sample (interval in cm) | Selected genera | | | | | | | Discoaster/Coccolithus Ratio | Selected species | | | | | | | | | | | |
	Amaurolithus	*Ceratolithus*	*Coccolithus*	*Discoaster*	*Helicosphaera*	*Sphenolithus*	*Triquetrorhabdulus*		*Discoaster asymmetricus*	*D. blackstockae*	*D. brouweri*	*D. challengeri*	*D. intercalaris*	*D. pentaradiatus*	*D. sp. aff. D. surculus*	*D. tamalis*	*D. triradiatus*	*D. variabilis*	*D. spp. (indeterminate)*	*Hayaster perplexus*
173-13-6, 17—18	–	–	94	1	5	–	–	0.01					100							
467-25-3, 9—10	–	–	57	43	–	–	–	0.75	2	23	35		9					5	26	
469-8-3, 100—102	–	–	16	83	1	–	–	5.2	5	17	14		29	11	18	5			1	
470-5-3, 50—51	–	7	2	91	–	–	–	46.0	11		32	1	4	12	18	14	1		6	
471-4-5, 100—102	–	–	2	86	12	–	–	43.0	1	1	6			56	12	16			6	2

Figure 10. Percentages of selected coccolith genera in Pacific Coast assemblages of Subzone CN12a. (Values for each sample are from a survey of 100 specimens of the selected genera. Large differences in the Discoaster/Coccolithus ratios occurred in Subzone CN12a from north to south. All of the *Discoaster* and tropical *Hayaster* species encountered in a separate 100-specimen count are enumerated [the lone *Discoaster* specimen in the generic count for Site 173 precluded a 100 count].)

| Miocene *Amaurolithus primus* Subzone CN9b | | | | | | | | | | | | | | | | |
| DSDP Sample (interval in cm) | Selected genera | | | | | | | Discoaster/Coccolithus Ratio | *Discoaster* Miocene | | | | | | | |
	Amaurolithus	*Ceratolithus*	*Coccolithus*	*Discoaster*	*Helicosphaera*	*Sphenolithus*	*Triquetrorhabdulus*		*Discoaster brouweri*	*D. sp. aff. D. challengeri*	*D. intercalaris*	*D. pentaradiatus*	*D. quinqueramus s. ampl.*	*D. triradiatus*	*D. variabilis*	*D. spp. (indeterminate)*
173-15-4, 20—21	2	–	22	74	–	2	–	3.4	3	3	14		5		76	
467-52-1, 50—51	1?	–	–	99	–	–	–	> 99.0			60				40	
469-13-1, 50	1	–	1	98	–	–	–	98.0	9		11		6		53	21
470-8-1, 75	5	–	1	92	–	1	1	92.0	9		4	4	4	3	76	
473-27-1, 76	–	–	4	20	10	66	–	5.0	10				10	50	30	

Figure 11. Percentages of selected coccolith genera in Pacific Coast assemblages of Subzone CN9b. (Values for each sample are from a survey of 100 specimens of the selected genera. A predominance of temperate species *Discoaster intercalaris* and *D. variabilis* among the discoasters suggests that the temperature indicating capability of the *Discoaster/Coccolithus* ratio is poorer for the Miocene than the Pliocene. The *Discoaster* species count for Site 473 is part of the generic count, owing to the sparsity of specimens in the terrigenous-rich sediment.)

values for Site 467 suggest the opposite trend, with temperature overriding any solution effect. More detailed work on this relation should be done in future studies using coccoliths to analyze paleoenvironment.

An additional factor that might account for the reversals in Zone CN8, for example, are high-frequency climatic oscillations during the interval examined. Preliminary comparisons of climatic indices from foraminifers, diatoms, and silicoflagellates indicates a high-frequency oscillation during Subzone CN8a (Richard Z. Poore, personal communication, 1980). Therefore, the sampling of different parts of the climatic curve at dif-

| | Miocene *Discoaster bellus* Subzone CN8a | | | | | | | | | | | | | | | | | | | | | |
| | Selected genera | | | | | | | | Catinaster and Discoaster species | | | | | | | | | | | | | |
DSDP Sample (interval in cm)	*Amaurolithus*	*Ceratolithus*	*Coccolithus*	*Discoaster*	*Helicosphaera*	*Sphenolithus*	*Triquetrorhabdulus*	*Discoaster/Coccolithus* Ratio	*Catinaster calyculus*	*Discoaster bellus*	*D. sp. cf. D. blackstockae*	*D. braarudii*	*D. brouweri s. ampl.*	*D. challengeri*	*D. intercalaris*	*D. neohamatus*	*D. pansus*	*D. pseudovariabilis*	*D. triradiatus*	*D. variabilis*	*D. spp. (indeterminate)*
173-19-4, 20—21	–	–	24	57	–	19	–	2.4					2	3	7					79	6
467-73-1, 45	–	–	6	87	–	6	1	14.5		8	3						2			59	28
469-17,CC	–	–	3	53	–	43	1	17.7	1	38		5	6							42	8
470A-5-1, 22	–	–	10	63	–	26	1	6.3		27	1	4	8	1		4	1	1	2	42	9

Figure 12. Percentages of selected coccolith genera in Pacific Coast assemblages of Subzone CN8a. (Values for each sample are from a survey of 100 specimens of the selected genera. Relative values for the *Discoaster/Coccolithus* ratio do not show a consistent north–south trend, but the high value for Site 469 is supported by the occurrences of warm-water *Catinaster calyculus* and *Discoaster bellus*. All of the *Catinaster* and *Discoaster* species encountered in a separate 100-specimen count are enumerated.)

ferent sites could easily produce apparent reversals. Establishing these relations will require detailed work beyond the scope of this initial report.

The northern four sites of the Pacific Coast traverse recovered assemblages of, or correlative to, the relatively brief mid-Miocene *Discoaster kugleri* Subzone CN5b. *Discoaster* species are similar at sites south of Site 173; *D. kugleri* is missing at Site 173, which was correlated by diatom stratigraphy (Barron, this volume). A high *Discoaster/Coccolithus* ratio at Site 173 (Fig. 13) seems to indicate warm-water conditions, whereas the low diversity of the assemblages is more typical of cool-water conditions. The exceptionally high *Discoaster/Coccolithus* ratios at all four sites were checked against tropical Pacific Site 77 (00°28.90′N). This tropical *Discoaster/Coccolithus* ratio for Subzone CN5b is dramatically lower than for the Pacific Coast traverse sites, indicating that the *Coccolithus* species *C. miopelagicus* and *C. pelagicus* (s. ampl., small) tolerated warm water and cannot be employed as strictly cool-water indicators for the middle Miocene. Clearly, the center of the biogeographic range of *Coccolithus* changed considerably from the middle Miocene to the Quaternary.

A comparison of Zone CN4 at California Continental Borderland Site 470 and nearby Sites 471 and 472 to equatorial Pacific Site 77 (Hole 77B) shows that the numbers of *C. miopelagicus* and *C. pelagicus* s. ampl. are as high at the equatorial site as at the southernmost traverse sites: 12% to 25% of the selected genera count at Hole 77B (Cores 25–27), 11% to 13% at Sites 471 and 472, and up to 60% at Site 470. The *Discoaster/Coccolithus* ratios for Zone CN4 at Hole 77B (Cores 25–27) are also similar but lower, with values of 1.0 to 2.4. These similarities between the assemblages (owing to the

broader range of *Coccolithus* in the lower middle Miocene) are only apparent because the equatorial assemblages can be discriminated by using their much greater abundances of *Sphenolithus*. For example, compare the following *Sphenolithus* (S), *Discoaster* (D), *Coccolithus* (C) values from the selected genera counts to those of Leg 63: Samples 77B-25-2, 20–22 cm, S = 64%, D = 14%, C = 19%; 77B-25-6, 94–98 cm, S = 50%, D = 24%, C = 25%; 77B-27-4, 67–68 cm, S = 59%, D = 29%, C = 12%.

