17. MIOCENE SILICOFLAGELLATES FROM CHATHAM RISE, DEEP SEA DRILLING PROJECT SITE 594[1]

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ABSTRACT

Miocene silicoflagellates, dominated by *Mesocena*, are identified and correlated from Site 594 to other Deep Sea Drilling Project sites. Relative paleotemperature values from silicoflagellates at Site 594 are very low, supporting the evidence of the associated cold-water, low-diversity coccolith assemblages. The greatest abundances of *Mesocena diodon nodosa* yet recorded occur at Site 594, which is near the present Subtropical Convergence. Similarities in the ecostratigraphic records between Chatham Rise (Site 594) and the Falkland Plateau (Site 329) in the late Miocene indicate widespread events within the circum-Antarctic water mass.

INTRODUCTION

Neogene silicoflagellate assemblages occur in Hole 594 of Deep Sea Drilling Project (DSDP) Leg 90 on Chatham Rise, east of New Zealand. This is the southernmost of a series of holes drilled during Leg 90 between New Zealand and the equator, to provide a latitudinal transect for paleoceanographic analysis. Although sparse Eocene silicoflagellates occur in Hole 588C (Core 19) and Hole 592 (Core 40), the only Neogene silicoflagellate sequence is from Hole 594 (Cores 20 to 48). Most of the Leg 90 sections that were examined lack silicoflagellates. Site 594 (45°31.41′S, 174°56.88′E, water depth 1204 m) is presently under the Subantarctic Water Mass, just south of the Subtropical Convergence. Cold-water silicoflagellates and coccoliths that are identified from Hole 594 support a similar water-mass pattern in the late Miocene.

A quantitative investigation of the Neogene silicoflagellate assemblages from Hole 594 was done to permit comparison of the species array to those in similar and contrasting regions, such as Site 329 (Falkland Plateau, 50°39.31′S, 46°05.73′W, water depth 1519 m) and Site 285 (South Fiji Basin, 26°49.16′S, 175°48.24′E, water depth 4658 m) and to determine relative paleotemperature values. In addition to the autochthonous late Miocene silicoflagellates, the samples from Hole 594 contain persistent reworked Paleogene specimens. Eocene and Oligocene biosiliceous deposits of similar age are now well exposed on New Zealand, as in the Oamaru section (Mandra et al., 1973), and form a potential local source for reworked Paleogene silicoflagellates.

The systematic paleontology covers the species of genus *Mesocena* which predominate in most samples of the upper Miocene at Hole 594. The distribution of abundant occurrences of these species at other DSDP localities is analyzed to help explain the high abundances in Hole 594.

METHODS

The samples taken aboard ship for shore-based silicoflagellate studies from the biosiliceous upper Miocene section of DSDP Site 594 were processed using HCl and H_2O_2 to help concentrate the silicoflagellates. Permanent strewn slides were prepared and a light microscope at 250× and 500× magnification, with mechanical stage translation, was used to systematically track the slide areas of 40 × 22 mm. Species were enumerated using a mechanical counter. All specimens encountered were recorded. Fragmented specimens were included in the counts by mental accumulation into whole specimens. Relative paleotemperature values (Ts) were calculated according to the scheme described by Bukry (1981, 1983).

Coccolith slides were prepared as standard whole-sediment smear slides as described in Bukry and Kennedy (1969). A light microscope with 250× and 500× magnification, rotating mechanical stage, and cross-polarized light was used to study the coccolith assemblages for identification of zones.

ZONATION

Several *Distephanus speculum speculum* zones representing partly different time intervals have been proposed for correlation of cool-water assemblages (Bukry, 1973b, 1976a; Ciesielski, 1975; Martini and Müller, 1976; Busen and Wise, 1977). In the late Miocene to early Pleistocene cool-water assemblages of the Northern Hemisphere, the *D. speculum speculum* zones are dominated by *D. speculum speculum* (Bukry, 1973b; Martini and Müller, 1976). At mid latitudes in the Northern Hemisphere, the *Distephanus longispinus* Zone and *Distephanus pseudofibula* Zone may also be recognized in the upper Miocene sediment below the *D. speculum speculum* Zone (Bukry, 1981). But the guide species for these zones are sparse in high-latitude assemblages from the Southern Hemisphere and limit recognition of these zones (Bukry, 1975c; Haq and Riley, 1976; specimens attributed to *D. pseudofibula* by Ciesielski, 1975, all show the morphology of *D. speculum varians*, a possibly cooler water phenotype). In the Southern Hemisphere a longer *D. speculum speculum* Zone has been identified by the first abundant occurrence of *Mesocena circulus* at the base (Bukry, 1975c, 1976a) and the first common occurrence of *Distephanus octonarius* at the top (Bukry, 1975c). The longer *D. speculum speculum* Zone in the Southern Hemisphere zone is used here, with the Miocene *Mesocena circulus* Subzone (Bukry,

[1] Kennett, J. P., von der Borch, C. C., et al., *Init. Repts. DSDP*, 90: Washington (U.S. Govt. Printing Office).
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1975c) identified by the common occurrences of *Mesocena circulus* and *M. diodon nodosa* (Fig. 1).

RELATIVE PALEOTEMPERATURES (Ts)

The percentages of cool- and warm-indicator taxa in a silicoflagellate assemblage have been used to indicate latitudinal paleotemperature trends (Bukry, 1981) and have permitted interregional paleotemperature comparisons between the Pacific and Atlantic oceans for coeval intervals (Bukry, 1984; in press). Late Miocene assemblages at Site 594 have low relative paleotemperature values (Ts = 0 to 39) which are similar to the low values (Ts = 0 to 57) that occur at Site 329 (see Bukry, 1976b), at similar latitude and in the same Subantarctic Water Mass, east of the Falkland Islands. By contrast, late Miocene values (Ts = 85 to 97) are distinctly warmer at Site 285 (Bukry, 1975b), in the Fiji Basin, to the north of Site 594.

Large abundances of *Mesocena* and *Distephanus* at Site 594 indicate very cool conditions for most of the examined sample levels. Warm-water *Dictyocha* and temperate *Distephanus* (quadrate) are common in only a few samples. The contrasting assemblages of Site 285 (Bukry, 1975b), nearer the equator, contain practically no *Mesocena* and only moderate numbers of *Distephanus*. Warm-water *Dictyocha* predominates (>50%) throughout.

A comparison of relative paleotemperature values between the late Miocene samples from Site 594 and from North Pacific Site 581 (lat 43°55.62′N, long 159°47.76′E, depth 5476 m) shows much higher values (warmer) for the North Pacific because of the predominance of the genus *Dictyocha*. Late Miocene values at Site 581 range from Ts = 52 to 94 (Bukry and Monechi, in press), instead of the lower values of Ts = 0 to 39 at Site 594, even though they are located at similar north (44°) and south (45°) latitudes. The great contrast between the assemblages is the predominance of *Mesocena* at Site 594, which reflects cool and nutrient-rich waters. At the eastern end of the North Pacific Current the relative paleotemperature values off the coast of California for late Miocene samples are also lower than at Site 581 and the assemblages contain more *Mesocena* (Bukry, 1981). Therefore, it is possible that the warm Kuroshio Current was intensified and advanced farther north during the late Miocene, enhancing the productivity of *Dictyocha* over *Mesocena* at Site 581. Late Quaternary assemblages in the area of Site 581 contain cool-water *Distephanus octangulatus* (Ling, 1980; Bukry and Monechi, in press).

Age	Northern Hemisphere		Southern Hemisphere	
	Legs 18 and 38	Leg 63	Leg 29	Leg 36
Quaternary	—	—	—	*D. speculum* A
Pliocene	*D. speculum*	*D. speculum*	*D. speculum*	*D. speculum* B
late Miocene	—	—	—	*D. speculum* *M. circulus* Subzone

Figure 1. Comparison of age ranges for various *Distephanus speculum* zones from Deep Sea Drilling Project Legs.

