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THE DIATOM GENUS *THALASSIOSIRA:* SPECIES FROM THE SAN FRANCISCO BAY SYSTEM

By

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Abstract: Twenty species of the diatom genus *Thalassiosira*, including one previously undescribed species, were collected from diverse habitats of San Francisco Bay, California, extending from nearly freshwater in Suisun Bay to marine salinity near the Golden Gate. In this paper the morphology of these 20 species is elucidated by scanning electron microscopy (SEM) and light microscopy (LM). The species range from large taxa with linear areolae to small, lightly silicified forms with eccentrically arranged areolae. The basic form of the genus is seen as a moderately small diatom with rectangular outline in girdle view and a simple process pattern of one central and one marginal ring of strutted processes and a single labiate process.

The distribution of species is influenced by salinity. Major species show limited distributions: *T. visurgis* Hustedt, fresh to brackish water; *T. decipiens* (Grunow) Jørgensen, brackish water; *T. nodulolineata* (Hendey) Hasle and G. Fryxell, tidal marine to brackish; *T. hendeyi* Hasle and G. Fryxell, and *T. wongii* Mahood sp. nov., tidal marine water; *T. nordenskioeldii* Cleve and *T. pacifica* Gran and Angst, coastal marine. These distributions demonstrate the value of species as indicators of salinity patterns within the bay ecosystem.

Introduction

The San Francisco Bay system has been studied by many investigators since 1816, when the Russian ship *Rurik* anchored in the bay (Hedgpeth 1979). The bay estuarine system extends from the mouth of the Guadalupe River in the south to the lower reaches of the Sacramento–San Joaquin delta near the city of Pittsburg (Fig. 1) in the north. Early studies of the bay concentrated on hydrology, fisheries, and physical parameters of the system. Not until the early 1920s was a serious effort to study the bay's biota and their interactions begun at the University of California, Berkeley (Hedgepeth 1979). The phytoplankton flora was not examined until 1939, when F. W. Whedon, using a Sedgewick-Rafter chamber, made a limited study of San Francisco Bay phytoplankton and presented a brief species list, including *Thalassiosira rotula* Meunier.

The flora of San Francisco Bay remained largely unstudied until 1958, when the Sanitary Engineering Research Laboratory (SERL) of the University of California, Berkeley, began a multidisciplinary study of the bay (Harris et al. 1961;

Table 1. Key to Collection Sites, Dates of Collection, and Collectors.

Date	Collector	Location
3 September 1980	R. L. J. Wong	1
16 October 1980	R. L. J. Wong	2
2 May 1971	A. D. Mahood	3
6 July 1981	G. A. Fryxell/ A. D. Mahood	3
6 June 1971	A. D. Mahood	4
20 February 1972	C. A. McNeil	4
6 July 1981	A. D. Mahood	5
24 April 1971	A. Hauser	6
June 1972	P. Wares	6
1 November 1979	L. L. Lack	7
3 September 1980	R. L. J. Wong	8
13 November 1980	R. L. J. Wong	9
12 September 1979	A. D. Mahood	10
7 July 1981	A. D. Mahood	10

Storrs et al. 1966). Although the species list generated by SERL was established from raw material (i.e., not cleaned of organic material so that the siliceous parts can be clearly seen) and was thus of limited systematic value, it is one of the few comprehensive references to the San Francisco Bay diatoms available. Hasle (1978*a, b*) published the first careful taxonomic papers on *Thalassiosira* from the bay system. The most recent inventory of bay diatom species (Wong and Cloern 1981), though still in progress, offers a basis for future diatom floristics and phytoplankton ecology studies of the bay.

Thalassiosira Cleve, one of the dominant diatom genera in the bay's phytoplankton, has been frequently mentioned in species lists: *T. decipiens* (Grunow) Jorgensen; *T. eccentrica* (Ehrenberg) Cleve; *T. lacustris* (Grunow) Hasle (=*Coscinodiscus lacustris* Hustedt); *T. nordenskioeldii* Cleve; *T. punctigera* (Castracane) Hasle (=*T. angstii* (Gran) Makarova); and *T. rotula* Meunier. The diversity of species of the genus in the bay system is not surprising because the *Thalassiosira* probably evolved in a similar estuarine and coastal environment (Round and Sims 1981).

The species diversity of diatoms is limited by salinity variations within the bay system (pers. comm. Wong, United States Geological Survey, 1983). The use of the genus *Thalassiosira* as an indicator of marine influence in the bay system has been hindered by several conditions: the confusion with other centric genera (e.g., *Coscinodiscus*), difficulty in identification (especially in water mounts), problems connected with sample preparation (including the need for mounting in a medium with a high refractive index for light microscopy), and widely scattered pertinent taxonomic literature.

In this paper we report on the distribution of *Thalassiosira* species in the bay and discuss morphology and its application to systematic problems within the bay.

Methods and Materials

Samples were collected with a Kemmerer water bottle and net over a broad range of the navigable section of the San Francisco Bay estuarine system (Fig. 1). Net hauls are particularly useful in concentrating material for identification before quantitative work is attempted on water samples. Fixed samples were examined in Utermohl settling chambers using an Olympus IMT inverted microscope. Most often positive identification must be made from cleaned material, mounted in medium of high refractive index such as Hyrax (Hanna 1930). Material was cleaned using the Van der Werff (1955) hydrogen peroxide method. Strewn and arranged slides were prepared for light microscope (LM) from cleaned materials and mounted in Hyrax. Similar strewn and also arranged material (mounted by the senior author) was prepared on scanning electron microscope (SEM) stubs for examination and photography using Jeolco JSM-35, Texas A&M University Electron Microscopy Center. Texas A&M Department of Oceanography phytoplankton cultures F190, F206, F209, and F226 were isolated by T. P. Watkins from collections made about a mile north of the Golden Gate Bridge, 6 July 1981. They were maintained in the Department of Oceanography phytoplankton culture collection: F/2 medium, 30‰ salinity, 16 hours light and 8 hours dark cycle, in 16°C growth chambers. Terminology follows that of the working Party on Diatom Terminology (Anonymous 1975; Ross et al. 1979).

Results and Discussion

Twenty species of *Thalassiosira* were recovered from 33 samples from San Francisco Bay: *T. anguste-lineata* (A. Schmidt) G. Fryxell and Hasle; *T. decipiens* (Grunow) Jørgensen; *T. eccentrica* (Ehrenberg) Cleve; *T. endoseriata* Hasle and G. Fryxell; *T. hendeyi* Hasle and G. Fryxell; *T. incerta* Makarova; *T. lacustris* (Grunow) Hasle; *T. lundiana* G. Fryxell; *T. minuscula*