Evidence of a change, or evolution, in the optimum temperature preference of *Coccolithus* species can be seen in the total absence of *Coccolithus* in the upper Pliocene Subzone CN12a at equatorial Site 77 (Sample 77B-4-6, 70–71 cm). On the other hand, *Coccolithus* is present at all Pacific Coast traverse sites with increasing abundance northward. The 14°C limitation of modern *Coccolithus* certainly did not apply to the substantial middle Miocene (Zones CN4 and CN5) populations of *Coccolithus* found at equatorial Site 77. The difference in representation of the genus at equatorial sites between the Miocene and Pliocene is a matter of changing temperature tolerance of biologic species evolving in the genus.

An interval from the upper *Sphenolithus heteromorphus* Zone CN4 of the middle Miocene was compared across six DSDP sites included in a Pacific Coast traverse (Fig. 14). *Discoaster exilis* is dominant in all of the discoaster assemblages, however, warm-water *D. signus* is limited to the three southern sites, suggesting the existence of a temperature gradient. Solution was strongest at northern Site 173 where *Coccolithus* may have been differentially dissolved, because the highly resistant placoliths of *Cyclicargolithus* and *Reticulofenestra* are fragmented and etched. As in other Miocene in-

Miocene *Discoaster kugleri* Subzone CN5b															
	Selected genera							*Discoaster* species							
DSDP Sample (interval in cm)	*Amaurolithus*	*Ceratolithus*	*Coccolithus*	*Discoaster*	*Helicosphaera*	*Sphenolithus*	*Triquetrorhabdulus*	*Discoaster/Coccolithus* Ratio	*Discoaster* sp. aff. *D. bollii*	*D. braarudii*	*D.* sp. cf. *D. deflandrei* (tiny)	*D. exilis*	*D. kugleri*	*D. moorei*	*D. variabilis*	*D.* sp. (5-rayed)	*D.* spp. (indeterminate)
173-21-3, 20–21	–	–	–	78	–	22	–	>78.0				96					4
467-90-2, 25	–	–	X	80	–	20	–	>80.0	1			37	17		9		36
469-19-1, 20–21	–	–	1	89	–	10	–	89.0		2	3	34	29	2	12		18
470-14-1, 7	–	–	1	93	–	6	–	93.0		3		39	2	1	18	1	36
77B-20-4, 63–64	–	–	30	41	–	26	3	1.4	1			27	27		11		34

Figure 13. Percentages of selected coccolith genera in Pacific Coast and tropical Pacific (Site 77) assemblages of Subzone CN5b. (Values for each sample are from a survey of 100 specimens of the selected genera. All of the *Discoaster* species encountered in a separate 100-specimen count are enumerated. *Discoaster kugleri* is exceptionally common at Sites 77, 467, and 469. All four Pacific Coast assemblages are dominated by *Reticulofenestra* placoliths and fragments; *Coccolithus* is extremely sparse [X = recorded as present after the 100-specimen count was completed]. Tropical Site 77, however, contains a significant number of *Coccolithus miopelagicus* and *C. pelagicus* [s. ampl., small].)

Miocene *Sphenolithus heteromorphus* Zone CN4															
	Selected genera							*Discoaster* species							
DSDP Sample (interval in cm)	*Amaurolithus*	*Ceratolithus*	*Coccolithus*	*Discoaster*	*Helicosphaera*	*Sphenolithus*	*Triquetrorhabdulus*	*Discoaster/Coccolithus* Ratio	*Discoaster aulakos*	*D. braarudii*	*D. challengeri*	*D. deflandrei*	*D. exilis*	*D.* sp. aff. *D. sanmiquelensis*	*D. signus*	*D. variabilis* s. ampl.	*D.* spp. (indeterminate)
173-29-2, 20–21	–	–	17	82	–	1	–	4.8		1	1	6	48	9		35	
467-100,CC	–	–	65	21	1	13	–	0.32				5	62			10	24
469-25,CC	–	–	22	72	1	5	–	3.3	4			1	57			19	35
470-18-2, 69–70	–	–	60	27	2	11	–	0.45					56	3	8	20	13
471-79-1, 34	–	–	11	37	17	35	–	3.4	3			3	32		24	8	32
472-12-2, 59–61	–	–	13	69	–	18	–	5.3	3			12	35		18	8	24

Figure 14. Percentages of selected coccolith genera in Pacific Coast assemblages of Zone CN4. (Values for each sample are from a survey of 100 specimens of the selected genera. *Discoaster/Coccolithus* ratios show a narrow range of variation but also show apparent reversals. The tropical *Discoaster D. signus* is limited to southern sites off Baja California. All of the *Discoaster* species encountered in a separate 100-specimen count are enumerated.)

tervals examined, the *Discoaster/Coccolithus* ratio for Zone CN4 does not show a consistent gradient across latitude; high and low ratios are interspersed.

This brief survey of 35 samples from eight upper Cenozoic sites involved counts of only 7,000 specimens from seven selected biostratigraphic units, but shows north–south gradients of *Discoaster* species for all intervals. The distribution of species of *Discoaster* is most helpful in identifying warm- and cool-water regimes at different times. The affinity of *Coccolithus* for cool-water (McIntyre et al., 1970) had evolved by the Pliocene, making the *Discoaster/Coccolithus* ratio an effective measure of paleotemperature trends through the 20° latitude of the traverse region for the Pliocene. In older Miocene assemblages, the temperature affinities of the species of *Coccolithus* appear to have been broader, with persistent occurrence into the tropics. Variable depths and dissolution histories at the sites, and even potential tectonic translations across latitude (Crouch, 1979), could have altered the trends, but the *Discoaster* species appear to be a consistent guide through the space–time matrix surveyed.

The key area in the traverse is between Site 467 and 470, near the outer California Continental Borderland. Reversals in abundance trends for indicator taxa for all the zones and subzones above upper Miocene Subzone CN8a are located between those sites. Older intervals are less clear. Some sites off central California are needed to assess biogeographic ranges for older intervals. The strongest gradients occur in the intervals examined from the Quaternary and upper Pliocene.

SYSTEMATIC PALEONTOLOGY

Genus *CALCIDISCUS* Kamptner, 1950

Remarks. In their report explaining the priority of *Calcidiscus* over *Cyclococcolithus* and *Cyclococcolithina*, Loeblich and Tappan (1978) transferred several recently described circular placoliths to *Calcidiscus*. Many of the other species assigned to this genus will likely be transferred elsewhere in future studies because of the specialized ultrastructure and crystallography of the type species, *Calcidiscus leptoporus* (Murray and Blackman), and of the similar species *C. macintyrei* (Bukry and Bramlette), both from the upper Cenozoic. Although a detailed study is not presented here, some of the obvious candidates for reassignment are indicated.

The partly obscured transmission electronmicrograph of the Upper Cretaceous species *Calcidiscus clockiradialis* (Huh) has rim and central area structures unrelated to *Calcidiscus*.

The Eocene and Oligocene species *Calcidiscus formosus* (Kamptner) and *Calcidiscus orbis* (Gartner and Smith) are synonyms and, on the basis of ultrastructure, should be assigned to *Coccolithus* (see synonymy and discussion by Wise, 1973).

Genus *CATINASTER* Martini and Bramlette, 1963

Catinaster mexicanus Bukry
(Plate 1, Figs. 1–3)

Catinaster mexicanus Bukry, 1971b, p. 50, pl. 3, figs. 7–9.
Catinaster mexicanus Bukry, Ellis, Lohman, and Wray, 1972, p. 37, pl. 10, fig. 1.
Remarks. *Catinaster mexicanus* occurs in the Gulf of Mexico DSDP Site 3, Core 9, Sections 2 and 3 in a brief interval in upper Miocene Zone CN9. The presence of *C. mexicanus* at DSDP Site 470 (in Sample 470A-3,CC to Section 470A-4-6) is also associated with upper Miocene coccoliths of Zone CN9 and CN8. Both occurrences are below the appearance of *Amaurolithus*. This species is rarely reported. A single specimen of *Catinaster* sp. (Plate 1, Fig. 4) lacks the characters of presently described species.

Genus *CRENALITHUS* Roth, 1973

Crenalithus taganus (Fonseca) n. comb.
(Plate 6, Figs. 16–17?)

