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# Diatom biostratigraphy and paleoecology of the type section of the Luisian Stage, central California

## ABSTRACT

Diatoms from the type section of the Luisian Stage in central California correlate with the lowermost part of the *Denticulopsis lauta* Zone through the lower part of subzone "a" of the *Denticulopsis hustedtii-D. lauta* Zone and are early Middle Miocene in age (about 16.0 to 14.0 Ma). Rocks assigned to the Luisian Stage by benthic foraminifers elsewhere in California exhibit little diachroneity in terms of diatom biostratigraphy; however, detailed studies of boundaries have not been done. Planktic diatoms dominate the assemblages, although an increase in benthic and tychopelagic diatoms in the overlying Hames Member of the Monterey Formation probably reflects shoaling. A cooling trend is suggested by diatom assemblages in the upper part of the section and is most marked near the top of the type Luisian. This cooling trend is supported by data elsewhere in the Pacific Basin as well as by both megafossil and microfossil studies in California. One hundred four diatom taxa are documented, and one new species, *Coscinodiscus volutus* Baldauf, is described.

## INTRODUCTION

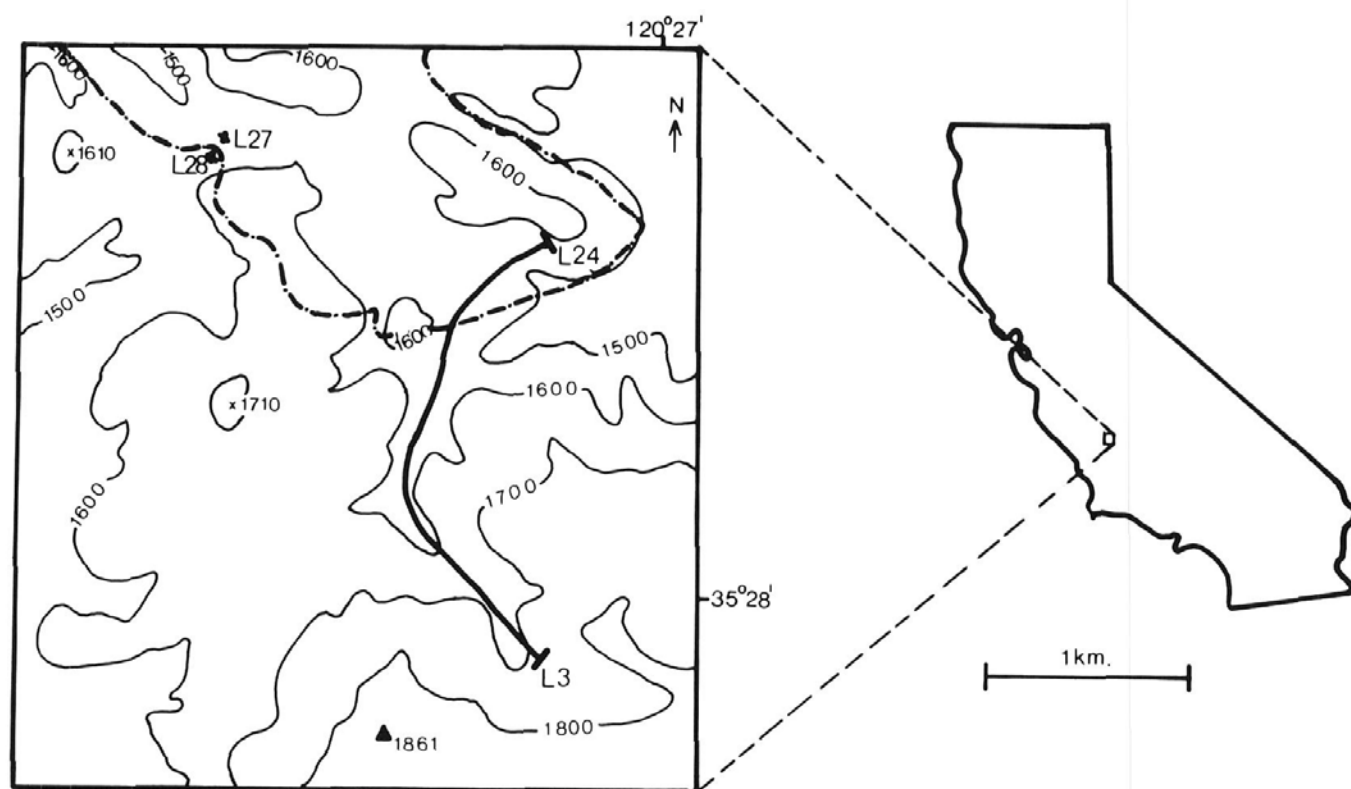
Although recent studies have questioned the isochroneity of correlations based on benthic foraminiferal assemblages associated with the provincial benthic foraminiferal stages of Kleinpell (1938), benthic foraminifers remain the principal means of dating Cenozoic marine rocks in California. Crouch and Bukry (1979), using calcareous nannofossil biostratigraphy, documented an overlap of Kleinpell's Miocene benthic foraminiferal stages in the Southern California Continental Borderland. Benthic foraminiferal assemblages are often greatly controlled by environmental conditions, and McDougall (1979) has reported that the Narizian and Refugian stages of Mallory (1959) are partially coeval, representing specific ecological conditions rather than a difference of time. In response to this problem, micropaleontologists at the U.S. Geological Survey, Menlo Park, California, have chosen to reevaluate the provincial benthic foraminiferal stages of Kleinpell (1938) by studying in detail the microfossils of the type sections, with initial efforts directed toward the Relizian and Luisian stages.

During April 1979 a field party collected the type sections of the Relizian and Luisian stages in central California. No diatoms were found in Relizian and Luisian strata in Reliz Canyon; however, diatomaceous rocks are common in the type section of the Luisian Stage in San Luis Obispo County (Kleinpell, 1938), and our reconnaissance showed diverse and abundant assemblages.

The preliminary study by Addicott et al. (1978) represents the only published study of microfossils from the type section of the Luisian Stage.<sup>1</sup> Only a few samples from the actual type section, however, were studied; the majority of samples came from a section along State Highway 58, a few miles to the east. Previous studies by Cushman (1926) and Lipps (1967) were limited to the study of foraminifers from adjacent areas. The preliminary study of the benthic foraminifers (McDougall), planktic foraminifers and coccoliths (Poore), and diatoms (Barron) in Addicott et al. (1978) provided a framework for collection and study by these workers of the type Luisian section. Although their assignment (in Addicott et al., 1978) of the type Luisian Stage to the early Middle Miocene supports previous assignments of Luisian rocks elsewhere in the state (Lipps, 1967; Lipps and Kalisky, 1972; Wornardt, 1973; Crouch and Bukry, 1979), a detailed study of the floras and faunas of the type Luisian section is needed for refined correlations and to establish the ecologic conditions.

The type section of the Luisian Stage is situated along "the prominent northwestward-draining gully in the extreme southwest corner of Section 21, T. 28 S., R. 14 E.," in the Wilson Corner 7½-minute quadrangle,

<sup>1</sup> However, while present paper was in press, Poore et al., 1981 was published. See References.



TEXT-FIGURE 1

Map showing location of samples collected from type section of Luisian Stage, sec. 21, T. 28 S., R. 14 E., Wilson Corner 7½-minute quadrangle, California. Dotted line represents phosphatic siliceous shale bed marking top of type Luisian section of Kleinpell (1938). Contour interval shown in feet; scale shown is for contour map.

San Luis Obispo County, California (Kleinpell, 1938) (text-fig. 1). The base of the section is the horizon of the distinct lithologic change from clay shale to overlying diatomaceous shale, and the top is placed at the base of a prominent, 1.2-m-thick bed of phosphatic siliceous shale (text-fig. 2). The base of the section lies between sample L3, which is barren of diatoms, and overlying sample L2, which contains abundant diatoms. Twenty-three samples from the type section, sample L2 through sample L27, were processed for diatoms, as were two overlying samples (L28 and L24) from the Hames Member of the Monterey Formation (text-fig. 2).

#### MATERIALS AND METHODS

These samples were processed in hydrogen peroxide and hydrochloric acid following the procedures of Barron (1976). Two strewn slides were prepared from each sample and were examined in entirety at  $\times 500$ . The first 300 diatoms observed in each sample were tabulated for their relative abundance. A species was recorded as abundant if it accounted for greater than 25% of the count, common if 16–24%, few if 6–15%, rare if 1–5%, and present if less than 1%, or if the species was observed independently of the counting.

Quality of preservation of each sample was based on

the absence and presence of selected diatoms. Fine delicate taxa such as *Synedra jouseana* Sheshukova-Poretzkaya, *Rouxia diploneides* Schrader, *Thalassiothrix longissima* Cleve and Grunow, and *Mediaria splendida* Sheshukova-Poretzkaya were used for determining well-preserved samples, whereas the presence only of heavily silicified forms such as *Coscinodiscus marginatus* Ehrenberg, *Actinocyclus ingens* Rattray, and *Stephanopyxis* spp. suggested poor preservation.

#### RESULTS

One hundred four taxa, characteristic of a nearshore marine environment, were recognized in the section (table 1). Both robust and finely silicified species occurred throughout the section, indicating a well-preserved assemblage. All taxa are typical of the early Middle Miocene of California, as described by Hanna (1932), Wornardt (1973), and Barron (1976). Taxonomic notes appear in the Appendix.

#### Biostratigraphy

Diatoms of the type Luisian Stage are assigned to the lower Middle Miocene *Denticulopsis lauta* Zone and the lowermost part of the *Denticulopsis hustedtii*-D.

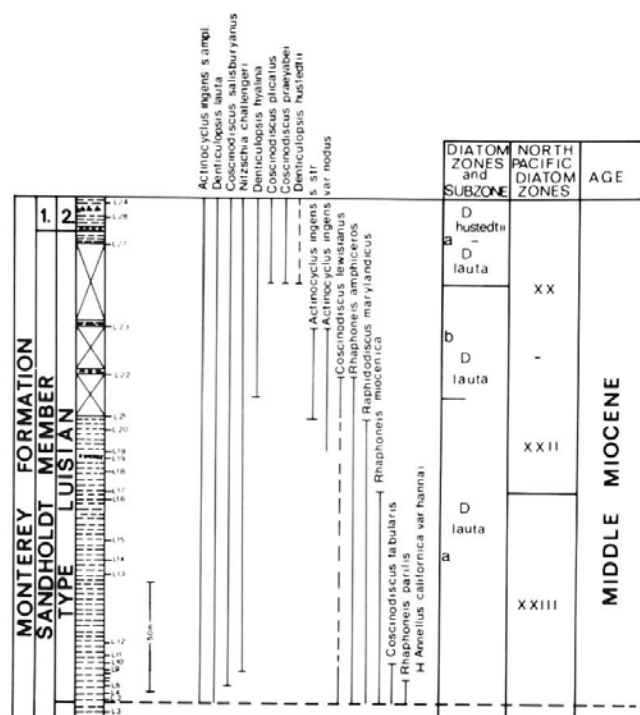
*lauta* Zone as emended by Barron (1980) (text-fig. 2). The assemblages also correlate with North Pacific Diatom Zones XXIII to XX of Barron (1976). The diatom assemblage of sample L2, the lowest sample of the type section, includes *Denticulopsis* sp. cf. *D. lauta* sensu Barron (1980), *Rhaphoneis miocenica* Schrader, *R. parilis* Hanna, and *Raphidodiscus marylandicus* Christian and is therefore suggestive of the basal assemblages of the *D. lauta* Zone as observed off Japan (Barron, 1980) and in the Southern California Continental Borderland (Barron, unpublished data).

The top of subzone "a" and the base of subzone "b" of the *Denticulopsis lauta* Zone is marked by the first occurrence of *Denticulopsis hyalina* (Schrader) Simonsen in sample L22. This subzonal boundary is recognizable in both offshore and onshore sections in the California area (Baldauf and Barron, 1980; Barron, 1981).

*Denticulopsis hustedtii* first occurs in sample L27 near the top of the section. Unfortunately, a 40-m-thick covered section below L27 prevents accurate placement of the boundary between the *D. hustedtii*-*D. lauta* and the *D. lauta* zones. Presumably, this boundary does not lie too far below sample L27, because the overlying samples L28 and L24 contain assemblages more typical of the lowermost portions of subzone "a" of the *Denticulopsis hustedtii*-*D. lauta* Zone including *Coscinodiscus praeyabei* Schrader, common *Denticulopsis hyalina*, and the absence of common *Denticulopsis hustedtii* (Simonsen and Kanaya) Simonsen.

The absence of *Denticulopsis hustedtii* from samples L28 and L24 above the common occurrence of *D. hustedtii* in sample 27 is not typical. The normal sequence observed throughout the middle latitudes of the North Pacific is initial sparse *D. hustedtii* followed upsection by more common and consistent occurrences of the species (Barron, 1981). The presence of *Coscinodiscus plicatus* Grunow and *C. praeyabei* in samples L28 and L24 ensure their assignment to the subzone "a" of the *Denticulopsis hustedtii*-*D. lauta* Zone, so that the absence of *D. hustedtii* in samples above L27 evidently represents either ecological or preservational exclusion. The latter is doubtful, because relatively delicate taxa including *Mediaria splendida*, *Rhizosolenia styliformis* Brightwell, *Rouxia diploneides*, and *Synedra jouseana* occur in both samples.

Text-figure 3 shows the correlation of the diatom biostratigraphy of the type Luisian with the international time scale, planktic foraminiferal zones of Blow (1969), and coccolith zones of Bukry (1973, 1975). The time scale and zonal correlations are those adopted by Bukry, Poore, and Barron in Haq and Yeats et al. (in press) after study of material collected by DSDP Leg 63 off



TEXT-FIGURE 2

Columnar section of type Luisian Stage showing stratigraphic distribution of samples, diatom biostratigraphy, and ranges of selected diatom taxa. Diatom zones and subzones from Barron (1980), left column, and North Pacific Diatom Zones from Barron (1976) and Schrader (1973), right column. 1, Hames Member. 2, Mohnian.

southern California and Baja California. Consequently, the type Luisian correlates with the early Middle Miocene between about 16.0 and 14.0 Ma, with planktic foraminifer Zones N8 through N11, and with the uppermost part of the *Helicosphaera ampliaperta* to lower part of the *Discoaster exilis* coccolith zones. These relations are supported by Poore's (in Addicott et al., 1978) study of Luisian coccoliths from the area, although Poore initially recognized only planktic foraminiferal Zones N8 and N9 in these rocks. Lipps's (1967) general correlation of Luisian rocks in California with the upper part of Zone N8 through the lower part of N12 is nearly identical with the correlation of the type section shown in text-figure 3.

Time equivalence of rocks containing Luisian benthic foraminiferal assemblages was disputed in part by Crouch and Bukry (1979). Baldauf and Barron (1980) correlated the Luisian-Mohnian boundary of Warren (1972) in the Upper Newport Bay section, south of Los Angeles, with the uppermost part of the *D. lauta* Zone, a horizon slightly older than the top of the type Luisian section suggested by this study. In general, Luisian benthic foraminiferal assemblages have shown little diachroneity in relation to diatom biostratigraphy in strata studied by Barron (1976, unpublished data) from

TABLE 1

Occurrence of diatom taxa in samples studied from type section of Luisian Stage. A—abundant, C—common, F—few, R—rare; + present but not recorded in counts of 300. Preservation: G—good, M—moderate, P—poor. See text for explanations.