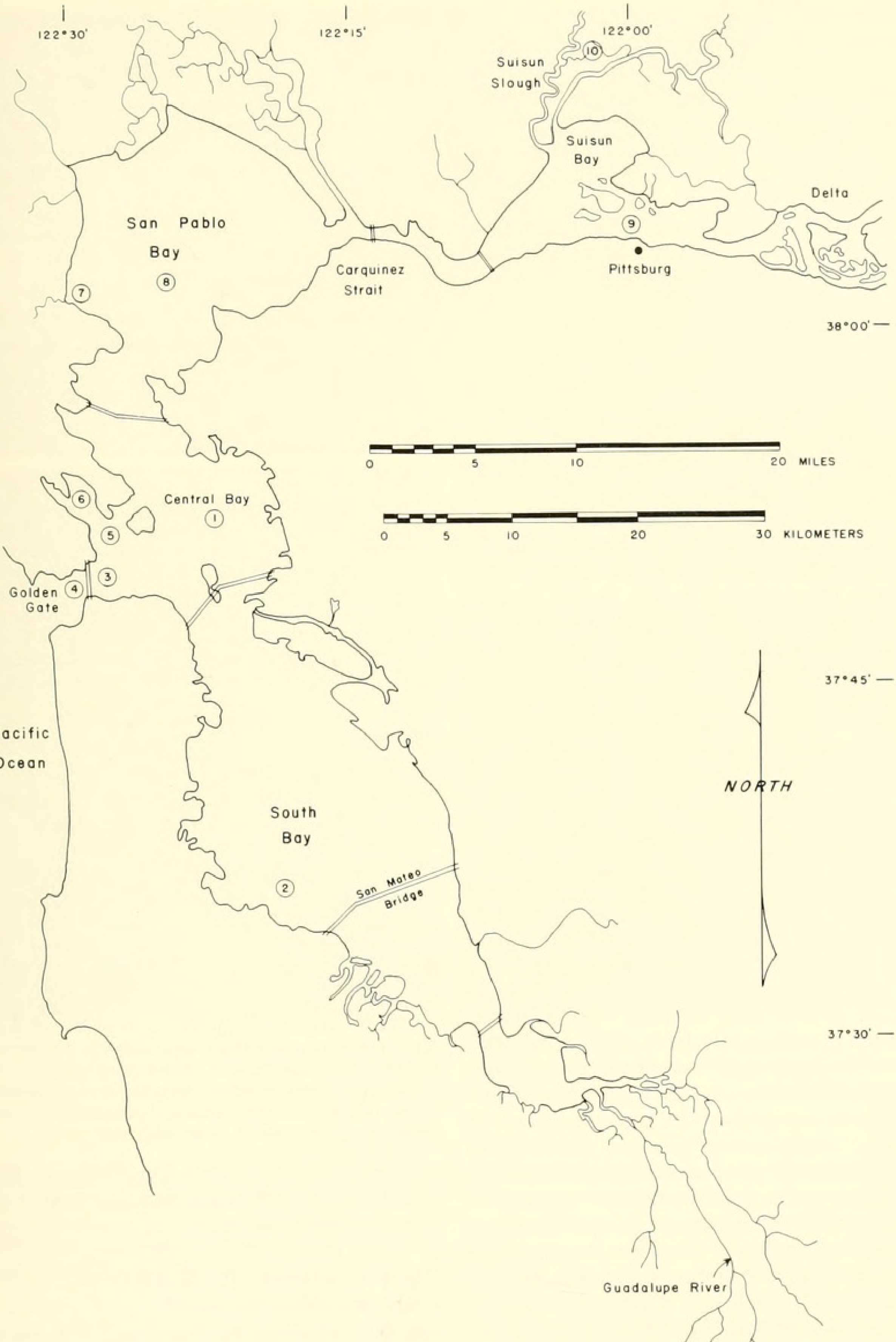


FIGURE 1. San Francisco Bay System.

Krasske; *T. nodulolineata* (Hendey) Hasle and G. Fryxell; *T. nordenskioeldii* Cleve; *T. oestrupii* var. *venrickae* G. Fryxell and Hasle; *T. pacifica* Gran and Angst; *T. punctigera* (Castracane) Hasle; *T. rotula* Meunier; *T. simonsenii* Hasle and G. Fryxell; *T. stellaris* Hasle and Guillard; *T. tenera* Proschkina-Lavrenko; *T. visurgis* Hustedt; and *T. wongii* Mahood sp. nov.

An understanding of the individual species, their similarities and differences, the habitats in which they occur, and their distributions within the bay system is essential to understanding the phytoplankton dynamics of the bay and the role of the *Thalassiosira* species in the bay ecosystem.

The genus is characterized by a number of morphological features: one to a few labiate processes (Fig. 16); many strutted processes (Fig. 11); none to many occluded processes (Fig. 38); eccentric, linear, or fasciculated patterns of the rows of areolae, in a basically radial pattern; and the placement of the areola cribrum on the internal side of the loculate areolae and the foramen on the external side (Fig. 14, 17). For this paper and to assist the light microscopist, we have stressed the characters particularly visible in LM: number and location of labiate processes; number and arrangement of the areolae; and location and number of strutted processes. Several species can be identified under LM, whereas others require SEM in order to resolve definitive characters.

Because our primary purpose includes gaining a greater understanding of San Francisco Bay, an essential goal is to distinguish between marker species with similar morphological characteristics but differing distributions, species which have been confused in earlier literature. For such comparisons, we have separated the *Thalassiosira* species in this paper into five morphological groups: 1) species with basic linear areola patterns, 2) species with eccentric areola patterns, 3) species with one central strutted process and one marginal ring of strutted processes, 4) species with no central strutted processes and modified rings of strutted processes, and 5) two otherwise dissimilar species that have radial areola patterns and multiple central strutted processes. These are form groupings only; they are not placed together to imply close taxonomic relationships.

GROUP 1.—*Thalassiosira* species with linear areola patterns.

Thalassiosira simonsenii Hasle and G. Fryxell, 1977

(Figures 2–5)

DETAILED DESCRIPTION. Hasle and Fryxell (1977).—Cell diameter 30–57 μm; areolae 4–5.5 in 10 μm across the valve, 8–10 in 10 μm at mantle edge (Fig. 2, 4); one small central strutted process (Fig. 5); two rows of alternating strutted processes on margin, five to six in 10 μm (Fig. 3); two opposing labiate processes (Fig. 2); distinctive marginal ribs, eight in 10 μm; large tubular occluded processes, one in 10 μm on margin above strutted processes (Fig. 4). Marginal ribs distinctive in SEM, but not always clear in LM.

DISTRIBUTION.—Marine, found only in central San Francisco Bay in association with other marine diatoms. Observed previously at 28°00′N, 112°17.5′W, Pacific (Hasle and Fryxell 1977).

Thalassiosira hendeyi Hasle and G. Fryxell, 1977

(Figures 6–11, 86)

DETAILED DESCRIPTION. Hasle and Fryxell (1977).—Cell diameter 38–120 μm; areolae, regularly linear, five to six 10 μm; prominent central strutted process (Fig. 6, 8) set to one side of central areola; two closely adjacent rings of marginal strutted processes (Fig. 9) alternating in orientation (Fig. 11, internal view), not easily resolved with LM (Fig. 86); wavy mantle ridge (Fig. 9, 86); two labiate processes (Fig. 6, external [arrow]; Fig. 10, internal); labiate process with two adjacent strutted processes (Fig. 7); valve slightly concentrically undulated (Fig. 6).

DISTRIBUTION.—Common but never abundant from San Pablo Bay to south San Francisco Bay. Previously found in warm coastal waters of West Africa (Hasle and Fryxell 1977), Uruguay and Brazil (Muller-Melchers 1953).

Thalassiosira nodulolineata (Hendey) Hasle and G. Fryxell, 1977

(Figures 12–17, 87, 90)

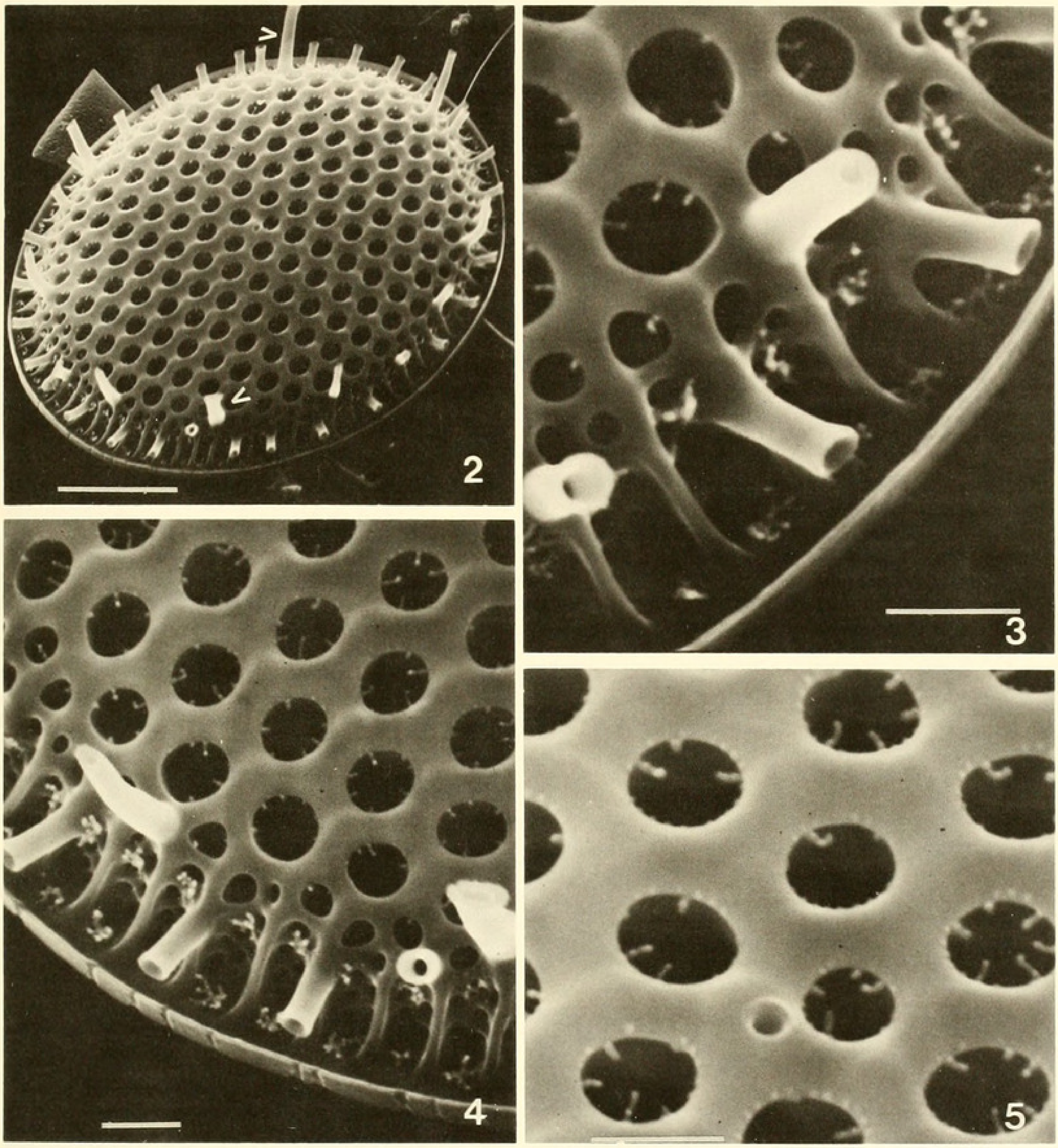
DETAILED DESCRIPTION. Hasle and Fryxell (1977).—Cell diameter 26–58 μm; areolae linear, regular, 3.5 (one with 9.0) in 10 μm (Fig. 12); four strutted processes in 10 μm with spines (Fig. 12, 15) along the margin; five to six strutted processes inside the central areola (Fig. 14, external; Fig. 17, internal; Fig. 90); single labiate process at valve margin (Fig. 12, 16). In our samples, central areolae surrounded by six symmetrical areolae (Fig. 90), although central areolae surrounded by five areolae have been reported (Hasle and Fryxell 1977).

