13. UPPER CENOZOIC SILICOFLAGELLATES FROM OFFSHORE ECUADOR, DEEP SEA DRILLING PROJECT SITE 504[1]

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ABSTRACT

Diverse and abundant late Miocene to Pleistocene silicoflagellates at DSDP Site 504 can be correlated by tropical biostratigraphic zones and relative paleotemperature values to eastern tropical Pacific reference site DSDP 503A farther to the west. Early Pliocene assemblages, which were poorly known until now, are present and can be correlated locally between DSDP Holes 504, 503A, and 495, using species events associated with the new *Dictyocha pulchella* Subzone and *Dictyocha angulata* Subzone. Silicoflagellate relative paleotemperature values show major warming at 4.7 to 5.0 Ma (Cores 45–48), 3.4 to 3.8 Ma (Cores 32–33), 1.5 to 1.7 Ma (Cores 12–16), and 0.5 to 0.8 Ma (Cores 3–6). Major coolings occurred at 5.0 to 5.1 Ma (Core 51), 3.9 to 4.4 Ma (Cores 38–44), and 1.0 to 1.3 Ma (Cores 8–10). The appearance of *Dictyocha longa* is proposed to replace the asperoid/fibuloid ratio reversal as the bottom of the *Dictyocha fibula* Zone, because the non-evolutionary ratio reverses several times in the upper Miocene of Hole 503A, and at least once in Hole 504. Three new Pliocene silicoflagellates are defined: *Dictyocha concinna* Bukry, n. sp., *D. helix* Bukry, n. sp., and *D. tamarae* Bukry, n. sp.

INTRODUCTION

A 237- to 264-meter section of rapidly accumulated pelagic sediment blankets the igneous basement in the DSDP Site 504 area of the Costa Rica Rift (1°13.58N, 83°43.93W; depth 3460 m). Hole 504 is an excellent reference section for latest Miocene to Pleistocene silicoflagellates (Figs. 1A–C). The 54 hydraulic-piston cores (HPC) cut in Hole 504 at this site provide a detailed, undisturbed sequence of biostratigraphic and paleoecologic events. This site was chosen to study geothermal problems in a young, non-rifted, flat area of oceanic crust that is cooling by simple conduction.

The low-latitude biostratigraphic zonation of silicoflagellates is recognized throughout the section by primary guide species. Redefinition of the base of the *Dictyocha fibula* Zone in the upper Miocene was required by the reversal or high readings for the asperoid/fibuloid ratio in upper Miocene Cores 49 to 53. Previous problems with the biostratigraphic use of this ratio were described for DSDP Hole 503A (Bukry, in press a). Several variants of distorted *Mesocena quadrangula* from the same upper Miocene interval may have local biostratigraphic significance because they are missing in younger populations (Bukry and Foster, 1973); these variants are illustrated (Plate 9).

Calculations of paleotemperature values (T_s) from quantitative silicoflagellate data and the application of diatom chronology for DSDP Hole 504 show cooling at approximately 5.0 to 5.1 Ma, 3.9 to 4.4 Ma, and 1.0 to 1.3 Ma, and major warming at 4.7 to 5.0 Ma, 3.4 to 3.8 Ma, and 1.5 to 1.7 Ma. Some of these peaks are correlated between sites and discussed because they are associated with several species events at both DSDP Hole 503A and DSDP Hole 504. A revision to the T_s equation is made to accommodate large abundances (73%) of *Mesocena quadrangula* in the Pleistocene.

METHODS AND MATERIALS

As for previous eastern tropical Pacific (ETP) photomicroscope silicoflagellate studies of DSDP Legs 16, 34, 54, 63, 67, and 68, sediment samples were cleaned in 250-ml beakers with H_2O_2 (35%), HCl (conc.) and H_2O (distilled), using low heat from a hot plate to speed chemical digestion of carbonate, organic matter, and clay from the biosiliceous residue. After settlings and rinsings in H_2O (distilled), the residue was bottled. Slides were prepared by re-suspending the whole acid residue by shaking the storage bottle and quickly pipetting 2 or 3 drops onto a glass slide. A metal spatula was used to spread the suspension evenly over the slide. This was dried at medium heat on a hot plate and sealed with a coverslip, using a thermoplastic mounting medium (Piccolyte). Mechanical stage traverses of all, or representative, slide areas and a mechanical counter were used to enumerate all the silicoflagellates encountered at magnifications of 200× to 500×, most commonly 250×, until 300 specimens were counted.

NEOGENE ZONATION

Similar ranges of several new species of silicoflagellates at DSDP Sites 504, 503, and 495 justify identification of two new subzones for the lower Pliocene and upper Miocene. A preliminary chronology is assigned to selected silicoflagellate events that are most compatible with the diatom chronology (see Sancetta, this volume). The zonation is defined in Bukry (in press a, b) and briefly characterized below, relative to the assemblages from DSDP Site 504 from youngest to oldest.

Dictyocha aculeata Zone

The *Dictyocha aculeata* Zone is identified by the common occurrence of *Dictyocha aculeata* above the Quaternary acme of *Mesocena quadrangula*. At DSDP Hole 504, Core 6 contains a transitional assemblage with 3 to 9% *D. aculeata* and 4% *M. quadrangula*. Because *M. quadrangula* is missing in shallower cores, this Core 6 assemblage is assigned to the upper *M. quadrangula* Zone. According to Burckle (1977), the extinction of *M. quadrangula* occurs above the Jaramillo magnetic event

[1] Cann, J. R., Langseth, M. G., Honnorez, J., Von Herzen, R. P., White, S. M., et al., *Init. Repts. DSDP*, 69: Washington (U.S. Govt. Printing Office).

(approximately 0.79 Ma). At DSDP Sites 504 and 503, and some Leg 54 sites, the *M. quadrangula* extinction occurred near that of the diatom *Nitzschia reinholdii*, at approximately 0.63 Ma (see Barron, 1980). In fact, for Hole 503A, shipboard results showed the *M. quadrangula* extinction to be slightly younger than the *N. reinholdii* in Core 4.

Mesocena quadrangula Zone

The *Mesocena quadrangula* Zone at Site 504 includes the Quaternary acme of *Mesocena quadrangula* (abundances up to 73%) in Cores 6 to 11. Although *M. quadrangula* is common (11–14%) in lower Quaternary Cores 12 and 13, the presence of *Dictyocha delicata* identifies the upper *D. delicata* Subzone of the underlying *Dictyocha stapedia* Zone in the eastern tropical Pacific. Auxiliary stratigraphic guides from higher-latitude areas, such as *Dictyocha hessii, D. lingii*, or *D. subarctios*, are missing. Among the low-latitude species present, *D. perlaevis perlaevis* displaces *M. quadrangula* as a dominant species near the top of the zone, which suggests that a warming trend contributed to the final disappearance of *M. quadrangula*.

Dictyocha stapedia Zone

Dictyocha delicata Subzone

The regional extinction of *D. delicata* is used to mark the top of the *Dictyocha delicata* Subzone. The base is the first common occurrence of *D. delicata*, which includes the uppermost Pliocene and lower Quaternary below the *Mesocena quadrangula* Zone. At Site 504, Cores 12 to 18 are assigned to the *D. delicata* Subzone; however, the nominate species is missing in samples from Cores 16 and 17. Instead, a similar taxon, *D. tamarae*, is present there. The highest significant populations (>5%) of *Distephanus* for the subzone occur up through the middle of the subzone. The Quaternary species *Octactis pulchra* appears only at the top of the zone, after *Distephanus* has declined.

Dictyocha ornata Subzone

The *Dictyocha ornata* Subzone at DSDP Site 504 has common *Dictyocha ornata africana* in the lower part and sparse *D. ornata ornata* in the upper part. As at Atlantic sites and other eastern tropical Pacific (ETP) sites, the range and common occurrence of *D. perlaevis flexatella* is similar to *D. ornata*. Both taxa are most abundant in Cores 24 to 27, in the lower upper Pliocene. Other typical events for this subzone in the ETP that are duplicated at Site 504 are the extinction of *D. longa*, the first abundant *D. stapedia stapedia*, and the final decline or extinction of *D. brevispina*. A new correlation horizon within the *D. ornata* Subzone is suggested by the distribution of *D. concinna*. This species occurs in sediments representing a brief time and is present in moderate numbers (5% and 7%) at the same stratigraphic position at DSDP Holes 503A and 504. The conjunction of these occurrences and the age–depth plot for diatom index species at these sites yields an estimated age of 2.3 Ma for the *D. concinna* horizon. This is also the level of the extinction of *D. longa* at the two sites. The first *D. ornata* and *D. perlaevis flexatella* occur in Core 27, which according to shipboard diatom chronology lies between the first *Rhizosolenia praebergonii* (2.92 Ma) and the last *Nitzschia jouseae* (2.48 Ma).

Dictyocha fibula Zone, Redefined

The lower part of Site 504, in Cores 30 to 53, is assigned to the uppermost Miocene and lower Pliocene part of the *Dictyocha fibula* Zone on the basis of the low asperoid/fibuloid ratio, the occurrence of *Dictyocha longa* throughout the zone, and the sparse occurrence of species appearing in the Miocene *D. neonautica* Subzone of Cores 52 or 53. Asperoid taxa dominate *Dictyocha* in Cores 51 and 53 and are numerically important in Cores 48 to 50, and 52. (See *Dictyocha brevispina* Zone redefinition, below). Fairly long-ranged species such as *Distephanus speculum* and *Dictyocha perlaevis* are common; however, the disappearance of common *Dictyocha pulchella* and the appearance of *D. angulata* are closely spaced in the lower Pliocene (Cores 42–47) and help to divide the zone. This same sequence is also suggested in the lower Pliocene at Site 503 between Cores 21 and 27, and at Site 495 between Cores 11 and 13.

The base of the *Dictyocha fibula* Zone is redefined herein to be the first common occurrence of *Dictyocha longa*. Although assemblages above this level generally have asperoid/fibuloid ratios of less than one, the ratios are auxiliary criteria and not a prerequisite for identifying the redefined *Dictyocha fibula* Zone.

Dictyocha angulata Subzone

The new *Dictyocha angulata* Subzone is defined herein as the interval from the first occurrence to the last common *Dictyocha angulata*, which occupies the upper part of the *Dictyocha fibula* Zone, but may not extend completely to the top of the zone. The subzone is limited to the Pliocene in the known occurrences in the ETP at DSDP 495 (Core 11), 503A (Cores 20 and 21), and 504 (Cores 36–42) (see Bukry, in press a, c, for assemblages).

Dictyocha pulchella Subzone

The new *Dictyocha pulchella* Subzone is defined herein as the interval from the last *Dictyocha neonautica* to the last common *D. pulchella*. Long-ranging *D. pulchella* is common and consistently present into the lower Pliocene, permitting identification of the subzone at DSDP Hole 504 (Cores 47–53), DSDP Hole 503A (Cores 27–32), and DSDP Hole 495 (Core 13). These DSDP sites and holes corner a large triangular area in the ETP; however, at northwestern Pacific DSDP Site 310 the subzone is not recognized (Bukry, 1978a) and thus may be only of regional significance.

Dictyocha neonautica Subzone

The upper Miocene *Dictyocha neonautica* Subzone is not fully developed at DSDP Site 504. Only sparse specimens characteristic of the subzone occur in the basal Core 54. The specimens of *D. neonautica* var. *cocosen-*

sis, D. sp. aff. *D. subclinata*, and *D. transenna* are sparse, but probably represent the top of the *D. neonautica* Subzone.

Dictyocha brevispina Zone, Redefined

The original upper boundary of this zone is the change from minor-axis bar domination (asperoid) in *Dictyocha* to major-axis bar domination (fibuloid). It is now recognized that this shift is not permanent, but has reversed several times at various sites (Bukry, in press a, b). The shift in bar orientation is independent of various taxonomic preferences because Martini's (1971) systematics were broadly based. The asperoid/fibuloid ratio shift of dominance between species of *Dictyocha* is only a general lower boundary guide because it can reverse and create difficulty in zonal nomination.

A possible evolutionary replacement criterion was suggested for the ETP by the first common occurrence of *Dictyocha longa*, which appeared (7.1–7.2 Ma, according to Leg 68 diatom datums) near the time of the first(?) asperoid/fibuloid shift in the late Miocene (Bukry, in press a). This event occurs just below the base of the lower *Dictyocha neonautica* Subzone, and therefore the redefinition of the zone boundary should not require any reassignment of subzonal biostratigraphic units. Although *D. longa* is designated as the zone boundary species, the appearance of *D. neonautica* is only slightly higher at DSDP 503A (7.0–7.1 Ma, according to diatom datums), and could serve as an auxiliary marker species in the ETP.

PALEOTEMPERATURE VALUES

Paleotemperature values (T_s) calculated from the abundances of warm and temperate silicoflagellate genera (Bukry, in press d) appear in the species distribution figures (Fig. 1A–C). Several major paleotemperature trends which correlate with similar trends identified by a combination of diatom and silicoflagellate species events at DSDP Hole 503A occur where comparable HPC stratigraphic control is available (Figs. 2 and 3). Rotary coring and the broader sample interval at DSDP Hole 495 in the northern ETP prohibit such detailed comparison. The paleotemperature record for DSDP Hole 504 covers a partially younger interval (0.5–5.2 Ma) than DSDP Hole 503A (2.5–7.4 Ma); therefore, the overlap between the two sites extends from 2.5 to 5.2 Ma.

Mesocena quadrangula Peak (late Miocene, ~5.1 Ma)

DSDP Holes 503A and 504 both show a local maximum in the abundance of *M. quadrangula* (21% and 19%) at about 5.1 Ma, in the latest Miocene, in a fibuloid-dominated assemblage. The paleotemperature values for these coeval occurrences range from T_s 50 to 80 at DSDP Hole 503A and T_s 50 to 74 at DSDP 504. Further sampling of this event is needed.

