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16. SILICOFLAGELLATES, EBRIDIANS, AND ACTINISCIDIANS FROM PLIOCENE AND QUATERNARY SEDIMENTS OFF SOUTHERN CHILE, ODP LEG 141[1]

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ABSTRACT

Three groups of siliceous flagellates are discussed from Sites 860 and 861 in the southeastern South Pacific Ocean off southern Chile. Three silicoflagellate zones and two ebridian/actiniscidian zones are recognized in upper Pliocene to Quaternary sediments. Repeated occurrences of *Dictyocha messanensis messanensis* demonstrate that the cool subpolar water masses of the Peru Current were mixed with or replaced by warm transitional water masses of the central South Pacific several times during late Pliocene to middle Pleistocene times. Continuous occurrences of *Dictyocha messanensis aculeata* in Zone NN21 sediments reflect an enhanced influence of transitional surface-water also during late Pleistocene and Holocene times. These Pliocene and Quaternary warming episodes may have been caused by strong El Niño activities, which resulted in a southward shift of the transitional water belt and an expansion of warmer surface-water over the study area.

INTRODUCTION

During Leg 141 of the Ocean Drilling Program (ODP), 13 holes were drilled at five sites between about 45°40′S and 47°00′S, off southern Chile (Fig. 1). This is the region where the active oceanic spreading center of the Chile Ridge is being subducted under the continental plate of South America. The main objective of drilling was to investigate the geologic and tectonic processes that are associated with the subduction of oceanic crust and sediment material under the continent.

To determine structural and depositional characters of the collision zone, three sites (Sites 859, 860, and 861) were arranged along a transect across the accretionary wedge and the forearc basin just north of the present-day Chile Triple Junction. The sediment sequences retrieved consist of upper Pliocene to Quaternary predominantly clayey to silty sediments of varying consolidation. These sediments contain diversified assemblages of calcareous and siliceous microfossils, of both planktic and benthic origin.

This study deals with three groups of planktic microorganisms possessing siliceous skeletons (i.e., silicoflagellates, ebridians, and actiniscidians). Neglecting specific taxonomic affinities, these groups may be summarized as siliceous flagellates. In general, representatives of siliceous flagellates were minor constituents of the plankton communities during Pliocene and Quaternary times. But, nevertheless, they provide important stratigraphic and paleoceanographic information. Because sediments at Sites 860 and 861 yielded plankton assemblages that were more diversified and better preserved, investigations were restricted to those sites. Stratigraphic results are summarized in Figure 2 and Tables 1, 2, and 3, and paleoceanographic interpretations are displayed in Figures 3 and 4 and Table 2.

METHODS

To concentrate skeletons of siliceous flagellates, sediment samples were processed successively with hydrogen peroxide, hydrochloric acid, and sodium pyrophosphate. After the use of acid and lye, respectively, samples were washed three times. Decalcified residues were strewn on cover glasses 22 × 22 mm in size and then embedded in Canada balsam.

Generally, eight traverses across a cover glass (21%) were counted with a magnification of ×390 and tabulated for species abundances. But, when searching for stratigraphically indicative species, more traverses were scanned. The following abundance classes were used:

B = barren
T = traces (specimens out of count)
R = rare (1–5 specimens)
F = few (6–15 specimens)
C = common (16–50 specimens)
A = abundant (>50 specimens)
+ = reworked specimens

Total abundances of silicoflagellates and ebridians/actiniscidians were classified as described above. Because siliceous flagellates were generally minor constituents of the protophyte assemblages that consisted mainly of diatoms, diatom abundances were estimated, too, and noted as an indicator for expected flagellate abundances. The following abundance classes were adopted:

B = barren
T = traces, single valves and/or remnants of corrosion
F = few, minor content of valves and fragments
C = common, major content of valves and fragments

In most studies, the preservational state of siliceous flagellates remains undescribed, as it is difficult to determine the original extent of fragmentation and corrosion. The fragile skeletons of silicoflagellates may be fragmented during preparation, and corrosion stages of ebridians and actiniscidians may be confused with juvenile skeletons. Because the slides of this study were prepared from suspended material, the state of preservation can be indicated in a general manner as follows. In samples containing complete skeletons, preservation is moderate; in samples containing only fragments, preservation is poor. The star-shaped skeletons of actiniscidians are most resistant and disappear last.

BIOSTRATIGRAPHIC ZONATIONS

Plankton biostratigraphy of upper Neogene to Quaternary sediments is strongly influenced by paleoceanography, especially by ecological adaptations of the former plankton communities to certain water masses and current systems. The biozonations used for Leg 141 obviously represent high-latitude subdivisions, which may be recog-

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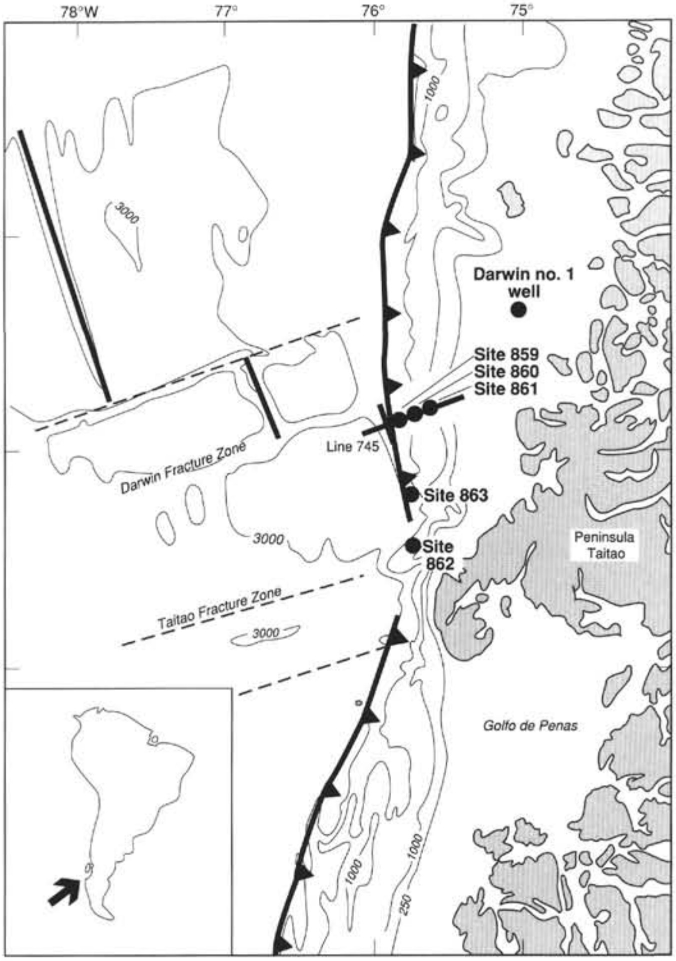

Figure 1. Location of ODP Leg 141 sites in the southeastern South Pacific and position of the subduction zone off southern Chile. Bathymetric contours in meters.