Coccolithus taganus Fonseca, 1976, p. 29, pl. 1, figs. 1–8.
Reticulofenestra haqii Backman, 1978, pl. 1, figs. 1–4; pl. 2, fig. 10.
Remarks. There is uncertainty about the taxonomic identifications and utility of very small placoliths. The lack of certitude from photomicroscope study arises from the inability to discern diagnostic features in order to differentiate among the small placoliths of different epochs and subepochs. There may be overlap and intergradation between the very generalized small (1–5 μm) placolith species. For example, lower Miocene *Crenalithus taganus* (Fonseca) is structurally like lower Miocene to Pliocene *Reticulofenestra? haqii* Backman. Both have very small central openings with no evident grill. The difficulty distinguishing subtle variations in size and proportions of rim and central area between such species is, of course, compounded by overgrowth or solution.

Because of the perception that small placoliths provide little information relative to the difficulty in unambiguously identifying them for every sample, they have been treated as general species groups for studies in paleoecologic variations (Haq and Lohmann, 1976). Detailed studies of ultrastructure, crystallography, and evolutionary lineages still need to be done for the numerous small placoliths that have been proposed, such as *Coccolithus minutulus* Gartner (1967) and *Crenalithus productellus* Bukry (1975).

Crenalithus taganus has ultrastructure that suggests closer affinities to *Crenalithus* (bright distal shield in cross-polarized light) than to *Coccolithus* (type species *C. pelagicus* [Wallich]; see the discussion of crystallography by Hay, Mohler, and Wade, 1966). *Crenalithus* differs from *Reticulofenestra* by the lack of any regular fenestrate grill (type species *R. caucasica* Hay, Mohler, and Wade; see the particular morphology of this grill in Hay, Mohler, and Wade, 1966, and in Perch-Nielsen, 1971, as *R. umbilica*). Genus *Crenalithus*, with its type species *C. doronicoides*, is constructed more similarly to *C. taganus* and is a better classification for these small, simple placoliths.

The generic names *Coccolithus, Cyclicargolithus, Dictyococcites*, and *Reticulofenestra* are also applied to species other than small placoliths without the presence of requisite diagnostic characters. For example, the large middle Tertiary placoliths with a prominent bright distal shield (cross-polarized light), *Cyclicargolithus abisectus* (Müller) Wise (1973), is still called *Coccolithus abisectus* by some authors (Müller, 1978). The numerous Cenozoic species proposed within genus *Reticulofenestra* are based primarily on differences in size and proportions of the rim and central area. The central area, however, can be filled in, due to natural changes in proportions or to overgrowth by secondary crystallites, producing closed and open species in the same sample (Bukry, 1972b). This effect occurs in both large and small members of the species. It is doubtful whether consistent species identifications would be achieved in this genus if the ages of samples were not already established by other criteria.

Crenalithus taganus or similar placoliths occur in most of the Leg 63 coccolith assemblages.

Genus *DISCOASTER* Tan, 1927

Discoaster okadai n. sp.
(Plate 1, Figs. 5–11; Plate 2, Figs. 1–6)

Discoaster sp. 2, Okada and Thierstein, 1979, p. 523, pl. 5, fig. 7; pl. 15, fig. 12.
Description. *Discoaster okadai* is a very large 4- to 7-ray discoaster. The straight rays are long, thin, and tapered, with simple pointed tips. There is no apparent central-area knob or ornamentation. Many specimens show asymmetry from regular equiangular arrangement of the rays. Five-rayed forms are most abundant, with 4-, 6-, and 7-rayed forms occurring in smaller quantities.
Remarks. *Discoaster okadai* was first observed in DSDP Hole 47.2 in the Pacific (Bukry, unpublished data, 1969) but was considered a local aberrant form. Publication of an identical specimen of the same Paleocene age from Atlantic DSDP Site 384 (Okada and Thierstein, 1979), however, confirms a transoceanic significance for this species. *D. okadai* is distinguished from other large Paleogene species, such as *D. tanii* Bramlette and Riedel and *D. nodifer* (Bramlette and Riedel), by pointed tapering rays lacking any ornamentation, and from *D. lo-*

doensis Bramlette and Sullivan by the straight, nonridged rays and lack of a central knob. Owing to overgrowth on discoasters at DSDP Sites 47.2 and 384, there is some resemblance to overgrown Neogene specimens of *D. hamatus* or *D. neorectus* Bukry; larger central areas help to distinguish these later species. Because of the large size and distinctive, long, free rays of *D. okadai*, it is easily discriminated from other Paleocene discoasters.

Occurrence. *Discoaster okadai* is known from the upper Paleocene Zone CP7 in Hole 47.2 in the North Pacific (Bukry, unpublished data, 1969) and from the same Zone CP7 at North Atlantic Site 384, with sparse specimens ranging into overlying Subzone CP8a (Okada and Thierstein, 1979). This close correlation in transoceanic occurrences suggests a biostratigraphic value for *D. okadai*.

Size. Maximum diameter: 20 to 45 μm (holotype 39 μm).

Holotype. USNM 307287 (Plate 2, Fig. 6).

Isotypes. USNM 307288 to 307301.

Type locality. Northwestern Pacific Ocean, DSDP Sample 47.2-8-6, 78–80 cm (82 m).

Discoaster sanmiguelensis n. sp.
(Plate 2, Figs. 7–10; Plate 3, Figs. 1–14)

Description. *Discoaster sanmiguelensis* has six short, broadly tapered rays with a slight indentation or slight bifurcation at the tips. The interray areas are broadly rounded. A large, star-shaped knob dominates the central area of one side of the asterolith; the knob rays point to the interray areas on most specimens.

Remarks. *Discoaster sanmiguelensis* is characterized by short, slightly bifid rays and a large, central-area knob on one side. It is distinguished from similar species *Discoaster bollii* Martini and Bramlette by less bifid rays and the lack of knobs on opposite sides, from *D. kugleri* Martini and Bramlette by a large knob, from *D. adamanteus* Bramlette and Wilcoxon by narrower bifid rays, from *D. altus* Müller by bifid rays and knob-ray alignment, from *D. deflandrei* Bramlette and Riedel by larger knob and much narrower ray tips, from *D. formosus* Martini and Worsley by shorter rays and smaller size, from *D. stellulus* Gartner by larger knob and bifid ray tips, and from *D. toralus* Ellis, Lohman, and Wray by larger knob and tapered, small, bifid ray tips.

Occurrence. *Discoaster sanmiguelensis* is known from the California Continental Borderland in strata of middle Miocene Zone CN5 and uppermost Zone CN4. The most prominent Leg 63 occurrences are at Site 468 in Cores 2 to 9, assigned to Subzone CN5a. It also occurs in USGS borderland dart cores S3-79-SC-259 and -312 from CN4 and CN5a, respectively.

Size. Maximum diameter: 9 to 15 μm (holotype 10 μm).

Holotype. USNM 307302 (Plate 3, Figs. 2, 3).

Isotypes. USNM 307303 to 307314.

Type locality. California Continental Borderland DSDP Sample 468-9,CC (79 m).

Discoaster tridenus Kamptner, emended
(Plate 3, Figs. 15–17)

Discoaster tridenus Kamptner, 1967, p. 166, text-fig. 30.
Discoaster brouweri tridenus (Kamptner) Hay, 1970, p. 461.

Remarks. This symmetric, five-rayed discoaster has long, slender, curved rays, little or no central area, and a very small central plug that was not illustrated in the original drawings. In cross-polarized light, the apparent birefringence of the five ray-crystallites is fainter than that associated with specimens of *Discoaster pentaradiatus* Tan. By size and structure, *D. tridenus* is related to *D. brouweri* Tan.

An unusually large abundance of *D. tridenus* is noted in DSDP Sample 470-5-2, 50–51 cm (40 m), which is assigned to lower Subzone CN12b. A lack of *D. asymmetricus* Gartner in this sample implies some threshold relation between the symmetric and asymmetric members of the *D. brouweri* group. *D. tridenus* occurrences may be poorly recorded, in part, because of general similarity to *D. pentaradiatus* with broken or poorly developed tips or because of lumping the typically small numbers of five-rayed forms with the more dominant six-rayed *D. brouweri*. See Hay and Beaudry (1973) for a quantitative evaluation of *D. tridenus* in the Pliocene. Miocene references to *D. tridenus* at DSDP Site 149 should be recorded as *D. bellus* Bukry

and Percival—which is a smaller form, with more-tapered and less-curved rays.