Mesocena quadrangula/Dictyocha pulchella Warm Peak (early Pliocene, ~5.0 Ma)

Following the period of oscillating lower paleotemperature values in the latest Miocene of DSDP Hole 503A, a warm peak at about 4.9 to 5.0 Ma is indicated by T_s values up to 92 at DSDP Hole 503A and 85 at DSDP Hole 504. A local reduction in *M. quadrangula* and *Distephanus speculum* s. ampl. at this peak indicates warming prior to the disappearance of *D. pulchella*.

Dictyocha pulchella/Dictyocha angulata Cool Peak (early Pliocene, ~3.9–4.4 Ma)

Following the disappearance of *Dictyocha pulchella*, a moderate but fairly broad cool peak, culminating at about 4.1 Ma, occurs at both DSDP Holes 503A and 504. The T_s values for this peak at DSDP Hole 504 are considerably cooler (42–61) than at DSDP Hole 503A (68–72), and sample coverage at DSDP Hole 504 reveals a warming to T_s 88 which is superimposed on the broader cooling trend. This superimposed and perhaps local warm peak (T_s 88) at DSDP Hole 504 occurs just before 4.2 Ma and interrupts the broader trend for a decline from T_s 61 to T_s 42. The *D. pulchella/D. angulata* cool peak between about 3.9 to 4.4 Ma correlates with the early Pliocene glacial event between 4.2 and 4.3 Ma suggested by Keigwin (1979) at DSDP Site 158.

Dictyocha angulata Warm Peak (~3.4–3.8 Ma)

A distinctive, broad warm peak in T_s values occurs at both DSDP Holes 503A and 504, with the same apex value of T_s 97 between about 3.4 and 3.8 Ma. *Dictyocha angulata* disappeared during this period, a maximum T_s occurring near 3.6 Ma. Data on DSDP Hole 503A are insufficient to subdivide the chronologic record from 3.2 to 3.6 Ma; however, the 3.5-Ma *Thalassiosira convexa* diatom event coincides with part of a silicoflagellate warm peak, establishing a general upper limit near 3.5 Ma for this warm peak at DSDP Hole 503A.

Mesocena Cool Peak (early Quaternary, ~1.0–1.3 Ma) and *Dictyocha aculeata* Warm Peak (late Quaternary, 0.8 to ? Ma)

Minor T_s oscillations through the late Pliocene at DSDP Hole 504 cannot be correlated, because of a paucity of matching data for DSDP Hole 503A. The Quaternary *Mesocena* acme cooling (to T_s 63 from the Quaternary high of T_s 91) and the following *Dictyocha aculeata* warming (to T_s 98) are the most distinctive features of the T_s record for the younger strata of DSDP Hole 504.

The degree of cooling suggested for the early Pleistocene from approximately 1.0 to 1.3 Ma by the original calculation of T_s values ranging from 20 to 40 was exaggerated by the extremely prolific bloom of *Mesocena quadrangula* at DSDP Hole 504. Because an increase in the percentage of cold-water *Distephanus* (hexagonal) did not occur, a much more moderate cooling must be accepted. This is expressed by the addition of *M. quadrangula* as part of the temperate factor in the calculation of T_s values. The cooling trend during the *M. quadrangula* blooms would then be of a magnitude comparable to those of the late Pliocene. Therefore, T_s value calculations should add all quadrate *Mesocena* to the summation $T_s = X_w + 0.5X_t$ as part of the temperate factor X_t.

A. Cores 36 to 53

Age	Early Pliocene												Late Miocene				
Zone	*D. fibula*														*		*
Subzone	*D. angulata*							—			*D. pulchella*						*D. n.*
Sub-bottom Depth (m)	167.3	168.8	174.7	183.5	186.4	190.4	191.4	197.4	198.4	202.4	210.4	214.4	218.4	222.4	226.4	230.4	234.3
Hole 504 Sample (interval in cm) / Taxa	36,CC	37-1, 42–43	38-2, 42–43	40-2, 42–43	41-1, 42–43	42-1, 42–43	42-2, 42–43	43-3, 42–43	44-1, 42–43	45-1, 42–43	47-1, 42–43	48-1, 42–43	49-1, 42–43	50-1, 42–43	51-1, 42–43	52-1, 42–43	53-1, 26–27
Dictyocha angulata	28	21	<1	<1	7	30	25										
D. sp. cf. *D. angulata*									10	1							
D. aspera aspera							1						1	1	1	1	
D. aspera clinata s. ampl.											1			<1	1		
D. brevispina	3	11	1	1	3	5	4	3	2	X		12	8	7	12	1	4
D. brevispina (no bar)										8							
D. brevispina (giant asymmetric)													2	X			
D. concavata			1			5		<1									2
D. fibula s. ampl.	2	2	3	5	6	5	4	4	2	5	7	1		2	1	2	7
D. longa	14	7	16	7	1	15	22	20	12	28		12	7	2	1	3	3
D. longa var. *paxilla*		<1	4	3	4	18	6		5	10	23	22	14	18	9	6	2
D. perfecta	5	7	2	20	11	2		3	8	7	18	5	1		<1	13	<1
D. perlaevis	36	27	12	7	30	3	1	21	12	8	10	6	9	1		8	1
D. pulchella			1	3		1		<1	1		13	22	21	15	24	14	18
D. sp. aff. *D. pulchella* (angular)															1	10	4
D. neonautica var. *cocosensis*																X	<1
D. sp. aff. *D. subclinata*																	2
D. transenna												<1					
D. sp. aff. *D. transenna* (spined)																<1	1
D. varia								1				<1				1	
D. spp.	4	5	1	10	9	3	11	17	5	6	12	3	3	2	<1	4	3
Distephanus boliviensis	<1	1		1			<1										
D. crux crux s. ampl.			<1	<1					2	<1			2	1	2		
D. crux bispinosus	<1		1						2			1					
D. crux carolae		<1			1	1	1	1	4	5						<1	
D. sp. cf. *D. frugalis*				<1						<1			1				
D. mesophthalmus												<1					
D. polyactis																	<1
D. quinquangellus				<1			1	<1	<1	<1			<1		<1	1	
D. speculum bispicatus	4	5	27	5	4	2	9	12	4	1		3	10	3	4	3	2
D. speculum f. *coronata*		1															
D. speculum minutus				<1													
D. speculum speculum	3	14	32	34	20	7	12	9	23	12	9	10	22	34	40	14	44
D. speculum tenuis		<1	<1					<1									
D. sp. A (Bukry, 1979)					2	<1											
Mesocena circulus	1			2	5	2	2	4	6								
M. diodon nodosa			<1R												<1	1	<1
M. quadrangula									2	8		<1	<1	13	2	8	
M. quadrangula (distorted)								4								11	6
M. quadrangula (transennoid)										X				<1			X
M. triodon																1	
Total Specimens	300	300	300	300	300	300	300	300	300	300	100	300	300	300	300	300	300
Paleotemperature Value	92	81	42	57	72	88	75	72	62	80	84	85	68	56	53	74	50

Figure 1. A. Silicoflagellates from Cores 3 to 53 of DSDP Hole 504 recorded as percentages. The asperoid/fibuloid ratio is greater than one in Cores 51 and 53 (*), which would have indicated the *Dictyocha brevispina* Zone prior to a redefinition of that zone herein; *D. n.* = *Dictyocha neonautica;* X = recorded after count; R = probably a reworked occurrence.

LOWER PLIOCENE SILICOFLAGELLATE CORRELATION FOR THE EASTERN TROPICAL PACIFIC OCEAN

The lower Pliocene is one of the least-known intervals in silicoflagellate biostratigraphy, but recent hydraulic-piston coring and rotary-coring operations by D/V *Glomar Challenger* in the eastern tropical Pacific Ocean have provided three excellent new reference sections at DSDP Holes 495 (12°29.78N, 91°02.26W; depth 4140 m), 503A (4°04.04N, 95°38.21W; depth 3672 m), and 504 (1°13.58N, 83°43.93W; depth 3460 m). The quanti-

B. Cores 19 to 35

Age	Late Pliocene									Early Pliocene							
Zone	*D. stapedia*											*D. fibula*					
Subzone	*D. ornata*									—		—					
Sub-bottom Depth (m)	91.1	95.5	98.4	102.8	107.2	111.6	119.0	120.4	124.8	130.7	136.6	138.0	142.4	146.8	151.2	156.0	160.0
Hole 504 Sample (interval in cm) / Taxa	19-2, 42–43	20-2, 42–43	21-2, 42–43	22-1, 42–43	23-1, 42–43	24-1, 42–43	25-3, 42–43	26-1, 42–43	27-1, 42–43	28-2, 42–43	29-3, 42–43	30-1, 42–43	31-1, 42–43	32-1, 42–43	33-1, 42–43	34-1, 82–83	35-1, 42–43
Dictyocha sp. aff. *D. aegea*								<1	1	1							
D. angulata										1			<1			1	
D. aspera													1		2		
D. brevispina	1							1	1	3	3	<1	1	3	5	2	
D. calida ampliata			<1														
D. calida calida	<1	4	5				1	2		3			<1				
D. concavata			<1	<1												10	
D. concinna						7											
D. sp. aff. *D. delicata*	<1								1	3							2
D. delicata var. *bisecta*			<1									4	19		8		
D. fibula s. ampl.							5		1		1	2	1			3	
D. helix	1	<1															
D. longa	<1R					6	9	11			3	3	4	15	6	4	22
D. longa var. *paxilla*								<1						38	22	11	39
D. neonautica var. *cocosensis*																1R	
D. ornata africana						1	2	22	8								
D. sp. aff. *D. ornata ornata*	2	<1	<1														
D. perfecta						4	<1				4	<1	8	13	5	23	
D. perlaevis flexatella				12		7	20	14	9					<1			
D. perlaevis perlaevis	7	2	1	7	9	17	29	25	59	51	46	56	25	10	40	29	19
D. pulchella							<1	1							1		
D. sp. aff. *D. pumila*											<1	2	1				
D. stapedia aspinosa	5	9	13	8		10				11	21	18	6				
D. sp. aff. *D. stapedia aspinosa*					62				<1								
D. stapedia stapedia	50	74	73	33	19	13			1	5	3	1					
D. varia																1	
D. spp.	7	2	2	3		6	3	4	3	2	4	2	7	15	7	6	5
Distephanus boliviensis	1			3	7	1	3	4	2	5	2	3	2			3	<1
D. boliviensis (divided ring)							<1		3								
D. crux bispinosus																	<1
D. major										1	2	<1					
D. sp. aff. *D. mesophthalmus*				2													
D. quinquangellus	5	4	3	28	1	15			<1	1	1	<1	4	1			
D. speculum bispicatus						1	3	2	1	3	2	1	2			2	3
D. speculum f. *coronata*				<1		1			1								
D. speculum elongatus									<1				1				
D. speculum speculum	2		<1	1	1	10	22	13	5	11	1	6	15	4	6	7	9
D. speculum tenuis				<1										<1			
D. sp. A (Bukry, 1979)	19	4	<1		<1		<1		1				<1		1	1	
D. spp. (cruxoid)											<1						
Mesocena circulus				2	<1	<1	1	3	3	3	1	<1	2				
M. quadrangula										1				1	1		
Total Specimens	300	300	300	300	300	300	300	300	300	200	300	300	300	300	200	200	300
Paleotemperature Value	74	92	95	64	90	71	70	80	84	76	85	89	74	95	97	87	87

Figure 1. (Continued).

tative analysis of silicoflagellates reveals a consistent sequence of appearances and disappearances between some old and new species at all three sites. The sequence within the redefined Miocene–Pliocene *Dictyocha fibula* Zone includes the disappearance of *Dictyocha pulchella* just above the Miocene/Pliocene boundary, followed closely by the appearance and acme of *D. angulata*. Both events help define new subzonal boundaries in the ETP between the *D. angulata* Subzone and *D. pulchella* Subzone. According to correlative diatom events and age

C. Cores 3 to 18

Age	Zone (Subzone)	Hole 504 Sample (interval in cm)	Sub-bottom Depth (m)	Total Specimens	Paleotemperature Value	*Dictyocha aculeata*	*D.* sp. aff. *D. aculeata*	*D. angulata*	*D. brevispina*	*D. calida calida*	*D. calida ampliata*	*D. delicata*	*D. delicata* var. *bisecta*	*D. fibula* s. ampl.	*D. helix*	*D. longa*	*D. neonautica* var. *cocosensis*
		3-3, 42–43	22.2	200	98	6	1			36							
	D. aculeata	4,CC	27.4	200	97	13	4			10	1	1R		2		1R	1R
		5-2, 42–43	29.5	300	95	9	15			7	1						
		5,CC	31.2	200	94	12	9										
		6-1, 42–43	32.4	300	96	3	3			<1							
Pleistocene		6-2, 42–43	33.9	300	98	9	5			3	1						
		7-2, 42–43	38.3	300	84					13	1						
	M. quadrangula	8-2, 42–43	42.7	300	63					1	1						
		9-2, 42–43	47.1	300	65					<1	1						
		10-2, 42–43	51.5	300	68	2		<1									
		11-2, 42–43	55.9	300	77				1R	2							
		12-1, 22–23	58.6	300	91							9					
		13-3, 42–43	66.2	300	90							29					
-----	*D. stapedia*	14-2, 42–43	69.1	200	78				1	1		6	1R	1			
	(D. delicata)	15-1, 112–113	72.7	300	87				1	1		23		<1			
Late		16-2, 42–43	77.9	300	88					2							
Pliocene		17-1, 42–43	80.8	300	69					1	<1				X		
		18-3, 42–43	88.2	300	91					43	1	6			<1		

Figure 1. (Continued).

estimates at DSDP Holes 503A and 504, the last common occurrence of *D. pulchella* is bracketed between the highest occurrence surface (HOS) of *Thalassiosira miocenica* and the lowest occurrence surface (LOS) of *Nitzschia jouseae* (~4.4–5.0 Ma). The *D. pulchella* event occurs between Core 47 and 45 of DSDP Hole 504.