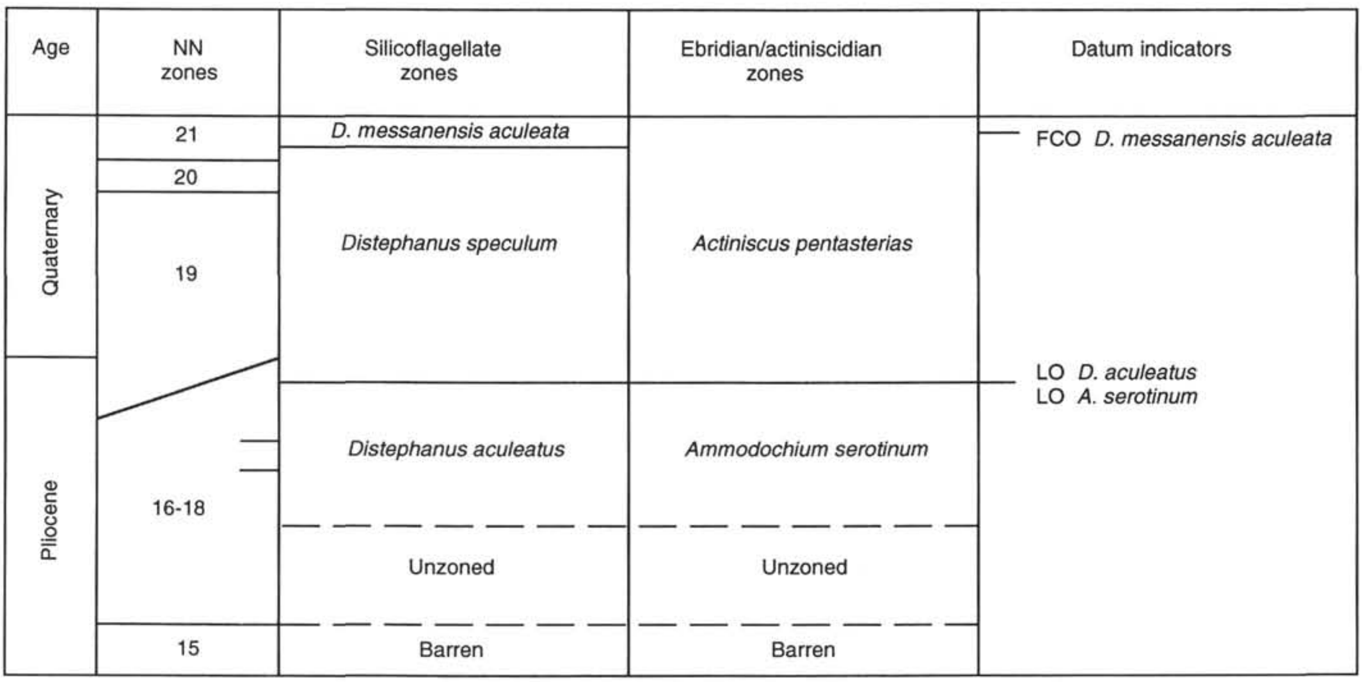

Figure 2. Silicoflagellate and ebridian/actiniscidian zonations used for Sites 860 and 861, FOs and LOs of diagnostic species and correlation to standard nannofossil zones (Spiegler and Müller, this volume).

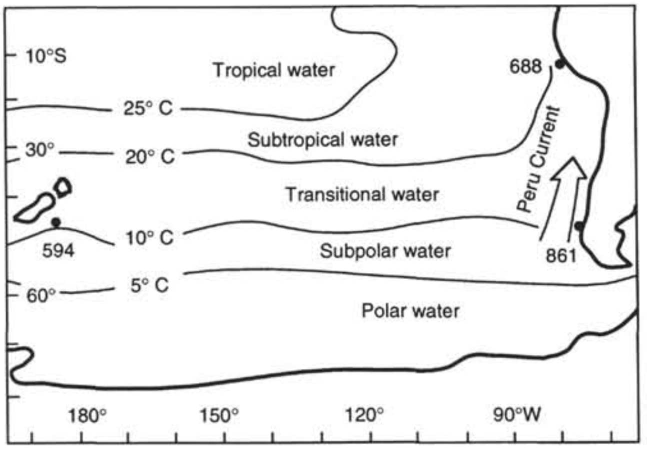

Figure 3. Distribution of surface-water masses in the southeastern South Pacific, based on present-day annual mean potential temperatures (according to Levitus, 1982). Location of Site 861 and position of Sites 594 and 688 where *Dictyocha messanensis aculeata* was found in Zone NN19–NN21 sediments.

nized in both hemispheres, but which differ distinctly from subdivisions described for middle and low latitudes.

The stratigraphic sequences cored at Sites 860 and 861 can be divided into three silicoflagellate zones and two ebridian/actiniscidian zones (Fig. 2). Definitions are given below. The correlations to nannoplankton zones are based on the data of Spiegler and Müller (this volume). The Pliocene/Pleistocene boundary was placed at the first occurrence of *Gephyrocapsa oceanica* (Spiegler and Müller, this volume), which corresponds to the base of Zone CN14 (Okada and Bukry, 1980) or an uplifted Zone NN18/NN19 boundary (Martini and Müller, 1986). This level has been dated at 1.6 Ma by Berggren et al. (1985). Paleomagnetic data could not be used for comparison, because of the strongly overprinted paleomagnetic signals.

Silicoflagellates

Distephanus aculeatus Zone

Definition: Interval from the last occurrence (LO) of *Mesocena diodon* to the LO of *Distephanus aculeatus* (Bukry and Foster, 1973; base redefined by Locker and Martini, 1989). Lower to uppermost Pliocene.

Occurrence: Found in Holes 860B and 861C. The LO of *M. diodon* was not discovered in both holes. The LO of *D. aculeatus* is well developed in Hole 861C, but poorly preserved in Hole 860B. In Hole 861C, the LO of *D. aculeatus* probably lies in the uppermost part of Zone NN18.

Remarks: The last appearance datum (LAD) of *M. diodon* is at or just above the Miocene/Pliocene boundary, which may correspond to the top of Zone NN12. The LAD of *D. aculeatus* (synonym *Dictyocha boliviensis*) approaches the Pliocene/Pleistocene boundary or the top of Zone NN18. This has been found in the eastern Pacific Ocean at Site 157 (Bukry and Foster, 1973), and in the Southern Ocean at Sites 266, 269, and 274 (Ciesielski, 1975). At other high-latitude sites, the LAD of *D. aculeatus* may be earlier, and then, some equivalent *Distephanus speculum* zones have been used by authors.

Distephanus speculum Zone

Definition: Interval from the LO of *Distephanus aculeatus* to the first consistent occurrence (FCO) of *Dictyocha messanensis aculeata* (Ciesielski, 1975; top modified in this study). Uppermost Pliocene to Pleistocene.

Occurrence: Found in Holes 860B and 861C.

Remarks: Depending on the LO of *D. aculeatus* and the first occurrence (FO) and FCO of *D. messanensis aculeata,* respectively, the content of this zone may vary regionally.

Dictyocha messanensis aculeata Zone

Definition: Interval above the FCO of *Dictyocha messanensis aculeata* (Dumitrica, 1973, Bukry and Foster, 1973; base modified in this study). Pleistocene to Holocene.

