

### 13. LATE CENOZOIC SILICOFAGELLATES FROM THE NORTHWEST PACIFIC, DEEP SEA DRILLING PROJECT LEG 86: PALEOTEMPERATURE TRENDS AND TEXTURE CLASSIFICATION<sup>1</sup>

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#### ABSTRACT

A quantitative study of late Cenozoic silicoflagellates from the northwestern Pacific sites of Deep Sea Drilling Project Leg 86 shows a relative paleotemperature ( $T_s$ ) gradient with lowest values ( $T_s = 30$ ) in the north. Some new ecostratigraphic relations for the region are indicated, such as the last common occurrence of *Dictyocha brevispina* at 2.6–3.0 m.y. ago during a cool interval. Elements of North Pacific and low-latitude biostratigraphic zonations can be identified, but the mixing of cool- and warm-indicator taxa prompted the definition of the new Miocene *Mesocena hexalitha* Subzone and Pliocene *Distephanus jimlingii* Subzone.

Scanning-electron microscope study of Leg 86 silicoflagellates was done to determine whether various types of skeletal surface texture are temperature dependent. To conduct the study we organized a new surface-texture descriptive code, which characterizes the apical structure/basal ring/spine sequence using new definitions of the terms crenulate (C), linear (L), nodular (N), reticulate (R), and smooth (S).

One new silicoflagellate genus, *Caryocha* Bukry et Monechi, n. gen., is described and several new combinations are made.

#### INTRODUCTION

The recovery of biosilica-rich sediment from the Northwest Pacific Basin and biosilica-bearing calcareous sediment from Shatsky Rise by Deep Sea Drilling Project (DSDP) Leg 86 provided the opportunity to investigate silicoflagellate relative paleotemperature trends in a region where the warm Kuroshio Current and cool Oyashio Current meet. A comparative interval through the Quaternary and late Pliocene was studied from three holes: Holes 577, 579A, and 580. A Miocene section was studied from Hole 581 (Fig. 1).

Although many assemblages contain cool-water or temperate-water taxa, such as *Dictyocha subarctios* and *Distephanus jimlingii*, and some warm-water taxa (*Octactis pulchra*) are missing, the low-latitude biostratigraphic zonation can be identified for most assemblages. North Pacific zonation is, however, applied to the Quaternary at Site 580 because of the predominance of cool-water taxa.

Relative paleotemperature fluctuations correspond fairly well with the regional disappearances of *Dictyocha brevispina* and *Mesocena circulus* in the Pliocene, providing ecostratigraphic correlations. The highest relative temperature values occur in southern Hole 577 and the lowest in northern Hole 580, supporting the presence of a latitudinal gradient during the late Cenozoic, which also supports the effectiveness of the relative paleotem-

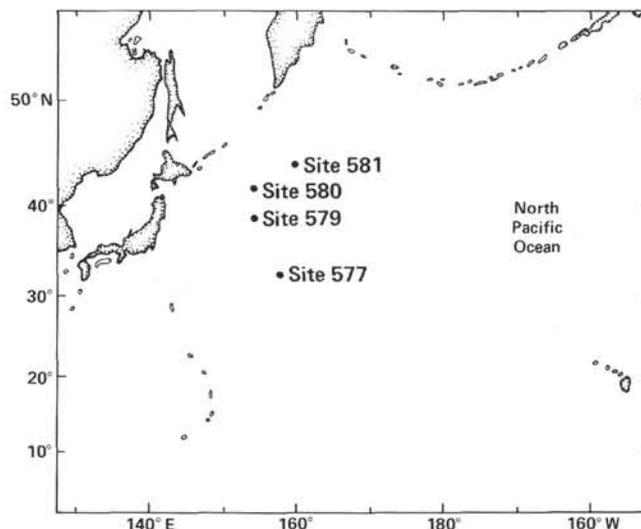


Figure 1. Location of coring sites from DSDP Leg 86 that were studied for silicoflagellates.

perature criteria. There is some correspondence between the silicoflagellate and the foraminiferal paleoclimatological scales. For example, Keller's (1979)  $C_2$  cool trough was characterized as intense and brief (3.0–3.2 m.y. ago). This may be related to the *D. brevispina* cool trough (Event c) which is calibrated here at 2.6 to 3.0 m.y. ago. The major foraminiferal cooling between 2.5 and 1.9 m.y. ago (Keller, 1979) is not evident in silicoflagellate assemblages at Leg 86 sites.

Surface textures on Leg 86 silicoflagellates were examined to determine whether the patterns are temperature dependent. The scanning electron microscope (SEM)

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study led to the establishment of a new system of descriptive coding in order to compare the results. Clear-cut temperature dependence could not be established, but speculation on evolution and preservation is discussed in the context of an analysis of the published literature on silicoflagellate surface textures.

This chapter was not intended to detail nomenclature, so a list of previously cited taxa is provided. One new genus, *Caryocha*, is described and several new combinations are made.

#### METHODS AND MATERIALS

Light-microscope study at magnification of 200 to 500× was used for biostratigraphic and paleotemperature enumeration of silicoflagellates for Leg 86. Structural details on silicoflagellate surfaces were studied with the scanning-electron microscope at Firenze at magnifications of 720 to 12,000×. Except for the carbonate-rich sediment from Shatsky Rise (Site 577), all samples were studied in smear preparations from unprocessed sediment. Processed acid residues were used for Site 577. The main goal of the study was to establish the pattern of Ts paleotemperature value fluctuations; therefore, counts were done mainly at the level of genus and morphologic group. Only selected species were counted individually.

The Leg 86 material studied includes:

1. Hole 577, Cores 577-1 to 577-7; 32°26.51'N, 157°43.40'E, depth 2675 m.
  2. Hole 578, Core 578-12; 33°55.56'N, 151°37.74'E, depth 6010 m.
  3. Hole 579A, Cores 579A-1 to 579A-15; 38°37.61'N, 153°50.28'E, depth 5737 m.
  4. Hole 580, Cores 580-1 to 580-17; 41°37.47'N, 153°58.58'E, depth 5375 m.
  5. Hole 581, Cores 581-2 to 581-8; 43°55.62'N, 159°47.76'E, depth 5476 m.
- A comparative sample from Hole 572A, Core 572-5, 01°26.09'N, 113°50.52'W, depth 3893 m, was also examined.

#### SILICOFLAGELLATE ZONATION

Low-latitude and North Pacific silicoflagellate zonation are used for biostratigraphic assignment of assemblages from DSDP Leg 86. The greatest differentiation between cool- and warm-water assemblages is in the Quaternary, where the North Pacific *Dictyocha subarctios* Zone (Ling, 1973) and the *Distephanus octangulatus* Zone (Bukry, 1973) are used for northern Site 580. Low-latitude zonation (Bukry, 1981b, 1983) is applied elsewhere, except for two new subzones that are described for northern Site 581 (Fig. 2). The zonal units are briefly characterized below from oldest to youngest.

##### *Corbisema triacantha* Zone

Two samples from Site 581 contain 11 and 16% *Corbisema triacantha* associated with predominant *Dictyocha pulchella*. Some mixing in the core-catcher of Core 581-8 is suggested by the association of *Mesocena hexalitha* with *C. triacantha*. *M. hexalitha* is typically younger than *C. triacantha* (Bukry, 1981a). *Distephanus longispinus* is sparse in both samples from Site 581, respectively 3% and <1%.

##### *Dictyocha brevispina* Zone

The interval between the last *Corbisema triacantha* and the first *Dictyocha neonautica* was used to identify the *D. brevispina* Zone for Site 581 because the primary guide to the top of the zone (*D. longa*) is missing. The

Age	Low-latitude		North Pacific zones and subzones
	Zone	Subzone	
Quaternary	<i>Dictyocha aculeata</i>	—	<i>Distephanus octangulatus</i> Zone
	<i>Mesocena quadrangula</i>	—	<i>Dictyocha subarctios</i> Zone
Pliocene	<i>Dictyocha stapedia</i>	<i>Dictyocha ornata</i>	—
	<i>Dictyocha fibula</i>	—	<i>Distephanus jimlingii</i> Subzone
late Miocene		<i>Dictyocha neonautica</i>	—
	<i>Dictyocha brevispina</i>	—	<i>Mesocena hexalitha</i> Subzone
middle Miocene	<i>Corbisema triacantha</i>	—	—

Figure 2. Correlation of silicoflagellate zones and subzones identified for DSDP Leg 86. Low-latitude zonations were used for silicoflagellate assemblages at Sites 577, 579, and 581; North Pacific zonations were used for Site 580. The *Distephanus jimlingii* Subzone and *Mesocena hexalitha* Subzone are new subzones described in this study.

lower part of the zone is distinguished by the presence of rarely reported *Distephanus paradistephanus* followed directly, in possible evolutionary transition, by *Mesocena hexalitha*. *Dictyocha brevispina* and *D. pulchella* dominate the assemblages.

##### *Mesocena hexalitha* Subzone (new subzone)

The stratigraphic range of *Mesocena hexalitha* defines the *M. hexalitha* Subzone as a short interval at the boundary between middle and upper Miocene. It is limited to Core 581-8 for Leg 86, but can be identified in the coccolith *Discoaster hamatus* Zone at Site 470 (Bukry, 1981a) and the diatom Subzone c of the *Denticulopsis hustedtii*-*D. lauta* Zone (Barron, 1980) at Hole 438A

and in the Monterey Formation at upper Newport Bay, California (Barron, 1976).

#### *Dictyocha fibula* Zone

The interval between the first *Dictyocha neonautica* and the first *D. stapedia stapedia* is assigned to the *D. fibula* Zone at Holes 579A and 581. Fibuloid specimens dominate the assemblages of *Dictyocha* in the upper part of the zone at Hole 579A, but asperoid specimens are dominant in the lower part of the zone at Hole 581.

#### *Dictyocha neonautica* Subzone

The range of *Dictyocha neonautica* is used to identify the *D. neonautica* Subzone (Bukry, 1981b). This interval occupies the lower part of the *D. fibula* Zone and is typically latest Miocene in age. At Site 581 the *D. neonautica* Subzone occurs in Cores 3 to 6, where it contains *D. aspera clinata* and *Distephanus quinquangellus*. *Dictyocha neonautica* is missing in the middle of the subzone in Core 4, a relationship that exists at Hole 503A in the eastern Pacific (Bukry, 1982).

#### *Distephanus jimlingii* Subzone (new subzone)

A new subzone, based on the first occurrence of *Distephanus jimlingii* s. ampl. is identified at Site 581 in Core 581-2, and probably in Cores 579A-12 and 579A-13 from Hole 579A.

The interval from the first occurrence to the last occurrence of *D. jimlingii* in the *Dictyocha fibula* Zone is used to identify the *Distephanus jimlingii* Subzone. This subzone is correlative with the early Pliocene *Dictyocha pulchella* Subzone and possibly the *D. angulata* Subzone of lower latitude (Bukry, 1983).

Ling's (1973) *Cannopilus hemisphaericus* Zone is based on a species concept that partly includes *Distephanus jimlingii* (Ling, 1973, Plate 1, Figs. 1 and 2). His zone ranges from the last *D. quinquangellus* to the last *D. jimlingii*. Because Ling's taxonomic concept is not directly equivalent to *D. jimlingii* and because *D. quinquangellus* occurs with *D. jimlingii* in the lower Pliocene of Hole 579A, that biostratigraphic unit is not equivalent to the newly defined *D. jimlingii* Subzone.

Ling (1975) illustrated a specimen called *Cannopilus hemisphaericus* (Ehrenberg) which resembles *D. jimlingii* (Bukry). His occurrence charts for Sites 301 and 302 in the Sea of Japan show *C. hemisphaericus* mainly in the late Miocene. A zonal correlation chart, however, lists a *C. hemisphaericus* Zone in the early Pliocene. Ling (1980) adopted the name *D. jimlingii* Zone for the 1973 zone, but used the same definition. However, his broad taxonomic concept for *D. jimlingii*, exemplified in Ling (1973), ranges into taxa with large apical openings, which have different stratigraphic ranges. This, together with the variable range of *D. quinquangellus*, supports definition of the more biostratigraphically circumscribed, new *D. jimlingii* Subzone. See Barron (1976, 1980) for additional information concerning the biostratigraphic significance of *D. jimlingii* near the Miocene/Pliocene boundary.

#### *Dictyocha stapedia* Zone

The low- to mid-latitude *Dictyocha stapedia* Zone is defined as the interval between the first *D. stapedia stapedia* and the first *Mesocena quadrangula*. The base can be alternately identified by the first occurrence of *D. flexatella* and *D. ornata*. In the Leg 86 area, *D. ornata* is more sporadic than *D. flexatella* or *D. stapedia stapedia*.

The top of the zone is influenced, here, by the variable association with *D. subarctios*, which defines a regional North Pacific zone that is coeval with the upper part of the *D. stapedia* Zone in the Quaternary. For example, *D. subarctios* first occurs with the *M. quadrangula* acme, above the *D. stapedia* Zone in Hole 579A. But at more northerly Site 580, *D. subarctios* appears earlier than the *M. quadrangula* acme, providing an overlap in the defined limits for the upper *D. stapedia* Zone and lower *D. subarctios* Zone. Mixed cool, cosmopolitan, or warm indicator species in the Northwest Pacific Basin represent the regional meeting of warm- and cool-water masses.

#### *Dictyocha ornata* Subzone

The *Dictyocha ornata* Subzone is identified in Holes 577 and 579A mainly by the range of *D. flexatella* which has a range similar to *D. ornata* (= *D. ornata africana* and *D. ornata ornata*) at lower latitudes. *D. ornata* is sparse and sporadic at Leg 86 sites. At low latitude, the first common *D. delicata* marks the top of the subzone, but this species is missing in Leg 86 samples. Therefore, the alternative disappearance of either *D. flexatella* or *D. ornata* is used.

#### *Dictyocha subarctios* Zone

The *Dictyocha subarctios* Zone was defined for North Pacific high latitudes (Ling, 1973) as the interval from the last *Ammodochium rectangulare* (an ebridian) to the last *D. subarctios*. An alternate criterion, the local range zone for *D. subarctios* was also provided in the original definition. The alternate definition is used for Site 580. *Mesocena quadrangula* has an acme at the top of the *D. subarctios* Zone of Hole 580, which suggests partial correlation with the low-latitude *M. quadrangula* Zone.

#### *Mesocena quadrangula* Zone

The middle Quaternary acme of *Mesocena quadrangula* occurs at Holes 577, 579A, and 580. This acme defines the low-latitude *M. quadrangula* Zone. At Site 580 the *Dictyocha subarctios* Zone encompasses the *M. quadrangula* acme Zone.

#### *Distephanus octangulatus* Zone

The original *Distephanus octangulatus* Zone from DSDP Leg 18 (Bukry, 1973) is defined from the first *D. octangulatus* at the base to living assemblages at the top. A second *D. octangulatus* Zone was described for DSDP Leg 19 (Ling, 1973) from the last *D. floridus* to an undefined top. The first *D. octangulatus* is used for

Site 580, but the overlap with *D. floridus* is short, so the original zone is somewhat longer. The assemblages have low diversity with *Dictyochoa aculeata*, *D. stapedia stapedia*, and *Distephanus octangulatus* as the dominant taxa.

### *Dictyochoa aculeata* Zone

Low- to mid-latitude assemblages from the end of the acme of *Mesocena quadrangula* to living assemblages are assigned to the *Dictyochoa aculeata* Zone. *D. aculeata* and small *D. stapedia stapedia* dominate these assemblages. No warm water *Octactis pulchra* were observed in the *D. aculeata* Zone at either Hole 577 or 579A.

### SILICOFLAGELLATE RELATIVE PALEOTEMPERATURE VALUES (Ts)

A latitudinal array of sites was cored by DSDP Leg 86 to the east of Japan and south of Kamchatka in a region where the warm Kuroshio and cool Oyashio oceanic currents converge. The silicoflagellates preserved in the sediment deposited under these currents in the Northwest Pacific Basin and on the Shatsky Rise include variable proportions of cool, warm, and cosmopolitan taxa. Quantitative study of silicoflagellate assemblages from the Leg 86 sites permits comparison of paleotemperature trends through calculation of relative paleotemperature values (Bukry, 1981a, 1983, in press b). The

array of sites examined ranges 11° of latitude from 32°26.51'N on Shatsky Rise (Site 577) to 43°55.62'N near the Hokkaido Fracture Zone (Site 581). Coeval stratigraphic successions are available only for the southern three holes—Holes 577, 579A, and 580—which range up to 41°37.47'N. These sections contain coeval silicoflagellates from the late Pliocene (3.4 m.y. ago) to late Pleistocene (0.7 m.y. ago). The northernmost Hole 581 sampled a middle Miocene (14 m.y. ago) to early Pliocene (3.6 m.y. ago) section. Quantitative silicoflagellate results are presented for all four sites as annotated summaries (Tables 1–4) and time-calibrated curves (Figs. 3–6). Chronology for silicoflagellate paleotemperature results is based on paleomagnetic and correlative diatom time scales determined for the northwestern Pacific region (see Barron, 1980, 1981; Koizumi and Tanimura, this volume; Monechi, this volume).

The major horizons of biostratigraphic and relative paleotemperature correlation between the Pliocene and Pleistocene curves for Holes 577 (Fig. 3), 579A (Fig. 4), and 580 (Fig. 5) include the cool trough at approximately 0.95 m.y. ago, during the *Mesocena quadrangula* acme. Other points of correlation are signified by the letters a to e on the paleotemperature curves (Table 5; Fig. 3).

*M. circulus* disappeared at about 2.4 m.y. ago at all three sites (reference point a; Figs. 3–5). This species had

Table 1. Late Cenozoic silicoflagellate biostratigraphy, relative paleotemperature values (Ts), and percent distribution of various genera and morphologic subgroups with remarks on noteworthy occurrences for Hole 577.

Age	Zone or subzone	Hole 577 sample (interval in cm)	Depth (m)	Total specimens	Ts value	Generic percentages						Noteworthy occurrences
						<i>Dictyochoa</i>	<i>Distephanus</i> (quadrate)	<i>Distephanus</i> (nonquadrate)	<i>Mesocena</i> (quadrate)	<i>Mesocena</i> (nonquadrate)	<i>Octactis</i>	
Quaternary	<i>D. aculeata</i>	1-1, 125-126	1	100	100	100						<i>Dictyochoa stapedia</i> 40% <i>D. aculeata</i> > <i>D. stapedia</i>
		1-3, 40-41	3	100	100	100						
		1-4, 40-41	5	100	100	100						
		1-5, 46-47	6	50	99	99			1			
		2-1, 103-104	8	100	95	94		5	1			
<i>M. quadrangula</i>	2-3, 43-44	10	100	92	85		1	14				
	2-4, 43-44	12	300	88	79	1	4	16				
	2-4, 103-104	12	100	95	90			10				
	—	—	2-6, 103-104	15	50	98	98		2			
3-1, 140-141			18	100	96	95	1	3	1			
3-2, 54-55			18	100	95	95			5			
3-3, 96-97			20	100	93	92		6	2			
3-5, 44-45			23	300	96	96			4			
late Pliocene	<i>D. stapedia</i>	<i>D. ornata</i>	3-5, 110-111	24	200	97	96		2	2		<i>Dictyochoa flexatella</i> 3%  First <i>D. ornata</i> <i>Dictyochoa flexatella</i> 25% Last <i>D. brevispina</i> <i>Dictyochoa flexatella</i> 20%  First <i>D. flexatella</i> , <i>D. stapedia</i>
			3-6, 30-31	24	200	93	93	2	6			
			4-1, 33-34	26	200	92	90	2	4		3	
			4-2, 112-113	28	100	92	91	2	5		2	
			4-4, 112-113	31	200	80	78	3	10		8	
			4-6, 25-26	34	100	58	56	4	28		12	
			5-1, 30-31	36	50	71	68	6	24		2	
			5-2, 30-31	37	50	92	90	4	6			
			5-3, 34-35	39	50	81	80	2	10		8	
			early Pliocene	—	5-6, 20-21	43	50	68	64	6	6	
6-1, 120-121	46	100			82	80	4	9		7		
6-3, 20-21	48	50			91	90	2	6		2		
late Miocene	—	6-7, 12-13	54	200	92	90	3	6		1		
		7-1, 86-87	55	80	92	90		7	3			
		7-3, 130-131	59	25	80	80		20				

Table 2. Late Cenozoic silicoflagellate biostratigraphy, relative paleotemperature values (Ts), and percent distribution of various genera and morphologic subgroups with remarks on noteworthy occurrences for Hole 579A.