The first *Dictyocha angulata* s. str. is in Core 42 at DSDP Hole 504, which is bracketed below by diatom HOS *Nitzschia cylindrica* and above by LOS *Thalassiosira convexa* (~3.5–4.2 Ma) at DSDP Holes 503A and 504. *D. angulata* has significant abundances up to 30%, or consistent presence, through Cores 36 to 42 of DSDP Hole 504. Compared specimens of *D. angulata* appear slightly lower in Cores 44 and 45; sparse, sporadic, possibly displaced specimens occur between Cores 28 to 34 in the lower Pliocene.

The next-higher event at DSDP Holes 495, 503A, and 504 is the brief appearance of *Dictyocha delicata* var. *bisecta*, which is in the lowest *Dictyocha stapedia* Zone of DSDP Holes 495 and 503A, but in the highest *Dictyocha fibula* Zone of DSDP Hole 504. All occurrences are near the upper/lower Pliocene boundary, DSDP Hole 504 occurrences being the oldest. *D. delicata* var. *bisecta* is bracketed at both DSDP Holes 503A and 504 by the diatom events LOS *Thalassiosira convexa* s. str. below and LOS *Rhizosolenia praebergonii* above (~3.0–3.5 Ma).

This comparison of significant silicoflagellate and diatom events between ETP sites shows divergence of the first *Dictyocha stapedia stapedia* from the diatom age curve of DSDP Holes 503A and 504. This may be a result of the sparseness of early occurrences and of the interpretation of possible transitional specimens in early populations. Note the overlapping occurrences between *D. longa* var. *paxilla* and *D. stapedia stapedia* near the upper/lower boundary at DSDP Hole 503A (Bukry, in press a). Allowing for the abbreviated stratigraphic coverage at DSDP Hole 495, however, the general sequence near the boundary includes *Dictyocha delicata* var. *bisecta* acme below, followed closely by first *D. stapedia stapedia* s. str., and finally at or just above the boundary the appearances of *D. ornata africana* and *D. perlaevis flexatella*. The distinctive morphologies of the latter two subspecies are convenient guides to distinguish upper from lower Pliocene silicoflagellate assemblages at these DSDP sites in the ETP.

The basal subzone of the upper Pliocene, *Dictyocha ornata* Subzone, occurs at both DSDP Holes 503A and 504. The brief acme of new species *Dictyocha concinna* has been recorded in single Cores 503A-13 and 504-24 near the top of the range of *D. longa*. These occurrences of *D. concinna* coincide with the diatom age–depth curve between HOS *Nitzschia jouseae*, below, and HOS *Thalassiosira convexa*, above (~2.1–2.5 Ma).

D. perfecta	*D. perlaevis flexatella*	*D. perlaevis perlaevis* s. ampl.	*D. stapedia aspinosa*	*D. stapedia stapedia*	*D. subaculeata*	*D.* sp. aff. *D. subaculeata*	*D. tamarae*	*D. vexativa*	*D.* spp. (indeterminate)	*Distephanus boliviensis*	*D.* sp. aff. *D. mesophthalmus*	*D. quinquangellus*	*D. speculum bispicatus*	*D. speculum* f. *coronata*	*D. speculum speculum*	*D.* sp. A (Bukry, 1979)	*D.* spp. (cruxoid)	*Mesocena circulus*	*M.* sp. cf. *M. circulus*	*M. quadrangula*	*Octactis pulchra*
		18	5	26	7				1												2
		8	32	12	7				10						2						1
		4	1	41	17											3			<1		1
		25	14	6	25				6							2					4
		61	18	6					3							1				4	1
		58	<1	13	3				4											4	1
		38		12	3				1							2				31	<1
		7		12	4				1						<1	1				73	<1
		1	1	27	<1				<1	<1						1				68	<1
		2		30		4			1	<1			<1		1					58	
		7		42		4			1				1		1					40	2
		8		67						<1			<1		1	<1				14	1
		25	1	27		1									<1	5	1			11	
		8		62				1	2	3		5	1	1	5	6		1			
		28	1	31					<1			6	<1		2	5	<1			2	
	1	10	1	39			30		5			5			<1	6					
<1R	X	9	10	44		3	1					7			2	23					
		23	<1	12					1	2	9	1			<1	1					

Figure 1. (Continued).

Similarities in the Pliocene silicoflagellate sequences of events for the ETP DSDP sites, especially the two hydraulic-piston-cored sites, indicates that local biostratigraphic correlation using silicoflagellates is possible, and that considerable improvement can be expected when taxonomic discrimination is refined.

SYSTEMATIC PALEONTOLOGY OF NEW TAXA

Genus *DICTYOCHA* Ehrenberg, 1837

Dictyocha concinna **Bukry, n. sp.**
(Plate 2, Figs. 5–11)

Dictyocha sp. A Bukry, in press c, pl. 5, fig. 3.

Description. *Dictyocha concinna* has a moderate-sized ring that is only very slightly scalloped and nearly square in format; the minor axis internal diameter is 93 to 98% (96% mean) of the major axis. All spines are short and essentially equant. Basal pikes are short and are under or just beside the strut-ring junctions. The bar is short and the struts are oriented symmetrically.

Remarks. *Dictyocha concinna* is distinguished from *D. calida calida* by much shorter spines, shorter and thicker bar, less-scalloped outline, more-equant axial diameters yielding a squarer format. *D. calida calida* axial ratios range from 87 to 93% (mean 91%). Shorter spines and the squarer format are most distinctive. *D. concinna* is distinguished from *D. stapedia aspinosa* by symmetric strut orientation and short spines.

Occurrence. *Dictyocha concinna* was first tabulated and illustrated from a single upper Pliocene sample at DSDP Hole 503A, northwest of the Islas Galapagos (Bukry, in press a). The abundance of 5% and short range in the *Dictyocha ornata* Subzone justified distinction from "*D.* spp." At DSDP Hole 504, this identical species occurs at 7% in a single sample in the *D. ornata* Subzone. In addition, the *D. concinna* occurrences from DSDP Holes 503A and 504 plot onto the diatom age curve for these two sites at a level between HOS of *Nitzschia jouseae* and HOS of *Thalassiosira convexa* (~2.1–2.5 Ma). This suggests that *D. concinna* provides a new marker horizon within the upper Pliocene *D. ornata* Subzone of the ETP.

Size. Maximum internal diameter 19 to 28 μm (holotype 22 μm).

Holotype. USNM 321351 (Plate 2, Fig. 5).

Isotypes. USNM 321352 to 321356.

Type locality. Eastern tropical Pacific, DSDP Sample 504-24-1, 42–43 cm.

Dictyocha helix **Bukry, n. sp.**
(Plate 3, Figs. 5–10; Plate 4, Figs. 1, 2)

Description. *Dictyocha helix* has a strongly canted, short apical bar which has a spire on some specimens. The strut-ring junctions are nonsymmetric. The basal-ring pattern is slightly torqued in a clockwise sense in apical view, as seen by nonalignment of spine sets and ring curvature. Spines are moderate to typically long, but basal pikes are missing or very small, directly below the struts. The minor-axis inner diameter is 92 to 100% (mean 94%) of the major axis, producing nearly equant rings. Bar orientation is about equally divided between asperoid and fibuloid forms.

Remarks. *Dictyocha helix* is distinguished from the similarly torqued subspecies *D. perlaevis flexatella* by much shorter bar and squarer, less-elongate ring format, resulting in struts that are more equant. *D. helix* is distinguished from older *D. aspera clinata* by shorter bar and thinner spines.

Occurrence. *Dictyocha helix* is most abundant (1%) in the upper Pliocene of Core 19 at DSDP Hole 504. It is sparser above and below in Cores 18 and 20. This range straddles the *Dictyocha ornata* Subzone/*D. delicata* Subzone boundary.

Size. Maximum internal diameter 20 to 24 μm (holotype 22 μm).

Holotype. USNM 321357 (Plate 3, Figs. 5,6).

Isotypes. USNM 321358 to 321362.

Type locality. Eastern tropical Pacific, DSDP Sample 504-19-2, 42–43 cm.

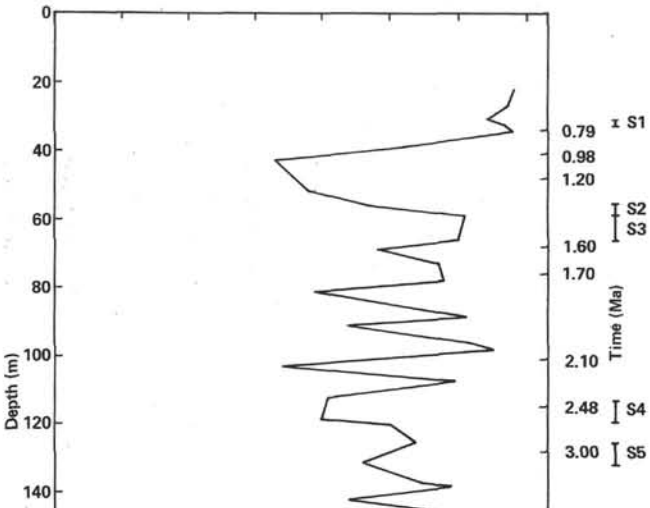

Figure 2. Silicoflagellate relative paleotemperature curve for DSDP Hole 504 samples. Approximate chronology based on shipboard diatom ages (Ma); see also Sancetta (this volume). Silicoflagellate data for the curve are available in the species-occurrence figures. Useful silicoflagellate biostratigraphic events include: S1 = Last *Mesocena quadrangula*. S2 = Last *Dictyocha delicata*. S3 = First *Octactis pulchra*. S4 = First *Dictyocha concinna*. S5 = First *Dictyocha ornata africana*. S6 = First *Dictyocha delicata* var. *bisecta*. S7 = First *Dictyocha angulata*. S8 = Last common consistent occurrence of *Dictyocha pulchella*. S9 = Local late Miocene acme of *Mesocena quadrangula*.

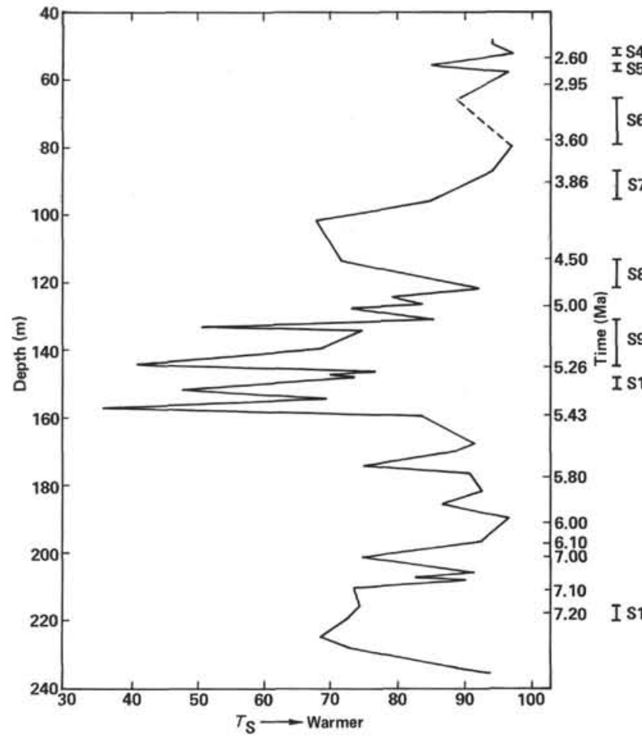

Figure 3. Silicoflagellate relative paleotemperature curve for DSDP Hole 503A samples. Approximate chronology based on shipboard diatom ages (Ma); see also Sancetta (this volume). Silicoflagellate data for the curve are available in the original species-occurrence figures (Bukry, in press a). Useful silicoflagellate biostratigraphic events include: S10 = First *Dictyocha neonautica* var. *cocosensis*. S11 = First *Dictyocha longa*. See Figure 2 for definitions of S1 to S9.

Dictyocha tamarae **Bukry, n. sp.**
(Plate 5, Figs. 7–11; Plate 6, Fig. 1)

Description. *Dictyocha tamarae* has a large ring with fairly angular corners, especially along the major axis. Basal pikes are long and conspicuous; one opposed set is at strut-ring junctions and the other well offset, between the strut junction and minor axis. The bar is very long and may have a low spire. The width of the bar equals that of the ring or is very slightly narrower. Struts are short and oriented slightly asymmetrically. Spines are moderate, and the major-axis spines are longer than the minor-axis spines.

Remarks. *Dictyocha tamarae* is distinguished from *D. delicata* var. *bisecta* by more-equant axial lengths and more-angular basal ring. It is also distinguished by conspicuous basal pikes, spire, and thicker bar. Both have a prominent long bar as a main characteristic. *D. tamarae* is distinguished from *D. delicata* by longer and thicker bar, longer basal pikes, more-angular ring apices, and less-scalloped outline.

Occurrence. *Dictyocha tamarae* occurs in the upper Pliocene Cores 16 and 17 of DSDP Hole 504 at abundances of 1 and 30%. These occurrences are within the *Dictyocha delicata* Subzone, but *D. delicata* is missing in these cores, and *D. tamarae* seems to have taken its place.

Size. Maximum internal diameter 25 to 30 μm (holotype 27 μm).

Holotype. USNM 321363 (Plate 5, Figs. 7,8).

Isotypes. USNM 321364 to 321367.

Type locality. Eastern tropical Pacific, DSDP Sample 504-17-1, 42–43 cm.

Dictyocha **sp. A**
(Plate 6, Figs. 5–8)

Remarks. During photography, one of the silicoflagellates tabulated among the unspecified *Dictyocha* spp. from Sample 504-44-1, 42–43 cm was distinguished by small size, short spines, short bar, and great width along the minor axis. *Dictyocha* sp. A is distinguished from *D. concinna* by smaller size and less-equant spines, and by a more-inflated appearance along the minor axis, which is created by great width and more-rounded portals. Size and shape are consistent within the sample. Maximum internal diameter is 16 to 18 μm.