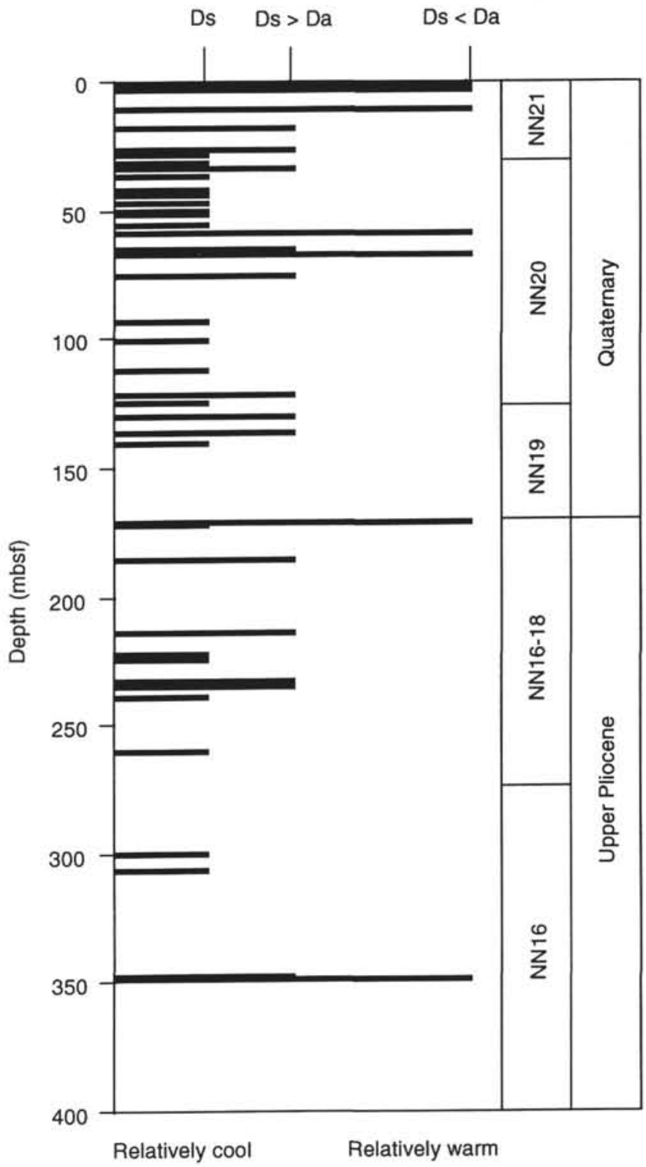

Figure 4. Generalized stratigraphic distribution of *Distephanus speculum* and *Dictyocha messanensis* at Site 861 and correlation to standard nannofossil zones (Spiegler and Müller, this volume). Abbreviations: Ds = only *D. speculum* present, Ds > Da = minor occurrence of *D. messanensis*, Ds < Da = major occurrence of *D. messanensis*.

Occurrence: Found in Holes 860B and 861C. The FCO of *D. messanensis aculeata* commences in Zone NN21 of both holes.

Remarks: Because specimens of *Mesocena quadrangula* were not found in the material, the original zonal definition had to be modified for Leg 141 use. Here, the base has been placed at the FCO of *D. messanensis aculeata*, which corresponds to a paleoceano-graphically determined level above its first appearance datum (FAD).

The FAD of *D. messanensis aculeata* is in the middle Pleistocene or within Zone NN19. This has been found, for instance, in the northwestern and northern Pacific Ocean at Sites 299 and 310 (Ling, 1975; Bukry, 1978), in the eastern Pacific at Sites 157, 425, and 688 (Bukry and Foster, 1973; Bukry, 1980; Martini, 1990), in the southwestern Pacific at Sites 206, 278, and 594 (Dumitrica, 1973; Perch-Nielsen, 1975; Locker and Martini, 1986b), in the northeastern and northern Atlantic at Sites 397 and 412 (Bukry, 1979a, 1979b).

Table 1. Stratigraphic distribution of siliceous flagellates in upper Pliocene to Quaternary sediments of Hole 860B and correlation to standard nannofossil zones (Spiegler and Müller, this volume).

Nanno-plankton zone	Hole 860B, core, section, interval (cm)	Depth (mbsf)	Slide area (%)	Diatom abundance	*Da. messanensis*, total	*Da. mess. aculeata*	*Da. mess. messanensis*	*Da. mess. stapedia*	*Da. perlaevis*	*Da.* spp.	*Ds. aculeatus*
	1H-1, 90-91	00.90	63	C	R	T	R	.	.	1+	.
NN21	2H-1, 40-42	01.80	21	C	F	R	R	.	.	.	.
	2H-2, 19-21	03.09	21	T				Barren			
	2H-4, 29-31	06.19	42	C	F	.	F	.	.	.	.
?	2H-5, 18-20	07.58	42	F	.	.	.	.	.	.	.
	2H-7, 19-21	10.59	63	C	R	R	.	.	.	.	.
NN20	3H-3, 100-101	14.90	42	C	.	.	.	.	.	.	.
	4H-3, 100-101	24.40	21	T	.	.	.	.	.	.	.
	5H-3, 37-38	33.27	21	T				Fragments			
	6H-3, 94-95	43.34	21	T				Barren			
NN19	7H-4, 60-61	54.00	21	T				Fragments			
	12X-3, 100-101	91.70	42	T	.	.	.	.	.	.	.
	14X-2, 48-49	101.08	21	T				Barren			
	15X-3, 100-101	111.20	42	F	R	.	R	.	.	1+	.
	16X-2, 68-69	118.98	21	T				Fragments			
	17X-CC	136.10	21	T				Barren			
	19X-3, 100-101	141.10	63	C	R	.	R	R	T	1,2+	.
	20X-1, 127-128	147.07	63	F	.	.	.	.	R	1+	.
	21X-1, 72-73	156.22	42	F	.	.	.	.	.	.	T
	22X-2, 103-104	167.63	42	C	.	.	.	.	.	.	.
	24X-2, 25-26 to	186.15	10	T				Barren			
	30X-2, 75-76	243.82	05	T							
NN16-18	31X-3, 6-7	254.96	21	F				Fragments			
	32X-1, 27-28	261.87	63	F	.	.	.	.	.	1+	.
	34X-3, 66-67	284.46	05	B				Barren			
	35X-1, 79-80	291.19	05	T				Barren			
	36X-3, 91-92	304.01	42	F				Barren			
	37X-3, 98-100	313.78	42	T	.	.	.	.	.	.	.
	39X-2, 76-77 to	330.96	05	B				Barren			
	60X-3, 44-46	514.84	05	B							
	61X-4, 60-62	526.80	21	T				Fragments			
NN15?	64X-3, 19-20 to	552.39	05	B				Barren			
	67X-3, 83-84	583.03	05	B							

Note: Barren samples are summarized in Table 3. Numbers under *Dictyocha* spp. refer to trace or rare occurrences of *Dictyocha fibula* (1) and *Dictyocha varia* (2).

Ebridians and Actiniscidians

Ammodochium serotinum Zone

Definition: Interval from the LO of *Ebriopsis cornuta* to the LO of *Ammodochium serotinum* (Ling, 1973, cited as *Ammodochium rectangulare*). Upper Pliocene.