This poleward heat transfer (Csanady, 1984) by the warm-water mass in the Kuroshio Current might be linked to overall cooling in the late Miocene. There are advected cool-water pulses recorded in the late Miocene of the central equatorial Pacific Hole 572D (Bukry, in press) and a general North Pacific cooling has been described (Keller, 1981). But there is a notable lack of *Mesocena* in the samples with cool-water pulses at the equatorial Pacific hole (Ts = 18, 30, 32, and 36). Thus the *Mesocena* abundances for Site 594, which yield low Ts values, result from both cool temperature and rich nutrient levels. Although better time scales will be needed to make coeval comparisons, the distinctive silicoflagellate assemblage of Site 594 represents an important new reference for analysis of silicoflagellate ecostratigraphy in the Pacific.

Diatom chronostratigraphic correlations (*Denticula hustedtii* Zone) of DSDP Sites 158, 329, 470, 472, 572, 581, and 594 (J. A. Barron, written communication, 1984) were used to make a preliminary check of silicoflagellate Ts trends for the early late Miocene. The sampling array in the *Initial Reports* is inadequate for detailed silicoflagellate comparisons, but similar, consistent low Ts values occur at Sites 173, 329, and 594, where cool or transitional waters probably occurred in the late Miocene. The only changing trend observed for the interval was one of the declining Ts values at the Pacific equatorial Site 158 (Ts = 92 to 63) and Site 572 (Ts = 96 to 36).

The four silicoflagellate samples from Cores 594-23 to 594-25 (214 to 228 m) occur in the interval assigned to the late Miocene cool-water *Thalassiosira antiqua* Zone by Ciesielski (J. A. Barron, written communication, 1984). The Ts values are very low (Ts = 2 or 3) except at the bottom of this interval (Ts = 30) in Sample 594-25-2, 8–9 cm. A comparison of the same diatom zone at offshore California Sites 469 and 470 shows that the coolest value is Ts = 27 and the warmest Ts = 61. Farther south, off Baja California at Site 472, warmer values occur, Ts = 58 to 94. This zone was not used for Site 581 and was not cored at Site 329. The coeval interval according to diatoms at northwest Pacific Site 581 is in Cores 581-5 to 581-6; at equatorial Pacific Hole 572D it is in Cores 572D-6 to 572D-11 (J. A. Barron, verbal communication, 1984). At both locations there is a general warming upward through the interval. Maximum Ts values at Site 581 (Ts = 96) are higher than at Hole 572D (Ts = 82), but minimum values are more disparate, with a minimum of Ts = 32 for Hole 572D and Ts = 79 for Site 581. The exceptionally cold conditions at Site 594 appear to have persisted through the late Miocene, according to the relative paleotemperature values of silicoflagellates, correlated by diatom zonation.

COMPARISON OF *MESOCENA* OCCURRENCES

Mesocena circulus s. ampl. is most numerous at oceanic locations where cool-water currents or upwelling are most intense. Comparison of peak abundances at DSDP sites shows generally higher numbers at higher latitudes but equatorial abundances up to 34% at Site 157 show that the local cool, nutrient-rich waters of the Peru Current determine the productivity of *M. circulus* s. ampl.

Actual latitude is too general a guide. Other fairly high abundances at low latitudes (Table 1) are noted for Holes 321 and 572A, which are also influenced by the Peru Current. In the South Atlantic, the cool nutrient-rich upwelled waters at the Walvis Ridge account for the relatively high 19% abundance of *M. circulus* s. ampl. at Site 362. At high-latitude Site 594 the highest value of 95% follows moderate values of 28%.

A comparison of the maximum abundance for *M. diodon nodosa* s. ampl. in the Atlantic and Pacific oceans shows similar maximum values near Ts = 40 (Table 2), except for Site 594. As with *M. circulus* s. ampl., data are more numerous for the Pacific Ocean. Comparison of the relative timing of the maximum abundances between these two taxa shows that *M. diodon nodosa* s. ampl. typically precedes *M. circulus* s. ampl. At 17 localities compared, *M. diodon nodosa* s. ampl. has an earlier maximum abundance peak at 11 sites (DSDP 157, 158, 285, 303, 304, 472, 503A, 504, 579A, and 581, and EM site). The order is reversed at five sites (DSDP 173, 310, 278, 469, and 470). The general stratigraphic range of *M. diodon nodosa* s. ampl. is briefer and earlier than for *M. circulus* s. ampl. Site 594 does show the reverse relation in maximum abundances but the base of the section is not established. More significantly, the highest abundances of *M. diodon nodosa* ever recorded (86%, 77%, 75%, etc.) are in Cores 594-23 through 594-30. This pre-eminence of *M. diodon nodosa* indicates a specialized condition for this area.

Previous studies from the Southern Ocean, off Antarctica (Ciesielski, 1975; Perch-Nielsen, 1975; Bukry, 1975c; Haq and Riley, 1976; Busen and Wise, 1977), have shown low and sporadic abundances except at one

Table 1. Maximum abundance (percent) of *Mesocena circulus* s. ampl. recorded from Deep Sea Drilling Project (DSDP) and Experimental Mohole (EM) coring locations in the Pacific and Atlantic oceans, arranged from north to south.

Site or Hole	Latitude	Abundance	Age	Total range
Pacific Ocean				
433A	44°46.60′N	X	—	l. Miocene to Pliocene or Pleistocene
581	43°55.62′N	7	l. Miocene	l. Miocene
580	41°37.47′N	34	l. Miocene	l. Miocene
303	40°48.50′N	7	l. Miocene or e. Pliocene	m. or l. Miocene to l. Miocene or e. Pliocene
173	39°57.71′N	3	m. Miocene and Pleistocene	m. Miocene to Pleistocene
464	39°51.64′N	24	e. Pliocene	l. Miocene to e. Pleistocene
304	39°20.27′N	17	l. Miocene or e. Pliocene	l. Miocene to l. Miocene or e. Pliocene
579A	38°37.61′N	26	e. Pliocene	e. and l. Pliocene
310	36°52.11′N	20	l. Pliocene	l. Miocene to Pleistocene
466	34°11.46′N	13	Pleistocene	Pleistocene
469	32°37.00′N	74	l. Miocene	m. and l. Miocene to l. Miocene or Pliocene
577	32°26.51′N	22	e. Pliocene	e. and l. Pliocene
470	28°54.46′N	45	m. Miocene	m. and l. Miocene
EM	28°00.58′N	20	m. and l. Miocene	m. and l. Miocene
472	23°00.35′N	4	l. Miocene	l. Miocene
495	12°29.78′N	1	l. Miocene and Pliocene	l. Miocene and Pliocene
158	6°37.36′N	5	m. and l. Miocene	m. and l. Miocene
65.0	4°21.21′N	X	—	l. Miocene or Pleistocene
503A	4°04.04′N	2	l. Pliocene	e. and l. Pliocene
166	3°45.70′N	X	—	Miocene or Pliocene
572A	1°26.09′N	12	e. Pliocene	e. Pliocene
572D	1°26.09′N	2	m. Miocene	m. and l. Miocene
425	1°23.68′N	2	Pleistocene	Pleistocene
504	1°13.58′N	6	e. Pliocene	Pliocene and Pleistocene
157	1°45.70′S	34	e. Pliocene	l. Miocene to Pleistocene
157A	1°45.70′S	1	Pleistocene	Pleistocene
321	12°01.29′S	13	l. Pliocene	l. Pliocene
205	25°30.99′S	6	l. Miocene	l. Miocene
285	26°49.16′S	1	l. Miocene	l. Miocene
278	56°33.42′S	48	Pliocene	l. Miocene or Pliocene
322	60°01.45′S	4	Pliocene	Pliocene
Atlantic Ocean				
348	68°30.18′N	X	—	m. or l. Miocene
338	67°47.11′N	X	—	m. or l. Miocene
407	63°56.32′N	18	Pliocene	Pliocene
408	63°22.63′N	41	m. Miocene	m. Miocene to Pliocene
555	56°33.70′N	16	m. Miocene	m. and l. Miocene
554A	56°17.40′N	5	l. Miocene	l. Miocene
552A	56°02.56′N	4	e. Pliocene	e. Pliocene
410	45°30.53′N	4	l. Pliocene	l. Pliocene
335	37°17.74′N	4	Pleistocene	Pleistocene
334	37°02.13′N	4	l. Miocene	l. Miocene
332B	36°52.72′N	<1	l. Pliocene	l. Pliocene
333	36°50.45′N	6	l. Pliocene	l. Pliocene
397	26°50.70′N	3	l. Pliocene	l. Pliocene
362	19°45.45′S	19	l. Pliocene	Pliocene and Miocene or Pliocene
328	49°48.67′S	6	l. Miocene	l. Miocene
329	50°39.31′S	92	Miocene	Miocene
327	50°52.28′S	1	Pleistocene	Miocene to Pleistocene

Note: Ages for the maximum abundance event and the range of *M. circulus* s. ampl. are also shown. X = present, but too sparse for accurate percentage.