Age	Zone	Hole 579A sample (interval in cm)	Depth (m)	Total specimens	Ts value	Generic percentages						Noteworthy occurrences
						<i>Dictyochoa</i>	<i>Distephanus</i> (quadrate)	<i>Distephanus</i> (nonquadrate)	<i>Mesocena</i> (quadrate)	<i>Mesocena</i> (nonquadrate)	<i>Octactis</i>	
Quaternary	<i>D. aculeata</i>	1-2, 40-42	16	200	99	99	1					<i>Dictyochoa aculeata</i> 57% <i>Dictyochoa aculeata</i> 70%
		1-5, 75-77	21	300	96	96	4					
	<i>M. quadrangula</i>	2-4, 115-117	29	200	92	85	2	14				<i>Mesocena quadrangula</i> acme peak <i>Dictyochoa subarctios</i> 4% (cool water) <i>Dictyochoa subarctios</i> 7% (cool water)
		3-2, 30-32	35	50	68	50	14	36				
		3-5, 93-95	40	200	79	69	4	28				
late Pliocene	<i>D. stapedia</i>	4-2, 14-16	44	100	84	84	1	2	13			<i>Mesocena circulus</i> 20% <i>D. ornata</i> 1%, <i>D. flexatella</i> 23% Asperoid/fibuloid ratio > 1 Asperoid/fibuloid ratio > 1 <i>Dictyochoa flexatella</i> 10% First <i>Dictyochoa stapedia stapedia</i>
		5-5, 38-40	58	200	98	97	2	1				
		6-5, 28-30	68	300	94	94	<1	7				
		7-2, 20-22	73	100	94	94		6				
		7-5, 20-22	77	200	83	81	3	18				
		8-2, 80-82	83	100	82	81	1	18				
		8-5, 80-82	87	300	64	64		15	20			
		9-2, 40-42	92	100	73	73		24	3			
9-5, 50-52	97	100	66	66		20	14					
early Pliocene	<i>D. fibula</i>	10-2, 75-77	102	100	57	56	1	32	11			<i>Distephanus speculum minutus</i> 2% <i>Distephanus speculum minutus</i> 3% <i>Distephanus quinquangellus</i> 5% Last <i>Dictyochoa pulchella</i> <i>Distephanus quinquangellus</i> 5% Asperoid/fibuloid ratio < 1
		10-4, 75-77	105	300	63	62	1	17	20			
		11-2, 34-36	111	100	85	84	1	14	1			
		11-4, 34-36	114	200	66	64		26	4	7		
		12-2, 34-36	120	200	62	54	3	28	13	4		
		12-5, 34-36	125	200	50	49	1	48	1	3		
		13-2, 30-32	130	300	78	77	<1	17	1	4		
?early Pliocene	<i>D. fibula</i>	13-4, 30-32	133	300	56	54	<1	16	4	26		
		14-2, 36-38	139	300	85	83	<1	12	3	2		
		14-5, 36-38	144	300	52	41	<1	24	22	13		
		15-1, 16-18	147	200	68	56	1	18	22	5		
		15-2, 16-18	149	300	74	65	1	15	16	3		

its most numerous blooms at high southern latitudes (Stadum and Burckle, 1973; Bukry, 1975, 1976a) in the late Miocene. For Leg 86, *M. circulus* is most numerous at Hole 580 where it disappeared at a pronounced cool event (Ts = 58). The coeval cool trough at the intermediate latitude Hole 579A is less pronounced (Ts = 64). At southern latitude Site 577, where *M. circulus* is least numerous, it disappeared during a warm peak. This suggests that the regional disappearance of *M. circulus* was coeval and that a cooling event at the northern location was more intense than to the south. Also, the *M. circulus* disappearance in the region did not result directly from the cold pulse, unless the southern population was exotic and required continual "resettlement" from the more numerous northern population. The disappearance of *M. circulus* at a warm peak at Site 577 shows the removal was not related to cool temperatures at that location. A significant warming occurred at the northern location following 2.4 m.y. ago (Fig. 5).

A warm peak (reference point b) occurs at northern Holes 580 and 579A, but the coeval point (2.6 m.y. ago) at southern Hole 577 appears to be part of a general warming trend. The calculated Ts values are warmest (Ts = 80) in the south and coolest (Ts = 69) at the northern limit (Figs. 3, 4, and 5).

The last common occurrence of *Dictyochoa brevispina* (reference point c) in Holes 577, 579A, and 580 correlates with a distinct cool trough between 2.6 and near 3.0 m.y. ago. Cooling across latitude for this event is

shown by the relative paleotemperature values which decrease northward from Ts = 58 at Site 577 to Ts = 45 at Site 580.

A short warm peak (reference point d), between 3.0 and 3.3 m.y. ago precedes the *D. brevispina* cool event (c) at all three sites and is near the first occurrence of *D. stapedia stapedia*. The latitudinal order of the sites is shown by the Ts relative paleotemperature values, which range from Ts = 92 for this warm peak at Site 577 to Ts = 60 at Site 580.

The final correlation point between the sites (reference point e) is a warming trend that occurs at about 3.4 m.y. ago (Figs. 3-5). The Ts curves for the sites show lowest values in the north and highest, or warmest, values in the south, which indicates the potential for silicoflagellates to contribute to other more sophisticated paleotemperature analyses for the North Pacific (Barron, in press; Barron and Keller, 1983; Ingle, 1973; Keller, 1979, 1980a,b, 1981a,b; Vincent, 1975, 1981).

In detail these paleotemperature and occurrence events for silicoflagellates are believed to be most effective for local correlations such as the Leg 86 sites; however, comparison to distant Pacific Site 504 suggests some transoceanic similarity, too. At Site 504 off Ecuador (Bukry, 1983), *D. brevispina* disappears at a cool trough (~2.5 m.y. ago) followed by a brief warm peak and then a second cool trough (~2.1 m.y. ago) where *M. circulus* disappears. This sequence matches that described as events (c, b, and a) for Leg 86. The ages for

Table 3. Late Cenozoic silicoflagellate biostratigraphy, relative paleotemperature values (Ts), and percent distribution of various genera and morphologic subgroups with remarks on noteworthy occurrences for Hole 580.

Age	Zone or subzone	Hole 580 sample (interval in cm)	Depth (m)	Total specimens	Ts value	Generic percentages						Noteworthy occurrences
						<i>Dictyocha</i>	<i>Distephanus</i> (quadrate)	<i>Distephanus</i> (nonquadrate)	<i>Mesocena</i> (quadrate)	<i>Mesocena</i> (nonquadrate)	<i>Octactis</i>	
Quaternary	<i>D. octangulatus</i>	1,CC	3	50	84	82	4	16				<i>Distephanus octangulatus</i> 13% <i>Distephanus octangulatus</i> 52%  <i>Distephanus octangulatus</i> 11%  <i>D. octangulatus</i> 4%, last <i>D. floridus</i>
		2-2, 42-44	5	100	76	76		24				
		2-5, 42-44	10	50	40	40		60				
		2,CC	12	50	36	32	8	60				
		3-3, 40-42	16	100	58	57	1	42				
		3-6, 110-111	21	50	96	96		4				
		4-5, 20-22	29	50	66	66		34				
		4,CC	31	50	84	84		16				
	—	5,CC	41	300	88	85	5	10				<i>Dictyocha lingii</i> 4%
		6-2, 42-44	43	200	98	98		2				
	<i>D. subarctios</i>	6-5, 42-44	48	100	78	90		1	9			<i>Dictyocha</i> sp. aff. <i>D. subarctios</i> 17%  <i>Dictyocha subarctios</i> 5% <i>Dictyocha subarctios</i> 24% <i>Dictyocha subarctios</i> 15% <i>D. subarctios</i> 9%; <i>D. floridus</i> 30%  <i>D. subarctios</i> 3%
		6,CC	50	300	86	83		11	6			
		7-2, 49-51	53	100	82	75		2	23			
		7-6, 10-11	58	200	72	96		4				
8-2, 18-20		62	300	70	84		16	1				
8-5, 17-19		66	300	22	30		69	1				
8,CC		70	300	73	73		26		1			
9-2, 28-30		72	300	89	91	1	7					
9,CC	77	100	82	82		14		4				
late Pliocene	—	10-5, 90-92	86	200	84	83	2	16			<i>Dictyocha calida ampliata</i> 16%  <i>Dictyocha perlaevis</i> predominant	
		10,CC	88	100	92	92		8				
		11-3, 60-62	92	100	94	94		6				
		11,CC	96	100	76	76		24				
	<i>D. stapedia</i>	<i>D. ornata</i>	12-3, 20-22	102	300	84	83	1	17			<i>D. calida ampliata</i> 22%; <i>D. ornata</i> 1%  <i>Dictyocha flexatella</i> 3%  <i>Dictyocha flexatella</i> 13%  <i>D. brevispina</i> 39%; <i>D. flexatella</i> 6%
			12,CC	108	100	79	76	5	19			
			13-3, 54-56	111	200	36	36		65			
			13,CC	117	300	56	55	1	33	<1	10	
			14,CC	127	300	69	69		29		2	
			15-2, 25-27	129	300	53	53		21		26	
			15,CC	135	100	52	47	10	33		10	
			16,CC	145	100	45	44	2	36		18	
			17-2, 27-29	148	100	60	60		6		34	
			17,CC	154	300	38	30	2	28	14	26	

the events at both locations are based on diatom chronology and show that the Ecuadorian sequence is 0.1 to 0.3 m.y. younger than in the northwest Pacific. An offset in ages for the sequence could have several causes including diatom and paleomagnetic calibration, lag in latitude transfer, or microclimatics. The local or global significance of ecostratigraphic events will become even clearer as more quantitative data is created for different regions.

Interpretation of the Miocene to early Pliocene paleotemperature trend for Site 581 (Fig. 6) is hindered by a paucity of diatom correlation points and by potential hiatuses. The major features of the record, following about 7 m.y. ago at 225 m (Fig. 6), can be tentatively correlated with Hole 503A in the eastern equatorial Pacific (Bukry, 1982, 1983). A cool trough between 3.9 and 4.4 m.y. ago in the early Pliocene is prominent at both holes, but the Ts = 34 to 41 for Site 581 is markedly cooler than the Ts = 68 to 72 for Hole 503A. The preceding warm peak near the Miocene/Pliocene boundary at about 5 m.y. ago is a widespread feature reported in various areas including the North Atlantic (Bukry, in press a). A cool interval with many fluctuations occurs from about 5.1 to 5.4 m.y. ago at Hole 503A, but a sin-

gle cool trough is recorded in that interval at Site 581, probably because of the fewer samples examined. Preceding the cooling at 5.1 to 5.4 m.y. ago there are warm peaks at about 5.8 and 6.0 m.y. ago separated by a minor cool trough at 5.9 m.y. ago. A warming trend between 6 and 7 m.y. ago is also noted at both sites. Below these levels the time framework is less definite and trends are not coordinated, because of hiatuses, sparse samples, or local effects. Detailed study of Site 581 between 180 and 230 m may demonstrate whether the broad trends in Ts values shown here are indicative for transoceanic correlation.

In calculating relative paleotemperature values for Leg 86, *D. pentagona* and *D. subarctios* were considered to be cool indicators and therefore not included in the Ts summation.

#### SURFACE TEXTURE OF SILICOFLAGELLATE SKELETONS

Small structural features on the surface of the opaline rod structure forming a silicoflagellate were noted and illustrated by Lemmermann (1901). In later studies, Deflandre (1950) illustrated silicoflagellate surfaces of several genera (*Dictyocha*, *Lyrarula*, *Naviculopsis*, and

Table 4. Late Cenozoic silicoflagellate biostratigraphy, relative paleotemperature values (Ts), and percent distribution of various genera and morphologic subgroups with remarks on noteworthy occurrences for Hole 581.

Age	Zone or subzone	Hole 581 sample (interval in cm)	Depth (m)	Total specimens	Ts value	Generic percentages						Noteworthy occurrences	
						<i>Corbisema</i>	<i>Dictyochoa</i> (pentagonal)	<i>Dictyochoa</i> (nonpentagonal)	<i>Distephanus</i> (quadrate)	<i>Distephanus</i> (nonquadrate)	<i>Mesocena</i> (quadrate)		<i>Mesocena</i> (nonquadrate)
early Pliocene	<i>D. jimlingii</i>	2-1, 46-47	182	200	38	13	34	5	45	3	3	A < F First <i>D. jimlingii</i> ; last <i>D. pulchella</i>	
		2-3, 123-124	186	300	41	20	41	2	37	< 1	< 1		
		2-5, 45-46	188	300	34	11	34		55				
late Miocene	<i>D. fibula</i>	—	191	300	75	< 1	74		24	1	1	Last <i>D. aspera clinata</i> ; A > F	
		3-2, 45-46	193	300	77		77		22			<i>D. aspera clinata</i> 41%; <i>D. neonautica</i> 2%; A > F	
		3-6, 45-46	199	200	73		73		27				
		3, CC, 10-11	200	300	73		72	< 1	27			<i>D. quinquangellus</i> 11%; last <i>M. diodon nodosa</i> ; A < F <i>Distephanus quinquangellus</i> 21%; A < F	
		4-2, 48-49	203	300	62	1	62		34		2		
		4-4, 48-49	205	200	60		60		37		4	A > F A > F First <i>Dictyochoa</i> sp. cf. <i>D. flexatella</i> <i>D. neonautica</i> 17%; <i>D. aspera clinata</i> 15% First <i>D. neonautica</i> ; first <i>D. aspera clinata</i> ; A < F	
		4, CC, 2-3	210	300	87		85		10	4	1		
		5-2, 69-70	212	200	87		86	1	13		1	A > F A > F First <i>Dictyochoa</i> sp. cf. <i>D. flexatella</i> <i>D. neonautica</i> 17%; <i>D. aspera clinata</i> 15% First <i>D. neonautica</i> ; first <i>D. aspera clinata</i> ; A < F	
		5-4, 50-51	215	300	92		91		7	1	2		
		5, CC, 4-5	218	300	88		85	1	8	4	2	<i>Mesocena circulus</i> 7%  Elongate mode in several taxa <i>Mesocena diodon nodosa</i> 10% <i>Distephanus longispinus</i> 10%	
		6-1, 50-51	220	200	87		79	15	6		1		
		6-2, 50-51	221	300	96		94	1	< 1	4	1		
		middle Miocene	<i>D. brevispina</i>	—	223	100	86		82	7	7	4	<i>Mesocena hexalitha</i> 12% <i>Mesocena hexalitha</i> 8% <i>Distephanus paradistephanus</i> 2%
				6-4, 50-51	225	200	79	2	68	11	6	7	
				6-6, 50-51	227	300	79		76	6	17	2	
6, CC, 10-11	229			300	54		52	3	36	9			
7-1, 55-56	229			200	90		89	2	4	6			
7-4, 55-56	234			300	77		71	11	8	11			
8-1, 55-56	239			200	83		75	16	8	2			
8-2, 55-56	241			300	69		56	20	4	3	18		
8-2, 60-62	241			300	67		55	17	2	7	16		
8-3, 55-56	242			300	62		37	49	8	1	5		
<i>C. triacantha</i>	8-4, 60-62	244	100	74		54	36	6	3	1			
	8-4, 75-76	244	100	82	11	62	15	10	2				
	8-5, 55-56	245	0	—									
		8, CC, 6-7	248	300	72	16	40	27	10	5	2		

*Vallacerta*) that have complex reticulate networks of intersecting ridges. Through the use of scanning and transmission electron microscopy (SEM and TEM), the junctions between the linear ridges were shown to be elevated into peaks (Bachmann and Keck, 1969; Jerković, 1969; Mandra and Mandra, 1971; McPherson and Ling, 1973; Wornardt, 1971). These studies also showed that the reticulation was not necessarily constant over the whole surface; instead, some areas had long subparallel ridges (Bachmann and Keck, 1969). Mandra and Mandra (1972) found specimens of *Distephanus* with smooth surfaces. Finally, Martini and Müller (1976) conducted a comprehensive description and analysis of the occurrence of surface textures in silicoflagellates using SEM. They described several major patterns that we have adopted with some modifications in this study. We have classified the patterns into general categories for whole skeleton and separate categories for various areas of the skeleton such as basal ring, apical structures, spines, and pikes. The terminology for the general whole skeleton patterns includes combinations of the following terms which can describe particular areas: crenulate (C), linear (L), nodular (N), reticulate (R), and smooth (S).

To systematically describe the surface texture variation on an individual skeleton the following subsection sequence is used: apical structure/basal ring/spine. There-

fore, an individual skeleton can have its complete surface texture characterized for these three areas as reticulate (R)/linear (L)/linear (L), or simply R/L/L. If the distal and proximal surfaces had different textures then the proximal texture could be cited in parentheses: R/R(L)/L. The surface textures on proximal (abapical) surfaces are typically fainter than on distal (apical) surfaces because of lower relief. For example, see the reticulate texture illustrated for *Corbisema dissymmetrica communis* (as *C. naviculoidea*) by Perch-Nielsen (1976) and the contrast in apical ring textures for *Distephanus crux* (as *Dictyochoa crux*) by Bachmann and Keck (1969). The inequant (i) form of the reticulate pattern with interpeak ridges of disparate lengths could be added when needed: R/Ri(L)/L. A simple dash means that information is not available. Although such a system may be overdetailed, it provides the opportunity for more specific comparisons of structures from different ages and regions.

Definition of the descriptive terms are as follows:

1. *Crenulate* (C). Long subparallel ridges are interrupted by peaks that are aligned to form rows perpendicular to ridge axes. At low magnification these rows resemble periodic crenulations. This is a typical surface texture of *Mesocena diodon nodosa* (Plate 9, Figs. 1-3).