Occurrence: Found in Holes 860B and 861C. The LO of *E. cornuta* was not discovered in both holes. The LO of *A. serotinum* is well developed in Hole 861C, but indistinctly represented in Hole 860B. In Hole 861C, the LO of *A. serotinum* probably lies in the uppermost part of Zone NN18.

Remarks: Both the LADs of *E. cornuta* and *A. serotinum* are loosely defined at some northern Pacific sites, due to the absence of calcareous nannofossils. Generally, the LAD of *E. cornuta* is known for the early to late Pliocene transition, and the LAD of *A. serotinum* for the latest Pliocene. This is documented, for instance, in the northeastern Pacific Ocean at Site 173 (Ling, 1977), and in the northern Pacific at Site 192 (Ling, 1973). Both levels are most exactly determined at Site 644 in the Norwegian Sea (Locker and Martini, 1989) and at Site 798 in the Japan Sea (Ling, 1992). At Site 644, the LAD of *E. cornuta* is at the top of the Gauss Chron (top of Zone NN16) and the LAD of *A. serotinum* is below the Olduvai Subchron (near the top of Zone NN18). At Site 798, the LAD of *E. cornuta* is above the Gauss Chron (probably Zone NN17) and the LAD of *A. serotinum* lies within the Olduvai Subchron.

Actiniscus pentasterias Zone

Definition: Interval above the LO of *Ammodochium serotinum* (Locker and Martini, 1989). Uppermost Pliocene to Holocene.

Occurrence: Found in Holes 860B and 860C.

Remarks: This zone fills the interval above the LO of *A. serotinum*, as the last distinct ebridian marker.

SITE SUMMARIES

Site 860 (Tables 1 and 3)

From this site, one hole was investigated for siliceous flagellates. Hole 860B (45°51.972′S, 75°45.101′W; water depth 2145.9 m) was drilled on the middle slope of the Chile Trench, as the central member of the transect across the forearc basin. The sediment sequence recovered comprises predominantly clayey to silty sediments

Table 1 (continued).

Ds. bioctonarius	*Ds. speculum*, total	*Ds. speculum* f. *speculum*	Silicoflagellate abundance	Silicoflagellate zone	*A. serotinum*	*A.* sp., small triodes	*E. tripartita*	*E. tripartita*, large triodes	*A. pentasterias*	Ebrid./actin. abundance	Ebridian/ actiniscidian zone
.	R	R	R	*Dictyocha*	.	.	.	.	R	R	
.	R	R	F	*mess. aculeata*	.	.	.	.	R	R	
	Barren		B				Barren			B	
.	R	R	F		.	.	T	.	R	R	
.	R	R	R		.	.	.	.	R	R	
.	R	R	R		.	.	.	.	T	T	
.	R	R	R	*Distephanus*	.	.	.	.	R	R	*Actiniscus*
.	R	R	R	*speculum*	.	.	.	.	R	R	*pentasterias*
	Fragments		T		.	.	.	.	R	R	
	Barren		B				Barren			B	
	Fragments		T		.	.	.	.	R	R	
.	R	R	R				Barren			B	
	Barren		B				Barren			B	
.	R	R	R		.	.	.	.	R	R	
	Fragments		T				Barren			B	
	Barren		B		.	.	.	.	R	R	
.	R	R	F		.	T	R	R	R	F	
.	F	F	F		.	.	.	.	R	R	*Ammodochium*
.	R	R	R	*Distephanus*	.	.	.	.	T	T	*serotinum*
.	F	F	F	*aculeatus*	R	T	.	R	R	R	
	Barren		B				Barren			B	
			B							B	
	Fragments		T		.	.	.	.	R	R	
R	R	R	R		.	.	.	.	R	R	
	Barren		B				Barren			B	
	Barren		B	Unzoned			Barren			B	Unzoned
	Barren		B		.	.	.	.	R	R	
.	R	R	R		.	.	.	.	R	R	
	Barren		B				Barren			B	
			B							B	
	Fragments		T				Barren			B	
	Barren		B				Barren			B	
			B							B	

with a higher degree of consolidation toward the base (Shipboard Scientific Party, 1992a).

The sediments studied contain rather poorly preserved but, nevertheless, diversified assemblages of siliceous microfossils. These include protophytes (diatoms, silicoflagellates, ebridians, actiniscidians), protozoans (radiolarians), and remnants of metazoans (sponge spicules). Although abundances may be very low in certain layers, 19 out of 46 samples yielded siliceous flagellates. With a few exceptions, most of the flagellate assemblages are low in abundance and moderate to poor in preservation.

Samples 141-860B-1H-1, 90–91 cm, and -2H-1, 40–42 cm, contain *D. messanensis aculeata* and *A. pentasterias* and have been assigned to the *Dictyocha messanensis aculeata* and the *Actiniscus pentasterias* Zones. The interval between Samples 141-860B-2H-2, 19–21 cm, and -22X-2, 103–104 cm, shows fluctuating abundances of siliceous flagellates that range from few to barren. But occurrences of *D. speculum* and *D. aculeatus* allow one to place Samples 141-860B-2H-2, 19–21 cm, to -20X-1, 127–128 cm, into the *Distephanus speculum* Zone, and Samples 141-860B-21X-1, 72–73 cm, and -22X-2, 103–104 cm, into the *Distephanus aculeatus* Zone. The presence of *A. pentasterias* and *A. serotinum* (including *Ammodochium* sp.) indicates the *Actiniscus pentasterias* Zone down to Sample 141-860B-17X-CC, and the *Ammodochium serotinum* Zone from Sample 141-860B-19X-3, 100–101 cm, to -22X-2, 103–104 cm. Several occurrences of *D. messanensis* in Cores 141-860B-2H, -15X, and -19X obviously mark time levels of warmer surface-water conditions. With the exception of four samples displaying nonindicative silicoflagellate and actiniscidian species, the interval from Sample 141-860B-24X-2, 25–26 cm, down to the bottom of the hole remains barren of siliceous flagellates.

According to nannofossil data (Spiegler and Müller, this volume), the Pleistocene/Pliocene boundary lies above the LOs of *D. aculeatus* and *A. serotinum*. Although reworked Miocene to lower Pliocene silicoflagellates, such as *Dictyocha fibula* and *Dictyocha varia*, were found, the bulk of skeletons seems to be in place. No slumping or major reworking could be recognized.

Site 861 (Tables 2 and 3)

From this site, two holes were investigated for siliceous flagellates. Holes 861C (45°51.025′S, 75°41.531′W; water depth of 1652.2 m) and 861D (45°51.008′S, 75°41.499′W; water depth of 1652.2 m)

Table 2. Stratigraphic distribution of siliceous flagellates in upper Pliocene to Quaternary sediments of Holes 861C/D and correlation to standard nannofossil zones (Spiegler and Müller, this volume).