Table 2. Maximum abundance (percent) of *Mesocena diodon* s. ampl. recorded from Deep Sea Drilling Project (DSDP) and Experimental Mohole (EM) coring locations in the Pacific and Atlantic oceans, arranged from north to south.

Site or Hole	Latitude	Abundance	Age	Total range
Pacific Ocean				
192	53°00.57′N	6	l. Miocene	l. Miocene
433A	44°46.60′N	X	—	m. Miocene to Pleistocene
581	43°55.62′N	10	l. Miocene	l. Miocene
303	40°48.50′N	4	m. or l. Miocene	m. Miocene to e. Pliocene
173	39°57.71′N	4	l. Miocene	m. and l. Miocene
464	39°51.64′N	6	e. Pliocene	e. Pliocene
33	39°28.48′N	8	l. Miocene	m. and l. Miocene
304	39°20.27′N	1	l. Miocene and e. Pliocene	l. Miocene to e. Pliocene
579A	38°37.61′N	6	e. Pliocene	e. Pliocene
310	36°52.11′N	2	Pliocene	Pliocene
466	34°11.46′N	33	e. Pliocene	e. Pliocene
469	32°37.00′N	5	l. Miocene	m. and l. Miocene
470	28°54.46′N	20	l. Miocene	m. and l. Miocene
EM	28°00.58′N	10	m. Miocene	m. Miocene
472	23°00.35′N	5	m. Miocene	m. and l. Miocene
495	12°29.78′N	1	m. Miocene	m. Miocene
158	6°37.36′N	8	m. Miocene	m. and l. Miocene
503A	4°04.04′N	40	l. Miocene	l. Miocene to l. Pliocene
572A	1°26.09′N	0	—	e. Pliocene
572D	1°26.09′N	0	—	m. and l. Miocene
504	1°13.58′N	1	l. Miocene	l. Miocene
157	1°45.70′S	1	l. Miocene	l. Miocene to Pleistocene
285	26°49.16′S	<1	m. Miocene	m. Miocene
206	32°00.75′S	X	—	m. and l. Miocene
281	47°54.84′S	20	l. Miocene	l. Miocene
278	56°33.42′S	16	l. Miocene	l. Miocene or Pliocene
322	60°01.45′S	6	Pliocene	Pliocene
323	63°40.84′S	X	m. Pliocene	m. Pliocene
Atlantic Ocean				
348	68°30.18′N	X	m. Miocene to e. Pliocene	m. Miocene to e. Pliocene
338	67°47.11′N	34	m. Miocene	m. Miocene
407	63°56.32′N	X	e. Pliocene	e. Pliocene
408	63°22.63′N	14	l. Miocene	m. Miocene to Pliocene
555	56°33.70′N	1	m. Miocene	m. Miocene
554A	56°17.40′N	37	l. Miocene	l. Miocene
552	56°02.56′N	22	l. Miocene	l. Miocene
552A	56°02.56′N	1	l. Miocene	l. Miocene to e. Pliocene
334	37°02.13′N	<1	l. Miocene	l. Miocene
391A	28°13.61′N	3	m. Miocene	m. Miocene
394A	28°11.70′N	2	m. Miocene	m. Miocene
358	37°39.31′S	X	l. Miocene	l. Miocene
328B	49°48.67′S	X	l. Pliocene	l. Pliocene
329	50°39.31′S	33	l. Miocene	l. Miocene
327	50°52.28′S	<1	Pleistocene	Miocene to Pleistocene

Note: Ages for the maximum abundance event and the range of *M. diodon* s. ampl. are also shown. X = present, but too sparse for accurate percentage.

site (Site 329) where 2 to 33% *M. diodon nodosa* occur. The location of Site 329 at 50°39′S latitude, at 1519 m water depth on the Falkland Plateau, is also analogous to Site 594, at 45°31.41′S and 1204 m, east of New Zealand. Higher-latitude sites to the south (nearer Antarctica) lack *M. diodon nodosa* or have only sparse (1–3%) occurrences. The highest abundances of *M. diodon nodosa* at Sites 594 and 329 identify intensified activity at the Subtropical Convergence in the late Miocene. High abundance of *M. diodon nodosa* elsewhere may also signify convergence zone conditions.

DSDP HOLE 594 COMPARED TO DSDP HOLE 329

The presence of *Mesocena triangula* and reworked Paleogene silicoflagellates in samples from Cores 20 to 31 at Site 594 suggested a potential similarity and ecostratigraphic correlation to Site 329, which was cored earlier on the Falkland Plateau. A comparison of quantitative silicoflagellate occurrences for Site 594 (Table 3) and Site 329 (Bukry, 1976b) demonstrates a sequence of similar events (Table 4). Three lower correlation events in the upper Miocene are the boundary between moderate (Ts = 26 to 57) and very low (Ts = 0 to 9) relative paleotemperature values (Ts) and the bracketing by major and minor concentrations of *Distephanus crux crux* above and below. The middle three events are an increase of Paleogene reworked silicoflagellates, bracketed by concentrations of *Mesocena circulus* below and *Dictyocha aspera clinata* above. The final trio of correlation events includes a dominance reversal of *M. diodon* s. ampl. and *M. circulus* s. ampl. followed by the highest Ts values (Ts = 30 and 10) above the lower part of the section, and finally the conjunction of *M. triangula* with *M. quadrangula*. These events are believed to represent interregional changes that are probably related to circum-Antarctic ocean circulation. Both drill sites lie within the present area of Subantarctic Water, south of the Subtropical Convergence (see Kennett, 1980, fig. 2) and just south of the Subantarctic Convergence (Burkov, 1966). Periods of major current scour may be recorded by the reworked Paleogene taxa at both areas. Similarities in temperature and nutrient changes account for the species correlations.

Some of the species events compared between the two sites did not prove to be sequentially correlative between the two regions. These included the local acmes of *Dictyocha brevispina, D. fibula augusta, D. pentagona, Distephanus speculum minutus*, and *D. speculum speculum*.

The similarity in the sequence of silicoflagellate events between Site 594, Cores 23 to 31, and Site 329, Cores 2 to 17, suggests that the late Miocene age of Site 329 may be applied to Site 594.

Shipboard identification of a fairly complete middle Miocene to early Pliocene sequence of coccolith Zones NN7/8, NN9, NN10, NN11, and NN12/14 for Cores 20 to 31 at Site 594 is not supported by shore-based examination of the section. The samples contain limited cool-water assemblages that lack all of the zonal guide species which define these numbered zones (Martini, 1971), including *Discoaster kugleri, D. hamatus, D. quinqueramus*, and *Amaurolithus tricorniculatus*. Among the low-diversity, placolith-dominated assemblages, only a few contained coccolith species with ranges useful for stratigraphic correlation. Cores 26 and 29 contain sparse *D. brouweri* s. ampl. and *D. bellus*, and Cores 23 and 26 contain *Triquetrorhabdulus rugosus* which, together, indicate a probable late Miocene correlation of these cores, if the specimens are stratigraphically in place. Actually, there is a significant number of reworked Paleogene species such as *Chiasmolithus oamaruensis* and *Isthmolithus recurvus* in these samples. Therefore, identification of coccolith zonal boundaries should be considered as tenuous and only a general late Miocene age is indicated.

SUMMARY

The main results of this initial study of silicoflagellates from Site 594 are summarized below.