2. *Linear* (L). Long subparallel ridges which are not, or very rarely, interrupted by peaks. The ridges are sub-

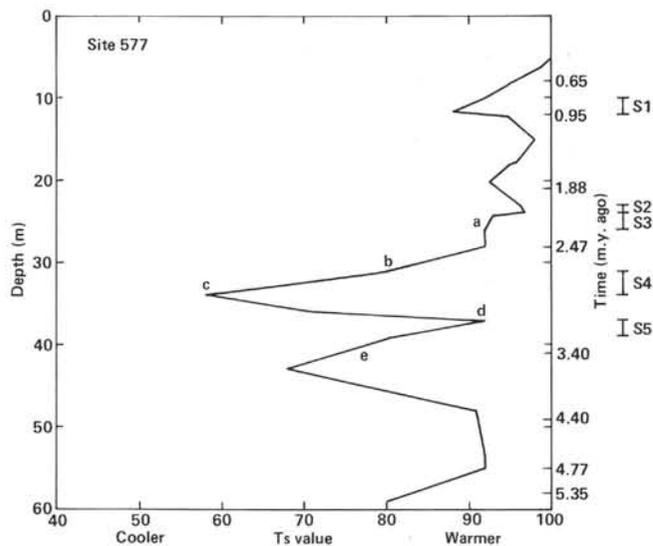


Figure 3. Silicoflagellate relative paleotemperature curve for Site 577 samples. The chronology is based on paleomagnetic correlation (Monechi, this volume). Silicoflagellate data for the curve are available in Table 1. Useful silicoflagellate events include: S1 = Acme of *Mesocena quadrangula*. S2 = Last *Dicytocha flexatella*. S3 = Last common *M. circulus*. S4 = Last common *D. brevispina*. S5 = First *D. stapedia*. The reference points (a to e) are selected correlation points between Leg 86 sites:

- a = Disappearance of *M. circulus*, near 2.4 m.y. ago, is associated with a cooling event in Holes 580 and 579A, which is not observed at southern Site 577.
- b = A warming event, near 2.6 m.y. ago, is observed in Holes 580 and 579A, but is not observed at Site 577.
- c = A distinct cooling event, between 2.6 and 3.0 m.y. ago, is associated with the last common *D. brevispina* at Holes 580 and 579A.
- d = A warm peak, between about 3.0 to 3.3 m.y. ago, occurs at Holes 580, 579A, and 577.
- e = Part of a distinct warming trend near 3.4 m.y. ago which is least intense ( $T_s = 50$ ) in northern Hole 580, moderate ( $T_s = 62$ ) in intermediate Hole 579A, and most intense ( $T_s = 77$ ) in southern Hole 577.

parallel to the rod axes. For example, see *Distephanus speculum* and *Caryocha ernestinae* in Martini and Müller (1976, plate 6, figs. 1–4).

3. *Nodular* (N). Nodular swellings, or rounded protuberances arising from a smooth rod occur in several taxa of *Distephanus*, especially on the apical structure (Plate 8, Fig. 1).

4. *Reticulate* (R). A network of intersecting ridges that may form peaks at their junctions. Hexagonal arrays occur where peaks are most numerous, such as on apical structures. Pentagonal and triangular arrays also occur. The vertical relief of the ridges and peaks is variable. Martini and Müller (1976) showed that inequant long and short ridge lengths occurred in *Dicytocha pentagona* and *D. sp. cf. D. fibula*. Regular reticulate texture with nearly equant ridges occurs in *M. apiculata apiculata*, *Corbisema apiculata*, and *D. challengerii*.

5. *Smooth* (S). Uniform finely granular surfaces with no nodes, peaks, or ridges are classified as smooth. Mandra and Mandra (1972) showed specimens of binocular *Distephanus* with nodular spines and apical structures, but featureless basal rings. Etching or inhibited ridge formation could account for some smooth rods.

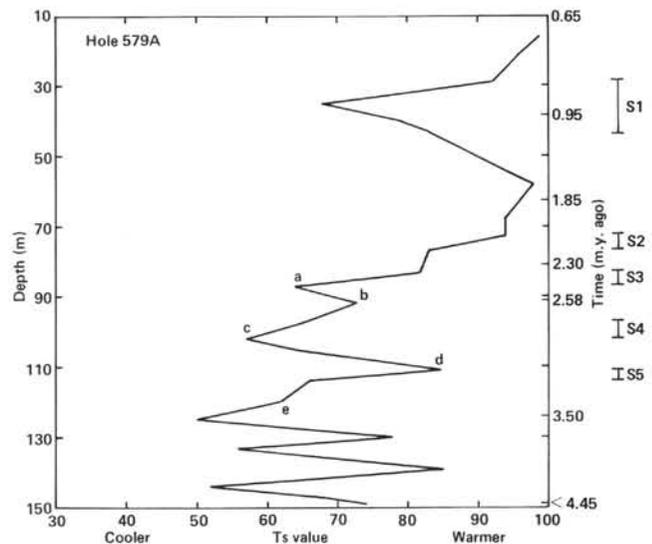


Figure 4. Silicoflagellate relative paleotemperature curve for Hole 579A samples. The chronology is based on diatom and paleomagnetic correlation (Koizumi and Tanimura, this volume). Silicoflagellate data for the curve are available in Table 2. Useful silicoflagellate events include those cited in Figure 3.

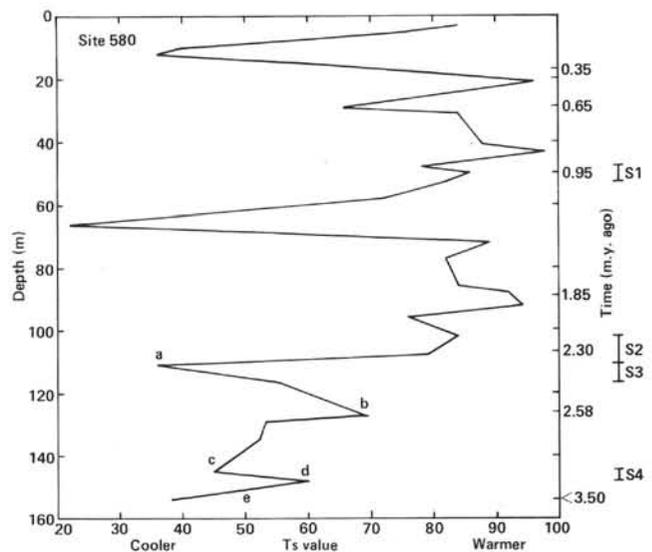


Figure 5. Silicoflagellate relative paleotemperature curve for Hole 580 samples. The chronology is based on diatom and paleomagnetic correlation (Koizumi and Tanimura, this volume). Silicoflagellate data for the curve are available in Table 3. Useful silicoflagellate events (S1 to S4) are described in Figure 3. Reference points (a to e) are described in Figure 3.

Like the larger apical structures and basal rings, the generally smaller spines and pikes can also have noteworthy surface texture. Dumitrică (1973, plate 1, fig. 6) showed clusters of small points at the ends of the spines on *M. quadrangula*. Our studies have shown similar clusters in *Dicytocha* on spines and pikes (Plate 7), but not on *Distephanus*. But specimens of *M. circulus* from Leg 86 have a large well-organized rosette termination to the spines (Plate 10). Rosette spine or pike terminations and other simpler patterns might yield additional insight into silicoflagellate paleoenvironmental responses or evo-

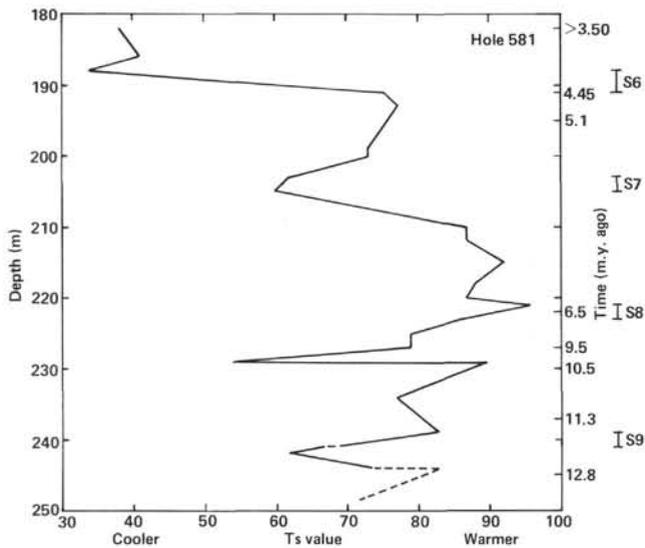


Figure 6. Silicoflagellate relative paleotemperature curve for Hole 581 samples. The chronology is based on diatom and paleomagnetic correlation; see Barron (1980, 1981) and Koizumi and Tanimura (this volume). Silicoflagellate data for the curve are available in Table 4. Useful silicoflagellate events include: S6 = First *Distephanus jimlingii*. S7 = Acme of *D. quinquangellus*. S8 = First *Dictyocha neonautica*. S9 = Last *Mesocena hexalitha*. Dashed parts of curve indicate a degree of uncertainty.

Table 5. Ts relative paleotemperature values for correlative events at Leg 86 holes show latitudinal gradients in the Northwest Pacific Basin for the Pliocene.

Events	Hole (latitude)		
	580 (41°37'N)	579A (38°38'N)	577 (32°27'N)
a	36	64	92
b	69	73	80
c	45	57	58
d	60	85	92
e	50	62	77

Note: See Figure 3 for identification of the events.

lutionary lineages. Stadum and Burckle (1973) suggested that the rosettes formed in nutrient enriched waters and smooth spines in less enriched waters.

To help to interpret the surface textures determined for Leg 86 specimens, a survey of published SEM and TEM illustrations of silicoflagellates was made. Most illustrations lack the resolution needed to identify surface structures, but a few can be characterized for comparisons. For example, an illustration of *Distephanus* (like *D. speculum*) from the late Eocene of New Zealand (Mandra et al., 1973) shows a reticulate/linear/linear (R/L/L) pattern on distal surfaces. This contrasts with the *D. speculum* from the late Miocene of Spain (Berggren et al., 1976), which show a nodular(smooth)/linear(linear)/linear(linear) [N(S)/L(L)/L(L)] pattern. It also differs from our Pliocene specimen (Plate 5, Figs. 1, 2) and late Miocene specimens from California (Worwardt, 1971) which are basically smooth (S) with minor

nodules on apical and basal surfaces. Several explanations are possible for the differences: (1) temperature and nutrient levels affect surface texture; (2) dissolution and diagenesis can reduce or alter textures, such as reticulate to nodular or linear to smooth; (3) textures may trace polyphyletic origins of long-ranged taxa; (4) SEM metal-coating techniques may vary (we used gold coating with a maximum thickness less than 200 Å which would not alter surface patterns).

Differential dissolution between specimens in the same sample is suggested by comparing two specimens of *Dictyocha deflandrei completa* from Perch-Nielsen (1975b, plate 15, figs. 5 and 6). Reticulate texture is sharply defined on one specimen on the apical structure and down onto the adjoining basal ring area. The second specimen shows no definitive major textures and is more coarsely granular. Inspection of the basal ring adjoining the apical struts does reveal a remnant reticulate pattern, which implies dissolution because the apical structure generally has the highest relief texture. Similar dissolution evidence is suggested by our specimens of *M. quadrangula* (Plate 12) because the typical crenulate texture of long ridges with peaks aligned in rows is not seen in the enlargement of Plate 12, Figure 2. Instead, the rows of peaks remain, but the ridges are missing. Low- and moderate-ridged specimens are recorded on Plates 11 and 12.

Texture-pattern summaries for the most definitive published illustrations are summarized according to genus and age (Table 6). Preliminary determinations based on that information and on the Leg 86 results (Table 7 and Plates 1-17) help to confirm and expand certain observations.

Reticulate spines have only rarely been recorded (see Bukry, 1976c; Mandra and Mandra, 1971; and Martini and Müller, 1976). Although the taxa having this structure belong to several genera, they are all from Eocene strata, and no reticulate spined specimens are recorded from the Neogene. Spines on younger taxa are smooth, nodular, or linear.

Nodular spines are mainly recorded in hexagonal *Distephanus*, a cold-water indicator in the late Cenozoic. Dissolution of the crenulate or reticulate texture, as in *Mesocena diodon nodosa* or some *Dictyocha brevispina* might produce a remnant nodular pattern, but the general restriction to *Distephanus* suggests nodular spines are probably a cold indicator. If this assumption is extended to the Cretaceous genus *Vallacerta*, then *V. sidera* from the Arctic Ocean (McPherson and Ling, 1973), with apparently nodular spines, should represent a colder species than coeval *V. hortonii* with linear spines from lower latitudes. It is difficult to assess smooth spines because of uncertainty over diagenetic alterations. Linear spines are most typical in the Leg 86 assemblages.

Abapical surfaces are predominated by linear or by smooth textures. If the smooth texture is dismissed as partly (on basal ring and spine) a dissolution product, then the linear texture dominates abapical surfaces through time and space. The apical surfaces of the basal ring, especially toward the outer diameter and the strut junctions, are areas where the structurally more com-

Table 6. Summary of published silicoflagellate surface textures arranged by genus and age.

Taxon, textures	Reference	Age	Locality
<i>Caryocha</i>			
<i>C. depressa</i> , Ri/-/L	1	Miocene	California
<i>C. ernestinae</i> , L-Ri/L/L	1	Miocene	California
<i>C. ernestinae</i> , L/L/L	13	Miocene	Norwegian Sea
<i>Corbisema</i>			
<i>C. hastata</i> , R/?R/-	13	Eocene	Norwegian Sea
<i>C. triacantha</i> , R(S)/L-R(L)/L(L-R)	13	Eocene	Norwegian Sea
<i>C. apiculata</i> , (S)/(R)/-	13	Reworked	Norwegian Sea
<i>C. apiculata</i> , R/-/-	13	Eocene	Norwegian Sea
<i>C. sp.</i> , R/L/-	6	Eocene	New Zealand
<i>C. disymmetrica communis</i> , R/R/-	14	Paleocene or Eocene	Denmark
<i>C. geometrica</i> , S/S/-	7	Cretaceous	California
<i>Deflandryocha</i>			
<i>D. cymbiformis</i> , L/L/-	2	Miocene	Yugoslavia
<i>Dictyocha</i>			
<i>D. brevispina</i> , N/N/N	5	Miocene	Mexico
<i>D. brevispina</i> , -/L/L	5	Miocene	Mexico
<i>D. fibula</i> (s. ampl.), R/R/L	4	Miocene	California
<i>D. pulchella</i> , -/L/L	12	Miocene	Spain
<i>D. deflandrei completa</i> , (S)/(L)/(L)	10	Oligocene	Tasman Sea
<i>D. deflandrei completa</i> , R(S)/L(L)/L(L)	10	Oligocene	Tasman Sea
<i>Distephanus</i>			
<i>D. jimlingii</i> , N/-/-	13	Pliocene	Norwegian Sea
<i>D. pseudofibula</i> , N/S/S	8	Pliocene	Japan
<i>D. speculum speculum</i> , N/S/S	13	Pliocene	Norwegian Sea
<i>D. crux</i> , R(S)/L(L)/L(L)	1	Miocene	California
<i>D. crux</i> , (S)/(L)/(L)	12	Miocene	Spain
<i>D. schaumislandii</i> , R/R/-	2	Miocene	Yugoslavia
<i>D. quinquangellus</i> , N/S/S	13	Miocene	Norwegian Sea
<i>D. speculum binoculus</i> , N/S/N	5	Miocene	California
<i>D. speculum binoculus</i> , S/S/S	5	Miocene	California
<i>D. speculum speculum</i> , R-N/L/L	13	Miocene	Norwegian Sea
<i>D. speculum speculum</i> , N/S/S	12	Miocene	Spain
<i>D. speculum speculum</i> , N/L/L	12	Miocene	Spain
<i>D. speculum speculum</i> , (S)/(L)/(L)	12	Miocene	Spain
<i>D. speculum speculum</i> , S/S/S	4	Miocene	California
<i>D. speculum triommata</i> , S/S/S	5	Miocene	California
<i>D. stradneri</i> , -/L/L	2	Miocene	Yugoslavia
<i>D. crux</i> , (S)/(L)/(L)	10	Oligocene	Tasman Sea
<i>D. norwegiensis</i> , N/S/S	14	Eocene	Norwegian Sea
<i>D. rosae</i> , (S)/(L)/(L)	14	Eocene	Norwegian Sea
<i>D. sp.</i> (like <i>D. speculum</i> ), R/L/L	6	Eocene	New Zealand
<i>Lynamula</i>			
<i>L. sp.</i> , -/R/R	9	Cretaceous	Southwest Pacific
<i>L. sp.</i> , -/S/S	9	Cretaceous	Southwest Pacific
<i>Mesocena</i>			
<i>M. diodon nodosa</i> , -/C/L	13	Miocene	Norwegian Sea
<i>M. quadrangula</i> , -/C/L	13	Miocene	Norwegian Sea
<i>M. quadrangula</i> , -/C/L	13	Miocene	Norwegian Sea
<i>M. apiculata apiculata</i> , -/R/R	13	Eocene	Norwegian Sea
<i>M. oamaruensis</i> , -/R/R	3	Eocene	New Zealand
<i>Naviculopsis</i>			
<i>N. lata</i> , ?N/N/-	13	Miocene	Norwegian Sea
<i>N. punctilia</i> , R/-/-	13	Eocene	Norwegian Sea
<i>N. foliacea</i> , ?S(S)/S(S)/S(S)	14	Eocene	Norwegian Sea
<i>N. aspera</i> , N(S)/N(N)/N(N)	14	Paleocene/Eocene	Denmark
<i>N. constricta</i> , N(S)/S(S)/S(S)	14	Paleocene/Eocene	Denmark
<i>N. minor</i> , N(S)/S(S)/S(S)	14	Paleocene/Eocene	Denmark
<i>Vallacerta</i>			
<i>V. hortonii</i> , R/L/L	7	Cretaceous	California
<i>V. siderea</i> , Ri/L/N?	7	Cretaceous	Arctic Ocean
<i>V. tumidula</i> , S&R/-/-	11	Cretaceous	Southwest Pacific

Note: The texture code is defined in text; the sequence describes: apical structure/basal ring/spine. Reference code is as follows: (1) Bachmann and Keck, 1969; (2) Jerković, 1969; (3) Mandra and Mandra, 1971; (4) Wornardt, 1971; (5) Mandra and Mandra, 1972; (6) Mandra et al., 1973; (7) McPherson and Ling, 1973; (8) Uchio, 1974; (9) Hajós, 1975; (10) Perch-Nielsen, 1975b; (11) Perch-Nielsen, 1975a; (12) Berggren et al., 1976; (13) Martini and Müller, 1976; (14) Perch-Nielsen, 1976.

plex reticulate texture tends to develop. But reticulate structures are most prominent on apical structures in the genera *Corbisema*, *Dictyocha*, and *Vallacerta*. The occurrence of reticulate texture on the apical structure of *Caryocha depressa* (for example, Bachmann and Keck, 1969) prove it to be a silicoflagellate and also help to

demonstrate that more hexagonal species with subdivided apical rings should not be classified there (see Bukry and Foster, 1973, and Mandra and Mandra, 1972).

Nodular apical structures are recorded from Eocene high-latitude *Naviculopsis* (Perch-Nielsen, 1976) and for cool-water Neogene *Distephanus*, suggesting that fur-

Table 7. Summary of Leg 86 surface textures arranged alphabetically by genus.