DISTRIBUTION.—Central San Francisco Bay, San Pablo Bay, and Suisun Slough; common but never in large numbers.

Thalassiosira tenera Proschkina-Lavrenko, 1961

(Figures 18–23, 103–104)

DETAILED DESCRIPTION. Hasle and Fryxell (1977).—Cell diameter 10–29 μm; areolae 9–16 in 10 μm; marginal strutted



FIGURES 2–5. *Thalassiosira simonsenii* Hasle and G. Fryxell. SEM. Figure 2. Scale = 5 μm, external view of valve, two labiate processes across valve from each other (arrow). Figure 3. Scale = 2 μm, two rows of alternating strutted processes on margin. Figure 4. Scale = 1 μm, large tubular occluded process on margin above strutted processes. Figure 5. Scale = 1 μm, view of central strutted process.

processes three to five in 10 μm, one central strutted process (Fig. 18–20, 23); one labiate process (Fig. 20, 22, arrow); arrangement of areolae linear (Fig. 23, 103, 104) or fasciculated; marginal strutted processes often with siliceous overgrowths and flattened (Fig. 18, 21, 23).

DISTRIBUTION.—Restricted to coastal waters (Hasle and Fryxell 1977). Material examined from San Francisco Bay entirely prepared from cultures from samples taken just north of the Golden Gate (6 July 1981).

DISCUSSION.—*T. hendeyi, T. simonsenii,* and *T. nodulolineata* have been confused in bay studies and erroneously reported as *Coscinodiscus lineatus* Ehrenberg (=*T. leptopus* [Grunow] Hasle and G. Fryxell). In our samples, *T. nodulolineata* specimens were most easily distinguished from the other two by having a single labiate process and six symmetrical areolae surrounding the central areola (Fig. 14, 17). The five to six strutted processes inside the central areola further confirm the identification. Although *T. tenera* and *T. incerta* Makarova (to be discussed in Group 5) have a similar appearance to *T. nodulolineata,* the coarser areolae of *T. nodulolineata* distinguish it from the two with finer areolae. In addition, the marginal strutted processes of *T. tenera* often are in heavily silicified areas of the margin and are markedly distinct in LM, in contrast to other species.

Distinguishing specimens of *T. hendeyi* and *T. simonsenii* is extremely difficult under LM. Examination of SEM micrographs of the margin of *T. hendeyi* (Fig. 6) and the central area (Fig. 8) will assist the light microscopist in differentiating these two species. Both species have two labiate processes and similar central areas. For identification under the LM (Fig. 86), careful examination of the margin is necessary. Under the SEM (Fig. 6, 9), the margin of *T. hendeyi* is irregular and wavy, but with the light microscope a clean break can be noticed when focusing from the margin to the valve face. The valve face forms a rather sharp angle with the margin in *T. hendeyi,* while in *T. simonsenii* (Fig. 4) the transition from valve face to margin is smooth. Although the marginal strutted processes of *T. simonsenii* are more prominent than those of *T. hendeyi,* this characteristic is not easily resolved under LM.

In our samples the salinity ranges for *T. hendeyi* and *T. nodulolineata* overlap, and both are found from south San Francisco Bay to Suisun Bay, indicating a more brackish environment. *Thalassiosira simonsenii,* much less common than the others, was confined to the central San Francisco Bay and was associated with other marine diatoms. *Thalassiosira tenera* was collected near the Golden Gate Bridge in a marine habitat. *Thalassiosira tenera* is the only one of this group with strutted processes in the middle of the central areola.

Group 2.—*Thalassiosira* species with eccentric areola patterns.

Thalassiosira wongii Mahood, sp. nov.

(Figures 24–29, 99–101)

Detailed Description. Mahood.—Diameter 27–51 μm; areolae radial, fasciculated, 9–11 in 10 μm with areolar rows parallel to central areolar row of fascicle; strutted processes at margin three to five in 10 μm (Fig. 24–26, 29, 99–101); four to five strutted processes observed around central areola (Fig. 25, 26); strutted processes usually forming two irregular rings between central areola and margin (Fig. 26, 99, 100); one marginal ring of strutted processes near margin, four to five in 10 μm (Fig. 29); one labiate process set slightly inside marginal ring (Fig. 27, internal and external, Fig. 28, 99, 100), three spines in 10 μm around margin in same ring as labiate process (Fig. 24); small spines often above each strutted process on outside of valve (Fig. 27, internal and external; Fig. 29).

Diameter 27–51 μm; areolae 9–11 in 10 μm; fultoportulae ad marginem, 3–5 in 10 μm; 4–5 fultoportulae circum areolam centralem visae; fultoportulae plus minusve annulos duos irregulares formantes inter areolam centralem et marginem; annulus marginalis unicus fultoportularum prope marginem 4–5

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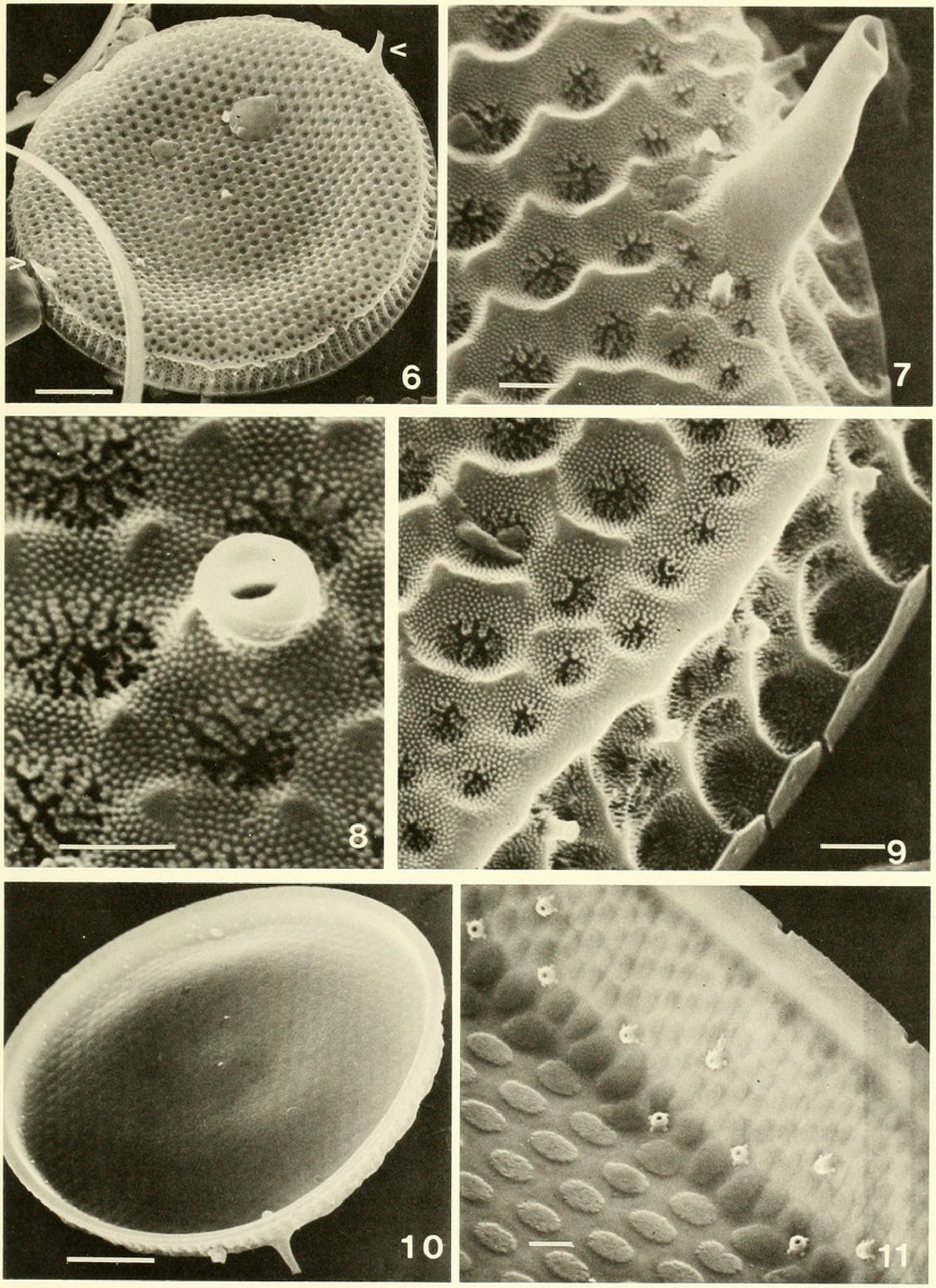
Figures 6–11. *Thalassiosira hendeyi* Hasle and G. Fryxell. SEM. Figure 6. Scale = 10 μm; external view of valve; two labiate processes (arrow), valve slightly concentrically undulated, distinctive marginal ridge, linear areolae. Figure 7. Scale = 1 μm, labiate process with two adjacent processes. Figure 8. Scale = 1 μm, prominent central process. Figure 9. Scale = 1 μm; wavy marginal ridge, two closely adjacent rows of strutted processes. Figure 10. Scale = 10 μm, internal view of valve, alternating marginal strutted processes. Figure 11. Scale = 1 μm, internal view of valve, alternating marginal strutted processes.