Nannoplankton zone	Holes 861C/D, core, section, interval (cm)	Depth (mbsf)	Slide area (%)	Diatom abundance	*Da. messanensis*, total	*Da. mess. aculeata*	*Da. mess. messanensis*	*Da. mess. stapedia*	*Da. perlaevis*	*Da.* spp.	*Ds. aculeatus*	*Ds. bioctonarius*	*Ds. speculum*, total	*Ds. spec.* f. *pentagonus*
	1H-1, 10-11	00.10	42	C	F	R	F	.	.	.	.	.	R	.
	1H-2, 40-41	01.90	21	C	F	R	F	.	R	.	.	.	F	.
	2H-5, 80-81	09.80	21	C	F	R	F	.	.	.	.	.	F	R
NN21	3H-3, 99-100	16.49	42	C	R	.	R	.	.	.	.	.	F	R
	4H-1, 110-11	23.10	42	F			Fragments					Fragments		
	4H-3, 33-34	25.33	42	C	R	.	R	.	.	.	.	.	.	.
	4H-4, 86-87	27.36	42	F	.	.	.	.	.	.	.	.	R	.
	4H-6, 130-131	30.80	42	F	.	.	.	.	.	.	.	.	R	.
	5H-2, 60-62	32.40	21	F	R	.	R	.	.	.	.	.	R	.
	5H-4, 60-62	35.40	21	T	.	.	.	.	.	.	.	.	R	R
	5H-6, 60-62	38.40	42	F			Fragments					Fragments		
	5H-8, 58-60	41.38	42	F	.	.	.	.	.	.	.	.	R	.
	6H-2, 29-30	42.79	42	F	.	.	.	.	.	.	.	.	R	.
	6H-4, 79-80	46.29	21	T	.	.	.	.	.	.	.	.	R	.
	6H-6, 90-91	49.40	21	F	.	.	.	.	.	.	.	.	R	.
NN20	6H-7, 60-61	50.60	42	F	.	.	.	.	.	2+	.	.	R	.
	7H-2, 120-121	53.20	21	T			Barren					Barren		
	7H-3, 89-90	54.39	21	F	.	.	.	.	.	.	.	.	F	.
	7H-6, 25-26	58.25	42	F	F	.	F	.	.	.	.	.	.	.
	8H-3, 71-72	63.71	42	C	R	.	R	.	.	.	.	.	R	.
	8H-5, 10-11	66.10	42	C	R	R	R	T	.	.	.	.	.	.
	10H-3, 100-101	75.00	84	F	T	T	.	.	.	.	.	T	R	T
	12X-2, 50-51	92.10	63	C	.	.	.	.	.	.	.	.	F	.
	13X-1, 35-36	100.15	42	F	.	.	.	.	.	.	.	.	R	R
	14X-2, 70-71	111.60	63	F	.	.	.	.	.	.	.	.	R	.
	15X-2, 68-69	121.18	42	C	R	R	.	.	.	.	.	.	F	T
	15X-4, 75-76	124.25	42	C	.	.	.	.	.	.	.	.	R	.
	16X-1, 72-73	129.62	42	C	T	T	.	.	.	.	.	.	R	.
	16X-5, 60-61	135.50	21	C	T	T	.	.	.	.	.	.	R	.
NN19	17X-1, 109-110	139.79	42	C	.	.	.	.	.	.	.	.	R	.
	18X-3, 119-120	152.69	42	F			Fragments					Fragments		
	19X-CC	168.20	21	T			Barren					Barren		
	20X-CC	170.20	42	F	R	.	R	.	.	3+	.	.	R	.
	21X-1, 100-101	171.20	84	F	.	.	.	.	.	.	R	.	R	.
?	22X-4, 87-88	185.27	84	C	F	.	F	.	.	2+	.	.	C	R
	25X-3, 99-100	212.89	42	C	R	.	R	.	.	.	R	.	R	.
	27X-2, 30-31	221.90	42	C	.	.	.	.	.	.	R	.	C	R
	27X-4, 30-31	223.81	21	C	.	.	.	.	.	2+	F	.	C	.
	28X-3, 40-41	231.50	21	C	T	.	T	.	.	.	F	.	F	.
NN16-18	28X-5, 29-30	234.03	21	C	R	.	R	.	.	.	R	.	R	.
	29X-1, 75-76	238.45	42	T	.	.	.	.	.	.	R	.	R	.
	32X-2, 44-46	258.94	42	F	.	.	.	.	.	.	.	.	R	.
	33X-2, 70-71	268.80	21	T			Barren					Barren		
	34X-3, 73-74	278.18	10	B			Barren					Barren		
	35X-3, 100-101	289.03	63	F	.	.	.	.	.	1+	.	.	.	.
	36X-3, 100-101	299.60	42	F	.	.	.	.	.	.	T	.	R	.
	37X-1, 90-91	305.80	42	F	.	.	.	.	.	.	.	.	R	.
NN16	39X-3, 100-101	327.32	21	T			Barren					Barren		
	40X-3, 87-88	337.77	21	T			Barren					Barren		
	1R-3, 100-101	346.30	42	F	R	.	R	.	.	2+	.	.	R	.
	41X-3, 99-100	347.39	42	F	R	.	R	T	.	.	.	.	R	.
	2R-1, 130-131 to	353.20	05	B			Barren					Barren		
	16R-2, 21-22	487.71	05	B										

Note: Barren samples are summarized in Table 3. Numbers under *Dictyocha* spp. refer to trace or rare occurrences of *Dictyocha fibula* (1), *Dictyocha varia* (2), and *Dictyocha* sp. (3).

Table 2 (continued).

Ds. spec. f. *speculum*	*Ds. spec.* f. *septenarius*	*Ds. spec.* f. *octonarius*	Silicoflagellate abundance	Silicoflagellate zone	*A. serotinum*	*A.* sp., small triodes	*E. tripartita*	*E.* sp., large triodes	*A. pentasterias*	Ebrid./actin. abundance	Ebridian/actiniscidian zone
R	.	T	F	*Dictyocha*	.	.	.	T	R	R	
F	.	.	C	*mess. aculeata*	.	.	T	T	R	R	
R	.	.	F		.	.	.	.	R	R	
R	.	.	F		.	.	R	R	R	R	
	Fragments		T		.	.	.	.	R	R	
.	.	.	R		.	.	.	R	R	F	
R	.	.	R		.	.	.	.	R	R	
R	T	.	R		.	.	.	.	R	R	
R	.	.	R		.	.	.	.	T	T	
.	.	.	R		.	.	.	.	T	T	
	Fragments		T		.	.	.	.	R	R	
R	.	.	R		.	.	.	.	T	T	
R	.	.	R		.	.	.	.	R	R	
R	.	.	R		.	.	.	.	T	T	
R	.	.	R	*Distephanus*	.	.	.	.	R	R	*Actiniscus*
R	.	.	R	*speculum*	.	.	.	.	R	R	*pentasterias*
	Barren		B				Barren			B	
F	.	.	F				Barren			B	
.	.	.	F		.	.	R	R	F	F	
R	.	.	R		.	.	R	R	R	R	
.	.	.	R		.	.	.	.	R	R	
R	.	R	R		R	T	T	.	F	F	
F	.	.	F		.	R	R	.	R	R	
R	.	.	R		.	.	R	R	T	R	
R	.	.	R		.	.	.	.	R	R	
F	T	.	F		.	.	.	.	T	T	
R	.	.	R		.	.	T	.	R	R	
R	.	.	R		.	.	.	R	R	R	
R	.	.	R		.	.	.	.	R	R	
R	.	.	R				Barren			B	
	Fragments		T		.	.	R	.	.	R	
	Barren		B				Barren			B	Unzoned
R	.	.	R				Barren			B	
R	T	.	R		.	R	.	.	.	R	
C	T	R	C		F	R	.	R	F	C	
R	.	R	R		.	.	.	.	R	R	
C	.	R	C		.	.	.	.	F	F	
C	.	R	C		.	.	.	.	F	F	
R	.	F	C	*Distephanus*	R	R	R	.	C	C	
R	.	.	R	*aculeatus*	R	R	.	.	F	F	
.	.	R	R		.	T	.	R	R	R	*Ammodochium*
R	.	.	R		R	.	.	.	R	R	*serotinum*
	Barren		B				Barren			B	
	Barren		B				Barren			B	
.	.	.	R		R	.	T	.	R	R	
R	.	R	R		R	.	.	.	T	R	
R	T	T	R		T	T	.	.	R	R	
	Barren		B				Barren			B	
	Barren		B	Unzoned			Barren			B	
R	.	.	F		R	.	.	.	.	R	
.	.	R	R		R	.	.	.	R	R	
	Barren		B				Barren			B	Unzoned
			B							B	

