

## 29. SILICOFLAGELLATE AND DIATOM STRATIGRAPHY, LEG 16, DEEP SEA DRILLING PROJECT<sup>1</sup>

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### ABSTRACT

The stratigraphic and paleoenvironmental significance of middle Miocene to upper Pleistocene silicoflagellate and diatom assemblages from the Panama Basin area of the eastern tropical Pacific Ocean is presented. The assemblages are dominated by warm-water open-ocean species. Paleotemperatures indicated by silicoflagellates are higher for the Pleistocene than for the Pliocene, and higher temperature correlates with lower productivity. Upwelling is believed to have been a persistent oceanographic feature in the basin, but it was probably reduced when higher surface temperature prevailed, as during the Pleistocene. Seven tropical silicoflagellate biostratigraphic zones are newly described or emended: *Dictyocha epidon* Zone, *Mesocena elliptica* Zone, *Distephanus boliviensis* Zone, *Cannopilus major* Zone, *Distephanus crux* Zone, *Distephanus longispinus* Zone, and *Distephanus octacanthus* Zone. Five tropical diatom biostratigraphic zones are newly described or emended; *Roperia tessellata* Zone, *Chaetoceros* sp. Zone, *Hemidiscus cuneiformis* Zone, *Coscinodiscus plicatus* Zone, *Craspedodiscus coscinodiscus* Zone. Two new silicoflagellate species, *Cannopilus quintus* Bukry and Foster and *Dictyocha vanandelii* Bukry and Foster, and one new replacement name, *Distephanus quinquangellus* Bukry and Foster, are presented.

### INTRODUCTION

Leg 16 of the Deep Sea Drilling Project (DSDP), February-March 1971, from Panama to Hawaii, recovered 210 cores at nine drilling sites. Light-microscope techniques were used to study the fossil silicoflagellates and diatoms of eighty-six samples from these cores.

Skeletal remains of silicoflagellates—microscopic, flagellated, one-celled algae—occur in the Pleistocene to Miocene at DSDP 157 and in the Miocene at DSDP 158. Both sites are located in the Panama Basin, and both were continuously cored. Other Leg 16 sites do not have significant silicoflagellate sequences. Comparison of these fossil assemblages to those in samples from other areas such as the Experimental Mohole in the Pacific Ocean west of Baja California, the Monterey Formation at Newport Bay, California, and the Fairhaven Diatomaceous Earth Member of the Calvert Formation at Fairhaven, Maryland, shows that the Panama Basin assemblages are diverse and well preserved.

Excellent preserved assemblages of microscopic skeletons of diatoms, a class of siliceous unicellular or colonial algae, are abundant at DSDP 157 and DSDP 158. Other Leg 16 sites do not have significant diatom sequences, but a low-diversity mid-Pleistocene assemblage occurs in the highest sample at DSDP 159, and some

poorly preserved Oligocene assemblages occur at DSDP 161. The rich diatom deposits extend from the upper Miocene to upper Pleistocene at DSDP 157 and from the middle Miocene to upper Pleistocene at DSDP 158, thus together providing a continuous stratigraphic record for most of the upper Cenozoic.

These silicoflagellate and diatom sequences are compared with those present in the Experimental Mohole (EM) (Figure 1). The continuous coring of the richly fossiliferous Panama Basin sites has allowed silicoflagellate and diatom biostratigraphic zones to be recognized for the upper Cenozoic of the eastern tropical Pacific Ocean. Abundant associated coccoliths permit these zones to be correlated with the previously established, more refined system of coccolith zones (Table 1).

### SILICOFLAGELLATES

#### Study Methods

Core samples tabulated for silicoflagellates include a fraction greater than 44 microns separated for diatom study and a fraction less than 44 microns. Core-catcher samples, generally separated by 9 meters, were used almost exclusively. For most core levels, 40 × 20-mm slide areas of both the coarse and fine fractions were counted at 250 or 100 ×, and the resultant totals were added together. All identifiable specimens were counted, and a total count of 100 specimens or more was attempted for most core levels. For sparse samples, a maximum of three slides were scanned completely, but even then the count

<sup>1</sup>Publication authorized by the Director, U.S. Geological Survey.

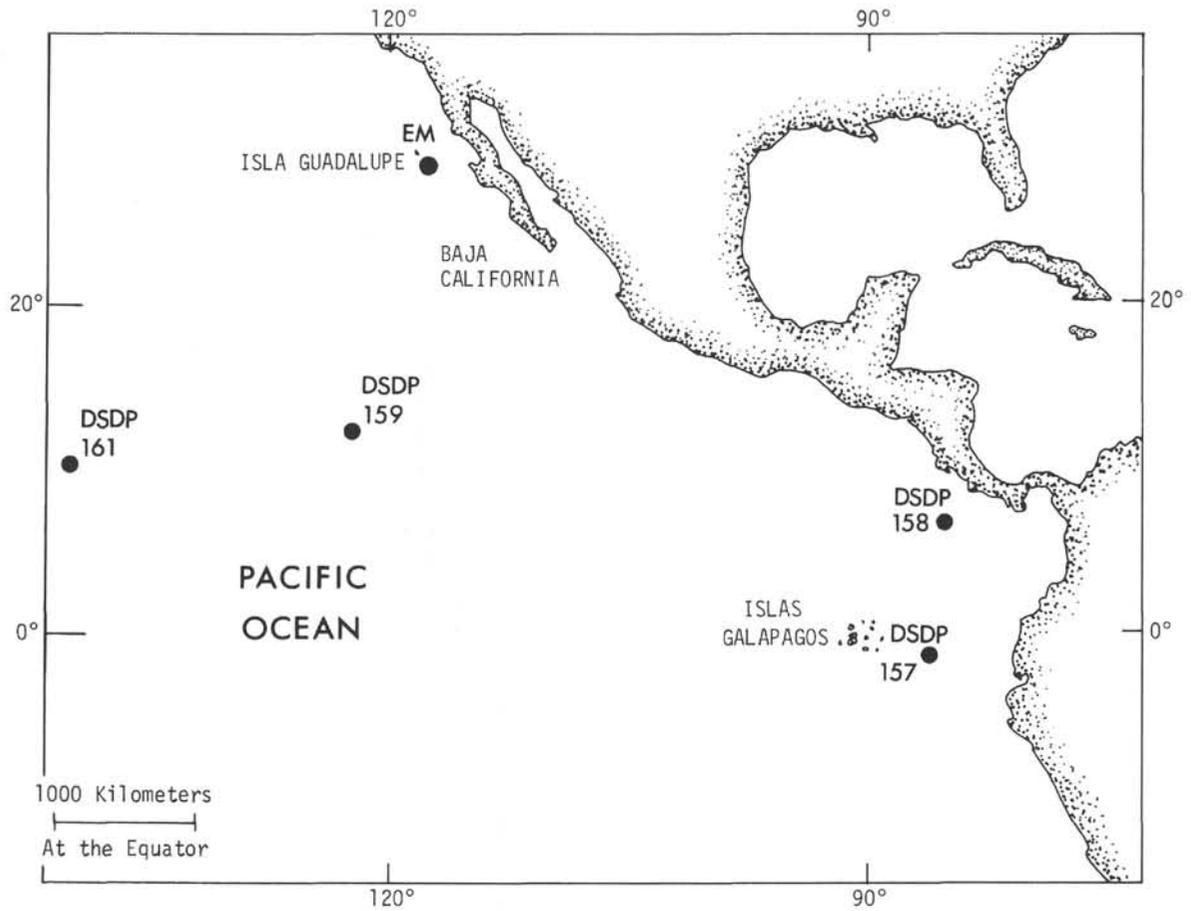


Figure 1. Locations of Deep Sea Drilling Project Leg 16 sites (DSDP) for which silicoflagellate or diatom assemblages are cited and the Experimental Mohole reference section (EM).

TABLE 1  
Approximate Temporal Relation of Tentative Late Cenozoic Phytoplankton Zones in the Eastern Pacific Ocean at Coring Sites DSDP 157, DSDP 158, and the Experimental Mohole (EM)

Series or Subseries	Age (my)	Coccolith Zone	Silicoflagellate Zone	Diatom Zone
Holocene and Pleistocene	1	<i>E. huxleyi</i>	<i>D. epiodon</i>	<i>R. tessellata</i>
		<i>G. oceanica</i>	<i>M. elliptica</i>	
Pliocene	2	<i>C. doronocoides</i>	<i>D. boliviensis</i>	<i>Chaetoceros</i> sp.
	3	<i>D. brouweri</i>	<i>C. major</i>	
	4	<i>R. pseudoumbilica</i>		
	5	<i>C. tricorniculatus</i>		
	6	<i>D. quinquerramus</i>		
Upper Miocene	7			<i>H. cuneiformis</i>
	8	<i>D. neohamatus</i>	<i>D. crux</i>	<i>C. plicatus</i>
	9			
	10			
	11			
Middle Miocene	12	<i>D. hamatus</i>	<i>D. longispinus</i>	
	13	<i>C. coalitus</i>		
	14	<i>D. exilis</i>	<i>C. triacantha</i>	
	15	<i>S. heteromorphus</i>	<i>D. octacanthus</i>	<i>C. coscinodiscus</i>
			?	?

for some samples did not reach 100. To confirm the distributions of stratigraphic marker species—*Dictyocha epiodon*, *Mesocena elliptica*, and *Octactis pulchra*—counts of 300 or more were made for the upper twelve cores of Hole DSDP 157. Percentages for species in the silicoflagellate assemblages and the total counts are presented in Tables 2 to 5.

#### Paleoenvironmental Analysis

Silicoflagellates, like diatoms, are most productive in areas of oceanic upwelling, where the near-surface water has high levels of silica and nutrients (Lipps, 1970). The taxonomic composition of living silicoflagellate populations is controlled to some extent by temperature, which is reflected in a reversal in dominance between the genera

*Dictyocha* and *Distephanus* in warm and cold water respectively (Gemeinhardt, 1934). A curve that gives an approximate relation between actual temperature and the ratio of *Dictyocha* to *Distephanus* has been prepared by Mandra (1969). This curve has been used as the basis for paleotemperatures determined for DSDP 157 and DSDP 158 in the Panama Basin. For paleotemperature calculations, the *Distephanus*-like genus *Octactis* was counted as *Distephanus*. To allow for very high *Dictyocha*/*Distephanus* ratios (warm water) in our assemblages, it was necessary to extrapolate Mandra's curve with 3 by 3 log paper. The curve asymptotically approaches 31°C, which is in good agreement with the highest annual open-ocean water temperature at low latitude. Temperatures determined for Miocene to Pleistocene cores of the Panama Basin range from 23 to 30°C, with fluctuations related to

TABLE 2  
Silicoflagellates in DSDP 157A Cores Recorded as Per Cents, with Zones  
and Geologic Series and Subseries Indicated

Sample	Taxa												Total Specimens	Zone	Series
	<i>Corbisema triacantha</i>	<i>Dictyochoa aspera</i>	<i>D. epiodon</i>	<i>D. fibula</i>	<i>D. navicula</i>	<i>D. pentagona</i>	<i>Distephanus crux</i>	<i>D. quinquangellus</i>	<i>D. speculum</i>	<i>Mesocena circula</i>	<i>M. elliptica</i>	<i>Octactis pulchra</i>			
157A-1A-2(8-10 cm)		3	33	60			1		3		1	1	105	<i>Dictyochoa epiodon</i>	Holocene or Pleistocene
157A-1A-4(8-10 cm)		4	35	51	1				6		5		109		
157A-1A(CC)		2	22	69		1	1		2		4		111		
157A-2A(CC)			9	85			1	1	1		1	1	85		
157A-3A(CC)	1	1	8	81			1	1	2	1	1	3	103		

variation in the percentage of *Dictyochoa* (Tables 6 and 7).

A second technique using silicoflagellate populations for determining paleotemperatures was presented by Martini (1971). This technique is based on a ratio of *Dictyochoa fibula* to *Distephanus speculum*. However, a test of that method resulted in an unreasonable temperature range of 0-40°C, with core to core variations of as much as 20°C, and it was therefore considered unreliable for the Panama Basin.

Fluctuation in the carbonate percentage of Pacific Ocean sediment has been related to climatic fluctuation (Arrhenius, 1952; Nayudu, 1964; Hays et al., 1969). The hypothesis of these authors is that an increased carbonate percentage corresponds to cooler climatic conditions. Muhina (1971) stated, however, that carbonate peaks correspond to warmer climatic conditions, on the basis of a study of the relation of these peaks to the distribution of cool- and warm-water diatoms in the equatorial Pacific. The variation of carbonate percentage and indicated temperature in our study is found to be mixed (Table 6).

Strata in the Panama Basin that have the most abundant silicoflagellates (presumably reflecting upwelling) correspond generally with low-temperature points on the indicated-temperature curve. Muhina (1971) demonstrated a similar relation for central equatorial Pacific strata. This correspondence could result from optimum production of silicoflagellates at lower temperatures or conversely from optimum preservation during periods of rapid sedimentation.

Because the Mandra (1969) indicated-temperature curve worked well for Panama Basin assemblages, it was applied to assemblages from the Miocene of California and Maryland, which were studied for stratigraphic comparison. An especially abundant population of the two quadrate *Distephanus* species *D. crux* and *D. longispinus* dominates the assemblages. The resultant indicated temperatures are very cold—less than 4°C. These temperatures are considered too low in view of the presence of discoasters at the California section—Monterey Shale at

Newport Beach (Wilcoxon, 1969)—and temperate-water fossils at the Maryland section—Calvert and Choptank Formations (T.G. Gibson, personal communication, 1972). In open-ocean assemblages of Miocene age, these quadrate *Distephanus* species are generally subordinate at both high and low latitude (Ling, 1970; Martini, 1971), whereas in assemblages from land localities (presumably representing more nearshore conditions), quadrate *Distephanus* species predominate. This relation suggests that coastal environmental factors, in addition to low temperatures, may contribute to the development of large populations of quadrate *Distephanus*.

The relation of temperature and environment to skeletal form of living silicoflagellates has been investigated by Van Valkenburg and Norris (1970). A laboratory culture of a low-temperature low-salinity stock of *Dictyochoa fibula* from Puget Sound, Washington, was found to produce a variety of irregular skeletal forms that are similar to living varieties of *D. fibula* illustrated from a somewhat similar environment in the Gulf of Matías, Argentina (see Pl. 10-11 in Loeblich et al., 1968). These irregular forms are missing from our samples from the Panama Basin and from other open-ocean areas (Ling, 1970), suggesting (a) that the irregular forms develop only in coastal waters or (b) that selective dissolution prevents their fossilization. Some of the largest silicoflagellate skeletons from the Panama Basin, *Cannopilus* spp. and *Distephanus bolivien-sis*, occur in late Pliocene sediment at DSDP 157. The indicated temperature for this time is relatively low in contrast to a higher indicated temperature for the early Pleistocene. Generally high temperature is noted for the Panama Basin during the Pleistocene. This Pleistocene temperature maximum is supported by the virtual absence of the cool-water coccolith *Coccolithus pelagicus* in the Pleistocene and by its common occurrence in the Pliocene (Bukry, this volume).

In summary, the silicoflagellate assemblages from the Panama Basin indicate that generally warm, nutrient-rich, open-ocean water has been characteristic of the area from

TABLE 3  
Silicoflagellates in DSDP 157 Cores Recorded as Per Cent, with Zones and Geologic Series and Subseries Indicated

Sample (All CC)	Taxa																Total Specimens	Zone	Series or Subseries										
	<i>Cannopilus binoculus</i>	<i>C. ernstinae</i>	<i>C. hemisphaericus</i>	<i>C. major</i>	<i>C. quintus</i>	<i>Corbisema triacantha</i>	<i>Dictyocha aspera</i>	<i>D. fibula</i>	<i>D. epiodon</i>	<i>D. japonica</i>	<i>D. medusa</i>	<i>D. navicula</i>	<i>D. polyactis</i>	<i>D. pseudofibula</i>	<i>Distephanus boliviensis</i>	<i>D. crux</i>				<i>D. minutus</i>	<i>D. parva</i>	<i>D. quinquantellus</i>	<i>D. speculum</i>	<i>Mesocena circula [apiculate]</i>	<i>M. diodon</i>	<i>M. elliptica</i>	<i>M. pentagona</i>	<i>M. triangula</i>	<i>Octactis pulchra</i>
1	1					<1	56	39										<1	<1	<1		<1				4	358	<i>Dictyocha epiodon</i>	Holocene and Pleistocene
2						1	86	6						<1					1							5	372		
3						<1	76	4						<1				2	<1				14			3	426		
4						<1	84							<1				<1	2			11			2	378			
5							36							<1				2	2			60			1	445			
6							41	1										1	7			45			5	468			
7						<1	71	<1						<1				<1	1			22			3	427			
8							2	89				<1		<1	<1				4		<1				3	417			
9							2	80				<1		<1	<1	<1		3	6			4			1	440			
10						<1	80											3	5	<1		10			1	445			
11						<1	75							4	16			4	<1								463	<i>Distephanus boliviensis</i>	Upper Pliocene
12						<1	1	82				<1		<1				7	9								457		
13							2	77						2	1	1		5	10	1							151		
14	1			2			3	71						20				5	2								194		
15							1	74						15				1	9								100		
16								87						5				3	8								106		
17					1	1	73							12				3	5	4		1		1			103		
18		2		1			4	89						3					1								100		
19	1	2		3			32	53						1	4				5								113		
20		1					4	86						1		2			6	1							125		
21	1		1	45			8	28						1	1	5			9			1					148		
22				1	2		11	68						1	7		1		4	4	1						168		
23	4			3			20	56				1		1	1			1	8	5		1					105		
24				5			9	63				1		1	1			11	7	1		1					148		
25	<1			1			1	86					<1	<1	<1			3	6								233		
26				<1			1	90							1	<1				6		<1					340		
27					<11	10	71					<1	<1	1	5			<1	11								221		
28							7	73				1		1	1	1			1	16							192		
29							15	50							2	3			2	27			1				117		
30							4	64				1		3		17			11								124		
31							6	67				1			2	6			16		2						122		
32							10	78						1	3	1			7	1							138		
33							8	60						1	8	3		1	15	5							177		
34							1	59							7	12			20	2							134		
35							11	63				<1			3	2			17				3				214		
36							9	62						3	4	4			13		1	6					144		
37							36	29					1		3	9			19			3					185		
38							30	12				1	<1		1	10	<1		25		1	19	<1				224		

TABLE 4  
Silicoflagellates in DSDP 158 Cores Recorded as Per Cents, with Zones and Geologic Series and Subseries Indicated

Sample (All CC)	Taxa														Total Specimens	Zone	Subseries	
	<i>Corbisema triacantha</i>	<i>Dictyochoa aspera</i>	<i>D. fibula</i>	<i>D. medusa</i>	<i>D. navicula</i>	<i>Distephanus crux</i>	<i>D. sp. cf. D. longispinus</i>	<i>D. minutus</i>	<i>D. quinquantellus</i>	<i>D. speculum</i>	<i>Mesocena circura</i> [apiculate]	<i>M. diodon</i>	<i>M. elliptica</i>	<i>M. pentagona</i>				<i>M. triangula</i>
10		75	5			5		5		5			5			20	<i>Distephanus crux</i>	Upper Miocene
11		14	29		36	1			20							106		
12		15	77					2	1	6						128		
13		11	77			8		4								100		
14		23	62			3		3		8					3	39		
15		23	69							7			1			109		
16		20	60		<1			13	2	8						274		
17		65	4							24			7			100		
18		24	65			2		6		3						100		
19		14	81	5		1										109		
20		84	3	1		1	1			9	2	1				163		
21		72		5				10		10	5					21		
22		71	3	1		7		1	1	15	3					120		
23		60	3			1		2	2	32			1			126		
24		73	2	1		15		2		5	2	1				130		
25		86	6							8						49		
26		62	2			13	15	1		5	5					131	<i>Distephanus longispinus</i>	Middle Miocene
27		69	1	3		1	1	6		10	3	3	2		1	144		
28		66				1	3	1		8	2	8	12		1	107		
29		88	5							4	2				1	101		
30		56	2	1		5		6		22		5	1	1		110		
31		94	1			3				2						102		
32		66	4	1		20	1	1		7						109		
33	3	74	5	2		3	6	2		4			1			117		

middle Miocene to Holocene. The typically small numbers of quadrate *Distephanus* specimens, especially in middle Miocene assemblages, contrast with an abundance of these forms at cooler nearshore mid-latitude localities and also suggest a warm open-ocean paleoenvironment for the Panama Basin. This study indicates that, because of reduced upwelling, surface water of the eastern tropical Pacific was especially warm during the time of Pleistocene glaciation. Whether the reduced upwelling was a cause or an effect of the glaciation, or whether both had a common cause, present-day periods of Pacific warming are associated onshore in the northern mid-latitudes with cold winters (Namias, 1969).

#### Tropical Silicoflagellate Zonation

Only with the advent of the Deep Sea Drilling Project has it been possible to determine the stratigraphic relations of silicoflagellate species at a single site for an extensive part of the geologic record (Martini, 1971). Previous

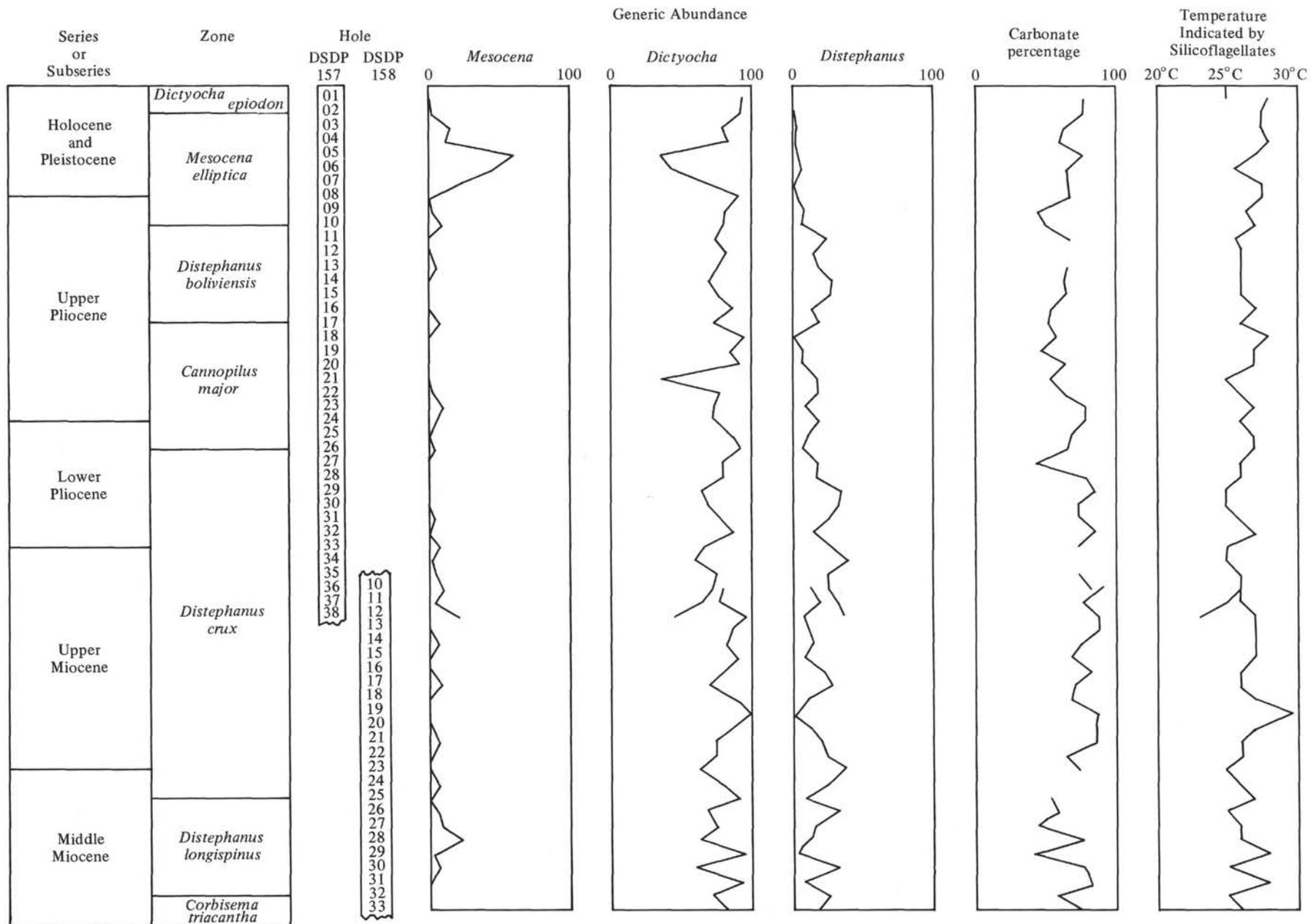
stratigraphic studies have been based on discontinuous outcrops ashore and on short cores from ocean areas (Mandra, 1968; Hays et al., 1969; Ling, 1970, 1971; Jousé, 1971). The continuously cored Miocene through Pleistocene sediments at DSDP 157 and DSDP 158 in the Panama Basin provide an excellent record of fossil silicoflagellate assemblages in the eastern tropical Pacific that can be related to the stratigraphic systems of associated fossil groups—diatoms, radiolarians, foraminifers, and coccoliths.