Figures 12–17. *Thalassiosira nodulolineata* (Hendey) Hasle and G. Fryxell. SEM. Figure 12. Scale = 5 μm; external view of valve; linear areolae, marginal strutted processes (sp), marginal spines (ms), single labiate process (lp). Figure 13. Scale = 1 μm, single labiate process, bands. Figure 14. Scale = 1 μm; strutted processes in the central areola, six symmetrical areolae surrounding central areola with radial threads. Figure 15. Scale = 0.5 μm, external marginal spine, strutted processes. Figure 16. Scale = 1 μm, internal view of valve, internal labia with external labiate process (arrow). Figure 17. Scale = 1 μm, internal view of central strutted processes.

Figures 18–23. *Thalassiosira tenera* Proschkina-Lavrenko. SEM. Figure 18. Scale = 2 μm; external view of valve; marginal strutted processes, one central strutted process. Figure 19. Scale = 1 μm, distinctive central strutted process. Figure 20. Scale = 2 μm, internal view of valve, one central strutted process. Figure 21. Scale = 1 μm, external view of marginal strutted process with siliceous overgrowths. Figure 22. Scale = 0.5 μm, internal view of labia (arrow). Figure 23. Scale = 2 μm; external view of valve; single external labiate process (arrow), marginal strutted processes with siliceous overgrowths.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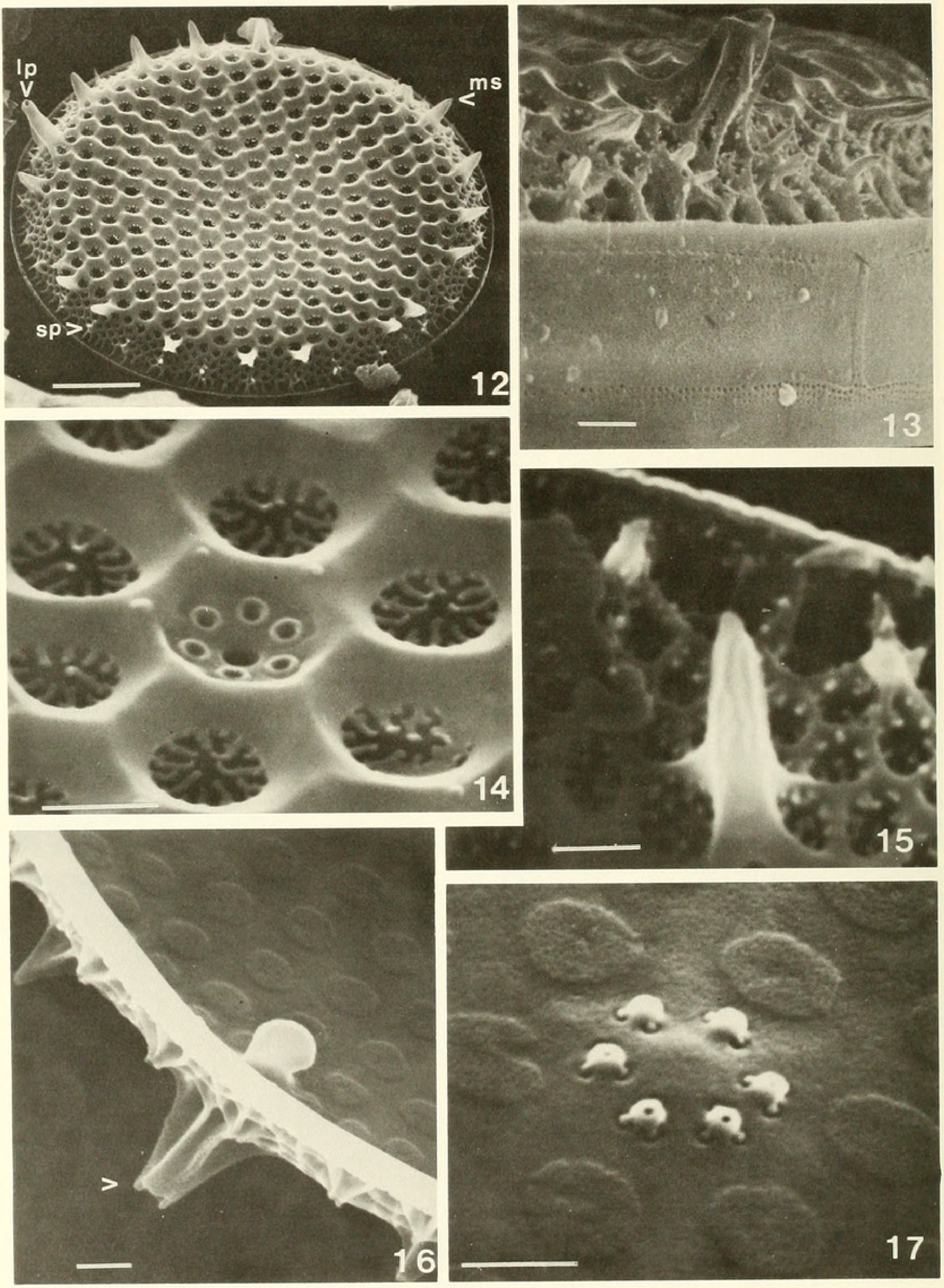
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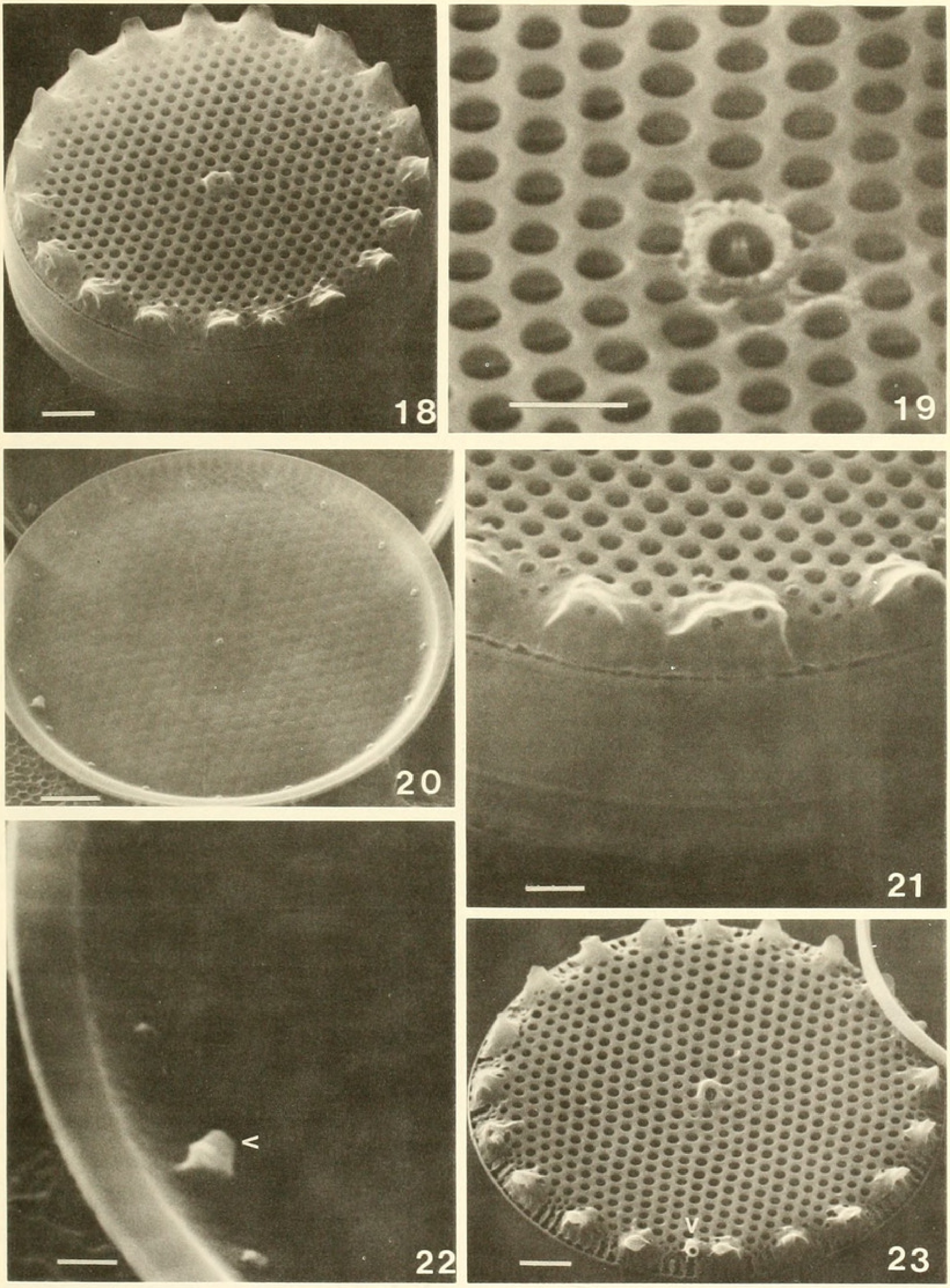
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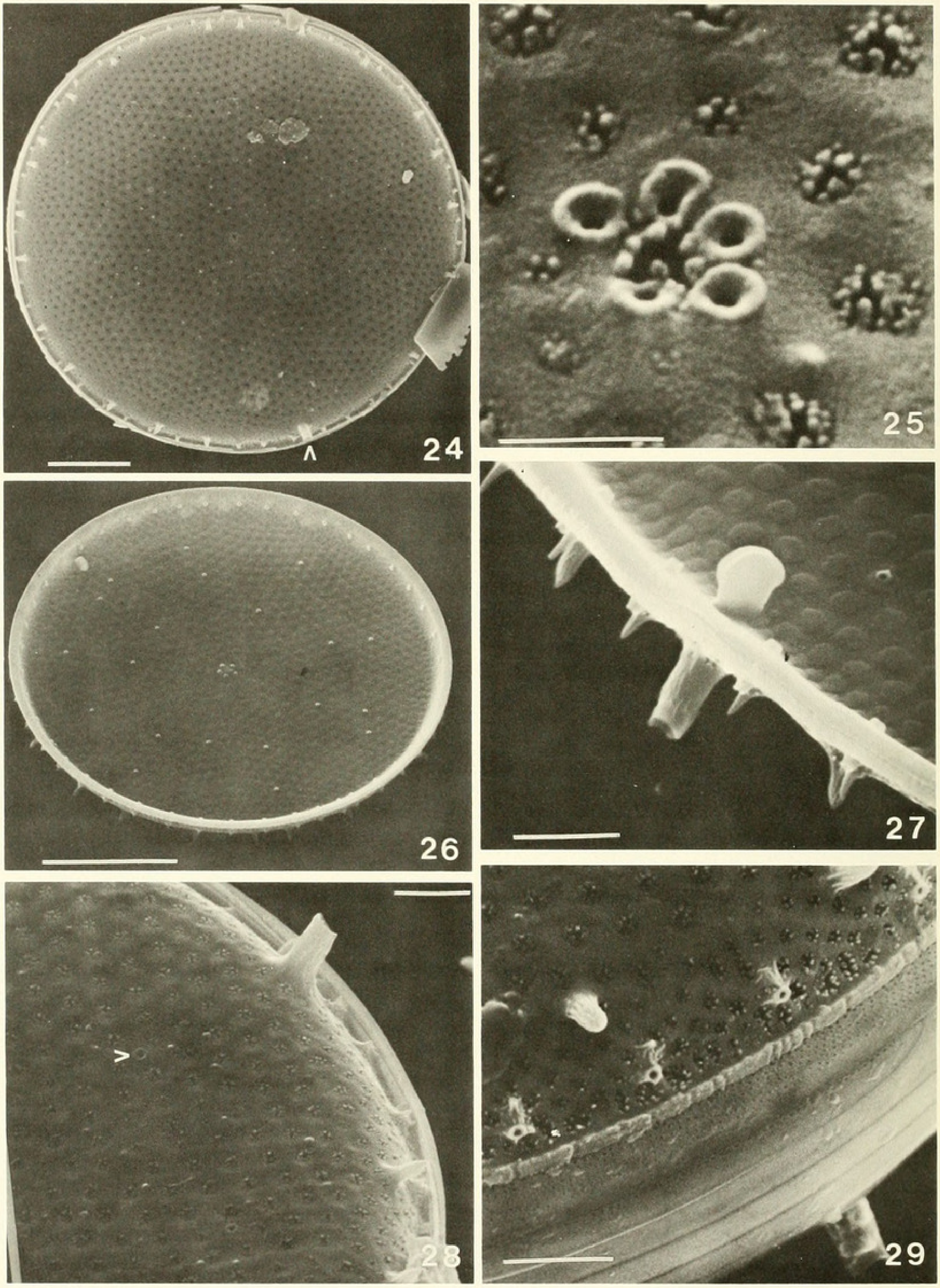