1. Very high abundances of *Mesocena diodon nodosa* occur in the upper Miocene from Site 594, and may be a guide to convergence zone conditions.
2. A sequence of similar silicoflagellate events between Site 594 and Site 329 in the Atlantic suggest possible ecostratigraphic correlation throughout the circum-Antarctic water mass. The increase in Paleogene reworking at both sites shows timing for widespread scour and current activity.
3. Comparison of low relative paleotemperatures from Site 594 (lat. 45°S) with high values at North Pacific Site 581 (lat. 44°N) supports an intensified and more northerly warm Kuroshio Current in the North Pacific for the late Miocene. The late Quaternary flora just south of Site 581 yields low Ts values typical of cool water conditions.
4. Taxonomic distinction of *M. circulus* var. *apiculata* from *M. dumitricae* may be useful for paleoecological reconstructions, as the latter appears to be favored by cooler conditions.

SYSTEMATIC PALEONTOLOGY OF GENUS *MESOCENA* EHRENBERG, 1843, FROM DSDP HOLE 594

Mesocena circulus (Ehrenberg) Ehrenberg
(Plate 3, Figs. 3–6)

Dictyocha (Mesocena) circulus Ehrenberg, 1840, p. 208. Figured by Ehrenberg, 1854, pl. 19, fig. 44.
Mesocena circulus (Ehrenberg) Ehrenberg, 1844, p. 65.
Mesocena circulus (Ehrenberg), Mandra and Mandra, 1972, pl. 31, fig. 36.
Mesocena circula (Ehrenberg), Bukry and Foster, 1973 (in part), p. 828, pl. 5, fig. 9.
Paradictyocha circulus (Ehrenberg) Dumitrică, 1973, p. 853, pl. 9, figs. 7–10.
Bachmannocena circulus (Ehrenberg) Locker, 1974, p. 636, pl. 2, fig. 11.
Mesocena circulus (Ehrenberg), Bukry, 1975a (in part), p. 718, pl. 2, fig. 4.
Paradictyocha circulus (Ehrenberg), Perch-Nielsen, 1975, p. 689, pl. 11, fig. 12.
Paradictyocha circulus (Ehrenberg) Dumitrică, Stradner and Bachmann, 1978, p. 808, pl. 2, figs. 13–15.

Remarks. For Site 594, *Mesocena circulus* is identified in a restricted sense which is limited to the morphology with numerous, small, irregular spines that was originally illustrated by Ehrenberg (1854) and repeated in lectotype material by Locker (1974). Previously, *M. circulus* s. ampl. of some authors has also included long-spined specimens of *M. dumitricae* (see Bukry, 1975a; Busen and Wise, 1977) and speci-

Table 3. Late Miocene silicoflagellates recorded as percentages from Cores 20 to 48 of Hole DSDP 594.

Age	late Miocene																	—	
Zone	*Distephanus speculum speculum* Zone																	—	
Subzone	*Mesocena circulus* Subzone																		
Depth (m)	180	190	214	219	223	228	233	241	247	252	257	262	267	276	281	286	290	438	449
Taxa / Sample (interval in cm)	20-2, 8–9	21-2, 8–9	23-5, 8–9	24-2, 8–9	24-5, 8–9	25-2, 8–9	25-5, 8–9	26-4, 8–9	27-2, 8–9	27-5, 8–9	28-2, 8–9	28-5, 8–9	29-2, 8–9	30-2, 8–9	30-5, 8–9	31-2, 8–9	31-5, 8–9	47-1, 8–9	48-2, 8–9
Caryocha sp.	1																	3	P
Dictyocha aspera aspera								1											
D. aspera clinata s. ampl.								4	4									1	P
D. brevispina		11																	
D. fibula augusta		1						1	•	11									
D. fibula fibula						3			9		1	4	1						P
D. pentagona					2														
D. pulchella		3		2		16		1	2	6		1	4			1	2		P
D. sp. aff. *pulchella* var. *inflata*																		25	
D. sp. (asperoid)	1				1	7										1	2	3	
D. sp. (fibuloid)	1				1			5	1				1			1	2	5	
Distephanus crux crux		5	2		1	7		•	1		2	1	5	2	12	4	66	32	P
D. frugalis				1															
D. polyactis crassus																			P
D. pseudofibula						1													
D. quinquangellus	2	2					1	1						1					P
D. speculum diommata									1										
D. speculum minutus	67	8	1	1	1														
D. speculum speculum	24	43	13	18	76	16	23	4	6	30	11	9	27	1	1	1			P
D. speculum triommata								1											
D. xenus		23																	
Mesocena circulus		1		1		22	1												
M. circulus var. *apiculata*	1				14	19		18	2	16	8	30	14	61	1	94	24	31	
M. circulus var. *apiculata* (knobby)								4						4		1	4		
M. dumitricae									24							1			
M. sp. cf. *diodon borderlandensis*									1										
M. diodon nodosa	3	3	70	77	4	9	75	59	51	29	78	44	38	29	86				
N. diodon nodosa (circular)			1						1	9	1	14	8	2		1			
M. diodon nodosa (oblate)			2										3						
M. quadrangula		1	2																P
M. triangula			9								1								
M. triodon								1			1			1					
Reworked																			
Corbisema apiculata		X			X	⊠				X					X	X	X	X	
C. sp. cf. *C. glezerae*								X								X			
C. hastata globulata								X											
C. hastata hastata		X				X						X				X			X
C. inermis							X									X			
C. triacantha s. ampl.		X			X				X				X		X			X	
C. spp.						X										X			
Dictyocha deflandrei completa		X		X				X	X	X					X			X	
D. sp. (asperoid)					X		X												
D. sp. (fibuloid)					X														
Mesocena apiculata apiculata		X			X	X		X			X			X	X	X	X		
M. apiculata curvata																			X
M. apiculata glabra								X											
Naviculopsis aspera									X										
N. biapiculata		⊠				X	X	X	X	X			X	X				X	
N. sp. aff. *N. biapiculata*									X										
N. constricta	X	X	X	X	X	X		X	⊠		X	⊠	X			X		⊠	X
N. eobiapiculata		X	X												X	X			
N. sp. cf. *N. trispinosa*		X											X						
Naviculopsis spp.																X			
Reworked diatoms																			
Rocella gelida		X			X	X					X	X	X	X		X	X		X
R. schraderi						X			X							X			X
Total specimens (plus reworked)	100 (1)	103 (25)	100 (2)	100 (2)	100 (7)	100 (10)	100 (3)	100 (7)	201 (11)	200 (3)	200 (4)	200 (2)	100 (4)	200 (3)	100 (5)	200 (31)	50 (4)	100 (11)	19 (7)
Paleotemperature value	2	17	2	2	3	30	0	12	17	17	2	6	9	1	6	5	39	50	—

Note: X = presence of reworked specimens; ⊠ = numerically predominant. • = recorded after counts. P = too sparse for percent.

Table 4. Matching silicoflagellate events between Site 594, east of New Zealand, and Site 329, east of the Falkland Islands, both within the present Subantarctic Water Mass.

Silicoflagellate event	Core or Section at Site 594	Core at Site 329
Mesocena triangula and *M. quadrangula* conjunction	23	2
Highest relative paleotemperature (Ts) above the basal interval	25-2	4
Coincident decline of *M. diodon* s. ampl. and concentration of *M. circulus* s. ampl.	25-2 and 25-5	8 and 9
Dictyocha aspera clinata s. ampl. concentration	26-4 and 27-2	11 and 12
Increase in Paleogene reworking	27-2	15
Mesocena circulus s. ampl. concentration	30-2	14
Distephanus crux crux minor concentration	30-5	15
Major reduction in relative paleotemperature values (Ts)	31-5 to 31-2	17 to 16
Distephanus crux crux major concentration	31-5	17

mens of *M. circulus* var. *apiculata* (see Bukry and Foster, 1973). Although the small spines of *M. circulus* may lie in the plane of the ring, they may also have variable positions along the outer periphery of the ring. The inner circumference lacks spines.

According to a subsequent designation by Loeblich et al. (1968), *Mesocena*? *octogona* is the type species for genus *Mesocena*. Previous designations of *M. circulus* or *M. elliptica* as type species could not be accepted by Loeblich et al. (1968) because they were not taken from the paper in which the genus name was defined. The simplistic illustration of *M.*? *octogona* could ambiguously represent several silica bodies. And its Holocene age separates it in time from all other taxa classified in *Mesocena* (Paleocene to mid Pleistocene). Locker's (1974) reexamination of Ehrenberg materials purports to reillustrate the holotype of *M.*? *octogona* and shows that it is the basal ring of *Octactis*. This is reasonable on the basis of the morphology and age of the specimen. Therefore, the status of the name *Mesocena* is in doubt; parenthetically, so is the status of *Octactis*. The other available species for *Mesocena* in the Ehrenberg publication, *M.*? *heptagona*, is simply a polymorph of *M.*? *octogona*. *Mesocena circulus* (Ehrenberg) Ehrenberg (1844, p. 65) appears to be the next best choice if the name *Mesocena*, with 140 years of continuous usage, is to be retained. If *Mesocena* were not conserved, then *Bachmannocena* of Locker (1974) could be substituted.