Taxon, textures	Plate	Age	Hole
<i>Dictyochoa</i>			
<i>D. aspera</i> , L/L/L	2	Plio-Pleistocene	579A
<i>D. brevispina</i> , (S)/(N)/(S)*	3	Miocene	581
<i>D. brevispina</i> , C/C/L	4	Pliocene	579A
<i>D. brevispina</i> , (S)/(L)/(L)	4	Pliocene	577
<i>D. brevispina</i> , (-)/(C)/(L)*	4	Pliocene	577
<i>D. brevispina</i> , C/C/C	5	Pliocene	579A
<i>D. brevispina</i> , -/R/L	5	?Miocene	579A
<i>D. brevispina</i> , C/C/-	5	Pliocene	579A
<i>D. calida ampliata</i> , N/N/S	6	Pleistocene	579A
<i>D. sp. cf. D. concinna</i> , L/L/L	1	Pliocene	579A
<i>D. flexatella</i> , R/R/L	13	Pliocene	572A
<i>D. flexatella</i> , N/N/L	14	Pliocene	579A
<i>D. hessii</i> , (S)/(S)/(S)	3	Pleistocene	581
<i>D. lingii</i> , S/N/S	3	Pleistocene	581
<i>D. sp. cf. D. longa</i> , (S)/(L)/(L)	2	Miocene	581
<i>D. perlaevis</i> , N/N/S*	7	Pleistocene	579A
<i>D. perlaevis</i> , (S)/(S)/(S)*	7	Cenozoic	581
<i>D. subarcticus</i> , (S)/(L)/(L)*	1	Pleistocene	581
<i>D. spp.</i> , N/N/S	2	Plio-Pleistocene	579A
<i>Distephanus</i>			
<i>D. crux</i> , R/L/L	8	Miocene	581
<i>D. sp. cf. D. floridus</i> , S/S/S	5	Pleistocene	581
<i>D. jimlingii s. ampl.</i> , N/N/N	8	Pliocene	579A
<i>D. pseudofibula</i> , S/S/S	15	Pliocene	579A
<i>D. quinquangellus</i> , N/S/S	15	Miocene	581
<i>D. speculum minutus</i> , (N)/(N)/(S)	8	Pliocene	579A
<i>D. speculum speculum</i> , S/S/S	5	Pliocene	579A
<i>Mesocena</i>			
<i>M. circulus</i> , -/N/S*	10	Pliocene	579A
<i>M. circulus</i> , -/S/S*	10	Miocene	581
<i>M. diodon nodosa</i> , -/C/L	9	Miocene	581
<i>M. hexalitha</i> , -/R?/L	9	Miocene	581
<i>M. quadrangula</i> , -/C/L	11	Miocene	579A
<i>M. quadrangula</i> , -/C/L	11	Pliocene	580
<i>M. quadrangula</i> , -/C/S*	12	Pleistocene	577

Note: The texture code is defined in text; the sequence describes: apical structure/basal ring/spine. \* = star-shaped spine terminations.

ther analysis of surface textures will improve the paleoecologic utility of silicoflagellates.

Martini and Müller (1976) observed that surface textures may have higher relief in colder areas. However, the lack of sufficient comparative materials from different latitudes and the unsolved problems of dissolution limit the interpretations that are possible. For example, we find that specimens showing smooth textures often have an especially coarse surface granularity, which because of sometimes surprising wall thickness (Plate 9, Fig. 7; Mandra and Mandra, 1972, fig. 26) can imply that the original surface textures could be dissolved without damaging the underlying rod structure. Diagenesis or dehydration of the opaline skeletal rods by sediment pore waters could cause surface granularity. Some granularity might also be produced during metal-coating preparation for SEM.

Analysis of the data from Tables 6 and 7 shows perfect matches of surface textures between Leg 86 and the world literature for Miocene *D. crux* (R/L/L), *D. quinquangellus* (N/S/S), *M. diodon nodosa* (-/C/L), and *M. quadrangula* (-/C/L). Two other near matches are indicated for Pliocene *D. pseudofibula* and *D. speculum spe-*

*culum*. Aside from the typical association of the crenulate texture with cool intervals at Leg 86, there is no marked allocation of textures between cool and warm fluctuations.

The most marked contrast between the texture compilations for Leg 86 and the world literature is in the occurrence of the reticulate texture. In Leg 86 material, reticulate surfaces are very sparse, occurring only in *Dictyochoa flexatella*, *Distephanus crux*, and *M. hexalitha*. There are a higher number of nodular-textured specimens in Leg 86 material than in the previously illustrated assemblages. These two relationships could be accounted for by differential preservation of surface peaks instead of ridges, which would make the reticulate texture appear to be nodular. Either way, there appears to have been a decline in the reticulate texture through time. The world literature compilation (Table 6) shows reticulate textures were typical in the dominant Cretaceous genera *Lyrarmula* and *Vallacerta*, and even more pervasive in early Cenozoic *Corbisema*. In this same vein, Eocene *M. apiculata apiculata* and *M. oamaruensis* are wholly reticulate, but Miocene to Pleistocene *Mesocena* do not have reticulate texture. Whereas preservation may have skewed our limited data, the Leg 86 results indicate that reticulate texture has declined during the late Cenozoic (Table 8). The younger *Mesocena* often exhibit the crenulate texture, which could have developed from the reticulate texture. Sufficiently detailed and organized study of modern silicoflagellate textures to establish the range of structures and their geographic distribution has not been done.

As part of the examination of possible temperature-dependent variation in surface texture, late Pliocene specimens of *Dictyochoa flexatella* from Leg 86 (Plate 14) were compared to tropical specimens from Leg 85 (Plate 13). The tropical specimens are narrower and have greater disparity in minor to major spine length, but surface textures on both are sparse. Very faint reticulate texture characterizes the apical and basal rings of tropical forms (R/R/L). High latitude specimens have nodular apical structures and some specimens have nodular basal rings, whereas others have a very faint linear pattern, which

Table 8. Summary of the average surface textures for silicoflagellate genera derived from compilations in Tables 6 and 7 for the available literature and for Leg 86.

Genus	Literature average texture	Leg 86 average texture
<i>Caryocha</i>	L-Ri/L/L	—
<i>Corbisema</i>	R/R-L/L	—
<i>Deflandryocha</i>	L/L/-	—
<i>Dictyochoa</i>	R/L-R/L	N-C/N/L-S
<i>Distephanus</i>	N/L-S/L-S	S-N/S/S
<i>Lyrarmula</i>	-/R/R	—
<i>Mesocena</i> , Neogene	-/C/L	-/C/L
<i>Mesocena</i> , Paleogene	-/R/R	—
<i>Naviculopsis</i> , Paleogene	N/S/S	—
<i>Vallacerta</i>	R/L/L	—

could be a residual reticulate pattern, because the rod-parallel linear ridges may be more robust than the intersecting ridges (see Jerković, 1969, plate 9, fig. 1).

Other comparisons of possible temperature-dependent texture for Leg 86 include:

1. *Dictyochoa*. The surface texture of *Dictyochoa* is slightly more marked in cooler intervals. For example, warm conditions produced specimens with smooth to slightly noded texture, whereas cooler conditions produced a more heavily noded specimen (Plate 6). A similar contrast in the higher frequency of nodes and peaks on cool specimens is illustrated by *Dictyochoa* spp. (contrast Plate 2, Fig. 7 with Fig. 9). Higher relief texture for cool intervals is also shown by *Dictyochoa* sp. cf. *D. concinna* (Plate 1, Figs. 7–9).

2. *Dictyochoa brevispina*. There is no particular difference in texture between Miocene and Pliocene specimens. All *D. brevispina* have similar crenulate texture on the apical structure and basal ring. This texture can be very faint or very marked, and does not seem to be related to warm or cold conditions in Leg 86 assemblages (Plate 4, Figs. 1–3, 6–9; Plate 5, Figs. 4–9).

3. *Dictyochoa perlaevis*. There are no differences in the texture between Miocene and Pliocene specimens and between warm and cool conditions for Leg 86 (Plate 7, Figs. 1–5, 7, 8). Star-shaped, rosette spine terminations can occur in this species, as well as *Dictyochoa brevispina*.

4. *Distephanus*. A wide variety of textures were observed in *Distephanus* including smooth (Plate 5, Figs. 1–3), nodular (Plate 8, Figs. 1–3), reticulate, and linear (Plate 8, Figs. 7–9). No temperature-dependent trend in textures was established for Leg 86. Comparison of higher and lower latitude coeval assemblages is needed. Hexagonal specimens from Leg 86 lack the reticulate texture seen in quadrate specimens (Plate 8). This may be a significant change from the Paleogene, where some hexagonal specimens have reticulate texture (e.g., Mandra et al., 1973).

5. *Mesocena*. Crenulate and smooth structures characterize the Leg 86 specimens.

6. *Mesocena quadrangula*. Pleistocene (warm) specimens show modified crenulate texture with reduced ridges (Plate 12, Fig. 2). The spines may taper to simple points or rosette terminations (Plate 12, Fig. 5; also Dumitrică (1973, plate 1, fig. 6). Although Dumitrică (1973, plate 3, fig. 4) illustrated an *M. quadrangula* having reticulate texture, we found only crenulate texture, reduced crenulate texture, or smooth textures for Leg 86 (Plate 11).

7. *Mesocena circulus*. Leg 86 specimens are smooth or slightly nodular with two kinds of spines—blunt and rosette. Both spine types were found in the Miocene and Pliocene and warm and cool intervals.

8. *Mesocena diodon nodosa*. The degree of relief varies, but all specimens observed have crenulate texture which may approach the regularity of the verticillate pattern of some sponge spicules (see Bukry, 1978, plate 5, fig. 15; plate 13, fig. 9).

9. *Mesocena hexalitha*. This species occurred only at a cold, middle Miocene interval of Leg 86. *M. hexalitha* has a faint reticulate texture (Plate 9, Figs. 5, 7) and

possibly(?) a very faint crenulate variation (Plate 7, Figs. 6, 9).

## NEW SILICOFLAGELLATE NOMENCLATURE

### Genus *CARYOCHA* Bukry et Monechi, n. gen.

**Type species.** *Halicalyptra depressa* Ehrenberg, 1854. Junior synonym: *Cannopilus sphaericus* Gemeinhardt, 1931.

**Description.** Silicoflagellates that have globular form, many apical portals, and nearly equant basal spines are classified in genus *Caryocha* Bukry et Monechi. The rounded apical structure is at least as high as the basal ring is wide and may have spires in some species. The apical structure pattern is well integrated with the basal ring. Although the apical portals are generally larger above the basal ring, they are generally rounded instead of polygonal. The basal ring is polygonal to round, but radially symmetric with little or no elongation. The diameter of the basal ring is equal to, or less than, the diameter of the apical structure. Basal spines are short to moderate in length and tilt down out of the plane of the basal ring.

**Remarks.** The species of globular silicoflagellates now classified in genus *Caryocha* Bukry et Monechi were previously assigned to either genus *Cannopilus* Haeckel or genus *Halicalyptra* Ehrenberg. Locker (1974), during a restudy of Ehrenberg material, found *Halicalyptra* and the proper type specimens to be radiolarians. But *Halicalyptra depressa* was found to be a silicoflagellate. The type species of *Cannopilus* has a fairly flat rosette of seven portals elevated by struts above a hexagonal basal ring with axially elongate spines that do not tilt down out of the plane of the basal ring. These are characteristics typically contained in genus *Distephanus* Stöhr. Because the type species of *Cannopilus* is more readily classified in genus *Distephanus* as *Distephanus speculum hemisphaericus* (Ehrenberg), than with silicoflagellates having globular apical structures, the new genus *Caryocha* is proposed for a more circumscribed classification. Silicoflagellate surface textures were demonstrated to occur on these globular forms by Bachmann and Keck (1969) and Martini and Müller (1976).

A case could be made for recognizing all three genera: *Distephanus*, *Caryocha*, and *Cannopilus*. But the phenotypic array of forms with subdivided rings (from 2 to 3 to 4, and more portals) within the same sample and species of *Distephanus* leads us to continue to include nonglobular specimens of *Cannopilus* in *Distephanus*.

### *Caryocha depressa* (Ehrenberg) Bukry et Monechi, n. comb.

*Halicalyptra depressa* Ehrenberg, 1854, pl. 18, fig. 111.

*Cannopilus sphaericus* Gemeinhardt, 1931, p. 105, pl. 10, figs. 3, 4. *Cannopilus sphaericus*, in Bachmann and Keck, 1969, p. 205, pl. 2, upper left.

*Cannopilus depressus* (Ehrenberg) Locker, 1974, p. 639, pl. 4, fig. 3. *Cannopilus depressus* (Ehrenberg), Martini and Müller, 1976, p. 868, pl. 3, figs. 11, 12.

### *Caryocha ernestinae* (Bachmann) Bukry et Monechi, n. comb.

*Cannopilus ernestinae* Bachmann, 1962, p. 255, fig. 1.

*Cannopilus ernestinae*, in Bachmann and Keck, 1969, p. 205.

*Cannopilus ernestinae* Bachmann, Bukry, 1976b, p. 696, pl. 1, figs. 1–6.

*Cannopilus ernestinae* Bachmann, Martini and Müller, 1976, p. 869, pl. 3, figs. 8–10; pl. 6, figs. 2–4; pl. 9, figs. 6, 7.

### *Caryocha ichikawai* (Bachmann) Bukry et Monechi, n. comb.

*Cannopilus ichikawai* Bachmann in Ichikawa et al., 1964, p. 110, pl. 6, figs. 59–61.

### *Caryocha jouseae* (Bachmann) Bukry et Monechi, n. comb.

*Cannopilus jouseae* Bachmann in Ichikawa et al., 1964, p. 109, pl. 6, figs. 54–58; figs. 1, 3–4.

### *Caryocha latifenestrata* (Bachmann) Bukry et Monechi, n. comb.

*Cannopilus latifenestratus* Bachmann in Ichikawa et al., 1964, p. 111, pl. 6, figs. 62–64.

### *Caryocha picasso* (Stradner) Bukry et Monechi, n. comb.

*Cannopilus picasso* Stradner, 1961, p. 92, pl. 3, figs. 101–104.

Genus *DISTEPHANUS* Stöhr, 1880*Distephanus paradistephanus* (Tsumura) Bukry et Monechi, n. comb.*Dictyocha paradistephanus* Tsumura, 1963, p. 57, pl. 11, figs. 6, 7; pl. 24, figs. 6, 7.

## OTHER TAXA CITED

*Corbisema apiculata* (Lemmermann) Hanna  
*C. dissymmetrica communis* Bukry  
*C. geometrica* Hanna  
*C. hastata* (Lemmermann) Frenguelli  
*C. naviculoidea* (Frenguelli) Perch-Nielsen (invalid basionym)  
*C. triacantha* (Ehrenberg) Hanna  
*Deflandryocha cymbiformis* Jerković  
*Dictyocha aculeata* (Lemmermann) Dumitrică  
*D. aspera aspera* (Lemmermann) Frenguelli  
*D. aspera clinata* Bukry  
*D. brevispina* (Lemmermann) Bukry  
*D. calida ampliata* Bukry  
*D. challengerii* Martini et Müller  
*D. concinna* Bukry  
*D. deflandrei completa* (Glezer) Bukry  
*D. fibula* Ehrenberg  
*D. flexatella* (Bukry) Bukry  
*D. hessii* Bukry  
*D. lingii* Dumitrică  
*D. longa* Bukry  
*D. neonautica* Bukry  
*D. ornata ornata* (Bukry) Bukry  
*D. ornata africana* Bukry  
*D. perlaevis* Frenguelli  
*D. pulchella* Bukry  
*D. stapedia stapedia* Haeckel  
*D. subarctios* Ling  
*Distephanus crux* (Ehrenberg)  
*D. floridus* Bukry  
*D. jimlingii* (Bukry) Bukry  
*D. norvegiensis* Perch-Nielsen  
*D. pseudofibula* (Schulz) Bukry  
*D. quinquangellus* Bukry et Foster  
*D. rosae* Perch-Nielsen  
*D. schauinslandii* Lemmermann  
*D. speculum binoculus* (Ehrenberg) Bukry  
*D. speculum hemisphaericus* (Ehrenberg) Bukry  
*D. speculum minutus* Bachmann, emend. Bukry  
*D. speculum speculum* (Ehrenberg) Haeckel  
*D. speculum triommata* (Ehrenberg) Bukry  
*D. stradneri* (Jerković) Bukry  
*Mesocena apiculata apiculata* (Schulz) Hanna  
*M. circulus* (Ehrenberg) Ehrenberg  
*M. diodon nodosa* Bukry  
*M. hexalitha* Bukry  
*M. oamaruensis* Schulz  
*M. quadrangula* Ehrenberg ex Haeckel  
*Naviculopsis aspera* (Schulz) Perch-Nielsen  
*N. constricta* (Schulz) emend. Bukry  
*N. foliacea* Deflandre  
*N. lata* (Deflandre) Frenguelli  
*N. minor* (Schulz) Bukry  
*N. punctilia* Perch-Nielsen  
*Octactis pulchra* Schiller  
*Vallacerta hortonii* Hanna  
*V. siderea* (Schulz) Bukry  
*V. tumidula* Glezer

## CONCLUSIONS

Quantitative relative paleotemperature values calculated for Leg 86 silicoflagellate assemblages show that a north-south gradient existed between Holes 577 and 580 during the Pliocene. A comparison between selected correlation events at the Leg 86 holes indicates a maximum difference between  $T_s = 92$  at Site 577 and  $T_s =$

36 at Site 580 occurred during the late Pliocene about 2.4 m.y. ago. The widely recorded warming across the Miocene/Pliocene boundary and the subsequent major cooling in the early Pliocene (about 3.9 to 4.4 m.y. ago) are indicated by the silicoflagellates at Site 581. Therefore, transoceanic paleotemperature events may be detected by relative paleotemperature values for Leg 86, but local gradients and fluctuations also appear to be significant.

The relationship of surface texture of silicoflagellates to relative paleotemperature values for Leg 86 is not clear-cut, but cool intervals appear to have specimens with high frequency and high relief texture. Cool-water indicator *Distephanus* (hexagonal) has either smooth or nodular texture in Leg 86 assemblages. No reticulate *Distephanus* (hexagonal) occur, and the reticulate texture is sparse in other taxa, too. Considerably more information on textures from living specimens and from a wider geographic range of fossils are needed to determine the usefulness of surface textures. Together with the DSDP Leg 38 analysis of surface textures from the Atlantic Ocean (Martini and Müller, 1976), the Leg 86 information for the Pacific Ocean should provide a useful step in understanding silicoflagellate textures.