FIGURES 24–29. *Thalassiosira wongii* Mahood, sp. nov. SEM. Figure 24. Scale = 10 μm; external view of valve; fasciculated areolae, small marginal spines, single labiate process (arrow). Figure 25. Scale = 1 μm, external view of irregularly arranged processes surrounding the central areola. Figure 26. Scale = 10 μm; internal view of valve; single labia, two irregular rings of strutted processes, marginal ring of strutted processes. Figure 27. Scale = 2 μm; internal view of labia and external labiate

in 10 μm; rimportula unica annuli marginalis parum penitus posita, spinis 3 in 10 μm circum margineum in eodem annulo cum rimoportula; spinae parvae saepe supra fultoportulam omnem extus valvarum.

DISTRIBUTION.—South and central San Francisco Bay, associated with marine diatoms.

HOLOTYPE.—Slide, deposited at California Academy of Sciences, CAS 61243.

Thalassiosira oestrupii var. **venrickae** G. Fryxell and Hasle, 1980
(Not figured)

DETAILED DESCRIPTION. Fryxell and Hasle (1980).—Cell diameter 5.5–39 μm; areolae 6–9 in 10 μm in central area, 7–11 in 10 μm toward margin; one labiate process, usually located three areolae from center; one central strutted process, one to two in 10 μm, on margin. May be confused with *T. decipiens*, but marginal strutted processes internal rather than external. Dominant characteristics: labiate process away from margin and marginal strutted processes with internal projection seen in same plane of focus (Fryxell and Hasle 1980, fig. 15A, B, 17).

DISTRIBUTION.—Coastal, temperate waters. Central San Francisco Bay, rare.

Thalassiosira eccentrica (Ehrenberg) Cleve, 1904
(Figures 30–35, 102)

DETAILED DESCRIPTION. Fryxell and Hasle (1972).—Cell diameter 12–101; areolae 5–8 in 10 μm in central area, 7–10 in 10 μm toward margin (Fig. 102); scattered strutted processes across valve face (Fig. 32); irregular spines around margin, three to four in 10 μm; central areola surrounded by seven areolae with single strutted process next to the central areola (Fig. 30, 33); two to three rings of strutted processes in 10 μm near margin (Fig. 31; Hasle 1979); one prominent labiate process (Fig. 34, internal; Fig. 35). Valve face relatively flat.

DISTRIBUTION.—Possibly brackish to definitely saline waters, common in central San Francisco Bay.

DISCUSSION.—The confusion within this group stems in part from the areola patterns of *T. eccentrica* (Fryxell and Hasle 1972), which varies from the classic eccentric pattern to a fasciculated arrangement. For example Cupp (1943), a primary reference source for Bay studies, does not clearly distinguish *T. decipiens* (to be discussed in Group 3) and *T. eccentrica* (=*Coscinodiscus eccentricus*). The overall eccentric pattern is representative of three species in this group. Other morphological characteristics may be used to facilitate identification. *Thalassiosira oestrupii* var. *venrickae* lacks external labiate process tubes. Only *T. wongii* has multiple central processes, fasciculated valves, and spines above each strutted process. A single row of marginal strutted processes further distinguishes *T. wongii* from *T. eccentrica*. The spines above each strutted process of *T. wongii* are only seen under SEM.