As with diatoms, silicoflagellate stratigraphy of warm-water areas may not be comparable with that of cool-water areas owing to the ecologic limitations of various taxa. For example, the short-spined, compact silicoflagellates *Dictyochoa subarticos* Ling, *Distephanus crux* cf. "var." *stauracanthus* (Ehrenberg), and *Distephanus octangulatus* Wailes of North Pacific cores (Ling, 1970) do not occur in samples from the Panama Basin. Species of *Canopilus* occur only in the Miocene of North Pacific cores,

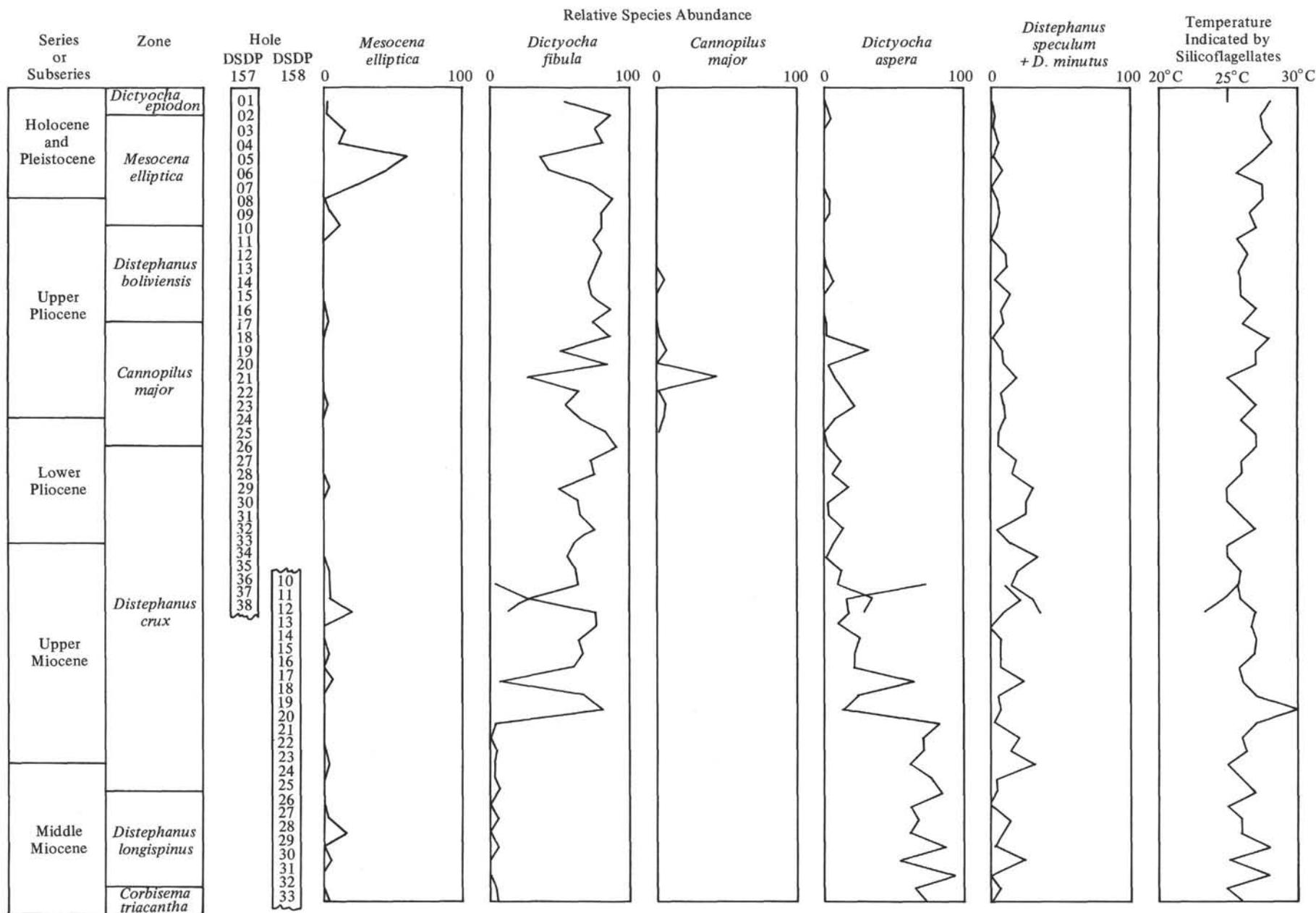
TABLE 5  
Silicoflagellates in Experimental Mohole Cores Recorded as Per Cents,  
with Zones and Geologic Series and Subseries Indicated

Sample	Taxa																			Total Specimens	Zone	Subseries
	<i>Cannopilus major</i>	<i>Corbisema triacantha</i>	<i>Dictyocha aspera</i>	<i>D. fibula</i>	<i>D. medusa</i>	<i>D. octagona</i>	<i>D. pentagona</i>	<i>D. pseudofibula</i>	<i>Distephanus</i> sp. cf. <i>D. boliviensis</i>	<i>D. crux</i>	<i>D.</i> sp. cf. <i>D. longispinus</i>	<i>D. longispinus</i>	<i>D. minutus</i>	<i>D. octacanthus</i>	<i>D.</i> sp. cf. <i>D. quinquangellus</i>	<i>D. speculum</i>	<i>Mesocena circula</i> [apiculate]	<i>M. diodon</i>	<i>M. elliptica</i>			
EM 6-2, 7-9 cm			20					40					20				20			5	<i>Distephanus crux</i>	Upper Miocene
EM 8-9, 150-152 cm												100								4		
EM 8-10, 383-385 cm			45					4			4				41	7				27		
EM 8-11, 286-288 cm	3		21	21					12	27					15				3	34	<i>Distephanus longispinus</i>	Middle Miocene
EM 8-11, 421-423 cm			9	4						65						17			4	23		
EM 8-12, 25-27 cm			38					6	38		6			6	6					16		
EM 8-12, 92-94 cm			40							40						20				5		
EM 8-12, 226-229 cm			30						13		53			3						30		
EM 8-13, 50-52 cm			13	4							83									24		
EM 8-14, 384-387 cm		9	26	7	2						53				3					91	<i>Corbisema triacantha</i>	
EM 8-15, 34-37 cm		31	39	5	5		2				15				3		2			62		
EM 8-15, 504-506 cm		28	33	5	3						18				3		10			39		
EM 7-1, 36-38 cm		7	11	11		25				14				32						28	<i>Distephanus octacanthus</i>	

TABLE 6  
 General Paleoenvironmental Aspects of Core Samples and Silicoflagellate Assemblages from DSDP 157  
 and DSDP 158 in the Panama Basin. Percentages of Three Major Silicoflagellate Genera for Each Core Are  
 Compared with Carbonate Percentage of Sediment and Indicated Temperature.



**TABLE 7**  
**Percentages of Important Silicoflagellate Species in Panama Basin Cores Compared to Temperatures Indicated by Silicoflagellates and Relative Stratigraphic Position. Peak Abundance of *Mesocena elliptica* and *Cannopilus major* Are Associated with Low-Temperature Intervals and Corresponding Low Points in *Dictyocha fibula* abundance.**



whereas they are restricted to the upper Pliocene in the Panama Basin. Slightly lower temperature is indicated in the upper Pliocene of the Panama Basin by a reduction of the *Dictyocha*/*Distephanus* ratio (see preceding section). Similarly, very cool temperatures of 4 to 9°C are indicated by this ratio for Ling's North Pacific Miocene *Cannopilus*-bearing assemblages. The apparent cool-temperature association of *Cannopilus* suggests that stratigraphic units of the tropics, based on silicoflagellates, are locally useful but may lack chronostratigraphic significance in other regions. The equatorial stratigraphy of the central Pacific suggested by Martini (1971) is most comparable to that observed in the eastern tropical Pacific. The presence of more diverse assemblages in the eastern Pacific, however, allows recognition of some additional biostratigraphic units. The occurrence of some key species in these units is shown in Table 8.

#### *Dictyocha epidon* Zone

This zone is characterized by the range of *Dictyocha epidon* and by the relative abundance of the following other species: dominant *Dictyocha fibula*, common *D. epidon*, and rare *D. aspera*, *Distephanus crux*, *Mesocena elliptica*, and *Octactis pulchra*.

The first common occurrence of *D. epidon* in tropical sediment of late Pleistocene age and its common preservation provide a convenient guide to this zone. Reference sections for this zone are Hole DSDP 157, Cores 1 and 2, and Hole DSDP 157A, Cores 1A to 3A.

#### *Mesocena elliptica* Zone

This zone is characterized by the common to abundant presence of *Mesocena elliptica* and *Dictyocha fibula*. *Distephanus quinquangellus*, *D. speculum*, *D. crux*, and *Octactis pulchra* are meager to rare. The two-species domination of the assemblage is very distinctive. The upper limit of the zone is defined by the first consistent occurrence of *Dictyocha epidon*, the lower limit by the first post-Miocene common occurrence of *M. elliptica*, which also coincides with the highest common *Distephanus boliviensis* and with the first occurrence of *Octactis pulchra*.

The predominance of *Mesocena elliptica* in middle Pleistocene assemblages of the tropical Pacific has been demonstrated by Jousé (1969) and by Hays et al. (1969). This concentration prompted Hays et al. to note that *M. elliptica* could be used as a guide fossil. Our cores partly support this finding because the greatest abundance of *M. elliptica* occurs in the middle Pleistocene. However, the range of the species encompasses at least the majority of the Pleistocene and the uppermost part of the Pliocene. The Pleistocene range of *M. elliptica* (junior synonym = *M. quadrangula*) led Martini (1971) to define an upper Pliocene to Holocene "*M. quadrangula* Zone" based on the total range of *M. elliptica*. Evidence from DSDP Leg 16, however, shows that upper Miocene populations of *M. elliptica* exist. The name and definition of Martini's zone has therefore been emended. A reference section for the *Mesocena elliptica* Zone includes Cores 3 to 10 of DSDP 157.

TABLE 8  
Zonal Occurrence of Some Key Upper Cenozoic Silicoflagellates in the Eastern Pacific Ocean. Consistent Occurrences are Indicated by an X, Sporadic Occurrences by a Dash.

Age	Zone	Taxa																
		<i>Dictyocha octagona</i>	<i>Distephanus octacanthus</i>	<i>Corbisema triacantha</i>	<i>Distephanus crux</i>	<i>Dictyocha medusa</i>	<i>Distephanus longispinus</i> s. l.	<i>Mesocena diodon</i>	<i>M. elliptica</i> s. l.	<i>M. circula</i>	<i>Distephanus quinquangellus</i>	<i>Dictyocha navicula</i>	<i>Dictyocha polyactis</i>	<i>Distephanus boliviensis</i>	<i>Cannopilus binoculus</i>	<i>C. major</i>	<i>Octactis pulchra</i>	<i>Dictyocha epidon</i>
Pleistocene and Holocene	<i>Dictyocha epidon</i>			-	-												X	X
	<i>Mesocena elliptica</i>							X	X								X	-
Pliocene	<i>Distephanus boliviensis</i>			-	-								X	X				
	<i>Cannopilus major</i>															X	X	
Miocene	<i>Distephanus crux</i>				X			X	X									
	<i>Distephanus longispinus</i>				X	-	X	X	X									
	<i>Corbisema triacantha</i>			X	X	-	X	X										
	<i>Distephanus octacanthus</i>	X	X		X													

*Distephanus boliviensis* Zone

This zone is characterized by the common presence of the large, distinctive species, *Distephanus boliviensis*. *Dictyocha fibula* is dominant; other meager to rare but consistently present species include *Distephanus quinquangellus*, *D. speculum*, and *Dictyocha aspera*. The top of the zone is indicated by the last common *Distephanus boliviensis* and by the first common occurrence of post-Miocene *Mesocena elliptica*. The base of the zone is indicated by the highest consistent occurrences of *Cannopilus* sp. and *Distephanus minutus* and by a general increase in the abundance of *D. boliviensis*. Cores 11 to 17 of DSDP 157 provide a reference section.

*Cannopilus major* Zone

This zone is characterized by the consistent presence of species of *Cannopilus*, with *C. major* most prominent. *Dictyocha fibula* is dominant, and *D. aspera*, *Distephanus boliviensis*, *D. minutus*, *D. speculum*, and *Mesocena circula* are present in lesser numbers. The top of the zone is marked by the last consistent occurrence of *Cannopilus*, and the base by the first consistent occurrence of both *Distephanus boliviensis* s.s. and *Cannopilus*.

The upper Pliocene occurrence of *Cannopilus* in the tropical Pacific Ocean was indicated by Jousé (1969). Owing to their large size, subdivided apical rings, and limited stratigraphic range in the eastern tropical Pacific, these forms provide excellent zonal markers. Cores 18 to 26 at DSDP 157 are a reference section for the zone.

*Distephanus crux* Zone

This zone is characterized by the consistent presence of *Distephanus crux*, *D. minutus*, *D. speculum*, *Dictyocha aspera*, and *D. fibula*. Other species present sporadically through the zone are *Dictyocha navicula*, *Distephanus boliviensis* s. l., *D. polyactis*, and *D. quinquangellus*. The top of the zone is indicated by the first occurrence of the *Cannopilus major* group, the first consistent *D. boliviensis* s.s., and by the last consistent occurrence of *D. crux*. The base of the zone is indicated by the last common occurrence of *Distephanus longispinus* or *D. sp. cf. D. longispinus*, which approximates the earliest occurrence of *D. quinquangellus*. This long zone can be subdivided into an upper *Dictyocha fibula* Subzone and a lower *Dictyocha aspera* Subzone on the basis of relative abundances. In the upper subzone, *D. fibula* is usually more abundant than *D. aspera*, and *D. navicula* is more abundant than below. In the lower subzone, *D. aspera* is typically more abundant than *D. fibula*. Also, *Mesocena diodon* and Miocene *Mesocena elliptica* are more numerous than above. *Mesocena diodon* is apparently restricted to the lower subzone. The chronostratigraphic value of these subzones is limited, as the reversal in dominance between *D. aspera* and *D. fibula* occurs in the upper *Discoaster quinquangellus* Zone of coccoliths at DSDP 157 and in the upper *Discoaster neohamatus* Zone of coccoliths at DSDP 158. Cores 10 to 24 at DSDP 158 and Cores 27 to 38 at DSDP 157 provide reference sections for the *Distephanus crux* Zone.

*Corbisema triacantha* Zone

This zone is characterized by the consistent meager to common occurrence of *Corbisema triacantha* in conjunction with abundant *Dictyocha aspera* and meager to common *D. fibula*, *D. medusa*, *Distephanus crux*, *D. longispinus* s. l., and *D. speculum*. The top of the zone is marked by the last consistent occurrence of *C. triacantha* in the presence of *D. longispinus* s. l. All higher occurrences are rare and sporadic, with *D. longispinus* missing. The base of the zone is indicated by the last consistent occurrences of two distinctive eight-spined species, *Dictyocha octagona* and *Distephanus octacanthus*. This zone was described by Martini (1971) in cores from the central equatorial Pacific that were assigned to the lower(?) to middle Miocene. The occurrence of this zone within the middle Miocene *Discoaster exilis* Zone of coccoliths at the base of the Leg 16 Panama Basin section and at the Experimental Mohole section supports this assignment.

*Distephanus octacantha* Zone

This zone is characterized by the abundant occurrence of *Distephanus octacanthus* and *Dictyocha octagona*. Other members of the assemblage include *Corbisema triacantha*, *Dictyocha aspera*, *D. fibula*, and *Distephanus crux*. This zone is distinguished from the overlying *Corbisema triacantha* Zone by the dominance of both *D. octacanthus* and *D. octagona* over *C. triacantha* and by the lack of *Distephanus longispinus*. The top of the zone is distinguished by the last common occurrence of *D. octacanthus* and *D. octagona* and by the earliest local occurrence of *D. longispinus*. Because this unit has been seen only at the base of the Experimental Mohole section, the base of the zone is unknown.

## Taxonomic Usage

In the past, a combination of trinomial and even quadrinomial systematics with a repetitive use of the same or similar names has made silicoflagellate taxonomy and recombinations difficult. In the system of taxonomy presented in this report, binomial usage is preferred.

Only six genera are used in this report. *Cannopilus* includes all forms with subdivided apical rings. *Corbisema* includes all forms with triangular body rings and simple, three-strut central structures. *Dictyocha* includes all other forms with simple strut structures or struts with an apical bar. *Distephanus* includes all forms with an open apical ring. *Mesocena* includes all forms possessing only a body ring with no central structures. *Octactis*, possibly a special octasymmetric form of *Distephanus*, has only a vestigial apical structure.

## SILICOFLAGELLATE SYSTEMATIC PALEONTOLOGY

Specific literature references to all silicoflagellate taxa published through 1967 have been indexed by Loeblich et al., 1968. The sources of silicoflagellate taxonomy are given fully in that work, therefore full synonymies are not given here.

Genus CANNOPILUS Haeckel, 1887

*Cannopilus binoculus* (Ehrenberg) Lemmermann, 1901

(Plate 1, Figures 1-2)

**Remarks:** This species is characterized by a large apical ring that is symmetrically divided by a bar into two openings. The basal ring is

hexagonal and symmetric in Panama Basin specimens. *Cannopilus binocularis*, owing to its occurrence and large size, seems related to the *Cannopilus major* group.

***Cannopilus ernstinae* Bachmann, 1962**

**Remarks:** Forms assigned to this species in Table 3 have a long spine atop the apical complex. They are identified only in side view (see pl. 1, fig. b. in Loeblich et al., 1968) and may be side views of *Cannopilus major* specimens. They are noted only in upper Pliocene samples from DSDP 157.

***Cannopilus hemisphaericus* (Ehrenberg) Haeckel, 1887**  
(Plate 1, Figure 3)

**Remarks:** The irregular multi-punctate apical structure, which is closely appressed to the basal ring, characterizes this species. It is distinguished from *Cannopilus major* by its lack of large portals between struts connecting apical and basal rings.

***Cannopilus major* (Frenguelli) n. comb.**  
(Plate 1, Figures 4-7; Plate 7, Figure 4)

*Dictyocha boliviensis* var. *major* Frenguelli, 1951, p. 277, figs. 3a-c.

**Remarks:** This especially large species is classified as a *Cannopilus* owing to the subdivided nature of the apical ring. Specimens having three to seven openings within the apical ring, and showing no particular symmetry, occur in the upper Pliocene of DSDP 157. The basal ring is typically six- or seven-sided.

A single example of two silicoflagellate skeletons that are juxtaposed involves forms that are here classified as two species *Cannopilus major* and *Distephanus boliviensis* (Frenguelli) n. comb. If this pairing represents the product of a single cell, the classification key for the genus *Cannopilus* employed here would be clearly artificial. However, the pairing was observed only in a sample where the ranges of these two species overlap. *Distephanus boliviensis* has a longer range, which suggests that the pairing could be fortuitous. As the skeletal variability of naturally reproducing silicoflagellate populations is not fully understood, *Cannopilus* may have been derived from *Distephanus* as a result of ecologic threshold factors, as yet unknown.

Stratigraphically, *Cannopilus major* is restricted in Panama Basin cores to a short interval in the upper Pliocene. Because of its large size and distinctive structure, it provides a convenient guide to the *Cannopilus major* Zone. Jousé (1971) indicated that *Distephanus speculum* var. *cannopiloides* [invalid according to Loeblich et al., 1968, p. 48] = ?*Cannopilus major* occurs in the upper Pliocene of paleomagnetically dated Core V20-119 (47°57'N., 168°47'E.) but not in the overlying Pleistocene. In addition, Ling (1970) included forms with *Cannopilus hemisphaericus* that are here considered *Cannopilus major* and that occur in the Miocene of North Pacific Ocean cores.

The restricted upper Pliocene range of *Cannopilus major* in the Panama Basin suggests that it may have flourished there during a period of slightly cooler water, because the paleotemperature indicated by the *Dictyocha/Distephanus* ratio is relatively low in the upper Pliocene.

***Cannopilus quintus* Bukry and Foster, n. sp.**  
(Plate 1, Figures 8-9; Plate 2, Figure 1)

**Description:** This fossil species is characterized by an essentially symmetric pentagonal basal ring having distal spines at the apices, and by a large apical ring divided into four asymmetric openings.

**Remarks:** *Cannopilus quintus* is distinguished from other species of *Cannopilus* by having a pentagonal basal ring and four asymmetric openings within the apical ring. *Distephanus quinquangellus* has a pentagonal basal ring but lacks the four openings within the apical ring. The trivial name signifies the five-sided basal ring, an unusual character for *Cannopilus*.

**Occurrence:** *Cannopilus quintus* is presently known only from a lower upper Pliocene sample from the Panama Basin.

**Size:** Apical ring diameter 32-38 microns. Basal ring diameter 50-58 microns.

**Holotype:** USNM 182794 (Plate 1, Figures 8-9).

**Paratype:** USNM 182795.

**Type locality:** DSDP 157-22(CC), approximate subbottom depth 207 m, Carnegie Ridge, Panama Basin.

***Cannopilus schulzii* Deflandre, 1962**  
(Plate 2, Figure 2)

**Remarks:** This species has an eight-sided basal ring. It was not tabulated because of a single occurrence in the Panama Basin samples.

Genus CORBISEMA Hanna, 1928

***Corbisema triacantha* (Ehrenberg) Hanna, 1931**  
(Plate 2, Figure 3)

**Remarks:** The triangular body ring of this species has rounded apices with distal spines at each apex. This species flourishes in the middle Miocene of the Pacific [see Table 5 on EM samples and Martini, 1971, on Leg 7 cores]. The basal silicoflagellate sample from DSDP 158, Core 33, is at the upper range of this acme, which is very pronounced in the EM cores. Higher occurrences are rare.

Genus DICTYOCHA Ehrenberg, 1837

***Dictyocha aspera* (Lemmermann) n. comb.**  
(Plate 2, Figures 4-6)

*Dictyocha fibula* var. *aspera* Lemmermann, 1901, p. 260, pl. 10, figs. 27, 28.

**Remarks:** This simple, long-ranging species is characterized by having the apical bar aligned with the short axis of the basal ring instead of with the long axis as in *Dictyocha fibula*. The length of the apical bar varies considerably, causing differences in the size of the short-axis portals with respect to the larger long-axis portals. Numerous synonyms exist for this species; among them are *Dictyocha ausonia* Deflandre, *Dictyocha fibula* var. *brevispina* Lemmermann, *D. mutabilis* Deflandre, and *Dictyocha fibula* var. *aspera* forma *rhombica* Schulz [see Loeblich et al., 1968].

Stratigraphically, this species occurs consistently in Miocene to Pleistocene sections examined and is missing in older sections. Bachmann (1970) found it missing in an upper Oligocene assemblage from Austria. Martini (1971) proposed a reversal in dominance between *Dictyocha aspera* and *Dictyocha fibula* as a potentially useful stratigraphic datum. Study of our Panama Basin sections suggests that this reversal does occur in the late Miocene but is probably controlled environmentally because it occurs at two different times between our northern and southern sites. Although the reversal does not represent a chronostratigraphic datum, it provides a general guide to the upper and lower parts of the *Distephanus crux* Zone.

***Dictyocha epidon* Ehrenberg, 1844**  
(Plate 2, Figures 7-8)

**Remarks:** This Pleistocene species is characterized by an eight-sided basal ring having four major spines and four alternate pikes; the opposing spines are slightly offset, and the apical bar is canted at an angle to the principal axes of the basal ring. No spine occurs on the apical bar, but there are generally four proximally directed pikes on the basal ring near the distally directed pikes.

The common occurrence of this species in upper cores from the Panama Basin and its absence in the underlying section provide a useful guide for the *Dictyocha epidon* Zone.

Ehrenberg's illustration of Holocene *Dictyocha epidon* from the North Atlantic (54°17'N., 22°33'W.) is accepted as the type of this species, and *Dictyocha fibula* var. *aculeata* (Lemmermann) is considered a probable junior synonym [compare illustrations of both in pl. 9 of Loeblich et al., 1968]. A high-latitude occurrence of this form in the Pacific was confirmed by Ling (1970), who noted that *D. fibula* var. *aculeata* is common in Quaternary cores from the North Pacific. The same form, called *Distephanus japonicus*, was illustrated by Jousé (1969) from an equatorial Pacific Ocean Pleistocene core (2°01.5'S., 172°32.5'W.). *Dictyocha epidon* is apparently a species tolerant of environmental fluctuations and developed from *Dictyocha fibula* during the Quaternary.