SYSTEMATIC PALEONTOLOGY OF PREVIOUSLY CITED TAXA

Genus *DICTYOCHA* Ehrenberg, 1837

Dictyocha aculeata **(Lemmermann) Dumitrică**

Dictyocha fibula var. *aculeata* Lemmermann, 1901, p. 261, pl. 11, figs. 1,2.

Dictyocha aculeata (Lemmermann) Dumitrică, 1973a, p. 907, pl. 9, figs. 5–10.

Remarks. Many of the forms with affinities to *Dictyocha aculeata* have a long apical bar.

Dictyocha aegea **Stradner and Bachmann**

Dictyocha aegea Stradner and Bachmann, 1978, p. 805, pl. 1, figs. 12–16; fig. 1.

Dictyocha venzoi Morlotti and Rio, 1978 [1980], p. 102, pl. 2, figs. 5, 6; pl. 3, fig. 1.

Dictyocha aegea Stradner and Bachmann, Bukry, in press c.

Remarks. Forms with affinities to *Dictyocha aegea* in Cores 27 and 28 are elongate but lack the typical recurved side portals (Plate 1, Fig. 1).

Dictyocha angulata **Bukry**
(Plate 1, Figs. 2-5)

Dictyocha angulata Bukry, in press c, pl. 1, figs. 9-12.

Remarks. Some aberrant specimens lacking minor-axis spines and some having asperoid bar alignment occur in the highest sample (Core 36), where *Dictyocha angulata* is abundant. In Core 44, below the range of *D. angulata* s. str., some specimens intermediate between *D. fibula* and *D. angulata* are tabulated as *D.* sp. cf. *D. angulata*. The high abundance of *D. angulata* near the top of the *Dictyocha fibula* Zone in Cores 36 to 42 aids in distinguishing the new *Dictyocha angulata* Subzone.

Dictyocha aspera aspera **(Lemmermann) Bukry and Foster**

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

Dictyocha aspera (Lemmermann) Bukry and Foster, 1973 (in part), p. 826, pl. 2, figs. 4,6.

Dictyocha aspera clinata **Bukry**

Dictyocha clinata aspera Bukry, 1975, p. 695, pl. 1, figs. 1-5.

Dictyocha brevispina **(Lemmermann) Bukry**
(Plate 1, Figs. 6-11; Plate 2, Figs. 1, 2)

Dictyocha fibula var. *brevispina* Lemmermann, 1901, p. 260.

Dictyocha brevispina (Lemmermann) Bukry, 1976, p. 723.

Dictyocha brevispina (Lemmermann), Bukry, in press d.

Remarks. Variant populations without bars (Core 45) and giant asymmetric forms are tabulated separately. Dumitrică (1973b) illustrated a barless variant at DSDP Hole 206 from lower Pliocene Core 18.

Dictyocha calida ampliata **Bukry**
(Plate 2, Fig. 4)

Dictyocha calida ampliata Bukry, 1979a, p. 982, pl. 2, figs. 1,2,9.

Remarks. One specimen with all portals elongate and a short bar was noted in Sample 504-5-2, 42-43 cm.

Dictyocha calida calida **Poelchau**

Dictyocha calida Poelchau, 1976, p. 169, pl. 1, figs. a-f.

Dictyocha calida calida Poelchau, Bukry, 1979a, p. 982, pl. 2, figs. 3,4.

Dictyocha concavata **Dumitrică**
(Plate 2, Fig. 3)

Dictyocha concavata Dumitrică, 1978, p. 212, pl. 3, figs. 1-4.

Dictyocha concavata Dumitrică, Bukry, in press d, pl. 1, figs. 1,2.

Dictyocha delicata **(Bukry) Bukry**
(Plate 3, Fig. 1)

Dictyocha perlaevis delicata Bukry, 1976, p. 724, pl. 1, figs. 5-10.

Dictyocha delicata (Bukry) Bukry, in press c, pl. 2, fig. 7.

Remarks. *Dictyocha delicata* is common only in late Pliocene and early Pleistocene Cores 12 to 18. Sparse *D.* sp. aff. *D. delicata* in lower cores have thin apical bars, but the ring is not proportionally as thick as in *D. delicata*. A new, possibly related species, *D. tamarae*, is distinguished by its long bar and angular ring; *D. delicata* var. *bisecta* has a long bar, but a rounded ring.

Dictyocha delicata **(Bukry) Bukry var.** *bisecta* **Bukry**
(Plate 3, Figs. 2-4)

Dictyocha delicata (Bukry) Bukry var. *bisecta* Bukry, in press c, pl. 2, figs. 3-6.

Remarks. This distinctive variety with an unscalloped ring occurred in a single sample at DSDP Hole 495, to the north, in the base of the *Dictyocha stapedia* Zone. At DSDP Hole 504, it occurs slightly lower, in the uppermost *D. fibula* Zone. The earliest population of *Dictyocha delicata* var. *bisecta* in Core 33 of DSDP Hole 504 contains several specimens with robust rings that suggest similarity to the form of *Mesocena quadrangula*. This species could be a source for polyphyletic *M. quadrangula*.

Dictyocha fibula **Ehrenberg**

Dictyocha fibula Ehrenberg, 1839, *fide* Loeblich et al., 1968, p. 90, pl. 9, figs. 7-12.

Dictyocha fibula fibula Ehrenberg, Bukry, 1976, p. 723, pl. 1, figs. 3,4.

Dictyocha fibula fibula Ehrenberg, Bukry, 1978b, p. 697, pl. 2, figs. 1,2.

Dictyocha fibula Ehrenberg, Bukry, 1980a, p. 514, pl. 2, figs. 1,2.

Remarks. Moderate to small forms with little scalloping of the ring are tabulated as *Dictyocha fibula* s. ampl. The morphologic pattern of this species is simple, and direct lineages to the original middle and upper Miocene populations illustrated from Ehrenberg in Loeblich et al. (1968, pl. 9) would be difficult. Figures 8 and 9 (especially) in the Loeblich reference are used for the species concept of *D. fibula*. Figure 12 is similar, but seems to have asymmetric strut placement, instead of the regular arrangement in *D. fibula* of Figure 9.

Dictyocha longa **Bukry**
(Plate 4, Figs. 3,4)

Dictyocha perlaevis perlaevis Frenguelli, Bukry, 1980b (in part), p. 553, pl. 4, figs. 10-13.

Dictyocha longa Bukry, in press c, pl. 2, figs. 8-13; pl. 3, figs. 1,2.

Remarks. A few specimens of *Dictyocha longa* in Core 31 lack minor-axis spines, otherwise the morphology is similar to forms at other ETP sites.

Dictyocha longa **var.** *paxilla* **Bukry**
(Plate 4, Figs. 5,6)

Dictyocha longa var. *paxilla* Bukry, in press c, pl. 3, figs. 3-8.

Dictyocha longa var. *paxilla* Bukry, Bukry, in press a, pl. 2, fig. 9.

Dictyocha neonautica **var.** *cocosensis* **Bukry**
(Plate 4, Fig. 7)

Dictyocha neonautica var. *cocosensis* Bukry, in press b.

Dictyocha navicula Ehrenberg, Bukry and Foster, 1973 (in part), p. 827, pl. 3, fig. 8.

Dictyocha neonautica var. *cocosensis* Bukry, in press d, pl. 3, figs. 1-3.

Remarks. Most of the strata cored at DSDP 504 are younger than the main range of *Dictyocha neonautica* var. *cocosensis*. The specimen in the basal part of Core 53 probably is the top of the natural range, but it could also be mixed from below, because shipboard scientists described intense bioturbation of Core 53.

Dictyocha ornata ornata **(Bukry) Bukry**

Dictyocha perlaevis ornata Bukry, 1977, p. 922, pl. 1, figs. 1-6.

Dictyocha ornata ornata (Bukry) Bukry, in press c.

Remarks. *Dictyocha* sp. aff. *D. ornata ornata* is less abundant than *D. ornata africana* at DSDP Hole 504, and occurs in the upper part of the *Dictyocha ornata* Subzone. These larger-than-normal specimens are recorded in Cores 19 to 21.

Dictyocha ornata africana **Bukry**

Dictyocha perlaevis ornata Bukry, Bukry, 1978a, p. 644, pl. 1, figs. 7,8.

Dictyocha ornata africana Bukry, in press c, pl. 3, fig. 11; pl. 4, figs. 1,2.

Remarks. *Dictyocha ornata africana* occurs earlier and more abundantly than *D. ornata ornata* at DSDP Hole 504 in upper Pliocene Cores 24 to 27.

Dictyocha perfecta **Bukry**
(Plate 4, Figs. 8,9)

Dictyocha perfecta Bukry, in press a, pl. 3, figs. 5-10.

Remarks. Typically formed *Dictyocha perfecta* are common in Pliocene Cores 26 and 32. *D. perfecta* is a large species, distinguished from *D. perlaevis* by both narrower format and shorter bar.

Dictyocha perlaevis flexatella Bukry
(Plate 4, Figs. 10,11)

Dictyocha perlaevis flexatella Bukry, 1979a, p. 984, pl. 3, figs. 1-3.

Remarks. *Dictyocha perlaevis flexatella* is limited to the upper Pliocene at DSDP Hole 504. Fully-developed forms occur with those showing partial torque symmetry.

Dictyocha perlaevis perlaevis Frenguelli
(Plate 4, Fig. 12)

Dictyocha perlaevis Frenguelli, 1951, p. 279, figs. 4b, c.

Dictyocha perlaevis perlaevis Frenguelli, Bukry, 1979a, p. 984, pl. 3, figs. 6-11.

Remarks. *Dictyocha perlaevis perlaevis* is a common to abundant warm-water species which attains its greatest abundance (59%) at DSDP Hole 504 (Core 27) in the middle of the Pliocene. Specimens in Core 17 have a shorter bar than is typical.

Dictyocha pulchella Bukry
(Plate 5, Fig. 1)

Dictyocha pulchella Bukry, 1975, p. 687, pl. 4, figs. 1-3.

Remarks. *Dictyocha pulchella* is smaller than *D. brevispina* and has relatively larger minor-axis portals. It is common to abundant from the upper lower Miocene to lower Pliocene. It is essentially absent above Core 47, which marks the top of the new *D. pulchella* Subzone of the *Dictyocha fibula* Zone.

Some specimens from Cores 52 and 53 have longer bars and more-angular short-axis portals than typical *D. pulchella* (Plate 5, Fig. 2); these are tabulated separately.

Dictyocha pumila (Ciesielski) Bukry

Dictyocha fibula var. *pumila* Ciesielski, 1975, p. 656, pl. 5, figs. 5-10; pl. 6, fig. 1, ?2.

Dictyocha pumila (Ciesielski) Bukry, 1978a, p. 642.

Dictyocha pumila (Ciesielski), Bukry, 1979a, p. 984, pl. 4, fig. 3.

Remarks. A few small lower Pliocene specimens in Cores 29 to 31 show flexed rings and slightly bent spines and resemble *Dictyocha pumila*. A population of *D.* sp. aff. *D. stapedia aspinosa* in Core 23 is suggestive of *D. pumila*, but these specimens have only slightly irregular rings and normal spines.

Dictyocha stapedia aspinosa Bukry

Dictyocha stapedia aspinosa Bukry, 1976, p. 724, pl. 2, figs. 6-9.

Remarks. This moderate-sized taxon ranges from the lower Pliocene to upper Pleistocene at abundances up to 32% at DSDP Hole 504. An unusual population with slightly irregular rings is tabulated as *D.* sp. aff. *D. stapedia aspinosa* for Core 23 (Plate 5, Fig. 3).

Dictyocha stapedia stapedia Haeckel

Dictyocha stapedia Haeckel, 1887, p. 1561, pl. 101, figs. 10-12.

Dictyocha stapedia stapedia Haeckel, Bukry, 1980b, p. 553, pl. 5, figs. 8-10.

Remarks. On the basis of DSDP Hole 503A assemblages, early *Dictyocha stapedia stapedia* appears to be derived from *D. longa* var. *paxilla* through at least one transitional form with lobed outline, but asymmetric struts. Such a transition form was not observed from DSDP Hole 504, and, aside from the early form in Cores 29 and 30, the other populations have typical morphologies.

D. stapedia stapedia is one of the dominant species through the upper Pliocene to Pleistocene in Core 24 and above.

Dictyocha subaculeata (Bukry) Bukry

Dictyocha aculeata subaculeata Bukry, 1980b, p. 552, pl. 1, figs. 8-17.

Dictyocha subaculeata (Bukry) Bukry, in press c.

Remarks. *Dictyocha* sp. aff. *D. subaculeata* in Cores 10 and 11 are large like *D. aculeata*, but lack the diagnostic peripheral pikes of that species (Plate 5, Fig. 4).

Dictyocha subclinata Bukry

Dictyocha subclinata Bukry, in press d, pl. 1, figs. 4-8; pl. 2, figs. 1-10.

Remarks. Only specimens with close affinities to *Dictyocha subclinata* (Plate 5, Figs. 5,6) were encountered in Core 53.

Dictyocha transenna Bukry
(Plate 6, Fig. 2)

Dictyocha transenna Bukry, in press a, pl. 4, figs. 1-12; pl. 5, figs. 1,2.

Remarks. One specimen of this late Miocene species is possibly displaced in earliest Pliocene Core 48. Sparse specimens bearing minor-axis spines occur in late Miocene Cores 52 and 53 and are tabulated as *D.* sp. aff. *D. transenna* (Plate 6, Figs. 3,4). It is not clear whether the extra spines are a recapitulation of the parent stock or a new, reiterative development in *D. transenna*.

Dictyocha varia Locker

Dictyocha varia Locker, 1975, p. 7, text-figs. 1/1 to 1/3 and 3 to 7.

Dictyocha vexativa Bukry

Dictyocha vexativa Bukry 1978a, p. 642, pl. 1, figs. 10-14.

Dictyocha spp.
(Plate 6, Figs. 9-12)

Remarks. This is a miscellaneous group that is largely composed of tilted or covered specimens and presently unclassified morphologies. The vast majority are fibuloid specimens which cannot be assigned with assurance to any currently used taxonomic concept.