GROUP 3.—*Thalassiosira* species with one central and one marginal ring of strutted processes and one labiate process near the margin.

Thalassiosira minuscula Krasske, 1941
(Figures 36, 37)

DETAILED DESCRIPTION. Hasle (1976).—Cell diameter 10–20 μm; areolae small, 30 in 10 μm in rows parallel to radial row; one large radially oriented labiate process located in from margin (Fig. 36); strutted processes in ring on margin four to five in 10 μm near margin, one strutted process in center (Fig. 36), plus one adjacent to labiate process (Fig. 37). Distinguished from other fasciculated species of *Thalassiosira* in San Francisco Bay by the unique arrangement of a strutted process adjacent to the labiate process and by the finer areolae.

DISTRIBUTION.—Originally described from coastal plankton of Chile (Krasske 1941). Central San Francisco Bay, rare.

Thalassiosira lundiana G. Fryxell, 1975*a*
(Figures 36–41, 89)

DETAILED DESCRIPTION. Fryxell (1975*a*).—Cell diameter 7–43 μm; areolae 24–30 in 10 μm, fasciculated; marginal striae; strutted processes in ring inside margin (Fig. 38), approximately 10 in 10 μm; often irregularly arranged large occluded processes in ring farther from margin (Fig. 38, 39); one central strutted process (Fig. 40, arrow; Fig. 41, csp); one labiate process inside marginal ring (Fig. 41, arrow) in same ring as occluded processes; weakly silicified.

DISTRIBUTION.—Inshore euryhaline (Fryxell 1975*a*); found in our samples from central San Francisco Bay to Suisun Bay, indicating a broader freshwater range than previously proposed.

Thalassiosira punctigera (Castracane) Hasle, 1983 (=*T. angstii* (Gran) Makarova)
(Figures 42–48, 92)

DETAILED DESCRIPTION. Gran and Angst (1931), G. Fryxell (1978).—Cell diameter 43–145 μm; areolae across valve face

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process, small spines above marginal strutted processes. Figure 28. Scale = 2 μm; external view of margin at the single labiate process, valve strutted processes (arrow). Figure 29. Scale = 2 μm, marginal strutted processes with short spines, large spines back from edge of margin.

15 in 10 μm; areolae fasciculated with areolae arranged parallel to center of fascicle (Fig. 45); strutted processes four to five in 10 μm along margin (Fig. 44, 46, 92); single central process (Fig. 43, arrow); one labiate process (Fig. 46; Fig. 47, internal); large occluded processes irregularly arranged around margin (Fig. 42), although some specimens lack large occluded processes entirely (Fig. 48).

Distribution.—Coastal, large population of *T. punctigera* reported in Richardson Bay (A. Hauser, pers. comm., 1976), which is constantly flushed by waters from the Golden Gate.

Thalassiosira nordenskioeldii Cleve, 1873

(Figure 106)

Detailed Description. Hasle (1978*b*).—Cell diameter 10–50 μm; areolae 14–18 in 10 μm across valve face; marginal strutted processes three in 10 μm; separated from margin by ca. 6–8 areolae. Single strutted process in center of valve (Fig. 106); one labiate process in same ring as marginal strutted processes but not in a constant position relative to a strutted process; marginal striae 18–20 in 10 μm in mantle rim.

Distribution.—Marine, cold water (Hasle 1978*b*); only in samples near the Golden Gate Bridge.

Thalassiosira pacific Gran and Angst, 1931

(Figures 49–55, 105)

Detailed Description. Hasle (1978*b*).—Cell diameter 7–46 μm; areolae 10–18 in 10 μm in central area, 20 in 10 μm at margin (Fig. 49); one labiate process (Fig. 54); pronounced, regular marginal strutted processes, four to seven in 10 μm (Fig. 52); single central strutted process (Fig. 51, internal; Fig. 53, external; Fig. 105) adjacent to central areolae. Areolae usually in fasciculated rows with areolae parallel to radius.

Distribution.—Marine, from central San Francisco Bay through Golden Gate to Gulf of Farallons.

Thalassiosira visurgis Hustedt, 1957

(Figures 56–61, 95, 96)

Detailed Description. Hasle (1978*a*).—Cell diameter 9–18 μm; areolae in central area 13–14 in 10 μm, 18 in 10 μm at the margin (Fig. 58); one central strutted process (Fig. 58, external; Fig. 60, internal [arrow]), and four to five strutted processes in 10 μm in ring near margin (Fig. 56, external; Fig. 57); two labiate processes on opposing sides, each found between marginal strutted processes and slightly inside the ring of strutted processes (Fig. 56, 58–60, 95, 96). In our preparation, valves often convex or concave, suggesting heterovalvate cells with one convex and one concave valve. Granules on valve often extending onto processes (Fig. 57).

Distribution.—Usually found surrounded with silt and clay, fresh to brackish water. *Thalassiosira visurgis* occasionally the dominant *Thalassiosira* in Suisun Slough, a brackish environment.

Thalassiosira decipiens (Grunow) Jørg., 1905

(Figures 62–67, 97, 98)

Detailed Description. Hasle (1979).—Cell diameter 9–29 μm; areolae across valve face 8–12 in 10 μm, much smaller on mantle (Fig. 62); single ring of marginal strutted processes four to six in 10 μm (Fig. 62, 64); one central strutted process (Fig. 63, arrow); labiate process located between two marginal strutted processes (Fig. 62, arrow; Fig. 97, arrow; Fig. 98), closer

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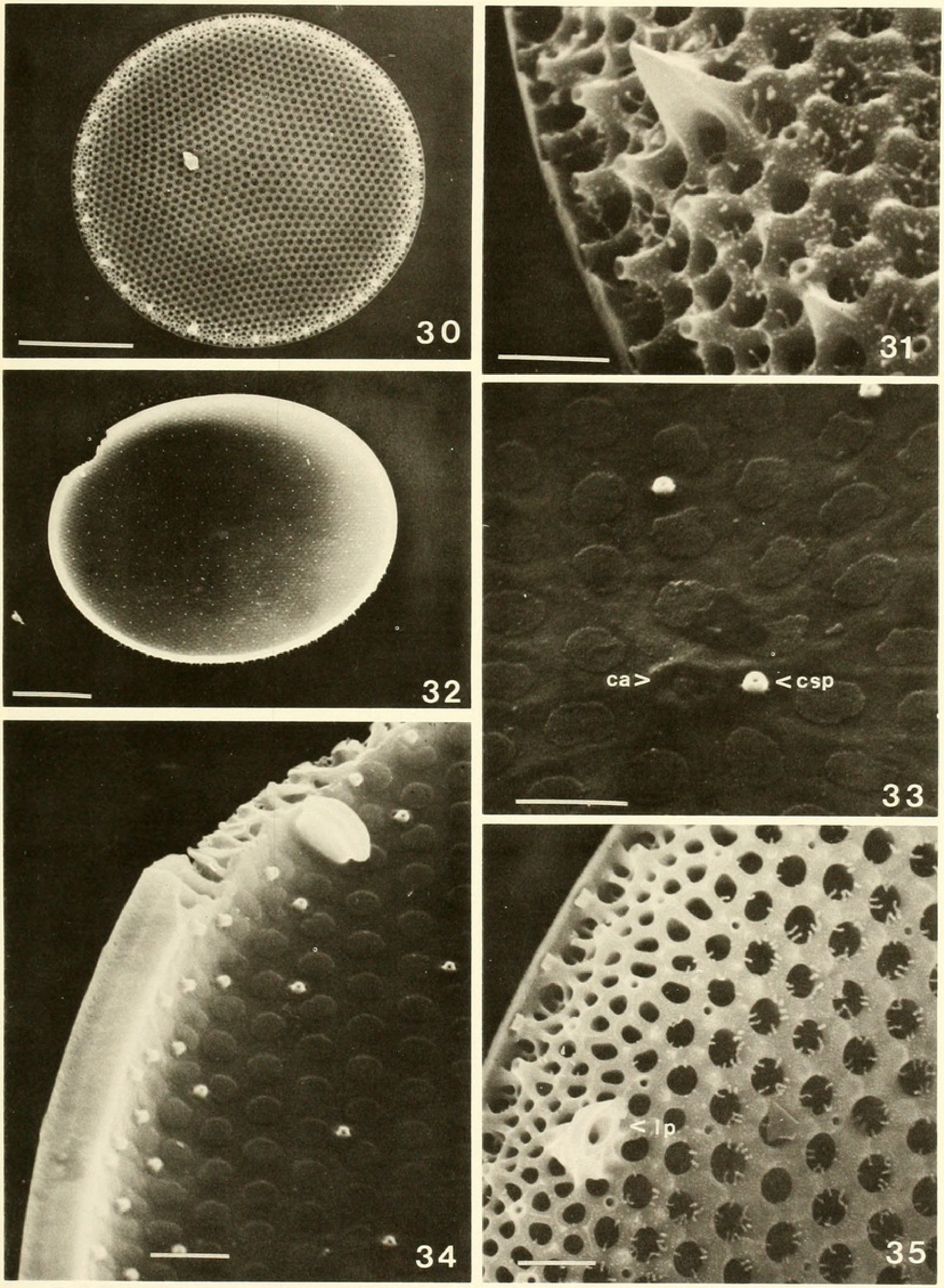
Figures 30–35. *Thalassiosira eccentrica* (Ehrenb.) Cleve. SEM. Figure 30. Scale = 20 μm; external view of valve; eccentric areolar pattern, irregular spines. Figure 31. Scale = 2 μm, large marginal spines, two rings of marginal strutted processes. Figure 32. Scale = 20 μm, internal view of valve, scattered processes across valve. Figure 33. Scale = 3 μm; internal view of central area, seven areolae with cribra surrounding central areola (ca), central strutted process (csp) just off center. Figure 34. Scale = 2 μm, internal view of labia, scattered strutted processes. Figure 35. Scale = 3 μm; external view of valve; single labiate process (lp), scattered strutted processes, marginal strutted processes.