SAMPLE -----	24	28	27	23	22	21	19c	19a	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	2	
ABUNDANCE -----	A	F	C	C	A	C	C	A	C	C	C	C	C	C	C	A	A	A	C	C	C	A	A	A	
PRESERVATION -----	G	G	G	M	M	M	G	G	M	M	M	M	M	M	M	G	G	G	M	M	M	M	M	M	
<u>Actinocyclus chalnoky</u> -----	+	-	-	-	+	-	+	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	
<u>Actinocyclus ehrenbergii</u> -----	R	+	+	+	R	-	-	+	+	-	+	-	-	-	-	+	+	-	+	+	+	+	+	+	
<u>Actinocyclus ehrenbergii</u> var. <u>rafsii</u> ----	R	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	+	-	+	+	-	-	-	-	
<u>Actinocyclus ehrenbergii</u> var. <u>tenella</u> ----	+	-	-	-	+	-	+	-	-	-	-	-	-	+	-	-	-	+	-	-	-	-	+	-	
<u>Actinocyclus ingens</u> s. ampl. (flat) -----	R	R	R	A	C	C	A	C	F	C	C	C	C	C	F	F	F	F	F	F	A	A	A	C	R
<u>Actinocyclus ingens</u> s. str. (undulated) --	-	-	-	R	+	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<u>Actinocyclus ingens</u> var. <u>nodus</u> -----	-	-	-	R	+	R	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<u>Actinoptychus splendens</u> var. <u>halionyx</u> ----	R	-	+	-	-	-	-	-	+	-	-	+	-	+	-	-	-	-	-	+	-	+	+	+	
<u>Actinoptychus thumii</u> -----	-	-	-	-	R	+	-	-	-	+	-	-	+	+	-	-	+	C	-	+	-	-	-	-	
<u>Actinoptychus undulatus</u> -----	R	-	R	+	R	R	-	R	R	+	F	R	R	R	-	+	R	-	R	R	R	R	R	R	
<u>Actinoptychus vulgaris</u> var. <u>monicae</u> -----	R	-	+	-	-	-	-	-	-	-	-	-	+	-	-	-	-	+	-	+	-	+	-	-	
<u>Annellus californica</u> var. <u>hannai</u> -----	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	+	-	-	-	-	-	
<u>Arachnoidiscus ornatus</u> var. <u>montereyanus</u> -	-	-	+	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	+	-	-	+	+	
<u>Asteromphalus flabellatus</u> -----	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	
<u>Asteromphalus robusta</u> -----	+	-	-	+	+	-	-	+	-	-	+	-	-	-	-	-	-	-	-	+	-	-	+	-	
<u>Aulacodiscus concentricus</u> -----	+	-	-	-	+	+	+	+	+	-	-	-	+	-	-	+	+	-	-	+	-	-	+	+	
<u>Aulacodiscus kittoni</u> -----	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	
<u>Biddulphia aurita</u> -----	-	-	-	+	-	-	-	+	+	+	-	-	-	-	-	+	+	+	+	+	+	-	+	+	
<u>Biddulphia tuomeyi</u> -----	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	+	-	
<u>Campyloneis grevillei</u> -----	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	
<u>Cestodiscus</u> sp. -----	+	-	-	-	+	+	+	-	-	-	-	+	+	-	-	-	-	+	+	-	-	-	+	-	
<u>Chaetoceros cinctus</u> -----	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	
<u>Chaetoceros dicladia</u> -----	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	
<u>Cladogramma dubium</u> -----	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	+	-	-	
<u>Cocconeis costata</u> -----	+	-	-	-	-	-	-	-	-	-	+	-	-	-	-	+	-	+	-	-	-	-	-	-	
<u>Cocconeis dirupta</u> -----	+	-	-	-	-	-	-	-	-	-	-	-	+	-	-	+	-	-	-	-	-	-	+	+	
<u>Cocconeis distans</u> -----	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-	
<u>Cocconeis scutellum</u> -----	+	+	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	+	+	-	+	+	-	
<u>Cocconeis vitrea</u> -----	+	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-	+	-	+	-	-	+	+	
<u>Coscinodiscus asteromphalus</u> -----	+	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	+	-	-	-	-	-	-	-	
<u>Coscinodiscus gigas</u> var. <u>diorama</u> -----	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	
<u>Coscinodiscus lewisianus</u> -----	-	-	-	-	R	+	-	-	-	-	-	-	-	-	-	-	R	+	+	+	+	-	+	-	
<u>Coscinodiscus marginatus</u> -----	F	R	+	F	R	F	R	R	-	R	-	F	R	F	-	+	F	F	R	R	F	R	F	+	
<u>Coscinodiscus nitidus</u> -----	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<u>Coscinodiscus obscurus</u> -----	+	-	-	-	+	-	-	-	-	-	R	-	-	-	-	+	R	-	-	+	-	-	+	-	
<u>Coscinodiscus oculus-iridis</u> -----	+	-	-	+	+	-	-	+	+	-	+	+	+	-	-	-	+	+	-	+	-	+	+	+	
<u>Coscinodiscus plicatus</u> -----	+	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<u>Coscinodiscus praeyabei</u> -----	+	R	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
<u>Coscinodiscus salisburyanus</u> -----	R	-	R	+	+	+	-	+	+	+	+	+	-	+	-	+	+	+	R	+	-	+	-	-	
<u>Coscinodiscus symbolophorus</u> -----	+	-	+	+	-	+	-	-	+	+	-	R	+	R	-	-	+	-	-	+	+	+	+	-	



TABLE 1 (Continued)

SAMPLE -----	24	28	27	23	22	21	19c	19a	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	2
ABUNDANCE -----	A	F	C	C	A	C	C	A	C	C	C	C	C	C	C	A	A	A	C	C	C	A	A	A
PRESERVATION -----	G	G	G	M	M	M	G	G	M	M	M	M	M	M	M	G	G	G	M	M	M	M	M	M
<i>Coscinodiscus tabularis</i> -----	-	-	-	-	-	-	-	-	-	+	-	-	+	-	-	+	+	+	R	+	+	R	+	+
<i>Coscinodiscus tuberculatus</i> -----	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-
<i>Coscinodiscus vetustissimus</i> -----	R	-	-	+	-	-	-	+	-	+	+	+	+	-	-	-	+	+	+	+	+	+	+	+
<i>Coscinodiscus volutus</i> -----	R	-	-	+	-	-	-	-	+	+	-	R	+	-	-	-	R	-	+	+	+	+	+	+
<i>Craspedodiscus coscinodiscus</i> -----	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-
<i>Craspedodiscus rhombicus</i> -----	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	+	-
<i>Cussia paleacea</i> -----	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	+
<i>Cymatogonia amblyoceras</i> -----	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-
<i>Delphineis angustata</i> -----	R	-	-	-	-	-	-	-	R	-	-	-	-	-	R	-	-	+	-	R	R	F	R	F
<i>Delphineis penelliptica</i> -----	-	-	-	+	-	-	-	-	+	-	-	R	+	-	+	-	+	-	-	-	-	+	+	R
<i>Denticulopsis hustedtii</i> -----	-	-	F	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Denticulopsis hyalina</i> -----	C	A	F	A	C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Denticulopsis lauta</i> -----	R	-	-	R	R	R	R	C	C	F	A	F	R	F	A	A	C	F	F	A	F	C	C	F
<i>Denticulopsis nicobarica</i> -----	-	-	-	-	-	+	-	-	-	R	-	+	-	-	-	-	-	-	-	-	-	-	-	-
<i>Denticulopsis punctata</i> -----	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Diploneis interrupta</i> -----	+	-	-	+	+	-	-	+	-	-	+	-	+	+	-	+	-	-	-	-	-	+	+	+
<i>Diploneis smithii</i> -----	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	+	+	+
<i>Dossetia lacera</i> -----	-	-	-	-	+	-	+	+	+	-	-	+	+	+	-	+	-	+	+	+	-	+	+	+
<i>Entopyla australis</i> var. <i>gigantea</i> -----	+	-	-	-	-	-	-	-	-	+	-	-	-	-	-	+	-	-	-	-	-	-	+	-
<i>Glyphodiscus stellatus</i> -----	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-
<i>Goniothecium rogersii</i> -----	+	-	-	-	-	-	-	+	-	+	-	+	+	-	-	+	-	+	-	-	+	+	+	+
<i>Grammatophora angulosa</i> -----	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
<i>Grammatophora merletta</i> -----	+	+	+	+	-	+	+	+	+	+	-	+	-	+	-	-	-	-	+	+	+	+	+	+
<i>Hemiaulus polymorphus</i> -----	+	-	-	+	+	-	-	+	+	+	+	+	-	+	-	+	+	+	-	+	+	+	+	-
<i>Hyalodiscus radiatus</i> -----	+	-	+	+	-	-	-	+	-	-	+	-	-	-	-	-	-	-	-	-	+	-	-	+
<i>Liradiscus bipolaris</i> -----	-	-	+	-	+	+	-	+	+	+	-	+	+	R	+	+	+	-	R	+	+	R	+	+
<i>Lithodesmium californicum</i> -----	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Macrora stella</i> -----	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-
<i>Mediaria splendida</i> -----	+	+	R	R	R	+	R	-	R	R	R	-	-	+	-	-	-	-	+	+	R	R	R	R
<i>Melosira clavigera</i> -----	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	+	-
<i>Melosira sulcata</i> var. <i>biserita</i> -----	-	-	R	+	+	-	-	+	+	-	+	+	+	+	-	-	-	-	+	+	+	-	+	R
<i>Melosira sulcata</i> var. <i>siberica</i> -----	+	R	R	-	-	-	-	-	+	+	R	-	-	+	R	R	-	-	-	-	-	+	+	R
<i>Melosira varians</i> -----	+	-	-	-	+	+	-	+	+	+	+	-	+	-	+	-	+	+	-	+	+	-	+	+
<i>Navicula hennedyi</i> -----	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Navicula lyra</i> -----	+	-	-	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-	+	+	-	+	+	-
<i>Navicula optima</i> -----	+	-	-	-	-	-	-	+	+	-	+	+	+	+	+	+	+	-	+	+	-	+	+	+
<i>Navicula praetexta</i> -----	+	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	+	+	-
<i>Nitzschia challengerii</i> -----	-	+	+	-	-	-	+	-	-	+	-	-	-	-	-	+	+	-	-	-	-	-	-	-
<i>Plagiogramma tesellatum</i> -----	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
<i>Pleurosigma affine</i> -----	+	-	-	-	-	-	-	-	+	-	+	-	-	-	+	-	-	-	-	-	-	+	-	-
<i>Podosira maxima</i> -----	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-

TABLE 1 (Continued)

SAMPLE	24	28	27	23	22	21	19c	19a	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	2
ABUNDANCE	A	F	C	C	A	C	C	A	C	C	C	C	C	C	C	A	A	A	C	C	C	A	A	A
PRESERVATION	G	G	G	M	M	M	G	G	M	M	M	M	M	M	M	G	G	G	M	M	M	M	M	M
<i>Pseudopyxilla americana</i>	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
<i>Raphidodiscus marylandicus</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
<i>Rhabdonema japiconicum</i>	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<i>Rhaphoneis amphiceros</i>	-	-	-	-	+	-	-	+	-	R	R	R	R	+	R	R	+	+	-	-	-	R	-	+
<i>Rhaphoneis miocenica</i>	-	-	-	-	-	-	-	-	-	R	-	R	-	-	+	-	+	+	-	-	-	R	+	R
<i>Rhaphoneis parilis</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	+	R
<i>Rhizosolenia styliformis</i>	+	+	R	-	+	+	-	-	+	-	R	-	-	+	+	+	+	+	-	+	+	+	-	-
<i>Rouxia diploneides</i>	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	R	+	R
<i>Rouxia naviculoides</i>	F	R	R	-	+	-	-	+	-	R	R	+	-	+	+	R	-	-	-	+	-	R	+	R
<i>Stephanogonia polyacantha</i>	+	-	-	-	+	-	+	+	-	-	-	+	+	R	-	+	-	+	+	+	+	+	+	-
<i>Stephanopyxis schenckii</i>	F	E	E	-	-	-	-	+	+	+	+	+	+	+	+	R	R	R	+	+	-	R	+	+
<i>Stephanopyxis turris</i>	R	+	F	-	R	-	-	+	+	+	R	+	R	R	-	-	R	R	R	+	-	+	+	+
<i>Stictodiscus californicus</i>	+	-	-	-	+	+	-	-	-	-	-	-	-	+	-	-	+	+	-	+	-	-	+	-
<i>Syndendrium diadema</i>	-	-	-	-	-	-	-	-	+	-	-	+	+	-	-	-	-	-	+	-	-	+	+	+
<i>Synedra jouseana</i>	+	-	R	R	C	C	A	C	A	F	C	A	A	A	C	C	C	C	C	A	+	F	R	R
<i>Thalassionema nitzschioides</i>	R	F	C	+	F	C	C	A	A	A	F	F	F	F	F	C	C	A	C	C	A	F	C	A
<i>Thalassiosira leptopus</i>	R	-	+	-	+	-	-	-	+	-	+	-	-	-	-	-	+	-	+	+	+	+	+	+
<i>Thalassiosira</i> sp. 1.	+	-	-	-	+	-	-	+	+	-	-	-	-	-	-	-	-	+	+	-	-	-	-	-
<i>Thalassiothrix longissima</i>	R	R	F	+	F	R	R	R	F	F	R	F	F	F	R	R	F	C	F	F	F	F	F	F
<i>Triceratium condecorum</i>	+	-	-	-	+	-	-	+	+	+	-	-	-	-	-	+	+	+	-	-	-	+	+	R
<i>Xanthiopyxis globos</i>	+	-	-	+	+	+	-	-	+	-	+	+	-	-	+	+	-	+	+	-	-	+	+	+
<i>Xanthiopyxis maculata</i>	-	-	-	-	-	-	-	-	+	-	-	+	+	-	-	-	+	-	-	+	-	-	+	+
<i>Xanthiopyxis ovalis</i>	+	-	-	-	+	-	-	+	-	-	-	+	+	+	+	+	-	+	+	+	-	+	+	-