Genus DISTEPHANUS Stöhr, 1880

Distephanus boliviensis (Frenguelli) Bukry and Foster
(Plate 7, Fig. 1)

Dictyocha boliviensis Frenguelli, 1940, p. 44, fig. 4.

Distephanus boliviensis (Frenguelli) Bukry and Foster, 1973, p. 827, pl. 4, figs. 1-3.

Remarks. Specimens with the divided apical rings, but having the same basal ring and spine configuration of *Distephanus boliviensis*, are not assigned to *D. major*. They occur in upper Pliocene Cores 25 and 27 and are tabulated as *D. boliviensis* (divided ring).

Distephanus crux crux (Ehrenberg) Haeckel

Dictyocha crux Ehrenberg, 1840, p. 207; Ehrenberg, 1854, pl. 18, fig. 56; pl. 20 (1), fig. 46; pl. 33 (15), fig. 9; pl. 33 (16), fig. 9; pl. 33 (17), fig. 5.

Distephanus crux (Ehrenberg), Bukry, in press c.

Distephanus crux bispinosus Dumitrică
(Plate 7, Fig. 2)

Distephanus crux spp. *bispinosus* Dumitrică, 1973b, p. 850, pl. 6, figs. 3,6,7.

Remarks. *Distephanus crux bispinosus* is sparse in lower Pliocene Cores 35 to 48 at DSDP Hole 504.

Distephanus crux carolae Bukry
(Plate 7, Fig. 3)

Distephanus crux (Ehrenberg) Haeckel subsp. *carolae* Bukry, in press a, pl. 5, figs. 4-11.

Remarks. *Distephanus crux carolae* is sparse in the lower Pliocene and upper Miocene at DSDP Hole 504. This extends its upper Miocene range at DSDP Hole 503A.

Distephanus frugalis (Bukry) Bukry

Distephanus boliviensis frugalis Bukry, 1975, p. 688, pl. 2, figs. 2-7.

Distephanus frugalis (Bukry) Bukry, 1979b, p. 561, pl. 3, figs. 5,6.

Remarks. Only sparse compared specimens occur between Cores 40 and 49.

Distephanus major (Frenguelli), n. comb.
(Plate 7, Fig. 4)

Dictyocha boliviensis Frenguelli, 1940 (in part), p. 44, figs. 4b,c.

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

Cannopilus major (Frenguelli) Bukry and Foster, 1973 (in part), p. 826, pl. 1, figs. 4-7, (*not* pl. 7, fig. 4).

Remarks. *Distephanus boliviensis* specimens having divided apical rings, so-called cannopilean forms, differ from *D. major* in several aspects (Bukry, 1979b). The equant, short-spined, straight-sided, polygonal basal ring of *D. major* is distinctive in lower Pliocene Cores 28 to 30 at DSDP Hole 504.

***Distephanus mesophthalmus* (Ehrenberg) Haeckel**

Dictyocha mesophthalma Ehrenberg, 1844, p. 64, 80; Ehrenberg, 1854, pl. 22, fig. 43.
Distephanus mesophthalmus (Ehrenberg) Haeckel, Bukry, in press c, pl. 5, fig. 3.

Remarks. The range for *Distephanus mesophthalmus* at DSDP sites has been extended upward considerably from its original range of upper middle to lower upper Miocene for DSDP Hole 21 (Dumitrică, 1973b). On the Pacific Coast, it occurs in the upper upper Miocene at DSDP Hole 471 (Bukry, in press d), and at DSDP Hole 504 it ranges to the upper upper Pliocene *Dictyocha delicata* Subzone of Core 18. Also, a re-examination of the abundant (16%) "*Distephanus crux*" reported from upper Pliocene Core 11 core-catcher at nearby DSDP Hole 157 (Bukry and Foster, 1973) shows that those specimens possess apical pikes and now can be assigned to *D. mesophthalmus*. Although both of these newly cited occurrences are upper Pliocene, the DSDP Hole 157 sample contains *Dictyocha ornata* instead of *D. delicata*, and the two therefore are assigned to different subzones. The high (9–16%) abundances of *D. mesophthalmus* is suggestive of close correlation potential beween DSDP Holes 157 and 504.

***Distephanus polyactis* (Ehrenberg) Deflandre**
(Plate 7, Fig. 5)

Dictyocha polyactis Ehrenberg, 1839, p. 129; Ehrenberg, 1854, pl. 22, fig. 50.
Distephanus polyactis (Ehrenberg) Deflandre, Bukry and Foster, 1973, p. 828, pl. 5, figs. 6, 7.

Remarks. A single specimen was counted at DSDP Hole 504 in upper Miocene Core 53.

***Distephanus quinquangellus* Bukry and Foster**
(Plate 7, Fig. 6)

Distephanus quinquangellus Bukry and Foster, 1973, p. 828, pl. 5, fig. 4.

Remarks. At DSDP Hole 504, most specimens of *Distephanus quinquangellus* have apical pikes. This, together with smaller size and more-radial symmetry, helps to distinguish *D. quinquangellus* from *Distephanus* sp. A (Bukry, 1979a). Both pentagonal forms occur through the Pliocene and are most abundant in the upper Pliocene, but *D. quinquangellus* is missing from the Pleistocene. In Core 22, where *D. quinquangellus* is most abundant (28%), some quadrangular variants could mimic *Distephanus mesophthalmus*, but these are recorded as *D.* sp. aff. *D. mesophthalmus* (2%). Similarly, the <1% *D. speculum* f. *coronata* from this sample could be a hexagonal variant. *D. speculum* f. *coronata* was noted sparsely and sporadically only in the Pliocene of DSDP Hole 504, where *D. quinquangellus* also is present. This implies that apical pikes are an ecophenotypic expression.

***Distephanus speculum bispicatus* Bukry**

Distephanus speculum (Ehrenberg) Haeckel subsp. *bispicatus* Bukry, in press a, pl. 6, figs. 2–4.

Remarks. Like those of DSDP Hole 503A, the DSDP Hole 504 populations of *Distephanus speculum bispicatus* are most abundant (27%) in the lower Pliocene. Only in Cores 29 and 43 does *D. speculum bispicatus* exceed *D. speculum speculum*. The only distinction of the *D. speculum bispicatus* distribution from that of *D. speculum speculum* at DSDP Hole 504 is that both Cores 29 and 43 coincide with transitional assemblages which fall between diagnostic subzone index ranges. Similar results are obtained at DSDP Hole 503A in Cores 16, 19, and 24. Both range into the Pleistocene, but they are sparse and sporadic there. One of the specimens of *D.* sp. cf. *D. frugalis* in Core 49 has two apical pikes in the manner of *D. speculum bispicatus*. Therefore, this morphologic feature is not an effective taxonomic guide unless the additional characteristics of the type specimens are used.

***Distephanus speculum* f. *coronata* Schulz**
(Plate 7, Fig. 7)

Distephanus speculum f. *coronata* Schulz, 1928, p. 262, fig. 50.

Remarks. *Distephanus speculum* f. *coronata* has a full cycle of six apical pikes, which distinguishes it from *D. speculum*.

***Distephanus speculum elongatus* Bukry**

Distephanus speculum elongatus Bukry, 1975, p. 688, pl. 2, figs., 8,9; pl. 3, figs. 1–3.

***Distephanus speculum minutus* Bachmann, emend. Bukry**

Dictyocha speculum f. *minuta* Bachmann *in* Ichikawa et al., 1967, p. 161, pl. 7, figs. 12–15.
Distephanus speculum minutus (Bachmann), emend. Bukry, in press d.

Remarks. This cool-water subspecies is recorded only in lower Pliocene Core 42, which has a low T_s value (57).

***Distephanus speculum speculum* (Ehrenberg) Haeckel**

Dictyocha speculum Ehrenberg, 1839, p. 150; Ehrenberg, 1854, pl. 18, fig. 57; pl. 19, fig. 41; pl. 21, fig. 44; pl. 22, fig. 47.
Distephanus speculum speculum (Ehrenberg), Bukry, 1980b, p. 553, pl. 5, figs. 15,16; pl. 6, figs. 1–3.

***Distephanus speculum tenuis* Bukry**

Distephanus speculum (Ehrenberg) Haeckel *tenuis* Bukry, in press a, pl. 6, figs. 5–11.

***Distephanus* sp. A. Bukry**
(Plate 7, Fig. 8)

Distephanus sp. A Bukry, 1979a, p. 985, pl. 5, figs. 7–10.

Remarks. Larger size and less-perfect radial symmetry distinguish *Distephanus* sp. A (Bukry, 1979a) from *D. quinquangellus*. *D.* sp. A is most prominent in upper Pliocene or lowermost Pleistocene Cores 13 to 20 at DSDP Hole 504.

Genus *MESOCENA* Ehrenberg, 1843

***Mesocena circulus* (Ehrenberg) Ehrenberg**
(Plate 8, Figs. 1,2)

Dictyocha (Mesocena) circulus Ehrenberg 1840, p. 208; Ehrenberg, 1854, pl. 19, fig. 44 as *Mesocena*.
Mesocena circulus (Ehrenberg) Ehrenberg, 1844, p. 65.
Mesocena circulus (Ehrenberg), Bukry, in press d.

Remarks. *Mesocena circulus* is a minor species in the Pliocene of DSDP 504. Abundance exceeds 3% only in Cores 41, 43, and 44, which are lower Pliocene. An unusual oblong variant occurs in Core 43. In Pleistocene Core 5, a spade-shaped specimen is tabulated as *M.* sp. cf. *M. circulus* (Plate 8, Fig. 3).

***Mesocena diodon nodosa* Bukry**
(Plate 8, Fig. 4)

Mesocena diodon nodosa Bukry, 1978c (in part), p. 818, pl. 5, figs. 14,15; pl. 6, figs. 1–3 (*not* figs. 4,5).

Remarks. The sparse *Mesocena diodon nodosa* in Cores 51 to 53 are in place, with typically associated upper upper Miocene species. The single occurrence above this level is a displaced specimen.

Because the basionym *M. crenulata* was considered a *nomen nudum* (Loeblich et al., 1968), the formation *M. diodon nodosa* was proposed (Bukry, 1978c) to classify obviously noded specimens related to smooth *M. diodon* s. str.

***Mesocena quadrangula* Ehrenberg *ex* Haeckel**
(Plate 8, Figs. 5–10; Plate 9, Figs. 1–10)

Mesocena quadrangula Ehrenberg *ex* Haeckel, 1887, p. 1556; Lemmermann, 1901, pl. 10, figs. 5–7; *fide* Loeblich et al., 1968, p. 57.
Mesocena quadrangula Ehrenberg *ex* Haeckel, 1887, Bukry, 1979b, p. 574, pl. 5, figs. 5,6.

Remarks. Within the Pleistocene acme of *Mesocena quadrangula* in Cores 6 to 10 there is a slight change to smaller size up-section. The contrast in size between larger specimens in Cores 9 and 10 and smaller in Core 8 is also augmented by the presence of four major peripheral pikes on the rings of many (>10%) of the specimens from Core 8. This morphologic feature is not present in the Core 9 or 10 assemblages. The upper Miocene *M. quadrangula* population of Cores 52 and 53 contains elongated and distorted forms with sides bowed in or out. Upper Miocene distorted forms also are illustrated from nearby DSDP Hole 157 (Bukry and Foster, 1973), and may provide a local correlation guide.

One specimen from Core 50 is tabulated as transennoid because it has a short bar in one of the ring corners; it could be a mesocenoid variant of a *Dictyocha* species.

Mesocena triodon Bukry

Mesocena triodon Bukry, 1973, p. 860, pl. 2, fig. 11.

Genus *OCTACTIS* Schiller, 1926

Octactis pulchra Schiller
(Plate 7, Fig. 10)

Octactis pulchra Schiller, 1926, p. 67, fig. c.

Remarks. *Octactis pulchra* is limited to Cores 1 to 12 of DSDP Hole 504, which contain Pleistocene assemblages. Slightly higher abundances in the *Dictyocha aculeata* Zone may suggest increased mixing and upwelling (see Donegan and Schrader, 1981, p. 151).

ACKNOWLEDGMENTS

The shipboard diatom biostratigraphy and ages for DSDP Legs 68 and 69 by Constance Sancetta, Lamont-Doherty Geological Observatory, greatly assisted the comparison between silicoflagellate paleotemperature values at DSDP Holes 503A and 504. I thank John A. Barron and Gerta Keller, U.S. Geological Survey, for constructive criticism of the manuscript and for recommendations on curve representation. The manuscript and tables were ably typed and proofed by Dorothy Blackstock, U.S. Geological Survey. I thank Roy Couzin, U.S. Geological Survey, for final drafting of the paleotemperature curves.