Figures 36, 37. *Thalassiosira minuscula* Krasske. SEM. Figure 36. Scale = 10 μm; internal view of valve, single labia set back from margin, single row of marginal strutted processes, central strutted process. Figure 37. Scale = 2 μm; same valve, internal view of marginal strutted processes, labia set back from margin.

Figures 38–41. *Thalassiosira lundiana* G. Fryxell. SEM. Figure 38. Scale = 10 μm; external view of valve; irregular strutted processes ring valve, irregular occluded processes (arrow). Figure 39. Scale = 2 μm; large occluded process, marginal strutted processes. Figure 40. Scale = 2 μm; external view of central area (arrow), fasciculation. Figure 41. Scale = 10 μm; internal view of valve; scattered valve strutted processes, single labiate process (arrow), single central strutted process (csp).

Figures 42–48. *Thalassiosira punctigera* (Castracane) Hasle. SEM. Figure 42. Scale = 20 μm; external view of valve; marginal strutted processes, irregular large occluded processes. Figure 43. Scale = 2 μm, single strutted process in central area. Figure 44. Scale = 2 μm, marginal strutted processes. Figure 45. Scale = 20 μm, internal view of fasciculated areolae, marginal strutted processes. Figure 46. Scale = 2 μm, external view of labiate process, marginal strutted processes. Figure 47. Scale = 2 μm, internal view of labia and external labiate process. Figure 48. Scale = 20 μm, external view of valve lacking occluded processes.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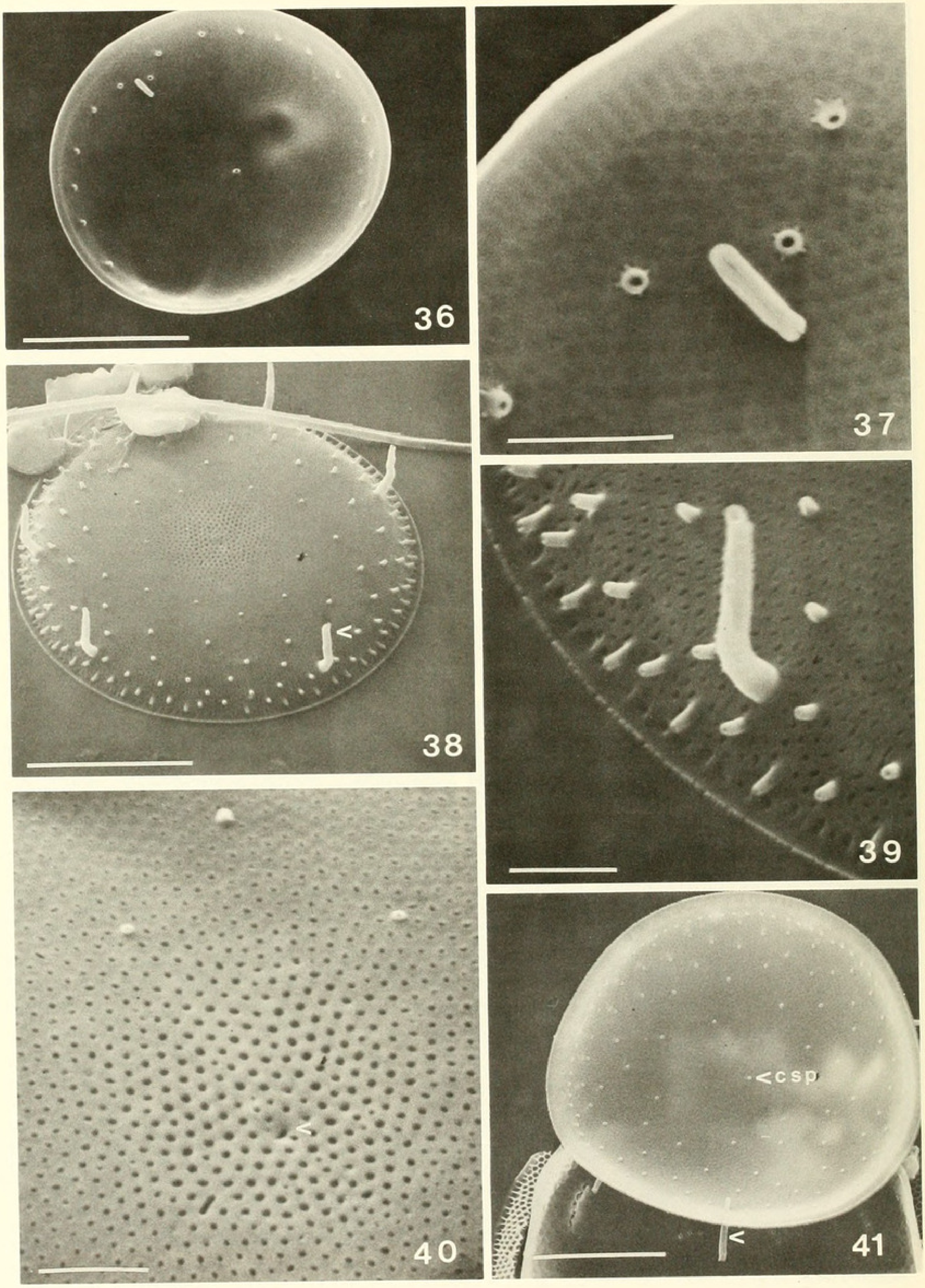
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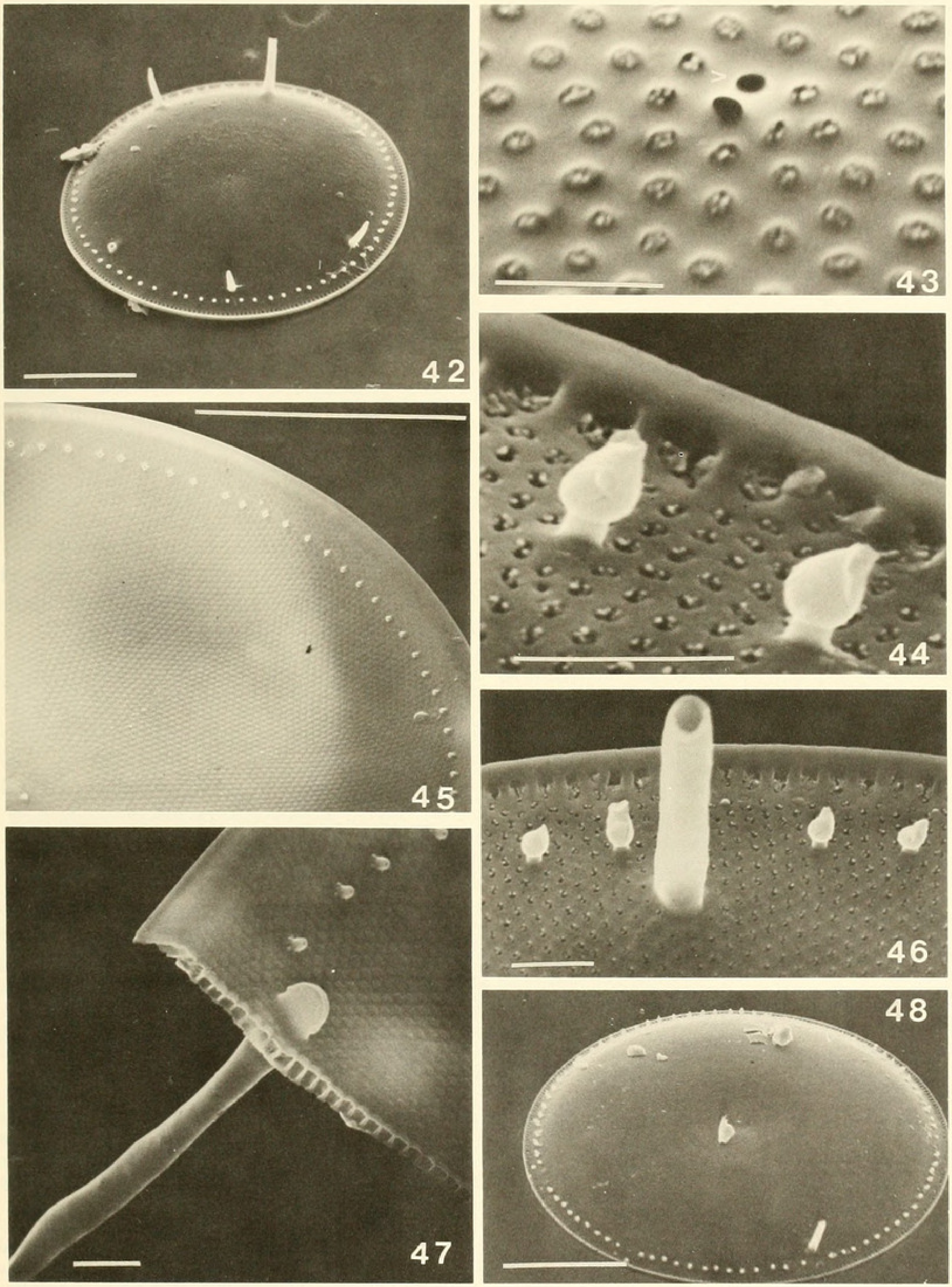
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to one than the other. Often found coated with sediment (Fig. 67).