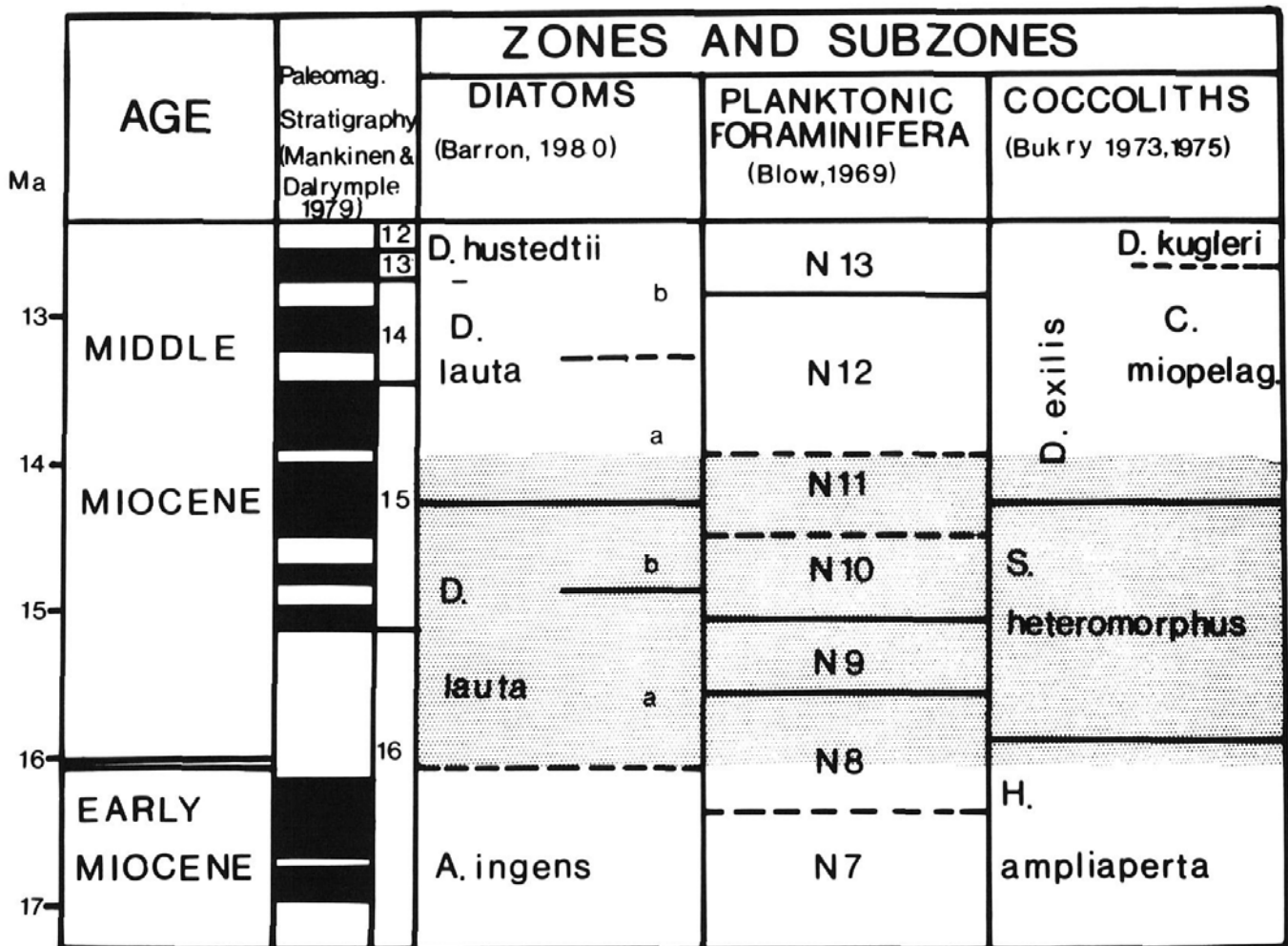
southern California. Data on boundaries from measured sections, however, are sparse, and assessment of the chronostratigraphic value of benthic foraminiferal correlations of the Luisian Stage awaits future study.

#### Paleoecology

The type Luisian diatom assemblage is composed primarily of planktic taxa (text-fig. 4). The benthic-tychopelagic component is seldom as great as 20% of the assemblage, although it increases dramatically to a maximum of 36% at the top of the section. Resting spore abundances are typically less than 5%, and peaks parallel those of the benthic-tychopelagic taxa. Benthic foraminiferal studies (McDougall, oral communication, 1980) suggest that many of these fluctuations may be due to downslope transport. Sample L24

in the Hames Member of the Monterey Formation is about 23 m stratigraphically below the base of the Santa Margarita Formation, and the basal Santa Margarita is a shoreline to shallow subtidal deposit according to Addicott (in Addicott et al., 1978), therefore, the relatively abundant and diverse benthic and tycho-pelagic taxa in L24 (table 1) may reflect a shoaling of the section.

Among the planktic diatoms, nine taxa account for approximately 75% of the assemblage throughout the section. These taxa include three species of *Denticulopsis* [*D. lauta* (Bailey) Simonsen, *D. hustedtii*, and *D. hyalina*], three different varieties of *Actinocyclus ingens* (*A. ingens* s. ampl., *A. ingens* s. str., and *A. ingens* var. *nodus* Baldauf), *Synedra jouseana*, *Thalassionema nitzschioides* Grunow, and *Thalassiothrix longissima* (text-fig. 5).



TEXT-FIGURE 3

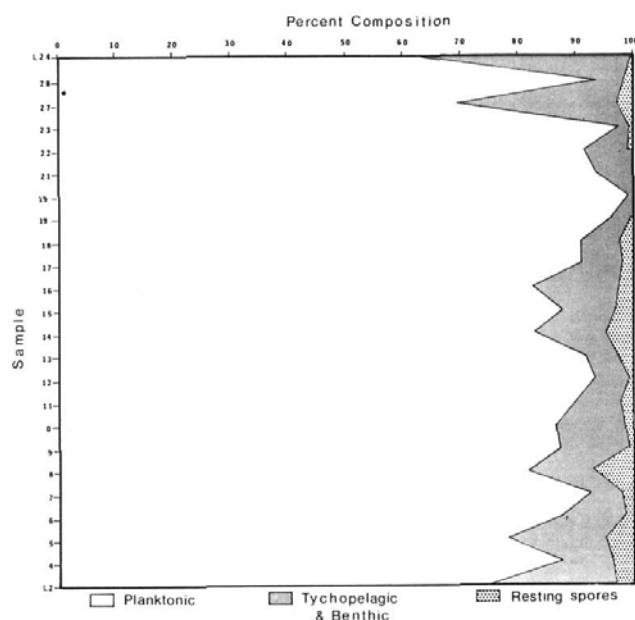
Diatom correlation of type Luisian Stage to geologic time scale. Time scale of Yeats, Haq et al. (1981).

The *Denticulopsis* group represents a cold-water component, because these species are consistently more common at the more northern latitudes of the Pacific during the Miocene, and because *D. seminae* Simonson and Kanaya (1961), the modern representative, is a northern boreal species (Kanaya and Koizumi, 1966; Jousé et al., 1971). During the late Middle Miocene, *D. hustedtii* is introduced into the tropics. This introduction coincides with major climatic cooling recorded by Kennett (1977), Woodruff et al. (1979) and Crouch and Bukry (1979).

The *Actinocyclus ingens* group represents a more temperate component. *Actinocyclus ingens* appears to be more common in the middle latitudes of the North Pacific during the Middle Miocene, and it is introduced into the tropics prior to the introduction of *D. hustedtii*, probably closer to the initiation of the

Middle Miocene cooling trend (Barron, unpublished data, DSDP Site 77).

*Synedra jouseana* is a consistent component of Early Miocene and early Middle Miocene assemblages from the tropical Pacific (Jousé, 1974; Gombos, 1975; Schrader, 1978). Although *S. jouseana* is also a common constituent of early Middle Miocene diatom assemblages from middle to high latitudes of the North Pacific (Burckle, 1978), it declines in abundance in the late Middle Miocene (Schrader, 1973; Barron, 1976, 1981), presumably in response to climatic cooling. Consequently, for purposes of this study *S. jouseana* is considered to represent a warm-water component. This conclusion is supported by *S. jouseana*'s inverse relationship with respect to *Denticulopsis* spp., a cold-water group, in text-figure 5.



TEXT-FIGURE 4

Percentage fluctuation of planktic diatoms, benthic and tychopelagic diatoms, and resting spores in samples studied from type Luisian (samples L2–L27) and overlying rocks (L28 and L24).

Adoption of this model suggests cool to temperate conditions at the base of the section, followed upsection by a warming trend beginning with sample L7 and culminating in sample L14. A cooling trend followed with some incorporated fluctuation and with pronounced intensification at about sample L27 at the top of the type Luisian Stage.

It is necessary to determine whether these temperature trends are applicable over a broad area or merely represent local basin conditions reflecting coastal configuration. For example, Middle Miocene diatom assemblages from Upper Newport Bay (Barron, 1976) generally possess less of a warm-water component than equivalent assemblages from offshore southern California (Barron, 1981), implying an offshore to onshore temperature gradient. Trends in equivalent sections in California should be compared to this study, and completion of studies of the type Luisian benthic foraminifers, planktic foraminifers, and coccoliths (Poore et al., 1981) will allow direct comparison within the area.

The widespread nature of the cooling in the upper part of the type Luisian section is, however, supported by other data. At DSDP Site 289 in the western equatorial Pacific, Woodruff et al. (1979) recorded a steady positive increase in the  $\delta O^{18}$  of benthic foraminifers beginning in the lower part of planktic foraminiferal Zone N9 and continuing through Zone N12 (compare text-

fig. 3), which we attribute to rapid growth of the Antarctic icecap. Earlier oxygen isotope studies by Shackleton and Kennett (1975) on DSDP sites off New Zealand also strongly support this cooling trend. Associated high-latitude cooling would certainly cause intensification of the cool-water California Current and resultant assemblage changes. Cooling at the top of the Luisian Stage in California is recorded by mollusks (Addicott, 1970), benthic foraminifers (Kleinpell, 1938), planktic foraminifers (Ingle, 1973), and coccoliths (Crouch and Bukry, 1979) and is supported by the increased siliceous character of overlying rocks.

## CONCLUSIONS

1. One hundred four diatom taxa typical of the early Middle Miocene of California are reported from the type section of Kleinpell's (1938) Luisian Stage. One new species, *Coscinodiscus volutus* Baldauf, is proposed.
2. The type Luisian section ranges from the lowermost part of the *Denticulopsis lauta* Zone to the lower part of the *Denticulopsis hustedtii*-*D. lauta* Zone. The type Luisian section is early Middle Miocene in age and ranges from about 16.0 to 14.0 Ma.
3. Planktic diatoms average 80% of the assemblage. Fluctuations in benthic and tychopelagic diatoms are interpreted to be due to downslope transport, with the exception of probable shoaling at the top of the section.
4. Interpreted climatic cooling in the upper part of the section is supported by both megafossils and microfossils and corresponds to similar events in the Pacific as shown by oxygen isotope studies.

## APPENDIX

### Description of a new species

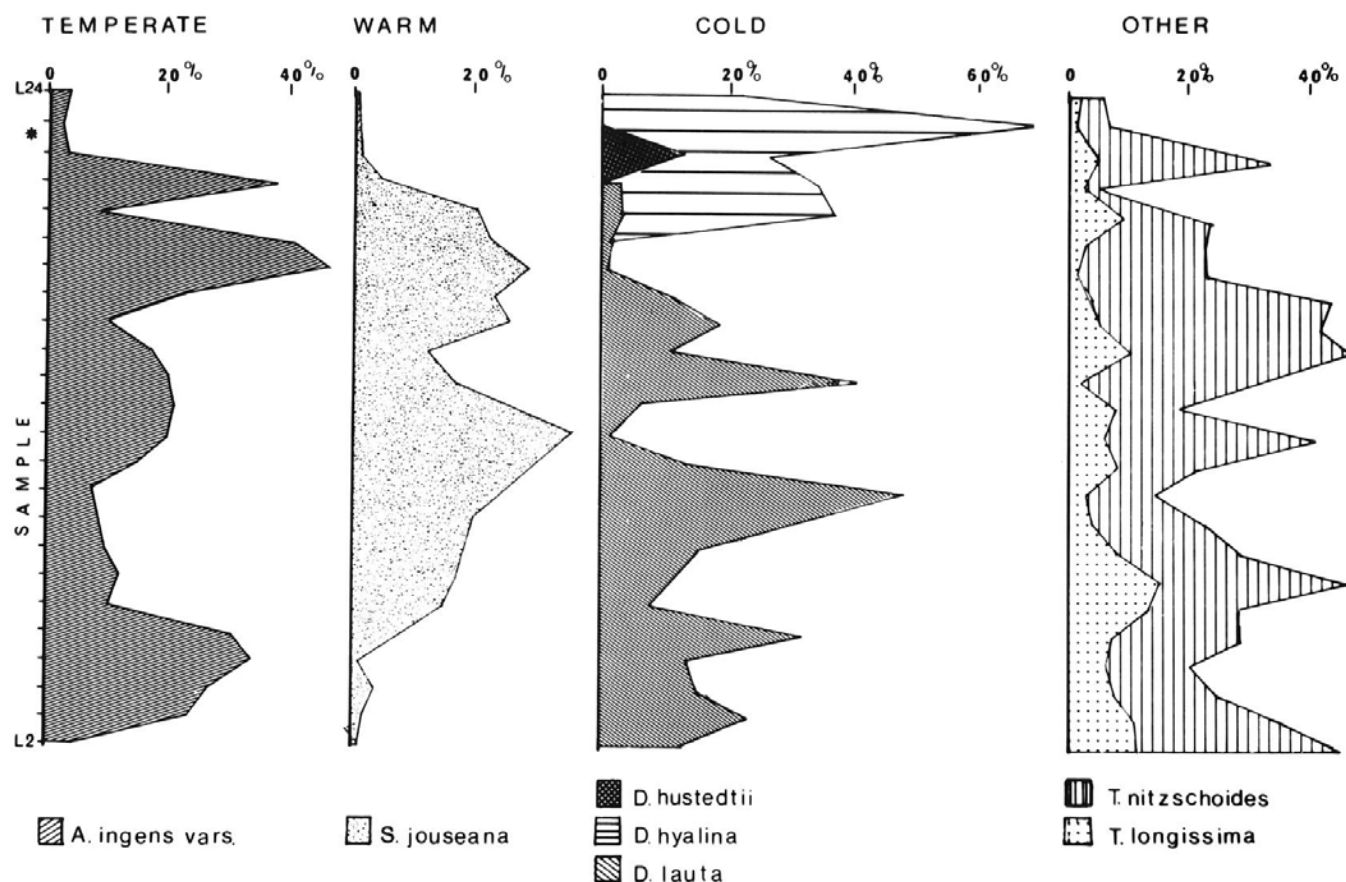
Genus COSCINODISCUS Ehrenberg

#### *Coscinodiscus volutus* Baldauf, n. sp.

Plate 2, figures 1–4; plate 3, figure 2

**Description:** Valve circular, 35 to 85  $\mu m$  in diameter, center slightly depressed, possessing distinct nodule. Areolae round, 6–7 in 10  $\mu m$  in size, from near center to approximately three-fifths of radius where they increase slightly in size (5 in 10  $\mu m$ ) toward margin. Areolae radially arranged, exhibiting slight fasciculation; pronounced secondary spiral present. Center of areolae pattern displaced from center of valve. Margin indistinct but possessing, at intervals of 10–15  $\mu m$ , tabular hyaline areas 1–2  $\mu m$  square (see pl. 2, fig. 2). Submarginal labiate processes 1  $\mu m$  in length on underside, at intervals of 10  $\mu m$  (see pl. 2, fig. 3).