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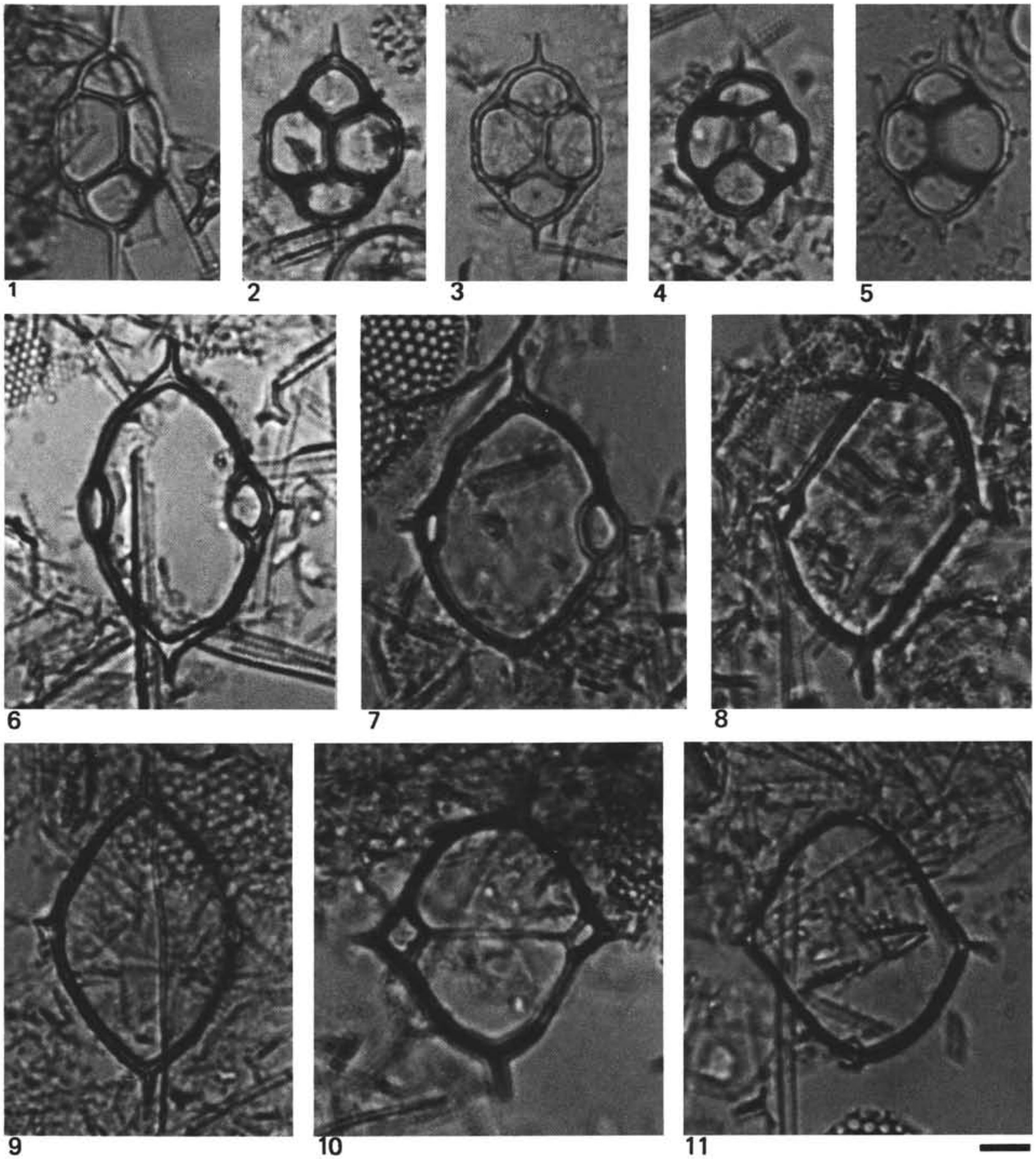

Plate 1. Silicoflagellates from DSDP Hole 504. Magnification 800×; scale bar equals 10 μm. 1. *Dictyocha* sp. aff. *D. aegea* Stradner and Bachmann, Sample 504-26-1, 42–43 cm. 2–5. *Dictyocha angulata* Bukry. (2) Normal, Sample 504-36,CC. (3) Minor-axis spines missing, Sample 504-36,CC. (4,5) Sample 504-42-2, 42–43 cm. 6–9. *Dictyocha brevispina* (Lemmermann) (no bar); all from Sample 504-45-1, 42–43 cm. (6,7) Typical specimens. (8) Distorted. (9) Nearly mesocenoid with one small portal. 10,11. *Dictyocha brevispina* (Lemmermann); apically thinned and mesocenoid specimens with the same ring form from Sample 504-45-1, 42–43 cm.

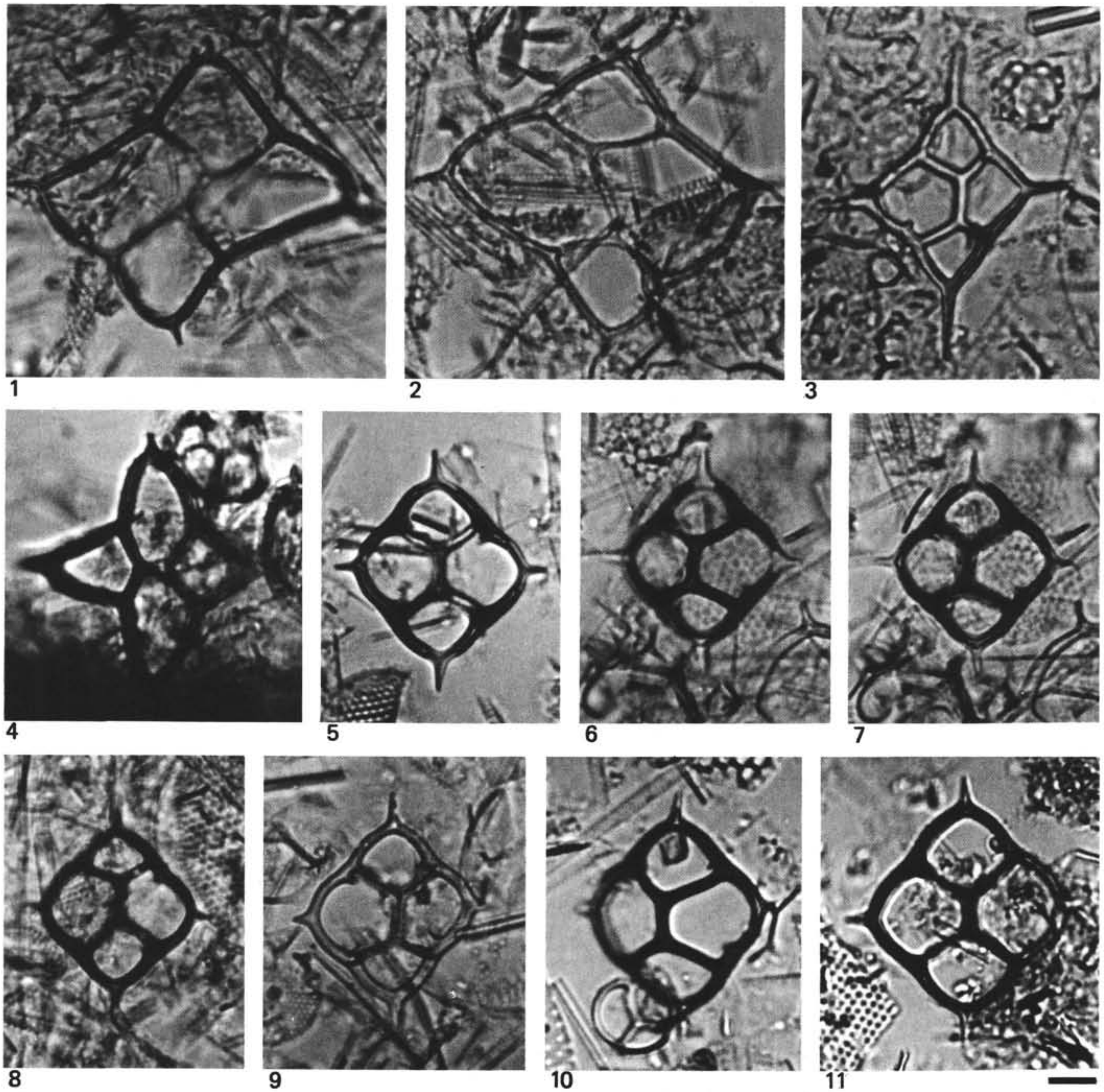

Plate 2. Silicoflagellates from DSDP Hole 504. Scale bar equals 10 μm. 1,2. *Dictyocha brevispina* (Lemmermann) (giant asymmetric). (1) Sample 504-50-1, 42–43 cm. (2) Sample 504-49-1, 42–43 cm. 3. *Dictyocha concavata* Dumitrică, Sample 504-42-1, 42–43 cm. 4. *Dictyocha calida ampliata* Bukry (extremely elongate), Sample 504-5-2, 42–43 cm. 5–11. *Dictyocha concinna* Bukry, n. sp.; all specimens from Sample 504-24-1, 42–43 cm, except Figures 10 and 11 from Sample 503A-13-2, 21–22 cm. (5) Holotype, USNM 321351. (6,7) USNM 321352, high and low focus. (8) USNM 321353. (9) USNM 321354. (10) USNM 321355. (11) USNM 321356.

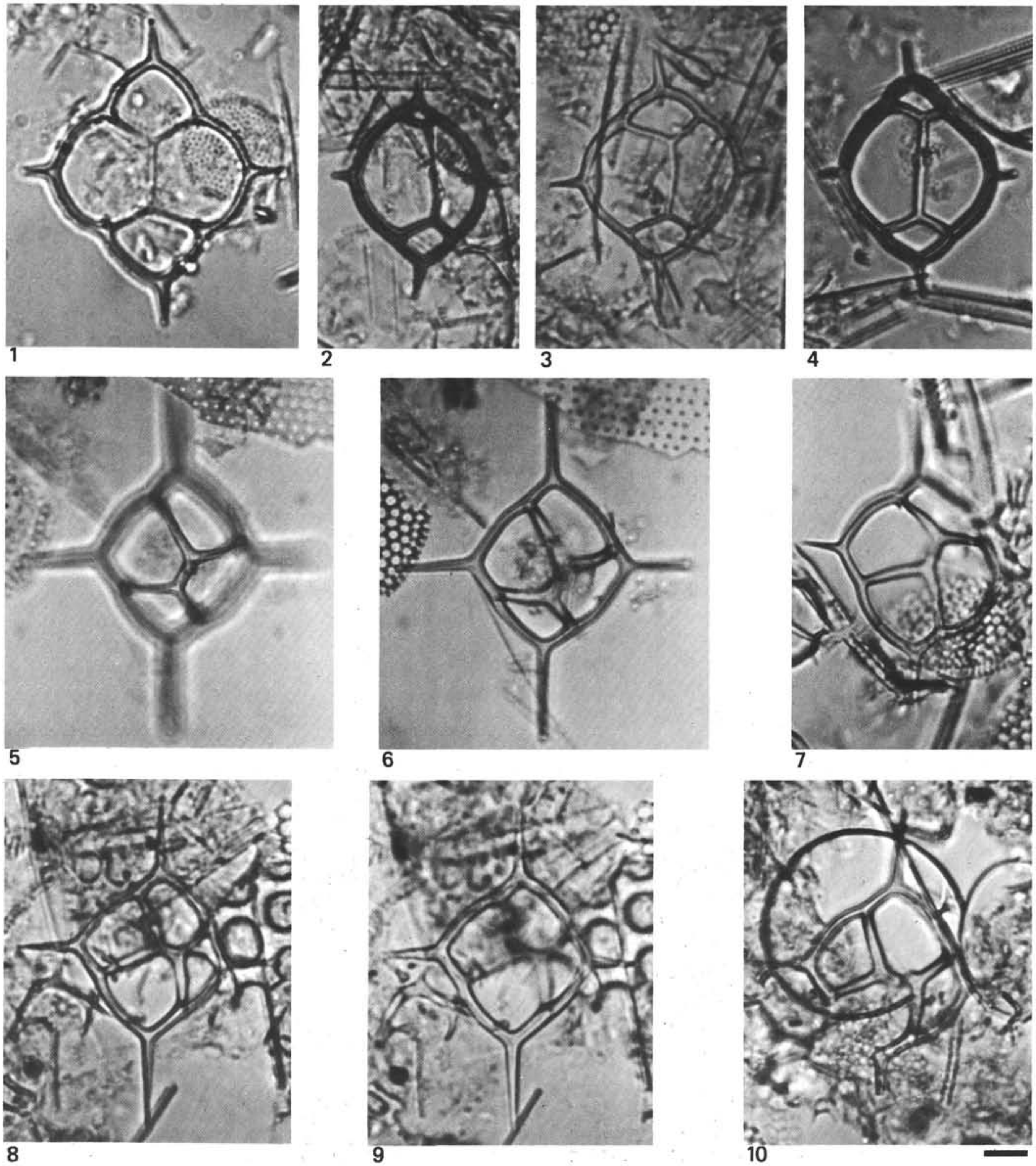

Plate 3. Silicoflagellates from DSDP Hole 504. Scale bar equals 10 μm. 1. *Dictyocha delicata* (Bukry), Sample 504-13-3, 42–43 cm. 2–4. *Dictyocha delicata* var. *bisecta* Bukry. (2,3) Normal, Sample 504-30-1, 42–43 cm. (4) Thick bar, Sample 504-31-1, 42–43 cm. 5–10. *Dictyocha helix* Bukry, n. sp. (5,6) Holotype, USNM 321357, Sample 504-19-2, 42–43 cm, high and low focus. (7) USNM 321358, Sample 504-19-2, 42–43 cm. (8,9) USNM 321359, Sample 504-19-2, 42–43 cm. (10) USNM 321360, Sample 504-18-3, 42–43 cm.