Table 3. Samples from Holes 860B, 861C, and 861D that are barren of siliceous flagellates.

Core, section, interval (cm)	Core, section, interval (cm)
141-860B-	64X-3, 19–20
2H-2, 19–21	65X-CC
6H-3, 95–95	141-861C-
14X-2, 48–49	7H-2, 120–121
24X-2, 25–26	19X-CC
25X-2, 32–33	33X-2, 70–71
29X-1, 126–127	34X-3, 73–74
30X–2, 75–76	39X-3, 100–101
34X-3, 66–67	40X-3, 87–88
35X-1, 79–80	
39X-2, 76–77	141-861D-
41X-3, 100–101	2R-1, 130–131
43X-1, 34–35	6R-3, 99–100
46X-1, 48–49	7R-3, 99–100
47X-CC	8R-1, 56–57
48X-3, 100–101	9R-2, 39–40
53X-2, 75–76	11R-2, 70–71
55X-CC	12R-2, 36–37
56X-CC	13R-3, 102–103
57X-CC	15R-2, 25–26
60X-3, 44–46	16R-2, 21–22

were drilled on the upper slope of the Chile Trench, as the eastern endmembers of the transect across the forearc basin. The sediment sequences recovered consist of clayey, silty, and sandy sediments with a higher degree of consolidation toward the base (Shipboard Scientific Party, 1992b).

The sediments studied contain assemblages of siliceous microfossils that are more diversified and better preserved than those in Hole 860B. The assemblages include protophytes (diatoms, silicoflagellates, ebridians, actiniscidians, and scattered chrysomonades), protozoans (radiolarians), remnants of metaphytes (scattered phytoliths) and metazoans (sponge spicules). Forty-six out of 62 samples yielded siliceous flagellates. Abundances of flagellate assemblages may be higher than those in isochroneous intervals of Hole 860B, but preservation is likewise moderate to poor.

The interval between Samples 141-861C-1H-1, 10–11 cm, and -2H-5, 80–81 cm, is characterized by *D. messanensis aculeata* and *A. pentasterias* and has been placed into the *Dictyocha messanensis aculeata* and the *Actiniscus pentasterias* Zones. Rather continuous occurrences of *D. speculum* and *D. aculeatus* indicate the *Distephanus speculum* Zone from Sample 141-861C-3H-3, 99–100 cm, to -20-CC, and the *Distephanus aculeatus* Zone from Sample 141-861C-21X-1, 100–101 cm, to -36X-3, 100–101 cm. Skeletons of *A. pentasterias* reflect the *Actiniscus pentasterias* Zone down to Sample 141-861C-18X-3, 119–120 cm. As evidenced by well-preserved specimens of *A. serotinum* (including *Ammodochium* sp.), the *Ammodochium serotinum* Zone follows from Samples 141-861C-21X-1, 100–101 cm, to -41X-3, 99–100 cm. Distinct occurrences of *D. messanensis* and of *Ebria tripartita* in the Quaternary to Pliocene sediment sequence obviously correspond to time levels of warmer surface-water conditions. The interval from Sample 141-861D-2R-1, 130–131 cm, down to the bottom of the hole remains barren of siliceous flagellates.

According to nannofossil data (Spiegler and Müller, this volume), the Pliocene/Pleistocene boundary lies immediately above the LOs of *D. aculeatus* and *A. serotinum*. Reworked Miocene to lower Pliocene silicoflagellates, such as *D. fibula* and *D. varia*, were found, but the bulk of skeletons seems to be in place. The somewhat misleading occurrences of *A. serotinum* and *Ammodochium* sp. in Sample 141-861C-10H-3, 100–101 cm, may be explained by minor slumping or by reworking.

PALEOCEANOGRAPHIC IMPLICATIONS

In recent time, the oceanography of the southeastern South Pacific is determined by subpolar and transitional surface-water masses (Fig. 3). South of the study area are polar and subpolar waters that are driven by the Antarctic Circumpolar Current in an easterly direction around the Antarctic continent. West and northwest of the study area are transitional and subtropical waters that are part of the South Pacific Central Water mass and are driven within the South Pacific Gyre. The most important feature of the study area is the Peru Current, which branches from the Antarctic Circumpolar Current and drives subpolar water along the coast of South America to the north (Bearman, 1993; Pickard and Emery, 1993).

Surface-water masses generally are inhabited by plankton organisms. According to their ecological preferences, these organisms may reflect particular surface-water conditions, especially temperature, salinity, and nutrient content. This holds true also for the plankton groups studied (i.e., silicoflagellates, ebridians, and actiniscidians). Recent data are scarce for the study area off southern Chile. Nevertheless, certain aspects of Pliocene and Quaternary paleoenvironmental changes can be revealed, if planktologic and oceanographic analogies are taken into consideration.

In recent time, the distribution of the silicoflagellate species *Dictyocha messanensis* and *Distephanus speculum* follows the temperature gradient from equatorial to polar regions, with *D. messanensis* solely present at the equator and *D. speculum* solely near the pole. The region inbetween is usually inhabited by mixed populations at varying proportions. This has been revealed by the investigation of water samples from the South Atlantic (Gemeinhardt, 1934) and of surface sediment samples from the North Pacific (Poelchau, 1976). The very detailed investigation of Poelchau exhibited, furthermore, that *D. messanensis messanensis* is sedimented in higher abundance beneath tropical and transitional waters and *D. messanensis aculeata* (cited as *Dictyocha epiodon*) beneath transitional water.

During late Pliocene time, plankton communities were obviously determined by cool surface-water conditions at Site 861 (Fig. 4, Table 2), which may be assumed to have been under the influence of an early Peru Current. This is indicated by higher percentages of the cool-adapted species *D. speculum* and the closely related *D. aculeatus*. But, during four time intervals prior to 1.6 Ma (top of Zone NN18, as used here), probably transitional surface-water masses intruded into the investigation area, which diminished the influence of the Peru Current. This may be deduced from the occurrence of the warm-adapted taxon *D. messanensis messanensis*. In general, communities of siliceous flagellates contained more taxa during late Pliocene time than during Quaternary time, which may hint at more favorable paleoenvironmental conditions.