**Remarks:** The absence of a central subcircular cluster of areolae surrounded by a hyaline band, the presence



TEXT-FIGURE 5

Percentage fluctuation of *Actinocyclus ingens* (vars.), *Synedra jouseana*, *Denticulopsis* spp. (*D. hustedtii*, *D. hyalina*, and *D. lauta*), and other taxa in samples studied from type Luisian. These are interpreted as temperate-, warm-, and cold-water components (see text).

of a secondary spiral, and the offset of the areolae pattern from the center of the valve, distinguish *Coscinodiscus volutus* from *Coscinodiscus vetustissimus* Pantocsek.

*Coscinodiscus tabularis* Grunow is easily separated from *C. volutus* by the presence of a marginal hyaline band, the absence of a secondary spiral, and the size of the areolae, which are 3–4 in 10  $\mu\text{m}$  in *C. tabularis* compared to 6–7 in 10  $\mu\text{m}$  in *C. volutus*.

**Distribution:** *Coscinodiscus volutus* occurs throughout the Middle Miocene *Denticulopsis lauta* and the lower part of the *Denticulopsis hustedtii*-*D. lauta* zones of Barron (1980) in the type Luisian area. Further studies to determine the stratigraphic as well as geographic limits of this taxon need to be conducted.

**Holotype:** Plate 3, figure 2, USNM 311178.

**Isotypes:** Plate 2, figures 1–4, USNM 311179 and 311180.

**Type locality:** Sample L10; the Sandholt Member of

the Monterey Formation; type Luisian section of Kleinpell (1938); SE  $\frac{1}{4}$  of section 21 of the Wilson Corner  $7\frac{1}{2}$ -minute quadrangle, California.

#### TAXONOMIC NOTES

No effort was made to separate individual species of *Cestodiscus* or varieties of *Actinocyclus ehrenbergii* Ralfs.

***Actinocyclus chalnokyi*** Van Landingham, 1967, p. 83; Koizumi, 1968, p. 207. *Synonym:* *Actinocyclus divisus* Kisselev, 1931, p. 113, pl. 1, fig. 1.

***Actinocyclus ehrenbergii*** Ralfs in Pritchard, 1861, p. 834; Hustedt, 1929, p. 525, fig. 298; Schrader, 1973, p. 701, pl. 19, fig. 1. *Remarks:* Many varieties of this species were observed. This taxon should be revised, but that is not the purpose of the present paper. [Plate 1, figure 5]

***Actinocyclus ehrenbergii* var. *ralfsii*** (Wm. Smith) Hustedt, 1929, p. 528, fig. 299; Cleve-Euler, 1951, p. 82, fig. 144b. *Synonym:* *Eupodiscus ralfsii* Wm. Smith, 1856, p. 86.

***Actinocyclus ehrenbergii* var. *tenella*** (Brébisson) Hustedt, 1929, p. 530, fig. 302; Kanaya, 1959, p. 95, pl. 7, figs. 2, 3. [Plate 1, figure 7]



**Actinocyclus ingens** Rattray, 1890b, s. str. (undulated), p. 149, pl. 11, fig. 7. *Synonym:* *Actinocyclus ingens* Rattray: Sheshukova-Poretzkaya, 1967, pl. 30, fig. 1; *Actinocyclus ingens* var. 1 Barron, 1980.

**Description:** Valve circular, observed specimens 10 to 65  $\mu\text{m}$  in diameter. Valve surface slightly undulated increasing from center to highest point at approximately one-third of radius, decreasing to margin. At highest point valve surface exhibiting distinct submarginal ring. Areolae subrounded, arranged in radial rows. Primary rows extending length of radius; several shorter secondary rows between two primary rows. Radial rows separated from one another by hyaline areas. Areolae increasing from 5 in 10  $\mu\text{m}$  in central region to 4 in 10  $\mu\text{m}$  at highest point; then decreasing from 6 in 10  $\mu\text{m}$  toward margin, where 8 in 10  $\mu\text{m}$  were observed.

**Remarks:** *Actinocyclus ingens* Rattray is characterized by having an undulating valve surface, and a depressed center. Rattray's (1890b) type description notes, "surface rising gradually from the center to about  $\frac{2}{3}$  of the radius to the highest zone; this zone slightly convex, its outer edge sloping down to the border so as to form a distinct submarginal band." Although a wide morphological variation has been observed by past workers, only specimens strictly fitting the definition were tabulated as *Actinocyclus ingens* s. str. (undulated). The other flatter varieties that were referred to as *Actinocyclus ingens* by past workers are tabulated as *Actinocyclus ingens* s. ampl. [Plate 1, figure 8]

**Actinocyclus ingens** Rattray, 1890b, s. ampl. (flat), p. 149; Koizumi, 1973, p. 831, pl. 1, figs. 13, 14; pl. 2, figs. 1, 2. *Synonym:* *Actinocyclus tsugaruensis* Kanaya, 1959, p. 99, pl. 8, figs. 5–8. **Remarks:** This form of *Actinocyclus ingens* differs from *A. ingens* s. str. by having a flat valve surface, and no raised submarginal ring of any kind. [Plate 1, figures 6, 10]

**Actinocyclus ingens** var. **nodus** Baldauf in Baldauf and Barron, 1980, p. 104, pl. 1, figs. 5–9. *Synonym:* *Actinocyclus ingens* Rattray: Jousé, 1977, pl. 53, fig. 1.

**Description:** Valve circular, 35 to 65  $\mu\text{m}$  in diameter. Valve concentrically undulated, with raised central and submarginal ring areas separated by continuous depression. Central area appearing as areolated node covering approximately one-fifth of diameter. Width of adjacent depression varying between specimens. Submarginal raised ring distinct and same height as central area. Areolae subrounded and arranged in radially lineate rows. Primary rows extending length of radius, secondary rows from depression region to margin. Areolae larger (5 in 10  $\mu\text{m}$ ) in central and submarginal zones and surrounded in hyaline areas. Areolae decreasing in size (9 in 10  $\mu\text{m}$ ) in the submarginal area, where they are indistinctly separated by hyaline areas. Pseudonodule near margin similar to that of *Actinocyclus ingens* Rattray, where it is de-

scribed as obscure, sharply angular, with irregular edges.

**Remarks:** *Actinocyclus ingens* var. **nodus** Baldauf differs from *Actinocyclus ingens* Rattray var. *ingens* by the presence of a raised central area, which is equal in height to the raised submarginal ring. Rattray's type concept of *Actinocyclus ingens* includes specimens with depressed center and raised submarginal rings. [Plate 1, figure 9]

**Actinoptychus splendens** var. **halionyx** Grunow in Van Heurck, 1883, pl. 119, fig. 3; pl. 120, fig. 3; Hustedt, 1929, p. 478, fig. 265. [Plate 1, figure 1]

**Actinoptychus thumii** (Schmidt) Hanna, 1932, p. 171, pl. 4, figs. 3, 4. *Synonym:* *Actinoptychus stellaris* var. *thumii* Schmidt in Schmidt et al., 1886, pl. 90, fig. 3; pl. 100, fig. 6. [Plate 1, figure 3]

**Actinoptychus undulatus** (Bailey) Ralfs in Pritchard, 1861, p. 839, pl. 5, fig. 88; Hustedt, 1929, p. 475, fig. 264. *Synonym:* *Actinocyclus undulatus* Bailey, 1842, pl. 2, fig. 11. [Plate 1, figure 4]

**Actinoptychus vulgaris** var. **monicae** Grunow in Van Heurck, 1883, pl. 121, fig. 9; Wornardt, 1967, p. 51, figs. 79–81; Barron, 1975, p. 121, pl. 2, fig. 11. [Plate 1, figure 2]

**Annellus californicus** var. **hannai** Barron, 1981, pl. 6, figs. 3, 4, 6, 9–12; pl. 7, figs. 1–3. *Synonym:* *Annellus californicus* Tempère: Hanna, 1932, pl. 4, figs. 5–7 (not 8). [Plate 5, figures 4, 6]

**Arachnoidiscus ornatus** var. **montereyanus** Schmidt, 1882, pl. 73, figs. 8, 9; Wornardt, 1967, p. 40, figs. 62, 63. [Plate 6, figure 5]

**Asteromphalus flabellatus** (Brébisson) Greville, 1859a, p. 161, pl. 7, fig. 6; Lohman, 1974, p. 346, pl. 4, fig. 2. *Synonym:* *Spatangidium flabellatum* Brébisson, 1857, p. 297, pl. 3, fig. 3.

**Asteromphalus robusta** Castracane, 1875, p. 393, pl. 6, fig. 5; Hustedt, 1929, p. 496, fig. 278.

**Aulacodiscus concentricus** (Mann) Boyer, 1926, p. 76; Wornardt, 1967, p. 52, fig. 83. *Synonym:* *Tripodiscus concentricus* Mann, 1907, p. 279, pl. 54, fig. 4.

**Aulacodiscus kittoni** Arnott ex Ralfs in Pritchard, 1861, p. 844, pl. 8, fig. 24; Hustedt, 1929, p. 506, fig. 283; Hendey, 1964, p. 98, pl. 22, fig. 5. [Plate 6, figure 6]

**Biddulphia aurita** (Lyngbye) Brébisson et Godey, 1838, p. 12; Hustedt, 1930, p. 846, fig. 501; Schrader, 1973, p. 702, pl. 13, figs. 1–3. *Synonym:* *Diatoma auritium* Lyngbye, 1819, pl. 52, fig. D.

**Biddulphia tuomeyi** (Bailey) Roper, 1859, p. 8, pl. 1, figs. 1, 2; Hustedt, 1930, p. 834, fig. 491; Lohman, 1974, p. 347, pl. 5, fig. 3. *Synonym:* *Zygoceros tuomeyi* Bailey, 1844, p. 138, pl. 3, figs. 3, 4. [Plate 6, figure 2]

**Campyloneis grevillei** (Wm. Smith) Grunow, 1870, p. 11; Van Heurck, 1896, p. 285, fig. 64; Hustedt, 1933, p. 321, fig. 781. *Synonym:* *Cocconeis grevillei* Wm. Smith, 1853, p. 22, pl. 3, fig. 35.

**Cestodiscus** sp.—Genus *Cestodiscus* Greville, 1865, pp. 13, 48, pl. 5, figs. 8, 9; Grunow in Van Heurck, 1883, pl. 126; Lohman, 1974, p. 339. **Remarks:** This genus is rare throughout the section. Specific identification of individual specimens was not attempted.

**Chaetoceros cinctus** Gran, 1897, p. 24, pl. 2, figs. 23–27; Hustedt, 1930, p. 748, fig. 432; Wornardt, 1967, p. 69, fig. 135.

**Chaetoceros dicladia** Castracane, 1886, p. 82, pl. 8, fig. 1; pl. 19, figs. 7, 8; Karsten, 1905, p. 119, pl. 16, fig. 2; Kanaya, 1959, p. 117,

pl. 11, figs. 1, 2. *Synonym: Dieladia pylea* Hanna and Grant, 1926, p. 142, pl. 16, figs. 4, 5.

***Cladogramma dubium*** Lohman, 1948, p. 168, pl. 9, fig. 5; Schrader, 1973, p. 702, pl. 13, figs. 17, 18, 21; pl. 24, fig. 11a; Barron, 1975, p. 128, pl. 5, fig. 10.

***Cocconeis costata*** Gregory, 1855, p. 39, pl. 4, fig. 10; Hustedt, 1933, p. 332, fig. 785; Sheshukova-Poretzkaya, 1967, p. 44, fig. 4.

***Cocconeis dirupta*** var. ***triumphis*** (Hanna and Grant) Frenguelli, 1949, p. 111, pl. 6, fig. 9. *Synonym: Cocconeis triumphis* Hanna and Grant, 1926, p. 135, pl. 14, figs. 11–13; Wornardt, 1967, p. 80, fig. 182.

***Cocconeis distans*** Gregory, 1857, p. 490, pl. 1, fig. 23; Hustedt, 1933, p. 343, fig. 797; Barron, 1975, p. 130, pl. 5, fig. 16.

***Cocconeis scutellum*** Ehrenberg, 1838, p. 194, pl. 14, fig. 8; Hustedt, 1933, p. 338, fig. 790; Barron, 1975, p. 130, pl. 5, fig. 19. [Plate 6, figure 1]

***Cocconeis vitrea*** Brun, 1891, p. 19, pl. 18, fig. 2; Kanaya, 1959, p. 110, fig. 6; Wornardt, 1967, p. 81, figs. 183–184.

***Coscinodiscus asteromphalus*** Ehrenberg, 1844, p. 77; 1854, pl. 18, fig. 45; pl. 33, figs. 7, 15; Hustedt, 1928, p. 452, fig. 250; Wornardt, 1967, p. 20, figs. 14–18; Barron, 1975, p. 132, pl. 6, fig. 3.

***Coscinodiscus gigas*** var. ***diorama*** (Schmidt) Grunow, 1884, p. 76; Rattray, 1890, p. 542, fig. 94; Barron, 1975, p. 133, pl. 6, fig. 11. *Synonym: Coscinodiscus diorama* Schmidt in Schmidt et al., 1874–1959, pl. 64, fig. 2.

***Coscinodiscus lewisianus*** Greville, 1866, p. 78, pl. 8, figs. 8–10; Reinhold, 1937, p. 96, pl. 8, fig. 11; Schrader, 1973, p. 703, pl. 8, figs. 1–6, 10, 15.

***Coscinodiscus marginatus*** Ehrenberg, 1841a, p. 142; 1854, pl. 18, fig. 44; Hustedt, 1928, p. 416, fig. 223; Hanna, 1932, p. 181, pl. 8, figs. 4, 5. *Remarks:* Two forms of this species were observed. Form 1 contains large central areolae (5 in 10  $\mu$ m) which decrease in size toward the coarsely striated (8 in 10  $\mu$ m) margin and has a valve surface that is greatly convex. Form 2 has a valve surface that is less convex, the central areolae are 7 in 10  $\mu$ m and decrease toward the finely striated margin (12 in 10  $\mu$ m). Both forms have diameters from 25 to 85  $\mu$ m. [Plate 5, figures 2–3, 7]

***Coscinodiscus nitidus*** Gregory, 1857, p. 499, fig. 45; Hustedt, 1928, p. 414, figs. 30, 31; Wornardt, 1967, p. 27, figs. 30, 31; Barron, 1975, p. 134, pl. 7, fig. 3.

***Coscinodiscus obscurus*** Schmidt, 1878, in Schmidt et al., 1874–1959, pl. 61, fig. 16; Rattray, 1890, p. 513, fig. 65; Hustedt, 1928, p. 418, pl. 224; Wornardt, 1967, p. 27, fig. 32. [Plate 3, figure 1]

***Coscinodiscus oculus-iridis*** Ehrenberg, 1839, p. 147; 1854, pl. 18, fig. 42; pl. 19, fig. 2; Hanna, 1932, p. 183, pl. 9, fig. 4; Barron, 1975, p. 135, pl. 7, fig. 9. [Plate 5, figure 1]

***Coscinodiscus plicatus*** Grunow, 1878 in Schmidt et al., 1874–1959, pl. 59, fig. 1; Grunow, 1884, p. 73, pl. 3c, fig. 10; Schrader, 1973, p. 703, pl. 6, fig. 23.