***Dictyocha fibula* Ehrenberg, 1839**  
(Plate 2, Figure 9; Plate 3, Figures 1 and 12)

**Remarks:** This species is identified by the alignment of the apical bar with the long axis of the basal ring, instead of with the short axis as in *Dictyocha aspera*. The apical bar is fairly long in post-Miocene specimens but may be short in the same Miocene samples where *D. aspera* has short apical bars. A specimen of *D. fibula* with auxiliary distal pikes on the basal ring is illustrated (Plate 2, Figure 9) to contrast with the structure

of *D. epidon* (Plate 2, Figure 8), with which it has only general similarity. *D. fibula* specimens having smooth basal rings are the overwhelmingly predominant form in Panama Basin cores, indicating that possession of distal pikes on the basal ring is not a warm-water character.

Geographically, *Dictyocha fibula* is cosmopolitan, occurring in oceanic areas at high and low latitudes. Ling (1970) demonstrated that, whereas *D. fibula* is present in core samples from high latitude in the Pacific, it is numerically dominated by *Distephanus speculum*. In our low-latitude, warm-water assemblages, *D. fibula* is the preeminent species. Though cosmopolitan, *D. fibula* is most successful in warm-water areas. A laboratory-culture study of *D. fibula* specimens collected near Edmonds, Washington, indicated optimum growth at 10°C and 24 per cent salinity (Van Valkenburg and Norris, 1970). As it is unlikely that the temperature of near-surface water inhabited by abundant *D. fibula* populations in the Panama Basin ever fell to 10°C, a latitudinal series of races of *D. fibula*, each suited to the ambient temperature of the region, probably exists. A repeat of the Van Valkenburg-Norris experiment on cultures of tropical and arctic *D. fibula* might demonstrate this supposition and show skeletal variation useful in paleoenvironmental interpretation. Would a clonal culture of tropical *D. fibula* produce the group of aberrant skeletons illustrated by Van Valkenburg and Norris? They show forms reminiscent of fossil *Dictyocha pentagona* and *D. pseudofibula*, which were noted only sporadically in samples from the Panama Basin. Do the fossil Panama Basin occurrences therefore indicate colder waters and lower salinities? Or, are other ecologic factors such as grazing or nitrogen supply chiefly responsible (McGowan, 1971; Tappan, 1971)?

Stratigraphically, *Dictyocha fibula* ranges throughout the Miocene to Pleistocene sections examined. Bachmann's (1970) upper Oligocene assemblage from Austria lacks *D. fibula*. A reversal in dominance between *D. fibula* and *D. aspera* in the upper Miocene (Martini, 1971) provides a general indication of the stratigraphic position of samples within the *Distephanus crux* Zone.

**Dictyocha japonica Deflandre, 1950**  
(Plate 3, Figure 3)

**Remarks:** A single small specimen of this cool-water species was observed in the upper Miocene at DSDP 157.

**Dictyocha medusa Haeckle, 1887**  
(Plate 3, Figures 4-5)

**Remarks:** This simple species is characterized by the absence of an apical bar or apical ring. Four struts meet at a central point, forming an x. This species is distinguished from forms of *Dictyocha aspera* that have a vestigial apical bar by the direct alignment of opposing struts across the center point. Mandra (1968) pointed out the Miocene age of this species under the name *Dictyocha staurodon*. The present study of sections at DSDP 157, DSDP 157A, DSDP 158, and the Experimental Mohole confirms the restriction of *D. medusa* to the Miocene.

**Dictyocha navicula Ehrenberg, 1839**  
(Plate 3, Figures 6-8)

**Remarks:** The form of the body ring is basically elliptical with varying degrees of elongation. The most typical forms in Panama Basin cores are those showing little elongation (Plate 3, Figure 8). *Dictyocha navicula* is generally rare and sporadic, being common only in sample DSDP 158-11-(CC).

**Dictyocha octagona (Tsumura) n. comb.**  
(Plate 3, Figure 9)

*Dictyocha fibula* var. *octagona* Tsumura, 1963, p. 55, 56, 71, pl. 2, fig. 4; pl. 10, figs. 11-13; pl. 23, figs. 8-10.

*Dictyocha octagona* Tsumura, of Martini, 1971, p. 1697, pl. 1, fig. 15.

**Remarks:** The basal ring of this species is symmetrically octagonal with distal spines at the apices. One pair of opposing spines is distinctly longer than the others. The apical bar is aligned nearly perpendicularly with this pair of spines.

*Dictyocha octagona* occurs only at the bottom of the Experimental Mohole section and is absent in the stratigraphically higher sections at DSDP 157 and DSDP 158. As it does not consistently range as high as *Corbisema triacantha* in warm-water Pacific sections, it may be a useful guide to the *Distephanus octacanthus* Zone.

**Dictyocha pentagona (Schulz) n. comb.**  
(Plate 3, Figure 10)

*Dictyocha fibula* var. *pentagona* Schulz, 1928, p. 255, figs. 41a, b. —Loeblich et al., 1968, p. 96, pl. 12, figs. 13, 14.

**Remarks:** The basal ring of this species is pentagonal and asymmetric, with five equant spines at the apices. The apical bar may be straight or crooked and is connected to the basal ring by five struts of unequal length. This species is rare in the cores examined, but occurrences are noted in the upper Pleistocene, Pliocene, and middle Miocene.

**Dictyocha pseudofibula (Schulz) Tsumura, 1963**  
(Plate 3, Figures 2 and 11)

**Remarks:** This form is rare and sporadic in our cores and may be an environmentally induced variant of *Dictyocha fibula* (see Van Valkenburg and Norris, 1970). It is more common in cool-water assemblages at higher latitudes.

**Dictyocha vanandelii Bukry and Foster, n. sp.**  
(Plate 7, Figure 1)

**Description:** This large species is bilaterally symmetric. The body ring is in the form of a modified ellipse with one end flattened. Three struts meet at the center point of the ellipse dividing the intra-ring area into three portals. Five distal pikes on the body ring are situated at the three apices and at the points where the two long struts meet the body ring.

**Remarks:** This unusual form is reminiscent of *Corbisema* owing to the tripartite division of the central area by struts. However, *Dictyocha vanandelii* is distinguished by having five basal-ring pikes and a modified elliptic outline. *Dictyocha tripyla* Ehrenberg has a three-part strut system but has four pikes and no flattening of the body ring. This species is named in recognition of the leadership of Dr. Tj. H. van Andel in marine geologic studies of the Panama Basin.

**Occurrence:** *Dictyocha vanandelii* is presently known only from DSDP 157-22(CC), which is lower upper Pliocene.

**Size:** Length and width about 75 microns.

**Holotype:** USNM 182796 (Plate 7, Figure 1).

**Type locality:** DSDP 157-22(CC), approximate subbottom depth 207 meters, Carnegie Ridge, Panama Basin.

Genus *DISTEPHANUS* Stöhr, 1880

**Distephanus boliviensis (Frenguelli) n. comb.**  
(Plate 4, Figures 1-3)

*Dictyocha boliviensis* Frenguelli, 1940, p. 44, fig. 4. —Loeblich et al., 1968, p. 83, pl. 9, fig. 3

**Remarks:** This especially large species is characterized by equant distal spines on six- or seven-sided basal rings, by an open apical ring, and usually by six of seven proximal pikes on the basal ring. Characteristic forms are most prominent in upper Pliocene samples from DSDP 157, although smaller forms with less equant spines (resembling *Distephanus speculum*) occur in the lower Pliocene and upper upper Miocene (Plate 4, Figure 4).

**Distephanus crux (Ehrenberg) Haeckle, 1887**  
(Plate 4, Figures 5-6)

**Remarks:** This species has four-part symmetry. The apical opening is typically small. Although *Distephanus crux* is long-ranging, it is relatively meager in the Panama Basin sections. Its greatest abundance, as much as 90 per cent of some assemblages, has been noted in middle Miocene samples from Maryland and California. Ling (1970) and the present study suggest that *Distephanus crux* dwindled into obscurity after the end of the Miocene, becoming rare in later epochs. Its great abundance in mid-latitude samples contrasts with its meager to common occurrence in coeval middle Miocene samples from the Panama Basin, suggesting that its optimum growth environment was temperate instead of tropical.

A specimen of *Distephanus crux* with a basal ring like that of associated *Dictyocha epidon* is illustrated (Plate 4, Figure 5). The occasional convergence of basal-ring structures, such as this, between coeval species of *Distephanus* and *Dictyocha* suggests close biologic affinities between certain members of these genera. Compare coeval *Dictyocha octagona* and *Distephanus octacanthus* illustrated here (Plate 3, Figure 9; Plate 4, Figure 12) and Gemeinhardt's (1930) illustrations of *Dictyocha pseudofibula* and *Dictyocha pseudocrux*.

***Distephanus longispinus* (Schulz) n. comb.**

(Plate 4, Figures 7-8)

*Distephanus crux* f. *longispina* Schulz, 1928, p. 256, fig. 44.—Loeblich et al., 1968, p. 120, pl. 24, fig. 29.

**Remarks:** This species has a relatively small, somewhat elliptic, quadrate basal ring, a large square apical ring, two extremely long opposed spines, and two short spines. *Distephanus* sp. cf. *D. longispinus* has relatively shorter long-axis spines and a smaller apical ring with respect to the basal ring. Stratigraphically, *sensu stricto* forms are noted only in the middle Miocene EM section. The comparable forms at DSDP 158 are likewise restricted to the Miocene.

***Distephanus minutus* (Bachmann) n. comb.**

(Plate 4, Figures 10-11)

*Dictyocha speculum* f. *minuta* Bachmann in Ichikawa et al., 1967, p. 161, pl. 7, figs. 12-25.—Loeblich et al., 1968, p. 115, pl. 52, figs. 26-39.

**Remarks:** The apical ring of this hexagonal species is so wide that the struts connecting it to the basal ring are practically covered in plan view. It is most common in middle Miocene to lower Pliocene samples.

***Distephanus octacanthus* (Desikachary and Maheshwari) n. comb.**

(Plate 4, Figure 12)

*Distephanus crux* var. *octacanthus* Desikachary and Maheshwari, 1956, p. 260, figs. 10, 12, 13; pl. 13, figs. 8.—Loeblich et al., 1968, p. 120, pl. 24, figs. 25-27.

**Remarks:** This symmetric octagonal form has a small square apical ring that distinguishes it from *Dictyocha octagona*, with which it occurs in sample EM 7-1, 36-38 cm. It does not occur in younger strata from the EM section, DSDP 157, or DSDP 158.

***Distephanus parvus* (Bachmann) n. comb.**

(Plate 5, Figures 2-3)

*Dictyocha crux* f. *parva* Bachmann in Ichikawa et al., 1967, p. 156, pl. 4, figs. 14-31.—Loeblich et al., 1968, p. 85, pl. 52, figs. 8-25.

**Remarks:** A single specimen of *Distephanus parvus* was observed in upper Miocene sample DSDP 157-38(CC). It is a species with four distal pikes on the apical ring. This species was originally described from the lower upper Miocene of Japan.

***Distephanus polyactis* (Ehrenberg) Deflandre, 1932**

(Plate 5, Figures 6-7)

**Remarks:** This large symmetric species is noted rarely in upper Miocene and lower Pliocene cores only from DSDP 157. The nine-spined form illustrated as *Distephanus speculum* by Ling (1970) from North Pacific cores matches our Panama Basin specimens.

***Distephanus quinquangellus* Bukry and Foster, nomen novum**

(Plate 5, Figure 4)

*Distephanus speculum* var. *pentagonus* Lemmermann, 1901, p. 264, pl. 11, fig. 19.—Loeblich et al., 1968, p. 122, pl. 25, fig. 5. *non Distephanus pentagonus* Wailes, 1939, p. 10, fig. 23.

**Description:** This species has symmetric five-sided basal and apical rings with equant spines at the apices of the basal ring. Typically, five small proximally directed pikes occur on the basal ring. Panama Basin specimens have apical ring diameters of 8-18 microns and basal ring diameters of 20-45 microns.

**Remarks:** The name *Distephanus quinquangellus* is used as a substitute for *Distephanus speculum* var. *pentagonus* (Lemmermann). Lemmermann's variety is considered to be of species rank but cannot be elevated because the name "*Distephanus pentagonus*" is occupied by *Distephanus pentagonus* Wailes.

**Occurrence:** *Distephanus quinquangellus* is most common in upper Miocene and Pliocene cores of the Panama Basin but also ranges through the Pleistocene. Only rare *Distephanus* sp. cf. *D. quinquangellus*, which are slightly asymmetric, were noted in middle Miocene samples.

***Distephanus speculum* (Ehrenberg) Haeckle, 1887**

(Plate 5, Figure 8)

**Remarks:** This hexagonal species is distinguished from *Distephanus boliviensis* by its smaller size, by its two opposing basal-ring spines that are longer than the other four, and by its generally smaller apical ring. *Distephanus speculum* is distinguished from *D. minutus* by its much

smaller apical ring. Although this long-ranging species occurs throughout the sections examined, it rarely achieves the levels of abundance indicated by Ling (1970) for North Pacific core samples. This presumably cool-water species is most numerous in upper Miocene samples of the Panama Basin. *Distephanus speculum* and *D. minutus* constitute the majority of specimens used to determine the *Distephanus* portion of the *Dictyocha/Distephanus* ratio for paleotemperature determination (see Mandra, 1969).

Genus MESOCENA Ehrenberg, 1843

***Mesocena circula* (Ehrenberg) Ehrenberg, 1844**

(Plate 5, Figure 9; Plate 6, Figure 1)

**Remarks:** These circular to elliptic rings are ornamented only by a series of regularly or irregularly spaced distally directed pikes. Some regular specimens have one set of pikes directed "upward" and an alternate set directed "downward" with respect to the plane of the ring. *Mesocena circula* occurs sporadically in the Miocene and Pliocene. Only a few specimens (reworked?) were noted from the Pleistocene.

***Mesocena elliptica* (Ehrenberg) Ehrenberg, 1844**

(Plate 6, Figures 2-4)

**Remarks:** The body ring of this species may take a variety of shapes between rhomboid and circular. Four distally directed spines at the apices of rhomboid forms or symmetrically 90 degrees apart on circular forms are a consistent character of this species. The body ring may be smooth or ornamented by irregularly spaced pikes.

Rhomboid and circular forms and smooth and ornamented forms occur together in Quaternary samples, where *Mesocena elliptica* is particularly abundant. Quaternary specimens as a group are more symmetric than older specimens assigned to this species. Only rare specimens were noted in Pliocene Panama Basin samples; these could represent minor contamination, reworking, or small or poorly preserved populations of *M. elliptica*. The occurrence of *M. elliptica* in upper Miocene samples, indicated in the shipboard Leg 16 report, has been confirmed by shore-laboratory studies. The unusual disjunct distribution of *M. elliptica* is partly explained by the skeletal forms of the Miocene populations. Although single specimens of *M. elliptica* from the Miocene may be identical in form to those of the Quaternary, the Miocene populations show a high percentage of irregular, elongate-rhomboid forms, many of which have one or more margins that are bowed-out or bowed-in. From structural evidence, the Miocene and Quaternary forms could represent two acmes of the same species. Alternately, the rare presence of *Mesocena*-like *Dictyocha fibula* specimens (Plate 6, Figure 5) with Miocene *M. elliptica* could indicate derivation from a *D. fibula* stock at two different times.

Stratigraphically, two essentially disjunct, Miocene and Quaternary populations occur in DSDP Leg 16 cores. The youngest middle Quaternary abundance of *Mesocena elliptica* matches the observations of Hays et al. (1970) and Muhina (1969), which were based on studies of cores from the tropical Pacific and Indian Oceans. Their studies indicated a very short stratigraphic range, and Hays et al. stated that, "*Mesocena elliptica* is stratigraphically useful, its range bracketing the Jaramillo event for which it is a useful guide fossil." They assigned a radiometric age of 0.927 m.y. to the base of the Jaramillo normal polarity event. Although *M. elliptica* is most abundant in the middle Quaternary of the Panama Basin cores, it ranges throughout the Quaternary (see Tables 2 and 3). Because little comparative information is available, the stratigraphic significance of the Miocene population is unclear.

***Mesocena diodon* Ehrenberg, 1844**

(Plate 6, Figures 6-7)

**Remarks:** This circular to elongate elliptic species has two distal pikes aligned with the major axis of the body ring. *Mesocena diodon* occurs only in the Miocene part of the sections examined.

***Mesocena pentagona* Haeckle, 1887**

(Plate 6, Figure 8)

**Remarks:** This species is bilaterally symmetric, having five distal spines on the body ring. Two specimens, Miocene and Pleistocene, were observed in Panama Basin samples.

**Mesocena triangula (Ehrenberg) Ehrenberg, 1844**  
(Plate 6, Figures 9-10)

**Remarks:** This roundly triangular species has distal pikes at the apices and is consistently ornamented with many tiny pikes along the distal margin of the body ring. It occurs rarely in Miocene and Pliocene samples

Genus OCTACTIS Schiller, 1925

**Octactis pulchra Schiller, 1925**  
(Plate 6, Figures 11-12)

**Remarks:** This symmetric octagonal species is dominated by the body ring and distal spines. It occurs only rarely in Quaternary samples. It is common in some late Pleistocene and Holocene core samples from the Black Sea (Bukry, unpublished data) and was originally described in living populations from the Adriatic Sea.

**DIATOMS**

**Study Methods**

Core samples tabulated for diatoms are from the same fractions, greater than 44 microns, used in the silicoflagellate study. These were separated to facilitate study of larger diatoms present at low levels of abundance. Preparations of the fraction less than 44 microns, which are more poorly preserved than the coarse fraction, typically contain common to abundant fragments of the elongate diatom genera *Thalassiothrix* and *Thalassionema* and lack many distinctive species characterizing the coarser fractions. In the diatom stratigraphic tabulations and general interpretations, which are based only on the coarse fractions, the letters *A*, *C*, *M*, and *R* indicate the relative abundance of each species (Tables 9, 10, and 11). *A* is used for abundant occurrences, *C* for common occurrences, *M* for meager occurrences (intermediate between common and rare), and *R* if only one to four specimens are found on a sample slide. Scanning of the 40 × 20 mm slide areas was done at magnifications of 100 and 250 ×.

**Paleoenvironmental Interpretation**

All diatom assemblages examined are dominated by oceanic, tropical to subtropical species. Only a single predominantly cool-water species, *Coscinodiscus curvatulus* Grunow [see Lohman, 1941; Hende, 1964], has

been identified. The consistent dominance of restricted warm-water taxa [Groups I and V of Kanaya and Koizumi, 1966] suggests that the abundance of the elongate diatoms *Thalassionema* and *Thalassiothrix* is indicative of upwelling and resultant productivity, not necessarily of cool-water conditions as has been suggested (Hende, 1937). Both of the principal species of elongate diatoms in the Panama Basin, *Thalassionema nitzschioides* and *Thalassiothrix longissima*, have been recorded as minor living components in the Pacific Ocean Subarctic group of Venrick (1971), but not of the Central Pacific group; nutrient enrichment is higher in the Subarctic area. *Denticula*, a common genus in Neogene high-latitude cool-water assemblages, is missing from all but Miocene assemblages in the Panama Basin. Actual temperature fluctuations in the basin were probably small during the late Neogene. The Miocene and Pliocene occurrences of *C. curvatulus* and temperate-water *Actinocyclus ehrenbergii* Ralfs [see Lohman, 1941] indicate that these taxa were then more cosmopolitan, or that Panama Basin waters may have been slightly cooler. Because the sample interval for this study is 9 meters (about 200,000-year increments for the Pleistocene at DSDP 157), short-term incursions of cool-water species might be as yet undetected. The consistent dominance of oceanic, warm-water species in the samples examined is, however, the most significant feature of the Panama Basin diatom assemblages.

Genera that are considered to be characteristic of coastal or nearshore areas can be used to indicate the presence of displaced shallow-water deposits, which may result from erosion during glacial periods of lowered sea level or from turbid-flow deposition. Representatives of such genera—*Auliscus*, *Aulacodiscus*, *Biddulphia*, *Diploneis*, *Grammatophora*, *Navicula*, *Pleurosigma*, and *Surirella*—are rare and sporadic in their occurrence, indicating normal pelagic deposition at DSDP 157 and DSDP 158.

The state of preservation varies to some extent and is best reflected by degree of solution and by the relative diversity of the assemblages. For example, no diatoms are present in DSDP 157 below Core 38, which contains hard chert. Diatom silica in deeper sediment was presumably remobilized during formation of the chert, because diversity and preservation of diatoms are fairly good directly above. *Hemidiscus cuneiformis* is represented by both whole valves and open girdle bands. Although thinning of the areolae structure of valves can be observed in several species, no intermediate stages between open girdle bands and thinned areolae has been observed. No attempt has been made to gauge various degrees of preservation, but Kamatani (1971) has stated that, "The rate of dissolution of diatomaceous silica varies considerably between species." Therefore the species diversity of an assemblage and possibly the percentage of open girdle bands could be combined to estimate a range of preservation states.

TABLE 9  
Diatoms Greater Than 44 Microns in Size at DSDP 157A

Sample	Taxa																			
	<i>Actinoptrychus senarius</i>	<i>A. sp. cf. A. vulgaris monicae</i>	<i>Asteromphalus arachne</i>	<i>A. brookei</i>	<i>A. heptactis</i>	<i>A. imbricatus</i>	<i>A. wyvillii</i>	<i>Coscinodiscus africanus</i>	<i>C. asteromphalus</i>	<i>C. excentricus</i>	<i>C. gigas diorama s. l.</i>	<i>C. lineatus</i>	<i>C. nodulifer</i>	<i>Ethmodiscus rex</i>	<i>Hemidiscus cuneiformis</i>	<i>Chaetoceros sp.</i>	<i>Roperia tessellata</i>	<i>Stictodiscus trigonus</i>	<i>Thalassiothrix spp.</i>	<i>Triceratium cinnamomeum</i>
1A-2(8-10 cm)	M	R	R		R	A		R	R	M	R	R		A	C	M	M	C	R	A
1A-4(8-10 cm)	R	R		R		C		R	R	M	R	R		C	R	M	R	A		C
1A(CC)	R			R		M		R	R		R			A	M	M	R	C		M
2A(CC)	R				M	C		C		R	M		R	A		C		M		R
3A(CC)					M					C		R	A	R	M	R		M		C

**Tropical Diatom Zonation**

Biostratigraphic zonation based on oceanic diatom assemblages is a relatively new field. Stratigraphic subdivisions of Pacific Ocean sediment by diatoms have been indicated recently by Kanaya (1971), Kanaya and





TABLE 12  
Zonal Occurrence of Some Key Upper Cenozoic Diatoms in the Eastern Pacific.  
Consistent Occurrences are Indicated by an X, Sporadic Occurrences by a Dash.

Age	Zone	Taxa																					
		<i>Craspedodiscus coscinodiscus</i>	<i>Coscinodiscus gigas diorama s. s.</i>	<i>Actinocyclus ellipticus</i>	<i>Denticula hustedtii</i>	<i>Coscinodiscus paleaceus</i>	<i>C. plicatus</i>	<i>Avachnoidiscus ornatus</i>	<i>Stictodiscus trigonus</i>	<i>Actinocyclus ehrenbergii</i>	<i>Asteromphalus decorus</i>	<i>Thalassionema nitzschioides s. l.</i>	<i>Fragilaritopsis plicocena</i>	<i>Coscinodiscus lineatus</i>	<i>C. nodulifer</i>	<i>Hemidiscus cuneiformis</i>	<i>Coscinodiscus elongatus s. l.</i>	<i>C. excentricus</i>	<i>Asterolampra</i> sp. [7-section]	<i>Chaetoceros</i> sp.	<i>Pseudoecunotia doliolus</i>	<i>Roperia tessellata</i>	
Holocene and Pleistocene	<i>Roperia tessellata</i>														X	X	X	X	X	X		X	X
	<i>Chaetoceros</i> sp.								X		X	X	X	X	X	X	X	X		X			
Pliocene																							
Late Miocene	<i>Hemidiscus cuneiformis</i>														X	X	X	X	X	X			
	<i>Coscinodiscus plicatus</i>																						
Middle Miocene	<i>Craspedodiscus coscinodiscus</i>	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

*Rhizosolenia bergonii*, and *Thalassiosira oestrupii*. The rare but distinctive species *Stictodiscus trigonus* occurs in this zone and in the much lower *Craspedodiscus coscinodiscus* Zone, but is not observed at intervening levels. This zone occurs at DSDP 157A, Cores 1A to 3A; DSDP 157, Cores 1 to 5, probably also Cores 6 to 9; and in the top sample at DSDP 159.