Discoaster tristellifer Bukry
(Plate 4, Figs. 1–6)

?*Discoaster altus* Muller, Martini, 1976, p. 420, pl. 12, figs. 17, 18.
Discoaster tristellifer Bukry, 1976, p. 499, pl. 1, figs. 1–17.

Remarks. This lower Pliocene warm-water species was not recorded from Leg 63 but was noted during a comparative study of DSDP tropical reference Site 83; the range of this species thus extends across the Pacific from DSDP Site 317 in the central Pacific and from DSDP Site 242 in the western Indian Ocean. The long rays and through-going central knob structure are very distinctive in well-preserved material.

Genus *HELICOSPHAERA* Kamptner, 1954

Helicosphaera californiana n. sp.
(Plate 4, Figs. 7–12)

Description. *Helicosphaera californiana* is a very small, very elongate (L/W ≥ 2) helicosphaerid with a long, narrow slit along the major axis of the central area. In cross-polarized light the rim is faint and narrow.

Remarks. *Helicosphaera californiana* is distinguished from similar *H. carteri* (Wallich) and *H. scissura* Miller by its much smaller size (~ 1:2), narrower format in cross-polarized light, and great length and uniform width of the central slit.

Occurrence. *Helicosphaera californiana* is common in California Continental Borderland USGS dart core GSCD-125, which contains a lower middle Miocene assemblage of Zones CN4 or CN5. It does not occur in the assemblages recovered by Leg 63.

Size. Maximum length: 6 to 7 μm (holotype 7 μm).

Holotype. USNM 307315 (Plate 4, Figs. 9–11).

Isotype. USNM 307316 and 307317.

Type locality. California Continental Borderland USGS dart core GSCD-125 (32°43.7′N, 119°20.5′W, 770 m).

Helicosphaera crouchii n. sp.
(Plate 4, Figs. 13–16; Plate 5, Figs. 1–4)

Description. This moderate to large helicosphaerid is elongate (L/W ≅ 2) and has two large equant, nearly as-long-as-wide pores that dominate the central area. The pores are separated by a long, narrow bar aligned with the minor axis. The rim cycle is moderately broad and smooth. In cross-polarized light the central area and bar are in optical continuity. A minor offset in the bar occurs on some specimens.

Remarks. *Helicosphaera crouchii* was noted as an early homeomorph for *H. sellii* (Bukry and Bramlette) on the basis of dart core studies on the California Continental Borderland. A wide geographic extent for *H. crouchii*—as far as eastern Europe—was indicated through discussions with Maria Baldi Beke (personal communication, 1977). Its existence onshore in California was confirmed by Richard Z. Poore (personal communications, 1978, 1980) from Zone CN2 of the Sandholdt Member of the Monterey Formation in Reliz Canyon. Although many species of *Helicosphaera* have a central bar dividing two pores, only a few species are closely similar. *H. crouchii* is distinguished from *H. sellii* (Bukry and Bramlette) by larger size and proportionally larger pores, from *H. transylvanica* (manuscript name, N. Gheta, personal communication, 1980) by a longer bar and larger, more equant, unelongated pores, and from *H. recta* Haq by the more elongate, elliptic outline. Besides structural distinction, these four helicosphaerids have different stratigraphic ranges: *H. recta* (CP18 and CP19), *H. transylvanica* (CN1), *H. crouchii* (CN2/CN4), *H. sellii* (CN11/CN14).

Occurrence. *Helicosphaera crouchii* occurs in Leg 63, Site 469, and is especially common in USGS dart core L2-78-SC-140 (from the California Continental Borderland area) in lower to lower middle Miocene assemblages of Zones CN2 to lower CN4.

Size. Maximum length: 10 to 15 μm (holotype 15 μm).

Holotype. USNM 307318 (Plate 4, Figs. 13–14).

Isotypes. USNM 307319 to 307323.

Type locality. California Continental Borderland, USGS dart core L2-78-SC-140 (32°04.6′N, 119°09.5′W, 800 m).

Helicosphaera gertae n. sp.
(Plate 5, Figs. 5–13; Plate 6, Figs. 1–4)

Description. *Helicosphaera gertae* is a large species with a broad rim with a nearly oval outline. Rim elements are discernible by photomicroscopy. Some specimens show minor dovetailing of the margin at the narrower end of the oval. The central area is characterized by solid construction on either side of a median slit along the major axis. The length-to-width ratio of the rim periphery is quite low (L/W = 1.17–1.26).

Remarks. *Helicosphaera gertae* is distinguished from similar species such as *H. compacta* (Bramlette and Wilcoxon) by the long slit dividing the central area (see Bramlette and Wilcoxon, 1967) and from *H. perchnielsenasae* (Haq) by the oval instead of subrectangular shape and by the long slit instead of two oblique grooves in the central area (see Haq, 1973).

Occurrence. *Helicosphaera gertae* is common in DSDP Sample 292-14-6, 50–54 cm (129 m), which is a clayey coccolith ooze of the lower Miocene Zone CN1. Site 292 is located on the Benham Rise in the western Philippine Sea, east of Luzon.

Size. Maximum length: 15 to 22 μm (holotype 19 μm).

Holotype. USNM 307324 (Plate 5, Figs. 5–7).

Isotypes. USNM 307325 to 307329.

Type locality. Western Philippine Sea, DSDP Sample 292-14-6, 50–54 cm (129 m).

Helicosphaera scissura Miller
(Plate 6, Figs. 5–7)

Helicosphaera scissura Miller, in press.

Remarks. *Helicosphaera scissura* is a narrow, moderate-sized species with a small median furrow. It is similar in appearance to *H. carteri* (Wallich) except for the furrow. *H. scissura* is prominent in several California Continental Borderland dart cores in Zone CN3. Miller (in press) records it as far north as Pt. Arena, California, in the same zone. It also occurs in DSDP Sample 469-37-2, 127–129 cm (343 m) in Zone CN3.

Gartner (1977) has described a possible Pleistocene homeomorph of *H. scissura* as *H. neogranulata* Gartner. The repetition of certain structural plans in *Helicosphaera* at various times limits their independent biostratigraphic utility. Besides the shared structures of the *H. scissura* group, other repeated similar forms include Eocene *H. seminulum* Bramlette and Sullivan with Oligocene *H. bramlettei* (Müller) and *H. wilcoxonii* (Gartner), and also Miocene *H. crouchii* with Pliocene–Pleistocene *H. sellii* (Bukry and Bramlette). See Haq (1973) for discussions of structural variation in *Helicosphaera*.

Helicosphaera vedderi n. sp.
(Plate 6, Figs. 8–17)

Description. *Helicosphaera vedderi* is a small, thin helicosphaerid with a large elliptic central opening spanned by a narrow diagonal bar. The rim cycle is faint. The elongate central opening occupies about a third of the length of the minor axis. In cross-polarized light, the bar is bright at 45° and dark at 0° to the polarization axes. The bar is continuous within the inner margin and is angled at about 45° to the major axis.

Remarks. *Helicosphaera vedderi* is distinguished from other helicosphaerid species with angled, central-area bars by its small size and proportionally larger opening relative to bar size. *H. rhomba* Bukry is larger and does not have margin-to-bar continuity in cross-polarized light. Other small helicosphaerids lack similar bar and central-area structures.

Occurrence. *Helicosphaera vedderi* occurs in the California Continental Borderland in USGS dart core S3-79-SC-289 from Garrett Ridge with lower or middle Miocene coccoliths of Zones CN3 and CN4. Its full range is yet to be determined.

Size. Maximum length 6 to 7 μm (holotype 7 μm).

Holotype. USNM 307330 (Plate 6, Figs. 8–11).

Isotypes. USNM 307331 to 307333.

Type locality. California Continental Borderland, USGS dart core S3-79-SC-289 (32°37.6′N, 119°33.7′W, depth 285 m).

Genus *WISEORHABDUS* n. gen.

Description. Elongate, calcite rods are composed of several radial keels parallel to the major axis. The ends of the rods are blunt or pointed. The multiple keels may not be arrayed symmetrically (Wise and Constans, 1976).

Type species. *Wiseorhabdus inversus* (Bukry and Bramlette, emended Wise and Constans).

Remarks. *Wiseorhabdus* is distinguished from *Lithraphidites* and *Triquetrorhabdulus* by having more than four keels and by lacking exact radial symmetry about the major axis (Wise and Constans, 1976).