For this publication, the name *Mesocena* is retained for silicoflagellate skeletons composed of a single ring, with or without spines of various sizes and orientations. This includes the widely reported forms *M. circulus* and *M. circulus* var. *apiculata* among others. Resolution of the *Mesocena* problem will have to treat *Bachmannocena*, *Paradictyocha*, and *Septamesocena*, also.

Mesocena circulus var. *apiculata* Lemmermann
(Plate 2, Figs. 3–7; Plate 3, Figs. 1, 2)

Mesocena circulus var. *apiculata* Lemmermann, 1901, p. 257, pl. 10, figs. 9, 10.

Mesocena circulus Ehrenberg, Martini and Müller, 1976, p. 872, pl. 4, figs. 7, 8.

Mesocena circulus var. *apiculata* Lemmermann, Ling, 1972, p. 176, pl. 28, figs. 7, 8.

Mesocena circula (Ehrenberg), Bukry and Foster, 1973 (in part), p. 828, pl. 6, fig. 1.

Paradictyocha apiculata (Lemmermann), Perch-Nielsen, 1975, p. 689, pl. 11, figs. 14, 15.

Mesocena circulus apiculata (Lemmermann) Ling, 1977, p. 214, pl. 2, fig. 24.

Remarks. The moderate-length spines of *Mesocena circulus* var. *apiculata* are equal to or longer than those on *M. circulus* and are more regularly spaced into two rows, or peripheral cycles, with offset between the spines of the two cycles. The regularity of the spine spacing and the limitation to two parallel cycles distinguishes *M. circulus* var. *apiculata* from *M. circulus* and *M. dumitricae*. Some variants with knobby spines or small nodes are illustrated.

Mesocena diodon borderlandensis Bukry
(Plate 4, Fig. 1)

Mesocena diodon borderlandensis Bukry, 1981, p. 547, pl. 4, figs. 5–9; pl. 5, figs. 1, 2.

Remarks. Only two compared specimens of *Mesocena diodon borderlandensis* were found among the abundant *Mesocena* at Site 594. The elongate morphology of *M. diodon borderlandensis* is most prominent at Site 469, off California, in the lower upper Miocene.

Mesocena diodon nodosa Bukry
(Plate 4, Figs. 2–6)

Mesocena diodon nodosa Bukry, 1978 (in part), p. 818, pl. 5, figs. 14, 15; pl. 6, figs. 1–3 (not figs. 4, 5 which are now classified as *Mesocena diodon borderlandensis* Bukry).

Mesocena diodon nodosa Bukry, Bukry and Monechi, in press, pl. 9, figs. 1–3; pl. 16, fig. 4.

Remarks. The most abundant populations of *Mesocena diodon nodosa* occur in the middle and upper Miocene. Aside from the normal specimens with prolate elliptic rings, two minor varieties that are circular or oblate were also found and recorded at Site 594. The circular variety is most common (14%) in Sample 594-28-5, 8–9 cm, whereas the oblate is most common (3%) just below in Sample 594-29-2, 8–9 cm.

Mesocena dumitricae (Perch-Nielsen) emend. Bukry, n. comb.
(Plate 5, Figs. 1, 2)

Mesocena circulus Ehrenberg, Ling, 1972 (in part), p. 175, pl. 28, figs. 5, 6.

Mesocena circulus Ehrenberg, Stadum and Burckle, 1973, p. 108, pl. 1, figs. 1–5.

Mesocena circulus Ehrenberg, Ciesielski, 1975, p. 661, pl. 11, figs. 6, 8, 9.

Mesocena circulus (Ehrenberg), Bukry, 1975a (in part), p. 718, pl. 2, fig. 5.

Paradictyocha dumitricae Perch-Nielsen, 1975, p. 689, pl. 11, figs. 1, 5–8.

Mesocena circulus Ehrenberg, Busen and Wise, 1977, p. 715, pl. 7, figs. 2, 3, 4? 6?; pl. 11, figs. 1, 2.

Remarks. *Mesocena dumitricae* was described as having a polygonal rather than round outline (Perch-Nielsen, 1975); however, four of the five type specimens show nearly continuous curvature around the ring. Also, the spines were characterized as short, but moderate to moderately long spines are also known in populations from different areas (see Stadum and Burckle, 1973; and Bukry, 1975a, c). The most diagnostic features of *M. dumitricae*, as emended herein, are the single cycle of regularly spaced equant spines which lie in the plane of the ring. Specimens of *M. dumitricae* with polygonal and essentially circular rings may occur together (Perch-Nielsen, 1975, pl. 11).

Occurrence. *Mesocena dumitricae* emend. has previously been tabulated as *M. circulus*, so the full stratigraphic and geographic range are not known, but the illustrations of high-latitude *Mesocena* by Busen and Wise (1977) and Stadum and Burckle (1973) suggest that *M. dumitricae* may favor cooler areas where upwelling is strong.

Mesocena quadrangula Ehrenberg ex Haeckel
(Plate 5, Fig. 3)

Mesocena quadrangula Ehrenberg ex Haeckel, 1887, p. 1556.

Mesocena quadrangula Ehrenberg ex Haeckel, Bukry, 1979, p. 574, pl. 5, figs. 5, 6.

Remarks. *Mesocena quadrangula* is largely missing from the assemblages at Site 594. Sparse specimens occur only in two samples from Cores 21 and 23 near the top of the silicoflagellate-bearing section. The conjunction of *M. quadrangula* and *M. triangula* in Core 23 suggests a correlation to the upper part of Site 329, which is considered upper Miocene.

Mesocena triangula (Ehrenberg)
(Plate 5, Figs. 3–6)

Dictyocha triangula Ehrenberg, 1839, p. 129. Figured by Ehrenberg, 1854, pl. 22, fig. 41.

Mesocena triangula (Ehrenberg) Ehrenberg, 1844, p. 65, 71.
Mesocena triangula (Ehrenberg), Bukry and Foster, 1973 (in part), p. 829, pl. 6, figs. 9, 10.
Mesocena triangula (Ehrenberg), Ling, 1977, p. 214, pl. 3, fig. 6.

Remarks. *Mesocena triangula* has surface texture and stratigraphic distribution which suggest derivation from *Mesocena quadrangula* or possibly *M. circulus*. A triangular variant of *M. diodon nodosa* from Site 594 (Plate 4, Figs. 5, 6) shows distinctive crenulate surface texture suggesting different affinities than *M. triangula* at Site 594.

Occurrence. The highest abundances reported for *Mesocena triangula* are 8% at Site 555 in the North Atlantic and 9% at Site 594 in the South Pacific. Both are in late Miocene samples. Infrequent occurrences in other areas are typically 1 or 2% in assemblages from Oligocene (Busen and Wise, 1977) to Quaternary (Bukry, 1975c). This long range supports polyphyletic or secondary origins for many of the occurrences of the species. But the late Miocene occurrences at Site 594, 555, and 329 show a potential correlation between the *Dictyocha brevispina* Zone and *Distephanus speculum* Zone. Because *M. triangula* occurs in cool (Ts = 2) to relatively warm (Ts = 42) assemblages no single temperature regime seems responsible for its occurrence.

Mesocena triodon Bukry

Mesocena triodon Bukry, 1973a, p. 860, pl. 2, fig. 11.
Mesocena triodon Bukry, Bukry, 1978, p. 819, pl. 7, figs. 9, 10.

Remarks. The occurrence of rare specimens of *Mesocena triodon* at Site 594, in assemblages lacking *M. quadrangula*, indicates that *M. triodon* is more closely related to *M. diodon nodosa* than to *M. quadrangula*.