#### *Chaetoceros* sp. Zone

This zone is bounded by the first common occurrence of *Chaetoceros* sp. at the base and by the first common occurrence of *Roperia tessellata* at the top. The disappearance of *Coscinodiscus elongatus* (lanceolate and typical forms) near the middle of the zone helps to distinguish an upper and a lower part. *Asteromphalus* is common in the upper part of the zone, whereas *Thalassionema* is most common in the lower part. The most common and consistently present species throughout the zone, besides *Chaetoceros* sp., are *Coscinodiscus lineatus*, *C. nodulifer*, *Ethmodiscus rex*, *Hemidiscus cuneiformis*, and *Thalassiothrix* spp. The highest local occurrences of several taxa are noted in the upper part of the zone: *Actinocyclus ehrenbergii*, *Asterolampra* spp. having seven or eight sections, and *Asteromphalus decorus*.

Changes in tropical diatom assemblages near the first occurrence of *Chaetoceros* sp. include (a) the first occurrence of seven-sectioned *Asterolampra* sp. and *Asteromphalus heptactis*, (b) the earliest consistent *Coscinodiscus excentricus* and *C. nodulifer*, and (c) the latest occurrences of *Denticula hustedtii*, *D. lauta*, *Coscinodiscus paleaceus*, and *C. plicatus*. Reference sections with representative assemblages of the zone are at DSDP 158, Cores 1 to 15, and DSDP 157, Cores 7 to 38.

#### *Hemidiscus cuneiformis* Zone

Between the uppermost *Coscinodiscus plicatus* and the lowermost *Chaetoceros* sp., this zone is recognized as a short interval in which *Hemidiscus cuneiformis*, *Thalassiothrix*, and *Coscinodiscus lineatus* are common. *Coscinodiscus nodulifer*, a dominant species in tropical fossil assemblages (Kolbe, 1954) first becomes numerically significant within this zone. Cores 16 to 19 at DSDP 158 contain representative assemblages of the zone.

#### *Coscinodiscus plicatus* Zone

This zone is characterized by the overlapping ranges of *Coscinodiscus plicatus* and *Hemidiscus cuneiformis* in the absence of *Craspedodiscus coscinodiscus*. Typical members of the zonal assemblage include *Actinocyclus ellipticus*, *Coscinodiscus curvatulus*, *C. lineatus*, *C. paleaceus*, *Denticula hustedtii*, *D. lauta*, *Thalassionema* spp., and *Thalassiothrix* spp.

This zone has been well typified by Kanaya (1971) as Zone III in his study of diatoms from the EM site. Equatorial Pacific reference cores assigned to this zone include Cores 20 to 30 at DSDP 158.

#### *Craspedodiscus coscinodiscus* Zone

This zone is distinguished by an assemblage containing abundant *Coscinodiscus gigas diorama s.s.*, common to abundant *Craspedodiscus coscinodiscus*, common *Actinocyclus ellipticus*, *Coscinodiscus curvatulus*, and *Denticula hustedtii*. Absent from the assemblage except for rare specimens at the top are *Coscinodiscus lineatus* and *Hemidiscus cuneiformis*. The top of the zone is identified

by the disappearance of *C. gigas diorama* s.s. and *C. coscinodiscus* and by the earliest occurrences of *H. cuneiformis*, *Coscinodiscus nodulifer*, and *Asteromphalus decorus*. The base of the zone is not present in DSDP Leg 16 cores, but, as indicated by Kanaya (1971) in his discussion of the essentially equivalent Zone II in the EM cores, the last common occurrence of *Coscinodiscus lewisianus* provides a convenient guide, which might serve as a marker species for the next lower zonal unit. This criterion would likely be applicable to tropical areas because a single reworked(?) specimen of this species was observed at DSDP 158 (Plate 13, Figure 7). Assemblages from Cores 31 to 33 of DSDP 158 are considered representative of this zone.

#### Diatom Taxonomic Usage

The names for diatoms in this report have been based on illustrations and descriptions in the following publications: Castracane, 1886; Cupp, 1943; Hanna, 1932; Jousé, 1968; Kanaya, 1971; Kanaya and Koizumi, 1966; Koizumi, 1968; Kolbe, 1954; Lohman, 1941; Muhina, 1969; Reinhold, 1937; and Wornardt, 1967.

#### DIATOM SPECIES TABULATED

##### *Actinocyclus ehrenbergii* Ralfs (Plate 8, Figures 1-2)

Following the usage of Hanna (1932), forms with varying numbers of rays are included. This species occurs through the middle Miocene to upper Pliocene sections at DSDP 157 and DSDP 158. It is missing in Pleistocene samples, and in the middle Pliocene at DSDP 157, it is most common in the fine fraction.

##### *Actinocyclus ellipticus* Grunow (Plate 8, Figure 3)

This thick species exhibits high interference colors. It is restricted to middle Miocene cores of the Panama Basin where it is commonly a conspicuous member of the assemblages.

##### *Actinocyclus ingens* Rattray (Plate 8, Figure 4)

This species occurs rarely only in middle Miocene samples from the Panama Basin but is recorded as a common species in both middle and upper Miocene samples from Experimental Mohole cores about 20 degrees farther north (Kanaya, 1971).

##### *Actinoptychus senarius* Ehrenberg (Plate 8, Figures 7-9)

This cosmopolitan species occurs throughout the Panama Basin cores but is most common in upper Pliocene sediment at DSDP 157. It is considered a subtropical species (Lohman, 1941).

##### *Actinoptychus* sp. cf. *A. vulgaris monicae* Grunow (Plate 8, Figure 10)

Specimens referred to this twelve-compartment species generally show no areolation structures preserved, unlike those specimens illustrated by Wornardt (1967). It occurs only rarely in Pleistocene cores at DSDP 157.

##### *Actinoptychus* sp. [8-section] (Plate 8, Figure 11)

Alternate compartments of this form have matching substructure producing a formée-cross pattern. It is only rarely present in Pleistocene and middle Miocene samples.

##### *Arachnoidiscus ornatus* Ehrenberg (Plate 8, Figure 6)

This species is recorded only rarely; most occurrences are in the middle to upper Miocene, and the specimens are fragmented.

##### *Asterolampra marylandica* Ehrenberg (Plate 9, Figures 3-4)

Only forms composed of five sections are assigned to this species. Frustules occur intact in several samples. This species is missing at DSDP 157, in the Pliocene and Pleistocene, but occurs consistently in the middle to upper Miocene at DSDP 158. Its highest sporadic occurrence is in the upper Miocene.

##### *Asterolampra* sp. [6-section] (Plate 9, Figure 5)

This symmetric six-section form is the most numerous and long-ranging *Asterolampra*, occurring regularly in the middle Miocene to Pleistocene of the Panama Basin.

##### *Asterolampra* sp. [7-section] (Plate 9, Figure 6)

This form occurs sporadically only in the upper Miocene to upper Pliocene.

##### *Asterolampra* sp. [8-section] (Plate 10, Figure 1)

Eight-section varieties of *Asterolampra* occur only sporadically in middle Miocene to upper Pliocene cores of DSDP 157 and DSDP 158. Hendey (1937) reported it only near the equator.

##### *Asteromphalus arachne* (Brebisson) (Plate 10, Figures 2-3)

This small, asymmetric, five-section species is thinly constructed and has developed practically no hyaline central area. Rare sporadic occurrences are noted only in the upper Miocene to Pleistocene at DSDP 157.

##### *Asteromphalus brookei* (Ehrenberg) (Plate 10, Figures 4-5)

This species is intermediate between *Asteromphalus heptactis* and *A. imbricatus*, having eight to ten sections. It occurs mainly in the Pliocene section at DSDP 157.

##### *Asteromphalus decorus* (Greville) n. comb. (Plate 10, Figures 6-9)

*Asterolampra decora* Greville, 1862, Quat. Jour. Micr. Sci., n.s., v. 2, p. 45, pl. 7, figs. 4-6.

*Asterolampra decora* Greville, var. nov. Castracane, 1886, Bot. Chall. Exp., pt. 4, p. 136, pl. 16, fig. 9.

This small- to medium-sized species has a complex central hyaline area more comparable to *Asteromphalus* than to the simple *Asterolampra*. It occurs sporadically through the Miocene and Pliocene sections in the Panama Basin. The circular central area shows a wide variety of complexity. Simplest forms have an inner cycle ranging from two to eight sections and have an adjacent cycle of eight to eighteen sections. More complex forms lack orderly central area cycles (see Castracane, 1886).

##### *Asteromphalus heptactis* (Brebisson) (Plate 11, Figures 1-2)

This species is restricted here to only seven-section forms, although eight-section forms show the same general proportions. It first occurs in the upper Miocene nannofossil *Discoaster quinqueramus* Zone of DSDP 157 and DSDP 158 and is missing at the older EM site to the north.

##### *Asteromphalus imbricatus* Wallich (Plate 11, Figures 3-4)

This long-ranging tropical species is restricted to forms having eleven to twenty-two sections. Pleistocene and Pliocene specimens from DSDP 157 tend to have subcircular central areas with a single recurved umbilical section line connecting the two appressed punctate areas (Plate 11, Figure 4). Miocene specimens from DSDP 158 have circular central areas and commonly more than one recurved umbilical section line (Plate 11, Figure 3), a character reminiscent of Castracane's (1886) illustration of "*Asterolampra grevillei* (Wall.) Grev., var. *eximia*, nov." Although occurring throughout our cores from DSDP 157 and DSDP 158, this species is most abundant in the late Pleistocene.

**Asteromphalus moronensis (Greville)**

(Plate 11, Figures 5-6)

This circular species is typically constructed in ten sections. It is distinctive in having a convex sulcate margin to the hyaline central area. Some specimens are slightly asymmetrical. This form is sporadic in the present cores, but as indicated by Kanaya (1971) and Kolbe (1954), it is most typical of the middle and upper Miocene, coincident with *Coscinodiscus plicatus*.

**Asteromphalus wyvillii Castracane**

(Plate 12, Figure 1)

This large species is characterized by a complex central area and punctate sections that number more than twenty-two. In Panama Basin cores, forms with as many as thirty-two sections occur. It is typically rare and sporadic, being numerically important only in Pleistocene sample 157A-2A(CC).

**Chaetoceros sp.**

(Plate 15, Figures 6-8)

Complete specimens of this unusual species—shaped like a shepherd's crook having a small cup at the end of the staff opposite the hook—were observed in several samples. The rare complete specimens in our Panama Basin cores show that the small cuplike valve at the end of the staff is very thin and therefore probably susceptible to both dissolution and breakage, either during deposition in the ocean or during subsequent laboratory preparation of samples. The hollow staff is nonperforate and apparently resistant to dissolution. It has nodular surface ornamentation, which on some specimens shows a spiralling pattern reminiscent of a candy cane. The Panama Basin form ranges from middle upper Miocene to upper Pliocene. The consistent and common occurrence of this species make it a useful late Cenozoic guide taxon.

**Coscinodiscus africanus Janisch**

(Plate 12, Figure 2)

This distinctive species is identified by the small, off-center circlet containing non-radial areolae and by the lines of small areolae that radiate away from the circlet. This warm-water species is found sporadically in Pleistocene and Pliocene cores. Rare isolated Miocene specimens are also noted.

**Coscinodiscus asteromphalus Ehrenberg**

(Plate 12, Figure 3)

As illustrated in Wornardt (1967), this large species has regularly sized, radially aligned areolae and a central rosette of enlarged areolae. It occurs sporadically in upper Miocene and higher cores.

**Coscinodiscus curvatus Grunow**

(Plate 12, Figures 4-5)

This species is characterized by the slight curvature of its longest lines of areolae, which extend from the center to the periphery, and by the shorter lines of areolae inclined between these. It occurs in coarse fractions from Panama Basin cores only in Miocene and Pliocene sediment. Its disappearance at DSDP 158 suggests a distinctive change in the sedimentary environment above Miocene Core 20 because its range at DSDP 157 extends into the upper Pliocene (to Core 17). This is one of the few large species in the Panama Basin assemblages that is considered to be primarily a cool-water or boreal indicator (Kanaya and Koizumi, 1966; and Lohman, 1941).

**Coscinodiscus elongatus Grunow**

(Plate 12, Figures 6-8)

In addition to the form with concave sides illustrated by Reinhold (1937), forms with straight and rounded convex sides are also included here. No specimens with rhomboid outlines (see *Coscinodiscus lanceolatus* in Kanaya, 1971) were noted. *C. elongatus* occurs fairly consistently from the middle Miocene to the upper Pliocene. Its reduction along with the earliest sporadic *Roperia tessellata* in the Panama Basin cores can be used to mark the upper part of the tropical *Chaetoceros* sp. Zone.

**Coscinodiscus excentricus Ehrenberg**

(Plate 13, Figure 5)

The curved lines of areolae in this species are eccentric with respect to the center of the disc. Stratigraphically, it is a prominent, consistent member of Pleistocene to upper Miocene assemblages in the Panama

Basin. Its first significant occurrence is at the bottom of the tropical *Chaetoceros* sp. Zone. Its appearance after the extinction of *Coscinodiscus plicatus* matches the stratigraphic relation observed by Kolbe (1954) in the tropical Swedish Deep-Sea Expedition cores.

**Coscinodiscus gigas diorama (Schmidt)**

(Plate 13, Figure 1)

This is the largest intact species observed in the Panama Basin cores. It is characterized by areolae that are radially aligned and that are largest at the periphery and become progressively smaller toward the center. The general stratigraphic significance of this form was suggested by Kolbe (1954), and its middle Miocene zonal significance was demonstrated by Kanaya (1971). The large size and great abundance of this species in DSDP 158, Cores 31 to 33, are distinctive and aid in recognition of the *Craspedodiscus coscinodiscus* Zone. The disjunct Pleistocene forms assigned to this taxon have thinner centers and are more convex than the Miocene forms.

**Coscinodiscus lewisianus Greville**

(Plate 13, Figures 6-7)

Only a single fragment of this species was found in the Panama Basin cores, but Kanaya (1971) indicated that it proved to be particularly common in the lower EM cores, which include the stratigraphic section just below that in which DSDP 158 terminated. This suggests that it may prove useful in subdividing the *Craspedodiscus coscinodiscus* Zone.

**Coscinodiscus lineatus Ehrenberg**

(Plate 13, Figures 2-5)

The alignment of the equant areolae into straight parallel rows and the typically broad margin characterize this circular species. The occurrence of spikes in the margin area is common. Distinctly elliptic forms of the species occur only in Pleistocene cores from the Panama Basin. This is one of the few long-ranging species that occurs in virtually every core examined.

**Coscinodiscus marginatus Ehrenberg**

(Plate 13, Figure 8)

This small robust species is considered to be representative of boreal to warm-temperate waters (Kanaya and Koizumi, 1966; Lohman, 1941). In the Panama Basin, its typical range is in the Miocene *Craspedodiscus coscinodiscus* Zone and the *Coscinodiscus plicatus* Zone. A few sporadic occurrences are noted higher in the section.

**Coscinodiscus nodulifer Schmidt**

(Plate 13, Figure 9)

As noted by Kolbe (1954), this distinctive warm-water diatom is exceedingly abundant in Pleistocene sediment from the equatorial Pacific. For combined range and abundance, it is the preeminent species at our Panama Basin sites in the upper Miocene to Pleistocene. Its first common occurrence is noted within the nannofossil *Discoaster quinqueramus* Zone at both DSDP 157 (Core 37) and DSDP 158 (Core 17). The central nodule and intersecting spiral patterns of areolae are useful identification keys. Kolbe (1954) pointed out that the dominance of this form as fossils and its relatively low abundance in the living plankton indicate that it is more resistant to dissolution than other species.

**Coscinodiscus paleaceus Grunow**

(Plate 13, Figure 10)

This small, narrowly lanceolate species has diagonally aligned areolae. It is a characteristic species in the nannofossil *Discoaster exilis* Zone in tropical Pacific cores from both DSDP Leg 8 and DSDP Leg 16. Its total range at Site DSDP 158 closely matches that of *Coscinodiscus plicatus*. These occurrences support Kanaya's (1971) work indicating that *C. paleaceus* is an important guide species for tropical Miocene assemblages.

**Coscinodiscus plicatus Grunow**

(Plate 13, Figure 11)

This species has radially aligned areolae and a single raised plication along one diameter. In typical orientation on strewn slides, only one side of the disk at a time can be focused. In the Panama Basin, this form ranges only from the middle Miocene to the lower upper Miocene. Kanaya (1971) has discussed the taxonomy and stratigraphy of this species. The Panama specimens tend to have finer areolae than those illustrated by Kanaya from the EM cores.

**Coscinodiscus vetustissimus Pantocsek**  
(Plate 14, Figure 1)

As illustrated in Kanaya (1971), this species is characterized by equant, radially aligned areolae. It is not present above the upper Miocene at DSDP 158, which confirms the earlier disappearance of this species in the tropical Pacific than in northern areas (Kanaya and Koizumi, 1970).

**Craspedodiscus coscinodiscus Ehrenberg**  
(Plate 14, Figure 3)

This unusual circular species is easily identified by its distinctive inflated central area and by the small size of the central area areolae. The areolae in the brim-like part of the disk are distinctly larger. The upper natural range of *Craspedodiscus coscinodiscus* at DSDP 158 is within the nannofossil *Discoaster exilis* Zone; this is comparable to the EM section, where it ranges through the *D. exilis* Zone into the adjacent *Catinaster coalitus* Zone (Kanaya, 1971; Bukry, unpublished data).

**Denticula hustedtii Simonsen and Kanaya**  
(Plate 14, Figures 4-5)

This small elongate diatom has been well characterized stratigraphically and taxonomically by Simonsen and Kanaya (1961), Kanaya and Koizumi (1970), and Kanaya (1971). Determining the full stratigraphic range of this form requires examination of fine and coarse fractions (H.J. Schrader, personal communication, 1971). In the present study of coarse fractions, its range is, nevertheless, comparable to that indicated by Kanaya and Koizumi from the tropical Pacific. A spot check of coeval horizons of the Monterey Formation at Newport Beach, California, shows this and other species of *Denticula* to be much more abundant than at DSDP 158.

**Denticula lauta Bailey**  
(Plate 14, Figure 6)

This species is smaller than *Denticula hustedtii* but has essentially the same middle Miocene to lower upper Miocene stratigraphic range at DSDP 158.

**Ethmodiscus rex (Rattray)**  
(Plate 14, Figure 7)

This large, finely areolate species is represented only as fragments in the samples examined, but it is a consistent and usually common member of our middle Miocene to Pleistocene sections. It has been classified as a typical tropical form by Lohman (1941) and Kanaya and Koizumi (1966). Resistance of this form to dissolution has been suggested by its occurrence in H.M.S. *Challenger* samples from depths of 8185 meters and 10,505 meters (Wiseman and Hendey, 1953).

**Fragilariopsis pliocena Brun**  
(Plate 14, Figures 8-10)

As tabulated here, this species includes both the long forms illustrated by Kanaya (1971) and the short forms called *Nitzschia praeamarina* by Muhina (1969). Both the long and short forms are similarly constructed and are most common in the same interval—lower Pliocene to upper Miocene, DSDP 157 (Cores 23 to 35). The stratigraphic relations of the whole group are currently being worked out by H.J. Schrader (personal communication, 1972).

**Hemidiscus cuneiformis Wallich**  
(Plate 14, Figures 11-12)

This species is semicircular in plan view and wedge-shaped in side view. It is considered a typical member of tropical assemblages (Kanaya and Koizumi, 1966) but does occur rarely in samples from as far north as Japan (Koizumi, 1968; Jousé et al., 1971). The variable form and size of tropical assemblages of *H. cuneiformis* described by Kolbe (1954) are apparent in the Panama Basin cores. Some variants are stratigraphically restricted—for instance, large angular forms of the Miocene at DSDP 158. The distinctive outline of this species and its variants allows identification by girdle bands alone in poorly preserved samples. The total stratigraphic range of *H. cuneiformis* in our cores is from the middle Miocene upper *Craspedodiscus coscinodiscus* Zone through the Pleistocene, although it first becomes prominent only at the top of the upper Miocene *Coscinodiscus plicatus* Zone.

**Liostephania sp.**  
(Plate 15, Figure 1)

As illustrated and discussed by Kolbe (1954), the exact nature of these silicified disks is uncertain. The single specimen observed in our samples is reminiscent of *Asteromphalus*, with slits occurring where hyaline rays would have been originally. Whether this is a biologically controlled structure or a preservation artifact is unknown.

**Nitzschia marina Grunow**  
(Plate 15, Figure 2)

This elongate, essentially parallel-sided species is similar in construction to short and long forms of *Fragilariopsis pliocena* but lacks their distinctly convex sides. Kanaya and Koizumi (1970) indicate a Miocene to Holocene range for *N. marina*. In the Panama Basin cores, it was noted in upper Pliocene and higher samples. Lohman (1941) considered it to be mainly a cool-water species, but it ranges into the tropics and has been classified as tropical by Kanaya and Koizumi (1966).

**Pleurosigma sp.**  
(Plate 15, Figure 3)

These large, thin, elongate, lozenge-shaped diatoms have a straight raphe and oblique and transverse striae (see Cupp, 1943). The rare and sporadic occurrences at DSDP 157 and DSDP 158 range from upper Miocene to Pleistocene.

**Pseudoeunotia doliolus (Wallich)**  
(Plate 15, Figure 4)

This small, elongate, asymmetric species, as illustrated by Kolbe (1954), is a meager to rare component noted mainly in the fine fraction of Pleistocene samples from DSDP 157. Sporadic occurrences in the coarse fraction are noted in and above the upper upper Miocene, although the early forms lack the full character of the species and are transitional from *Nitzschia fossilis* according to H.J. Schrader (personal communication, 1972). Kanaya and Koizumi (1970) indicate an upper Pliocene first occurrence in the tropics, but a lower Pliocene appearance at higher latitudes. Lohman (1941) considered it a warm-water, littoral species.

**Rhizosolenia bergonii Peragallo**  
(Plate 15, Figure 5)

As noted by Lohman (1941), this tropical species is usually represented in sediment only by apical spines. Owing to the small size of the spines, this species has been noted only rarely in our coarse fractions.

**Roperia tessellata (Roper)**  
(Plate 15, Figures 9-11)

This circular species is characterized by an irregular patchwork quilt appearance of its areolae alignments. It is considered a tropical to subtropical species (Kanaya and Koizumi, 1966) but has also been reported as a characteristic living species in the Central Water Mass of the Pacific (Venrick, 1971), suggesting a broader temperature range. In the Panama Basin it first appears near the base of the Pleistocene and is most common in the upper Pleistocene, which could suggest a general worldwide cooling in the upper Pleistocene (Burckle, 1971).

**Stictodiscus sp. cf. S. californicus Greville**  
(Plate 16, Figures 1-2)

Included under this taxon are a variety of circular diatoms that are characterized by elevated radial ridges and sparsely punctate central areas. No attempt has been made to separate varieties here because the group is present only in small numbers sporadically throughout the whole section examined. *Stictodiscus* has been variously considered to be littoral, benthonic, or epiphytic. Kolbe (1954) noted it only in cores near the Islas Galapagos, its occurrence probably representing displacement from shallower areas.

**Stictodiscus trigonus Castracane**  
(Plate 16, Figures 3-6)

This thick triangular species has been reported from recent dredge samples (Castracane, 1886) and from Miocene outcrops (Reinhold, 1937). In the Panama Basin, virtually identical forms were noted only in Pleistocene and middle Miocene samples.

*Thalassionema nitzschioides* (Grunow) s.l.  
(Plate 16, Figures 7-8)

This elongate species is narrowly rhomboid, and large specimens may be slightly curved. Included in this species is a cooccurring short, non-curved form called *Thalassionema parva* by Muhina (1969). *T. nitzschioides* is considered north temperate by Cupp (1943), cool-water by Heney (1937), and southern boreal by Kanaya and Koizumi (1966). Its occurrence in the Panama Basin cores is primarily in the upper Miocene. It also occurs sporadically in the middle Miocene and Pliocene; in the Pleistocene it is noted only in fine fractions.

*Thalassiothrix* spp.  
(Plate 16, Figure 9)

Included in this category are a variety of long, narrow, parallel-sided forms, which are straight or slightly wavy. The narrowest form, *Thalassiothrix longissima* Cleve and Grunow, has prominent transverse notches (see Koizumi, 1968). Heney (1937) considered this taxon to indicate cool water but also noted that the small living space and large amount of skeletal material in such elongate forms suggested inefficient utilization of silica. This suggests that, particularly in equatorial waters of the Panama Basin where these forms are abundant, upwelling providing excess silica and nutrients, not cool temperature, is the determining developmental factor. The associated diatoms there are clearly tropical to subtropical, so *Thalassiothrix* abundances, at least at the generic level, can be considered a guide to relatively strong upwelling. *Thalassiothrix* spp. occur from upper Miocene to Pleistocene in the Panama Basin; they are especially abundant in coarse fractions in Miocene and Pleistocene.