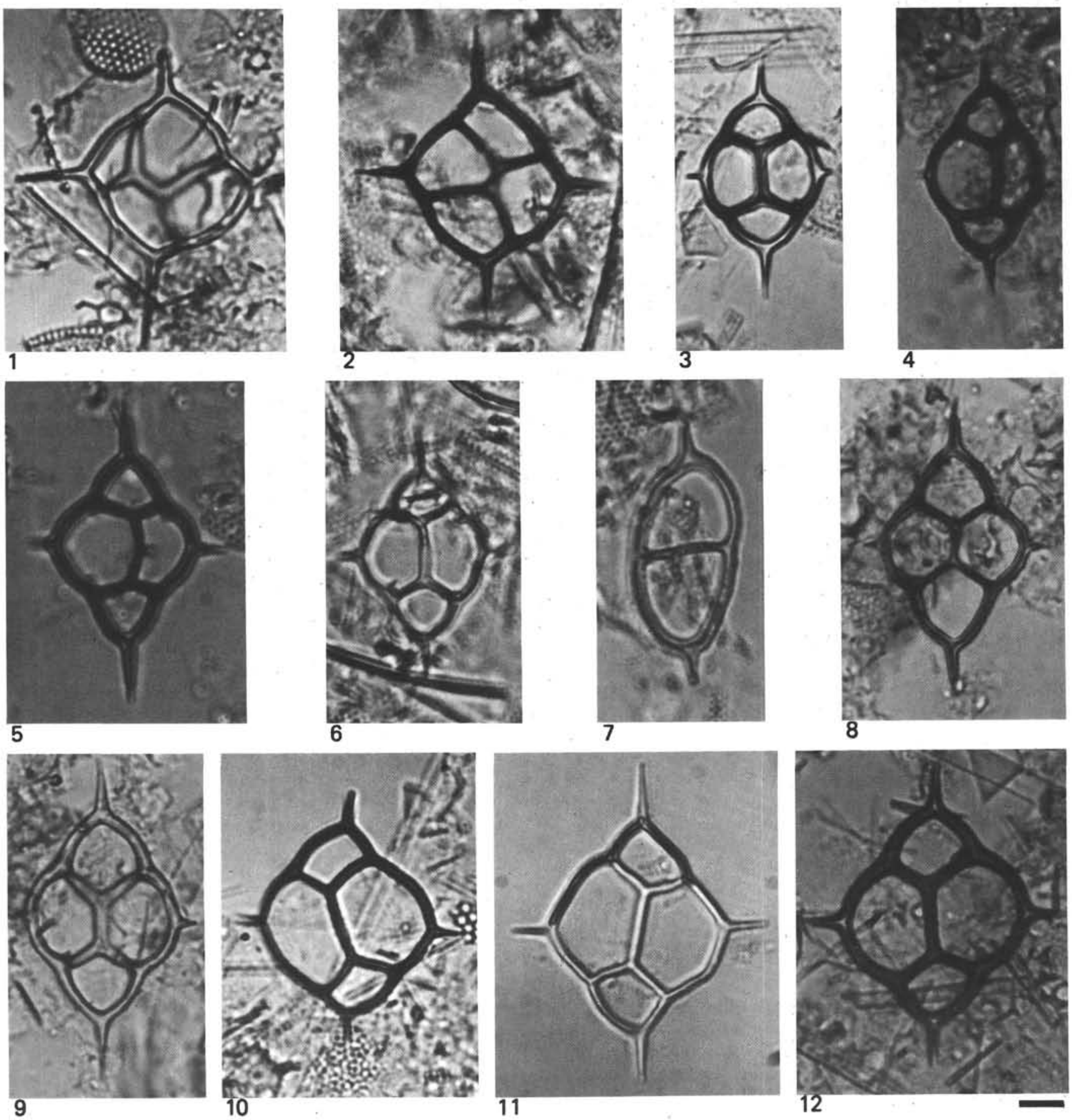

Plate 4. Silicoflagellates from DSDP Hole 504. Scale bar equals 10 μm. 1,2. *Dictyocha helix* Bukry, n. sp. (1) USNM 321361, Sample 504-19-2, 42–43 cm. (2) USNM 321362, Sample 504-20-2, 42–43 cm. 3,4. *Dictyocha longa* Bukry. (3) Sample 504-25-3, 42–43 cm. (4) Sample 504-32-1, 42–43 cm. 5,6. *Dictyocha longa* var. *paxilla* Bukry. (5) Sample 504-33-1, 42–43 cm. (6) Sample 504-41-1, 42–43 cm. 7. *Dictyocha neonautica* var. *cocosensis* Bukry, Sample 504-52-1, 42–43 cm. 8,9. *Dictyocha perfecta* Bukry, Sample 504-37-1, 42–43 cm. 10,11. *Dictyocha perlaevis flexatella* Bukry. (10) Unusually sinuous, Sample 504-23-1, 42–43 cm. (11) Sample 504-26-1, 42–43 cm. 12. *Dictyocha perlaevis perlaevis* Frenguelli, Sample 504-30-1, 42–43 cm.

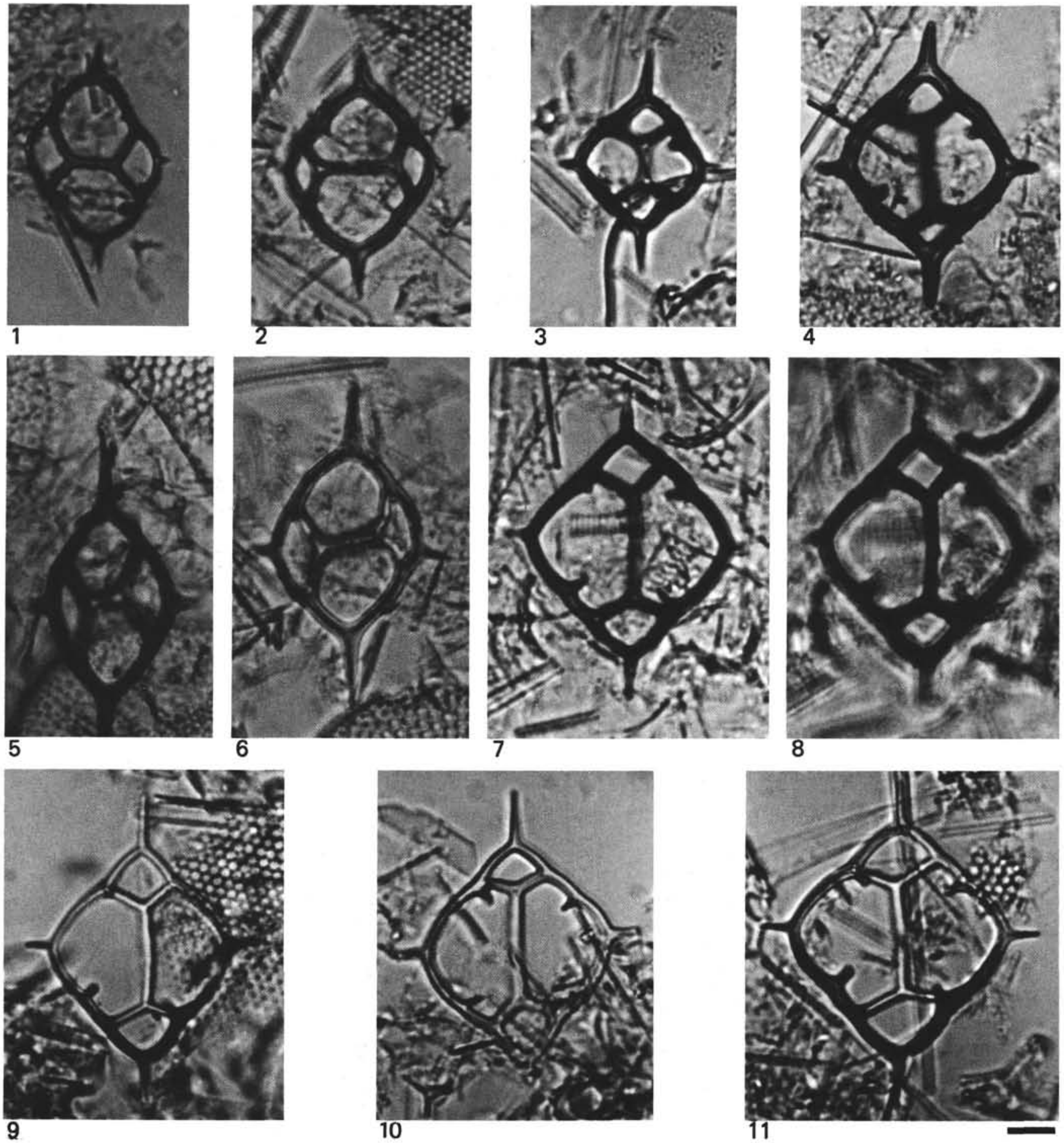

Plate 5. Silicoflagellates from DSDP Hole 504. Scale bar equals 10 μm. 1. *Dictyocha pulchella* Bukry, Sample 504-52-1, 42–43 cm. 2. *Dictyocha* sp. aff. *D. pulchella* Bukry (angular), Sample 504-52-1, 42–43 cm. 3. *Dictyocha* sp. aff. *D. stapedia aspinosa* Bukry, Sample 504-23-1, 42–43 cm. 4. *Dictyocha* sp. aff. *D. subaculeata* (Bukry), Sample 504-11-2, 42–43 cm. 5,6. *Dictyocha* sp. aff. *D. subclinata* Bukry, Sample 504-53-1, 26–27 cm. 7–11. *Dictyocha tamarae* Bukry, n. sp. (7,8) Holotype, USNM 321363, Sample 504-17-1, 42–43 cm, low and high focus. (9) USNM 321364, Sample 504-16-2, 42–43 cm. (10) USNM 321365, Sample 504-16-2, 42–43 cm. (11) USNM 321366, Sample 504-16-2, 42–43 cm.

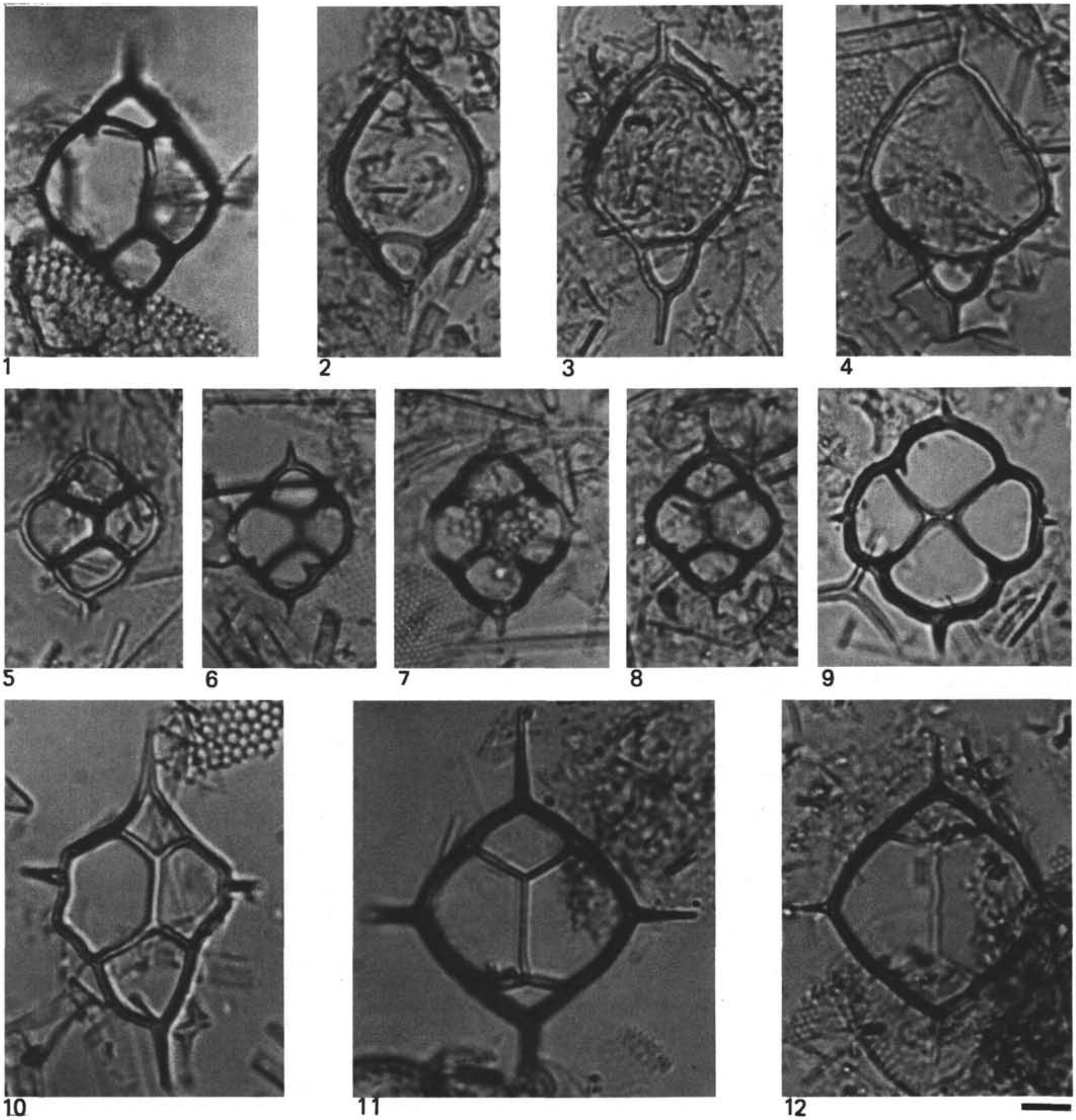

Plate 6. Silicoflagellates from DSDP Hole 504. Scale bar equals 10 μm. 1. *Dictyocha tamarae* Bukry, n. sp., USNM 321367, Sample 504-16-2, 42–43 cm. 2. *Dictyocha transenna* Bukry, Sample 504-48-1, 42–43 cm. 3,4. *Dictyocha* sp. aff. *D. transenna* Bukry (spined). (3) Sample 504-52-1, 42–43 cm. (4) Sample 504-53-1, 26–27 cm. 5–8. *Dictyocha* sp. A; consistent small specimens of the *Dictyocha* spp. category from Sample 504-44-1, 42–43 cm. 9. *Dictyocha* sp., reminiscent of smaller *D. angulata*, Sample 504-41-1, 42–43 cm. 10. *Dictyocha* sp., freak with the portal characteristics of several taxa, such as *D. aegea, D. concavata*, and *D. perlaevis flexatella*, Sample 504-50-1, 42–43 cm. 11,12. *Dictyocha* spp., possibly mesocenoid transitions from *D. delicata* var. *bisecta*, Sample 504-33-1, 42–43 cm.