During early and middle Pleistocene times, plankton communities were living mainly under cool surface-water conditions at Site 861, as continous occurrences of *D. speculum* and *Actiniscus pentasterias* demonstrate. But, surprisingly, also during those periodes, several expansions of transitional water masses proceeded off the coast of southern South America. This is indicated especially by occurrences of the warm- to temperate-adapted taxa *D. messanensis messanensis* and *D. messanensis aculeata*. The most prominent expansion of warm water masses was probably between 0.5 and 0.3 Ma (within Zone NN20), when *D. speculum* disappeared temporarily, but *Distephanus bioctonarius* and *Ebria tripartita* occurred in the area. In recent time, *D. bioctonarius* (often cited as *Octactis pulchra*) attains maximum densities in tropical and subtropical waters off Middle America and Peru.

After 0.3 Ma (base of Zone NN21), during late Pleistocene and Holocene times, warm surface-water masses intruded once more into the study area. According to the continuous occurrence of *D. messanensis aculeata*, transitional water expanded, probably iterately rather than permanently, from the central South Pacific Ocean toward the coast. This may have caused mixing with the cool water masses of the Peru Current, thus diminishing its intensity. But, narrowing or dislodging of the Peru Current may have occurred, too. Although definitive explanations cannot be given at present, the Pliocene to Quaternary warming episodes may have been affected by enhanced El Niño activities, which resulted both in a southward shift of the transitional surface-water belt and an eastward expansion of respective water masses.

TAXONOMY

Silicoflagellates, ebridians, and actiniscidians represent specific groups of siliceous flagellates that may be placed into two classes of protophytes (Tappan, 1980). Silicoflagellates are related to the Chrysophyceae, and ebridians and actiniscidians to the Dinophyceae. As the taxonomy and synonymies of the species found were discussed earlier (Locker, 1974; Locker and Martini, 1986a, 1986b, 1990), only a list of taxa is given. Remarks about autochthoneous species have been added.

Silicoflagellates

Dictyocha fibula Ehrenberg, 1840 (not figured)
Dictyocha messanensis Haeckel, 1861
Dictyocha messanensis subsp. *aculeata* (Lemmermann, 1901) Locker and Martini, 1986: Pl. 1, Fig. 2
Dictyocha messanensis Haeckel, 1861 subsp. *messanensis*: Pl. 1, Fig. 4
Dictyocha messanensis subsp. *stapedia* (Haeckel, 1887) Locker and Martini, 1986: Pl. 1, Fig. 3
Dictyocha perlaevis Frenguelli, 1951: Pl. 1, Fig. 1
Dictyocha varia Locker, 1975; synonym *Dictyocha pulchella* Bukry, 1975 (not figured)
Distephanus aculeatus (Ehrenberg, 1841) Haeckel, 1887; synonym *Distephanus boliviensis* Frenguelli, 1940
Distephanus aculeatus (Ehrenberg, 1841) f. *aculeatus*: Pl. 1, Fig. 14
Distephanus aculeatus f. *binoculus* (Ehrenberg, 1845) Locker and Martini, 1986: Pl. 1, Fig. 15
Distephanus bioctonarius (Ehrenberg, 1846) Martini, 1990; synonym *Octactis pulchra* Schiller, 1925: Pl. 1, Fig. 13
Distephanus speculum (Ehrenberg, 1840) Haeckel, 1887
Distephanus speculum f. *octonarius* (Ehrenberg, 1845) Locker and Martini, 1986: Pl. 1, Fig. 12
Distephanus speculum f. *pentagonus* (Lemmermann, 1901) Locker and Martini, 1986: Pl. 1, Fig. 9
Distephanus speculum f. *septenarius* (Ehrenberg, 1845) Locker and Martini, 1986: Pl. 1, Fig. 11
Distephanus speculum (Ehrenberg, 1840) f. *speculum*: Pl. 1, Fig. 10

Dictyocha messanensis typically has a rhombic basal ring and a longitudinal apical bar with a short pike (subsp. *messanensis*). One subspecies displays a basal ring with more curved bars (subsp. *stapedia*), and another one, a basal ring with additional spines (subsp. *aculeata*). Variants without an apical pike are not taxonomically discriminated here. As in other species, populations may include skeletons with thicker and with thinner skeletal bars.

Dictyocha perlaevis possesses a large basal ring with distinctly curved bars and a short longitudinal apical bar. Basal pikes are usually missing.

Distephanus aculeatus usually has a hexagonal basal ring and an apical ring without diagnostic pikes (f. *aculeatus*). This skeletal structure corresponds to *D. speculum*, but in *D. aculeatus* the basal ring generally appears larger, and apical pikes, if present, do not exhibit a preferential orientation. Variants with more than six basal spines (not found in Leg 141 material) or with a fenestrated apical window (f. *binoculus*) are rare in populations.

Distephanus bioctonarius normally has an octogonal basal ring and a delicate apical ring which often breakes off. Variants with more, or with less, than eight basal spines are usually rare in populations and have not been found in the material.

Distephanus speculum usually possesses a hexagonal basal ring and an apical ring with two pikes (f. *speculum*). But populations may contain a lot of other variants: forms with five basal spines (f. *pentagona*), with seven spines (f. *septenarius*), with eight spines (f. *octonarius*), or with a differently constructed apical apparatus (not found in the material). Here, a broad species concept is applied that embraces skeletons with basal pikes and a narrow apical ring, and skeletons without basal pikes and a wider apical ring.

Ebridians and Actiniscidians

Ammodochium serotinum Locker and Martini, 1986: Pl. 1, Fig. 6
Ammodochium sp.; small triodes: Pl. 1, Fig. 5
Ebria tripartita Schumann, 1867: Pl. 1, Fig. 8
Ebria sp.; large triodes: Pl. 1, Fig. 7
Actiniscus pentasterias Ehrenberg, 1841: Pl. 1, Fig. 16

Ammodochium serotinum has a triode that bears triplets of proclades and opisthoclades plus highly arched synclades. Juvenile (and corroded?) skeletons may be delivered by the triode alone, or by the triode and rudimentary proclades and opisthoclades. Small triodes that probably belong to this species have been indicated as *Ammodochium* sp. in tables.

Ebria tripartita has a large triode that is connected with the ring of synclades by short proclades. Juvenile (and corroded?) skeletons may solely consist of the large triode. Large triodes, which probably belong to this species, are indicated as *Ebria* sp. in tables.

Actiniscus pentasterias is usually represented by five-rayed stellate bodies that possess crests and depressions. Sometimes populations contain also four-, six- or seven-rayed specimens. Here, a broad species concept was used that includes skeletons having larger and smaller peripheral depressions, and longer and shorter arms.

CONCLUSIONS

1. The sediment sequences investigated from Holes 860B, 861C, and 861D were assigned to the *Distephanus aculeatus*, *Distephanus speculum*, and *Dictyocha messanensis aculeata* Zones of silicoflagellates and to the *Ammodochium serotinum* and *Actiniscus pentasterias* Zones of ebridians/actiniscidians. This indicates a late Pliocene to Quaternary age of related intervals. Sediments having a higher age could not be proven due to the absence of siliceous flagellates in the lower part of sequences.