*Triceratium cinnamomeum* Gréville  
(Plate 16, Figures 10-11)

These medium to large triangular diatoms have fine, radially aligned areolae and are considered to be typical of tropical assemblages (Kanaya and Koizumi, 1966). Although occurring sporadically throughout the Panama Basin section, *T. cinnamomeum* is most consistently present in the middle Miocene and lower Pliocene.

*Triceratium cinnamomeum minor* Grunow

This small somewhat rounded variety of *Triceratium* is rare in middle Miocene samples at DSDP 158. Kolbe (1954, fig. 20) presented an excellent illustration of this form.

?*Triceratium thumii* Schmidt  
(Plate 16, Figure 12)

A single specimen of this coarsely areolated, triangular form was observed in the upper Miocene at DSDP 158. Wornardt (1967) illustrated this species from the Miocene Monterey Formation of California.

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PLATE 1

Silicoflagellate Photomicrographs: 600 ×

- Figures 1-2     *Cannopilus binoculus* (Ehrenberg)  
1. DSDP 157-23(CC).  
2. DSDP 157-25(CC).
- Figure 3        *Cannopilus hemisphaericus* (Ehrenberg)  
DSDP 157-21(CC).
- Figures 4-7     *Cannopilus major* (Frenguelli)  
4. DSDP 157-21(CC).  
5. DSDP 157-26(CC).  
6. DSDP 157-21(CC).  
7. DSDP 157-21(CC).
- Figures 8-9     *Cannopilus quintus* Bukry and Foster, n. sp.  
DSDP 157-22(CC), Holotype USNM  
182794.  
8. High focus.  
9. Low focus.

PLATE 1

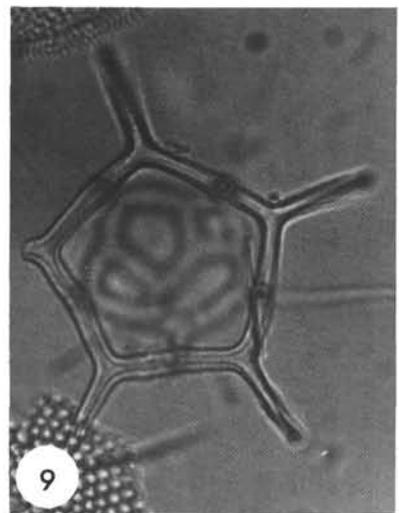
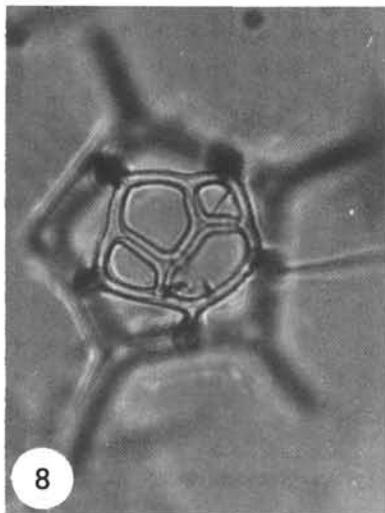
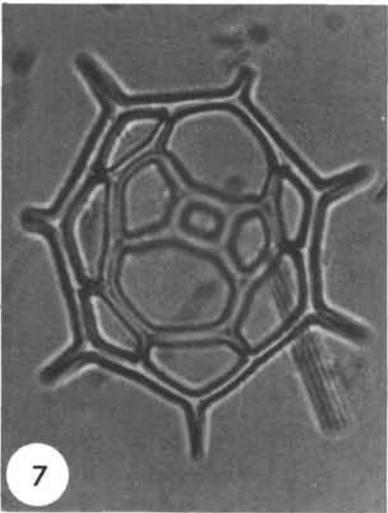
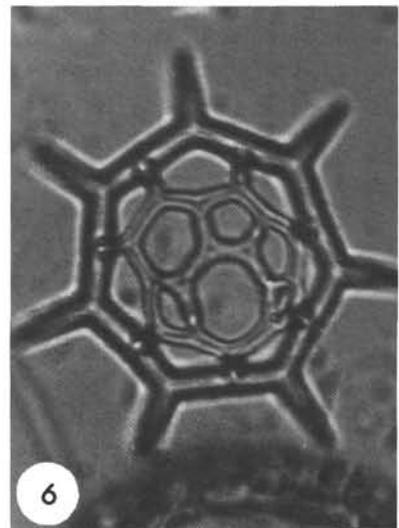
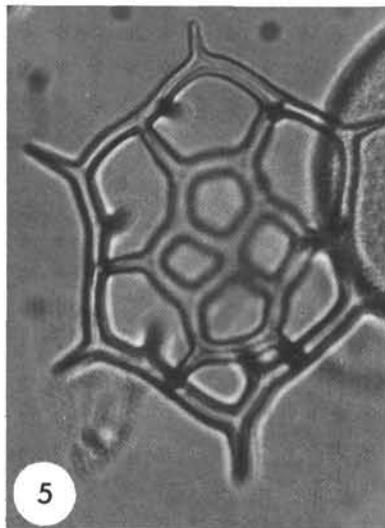
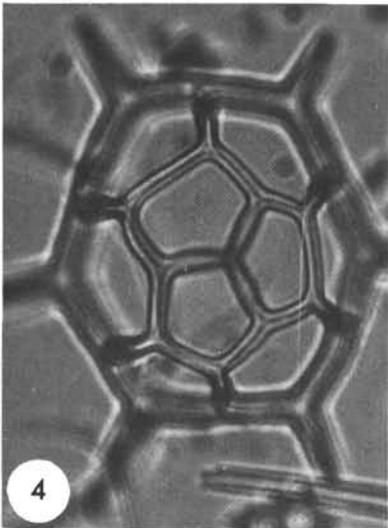
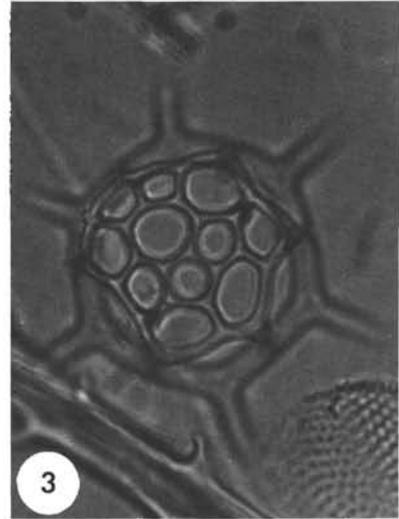
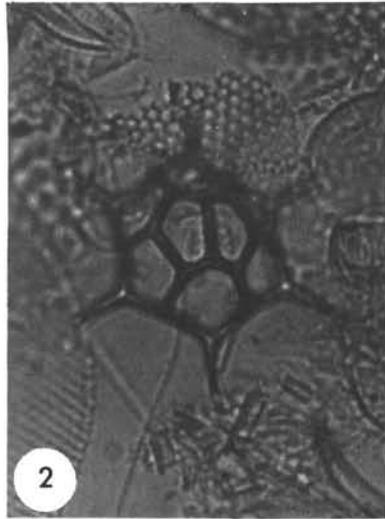
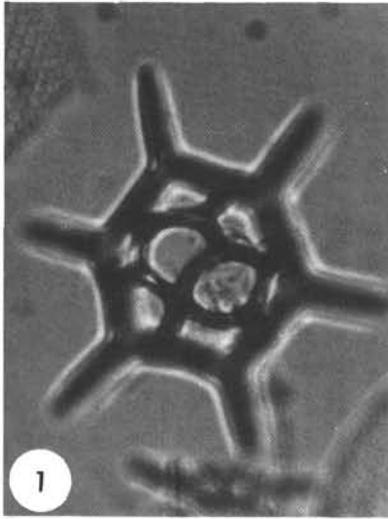


PLATE 2

Silicoflagellate Photomicrographs: 600 ×

- Figure 1      *Cannopilus quintus* Bukry and Foster, n. sp.  
DSDP 157-22(CC), Paratype USNM 182795.
- Figure 2      *Cannopilus schulzii* Deflandre  
DSDP 157-24(CC).
- Figure 3      *Corbisema triacantha* (Ehrenberg)  
EM 8-15, 34-37 cm.
- Figures 4-6    *Dictyocha aspera* (Lemmermann)  
4. DSDP 157-8(CC).  
5. DSDP 158-12(CC).  
6. DSDP 158-32(CC).
- Figures 7-8    *Dictyocha epiodon* Ehrenberg  
7. DSDP 157A-1A-2(8-10 cm).  
8. DSDP 157A-1A-2(8-10 cm).
- Figure 9      *Dictyocha fibula* Ehrenberg  
DSDP 157-18(CC).

PLATE 2

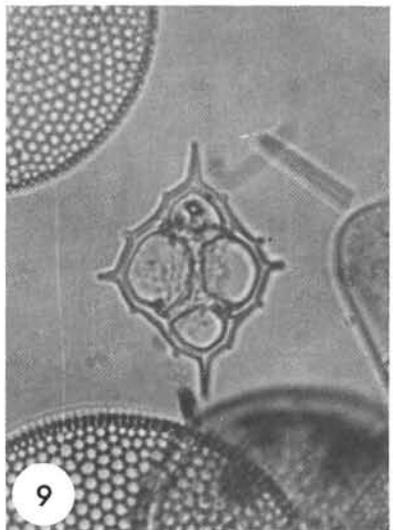
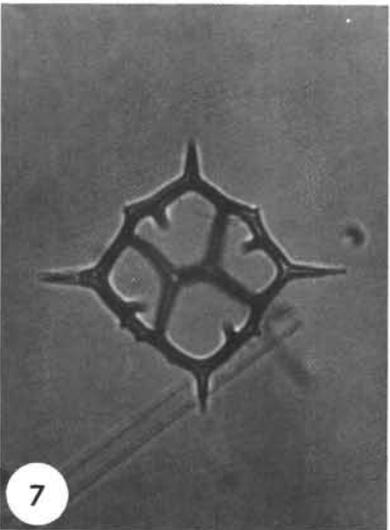
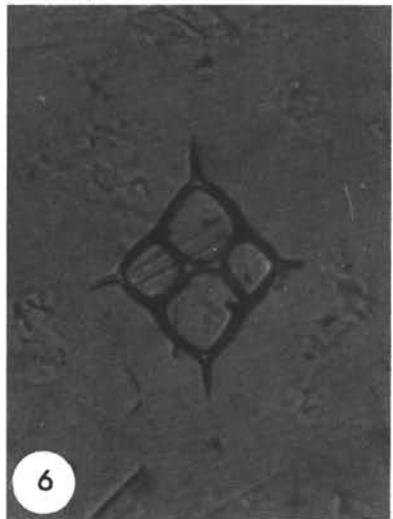
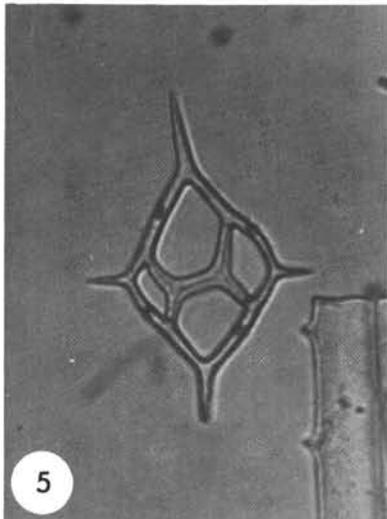
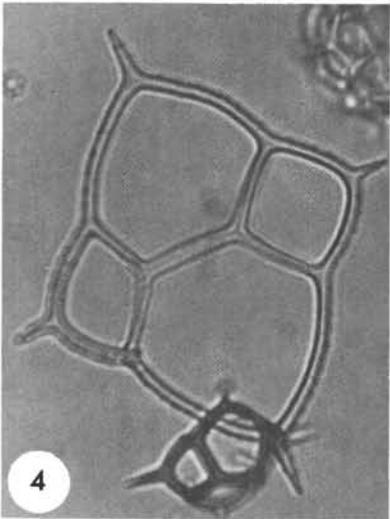
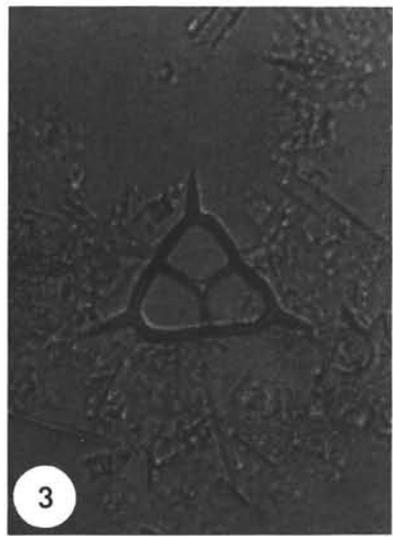
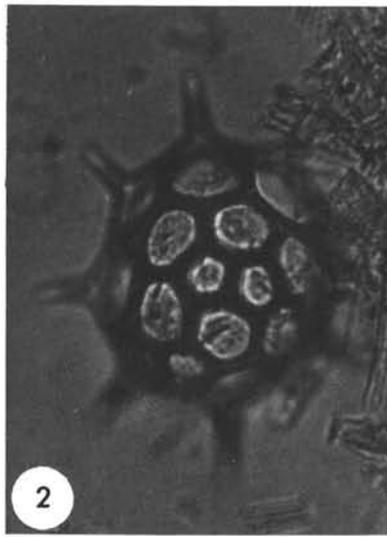
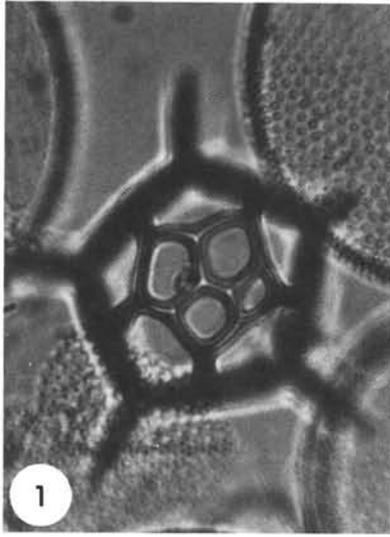


PLATE 3

Silicoflagellate Photomicrographs: 600 ×  
Except Figure 3 Which Is 1200 ×

- Figures 1, 12      *Dictyocha fibula* Ehrenberg  
1. DSDP 157-3(CC).  
12. DSDP 157-23(CC).
- Figure 3      *Dictyocha japonica* Deflandre  
DSDP 157-37(CC).
- Figures 4-5      *Dictyocha medusa* Haeckle  
4. DSDP 158-20(CC).  
5. DSDP 158-19(CC).
- Figures 6-8      *Dictyocha navicula* Ehrenberg  
6. DSDP 157-38(CC).  
7. DSDP 157-38(CC).  
8. DSDP 158-11(CC).
- Figure 9      *Dictyocha octagona* Tsumura  
EM 7-1, 36-38 cm.
- Figure 10      *Dictyocha pentagona* (Schulz)  
DSDP 157A-1A(CC).
- Figures 2, 11      *Dictyocha pseudofibula* (Schulz)  
2. DSDP 157-19(CC).  
11. DSDP 157-32(CC).

PLATE 3

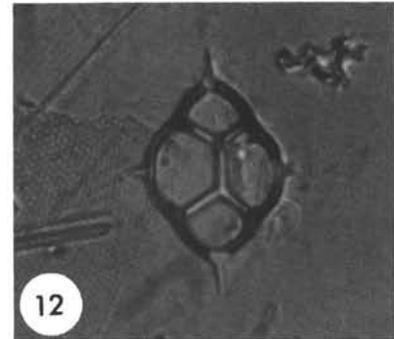
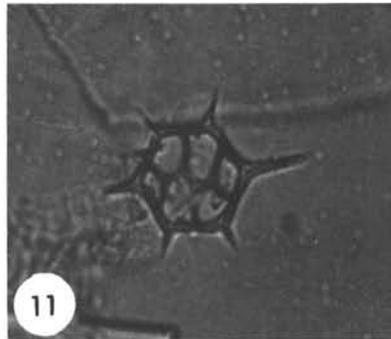
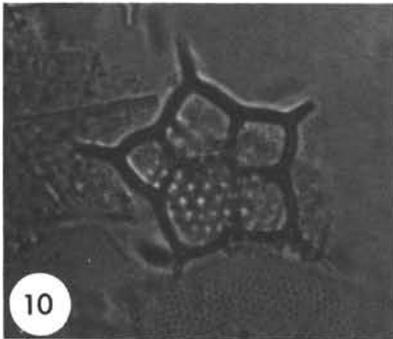
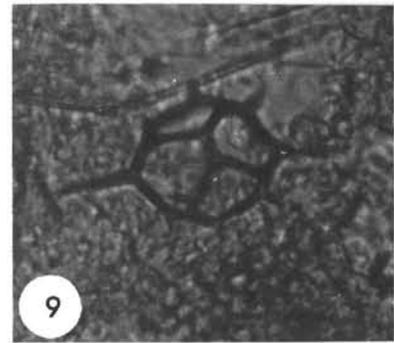
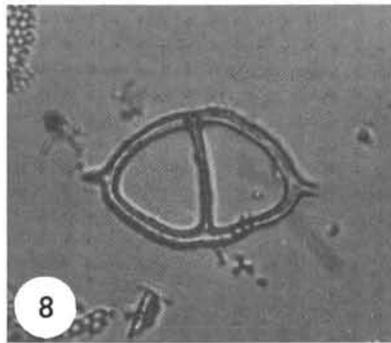
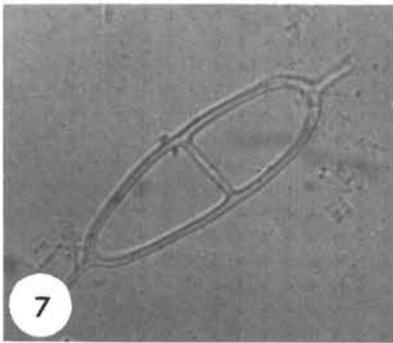
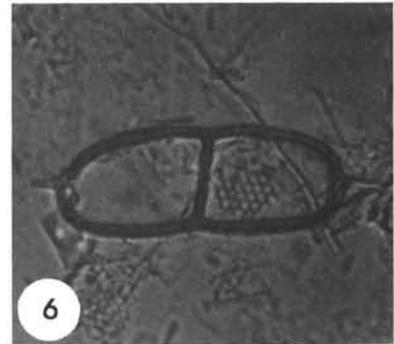
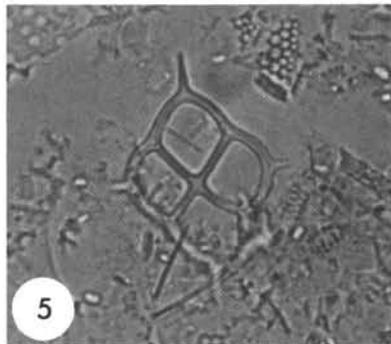
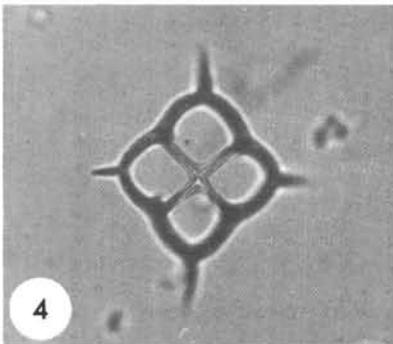
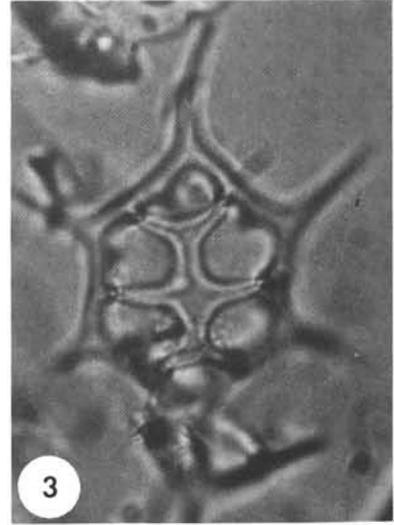
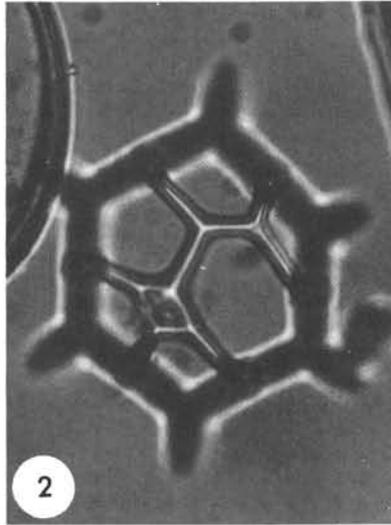
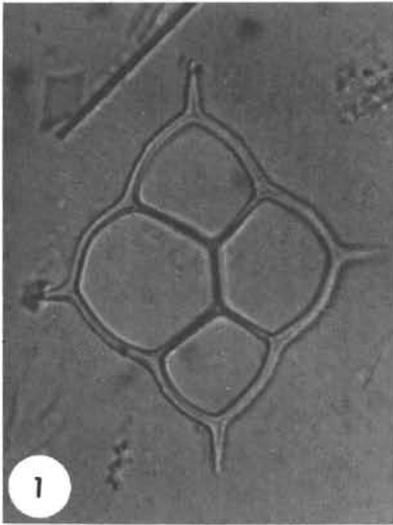


PLATE 4

Silicoflagellate Photomicrographs: 600 ×

- Figures 1-3     *Distephanus boliviensis* (Frenguelli)  
1. DSDP 157-30(CC).  
2. DSDP 157-11(CC).  
3. DSDP 157-32(CC).
- Figure 4        *Distephanus* sp. cf. *D. boliviensis* (Frenguelli)  
DSDP 157-36(CC).
- Figures 5-6     *Distephanus crux* (Ehrenberg)  
5. DSDP 157A-3A(CC), rim mimics *D. epiodon*.  
6. DSDP 158-31(CC).
- Figures 7-8     *Distephanus longispinus* (Schulz)  
7. EM 8-14, 384-387 cm.  
8. EM 8-14, 384-387 cm.
- Figure 9        *Distephanus* sp. cf. *D. longispinus* (Schulz)  
DSDP 158-31(CC).
- Figures 10-11   *Distephanus minutus* (Bachmann)  
10. DSDP 158-16(CC).  
11. DSDP 157-38(CC).
- Figure 12       *Distephanus octacanthus* (Desikachary and Maheshwari)  
EM 7-1, 36-38 cm.