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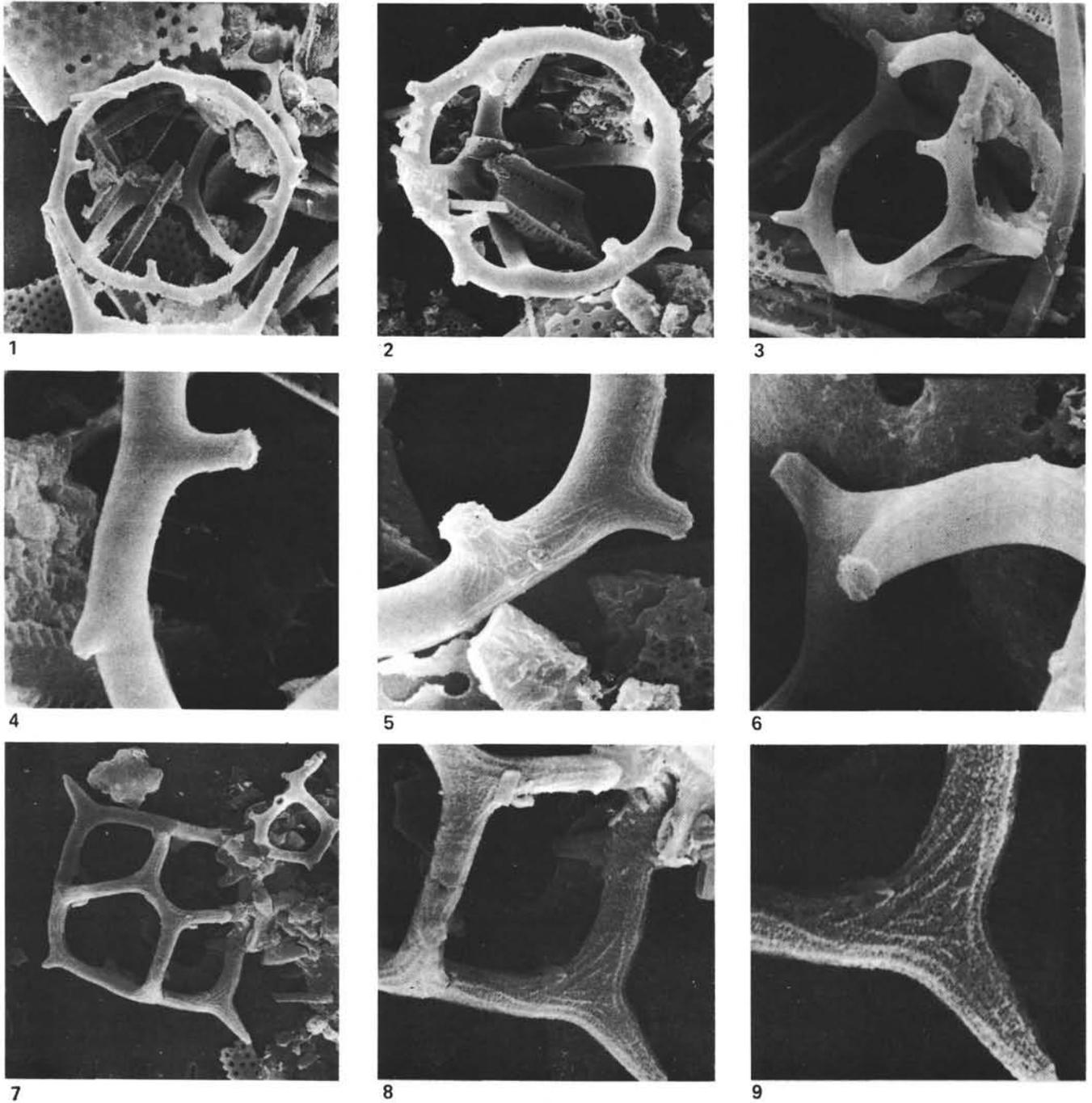


Plate 1. Silicoflagellates from DSDP Leg 86. 1-6. *Dictyocha subarctios* Ling. Sample 581-8, CC. Quaternary (cool). (1, 4)  $\times 960$  and  $\times 3600$ , negs. SM810-811. (2, 5)  $\times 1080$  and  $\times 3000$ , negs. SM890-891. (3, 6)  $\times 1440$  and  $\times 4200$ , negs. SM892-893. 7-9. *Dictyocha* sp. cf. *D. concinna* Bukry. Sample 579A-9-2, 40-42 cm. Late Pliocene (cool). (7)  $\times 1440$ , neg. SM784. (8)  $\times 3600$ , neg. SM785. (9)  $\times 6000$ , neg. SM786.

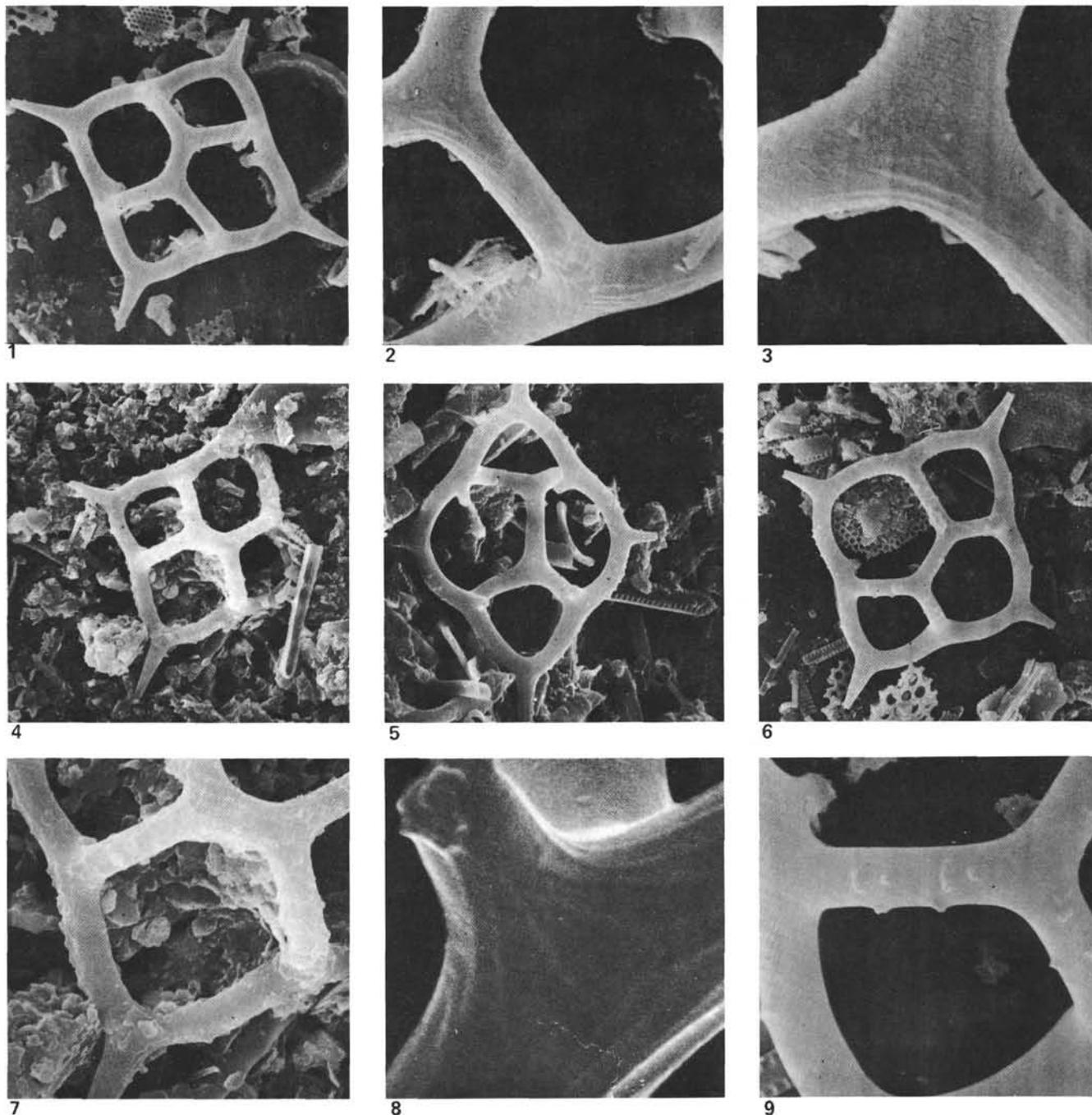


Plate 2. Silicoflagellates from DSDP Leg 86. 1-3. *Dictyocha aspera* (Lemmermann). Sample 579A-6, CC. Pliocene and Pleistocene (warm). (1)  $\times 1200$ , neg. SM757. (2)  $\times 4200$ , neg. SM758. (3)  $\times 7200$ , neg. SM759. 4, 6, 7, 9. *Dictyocha* spp. (4, 7) Sample 581-7-3, 30-31 cm. Late Miocene (cool). (4)  $\times 900$ , neg. SM717. (7)  $\times 1800$ , neg. SM718. (6, 9) Sample 579A-6, CC. Pliocene and Pleistocene (warm). (6)  $\times 980$ , neg. SM755. (9)  $\times 3500$ , neg. SM756. 5, 8. *Dictyocha* sp. cf. *D. longa* Bukry. Sample 581-3, CC. Late Miocene (cool). (5)  $\times 1200$ , neg. SM706. (8)  $\times 12,000$ , neg. SM707.

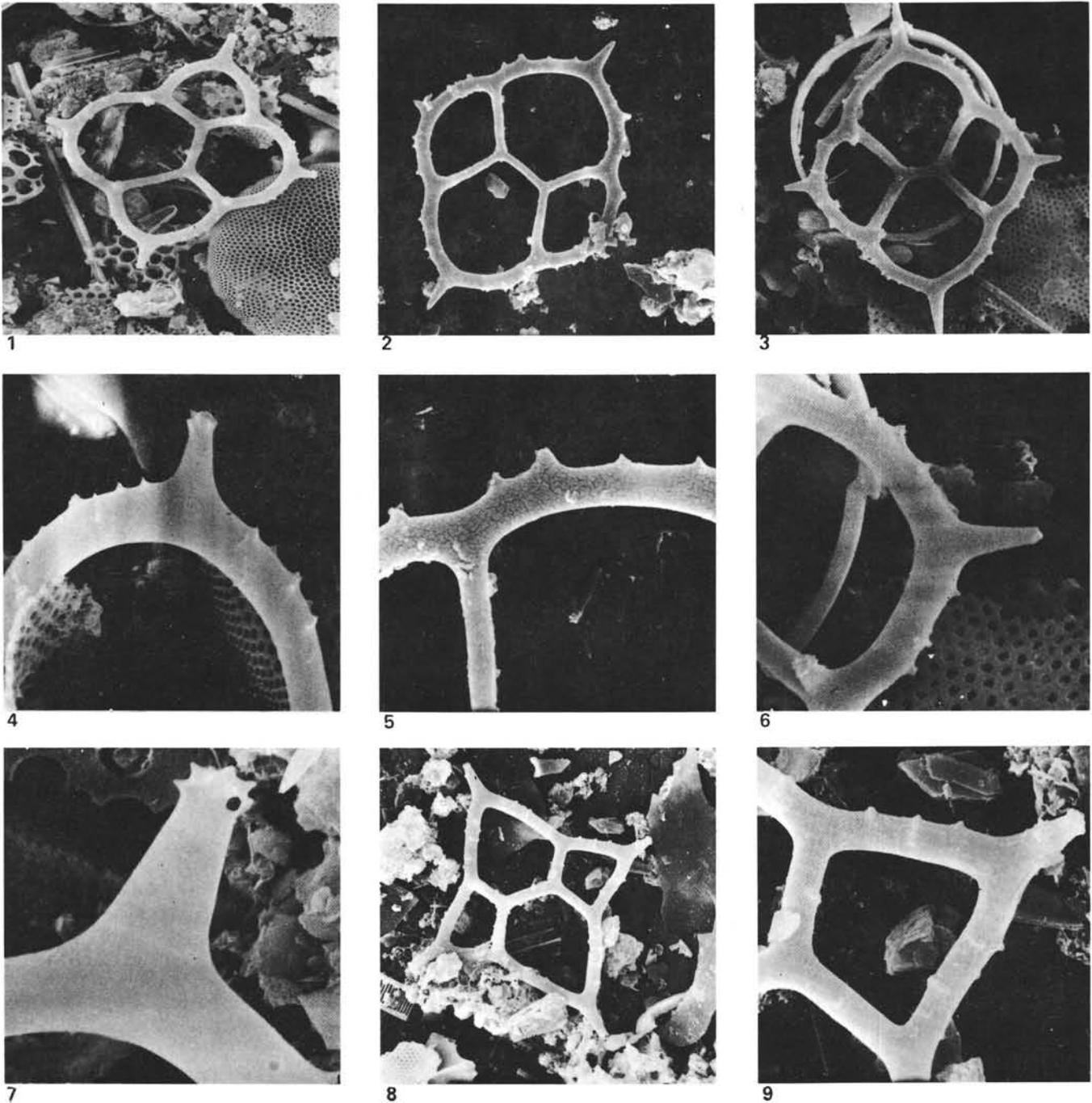


Plate 3. Silicoflagellates from DSDP Leg 86. 1, 4, 7. *Dictyocha brevispina* (Lemmermann). Sample 581-8, CC. Middle Miocene (cool). (1)  $\times 480$ , neg. SM806. (4)  $\times 1800$ , neg. SM809. (7)  $\times 3600$ , neg. SM807. 2, 5. *Dictyocha lingii* Dumitrica. Sample 579A-4, CC. Pleistocene (warm). (2)  $\times 1320$ , neg. SM885. (5)  $\times 3000$ , neg. SM886. 3, 6. *Dictyocha hessii* Bukry. Sample 581-8, CC. Quaternary (cool). (3)  $\times 1080$ , neg. SM896. (6)  $\times 3000$ , neg. SM897. 8, 9. *Dictyocha* sp. cf. *D. brevispina* (Lemmermann). Sample 579A-12, CC. Early Pliocene (cold). (8)  $\times 600$ , neg. SM776. (9)  $\times 1800$ , neg. SM777.

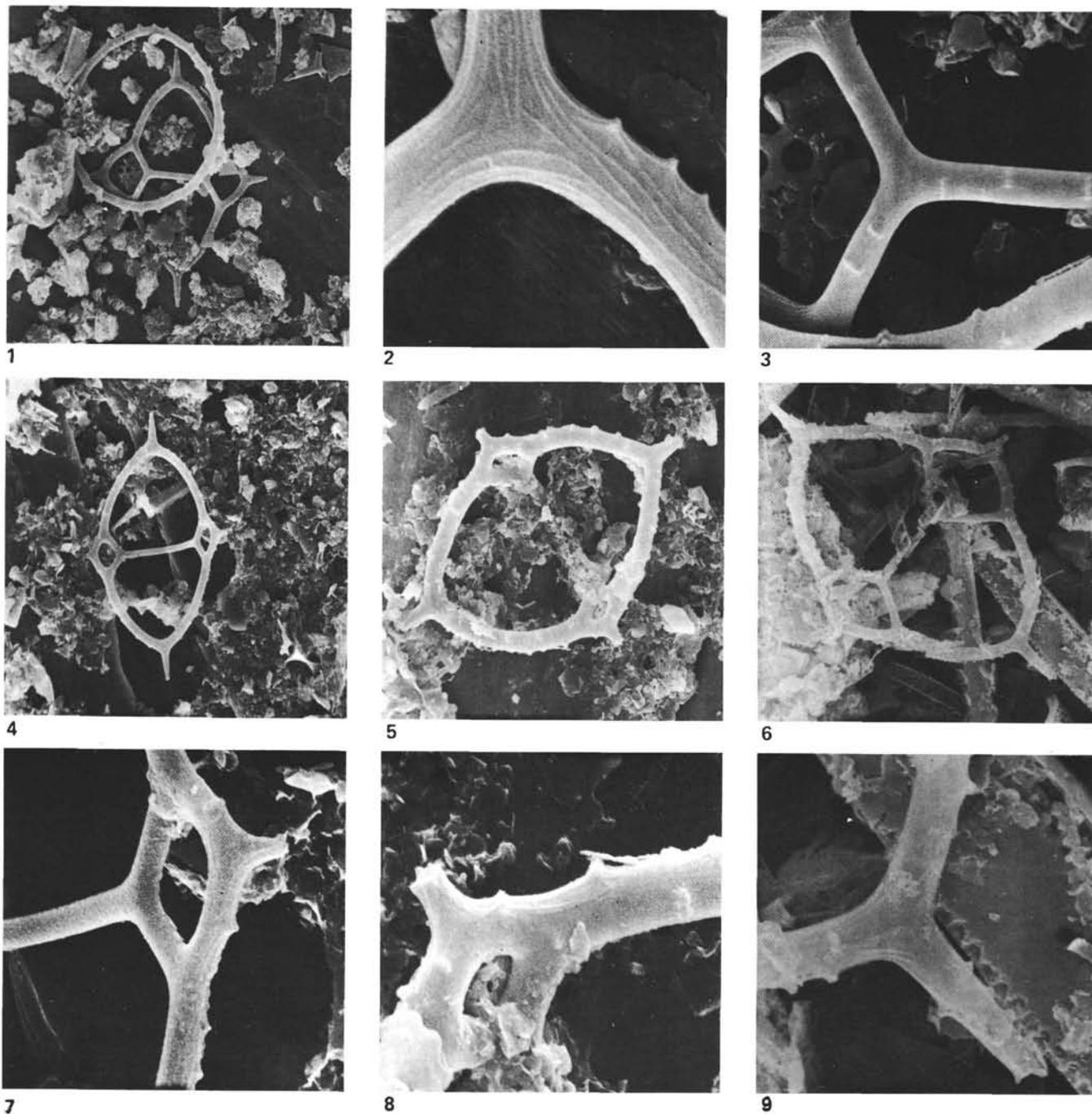


Plate 4. Silicoflagellates from DSDP Leg 86. 1-9. *Dictyocha brevispina* (Lemmermann). (1-3) Sample 579A-10, CC. Late Pliocene (cold). (1) With a *Mesocena*;  $\times 2400$ , neg. SM865. (2)  $\times 4800$ , neg. SM867. (3) With *Mesocena* at bottom;  $\times 3000$ , neg. SM868. (4, 7) Sample 577-6-7, 12-13 cm. Early Pliocene (warm). (4)  $\times 600$ , neg. SM871. (7)  $\times 3000$ , neg. SM872. (5, 8) Sample 577-6-7, 12-13 cm. Early Pliocene (warm). (5)  $\times 960$ , neg. SM869. (8)  $\times 3000$ , neg. SM870. (6, 9) Sample 580-17, CC. Late Pliocene (cold). (6)  $\times 960$ , neg. SM814. (9)  $\times 3600$ , neg. SM815.

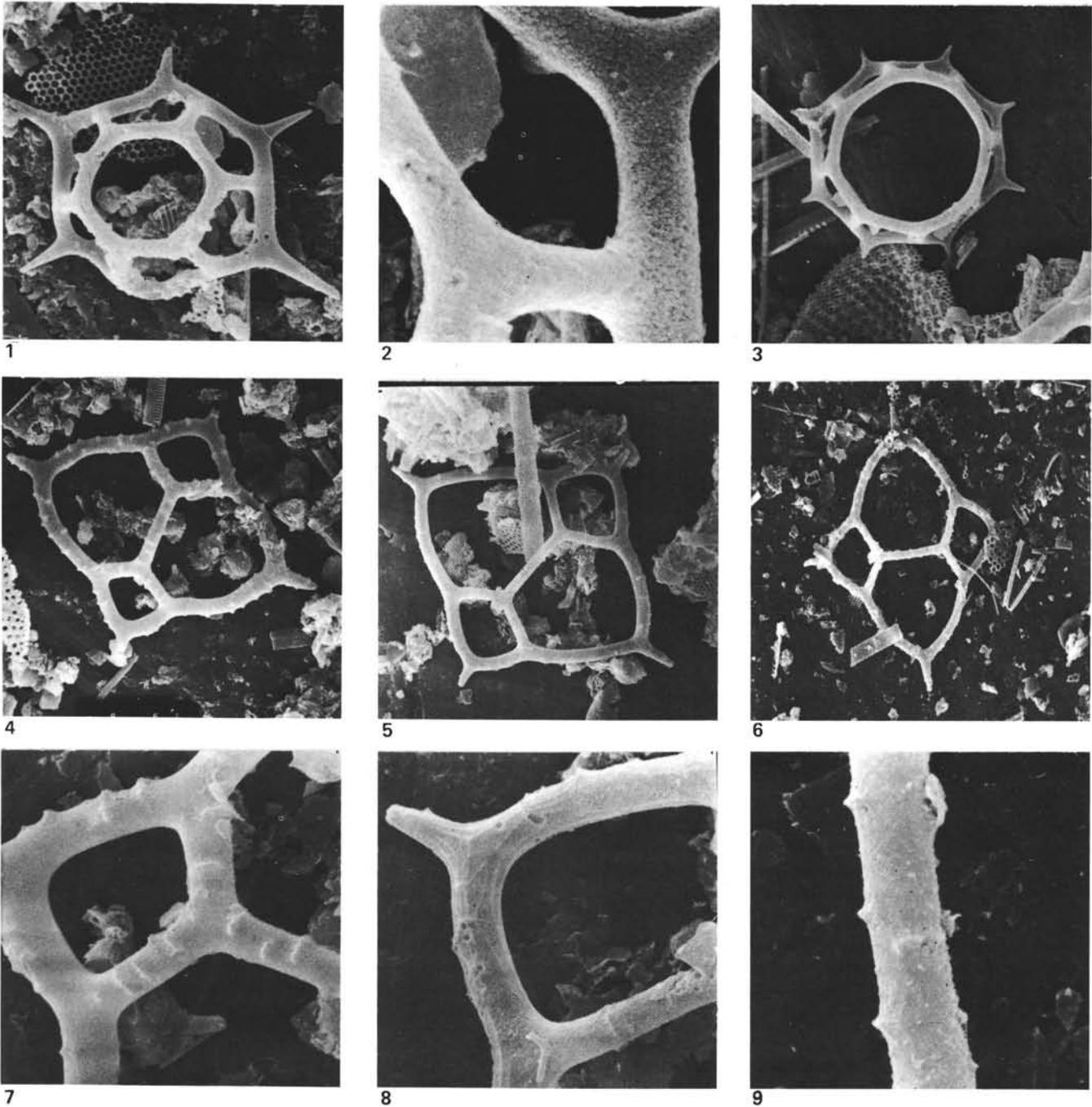


Plate 5. Silicoflagellates from DSDP Leg 86. 1, 2. *Distephanus speculum speculum* (Ehrenberg). Sample 579A-9-2, 40-42 cm. Late Pliocene (warm). (1)  $\times 1600$ , neg. SM741. (2)  $\times 4800$ , neg. SM742. 3. *Distephanus* sp. cf. *D. floridus* Bukry. Sample 581-8, CC. Quaternary (cool).  $\times 1200$ , neg. SM803. 4-9. *Dictyochoa brevispina* (Lemmermann). (4, 7) Sample 579A-10, CC. Late Pliocene (cool). (4)  $\times 840$ , neg. SM864. (7)  $\times 2400$ , neg. SM865. (5, 8) Sample 579A-15, CC. ?Late Miocene. (5)  $\times 840$ , neg. SM826. (8)  $\times 3000$ , neg. SM828. (6, 9) Sample 579A-12, CC. Early Pliocene (cool). (6)  $\times 420$ , neg. SM778. (9) Apical bar;  $\times 3600$ , neg. SM779.