Wiseorhabdus inversus (Bukry and Bramlette, emended Wise and Constans) n. comb.

Triquetrorhabdulus inversus Bukry and Bramlette, 1969, p. 142, pl. 1, figs. 9–14.

Pseudotriquetrorhabdulus inversus (Bukry and Bramlette) emended, new combination, Wise and Constans, 1976, p. 154, pl. 4, figs. 1–9.

Remarks. Following Loeblich and Tappan (1970), the proposed transfer of *Triquetrorhabdulus inversus* to *Pseudotriquetrorhabdulus* is invalid by ICBN Art. 33, par. 4 (Lanjouw, et al., 1966), because the original publication—title and journal name—was never cited by Wise and Constans (1976). In order to validate their emended-species concept and to provide a briefer, unencumbered genus name, the species is, herein, transferred from *Triquetrorhabdulus* to *Wiseorhabdus*. Because *Pseudotriquetrorhabdulus* has never had a validated type species, this genus has not had formal status. Whereas it might possibly have been corrected (ICBN, Art. 63, Note; Lanjouw, 1966), this was not done, and *Wiseorhabdus* is now proposed as the new genus for the epithet *inversus* (as emended by Wise and Constans, 1976).

SPECIES CITED OUTSIDE SYSTEMATIC PALEONTOLOGY

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A. delicatus Gartner and Bukry, 1975

A. primus (Bukry and Percival, 1971) Gartner and Bukry, 1975

Arkhangelskiella cymbiformis Vekshina, 1959

Broinsonia parca (Stradner, 1963) Bukry, 1969

Calcidiscus leptoporus (Murray and Blackman, 1898) Loeblich and Tappan, 1978

C. macintyrei (Bukry and Bramlette, 1969) Loeblich and Tappan, 1978

Catinaster calyculus Martini and Bramlette, 1963

C. coalitus Martini and Bramlette, 1963

Ceratolithus acutus Gartner and Bukry, 1974

C. cristatus Kamptner, 1950

C. rugosus Bukry and Bramlette, 1968

Chiasmolithus consuetus (Bramlette and Sullivan, 1961) Hay and Mohler, 1967)

C. grandis (Bramlette and Riedel, 1954) Radomski, 1968

Coccolithus crassus Bramlette and Sullivan, 1961

C. formosus (Kamptner, 1963) Wise, 1973

C. miopelagicus Bukry, 1971

C. pelagicus (Wallich, 1877) Schiller, 1930

C. pliopelagicus Wise, 1973

Cribrosphaera ehrenbergii Arkhangelsky, 1912

Cyclicargolithus abisectus (Müller, 1970) Bukry, 1973

C. floridanus (Roth and Hay, 1967) Bukry, 1971

Dictyococcites bisectus (Hay, Mohler, and Wade, 1966) Bukry and Percival, 1971

Discoaster asymmetricus Gartner, 1969

D. aulakos Gartner, 1967

D. barbadiensis Tan, 1927

D. bellus Bukry and Percival, 1971

D. berggrenii Bukry, 1971

D. blackstockae Bukry, 1973

D. bollii Martini and Bramlette, 1963

D. braarudii Bukry, 1971

D. brouweri Tan, 1927

D. challengeri Bramlette and Riedel, 1954

D. decorus (Bukry, 1971) Bukry, 1973

D. deflandrei Bramlette and Riedel, 1954

D. exilis Martini and Bramlette, 1963

D. hamatus Martini and Bramlette, 1963

D. kugleri Martini and Bramlette, 1963

D. intercalaris Bukry, 1971

D. loeblichii Bukry, 1971
D. mendomobensis Wise, 1973
D. moorei Bukry, 1971
D. multiradiatus Bramlette and Riedel, 1954
D. neohamatus Bukry and Bramlette, 1969
D. pansus (Bukry, 1971) Bukry, 1973
D. pentaradiatus Tan, 1927
D. prepentaradiatus Bukry and Percival, 1971
D. pseudovariabilis Martini and Worsley, 1971
D. quinqueramus Gartner, 1969
D. signus Bukry, 1971
D. surculus Martini and Bramlette, 1963
D. tamalis Kamptner, 1967
D. triradiatus Tan, 1927
D. variabilis Martini and Bramlette, 1963
Eiffellithus eximius (Stover, 1966) Perch-Nielsen, 1968
Emiliania annula (Cohen, 1964) Bukry, 1971
E. ovata Bukry, 1973
Gephyrocapsa caribbeanica Boudreaux and Hay, 1967
G. oceanica Kamptner, 1943
Hayaster perplexus (Bramlette and Riedel, 1954) Bukry, 1973
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H. carteri (Wallich, 1877) Kamptner, 1954
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H. sellii (Bukry and Bramlette, 1969) Jafar and Martini, 1975
H. seminulum Bramlette and Sullivan, 1961
Heliorthus distentus (Bramlette and Sullivan, 1961) Bukry, 1978
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Micula decussata Vekshina, 1959
Minylitha convallis Bukry, 1973
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S. heteromorphus Deflandre, 1954
S. neoabies Bukry and Bramlette, 1969
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Watznaueria barnesae (Black, 1959) Perch-Nielsen, 1968