PLATE 4

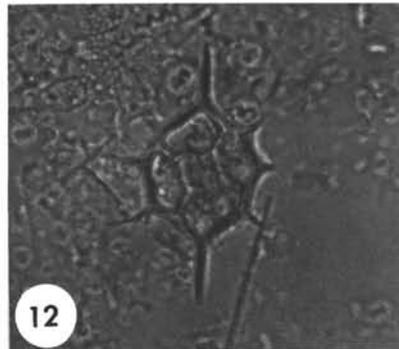
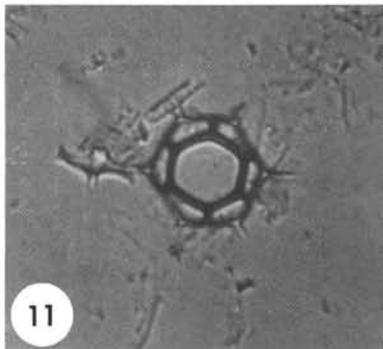
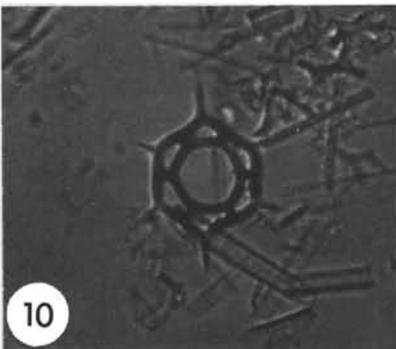
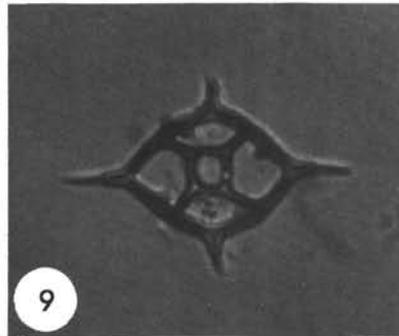
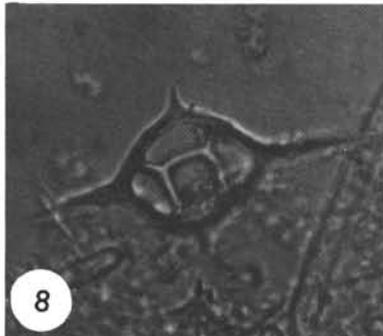
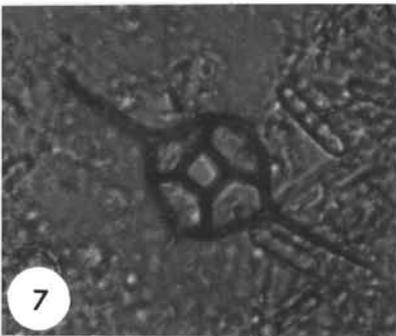
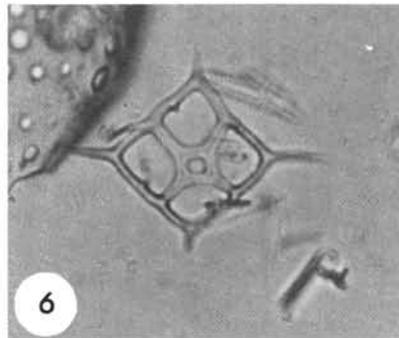
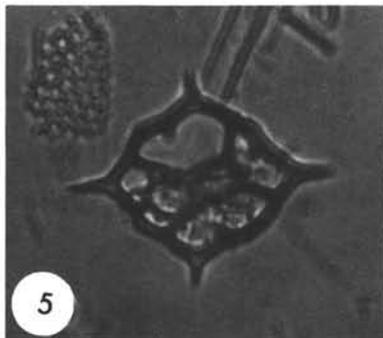
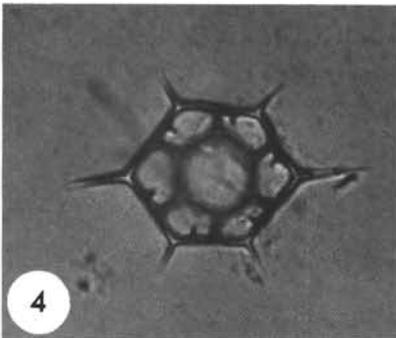
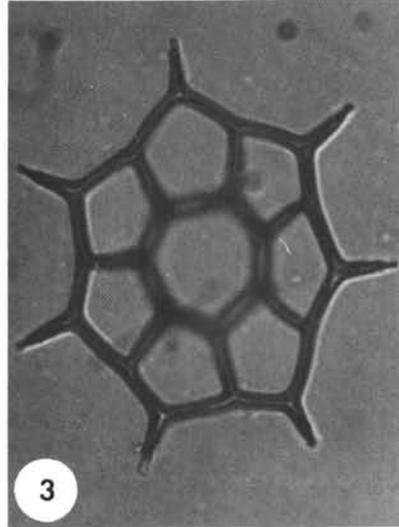
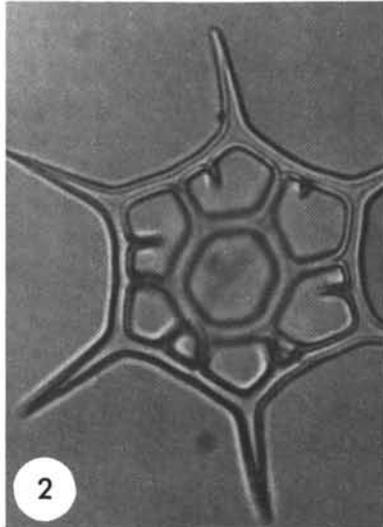
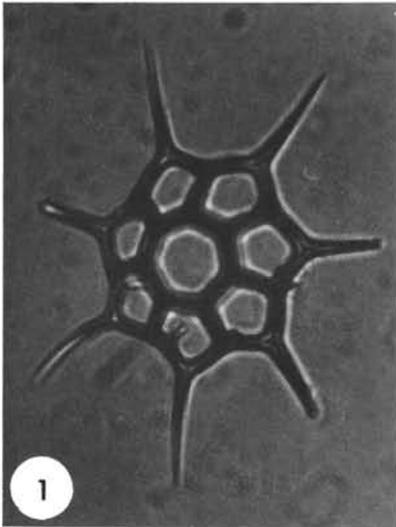


PLATE 5

Silicoflagellate Photomicrographs: 600 ×  
Except Figure 3 Which Is 1200 ×

- Figure 1 *Distephanus octacanthus* (Desikachary and Maheshwari)  
EM 7-1, 36-38, cm.
- Figures 2-3 *Distephanus parvus* (Bachmann)  
2. DSDP 157-38(CC).  
3. same, 1200 ×.
- Figure 4 *Distephanus quinquangellus* Bukry and Foster, *nomen novum*  
DSDP 157-3(CC).
- Figure 5 *Distephanus* sp. cf. *D. quinquangellus* Bukry and Foster  
EM 8-12, 25-27 cm.
- Figures 6-7 *Distephanus polyactis* (Ehrenberg)  
6. DSDP 157-27(CC).  
7. DSDP 157-30(CC).
- Figure 8 *Distephanus speculum* (Ehrenberg)  
DSDP 158-15(CC).
- Figure 9 *Mesocena circula* (Ehrenberg)  
DSDP 157-17(CC).

PLATE 5

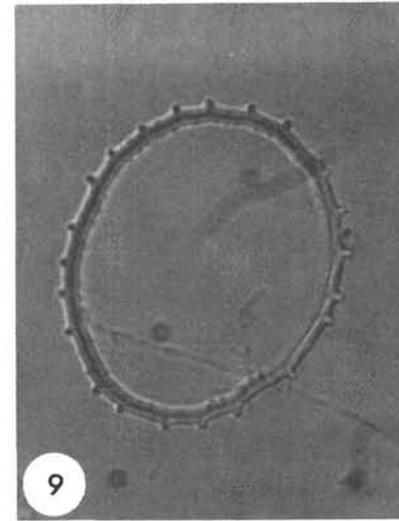
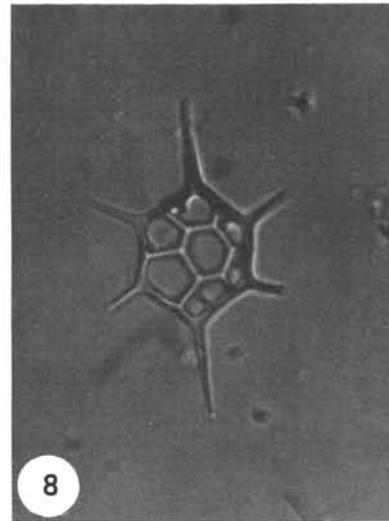
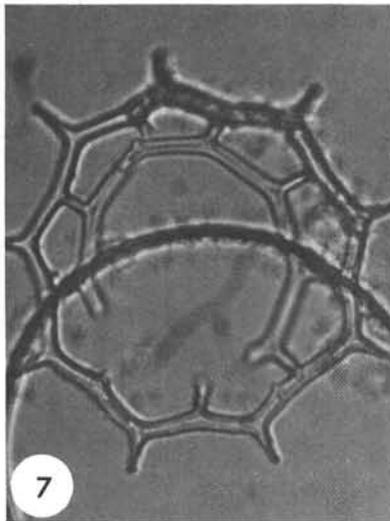
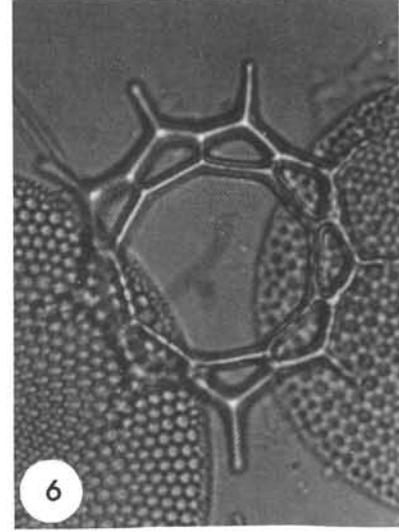
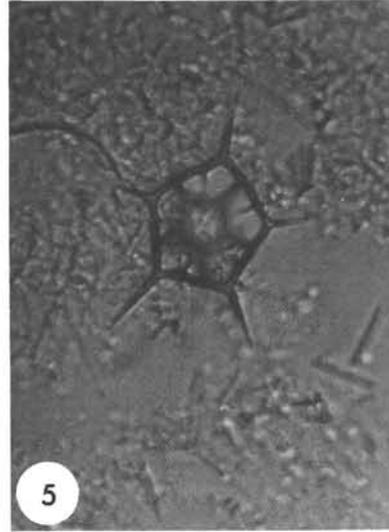
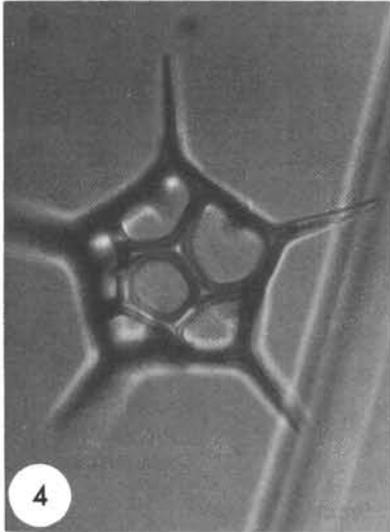
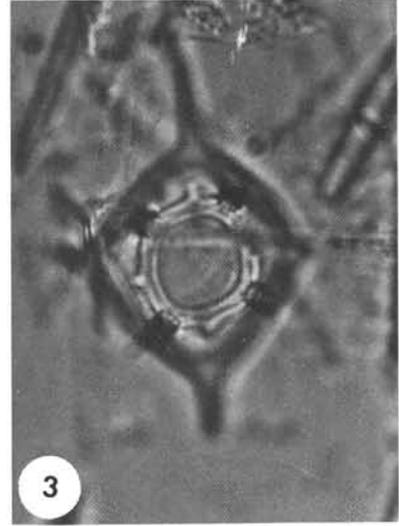
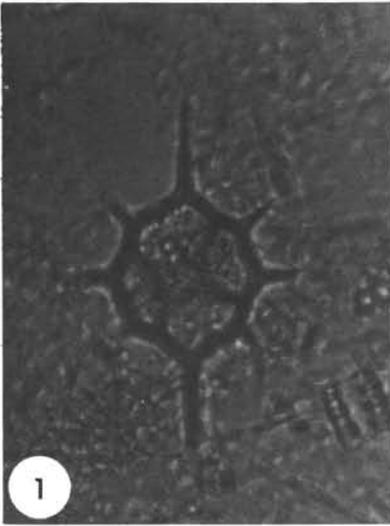


PLATE 6

Silicoflagellate Photomicrographs: 600 ×

- Figure 1      *Mesocena circula* (Ehrenberg)  
                  DSDP 158-20(CC).
- Figures 2-4    *Mesocena elliptica* (Ehrenberg)  
                  2. DSDP 157-3(CC).  
                  3. DSDP 157-38(CC).  
                  4. DSDP 157-7(CC).
- Figure 5      *Mesocena*-like *Dictyocha fibula* Ehrenberg  
                  DSDP 157-35(CC).
- Figures 6-7    *Mesocena diodon* Ehrenberg  
                  6. DSDP 158-28(CC).  
                  7. DSDP 158-20(CC).
- Figure 8      *Mesocena pentagona* Haeckle  
                  DSDP 157-6(CC)
- Figures 9-10   *Mesocena triangula* (Ehrenberg)  
                  9. DSDP 157-14(CC).  
                  10. DSDP 158-14(CC).
- Figures 11-12 *Octactis pulchra* Schiller  
                  11. DSDP 157A-2A(CC).  
                  12. DSDP 157-8(CC).

PLATE 6

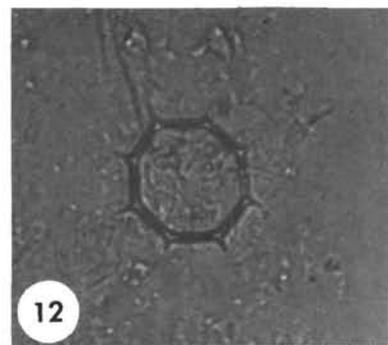
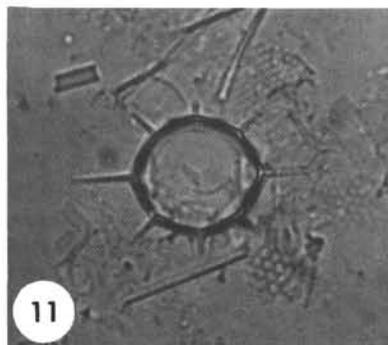
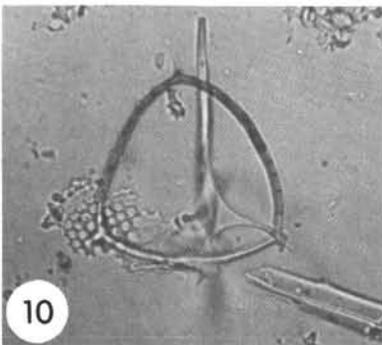
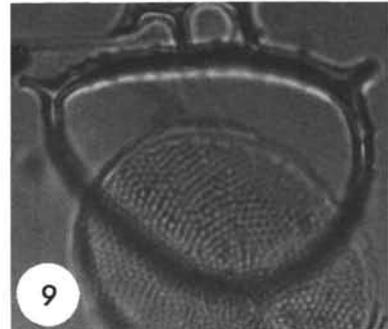
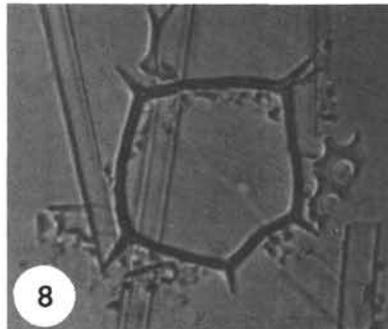
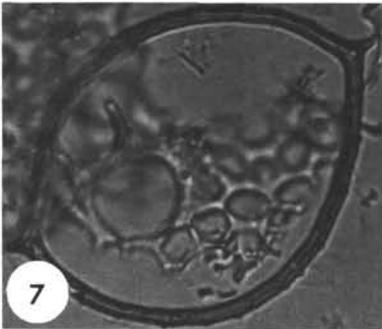
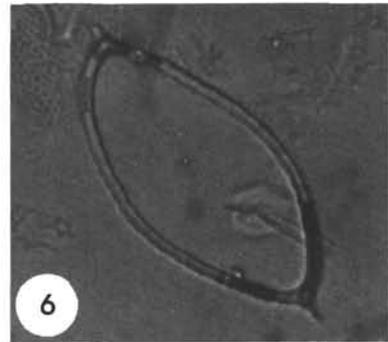
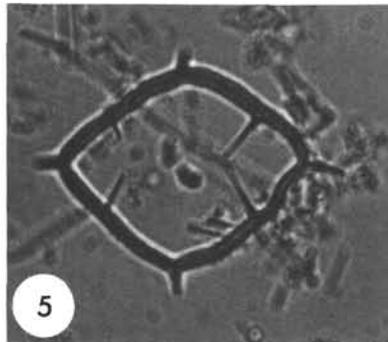
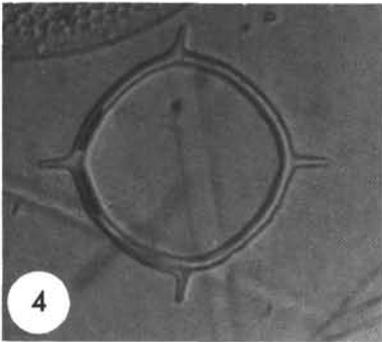
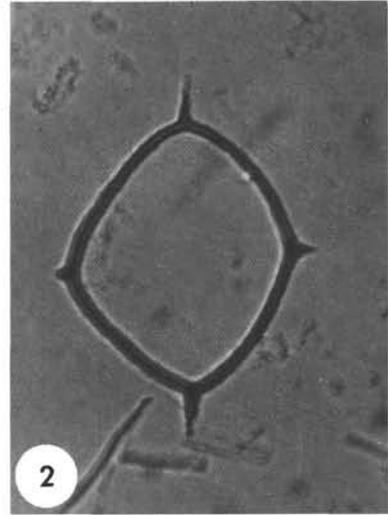
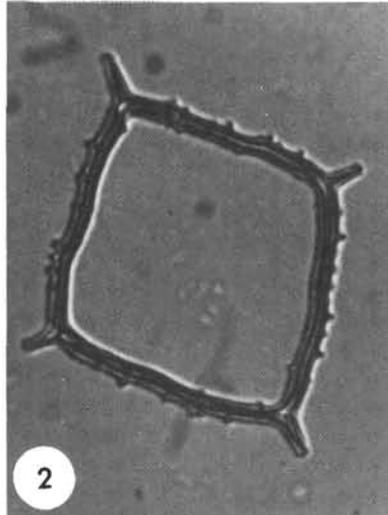
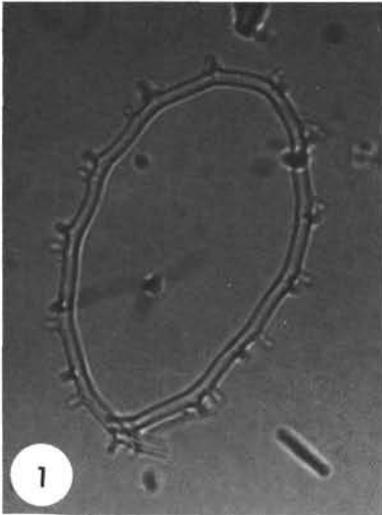


PLATE 7

Silicoflagellate Photomicrographs: 600 ×

- Figure 1      *Dictyocha vanandelii* Bukry and Foster, n. sp.  
                  DSDP 157-22(CC). Holotype USNM 182796.
- Figures 2-4    *Juxtaposed skeletons of two taxa*  
                  DSDP 157-14(CC).
2. High focus, *Cannopilus major* (Frenguelli).
  3. Mid focus, both basal rings.
  4. Low focus, *Distephanus boliviensis* (Frenguelli).

PLATE 7

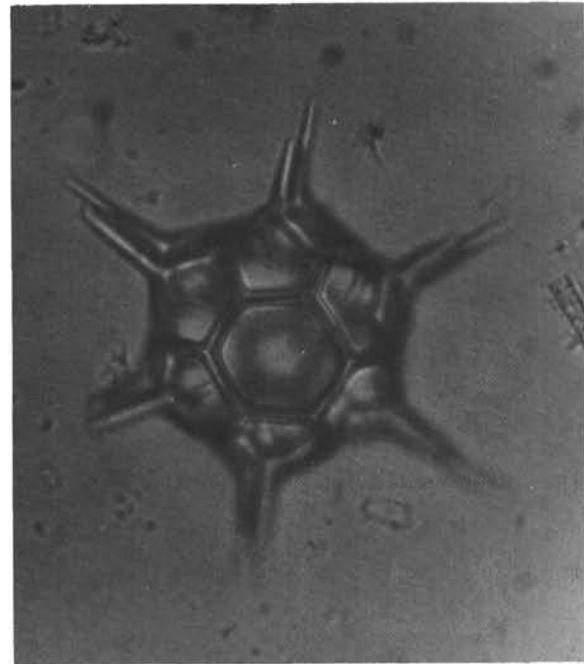
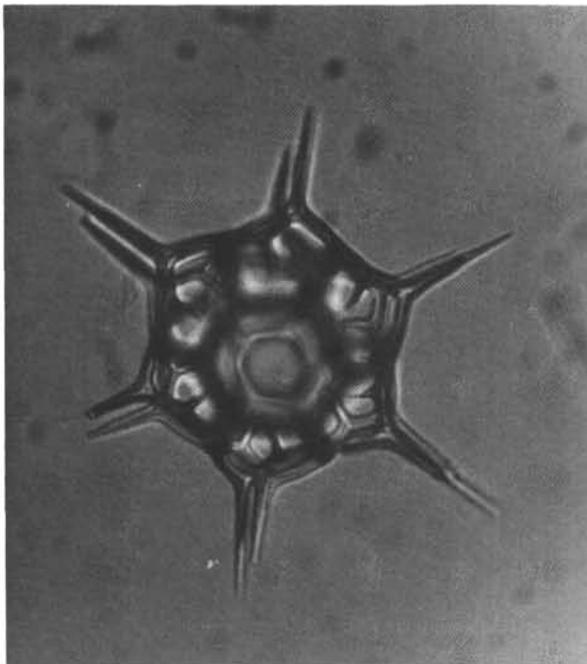
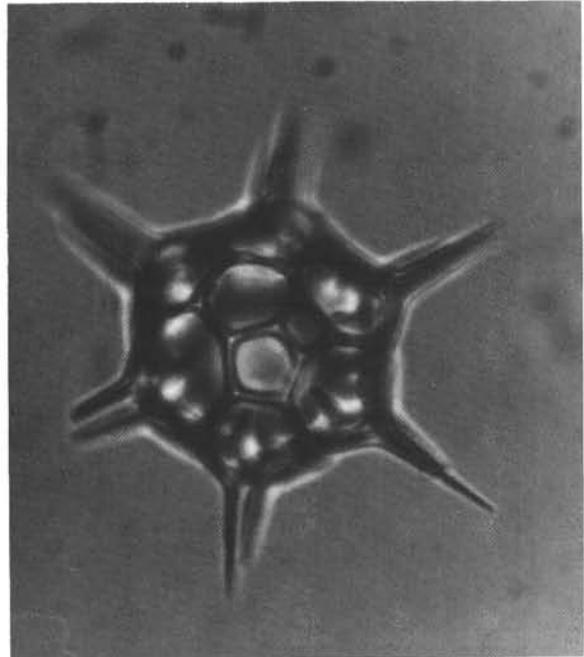
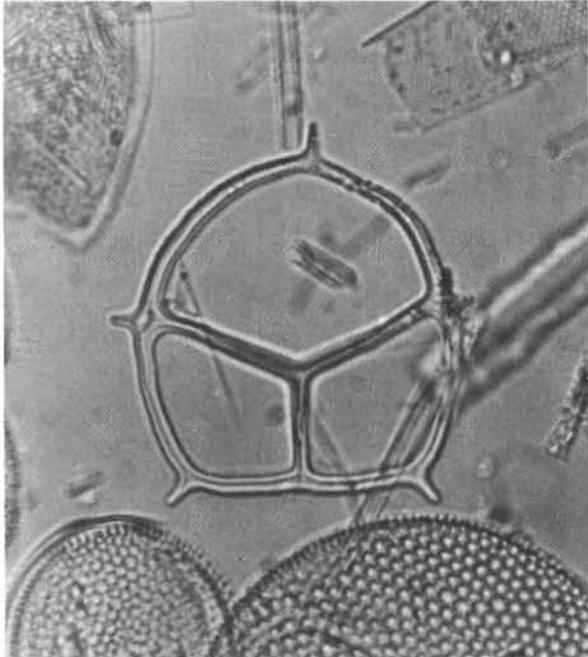


PLATE 8

Diatom Photomicrographs

- Figures 1-2 *Actinocyclus ehrenbergii* Ralfs  
1. DSDP 157-30(CC), 600 ×.  
2. DSDP 157-18(CC), 300 ×.
- Figure 3 *Actinocyclus ellipticus* Grunow  
DSDP 158-32-CC, 600 ×.
- Figure 4 *Actinocyclus ingens* Rattray  
DSDP 158-29(CC), 600 ×.
- Figure 5 *Actinocyclus* sp.  
DSDP 158-19(CC), 600 ×.
- Figure 6 *Arachnoidiscus ornatus* Ehrenberg  
DSDP 158-32(CC), 300 ×.
- Figures 7-9 *Actinoptychus senarius* Ehrenberg  
7. DSDP 157-16(CC), 300 ×.  
8. DSDP 157-16(CC), 600 ×, tilted.  
9. DSDP 158-13(CC), 600 ×.
- Figure 10 *Actinoptychus* sp. cf. *A. vulgaris monicae* Grunow  
DSDP 157A-1A-2, 8-10 cm, 600 ×.
- Figure 11 *Actinoptychus* sp. [8-section]  
DSDP 158-30(CC).