***Coscinodiscus praeyabei*** Schrader, 1973, pl. 6, fig. 16; pl. 7, figs. 17–20, 22, 23. [Plate 3, figure 4]

***Coscinodiscus salisburyanus*** Lohman, 1948, p. 164, pl. 7, fig. 5; 1974, p. 337, pl. 2, figs. 5, 7.

*Description:* Valve circular, flat, 25–60  $\mu$ m in diameter. Irregular central area occupied by obscure nodule and rounded to subrounded granules. Areolae hexagonal

(7 in 10  $\mu$ m) near center, increasing (5½ in 10  $\mu$ m) at one-half radius, then decreasing (6 in 10  $\mu$ m) near margin. Areolae radially arranged with fasciculated to subfasciculated pattern. Longest rows extending length of radius and parallel with radius. Margin narrow, finely striated (12 in 10  $\mu$ m).

*Remarks:* Lohman (1974) stated, "2–4 irregularly rounded granules occupy the central space." Specimens observed contain two or no granules. The small specimens were difficult to distinguish from *Coscinodiscus nodulifer* because their fasciculated areolar pattern is not well developed. [Plate 4, figure 4]

***Coscinodiscus symbolophorus*** Grunow, 1884, p. 86; Rattray, 1890a, p. 583, fig. 135; Hustedt, 1928, p. 427, fig. 230. [Plate 4, figure 1]

***Coscinodiscus tabularis*** Grunow, 1884, p. 86; Rattray, 1890a, p. 583, fig. 135; Hustedt, 1928, p. 427, fig. 230.

*Description:* Valve circular, 15–60  $\mu$ m in diameter. One distinct nodule present near center. Areolae round, 3–4 in 10  $\mu$ m throughout, radius decreasing slightly at margin. Areolae radially arranged, showing fasciculated pattern. Margin finely areolated (8 in 10  $\mu$ m) with distinct apiculi present every 10  $\mu$ m. Distinct hyaline band separating apiculi and margin from rest of valve.

*Remarks:* Hustedt (1959) and Fenner (1978) described a wide morphological variation in *Coscinodiscus tabularis*, which includes specimens matching *Coscinodiscus endoi* Kanaya. In this paper all specimens of *Coscinodiscus endoi* are tabulated as *Coscinodiscus tabularis*. [Plate 4, figures 6–7]

***Coscinodiscus tuberculatus*** Greville, 1861, p. 42, pl. 4, fig. 6; Grunow, 1888, p. 30, pl. 3, fig. 29; Rattray, 1890a, p. 482; Kolbe, 1954, p. 35, pl. 1, fig. 11. [Plate 4, figures 3, 5, 8]

***Coscinodiscus vetustissimus*** Pantocsek, 1886, p. 71, pl. 20, fig. 186; Rattray, 1890a, p. 477, fig. 29; Hustedt, 1928, p. 412, fig. 210; Andrews, 1976, p. 12, pl. 3, fig. 3.

*Description:* Valve circular, observed specimens ranging from 52 to 87  $\mu$ m in diameter. Central region slightly depressed containing distinct variably shaped nodule, also distinct, irregular to subcircular cluster of areolae. Cluster approximately 6–9  $\mu$ m broad, and surrounded by narrow hyaline band. Areolae hexagonal increasing slightly from center (6 in 10  $\mu$ m) to radius (5 in 10  $\mu$ m), then decreasing to margin (7 in 10  $\mu$ m). Areolae arranged in radial rows, with fasciculated pattern. Longest radial rows extending from center to margin and parallel to edge. Margin narrow and finely striated (18 in 10  $\mu$ m).

*Remarks:* *Coscinodiscus vetustissimus* can be readily distinguished from other *Coscinodiscus* species by its irregular central cluster of areolae, which is surrounded by a distinct hyaline band. [Plate 3, figures 5–7]

***Craspedodiscus coscinodiscus*** Ehrenberg, 1844b, p. 266; 1854, pl. 18, fig. 108; Rattray, 1890a, p. 600; Kolbe, 1954, p. 36, pl. 1, fig. 4; Kanaya, 1971, p. 555, pl. 40.4, figs. 1–3.

***Craspedodiscus rhombicus*** Grunow, 1881 in Schmidt et al., 1874–1959, pl. 61, fig. 13; Wornardt, 1967, p. 33, figs. 44, 45; Barron, 1975, p. 137, pl. 8, figs. 1, 2.

***Cussia paleacea*** (Grunow) Schrader, 1974, p. 543, pl. 1, figs. 11–14. *Synonym: Stoschia paleacea* Grunow in Van Heurck, 1883, pl. 128, fig. 6.

***Cymatogonia amblyoceras*** (Ehrenberg) Hanna, 1932, p. 186, pl. 10, fig. 5; Schrader, 1973, p. 704, pl. 26, fig. 8. *Synonym: Triceratium amblyocera* Ehrenberg, 1844, p. 88; 1854, pl. 18, fig. 51.

***Delphineis angustata*** (Pantocsek) Andrews, 1977, pp. 250–251, pl. 1, figs. 1–4; pl. 2, figs. 21–22; pl. 3, figs. 29–30; Abbott and Andrews, 1979, p. 242, pl. 4, fig. 1. *Synonym: Rhaphoneis angustata* Pantocsek, 1886, pt. 1, p. 33, pl. 11, fig. 97; pl. 30, fig. 313; Lohman, 1948, p. 180, pl. 11, fig. 11; Andrews, 1976, p. 20, pl. 7, figs. 1, 2. [Plate 7, figures 17–18]

***Delphineis penelliptica*** Andrews, 1977, p. 253, pl. 1, figs. 16–20; pl. 2, figs. 27, 28; pl. 4, figs. 35, 36.

***Denticulopsis hustedtii*** (Simonsen and Kanaya) Simonsen, 1979, p. 64. *Synonym: Denticula hustedtii* Simonsen and Kanaya, 1961, p. 501, pl. 1, figs. 19–25; pl. 2, figs. 36–47; Schrader, 1973, p. 704, pl. 2, figs. 28–34, 36–47. [Plate 7, figures 7, 8]

***Denticulopsis hyalina*** (Schrader) Simonsen, 1979, p. 64. *Synonym: Denticulina hyalina* Schrader, 1973, p. 704, pl. 1, figs. 12–22. [Plate 7, figures 2, 4]

***Denticulopsis lauta*** (Bailey) Simonsen, 1979, p. 64. *Synonym: Denticula lauta* Bailey, 1854, p. 9, figs. 1, 2. [Plate 7, figure 5]

***Denticulopsis nicobarica*** (Grunow) Simonsen, 1979, p. 65. *Synonym: Denticula nicobarica* Grunow, 1868, pl. 19, fig. 5. [Plate 7, figure 6]

***Denticulopsis punctata*** (Schrader) Simonsen, 1979, p. 65. *Synonym: Denticula punctata* Schrader, 1973, p. 705, pl. 1, figs. 25–30; pl. 3, figs. 16, 17. [Plate 7, figure 7]

***Diploneis interrupta*** (Kützinger) Cleve, 1894, p. 84; Hustedt, 1937, p. 604, fig. 1019; Barron, 1975, p. 140, pl. 8, fig. 15. *Synonym: Navicula interrupta* Kützinger, 1844, p. 100, pl. 29, fig. 93.

***Diploneis smithii*** (Brébisson) Cleve, 1894, p. 96; Hustedt, 1937, p. 647, fig. 1051; Barron, 1975, p. 140, pl. 8, fig. 17. *Synonym: Navicula smithii* Brébisson in Wm. Smith, 1856, p. 92.

***Dossetia lacera*** (Forti) Hanna, 1932, p. 190, pl. 11, fig. 3; Wornardt, 1967, p. 72, figs. 144, 145; Barron, 1975, p. 140, pl. 8, fig. 23. *Synonym: Xanthiopyxis lacera* Forti in Tempère and Peragallo, 1910, p. 197.

***Entopyla australis*** var. ***gigantea*** (Greville) Fricke, 1902 in Schmidt et al., 1874–1959, pl. 230, figs. 1–11; Wornardt, 1967, p. 80, figs. 177–180; Barron, 1975, p. 131, pl. 8, fig. 24. *Synonym: Gephyria gigantea* Greville, 1866, p. 122, pl. 11, figs. 7, 8. [Plate 7, figure 14]

***Glyphodiscus stellatus*** Greville, 1862, p. 91, pl. 9, fig. 5; Wornardt, 1967, p. 58, fig. 120a; Schrader, 1973, p. 705, pl. 22, fig. 6.

***Goniothecium rogersii*** Ehrenberg, 1841b, p. 406; 1854, pl. 18, figs. 92–93; Karsten, 1928, p. 301, fig. 419b; Hanna, 1932, p. 192, pl. 11, figs. 4–6.

***Grammatophora angulosa*** Ehrenberg, 1839, p. 153; 1841b, pl. 1, fig. 3; Hustedt, 1931, p. 39, fig. 564; Barron, 1975, p. 142, pl. 9, fig. 10.

***Grammatophora merletta*** Hanna and Grant, 1926, p. 146, pl. 16, figs. 11, 12, 14; Lohman, 1974, p. 354, pl. 6, fig. 3; Barron, 1975, p. 143, pl. 9, fig. 11.

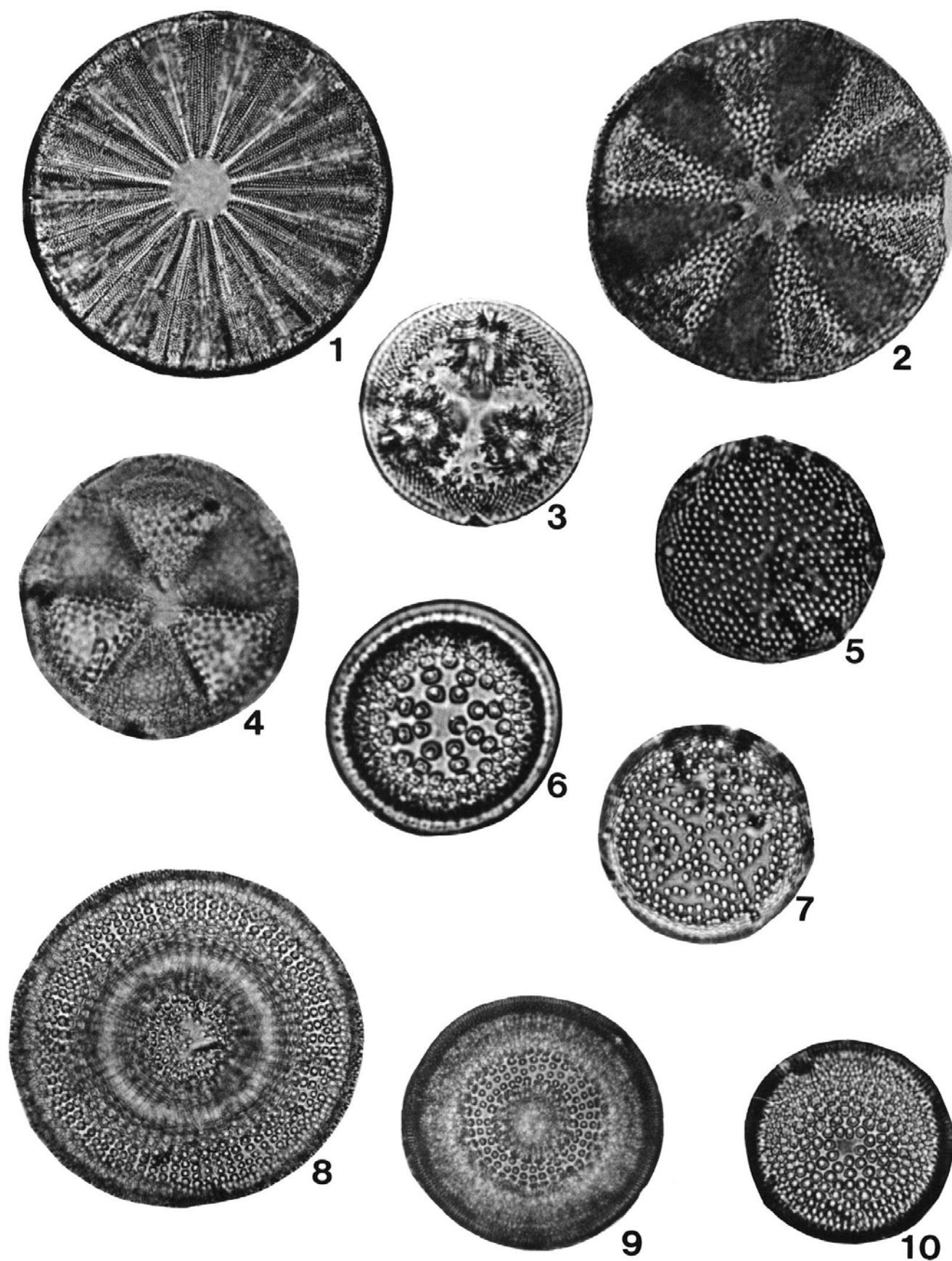
***Hemiaulus polymorphus*** Grunow, 1884, p. 66; Hustedt, 1930, p. 880; Hanna, 1932, p. 193, pl. 11, fig. 7; Lohman, 1974, p. 349, pl. 5, fig. 6.

***Hyalodiscus radiatus*** (O'Meara) Grunow in Cleve and Grunow, 1880, p. 117; Grunow, 1884, p. 93; Hustedt, 1928, p. 195, fig. 135. *Synonym: Pyxidicula radiata* O'Meara, 1877, p. 58, pl. 1, fig. 9. [Plate 6, figure 3]

***Liradiscus bipolaris*** Lohman, 1948, p. 165, pl. 8, fig. 5; 1974, p. 346, pl. 4, fig. 11.

## PLATE 1

- 1 *Actinocyclus splendens* var. *halionyx* Grunow  
Sample L7, diameter 152  $\mu\text{m}$ .
- 2 *Actinocyclus vulgaris* var. *monicae* Grunow  
Sample L5, diameter 147  $\mu\text{m}$ .
- 3 *Actinocyclus thumii* (Schmidt) Hanna  
Sample L9, diameter 22  $\mu\text{m}$ .
- 4 *Actinocyclus undulatus* (Bailey) Ralfs  
Sample L8, diameter 34  $\mu\text{m}$ .
- 5 *Actinocyclus ehrenbergii* Ralfs  
Sample L10, diameter 28  $\mu\text{m}$ .
- 6 *Actinocyclus ingens* Rattray s. ampl. (flat)  
Sample L21, diameter 32  $\mu\text{m}$ .
- 7 *Actinocyclus ehrenbergii* var. *tenella* (Brébisson)  
Hustedt  
Sample L9, diameter 25  $\mu\text{m}$ .
- 8 *Actinocyclus ingens* Rattray s. str. (undulated)  
Sample L23, diameter 145  $\mu\text{m}$ .
- 9 *Actinocyclus ingens* var. *nodus* Baldauf  
Sample L21, diameter 42  $\mu\text{m}$ .
- 10 *Actinocyclus ingens* Rattray s. ampl. (flat)  
Sample L21, diameter 30  $\mu\text{m}$ .