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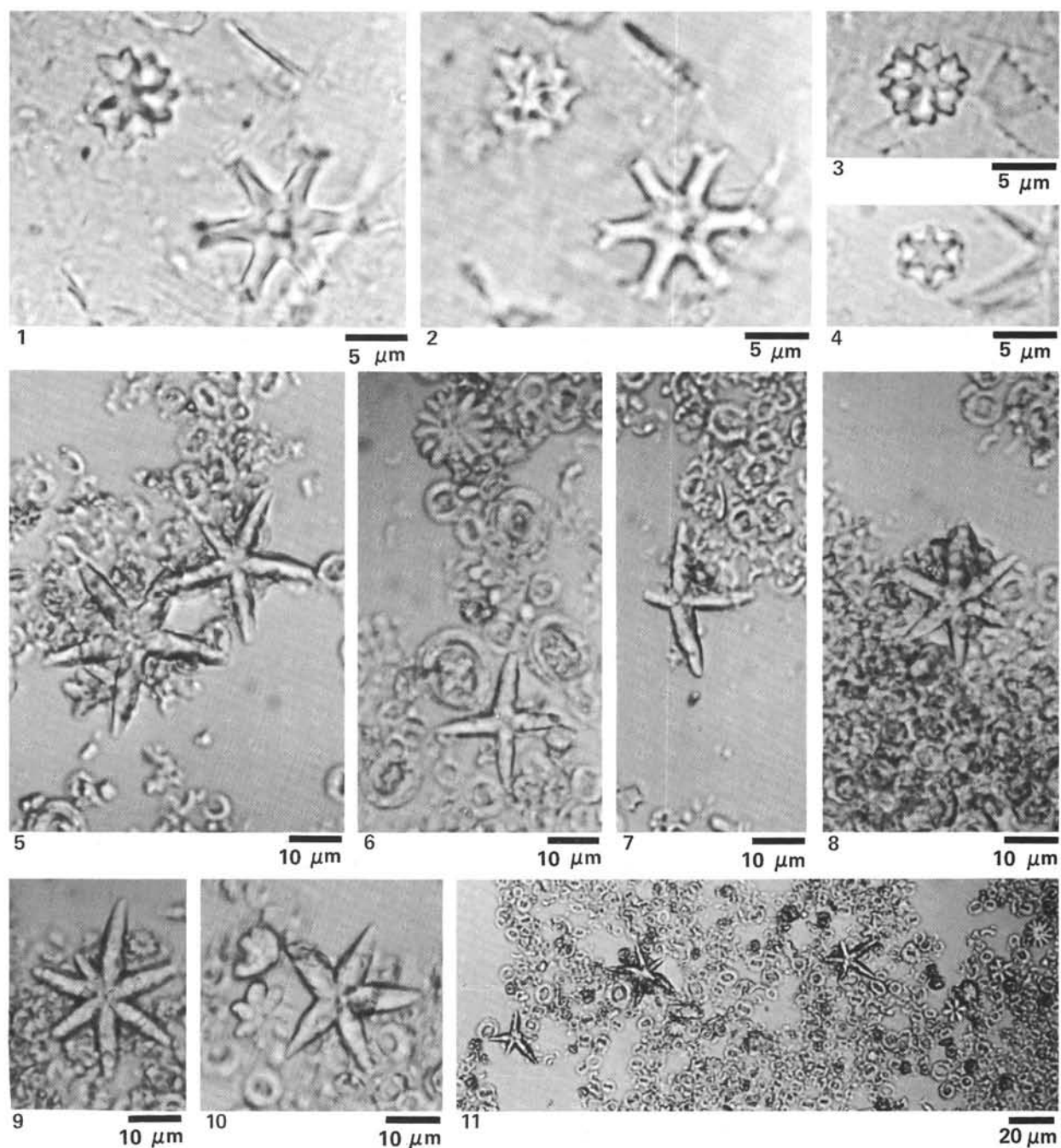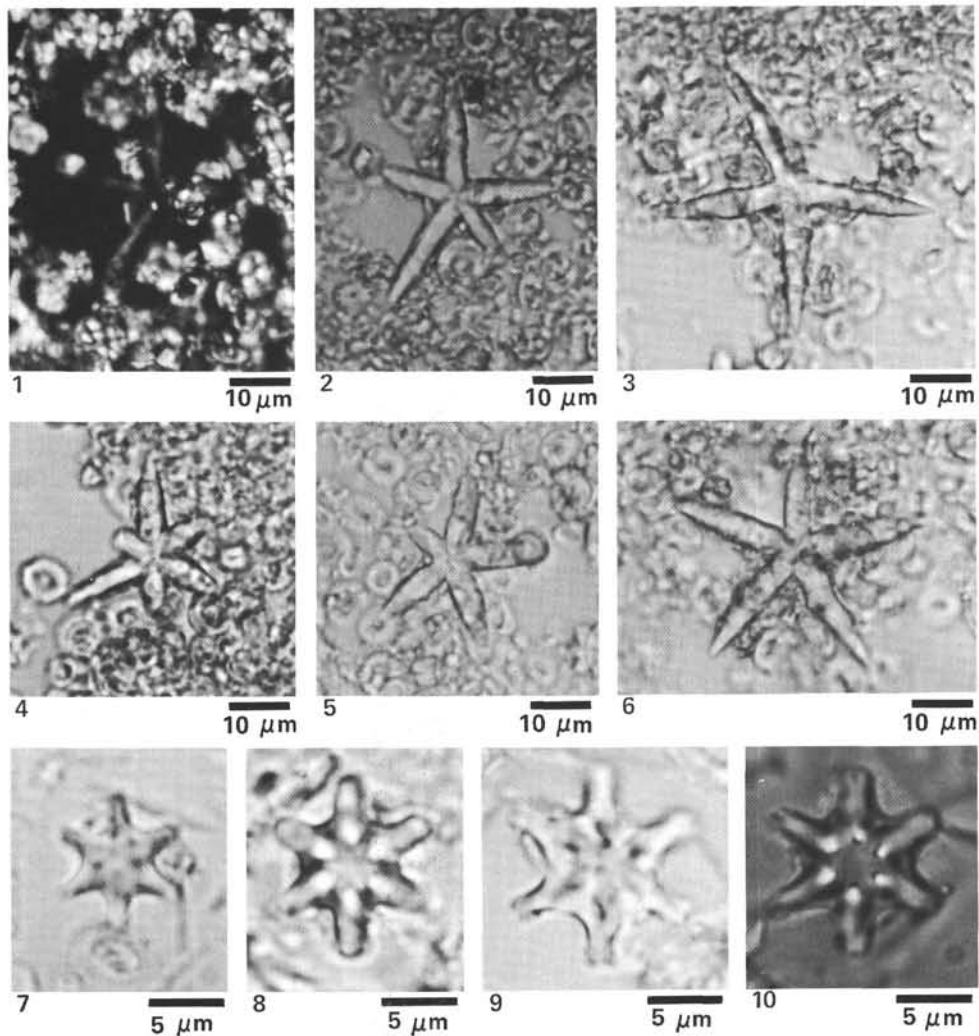
Plate 1. Cenozoic coccoliths from DSDP Legs 6 and 63. (Figs. 1–4 are magnified ×2050; scale bar equals 5 μm; Figs. 5–10 are magnified ×800; scale bar equals 10 μm. Fig. 11 is magnified ×350; scale bar equals 20 μm.) 1–3. *Catinaster mexicanus* Bukry. Sample 470A-4-6, 137 cm. (1, 2) low and high focus with *Discoaster variabilis* Martini and Bramlette. 4. *Catinaster* sp., Sample 470A-4-6, 137 cm. 5–11. *Discoaster okadai* n. sp. Sample 47.2-8-6, 78–80 cm. (5) USNM 307288 and 307289, (6) USNM 307290 with *Discoaster mohleri* Bukry and Percival above, (7) USNM 307291, (8) USNM 307292, (9) USNM 307293, (10) USNM 307294, (11) USNM 307295 to USNM 307297, left to right.