2. According to the LOs of *Distephanus aculeatus* and *Ammodochium serotinum*, the Pliocene/Pleistocene boundary can be placed above 141.10 mbsf in Hole 860B, and above 171.20 mbsf in Hole 861C. This confirms, in general, the nannofossil results of Spiegler and Müller (this volume), who draw this boundary between 128.07 and 126.50 mbsf in Hole 860B and between 170.64 and 170.20 mbsf in Hole 861C.

3. Fluctuating occurrences of *Dictyocha messanensis messanensis* throughout the upper Pliocene to Pleistocene section of Holes 860B and 861C record varying paleoceanographic conditions. Repeated occurrences of this subspecies indicate that the cool surface-water masses of the Peru Current were mixed with or replaced by warm transitional water masses of the central South Pacific several times.

4. The consistent occurrence of *Dictyocha messanensis aculeata* in sediments of late NN21 age reflects a longer period of prevailing warm surface-water conditions, caused by repeated expansions of transitional water masses toward the coast of southern South America.

5. The Pliocene and Quaternary warming episodes may have been caused by strong El Niño activities, which resulted in a southward shift of the transitional water belt and an expansion of warmer surface water over the study area.

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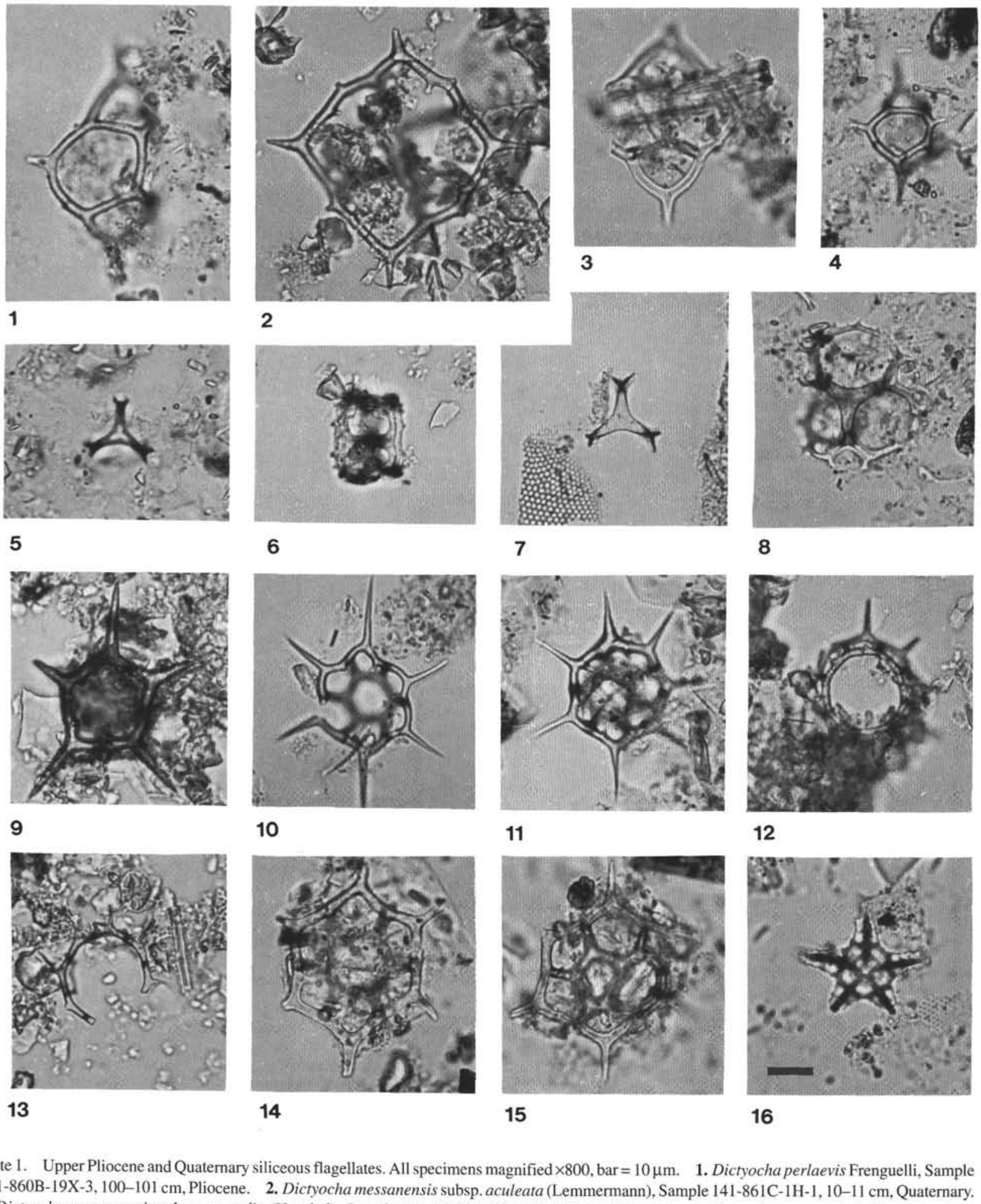

Plate 1. Upper Pliocene and Quaternary siliceous flagellates. All specimens magnified ×800, bar = 10 µm. **1.** *Dictyocha perlaevis* Frenguelli, Sample 141-860B-19X-3, 100–101 cm, Pliocene. **2.** *Dictyocha messanensis* subsp. *aculeata* (Lemmermann), Sample 141-861C-1H-1, 10–11 cm, Quaternary. **3.** *Dictyocha messanensis* subsp. *stapedia* (Haeckel), Sample 141-861C-41X-3, 99–100 cm, Pliocene. **4.** *Dictyocha messanensis* Haeckel subsp. *messanensis*, Sample 141-861C-20X-CC, Quaternary. **5.** *Ammodochium* sp., small triode, Sample 141-861C-28X-3, 40–41 cm, Pliocene. **6.** *Ammodochium serotinum* Locker and Martini, Sample 141-861C-22X-4, 87–88 cm, Pliocene. **7.** *Ebria* sp., large triode, Sample 141-861C-1H-1, 10–11 cm, Quaternary. **8.** *Ebria tripartita* Schumann, Sample 141-860B-2H-4, 29–31 cm, Quaternary. **9.** *Distephanus speculum* f. *pentagonus* (Lemmermann), Sample 141-861C-22X-4, 87–88 cm, Pliocene. **10.** *Distephanus speculum* (Ehrenberg) f. *speculum*, Sample 141-860B-12X-3, 100–101 cm, Quaternary. **11.** *Distephanus speculum* f. *septenarius* (Ehrenberg), Sample 141-861C-15X-2, 68–69 cm, Quaternary. **12.** *Distephanus speculum* f. *octonarius* (Ehrenberg), Sample 141-861C-22X-4, 87–88 cm, Pliocene. **13.** *Distephanus bioctonarius* (Ehrenberg), Sample 141-861C-22X-4, 87–88 cm, Pliocene. **14.** *Distephanus aculeatus* (Ehrenberg) f. *aculeatus*, Sample 141-861C-27X-2, 30–31 cm, Pliocene. **15.** *Distephanus aculeatus* f. *binoculus* (Ehrenberg), Sample 141-861C-28X-3, 40–41 cm, Pliocene. **16.** *Actiniscus pentasterias* Ehrenberg, Sample 141-861C-7H-6, 25–26 cm, Quaternary.