**Lithodesmium californicum** Grunow in Van Heurck, 1883, pl. 115, fig. 9; Wornardt, 1967, p. 67, fig. 130; Schrader, 1973, p. 706, pl. 12, figs. 11, 20.

**Macrora stella** (Azpeitia) Hanna, 1932, p. 196, pl. 12, fig. 7; Schrader, 1973, p. 706, pl. 12, figs. 21–24. *Synonym: Pyxidicula stella* Azpeitia, 1911, pp. 150, 153, pl. 1, fig. 1. *Remarks:* This genus is not a diatom, but is useful as a good guide fossil for Middle Miocene sediments (Schrader, 1973; Hanna, 1932).

**Mediaria splendida** Sheshukova-Poretzkaya, 1962, p. 210, pl. 2, fig. 5; 1967, p. 306, pl. 48, figs. 5, 6. [Plate 7, figure 15]

**Melosira clavigera** Grunow, 1876 in Schmidt et al., 1874–1959, pl. 175, figs. 21–24; Van Heurck, 1882, pl. 91, fig. 2; Barron, 1975, p. 146, pl. 10, fig. 6.

**Melosira sulcata** var. *biseriata* (Grunow) Peragallo and Peragallo, 1908, p. 448, pl. 119, fig. 14; Sheshukova-Poretzkaya, 1967, p. 127, pl. 7, fig. 2; pl. 10, fig. 6. *Synonym: Paralia sulcata* var. *biseriata* Grunow, 1884, p. 92, fig. 42.

**Melosira sulcata** var. *siberica* Grunow in Van Heurck, 1882, p. 91, fig. 22; Sheshukova-Poretzkaya, 1967, p. 128; Barron, 1975, p. 146, pl. 10, fig. 13.

**Melosira varians** Agardh, 1827, p. 628; 1832, p. 64; Wolle, 1890, pl. 57, figs. 11–15; Hustedt, 1927, p. 240, fig. 100.

**Navicula hennedyi** Wm. Smith, 1856, p. 93; Wornardt, 1967, p. 81, figs. 187, 188; Barron, 1975, p. 147, pl. 10, fig. 16.

**Navicula lyra** Ehrenberg, 1841, p. 419, pl. 1, fig. 9a; Hanna, 1932, p. 199, pl. 13, fig. 2; Wornardt, 1967, p. 82, figs. 189, 190, 192. [Plate 6, figure 4]

**Navicula optima** Hanna, 1932, p. 202, pl. 13, fig. 6; Wornardt, 1967, p. 84, fig. 193; Barron, 1975, p. 148, pl. 10, fig. 14.

**Navicula praetexta** Ehrenberg, 1840, p. 214; Hustedt, 1964, p. 411, figs. 1488, 1489; Wornardt, 1967, p. 84, figs. 195–197. *Synonym: Pinnularia preissei* Ehrenberg, 1854, pl. 19, fig. 28.

**Nitzschia challengerii** Schrader, 1973, p. 707, pl. 5, figs. 10–14, 34. [Plate 7, figure 16]

**Plagiogramma tesellatum** Greville, 1859b, p. 208, pl. 10, fig. 7; Wolle, 1890, pl. 45, figs. 18, 19; Hanna and Grant, 1926, p. 162, pl. 19, fig. 10; Hustedt, 1931, p. 107, fig. 633.

**Pleurosigma affine** Grunow in Cleve and Moller, 1879, no. 172, pp. 208–210; Grunow in Cleve and Grunow, 1880, p. 51; Van Heurck, 1896, p. 252, pl. 6, fig. 263.

**Podosira maxima** (Kützing) Grunow, 1879, p. 677, pl. 21, fig. 2; Hustedt, 1930, p. 285, fig. 126; Sheshukova-Poretzkaya, 1967, p. 130, pl. 10, fig. 9. *Synonym: Cyclotella maxima* Kützing, 1844, p. 50, pl. 1, fig. 5; pl. 21, fig. 6b.

**Pseudopyxilla americana** (Ehrenberg) Forti, 1909, p. 14, pl. 1, figs. 6, 7; Sheshukova-Poretzkaya, 1967, p. 227, pl. 29, fig. 2; Schrader, 1973, p. 708, pl. 10, fig. 22. *Synonym: Rhizosolenia americana* Ehrenberg, 1841 (1843), p. 422; 1854, pl. 33, figs. 3, 14, 17.

**Raphidodiscus marylandicus** Christian, 1887, p. 66–68; Hanna, 1932, p. 208, pl. 14, figs. 3, 4; Schrader, 1973, p. 708, pl. 22, fig. 7. [Plate 3, figure 3]

**Rhabdonema japonicum** var. *sparicostatum* Tempère and Brun in Brun and Tempère, 1889, p. 53, pl. 1, fig. 6; Barron, 1975, p. 152, pl. 11, fig. 16.

**Rhaphoneis amphiceros** Ehrenberg, 1844, p. 87; Hustedt, 1931, p. 174, fig. 680; Hanna, 1932, p. 211, pl. 15, figs. 3–5; Schrader, 1973, p. 708, pl. 25, figs. 2, 3; Lohman, 1974, p. 352, pl. 5, fig. 15. [Plate 7, figure 19]

**Rhaphoneis miocenica** Schrader, 1973, p. 709, pl. 25, figs. 1, 11. [Plate 5, figure 5]

**Rhaphoneis paralis** Hanna, 1932, p. 214, pl. 16, figs. 2–4; Proschkina-Lavrenko, 1949, p. 219, pl. 99, fig. 3.

**Rhizosolenia styliformis** Brightwell, 1858, p. 95, pl. 5, fig. 5a; Hustedt, 1930, pp. 584–588, figs. 333–335; Barron, 1975, p. 153, pl. 12, fig. 6.

**Rouxia diploneides** Schrader, 1973, p. 710, pl. 3, figs. 27–32. [Plate 7, figures 9–10]

**Rouxia naviculoides** Schrader, 1973, p. 710, pl. 3, figs. 27–32.

**Stephanogonia polyacantha** Forti, 1913, p. 1560, pl. 12, fig. 11; Hanna, 1932, p. 218, pl. 16, fig. 8; Barron, 1975, p. 154, pl. 12, fig. 13.

**Stephanopyxis schenckii** Kanaya, 1959, p. 67, pl. 2, figs. 2–4; Koizumi, 1973, p. 833, pl. 6, figs. 11, 12; Barron, 1975, p. 155, pl. 12, fig. 19.

**Stephanopyxis turris** (Greville and Arnott) Ralfs in Pritchard, 1861, p. 826, pl. 5, fig. 74; Karsten, 1905, p. 73, pl. 2, fig. 1; Hustedt, 1928, p. 304, fig. 140. *Synonym: Cresswellia turris* Greville and Arnott, 1857, p. 538, fig. 64.

**Stictodiscus californicus** Greville, 1861, p. 79, pl. 10, fig. 1; Hanna and Grant, 1926, p. 167, pl. 20, fig. 12; Wornardt, 1967, p. 38, figs. 54, 55.

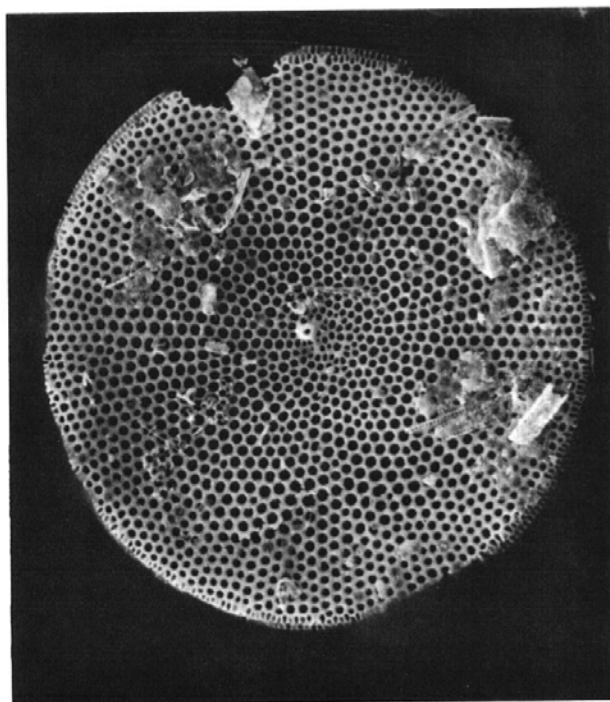
## PLATE 2

### Scanning electron micrographs

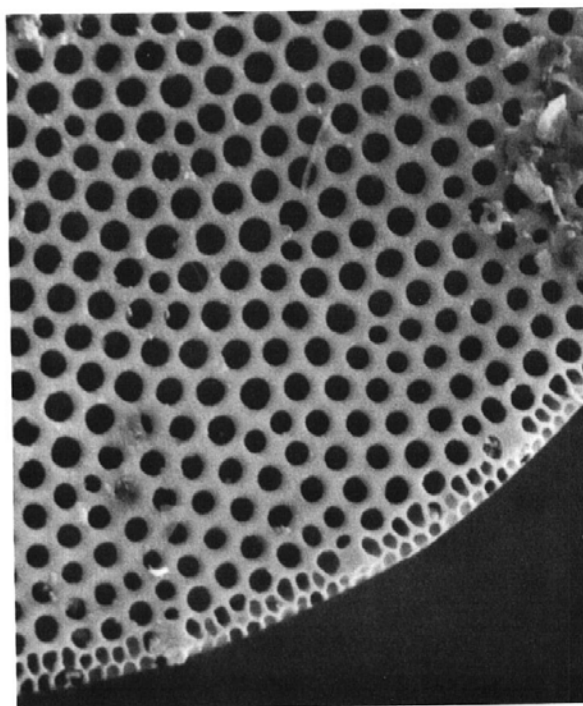
1–4 *Coscinodiscus volutus* Baldauf, n. sp.

1, lateral view, subcircular areolae pattern, sample L10, diameter of individual 93  $\mu\text{m}$ , isotype, USNM 311179; 2, closeup of hyaline intervals along margin, sample L10, diameter of individual 93  $\mu\text{m}$ , isotype, USNM 311179; 3, view of submarginal labiate processes on underside of valve, sample L10, diameter of individual 80  $\mu\text{m}$ , isotype, USNM 311180; 4, closeup of valve center, showing slightly depressed center, and distinct central nodule, sample L10, diameter of individual 93  $\mu\text{m}$ , isotype, USNM 311180.

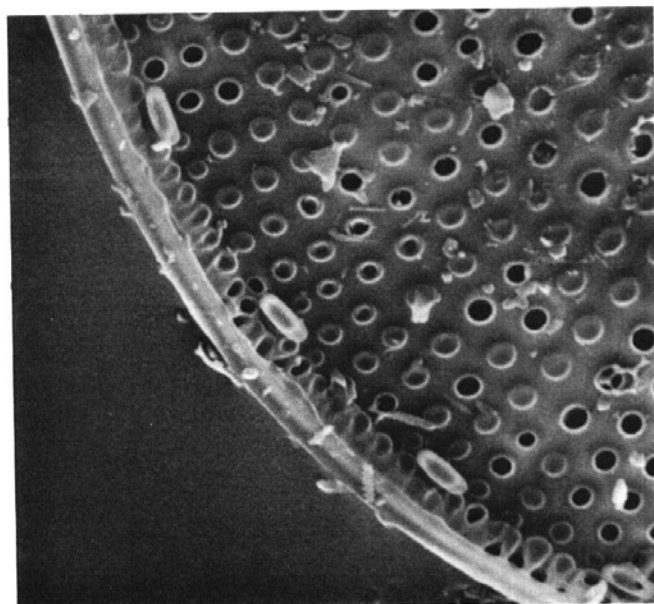




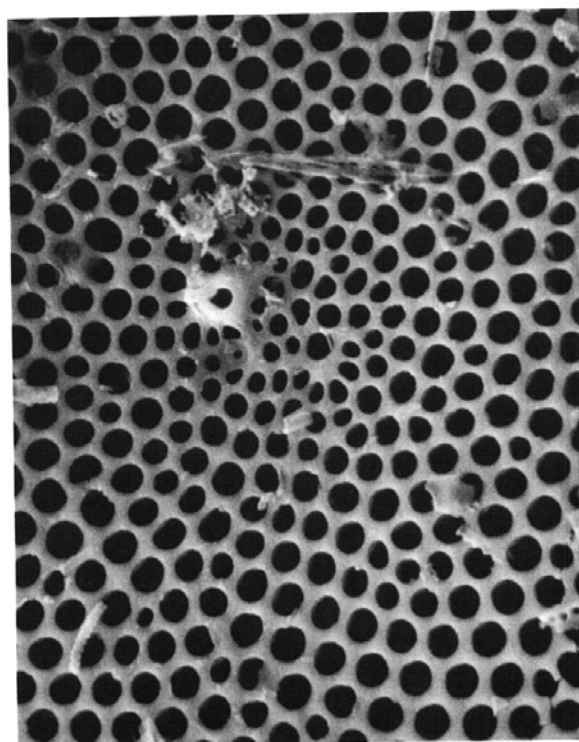
1



2



3



4

**Syndendrium diadema** Ehrenberg, 1845, p. 155; Lohman, 1974, p. 350, pl. 5, fig. 13.

**Synedra jouseana** Sheshukova-Poretzkaya, 1962, p. 208, fig. 4; Schrader, 1973, p. 710, pl. 23, figs. 21–23, 25, 38; Barron, 1975, p. 156, pl. 13, fig. 4. [Plate 7, figure 13]

**Thalassionema nitzschioides** Grunow in Van Heurck, 1896, p. 319, fig. 75; Hustedt, 1932, p. 244, fig. 725; Schrader, 1973, p. 712, pl. 23, figs. 2, 6, 8–10, 26.

**Thalassiosira leptopus** (Grunow) Hasle and Fryxell, 1977, pp. 20–22, figs. 1–14. *Synonym: Coscinodiscus lineatus* Ehrenberg, 1838, p. 129; 1841, p. 146, pl. 3, fig. 4; Ratray, 1890a, p. 472, fig. 24; Hanna, 1932, p. 180, pl. 8, figs. 1–3; Lohman, 1974, p. 335, pl. 2, fig. 3. [Plate 4, figure 2]

**Thalassiosira** sp. 1. *Synonym: Thalassiosira* sp. 2 Schrader, 1973, p. 712, pl. 14, figs. 17–18.

**Thalassiothrix longissima** Cleve and Grunow, 1880, p. 108; Hustedt, 1932, p. 247, fig. 726; Lohman, 1974, p. 353, pl. 6, fig. 2. [Plate 7, figures 11–12]

**Triceratium condecorum** Ehrenberg, 1844b, p. 272; Brightwell, 1853, p. 250, pl. 4, fig. 12; Wolle, 1890, pl. 102, fig. 6; Hanna, 1932, p. 221, pl. 17, figs. 1, 3.