Plate 2. Cenozoic coccoliths from DSDP Legs 6 and 63. (Figs. 1–6 are magnified ×800, scale bar equals 10 μm; Figs. 7–10 are magnified ×2050, scale bar equals 5 μm.) 1–6. *Discoaster okadai* n. sp. DSDP Sample 47.2-8-6, 78–80 cm. (1, 2) cross-polarized light and bright field of same specimen, USNM 307298, (3) USNM 307299, (4) USNM 307300, (5) USNM 307301, (6) Holotype, USNM 307287. 7–10. *Discoaster sanmiguelensis* n. sp., (7) USNM 307303, USGS-S3-79-SC-259, (8) USNM 307304, DSDP Sample 468-7-3, 50–51 cm, (9) USNM 307305, DSDP Sample 468-2-3, 50–51 cm, (10) USNM 307306, USGS-S3-79-SC-259.
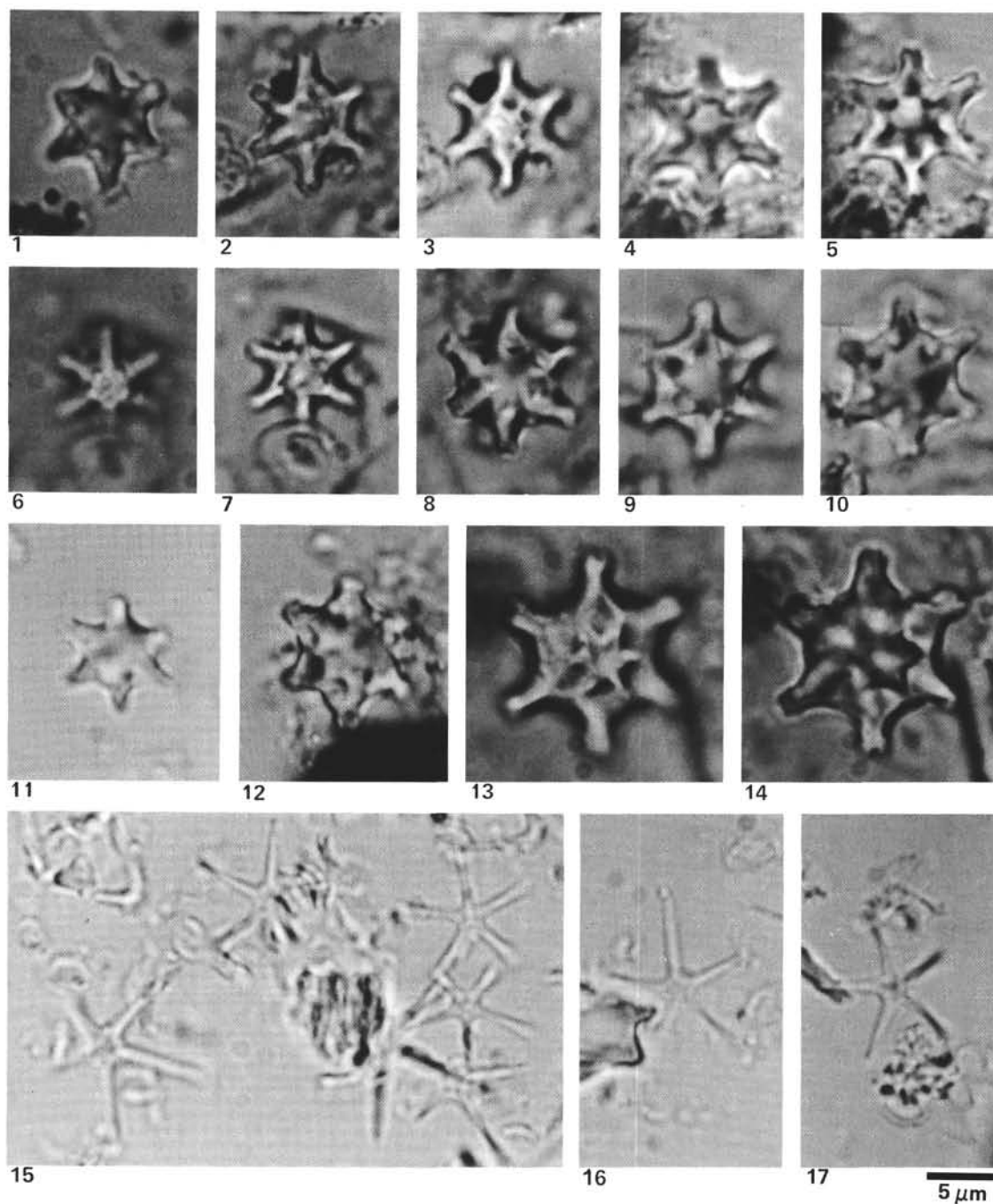
Plate 3. Cenozoic coccoliths from DSDP Leg 63 and USGS California Continental Borderland cores. (All figures are magnified ×2050; scale bar equals 5 μm.) 1–14. *Discoaster sanmiguelensis* n. sp. DSDP Sample 468-9,CC, except Figs. 6, 7, and 11. (1) USNM 307307, (2, 3) Holotype, USNM 307302, low and high focus (LF and HF), (4, 5) USNM 307308, HF and LF, (6, 7) USNM 307309, HF and LF, USGS-S3-79-SC-259, (8) USNM 307310, (9, 10) USNM 307311, HF and LF, (11) USNM 307312, USGS-S3-79-SC-312, (12) USNM 307313, (13, 14) USNM 307314, HF and LF. 15–17. *Discoaster tridenus* Kamptner, emended DSDP Sample 470-5-2, 50–51 cm, (15) five specimens in one field of view, (16, 17) individuals showing central-area ornamentation.
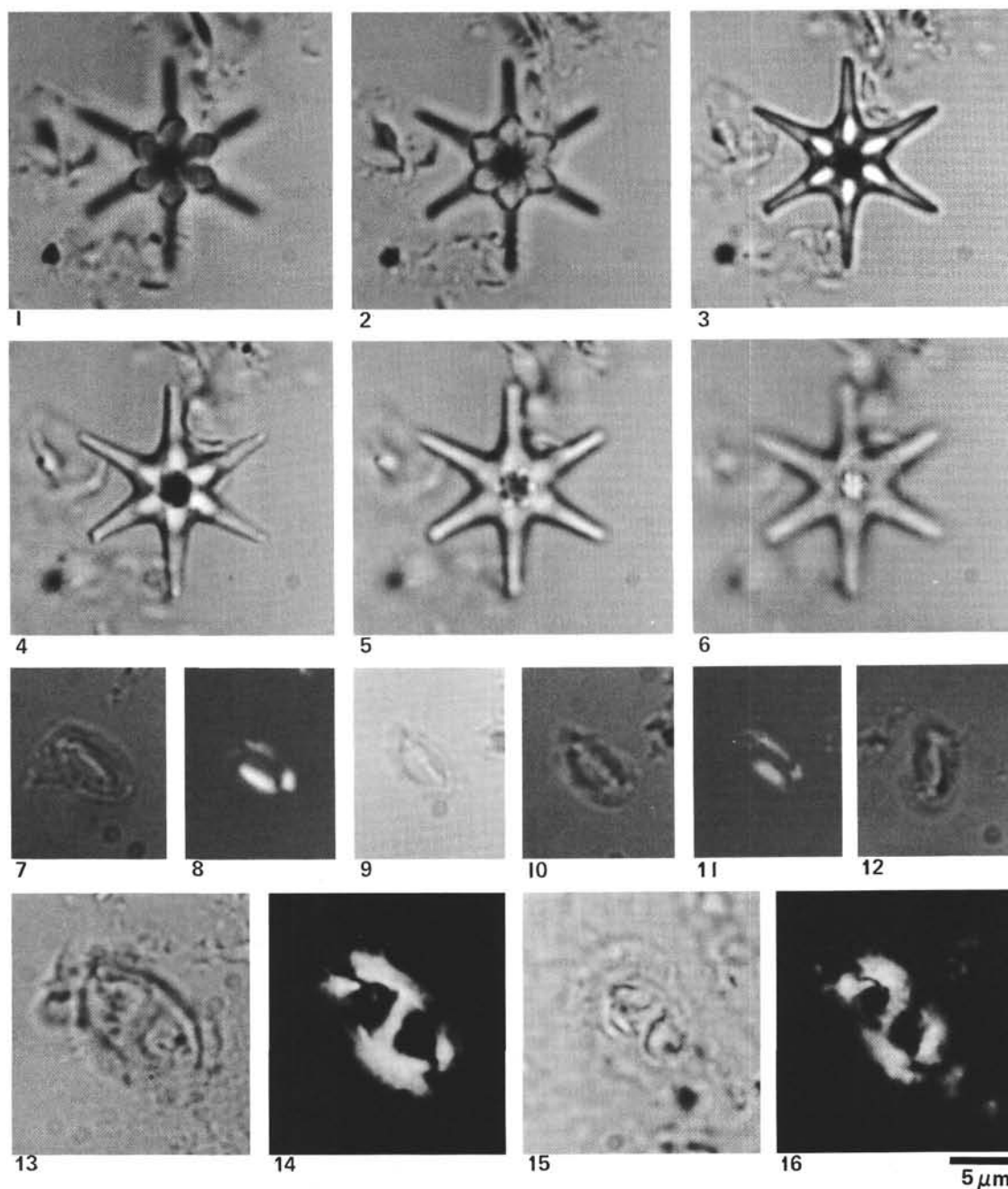
Plate 4. Cenozoic coccoliths from DSDP Leg 9 and USGS California Continental Borderland cores. (All figures are magnified ×2050; scale bar equals 5 µm.) 1–6. *Discoaster tristellifer* Bukry (through-focal series showing disparate star-shaped knobs above and below plane of rays). DSDP Sample 83A-8-2, 101–102 cm. 7–12. *Helicosphaera californiana* n. sp. USGS-GSCD-125. (7, 