OTHER TAXA CITED

Silicoflagellates

Bachmannocena Locker
Caryocha Bukry and Monechi
Corbisema apiculata (Lemmermann) Hanna
C. disymmetrica angulata Bukry
C. glezerae Bukry
C. hastata globulata Bukry
C. hastata hastata (Lemmermann) Frenguelli
C. inermis (Lemmermann) Dumitricǎ
C. triacantha (Ehrenberg) Hanna
Dictyocha aspera aspera (Lemmermann) Frenguelli
D. aspera clinata Bukry
D. brevispina (Lemmermann) Bukry
D. deflandrei completa (Glezer) Bukry
D. fibula augusta Bukry
D. fibula fibula Ehrenberg
D. pentagona (Schulz) Bukry and Foster
D. pulchella Bukry
D. pulchella var. *inflata* Bukry
Distephanus crux crux (Ehrenberg) Haeckel
D. frugalis (Bukry) Bukry
D. octangulatus Wailes
D. octonarius (Ehrenberg) Haeckel
D. polyactis crassus Bukry
D. pseudofibula (Schulz) Bukry
D. quinquangellus Bukry and Foster
D. speculum diommata (Ehrenberg) Bukry
D. speculum minutus (Bachmann) emend. Bukry
D. speculum speculum (Ehrenberg) Haeckel
D. speculum triommata (Ehrenberg) Bukry
D. varians (Gran and Braarud) Bukry
D. xenus Bukry
Mesocena apiculata apiculata (Schulz) Hanna
M. apiculata curvata Bukry
M. apiculata glabra (Schulz) Bukry
Naviculopsis aspera (Schulz) Perch-Nielsen
N. biapiculata (Lemmermann) Frenguelli
N. constricta (Schulz) emend. Bukry
N. eobiapiculata Bukry
N. trispinosa (Schulz) Glezer
Octactis Schiller
Paradictyocha Frenguelli
Septamesocena Bachmann

Diatoms

Rocella gelida (Mann) Bukry
R. schraderi Bukry

Coccoliths

Amaurolithus tricorniculatus (Gartner) Gartner and Bukry
Chiasmolithus oamaruensis (Deflandre) Hay et al.
Discoaster bellus Bukry and Percival
D. brouweri Tan, emend. Bramlette and Riedel
D. hamatus Martini and Bramlette
D. kugleri Martini and Bramlette
D. quinqueramus Gartner
Isthmolithus recurvus Deflandre
Triquetrorhabdulus rugosus Bramlette and Wilcoxon

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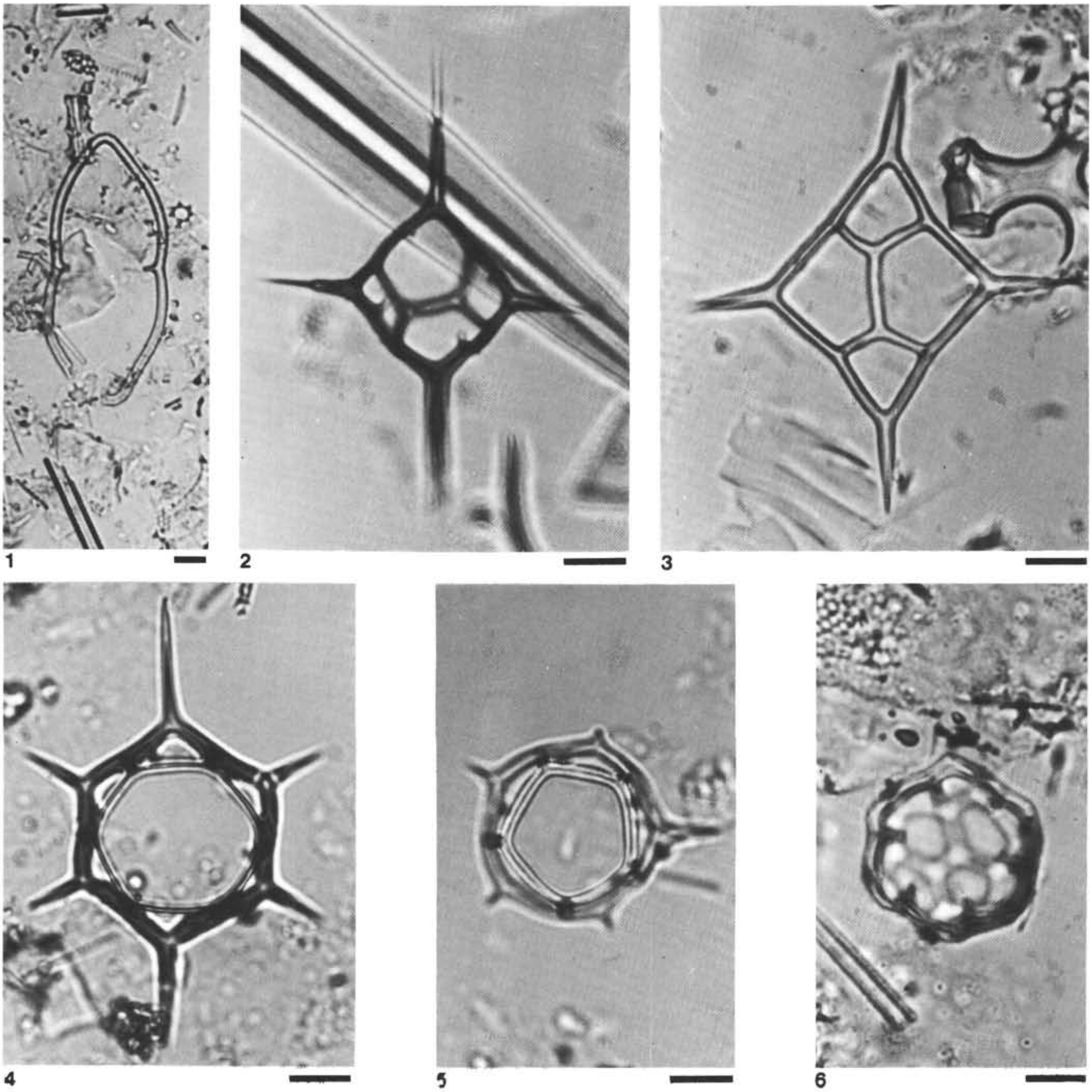

Plate 1. Silicoflagellates from DSDP Leg 90. (Scale bar equals 10 μm.) **1.** *Corbisema* sp; compare *Corbisema disymmetrica angulata* Bukry, Sample 594-31-2, 8–9 cm. **2.** *Dictyocha aspera clinata* Bukry s. ampl., Sample 594-27-2, 8–9 cm. **3.** *Dictyocha fibula augusta* Bukry, Sample 594-27-2, 8–9 cm. **4, 5.** *Distephanus speculum minutus* (Bachmann), Sample 594-20-2, 8–9 cm, (4) normal specimen, (5) pentagonal variant. **6.** *Distephanus xenus* Bukry, Sample 594-21-2, 8–9 cm; basal focus.