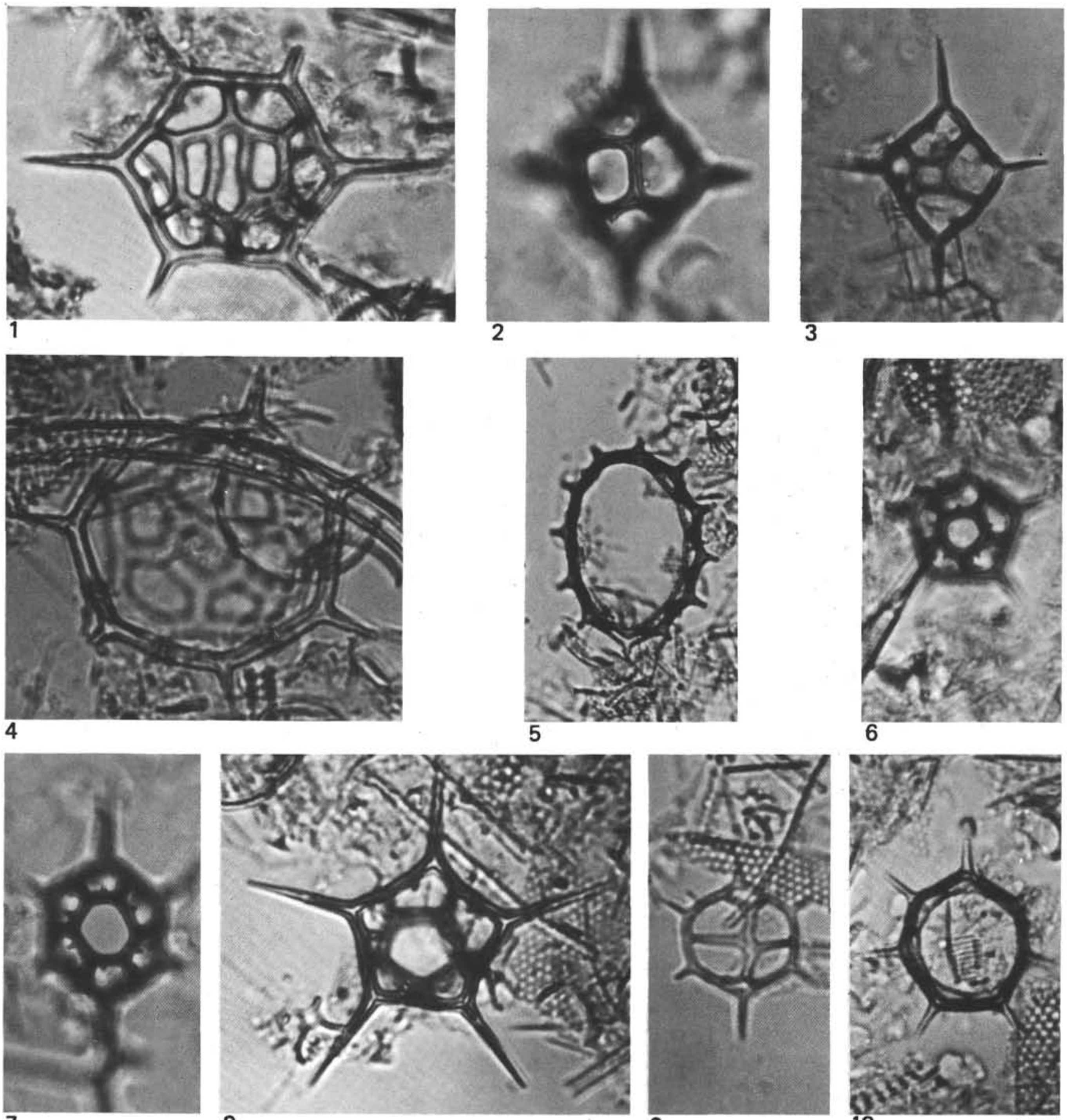

Plate 7. Silicoflagellates from DSDP Hole 504. The same scale bar equals 20 μm for Figure 5 and 10 μm for Figures 1 through 5 and 7 through 11. 1. *Distephanus boliviensis* (Frenguelli) (divided ring), Sample 504-10-2, 42–43 cm. 2. *Distephanus crux bispinosus* Dumitrică, Sample 504-36,CC. 3. *Distephanus crux carolae* Bukry, Sample 504-42-1, 42–43 cm. 4. *Distephanus major* (Frenguelli), Sample 504-29-3, 42–43 cm. 5. *Distephanus polyactis* (Ehrenberg), Sample 504-53-1, 26–27 cm. 6. *Distephanus quinquangellus* Bukry and Foster, Sample 504-20-2, 42–43 cm. 7. *Distephanus speculum* f. *coronata* Schulz, Sample 504-37-1, 42–43 cm. 8. *Distephanus* sp. A of Bukry (1979a), Sample 504-19-2, 42–43 cm. 9. *Distephanus* sp. with a bar resembling *D. japonica* or *D. pseudofibula;* unique specimen at DSDP Hole 504 observed after counts, Sample 504-40-2, 42–43 cm. 10. *Octactis pulchra* Schiller, robust basal ring, Sample 504-12-1, 42–43 cm.

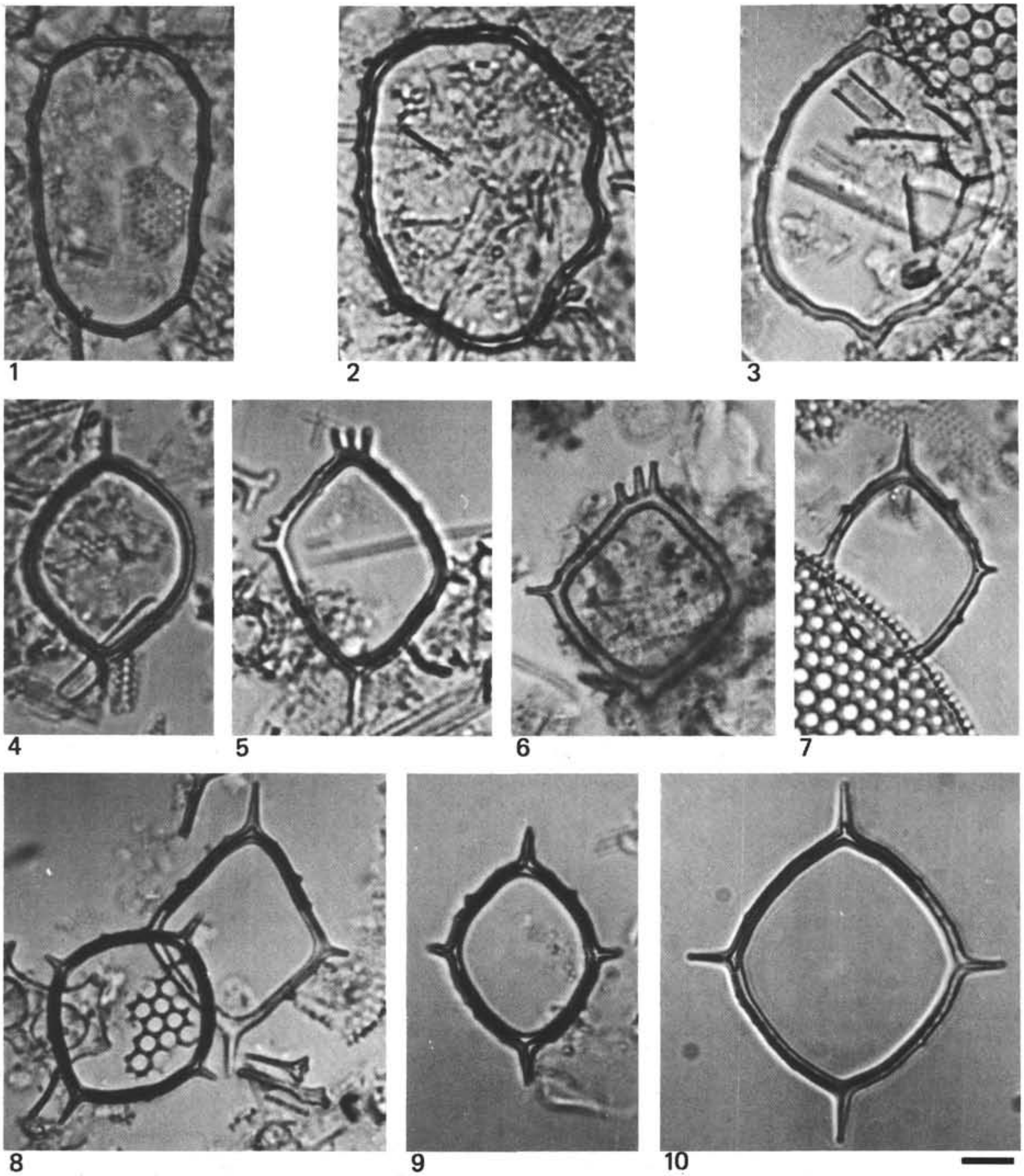

Plate 8. Silicoflagellates from DSDP Hole 504. Scale bar equals 10 μm. 1,2. *Mesocena circulus* (Ehrenberg). (1) Oblong with two spines at diagonal corners, Sample 504-43-3, 42–43 cm. (2) Irregular, Sample 504-24-1, 42–43 cm. 3. *Mesocena* sp. cf. *M. circulus* (Ehrenberg), Sample 504-5-2, 42–43 cm. 4. *Mesocena diodon nodosa* Bukry, Sample 504-52-1, 42–43 cm. 5–10. *Mesocena quadrangula* Ehrenberg *ex* Haeckel. (5) Multispined, Sample 504-9-2, 42–43 cm. (6) Multispined, Sample 504-10-2, 42–43 cm. (7–9) Small form with four peripheral pikes, all from Sample 504-8-2, 42–43 cm. (10) Typically sized and ornamented form, Sample 504-9-2, 42–43 cm.

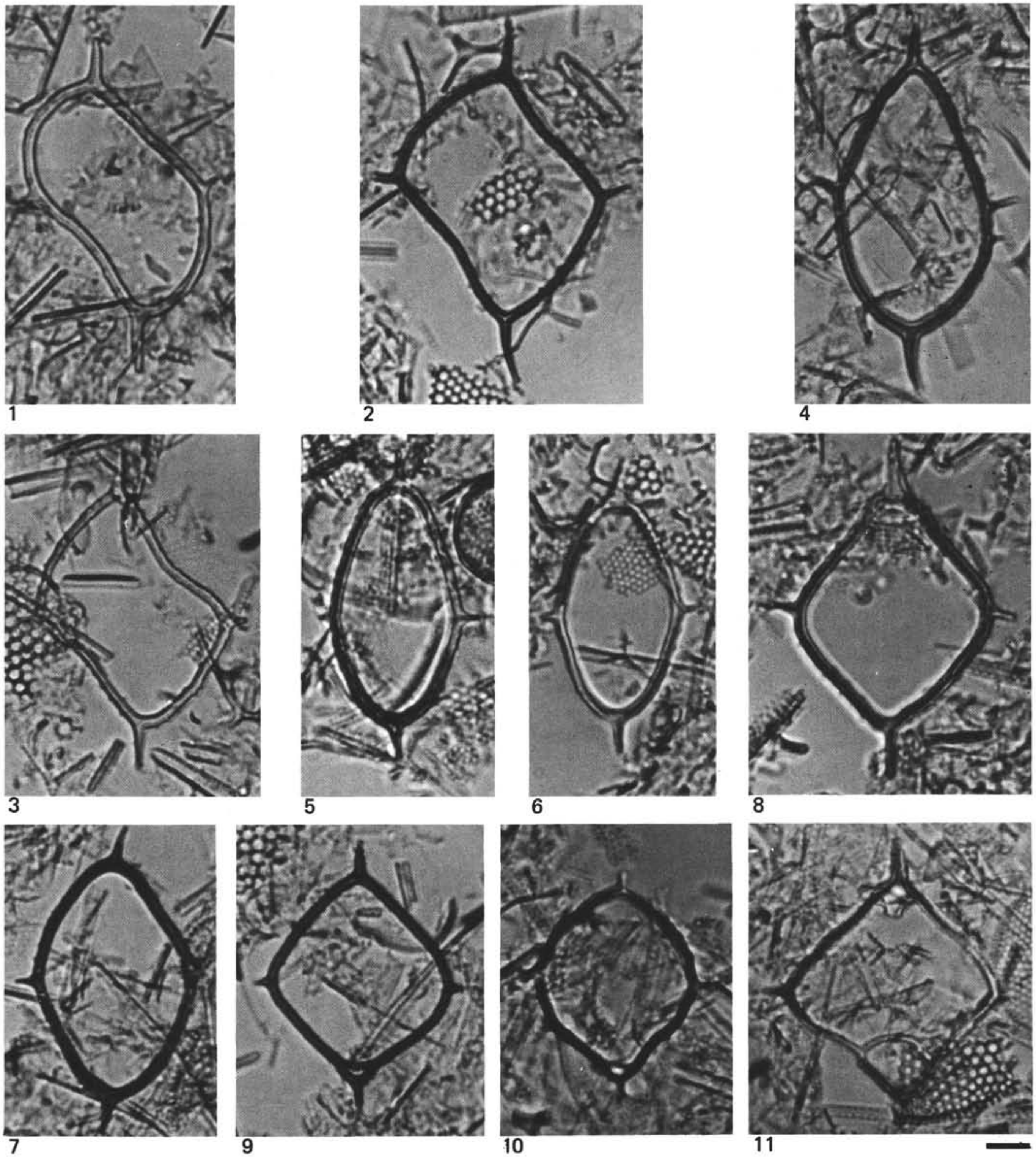

Plate 9. Silicoflagellates from DSDP Hole 504. Scale bar equals 10 μm. 1–3. *Mesocena quadrangula* Ehrenberg *ex* Haeckel (distorted: bowed), Sample 504-52-1, 42–43 cm. 4–7. *Mesocena quadrangula* Ehrenberg *ex* Haeckel (distorted: elongate). (4,6) Sample 504-52-1, 42–43 cm. (5,7) Sample 504-53-1, 26–27 cm. 8. *Mesocena quadrangula* Ehrenberg *ex* Haeckel, Sample 504-52-1, 42–43 cm. 9–11. *Mesocena quadrangula* Ehrenberg *ex* Haeckel (transennoid), possibly derived from *Dictyocha.* (9) Sample 504-53-1, 26–27 cm. (10) Sample 504-45-1, 42–43 cm. (11) Sample 504-50-1, 42–43 cm.