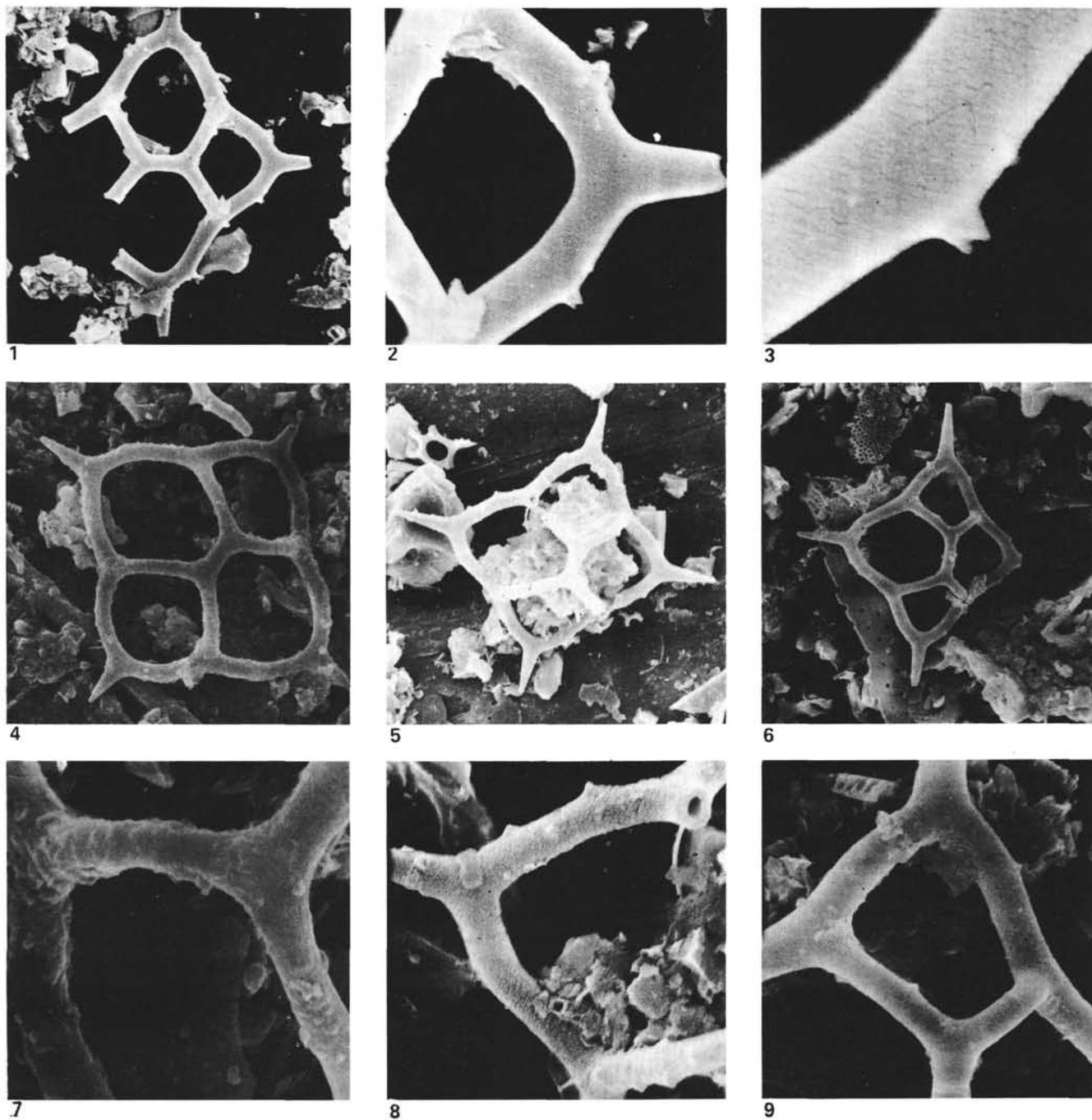


Plate 6. Silicoflagellates from DSDP Leg 86. 1-3, 5, 6, 8, 9. *Dictyocha calida ampliata* Bukry. (1-3) Sample 579A-4, CC. Pleistocene (warm). (1)  $\times 760$ , neg. SM878. (2)  $\times 4200$ , neg. SM879. (3)  $\times 10,800$ , neg. SM880. (5, 8) Sample 579A-4, CC. Pleistocene (warm). (5)  $\times 1080$ , neg. SM881. (8)  $\times 3000$ , neg. SM882. (6, 9) Sample 577-2-4, 43-44 cm. Pleistocene (warm). (6)  $\times 960$ , neg. SM846. (9)  $\times 3000$ , neg. SM847. 4, 7. *Dictyocha* sp. Sample 578-12, CC. Late Miocene (cool). (4)  $\times 900$ , neg. SM736. (7)  $\times 2400$ , neg. SM737.

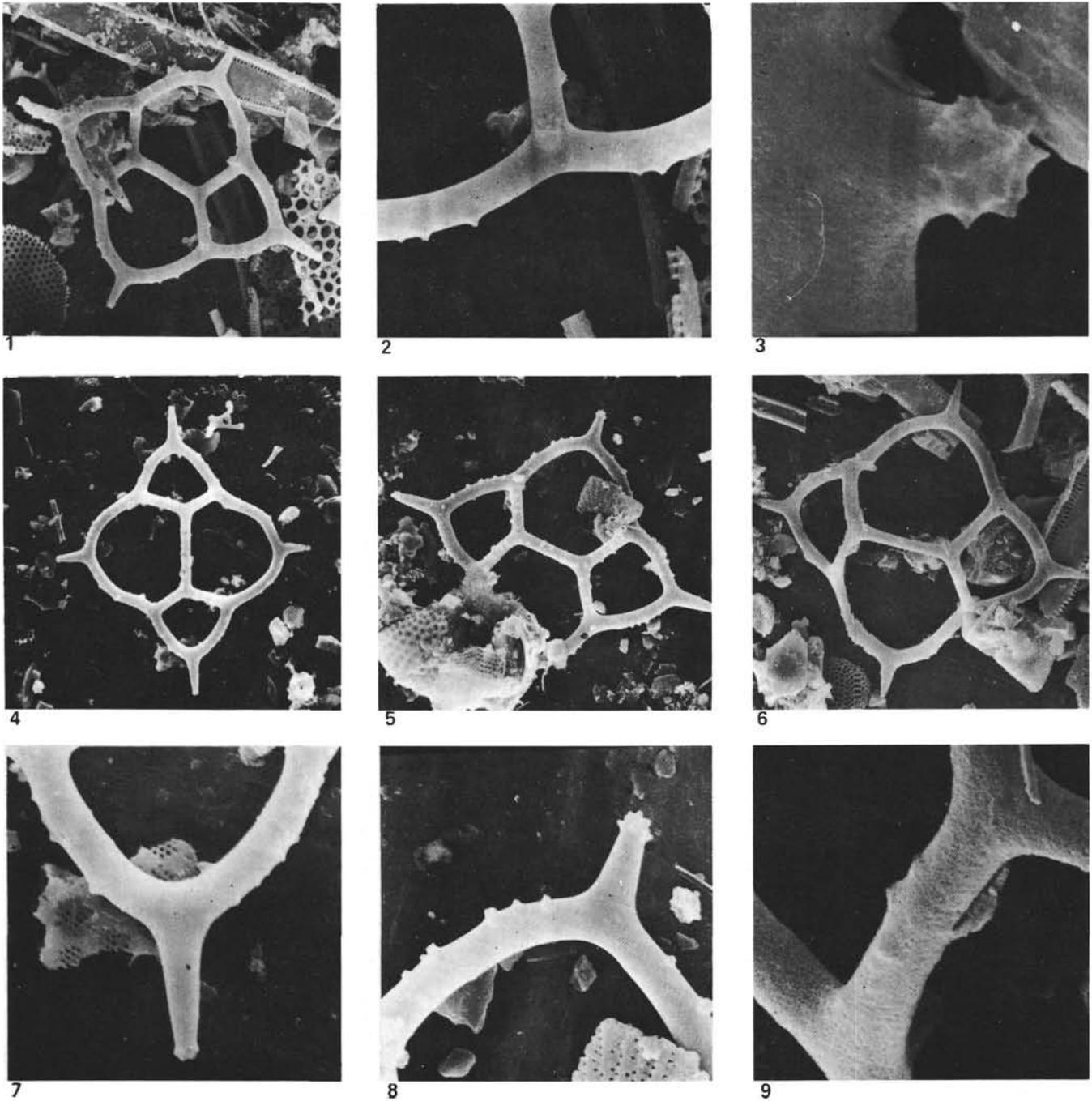


Plate 7. Silicoflagellates from DSDP Leg 86. 1-9. *Dictyocha perlaevis* Frenguelli. (1-3) Sample 581-8, CC. Late Cenozoic. (1)  $\times 720$ , neg. SM887. (2)  $\times 1800$ , neg. SM889. (3)  $\times 9600$ , neg. SM888. (4, 7) Sample 579A-4, CC. Pleistocene (warm) (4)  $\times 540$ , neg. SM883. (7)  $\times 1800$ , neg. SM884. (5, 8) Sample 579A-4, CC. Pleistocene (warm). (5)  $\times 600$ , neg. SM875. (8)  $\times 1800$ , neg. SM876. (6, 9) Sample 579A-6, CC. Near Pliocene/Pleistocene boundary (warm). (6)  $\times 980$ , neg. SM753. (9)  $\times 4200$ , neg. SM754.

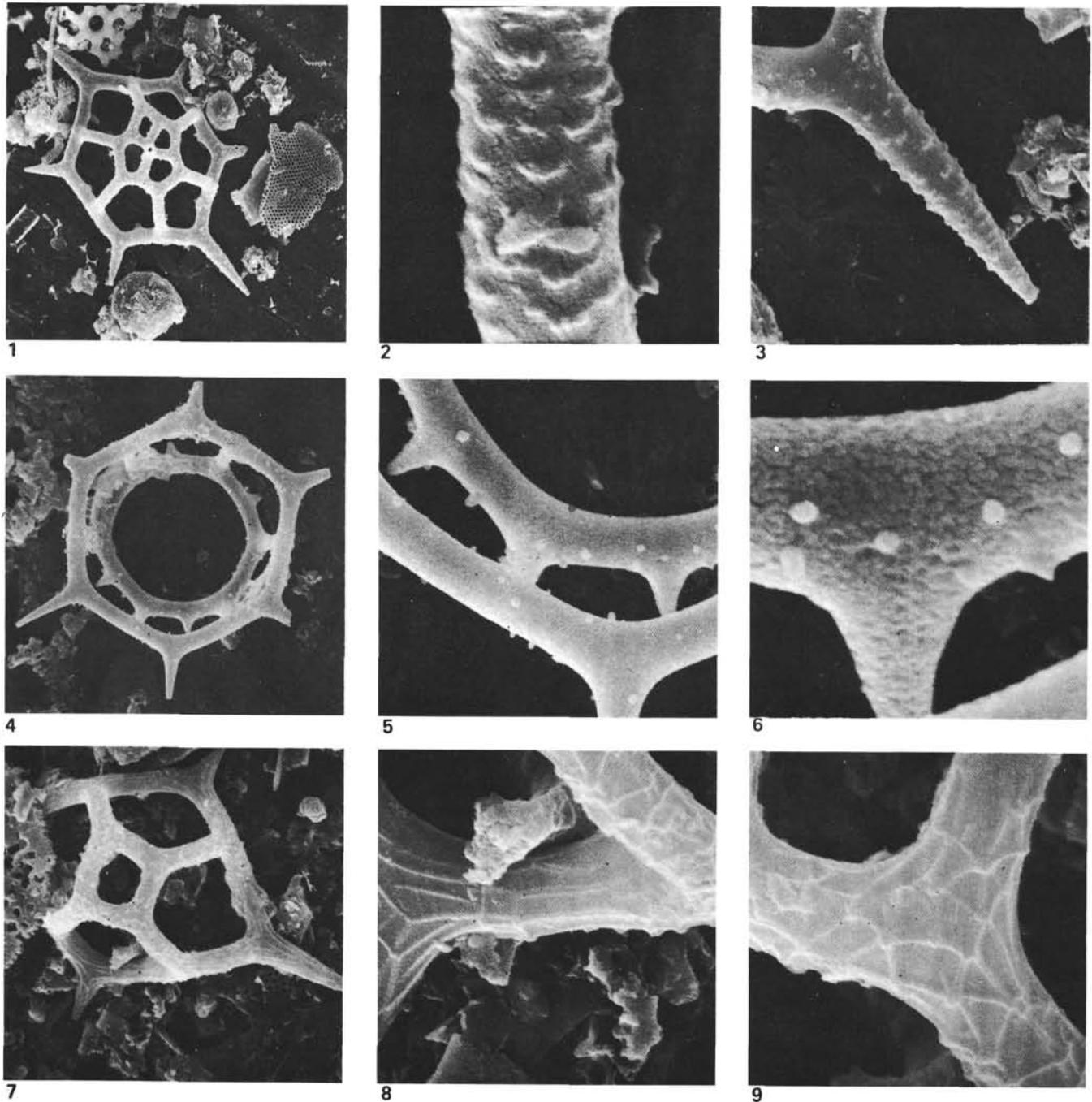


Plate 8. Silicoflagellates from DSDP Leg 86. 1-3. *Distephanus jimlingii* (Bukry) s. ampl. Sample 579A-9, CC. Late Pliocene (cold). (1)  $\times 840$ , neg. SM856. (2)  $\times 9600$ , neg. SM860, strut. (3)  $\times 3000$ , neg. SM858, spine. 4-6. *Distephanus speculum minutus* (Bachmann) emend. Sample 579A-9-2, 40-42 cm. Late Pliocene (cool). (4)  $\times 1400$ , neg. SM746. (5)  $\times 4200$ , neg. SM749. (6)  $\times 12,000$ , neg. SM748. 7-9. *Distephanus crux* (Ehrenberg). Sample 581-7-3, 30-31 cm. Late Miocene (warm). (7)  $\times 1080$ , neg. SM723. (8)  $\times 3600$ , neg. SM725, basal ring. (9)  $\times 4800$ , neg. SM724, apical ring.

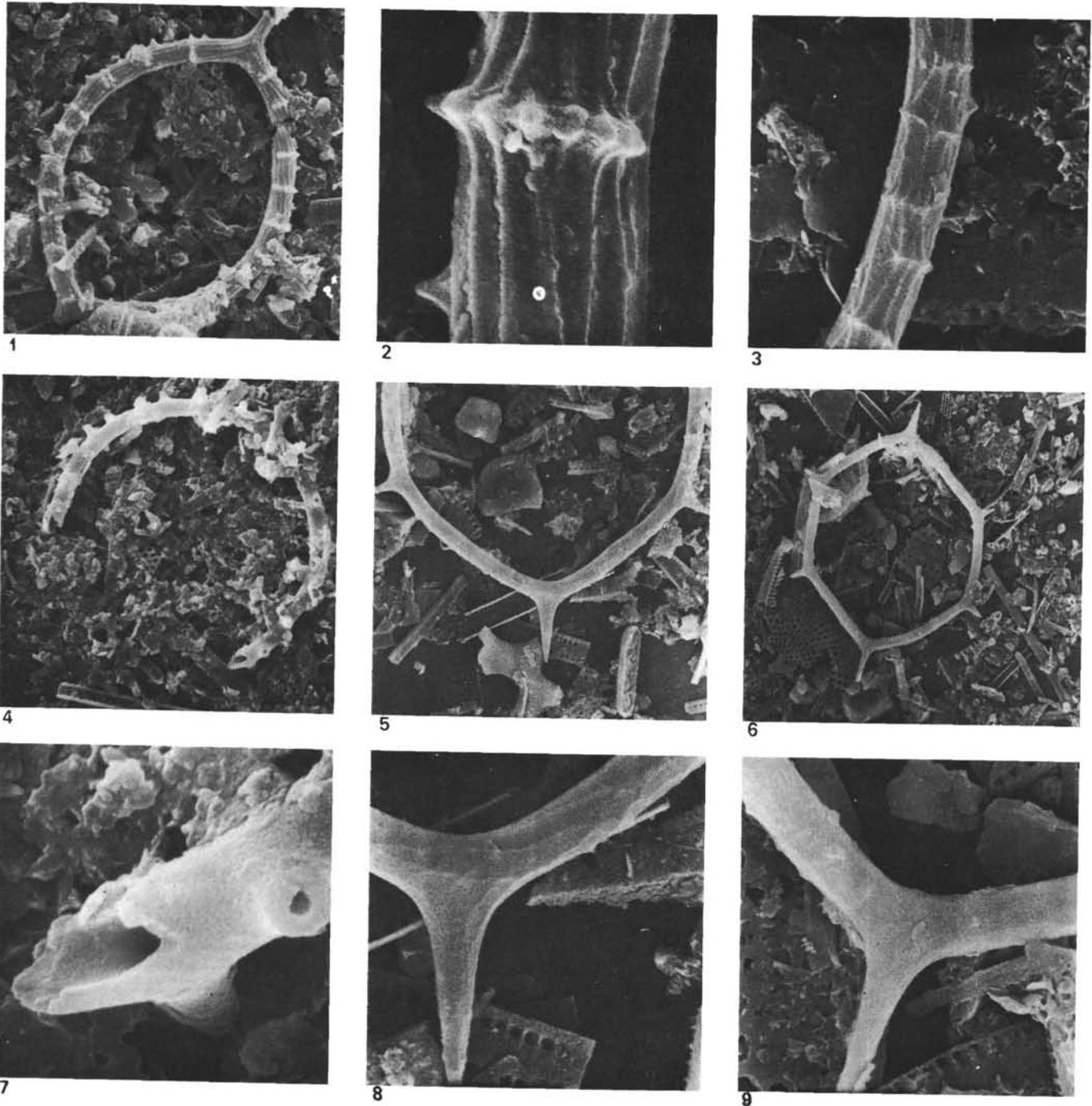


Plate 9. Silicoflagellates from DSDP Leg 86. 1, 2. *Mesocena diodon nodosa* Bukry. Sample 581-7-3, 30-31 cm. Late Miocene (warm). (1)  $\times 840$ , neg. SM721. (2)  $\times 4800$ , neg. SM722. 3. *Mesocena diodon nodosa* Bukry. Sample 581-8-2, 75-76 cm. Middle Miocene (cold).  $\times 3600$ , neg. SM788. 4, 7. *Mesocena circulus* (Ehrenberg). Sample 581-7-3, 30-31 cm. Late Miocene (warm). (4)  $\times 840$ , neg. SM734. (7)  $\times 4800$ , neg. SM735. 5, 8. *Mesocena hexalitha* Bukry. Sample 581-8-2, 55-56 cm. Middle Miocene (cold). (5)  $\times 960$ , neg. SM797. (8)  $\times 3000$ , neg. SM798. 6, 9. *Mesocena hexalitha* Bukry. Sample 581-8-2, 75-76 cm. Middle Miocene (cold). (6)  $\times 540$ , neg. SM789. (9)  $\times 3000$ , neg. SM790.