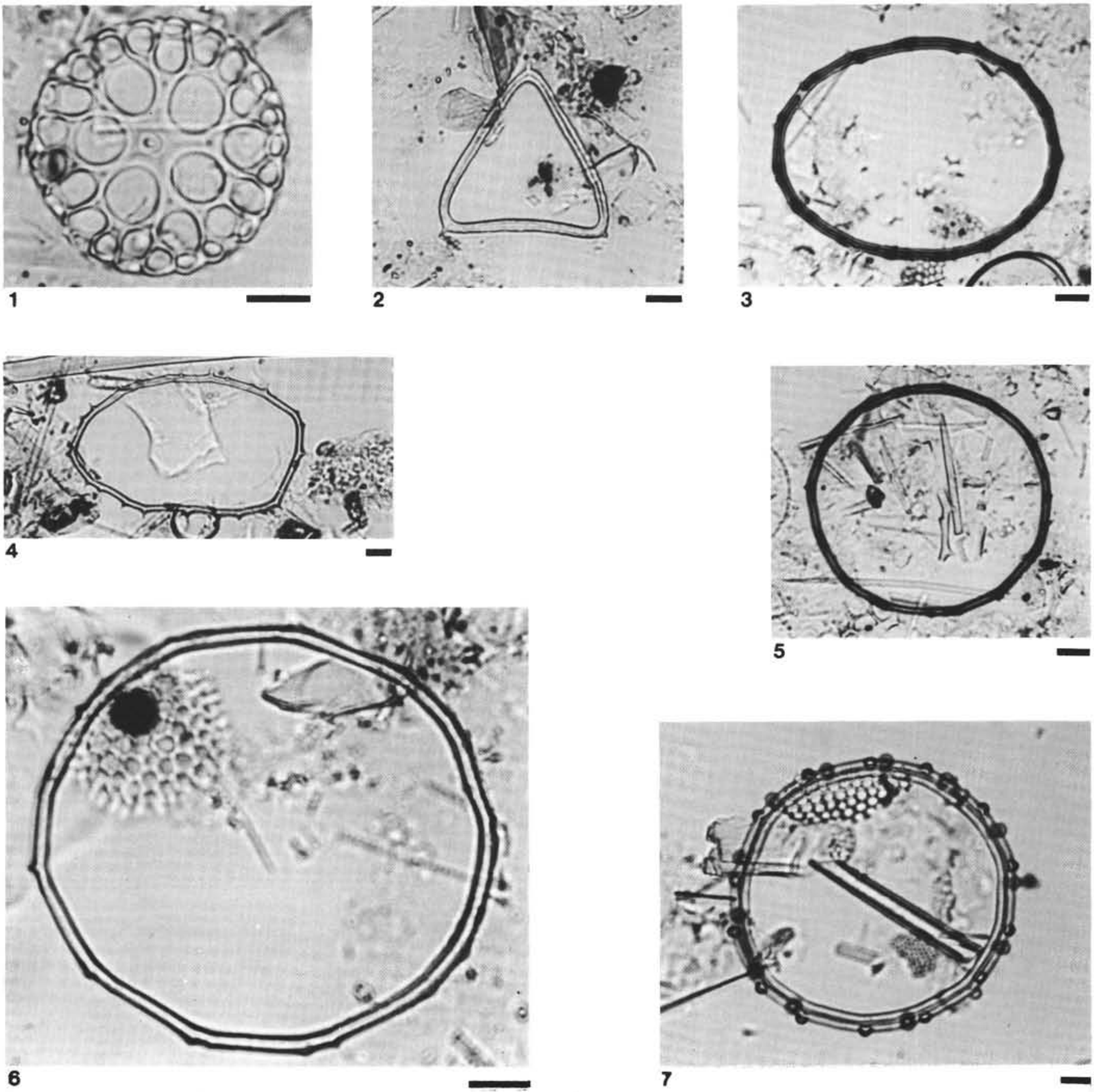

Plate 2. Diatom and silicoflagellates from DSDP Leg 90. (Scale bar equals 10 μm.) **1.** *Rocella schraderi* Bukry, Sample 594-31-2, 8-9 cm (diatom). **2.** *Mesocena apiculata curvata* Bukry, Sample 594-48-2, 8-9 cm. **3-7.** *Mesocena circulus* var. *apiculata* Lemmermann, (3) elliptic, Sample 594-31-2, 8-9 cm, (4) oblong, Sample 594-47-1, 8-9 cm, (5, 6) circular and nearly spineless, Sample 594-31-2, 8-9 cm, (7) knobby variant, Sample 594-30-2, 8-9 cm.

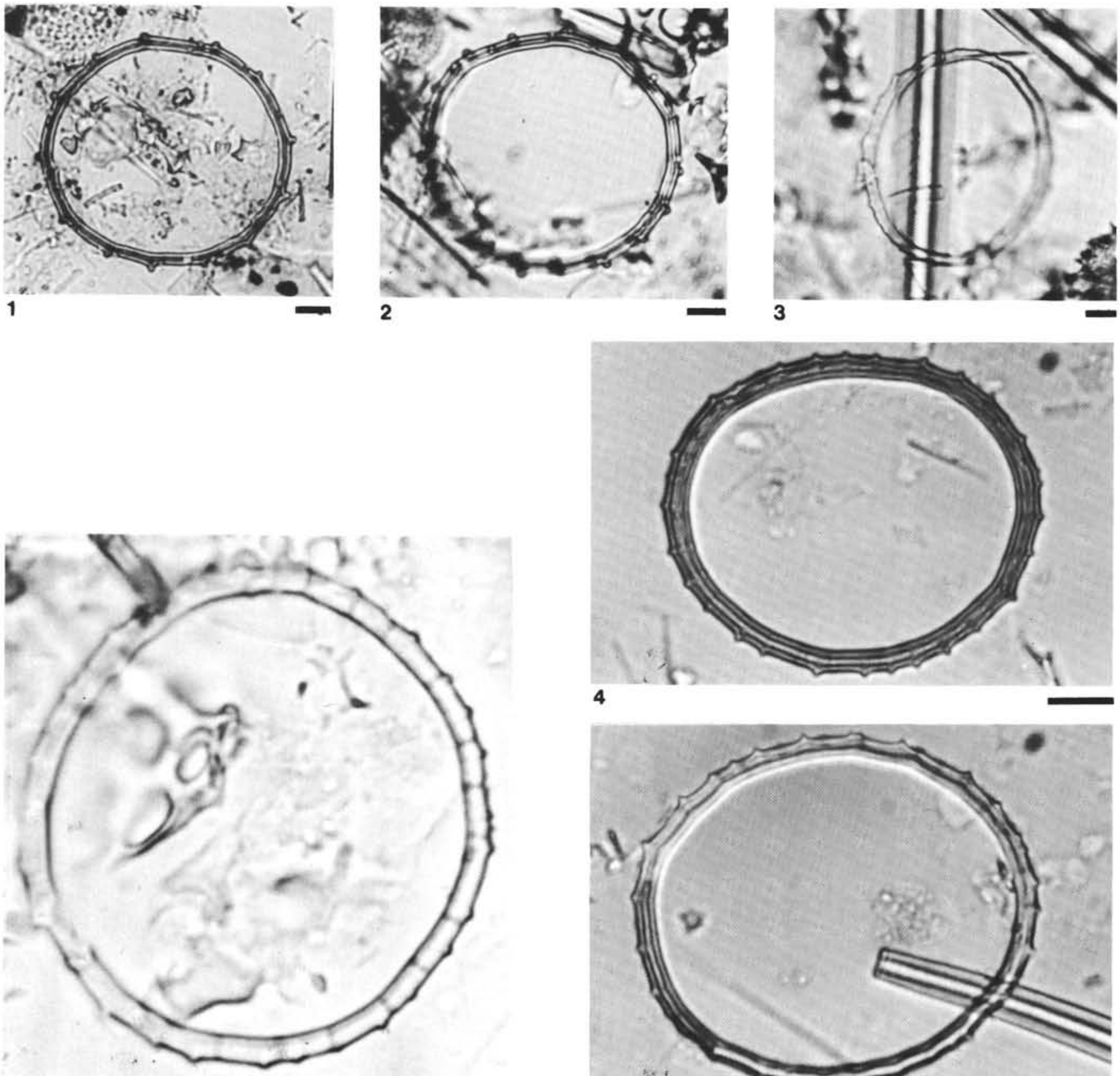

Plate 3. Silicoflagellates from DSDP Leg 90. (Scale bar equals 10 μm.) **1, 2.** *Mesocena circulus* var. *apiculata* Lemmermann, knobby variant, (1) Sample 594-31-2, 8–9 cm, (2) Sample 594-30-2, 8–9 cm. **3–6.** *Mesocena circulus* (Ehrenberg), (3) Sample 594-27-2, 8–9 cm, (4, 5) verticillate nodes suggest affinities with *Mesocena diodon nodosa;* Sample 594-25-2, 8–9 cm, (6) Sample 594-25-2, 8–9 cm.