PLATE 8



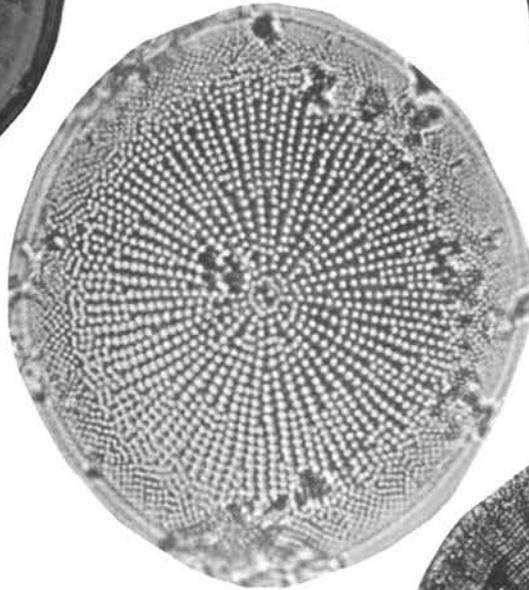
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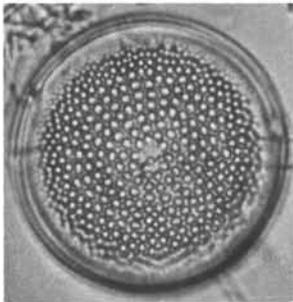
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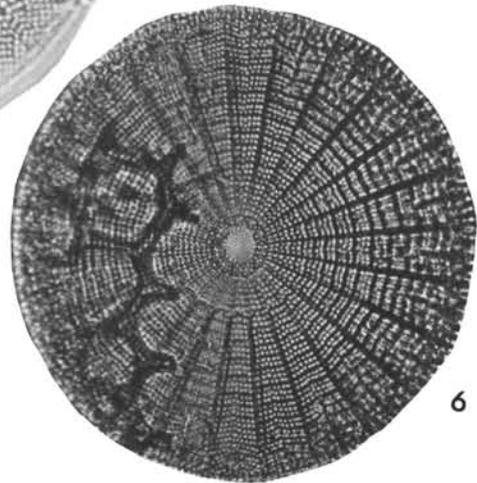
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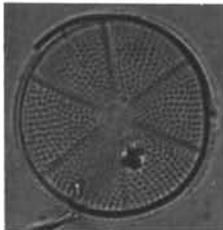
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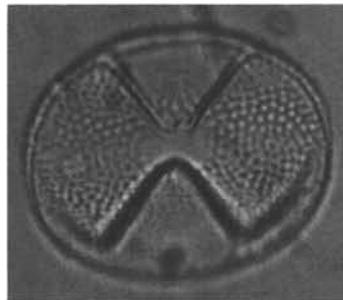
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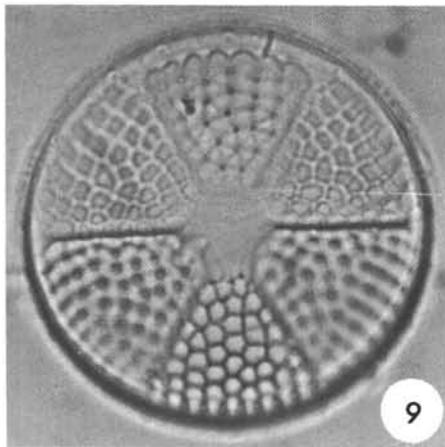
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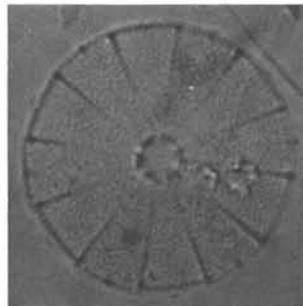
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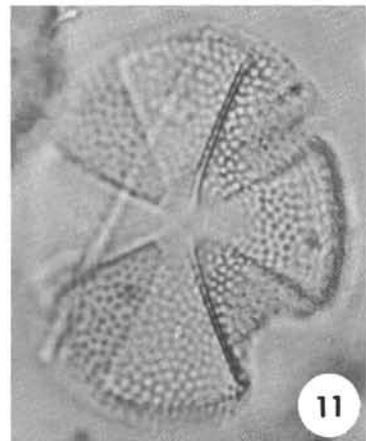
8



9



10



11

PLATE 9

Diatom Photomicrographs: 600 ×

- Figures 1-2    *Actinoptychus* sp.  
1. DSDP 158-31(CC), high focus.  
2. Same, low focus.
- Figures 3-4    *Asterolampra marylandica* Ehrenberg  
3. DSDP 158-30(CC).  
4. DSDP 158-30(CC).
- Figure 5        *Asterolampra* sp. [6-section]  
                    DSDP 157-8(CC).
- Figure 6        *Asterolampra* sp. [7-section]  
                    DSDP 158-19(CC).

PLATE 9

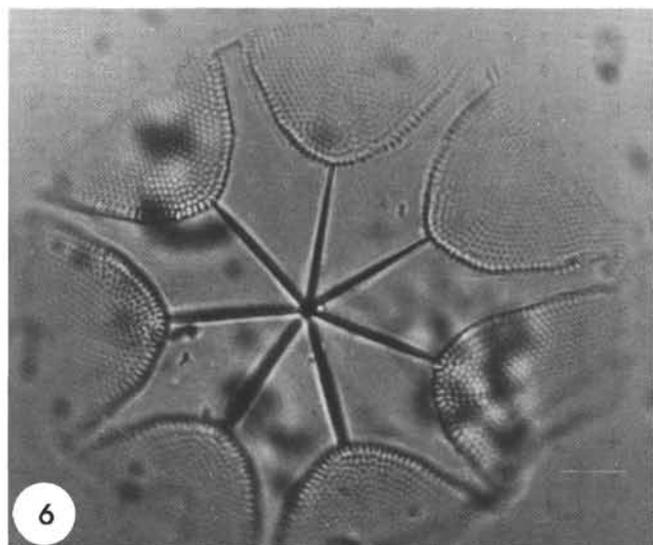
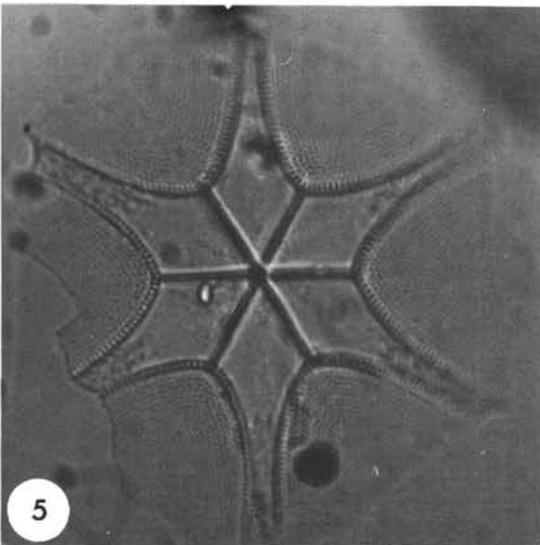
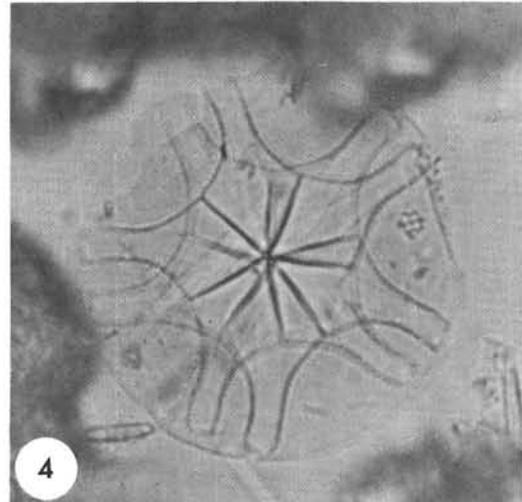
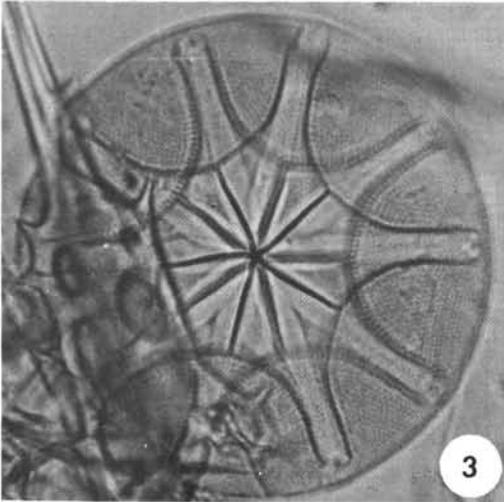
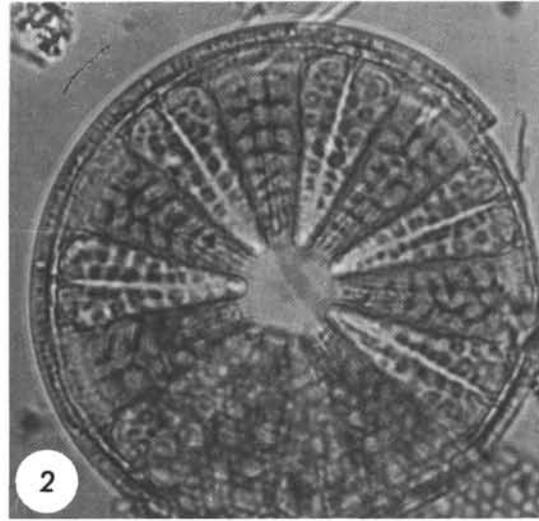
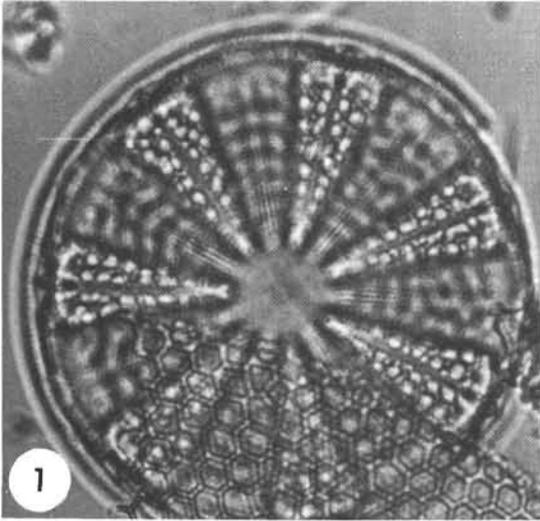


PLATE 10  
Diatom Photomicrographs: 600 X  
Except Figure 5, Which Is 300

- Figure 1      *Asterolampra* sp. [8-section]  
                  DSDP 157-26(CC).
- Figures 2-3    *Asteromphalus arachne* (Brébisson)  
                  2. DSDP 157-37(CC).  
                  3. DSDP 157-17(CC).
- Figures 4-5    *Asteromphalus brookei* (Ehrenberg)  
                  4. DSDP 158-13(CC).  
                  5. DSDP 157-2(CC).
- Figures 6-9    *Asteromphalus decorus* (Greville)  
                  6. DSDP 158-25(CC).  
                  7. DSDP 158-30(CC).  
                  8. DSDP 158-22(CC).  
                  9. DSDP 158-20(CC).

PLATE 10

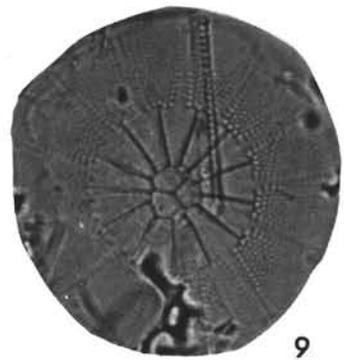
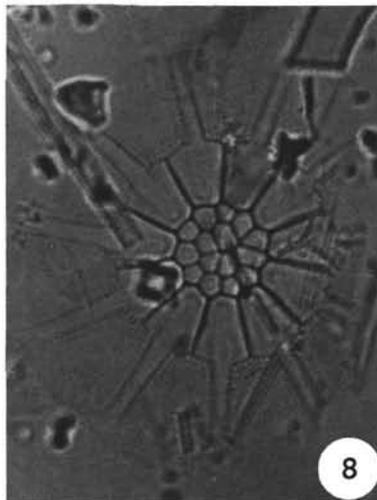
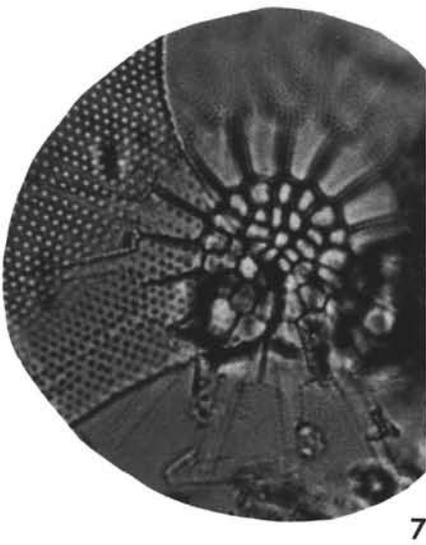
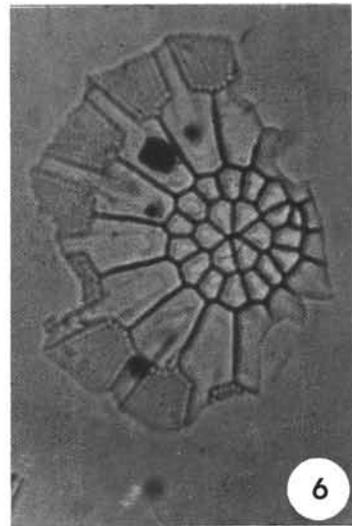
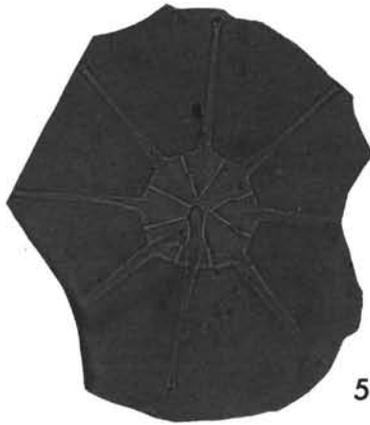
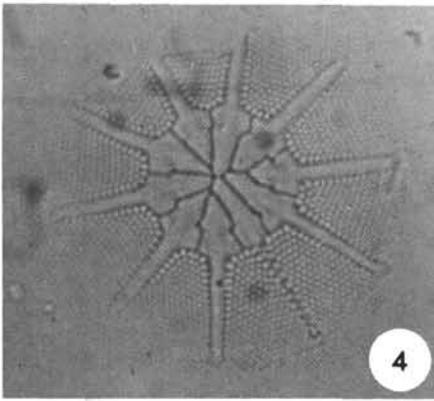
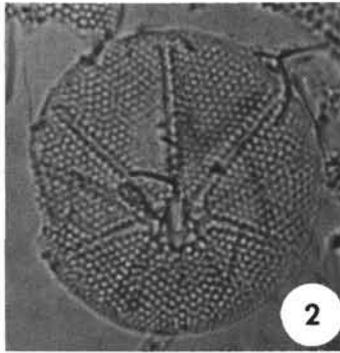


PLATE 11

Diatom Photomicrographs: 600 ×

- Figures 1-2     *Asteromphalus heptactis* (Brébisson)  
1. DSDP 157A-2A(CC).  
2. DSDP 157-18(CC).
- Figures 3-4     *Asteromphalus imbricatus* Wallich  
3. DSDP 158-14(CC).  
4. DSDP 157-3(CC).
- Figures 5-6     *Asteromphalus moronensis* (Greville)  
5. DSDP 158-20(CC).  
6. DSDP 158-20(CC).
- Figure 7         *Asteromphalus* sp., ?transitional to *Asterolampra*  
DSDP 158-32(CC).

PLATE 11

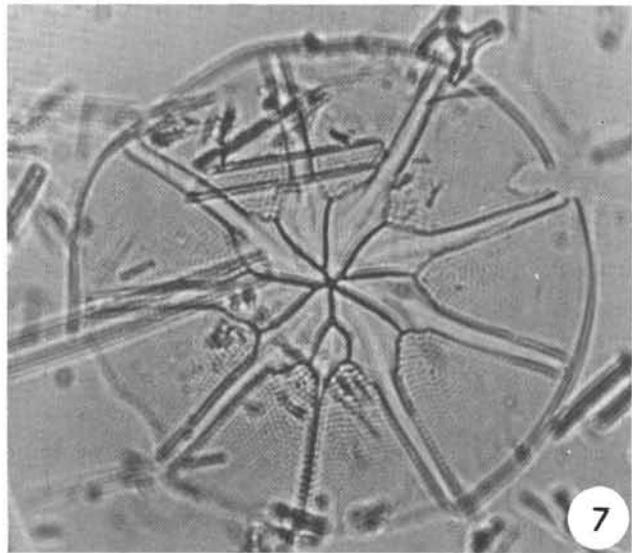
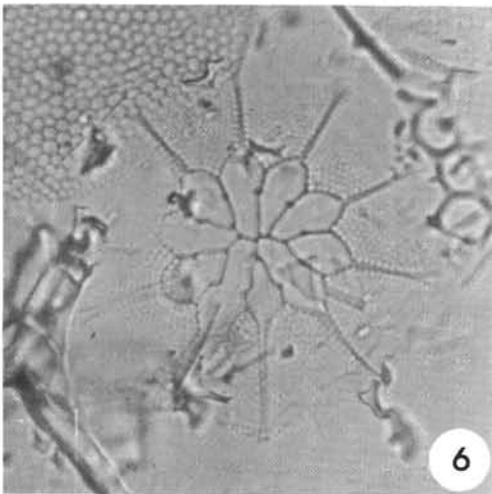
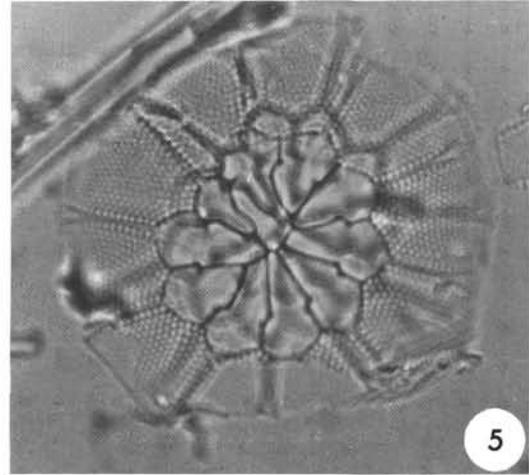
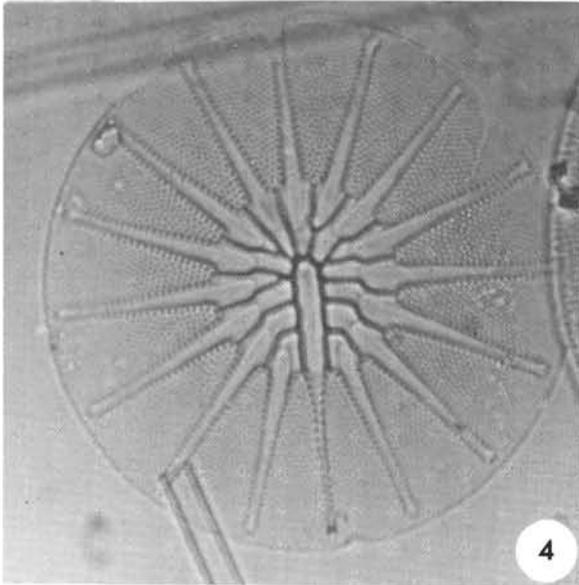
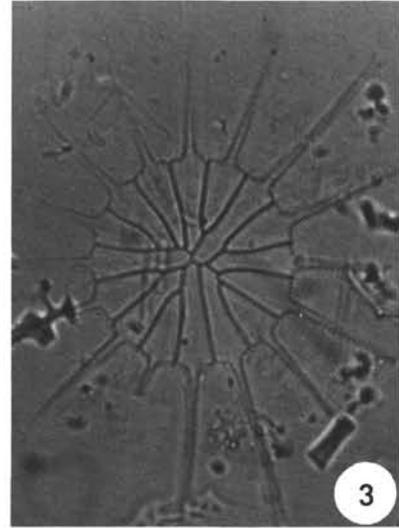
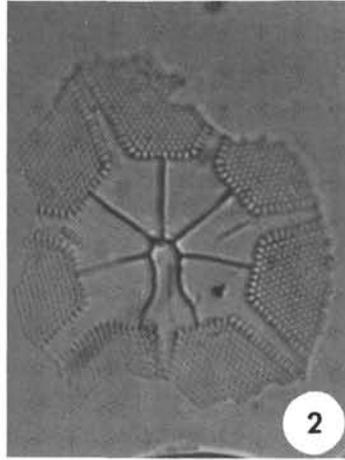
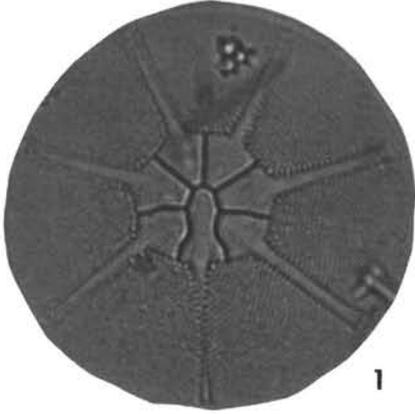


PLATE 12  
Diatom Photomicrographs

- Figure 1 *Asteromphalus wyvillii* Castracane  
DSDP 157-2A(CC), 600 ×.
- Figure 2 *Coscinodiscus africanus* Janisch  
DSDP 157-30(CC), 600 ×.
- Figure 3 *Coscinodiscus asteromphalus* Ehrenberg  
DSDP 157-11(CC), 300 ×.
- Figures 4-5 *Coscinodiscus curvatulus* Grunow  
4. DSDP 157-3(CC), 600 ×.  
5. DSDP 157-24(CC), 600 ×.
- Figures 6-8 *Coscinodiscus elongatus* Grunow  
6. DSDP 158-6(CC), 600 ×.  
7. DSDP 157-18(CC), 300 ×.  
8. DSDP 158-12(CC), 300 ×.

PLATE 12

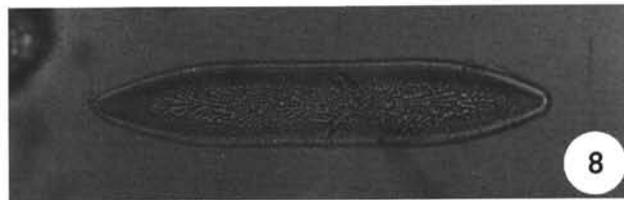
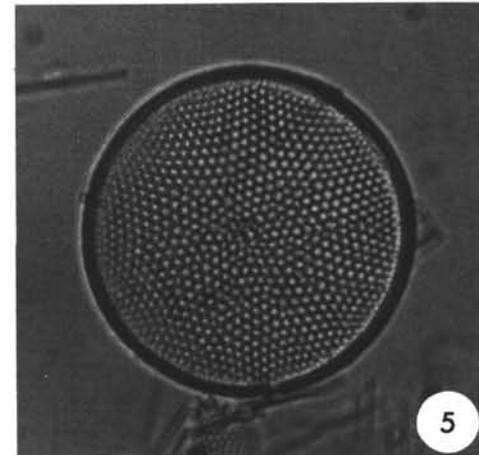
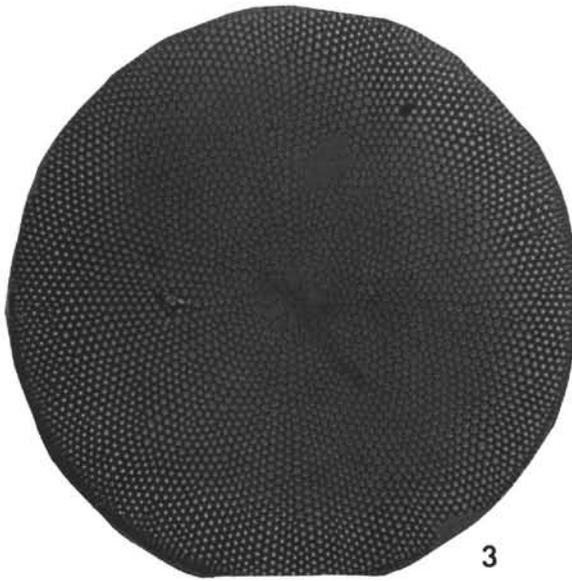
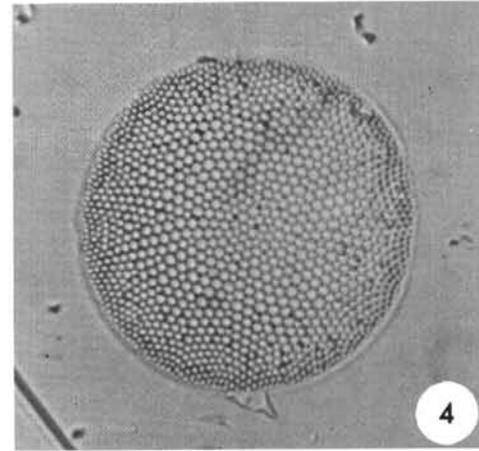
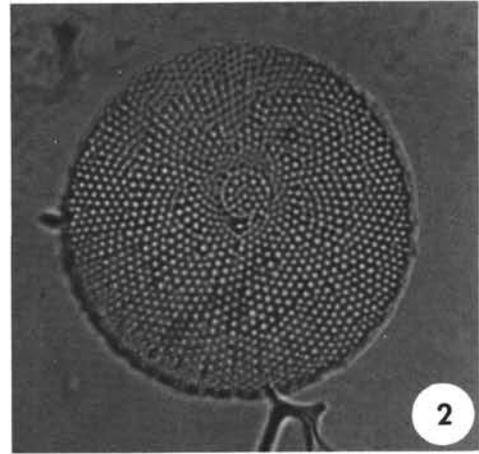
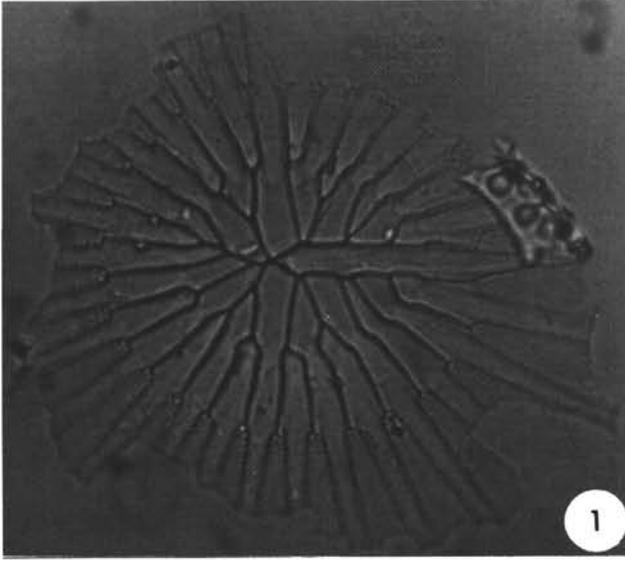


PLATE 13

Diatom Photomicrographs: 600 ×,  
Except Figures 5 and 9, Which Are 300 ×,  
and Figure 1, Which Is 120 ×

- Figure 1      *Coscinodiscus gigas diorma* (Schmidt) s. s.  
DSDP 158-31(CC), 120 ×.
- Figures 2-4    *Coscinodiscus lineatus* Ehrenberg  
2. DSDP 157-27(CC).  
3. DSDP 158-13(CC).  
4. DSDP 157-8(CC).
- Figure 5      *Coscinodiscus lineatus* Ehrenberg [at left]  
*Coscinodiscus excentricus* Ehrenberg [at right]  
DSDP 157-18(CC), 300 ×.
- Figures 6-7    *Coscinodiscus lewisianus* Greville  
6. EM 7-2, 25-27cm.  
7. DSDP 158-22(CC).
- Figure 8      *Coscinodiscus marginatus* Ehrenberg  
DSDP 158-32(CC).
- Figure 9      *Coscinodiscus nodulifer* Schmidt  
DSDP 157A-2A(CC), 300 ×.
- Figure 10     *Coscinodiscus paleaceus* Grunow  
DSDP 158-30(CC).
- Figure 11     *Coscinodiscus plicatus* Grunow  
DSDP 158-20(CC).