8) USNM 307316, bright field and cross-polarized light (BF and XP), (9–11) Holotype, USNM 307315 (9. BF low focus; 10. BF high focus; 11. XP), (12) USNM 307317, BF. 13–16. *Helicosphaera crouchii* n. sp. USGS-L2-78-SC-140. (13, 14) Holotype, USNM 307318, BF and XP, (15, 16) USNM 307319, BF and XP.
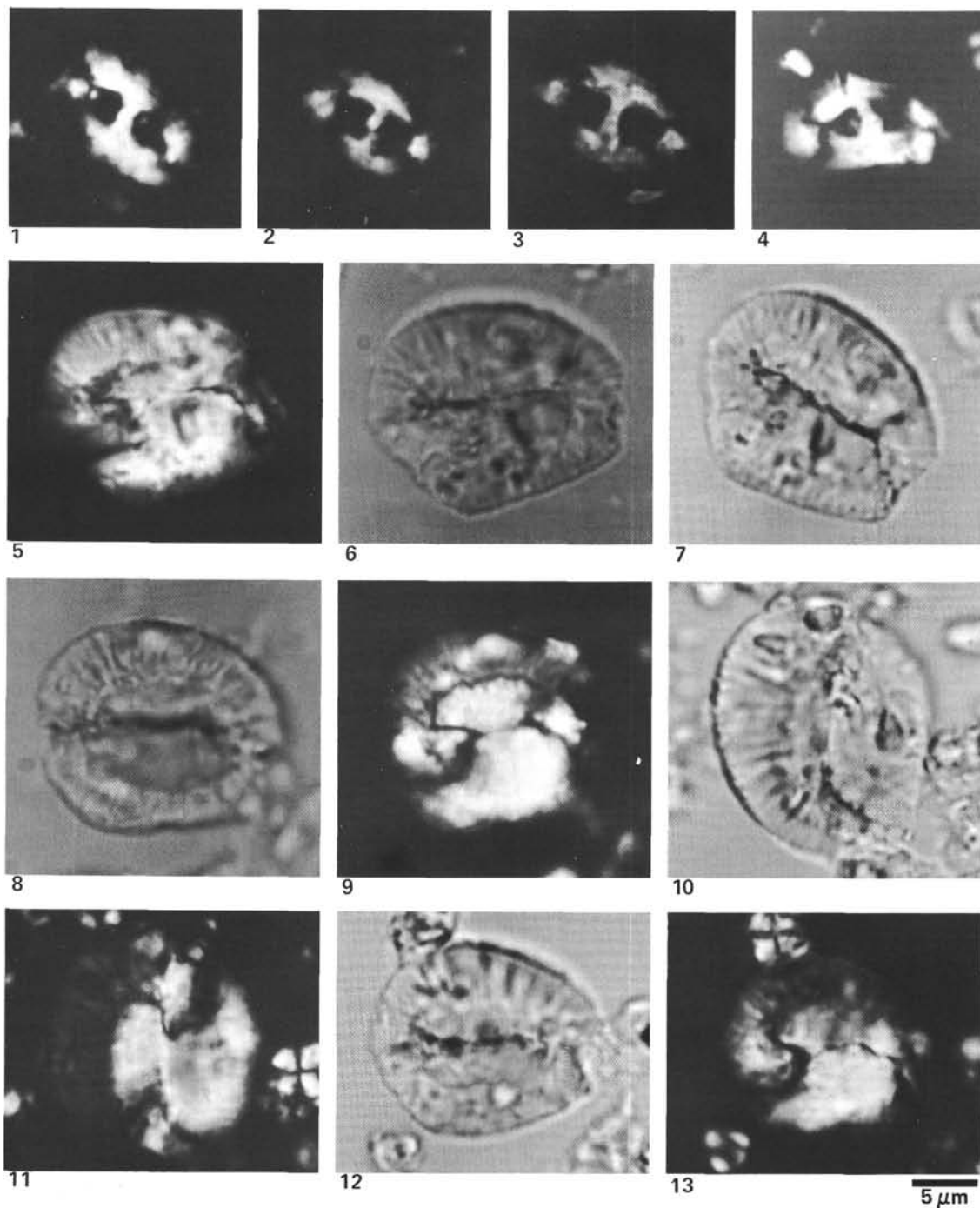
Plate 5. Cenozoic coccoliths from DSDP Leg 31 and USGS California Continental Borderland cores. (All figures are magnified ×2050; scale bar equals 5µm.) 1-4. *Helicosphaera crouchii* n. sp. USGS-L2-SC-140, except Fig. 4. (1) USNM 307320. (2) USNM 307321. (3) USNM 307322. (4) USNM 307323. DSDP Sample 469-35-1, 40 cm. 5-13. *Helicosphaera gertae* n. sp. DSDP Sample 292-14-6, 50-54 cm. (5-7) Holotype, USNM 307324, XP, BF high focus, and BF low focus, (8, 9) USNM 307325, BF and XP, (10, 11) USNM 307326, BF and XP, (12, 13) USNM 307327, BF and XP.
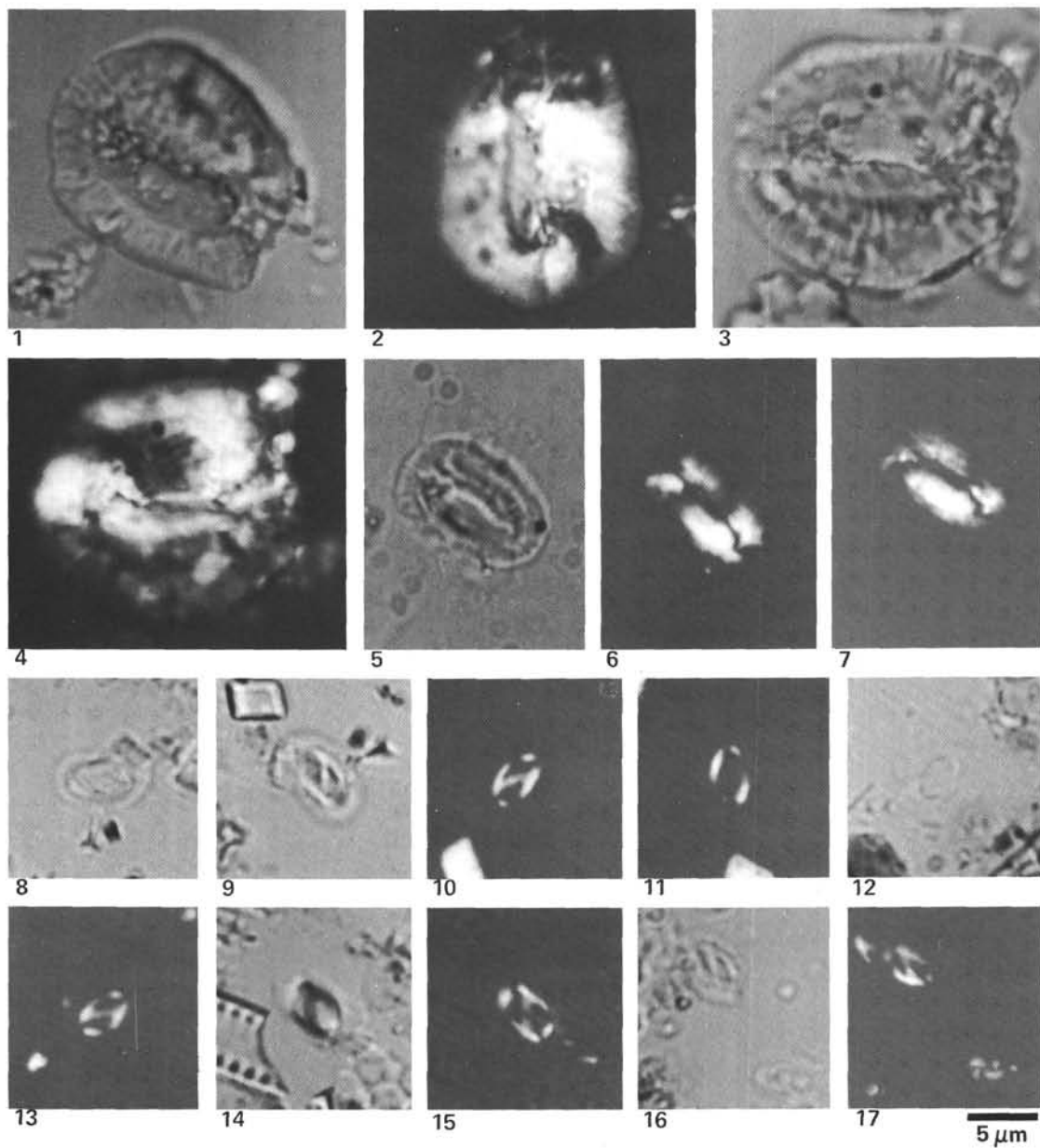
Plate 6. Cenozoic coccoliths from DSDP Legs 31 and 63 and USGS California Continental Borderland cores. (All figures are magnified ×2050; scale bar equals 5 μm.) 1–4. *Helicosphaera gertae* n. sp. DSDP Sample 292-14-6, 50–54 cm. (1, 2) USNM 307328, BF and XP, (3, 4) USNM 307329, BF and XP. 5–7. *Helicosphaera scissura* Miller. All figures of one specimen from DSDP Sample 469-37-2, 127–129 cm. (5) BF. (6) XP, 45°. (7) XP, >45° gives apparent slit elongation. 8–17. *Helicosphaera vedderi* n. sp. USGS-S3-79-SC-289. (8–11) Holotype, USNM 307330 (8. BF, low focus; 9. BF, high focus; 10. XP, 45°; 11. XP, 0°), (12, 13) USNM 307331, BF and XP, (14, 15) USNM 307332, phase contrast and XP. (16, 17) USNM 307333, BF and XP, at upper left; minute specimen at lower right is likely *Crenalithus taganus* (Fonseca).