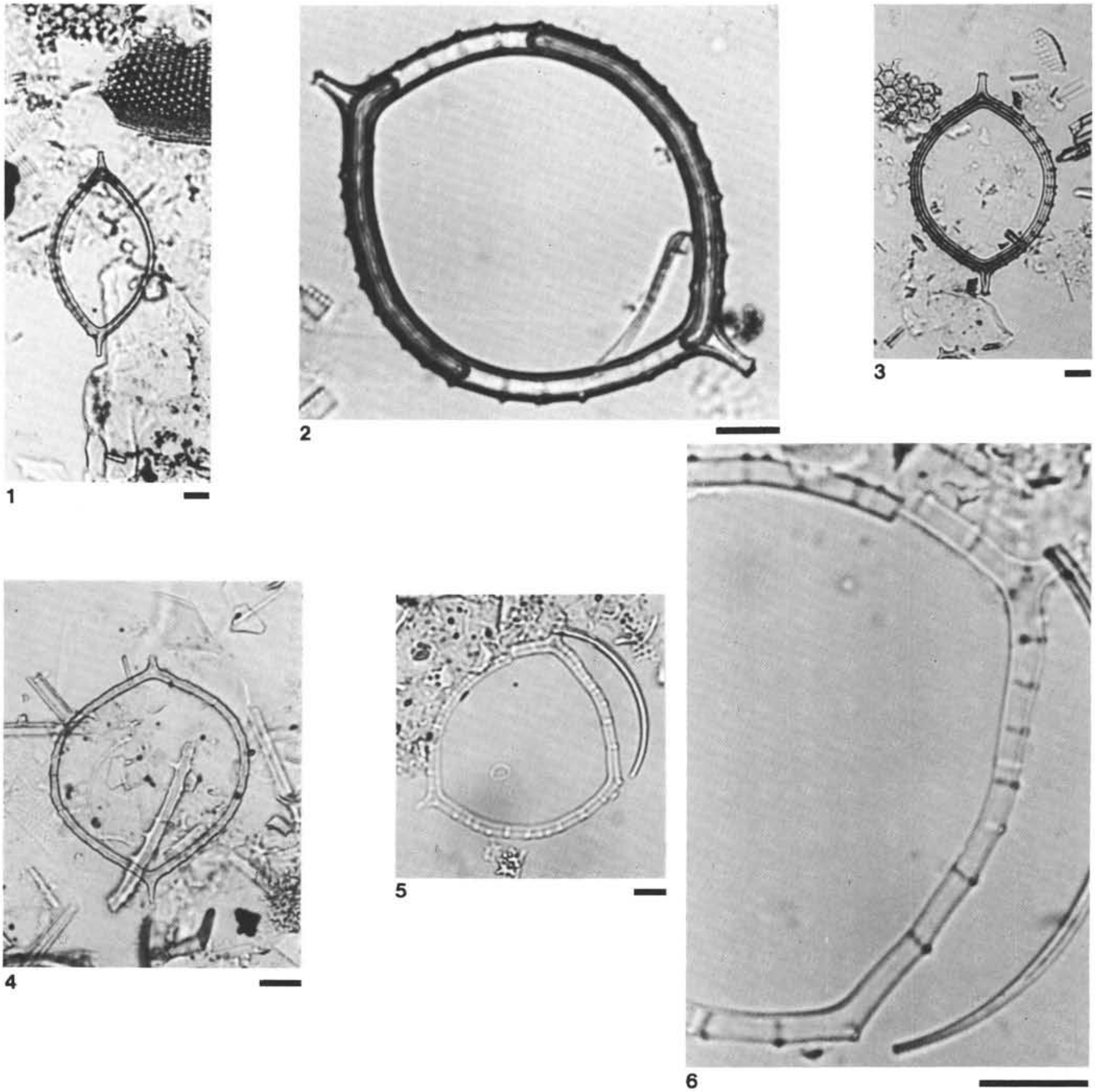

Plate 4. Silicoflagellates from DSDP Leg 90. (Scale bar equals 10 μm.) **1.** *Mesocena* sp. cf. *M. diodon borderlandensis* Bukry, Sample 594-27-2, 8–9 cm. **2–6.** *Mesocena diodon nodosa* Bukry, (2) Sample 594-30-2, 8–9 cm, (3) Sample 594-27-2, 8–9 cm, (4) oblate, Sample 594-23-5, 8–9 cm, (5, 6) triangular variant, Sample 594-23-5, 8–9 cm.

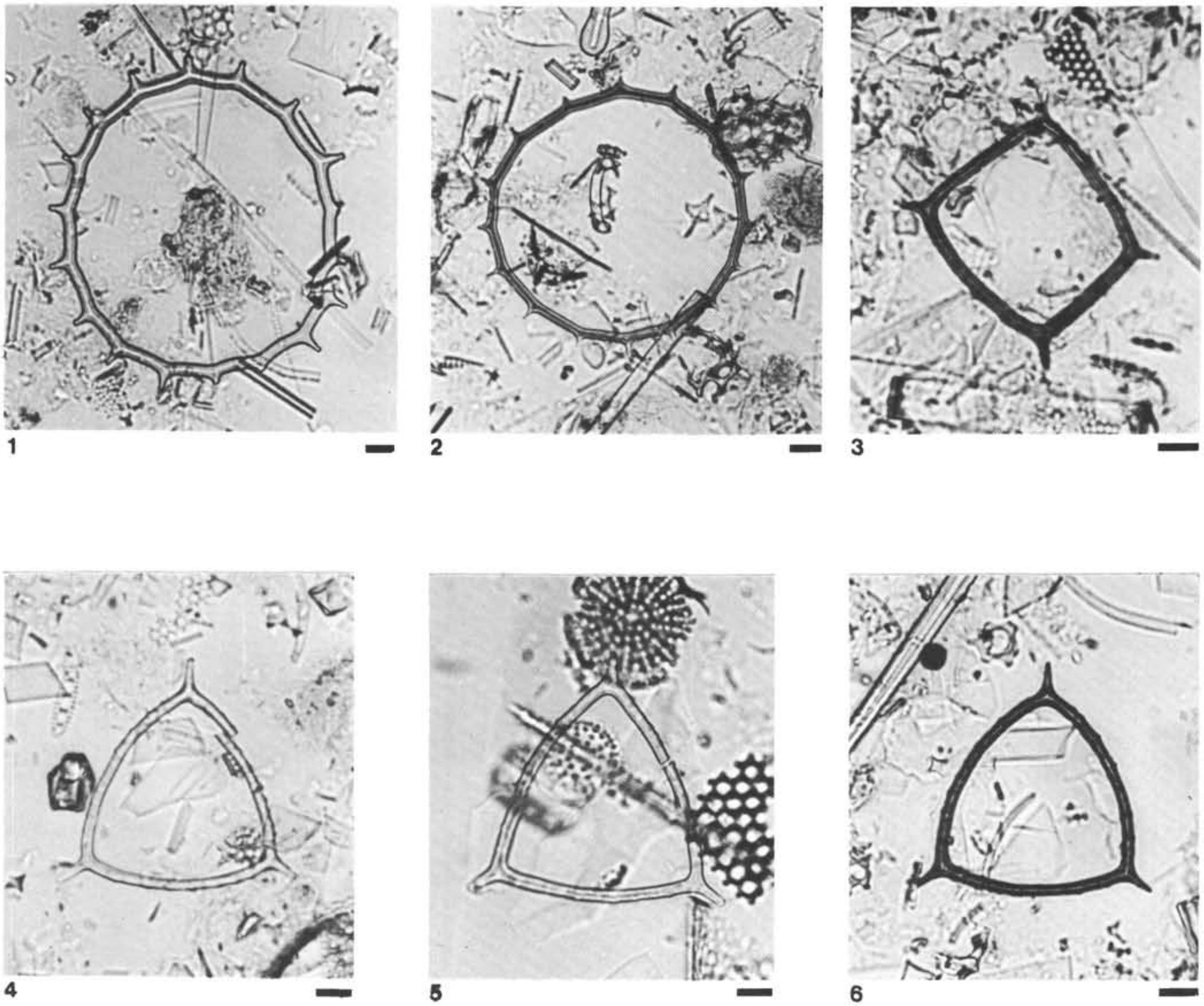

Plate 5. Silicoflagellates from DSDP Leg 90. (Scale bar equals 10 μm.) **1, 2.** *Mesocena dumitricae* (Perch-Nielsen), Sample 594-27-2, 8-9 cm. **3.** *Mesocena quadrangula* Ehrenberg ex Haeckel, Sample 594-23-5, 8-9 cm. **4-6.** *Mesocena triangula* (Ehrenberg), Sample 594-23-5, 8-9 cm.