PLATE 13

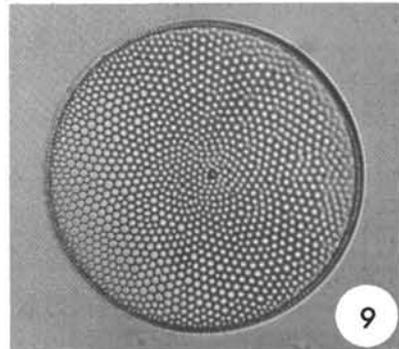
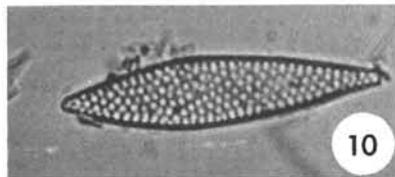
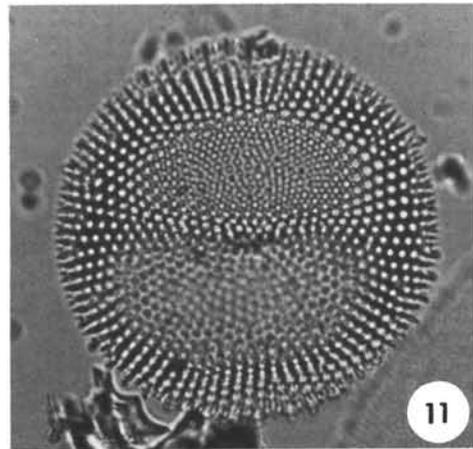
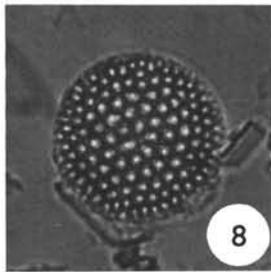
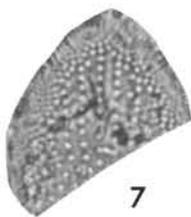
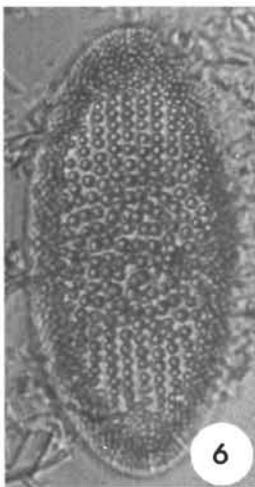
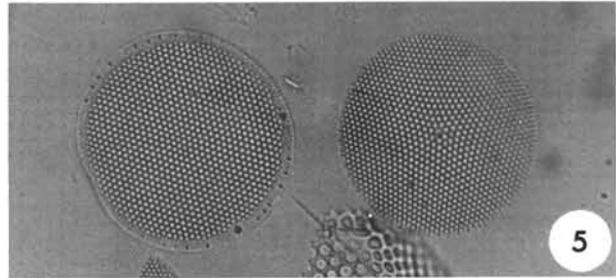
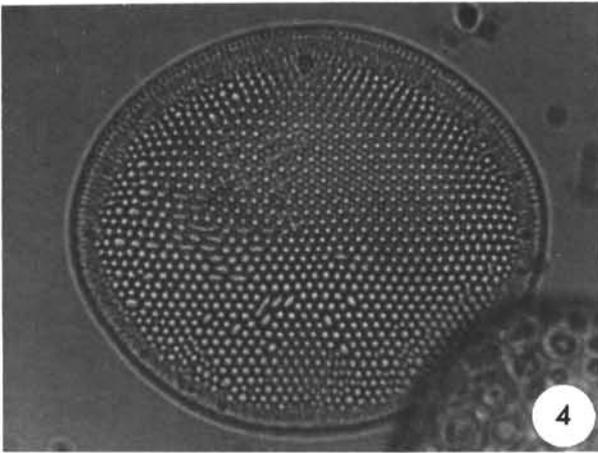
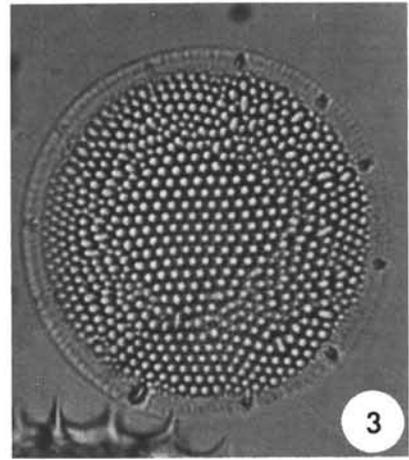
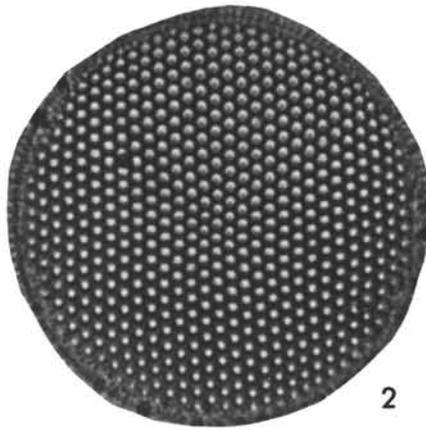
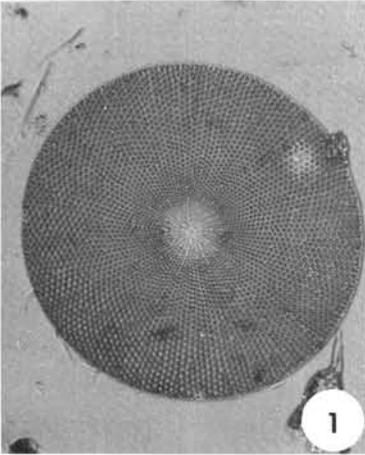


PLATE 14  
Diatom Photomicrographs

- Figure 1 *Coscinodiscus vetutissimus* Pantocsek  
DSDP 158-30(CC), 300 ×.
- Figure 2 *Coscinodiscus* sp. [irregular margin]  
DSDP 157-37(CC), 300 ×.
- Figure 3 *Craspedodiscus coscinodiscus* Ehrenberg  
DSDP 158-32(CC), 600 ×.
- Figures 4-5 *Denticula hustedtii* Simonsen and Kanaya  
4. DSDP 158-26(CC), 1200 ×.  
5. Same, dark field phase contrast.
- Figure 6 *Denticula lauta* Bailey  
DSDP 158-26(CC), 1200 N, dark field phase  
contrast.
- Figure 7 *Ethmodiscus rex* Rattray  
DSDP 158-10(CC), 600 ×, fragment.
- Figures 8-10 *Fragilariopsis pliocena* Brun  
8. DSDP 157-28(CC), 600 ×.  
9. DSDP 157-24(CC), 600 ×.  
10. DSDP 157-7(CC), 600 ×.
- Figures 11-12 *Hemidiscus cuneiformis* Wallich  
11. DSDP 158-21(CC), 300 ×.  
12. DSDP 158-16(CC), 600 ×.

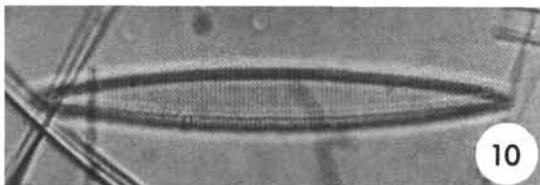
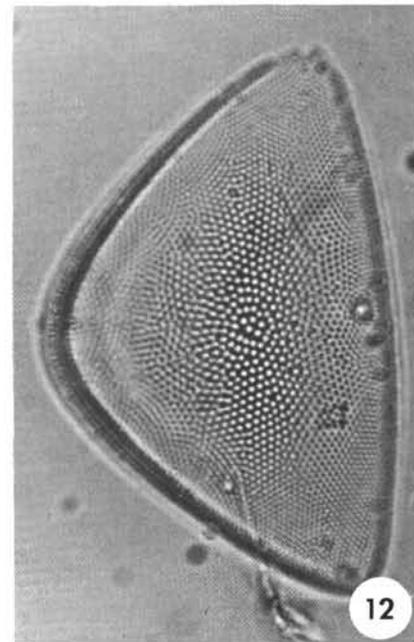
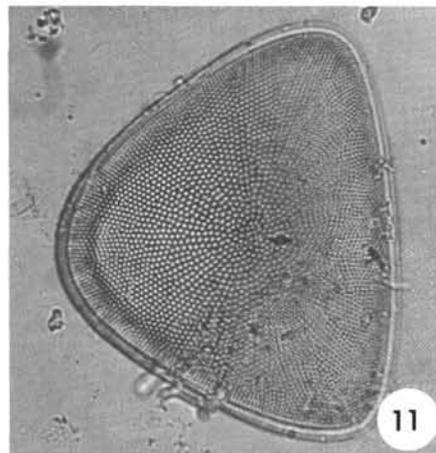
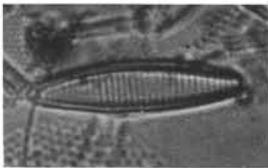
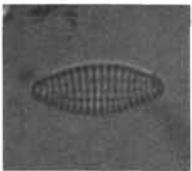
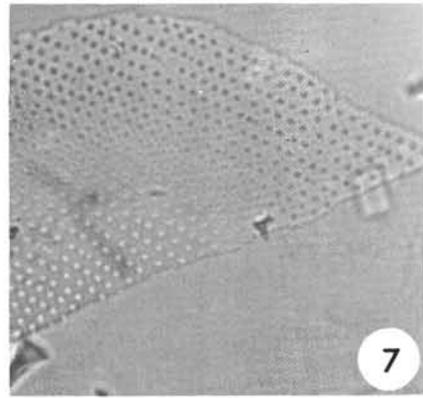
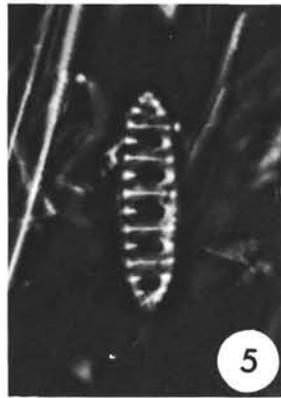
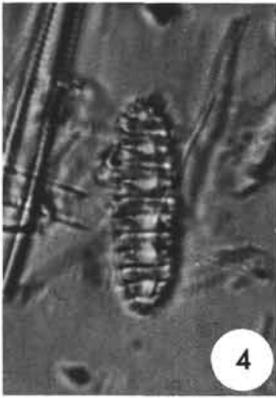
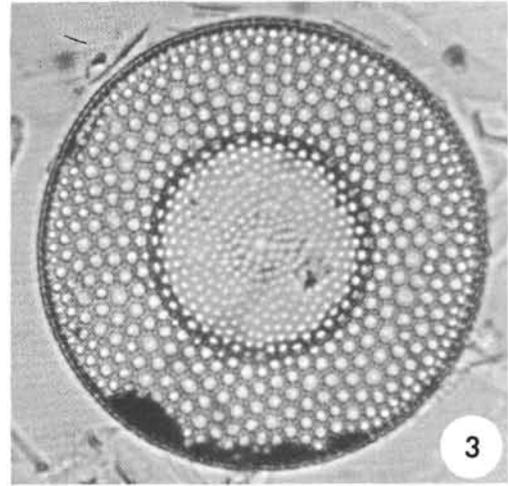
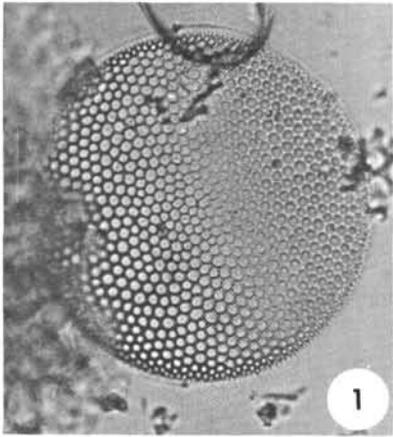


PLATE 15

Diatom Photomicrographs

- Figure 1 *Liostephania* sp.  
DSDP 158-25(CC), 600 ×.
- Figure 2 *Nitzschia marina* Grunow  
DSDP 158-12(CC), 300 ×.
- Figure 3 *Pleurosigma* sp.  
DSDP 157-19(CC), 300 ×.
- Figure 4 *Pseudoeunotia doliolus* (Wallich)  
DSDP 157-26(CC), 600 ×.
- Figure 5 *Rhizosolenia bergonii* Peragallo  
DSDP 157-1(CC), 600 ×.
- Figures 6-8 *Chaetoceros* sp.  
6. DSDP 158-9(CC), 300 ×.  
7. DSDP 157-11(CC), 300 ×.  
8. DSDP 158-11(CC), 600 ×.
- Figures 9-11 *Roperia tessellata* (Roper)  
9. DSDP 157A-1A(CC), 300 ×.  
10. DSDP 157A-2A(CC), 300 ×, high focus.  
11. Same, low focus.

PLATE 15

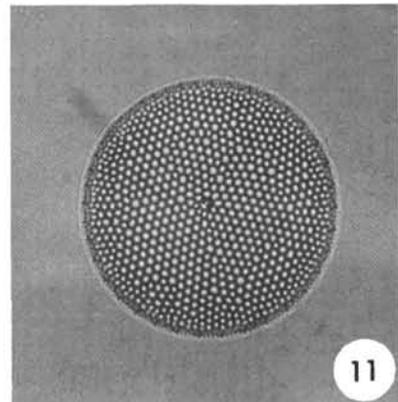
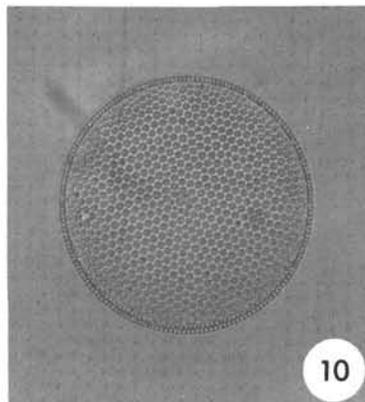
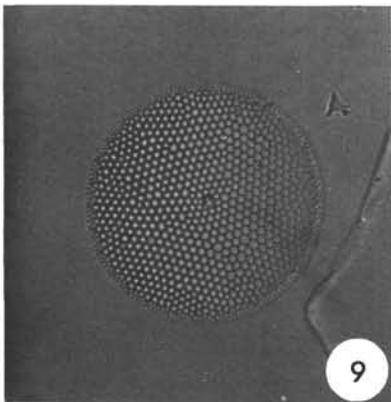
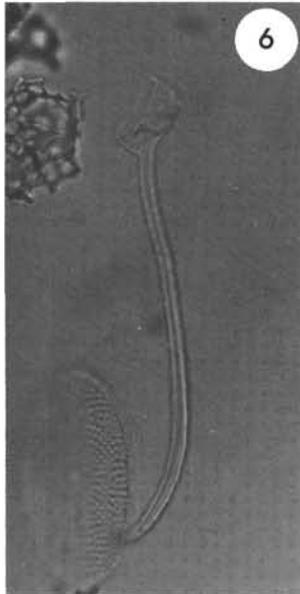
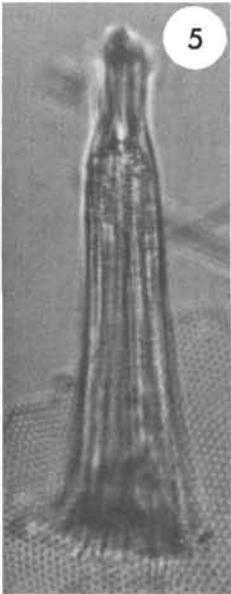
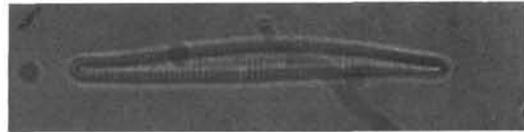
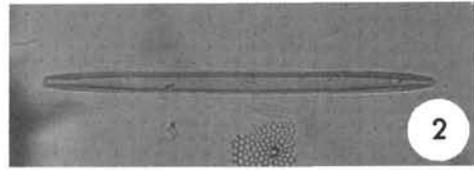
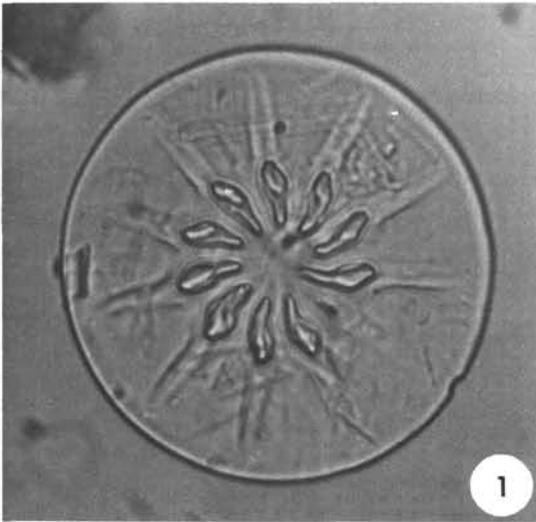


PLATE 16

Diatom Photomicrographs

- Figures 1-2     *Stictodiscus* sp. cf. *S. californicus* Greville  
1. DSDP 158-25(CC), 600 ×.  
2. DSDP 157-23(CC), 300 ×.
- Figures 3-6     *Stictodiscus trigonus* Castracane  
3. DSDP 157A-1A-2, 8-10, cm, 600 ×.  
4. DSDP 157-2(CC), 300 ×.  
5. DSDP 157-1(CC) 600 ×.  
6. DSDP 158-33(CC), 600 ×.
- Figures 7-8     *Thalassionema nitzschioides* (Grunow) *s. l.*  
7. DSDP 157-37(CC), 600 ×.  
8. DSDP 157-37(CC), 600 ×.
- Figure 9         *Thalassiothrix* sp.  
DSDP 158-27(CC), 1200 ×, fragment, dark  
field phase contrast.
- Figures 10-11   *Triceratium cinnamomeum* Greville  
10. DSDP 157-32(CC), 600 ×.  
11. DSDP 158-30(CC), 600 ×.
- Figure 12        ?*Triceratium thumii* Schmidt  
12. DSDP 158-30(CC), 600 ×.

PLATE 16

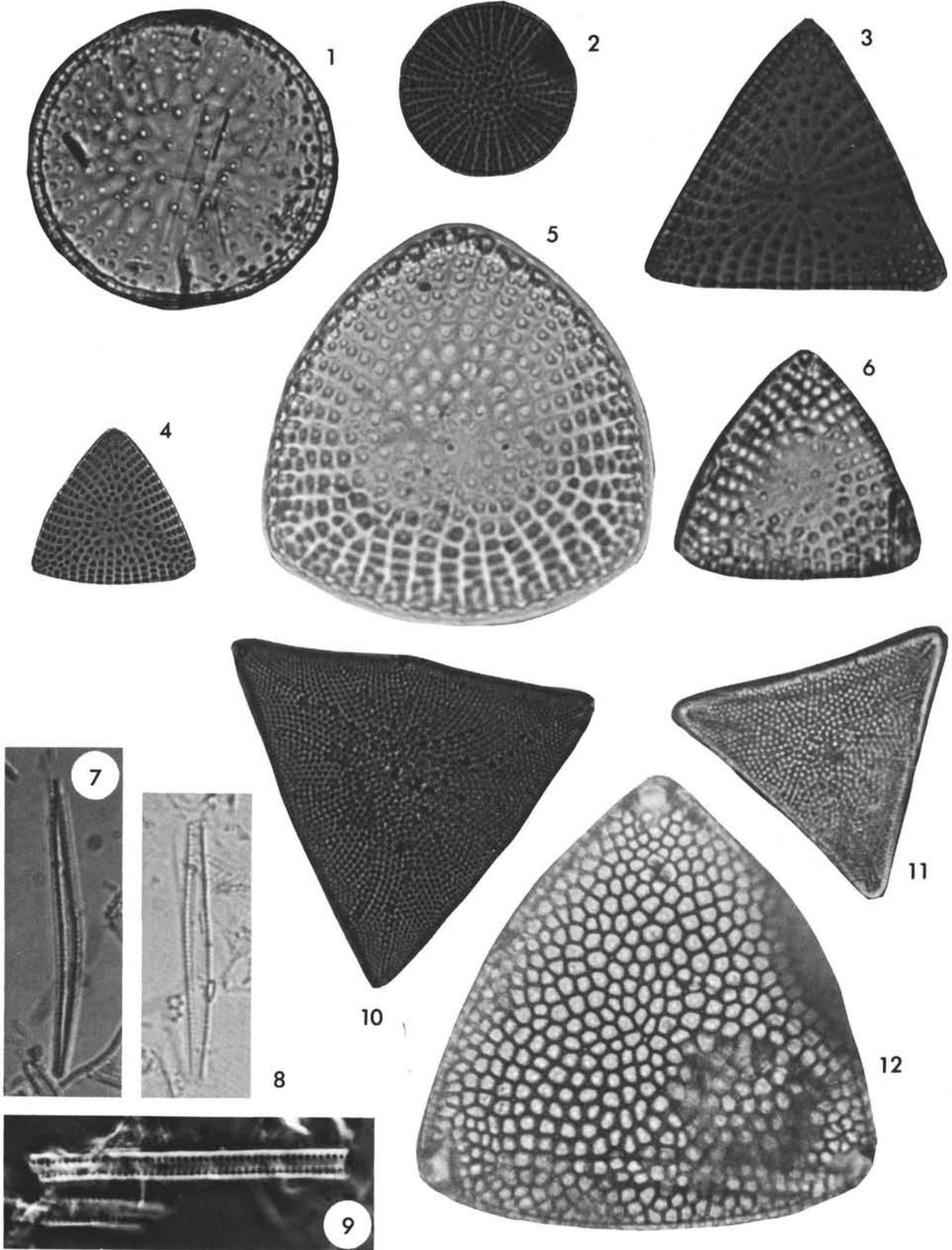


PLATE 17

Diatom Photomicrographs: 600 ×,  
Except Figures 1 and 3, Which Are 300 ×

- Figure 1 *Auliscus* sp.  
DSDP 157-18(CC), 300 ×.
- Figure 2 *Bacteriastrum* sp.  
DSDP 157-14(CC).
- Figure 3 *Biddulphia* sp.  
DSDP 157-23(CC), 300 ×.
- Figure 4 *Diploneis* sp.  
DSDP 157-15(CC).
- Figure 5 *Grammatophora* sp.  
DSDP 158-34(CC).
- Figure 6 *Navicula* sp.  
DSDP 157A-1A-4(8-10 cm).
- Figure 7 *Surirella* sp.  
DSDP 157-1(CC).
- Figure 8 *Thalassiosira decipiens* (Grunow)  
DSDP 157-25(CC).
- Figure 9 *Triceratium* sp.  
DSDP 157-8(CC).

PLATE 17