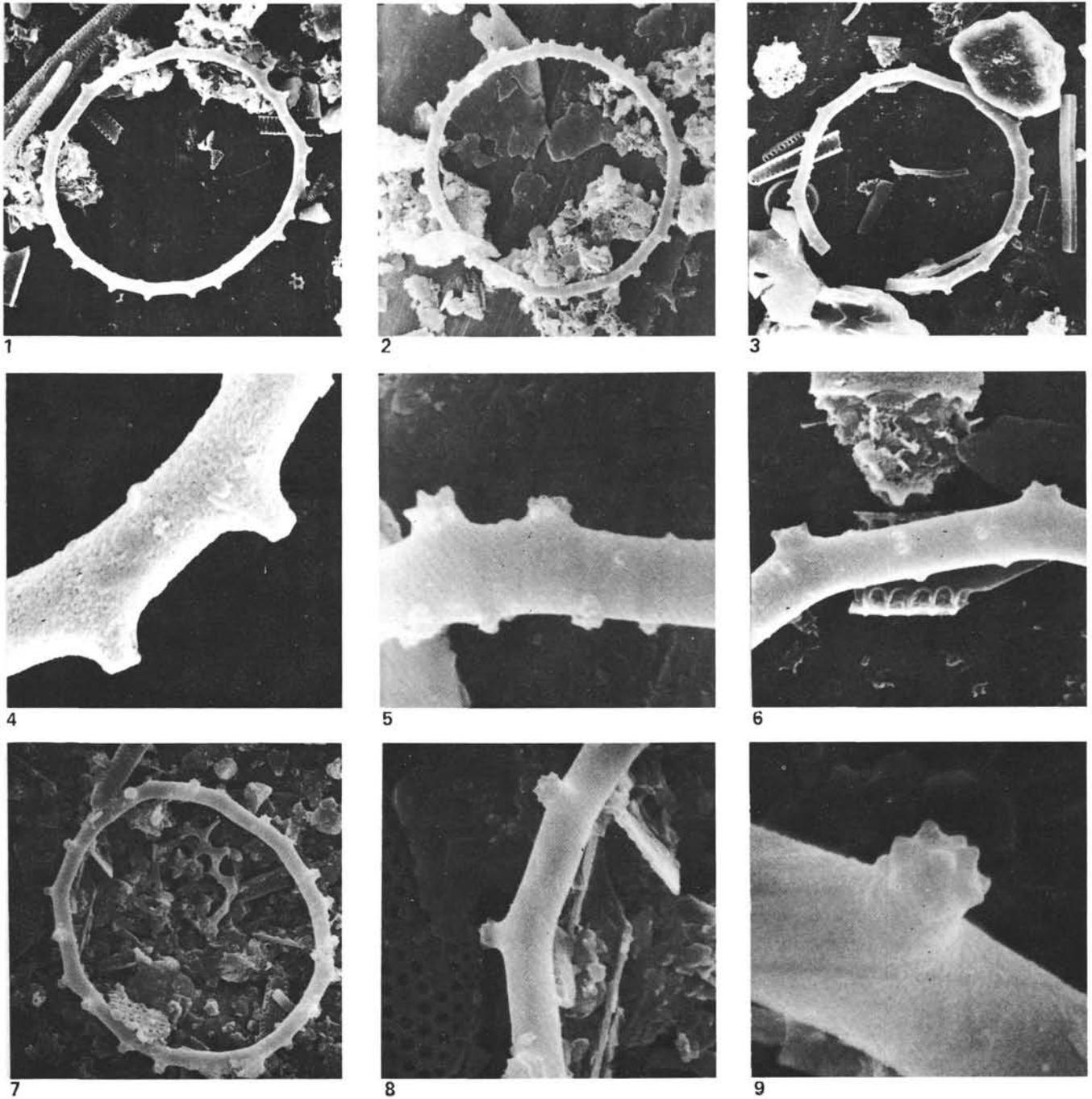


Plate 10. Silicoflagellates from DSDP Leg 86. 1-9. *Mesocena circulus* (Ehrenberg). (1, 4) Sample 579A-9, CC. Late Pliocene (cold). (1)  $\times 840$ , neg. SM772. (4)  $\times 6000$ , neg. SM773. (2, 5) Sample 579A-15, CC. Late Miocene? (2)  $\times 840$ , neg. SM819. (5)  $\times 6000$ , neg. SM820. (3, 6) Sample 579A-9, CC. Late Pliocene (cold). (3)  $\times 840$ , neg. SM774. (6)  $\times 3600$ , neg. SM775. (7-9) Sample 581-7-3, 30-31 cm. Late Miocene (warm). (7)  $\times 840$ , neg. SM731. (8)  $\times 2400$ , neg. SM733. (9)  $\times 8400$ , neg. SM732.

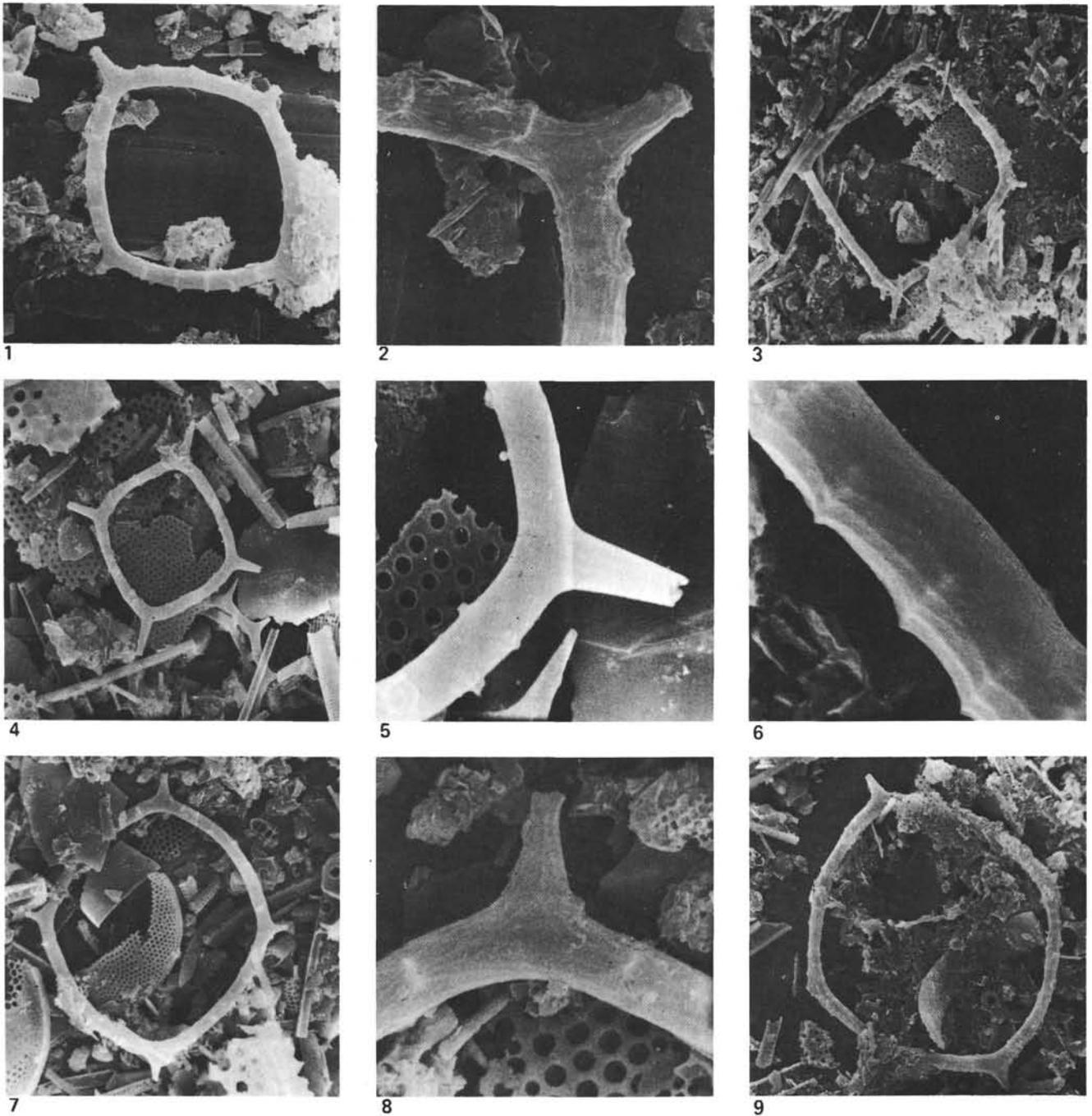


Plate 11. Silicoflagellates from DSDP Leg 86. 1-9. *Mesocena quadrangula* Ehrenberg ex Haeckel. (1, 2) Sample 579A-15, CC. Late Miocene? (1)  $\times 840$ , neg. SM824. (2)  $\times 2400$ , neg. SM825. (3, 6) Sample 581-8-2, 75-76 cm. Middle Miocene (cool). (3)  $\times 540$ , neg. SM854. (6)  $\times 6000$ , neg. SM855. (4, 5) Sample 581-8, CC. Late Cenozoic. (4)  $\times 600$ , neg. SM804. (5)  $\times 3000$ , neg. SM805. (7, 8) Sample 580-17, CC. Late Pliocene (cold). (7)  $\times 720$ , neg. SM812. (8)  $\times 3600$ , neg. SM813. (9) Sample 581-8-2, 75-76 cm. Middle Miocene (cold).  $\times 840$ , neg. SM795.

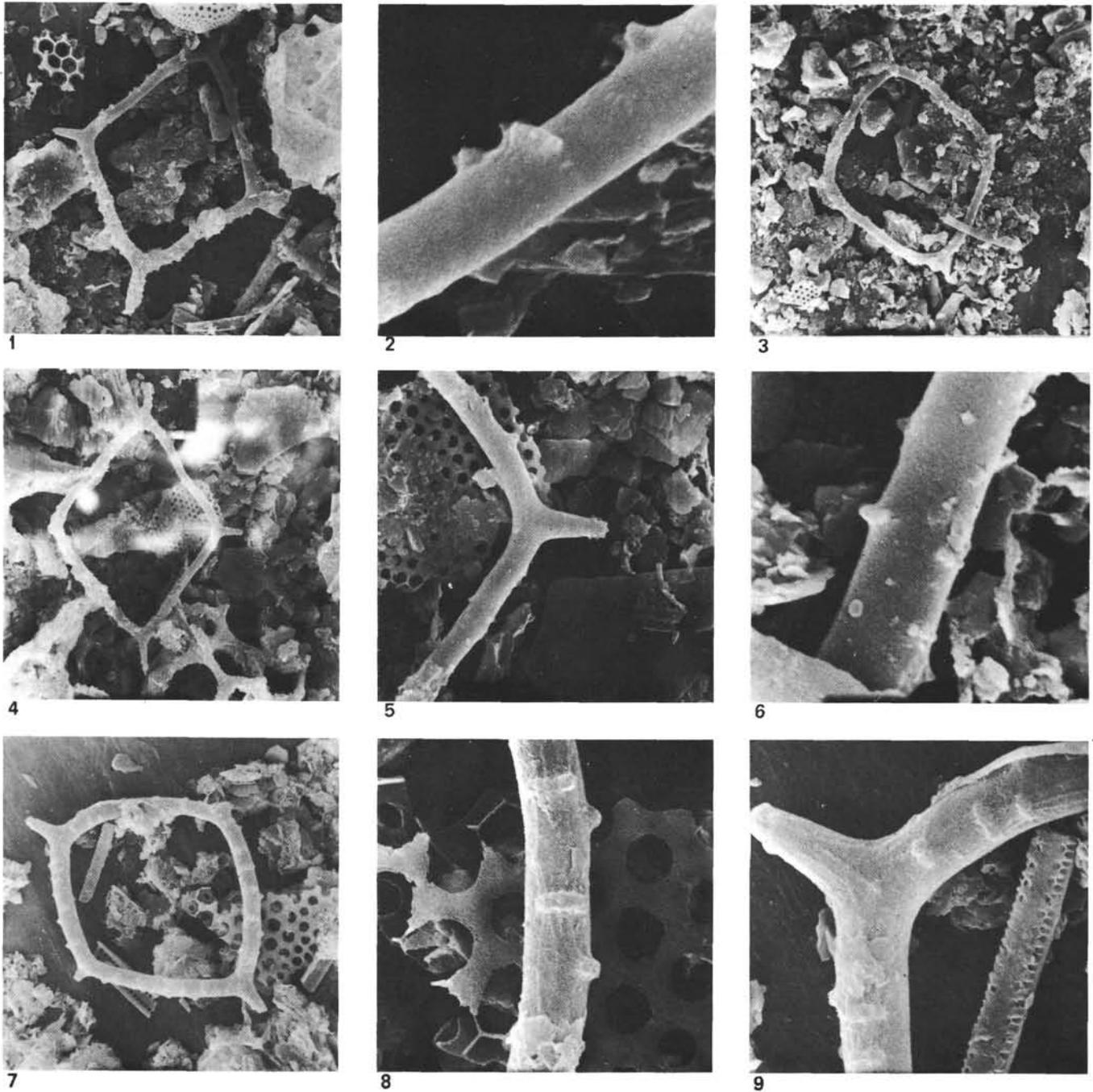


Plate 12. Silicoflagellates from DSDP Leg 86. 1-9. *Mesocena quadrangula* Ehrenberg ex Haeckel. (1-6) Sample 577-2-4, 43-44 cm. Pleistocene (warm). (7-9) Sample 579A-15, CC. Late Miocene? (1, 2)  $\times 840$ , neg. SM852;  $\times 6000$ , neg. SM853. (3)  $\times 6000$ , neg. SM844. (4, 5)  $\times 600$ , neg. SM841;  $\times 1800$ , neg. SM842. (6)  $\times 6000$ , neg. SM844b. (7-9)  $\times 840$ , neg. SM821;  $\times 3000$ , neg. SM822;  $\times 3000$ , neg. SM823.

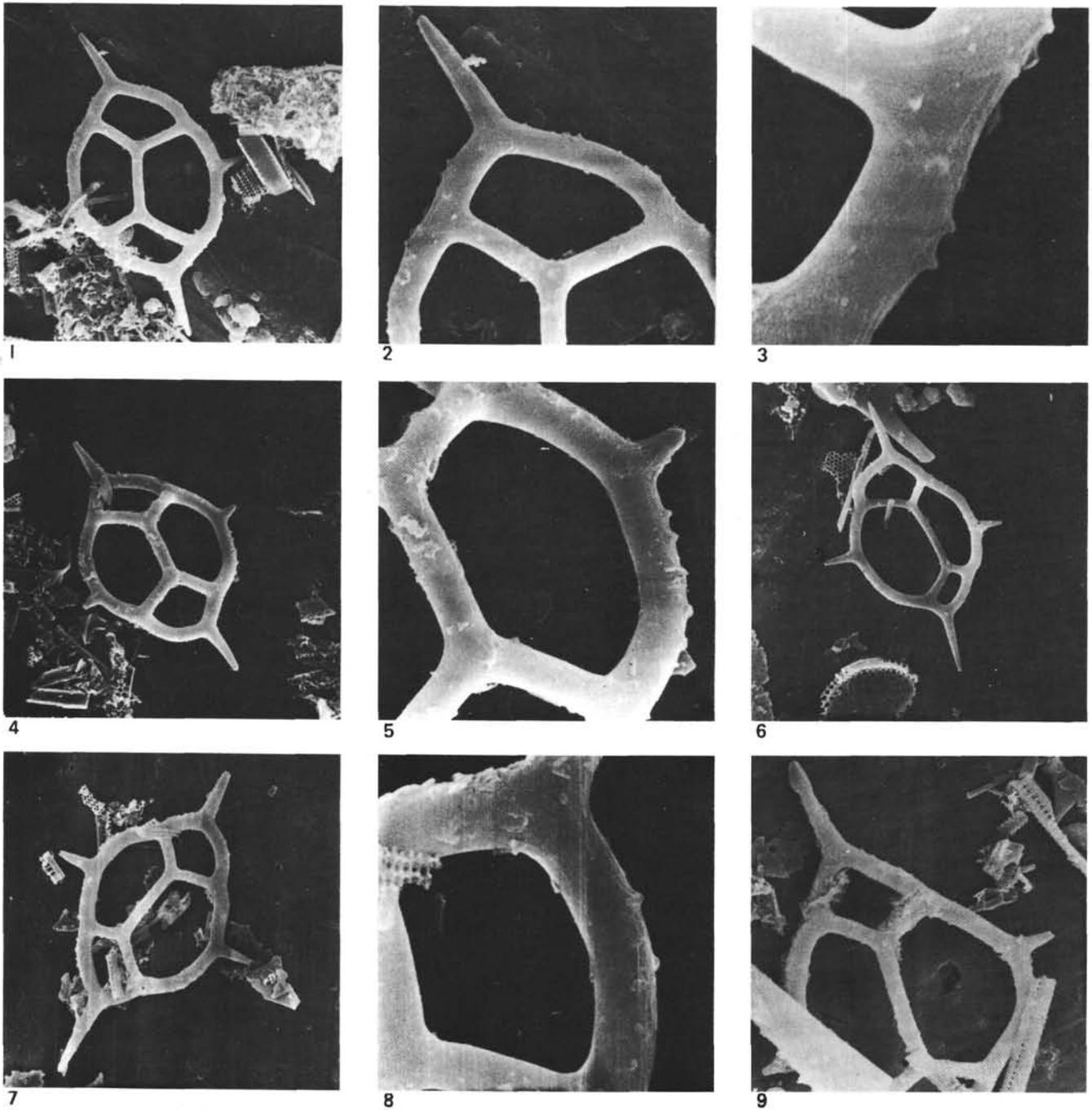


Plate 13. Silicoflagellates from DSDP Leg 85. 1-9. *Dictyocha flexatella* (Bukry). Sample 572A-5-3, 16-17 cm. Late Pliocene (warm). (1-3)  $\times 960$ , neg. SM762;  $\times 2400$ , neg. SM764;  $\times 6000$ , neg. SM763. (4, 5)  $\times 960$ , neg. SM767;  $\times 3000$ , neg. SM768. (6)  $\times 840$ , neg. SM765. (7, 8)  $\times 840$ , neg. SM835;  $\times 4200$ , neg. SM836. (9)  $\times 1320$ , neg. SM833.