**Xanthiopyxis globosa** Ehrenberg, 1844b, p. 273; De Toni, 1894, p. 1155; Hanna, 1932, p. 224, pl. 18, fig. 3; Barron, 1975, p. 161, pl. 15, figs. 8, 9.

**Xanthiopyxis maculata** Hanna, 1932, p. 255, pl. 18, fig. 4.

**Xanthiopyxis ovalis** Lohman, 1938, p. 91, pl. 20, fig. 6; pl. 22, fig. 12; Barron, 1975, p. 161, pl. 15, fig. 13.

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#### PLATE 3

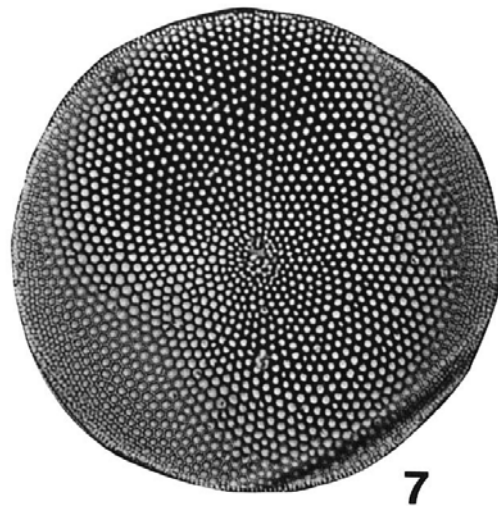
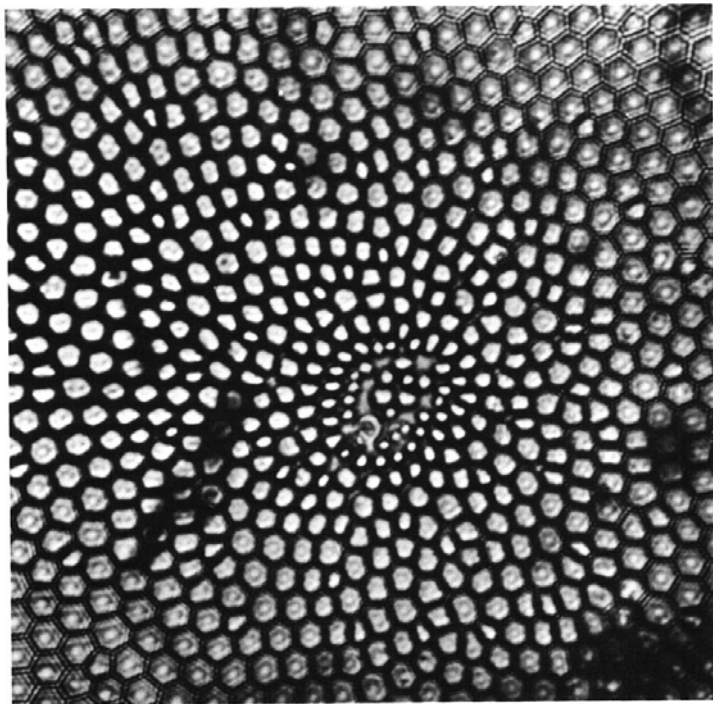
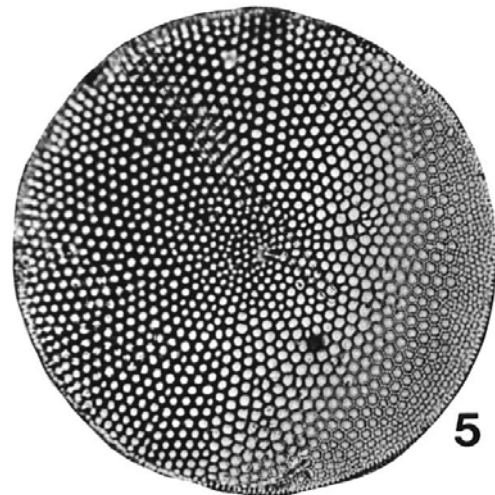
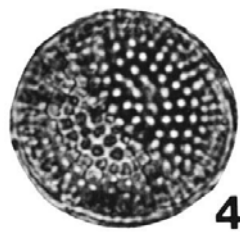
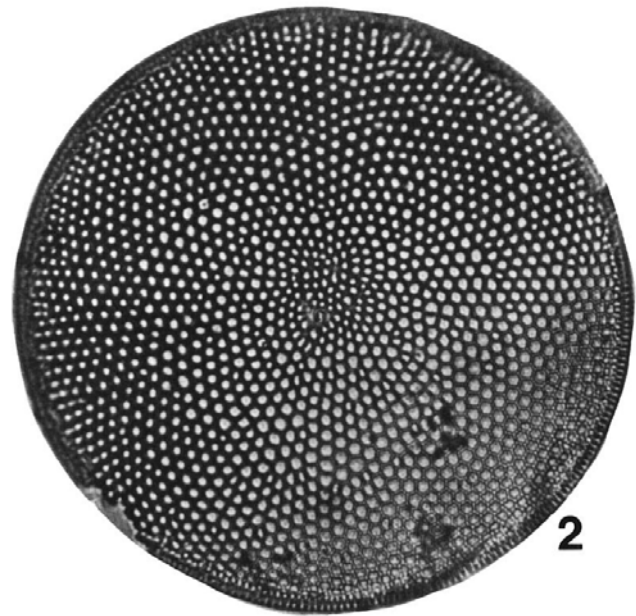
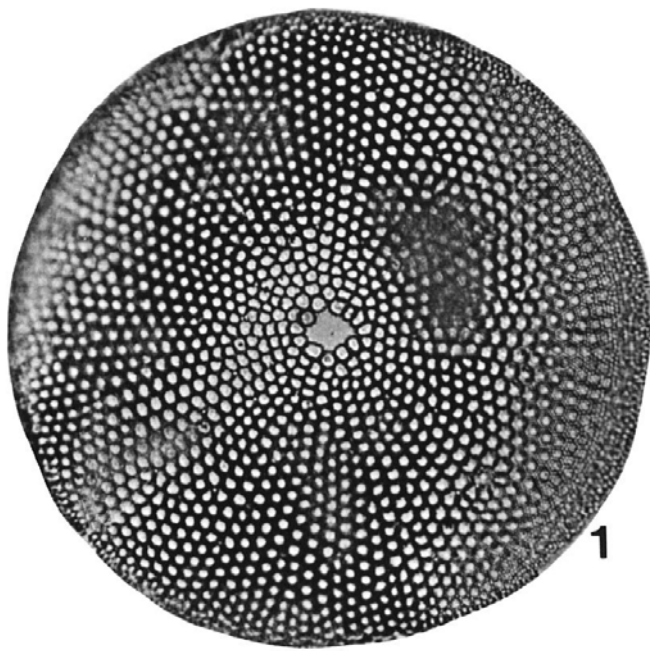
1 *Coscinodiscus obscurus* Schmidt  
Sample L10, diameter 90  $\mu$ m.

2 *Coscinodiscus volutus* Baldauf, n. sp.  
Sample L10, diameter 87  $\mu$ m. Holotype, USNM 311178.

3 *Raphidodiscus marylandicus* Christian  
Sample L10, diameter 32  $\mu$ m.

4 *Coscinodiscus praeyabei* Schrader  
Sample L24, diameter 18  $\mu$ m.

5–7 *Coscinodiscus vetustissimus* Pantocsek  
5, Sample L10, diameter 68  $\mu$ m; 6, closeup of central region. Notice hyaline ring around central areolae, sample L10, width of photograph 18  $\mu$ m; 7, sample L10, diameter 70  $\mu$ m.

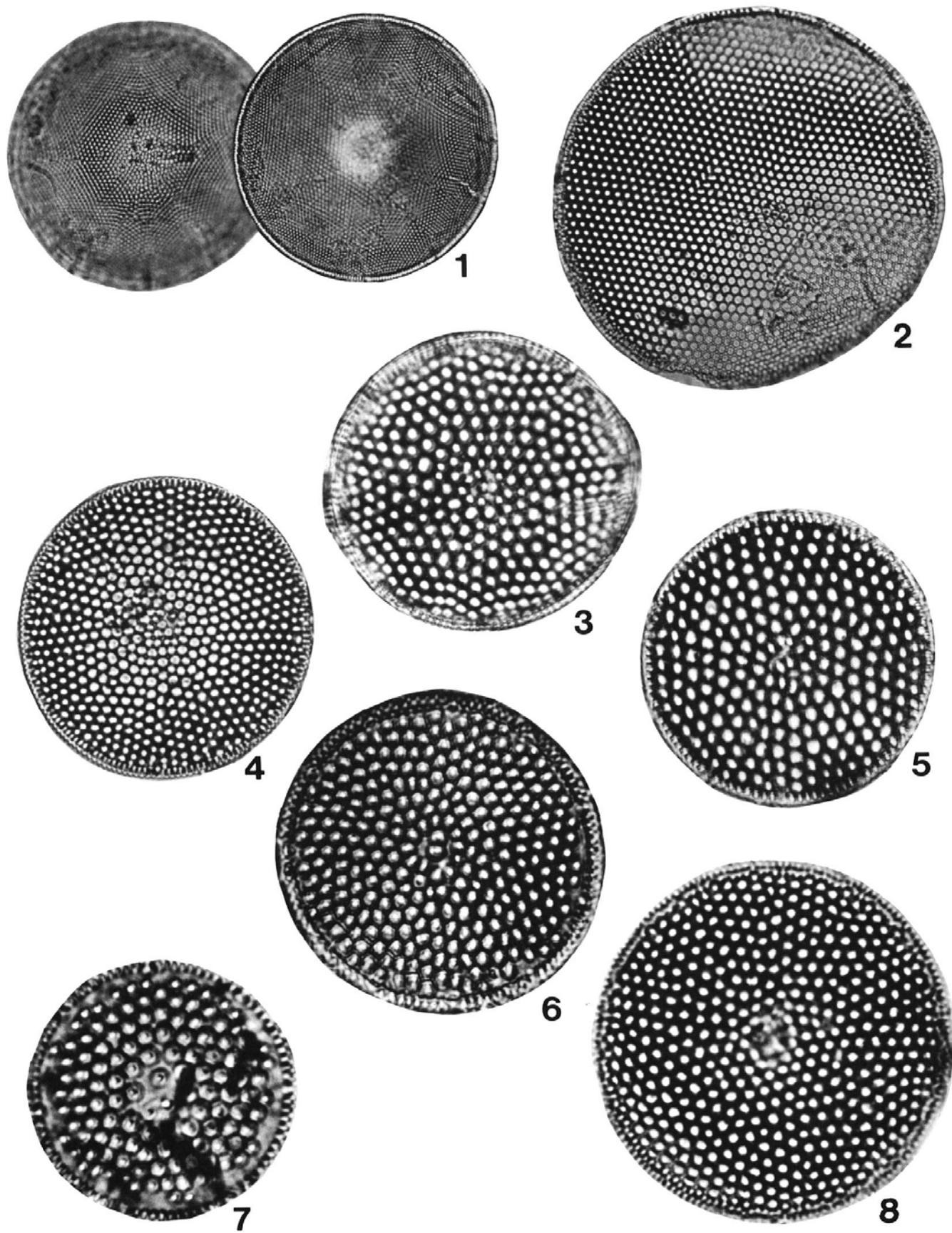


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#### PLATE 4

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|---|--|
| 1 <i>Coscinodiscus symbolophorus</i> Grunow<br>Sample L21, diameter 22 $\mu\text{m}$ . High and low<br>focus. | L10, diameter 32 $\mu\text{m}$ ; 8, sample L10, diam-<br>eter 37 $\mu\text{m}$ .   |
| 2 <i>Thalassiosira leptopus</i> (Grunow) Hasle and<br>Fryxell<br>Sample L22, diameter 75 $\mu\text{m}$ .      | 4 <i>Coscinodiscus salisburyanus</i> Lohman<br>Sample L10, diameter 29 $\mu\text{m}$ .   |
| 3, 5, 8 <i>Coscinodiscus tuberculatus</i> Greville<br>3, sample L10, diameter 32 $\mu\text{m}$ ; 5, sample    | 6–7 <i>Coscinodiscus tabularis</i> Grunow<br>6, sample L10, diameter 34 $\mu\text{m}$ ; 7, sample<br>L8, diameter 25 $\mu\text{m}$ . |



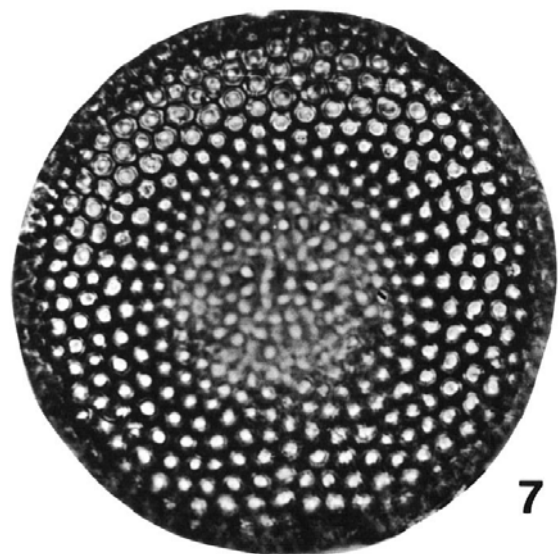
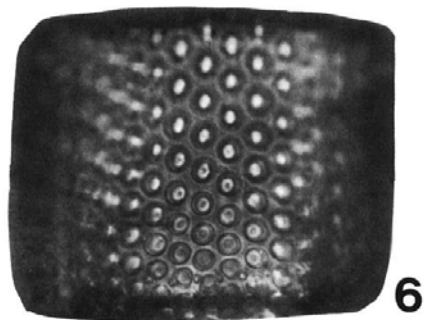
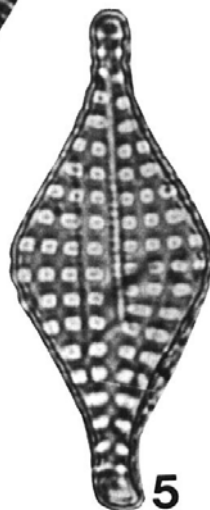
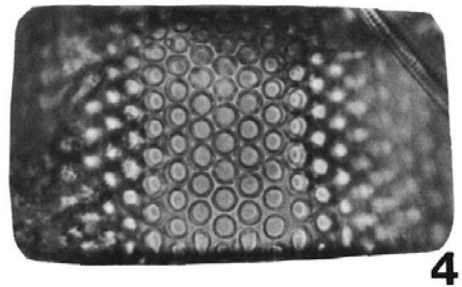
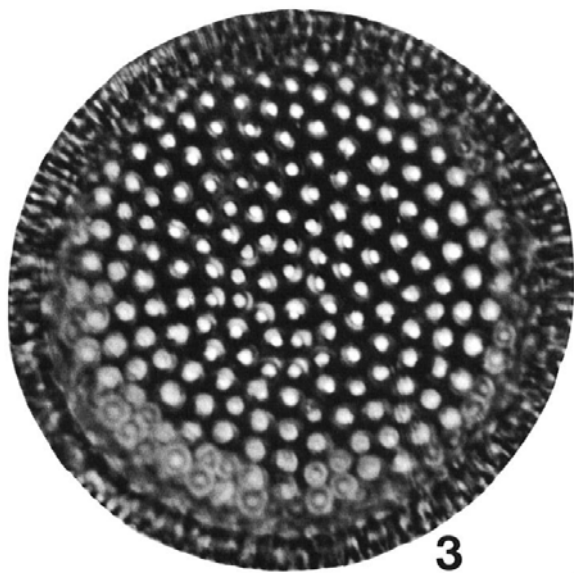
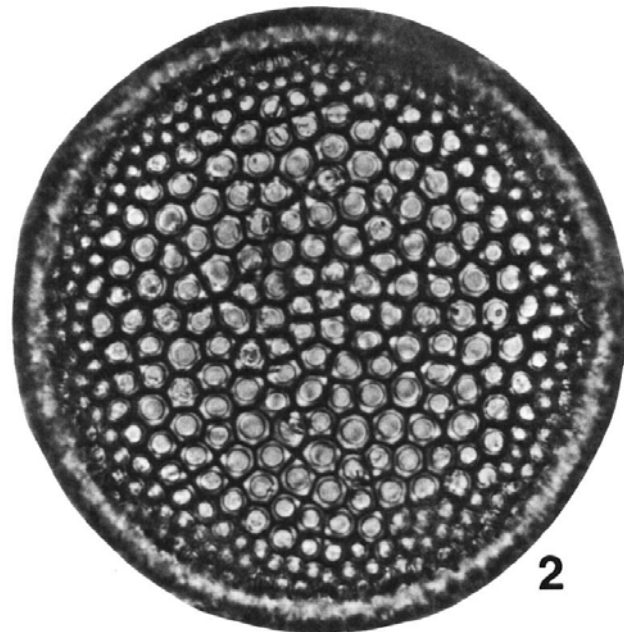
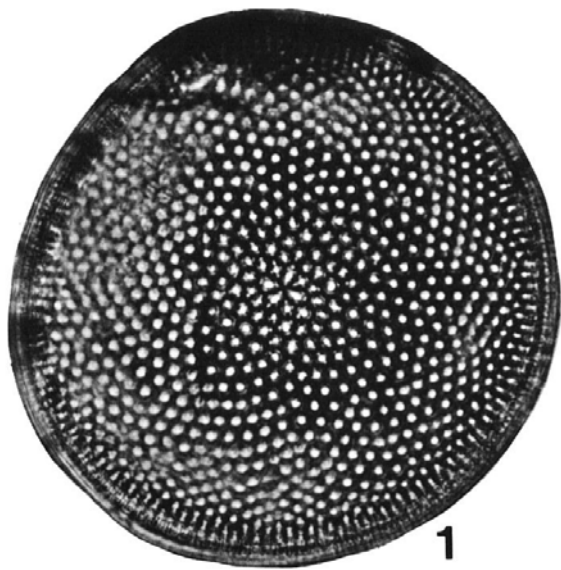




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## PLATE 5

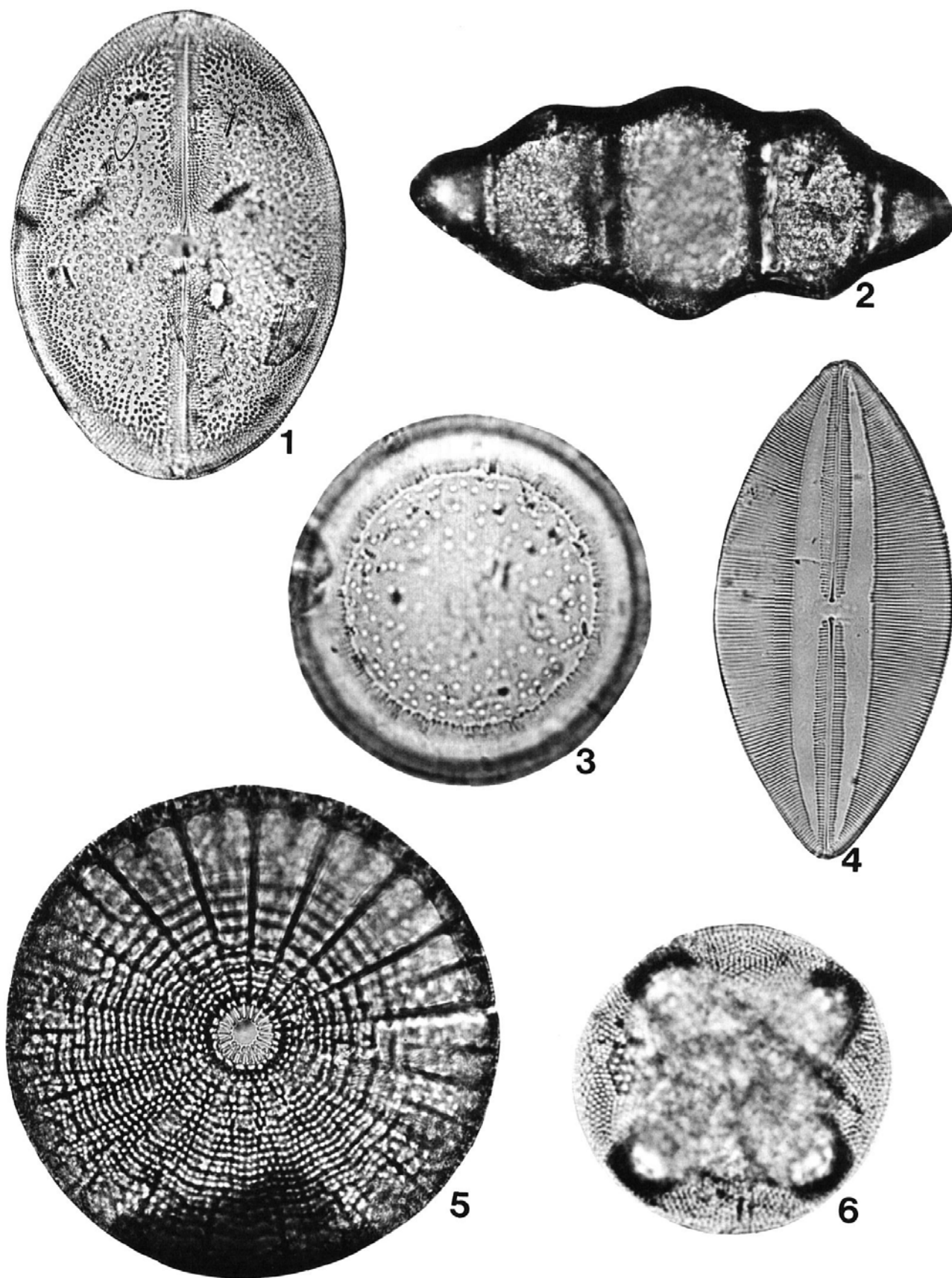
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|---|--|
| <p>1 <i>Coscinodiscus oculus-iridis</i> Ehrenberg<br/>Sample L18, diameter 107 <math>\mu\text{m}</math>.</p> <p>2–3 <i>Coscinodiscus marginatus</i> Ehrenberg<br/>2, sample L4, diameter 98 <math>\mu\text{m}</math>; 3, sample L4,<br/>diameter 81 <math>\mu\text{m}</math>.</p> | <p>4, 6 <i>Annellus californicus</i> var. <i>hannai</i> Barron<br/>4, sample L9, diameter 85 <math>\mu\text{m}</math>; 6, sample L9,<br/>diameter 50 <math>\mu\text{m}</math>.</p> <p>5 <i>Rhaphoneis miocenica</i> Schrader<br/>Sample L5, diameter 48 <math>\mu\text{m}</math>.</p> <p>7 <i>Coscinodiscus</i> sp. cf. <i>C. marginatus</i> Ehrenberg<br/>Sample L17, diameter 67 <math>\mu\text{m}</math>.</p> |
|---|--|



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## PLATE 6

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| <p>1 <i>Cocconeis scutellum</i> Ehrenberg<br/>Sample L28, length 142 <math>\mu\text{m}</math>.</p> <p>2 <i>Biddulphia tuomeyi</i> (Bailey) Roper<br/>Sample L8, length 125 <math>\mu\text{m}</math>.</p> <p>3 <i>Hyalodiscus radiatus</i> (O'Meara) Grunow<br/>Sample L6, diameter 80 <math>\mu\text{m}</math>.</p> | <p>4 <i>Navicula lyra</i> Ehrenberg<br/>Sample L5, length 134 <math>\mu\text{m}</math>.</p> <p>5 <i>Arachnoidiscus ornatus</i> var. <i>montereyanus</i> Schmidt<br/>Sample L7, diameter 156 <math>\mu\text{m}</math>.</p> <p>6 <i>Aulacodiscus kittoni</i> Arnott ex Ralfs<br/>Sample L6, diameter 71 <math>\mu\text{m}</math>.</p> |
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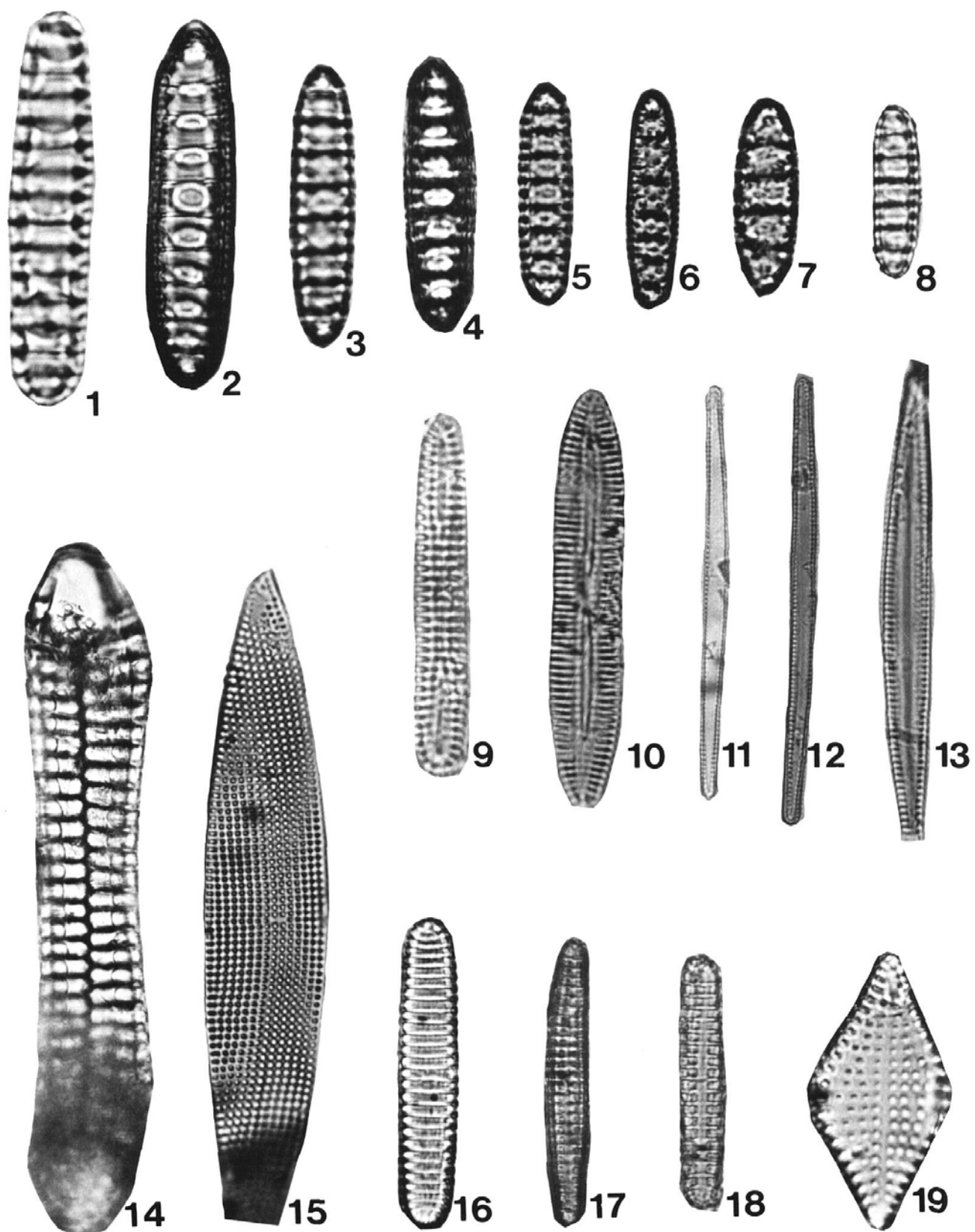


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## PLATE 7

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| <p>1, 8 <i>Denticulopsis hustedtii</i> (Simonsen and Kanaya) Simonsen<br/>1, sample L27, length 35 <math>\mu</math>m; 8, sample L27, length 16 <math>\mu</math>m.</p> <p>2–4 <i>Denticulopsis hyalina</i> (Schrader) Simonsen<br/>2, sample L24, length 31 <math>\mu</math>m; 3, sample L23, length 26 <math>\mu</math>m; 4, sample L24, length 23 <math>\mu</math>m.</p> <p>5 <i>Denticulopsis lauta</i> (Bailey) Simonsen<br/>Sample L24, length 20 <math>\mu</math>m.</p> <p>6 <i>Denticulopsis nicobarica</i> (Grunow) Simonsen<br/>Sample L17, length 17 <math>\mu</math>m.</p> <p>7 <i>Denticulopsis punctata</i> (Schrader) Simonsen<br/>Sample L24, length 20 <math>\mu</math>m.</p> <p>9–10 <i>Rouxia diploneides</i> Schrader<br/>9, sample L24, length 64 <math>\mu</math>m; 10, sample L2, length 72 <math>\mu</math>m.</p> | <p>11–12 <i>Thalassiothrix longissima</i> Cleve and Grunow<br/>11, sample L9, length 70 <math>\mu</math>m; 12, sample L9, length 80 <math>\mu</math>m.</p> <p>13 <i>Synedra jouseana</i> Sheshukova-Poretskaya<br/>Sample L21, length 80 <math>\mu</math>m.</p> <p>14 <i>Entopyla australis</i> var. <i>gigantea</i> (Greville) Fricke<br/>Sample L10, length 122 <math>\mu</math>m.</p> <p>15 <i>Mediaria splendida</i> Sheshukova-Poretskaya<br/>Sample L21, length 105 <math>\mu</math>m.</p> <p>16 <i>Nitzschia challengerii</i> Schrader<br/>Sample L18, length 50 <math>\mu</math>m.</p> <p>17–18 <i>Delphineis angustata</i> (Pantocsek) Andrews<br/>17, sample L2, length 55 <math>\mu</math>m; 18, sample L2, length 45 <math>\mu</math>m.</p> <p>19 <i>Rhaphoneis ampiceros</i> Ehrenberg<br/>Sample L1, length 35 <math>\mu</math>m.</p> |
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