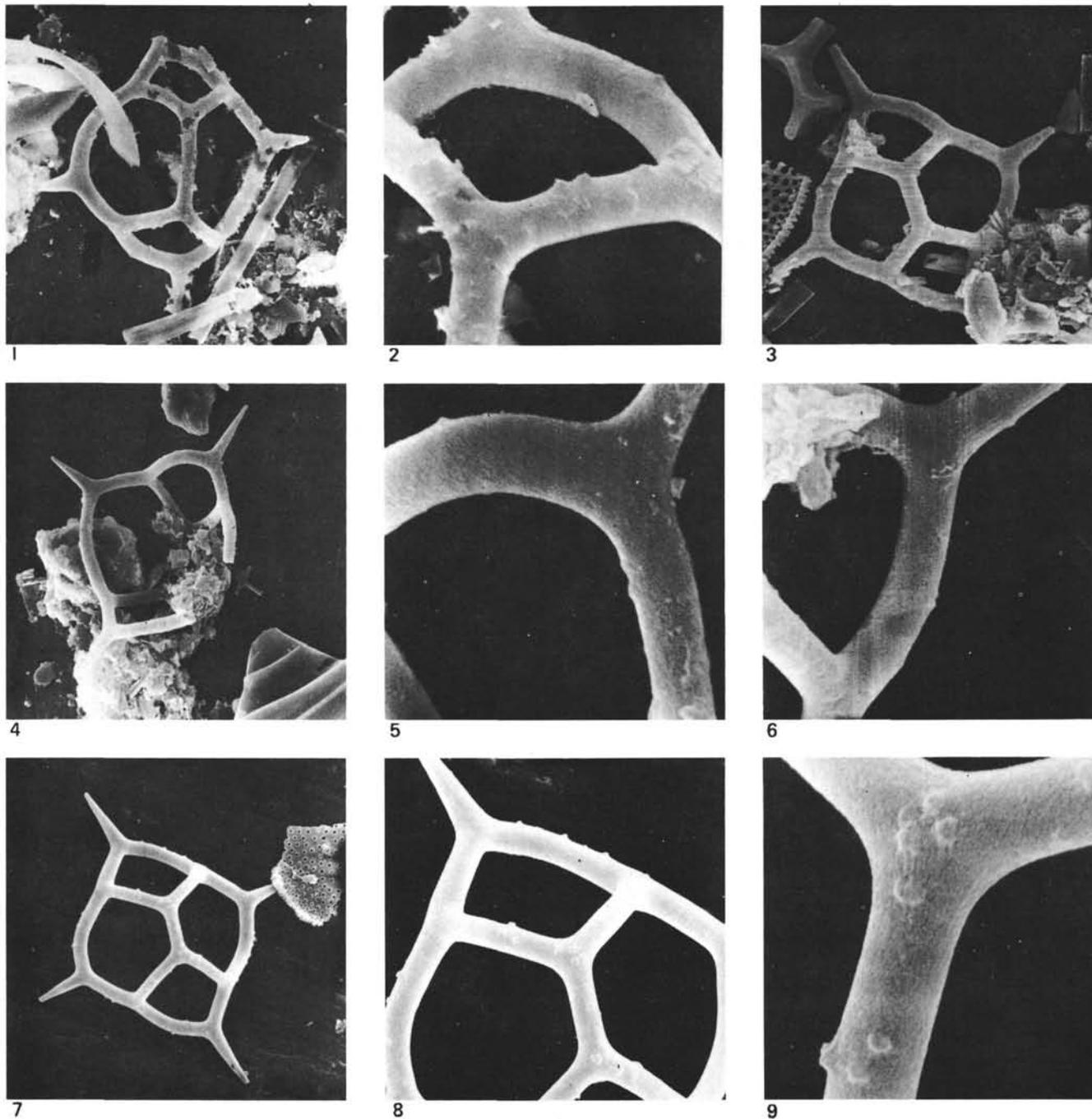


Plate 14. Silicoflagellates from DSDP Leg 86. 1-9. *Dictyocha flexatella* (Bukry). Sample 579A-9-2, 40-42 cm. Late Pliocene (cool). (1, 2)  $\times 1080$ , neg. SM780;  $\times 3600$ , neg. SM781. (3, 6)  $\times 960$ , neg. SM839;  $\times 3000$ , neg. SM840. (4, 5)  $\times 840$ , neg. SM782;  $\times 4200$ , neg. SM783. (7-9)  $\times 960$ , neg. SM769;  $\times 1800$ , neg. SM770;  $\times 6000$ , neg. SM771.

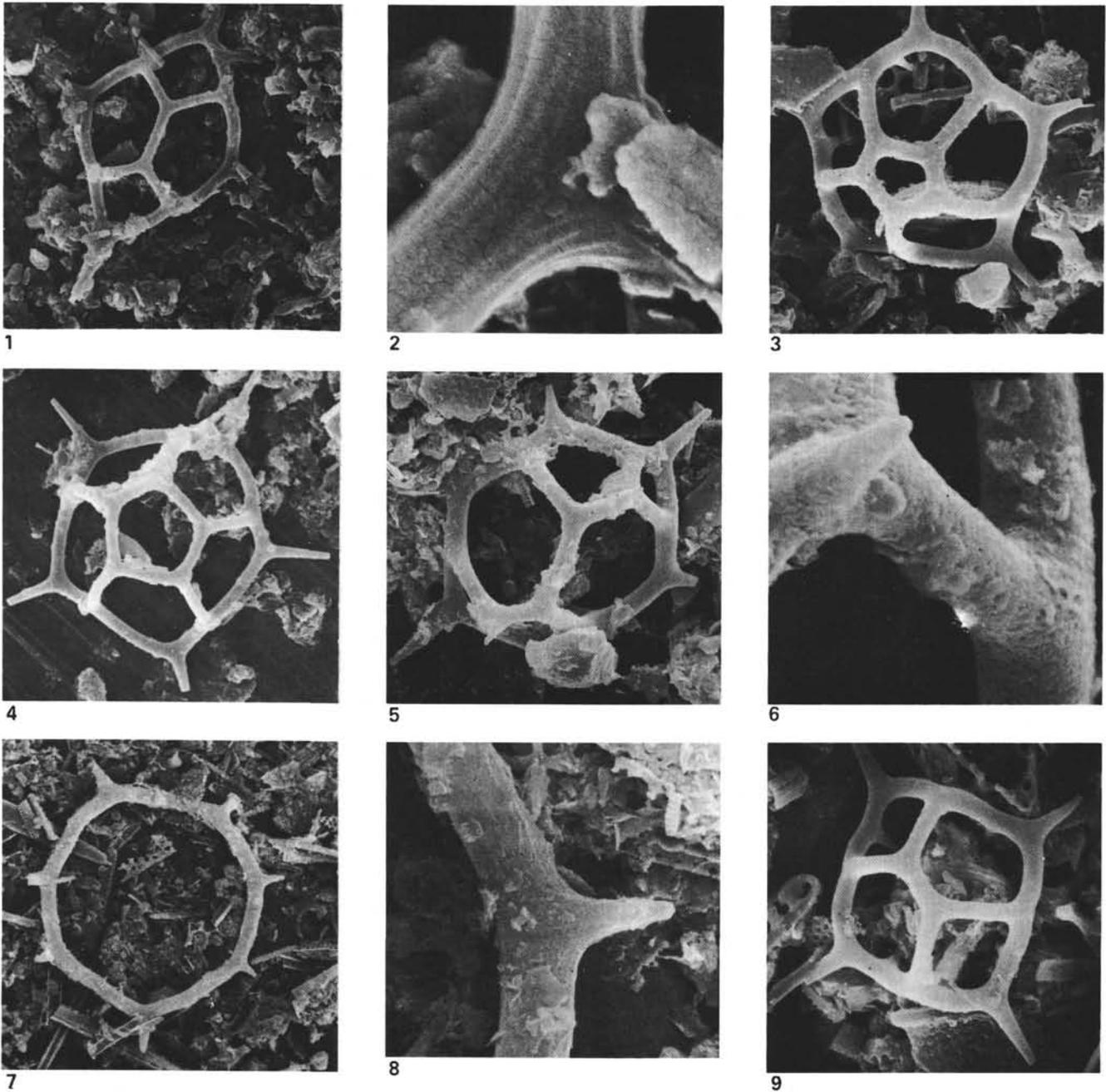
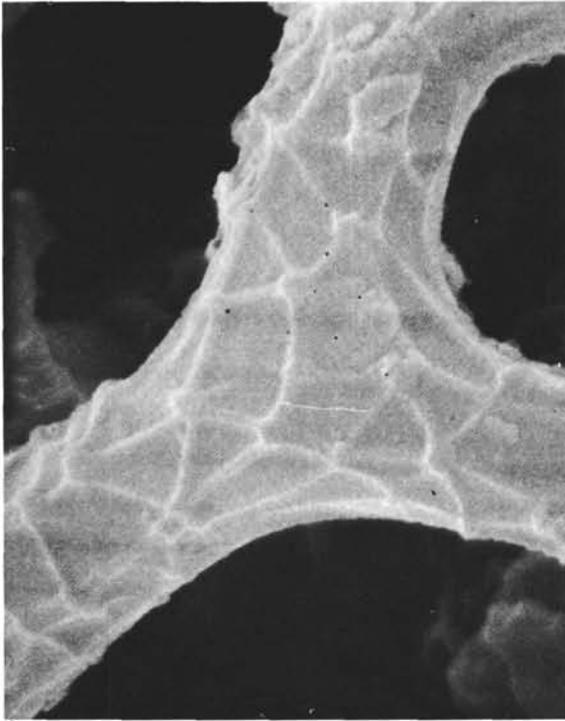
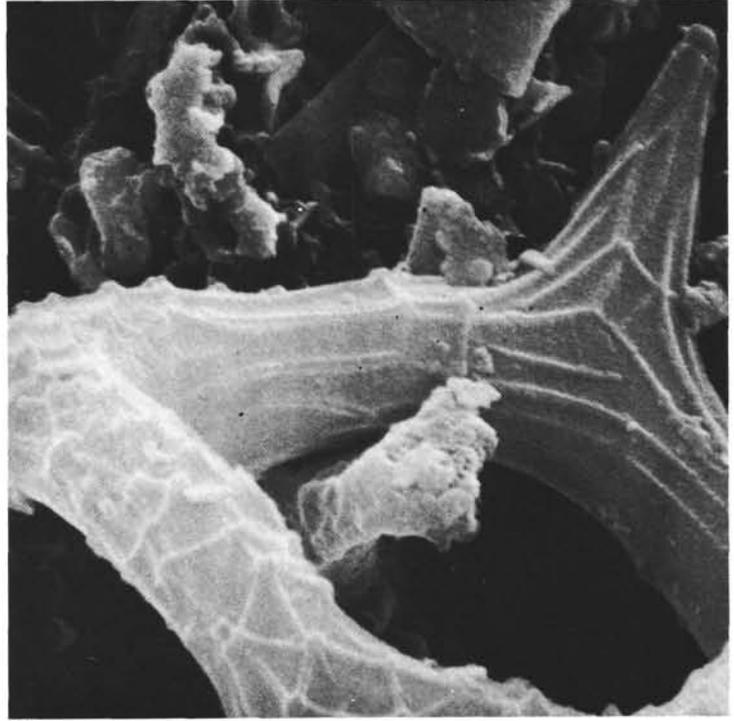


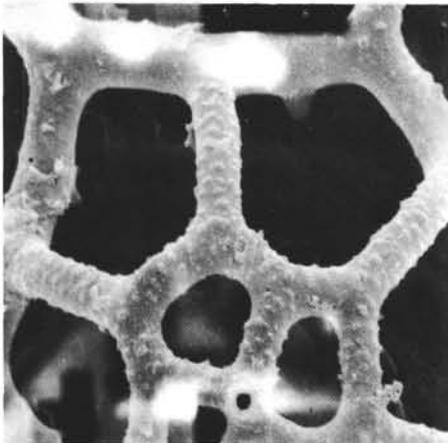
Plate 15. Silicoflagellates from DSDP Leg 86. 1, 2. *Dictyocha longa* Bukry. Sample 581-7-3, 30-31 cm. Late Miocene (warm). (1)  $\times 900$ , neg. SM715. (2)  $\times 9000$ , neg. SM716. 3, 4. *Distephanus quinquangellus* Bukry et Foster. (3) Sample 581-3, CC. Late Miocene (warm).  $\times 1320$ , neg. SM709. (4) Sample 579A-9-2, 40-42 cm. Late Pliocene (cool).  $\times 1200$ , neg. SM745. 5, 6 *Distephanus* sp. cf. *D. pseudofibula* (Schulz). Sample 579A-9-2, 40-42 cm. Late Pliocene (cool). (5)  $\times 1200$ , neg. SM743. (6)  $\times 7000$ , neg. SM744. 7, 8. *Mesocena hexalitha* Bukry. Sample 581-8-2, 75-77 cm. Middle Miocene (cool). (7)  $\times 600$ , neg. SM791. (8)  $\times 3000$ , neg. SM792. 9. *Dictyocha* sp. Sample 581-3, CC. Late Miocene (warm).  $\times 1500$ , neg. SM702.



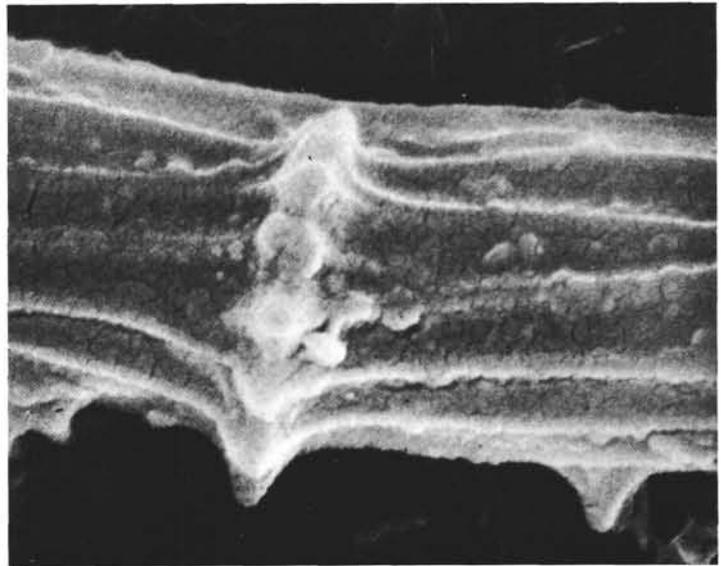
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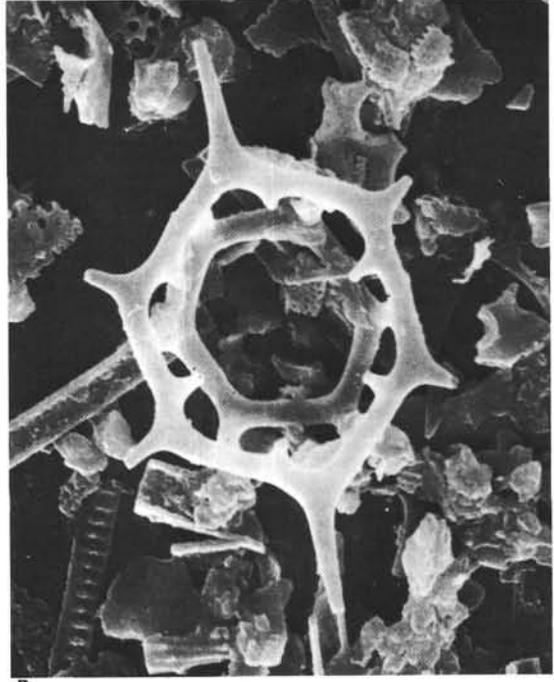


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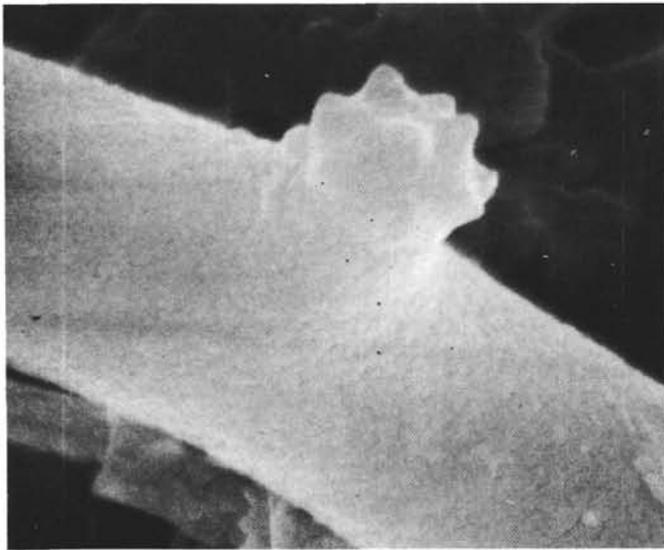
Plate 16. Enlargements of silicoflagellate textures from DSDP Leg 86. 1. Reticulate texture of intersecting ridges and peaks. Detail of apical ring and strut of *Distephanus crux* Ehrenberg. Sample 581-7-3, 30-31 cm.  $\times 10,000$ ; neg. SM724. 2. Reticulate texture on strut and linear texture on the basal ring and spine of the same specimen as Fig. 1.  $\times 8000$ ; neg. SM725. 3. Nodular texture on the apical ring and struts of *Distephanus jimlingii* (Bukry) s. ampl. Sample 579A-9, CC.  $\times 2400$ ; neg. SM859. 4. Crenulate texture on the ring of *Mesocena diodon nodosa* Bukry. Sample 581-7-3, 30-31 cm.  $\times 10,000$ ; neg. SM722.



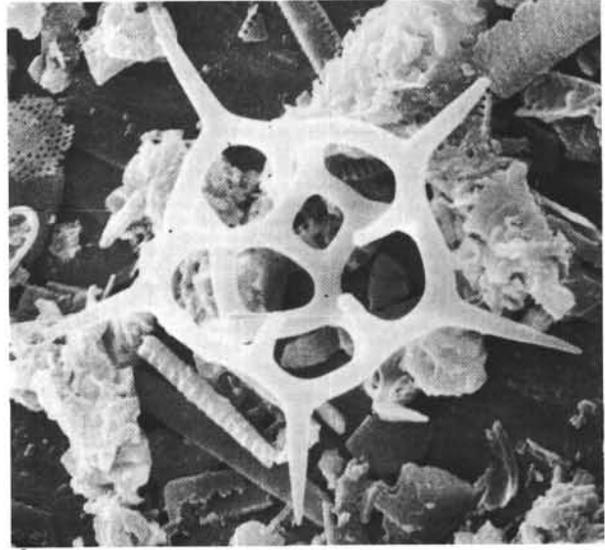
1



2



3



4

Plate 17. Enlargements of silicoflagellate textures from DSDP Leg 86. 1. Linear texture on basal ring and pike of *Dictyocha* sp. Pike has a semi-rosette termination. Sample 581-3,CC.  $\times 20,000$ ; neg. SM707. 2. Smooth texture on basal ring and short spine of *Mesocena circulus* (Ehrenberg). Spine has a rosette termination. Sample 581-7-3, 30-31 cm.  $\times 14,000$ ; neg. SM732. 3. Smooth texture on all proximal surfaces of *Distephanus speculum minutus* (Bachmann, emend.). Sample 581-3,CC.  $\times 2000$ , neg. SM708. 4. Smooth texture on all proximal surfaces of *Distephanus quinquangellus* Bukry and Foster (binocular). Sample 581-3,CC.  $\times 1800$ ; neg. SM714.