DISTRIBUTION.—San Joaquin estuary, a brackish environment (Hasle 1979). Dominant *Thalassiosira* in the Suisun Bay area (Arthur and Ball 1980; Wong and Cloern 1981).

DISCUSSION.—Confusion of the species *T. punctigera* and *T. lundiana* may lead to misinterpretation of environmental conditions. *Thalassiosira punctigera* is the larger of the two species, although there is a slight overlap between the smaller diameters of *T. punctigera* and the larger diameters of *T. lundiana.* The larger diameter of *T. punctigera,* the more heavily silicified valve, and the prominent marginal strutted processes are the most important distinguishing features (Fig. 44, 46, 48, 92), with only a single strutted process in the center of the valve. *Thalassiosira lundiana* is fragile and weakly silicified making the fine areolar pattern more difficult to resolve, but strutted processes are scattered over the valve face (Fig. 89).

The differentiation of *T. decipiens* and *T. visurgis* has proven both difficult and interesting. In our samples these species commonly appear in large numbers in Suisun Slough, Suisun Bay, and the delta of the Sacramento and San Joaquin rivers. The presence of the two labiate processes clearly distinguishes *T. visurgis* (Fig. 56, 60, 95, 96) from *T. decipiens.* Confusion of the species is possible if one process is obscured by detritus (Fig. 67). The best distinguishing character in both cleaned and uncleaned specimens is the arrangement of the areolae. In *T. decipiens* the number of areolae in 10 μm is constant across the valve face (Fig. 97, 98). On these small valves, the cell diameter, number of areolae, and the presence of the second labiate process may not be clear enough under the light microscope to differentiate the two species. A peculiar characteristic of *T. visurgis* is seen as the light microscope focuses through the valve: the central area areolae display a winking effect, optically separating the central area from the margin (Fig. 95, 96). Unless the material is cleaned and mounted in Hyrax or other suitable medium, however, we cannot differentiate these two species.

The overall eccentric pattern, overlap of cell diameter, and overlap of number of areolae in 10 μm make it difficult to differentiate *T. eccentrica* and *T. decipiens* in the 30 μm diameter range without reference to more recent works. Distinctive characteristics that aid their differentiation include pronounced, regular strutted processes seen on *T. decipiens* versus the irregular spines of *T. eccentrica* and the concave or convex valves of *T. decipiens* versus the relatively flat valve of *T. eccentrica. Thalassiosira eccentrica* is a coastal marine species, while viable *T. decipiens* cells in the bay system are usually restricted to the Suisun Bay–Delta, a brackish environment; non-viable cells may be flushed from Suisun Bay by tidal action.

It is possible that *T. eccentrica* reported in eco-

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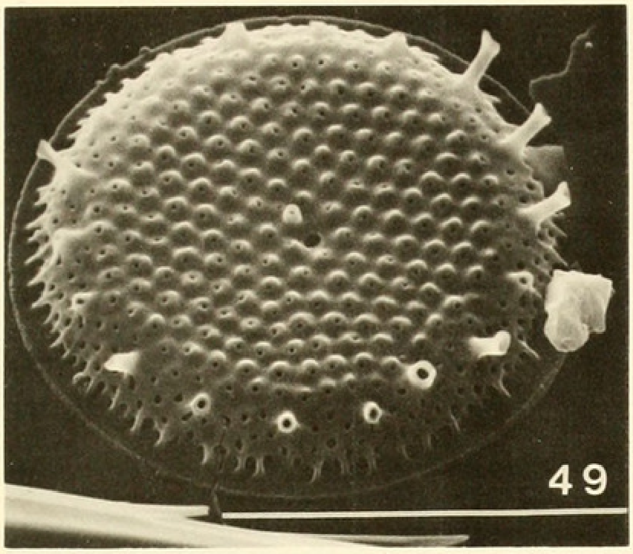
FIGURES 49–55. *Thalassiosira pacifica* Gran and Angst. SEM. Figure 49. Scale = 10 μm; external view of valve; fasciculated areolae, single central strutted process, marginal strutted processes. Figure 50. Scale = 2 μm, single labiate process (arrow) on margin between strutted processes. Figure 51. Scale = 1 μm, internal view of single strutted process. Figure 52. Scale = 10 μm, regular marginal strutted processes. Figure 53. Scale = 1 μm, external details of central strutted process. Figure 54. Scale = 1 μm, internal view of labia and external labiate process. Figure 55. Scale = 10 μm; internal view of valve; regular marginal strutted processes, single central strutted process, internal labia.

FIGURES 56–61. *Thalassiosira visurgis* Hustedt. SEM. Figure 56. Scale = 2 μm; external view of valve; strutted processes (sp) at margin, two labiate processes (lp), single central strutted process (csp). Figure 57. Scale = 2 μm, labiate process between two strutted processes on margin. Figure 58. Scale = 2 μm, central areolae distinct from those toward margin. Figure 59. Scale = 2 μm, internal view of convex valve, regular marginal strutted processes. Figure 60. Scale = 2 μm, internal view of concave valve, two opposing labia. Figure 61. Scale = 2 μm, external view of concave valve.

FIGURES 62–67. *Thalassiosira decipiens* (Grunow) Jørgensen. SEM. Figure 62. Scale = 10 μm; external view of valve; single labiate process (arrow), regular marginal strutted processes. Figure 63. Scale = 1 μm; single central process (arrow), fine siliceous granulations on external side of valve. Figure 64. Scale = 10 μm; internal view of valve; single labia (arrow), regular marginal strutted processes. Figure 65. Scale = 10 μm; external view of valve; consistent areola pattern across valve, regular arrangement of marginal strutted processes. Figure 66. Scale = 1 μm, labiate process between two strutted processes. Figure 67. Scale = 10 μm, detritus accumulation surrounding cell.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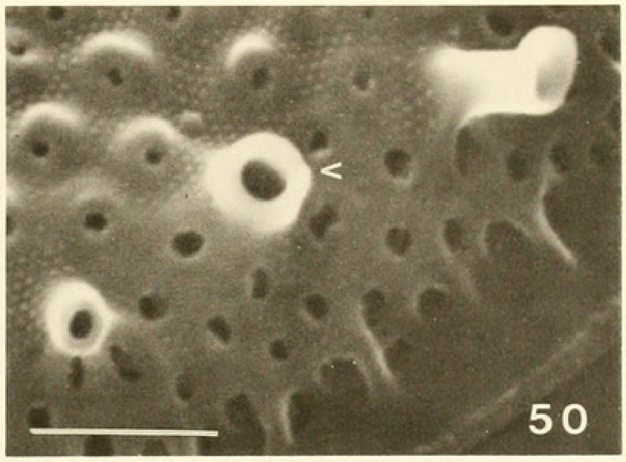
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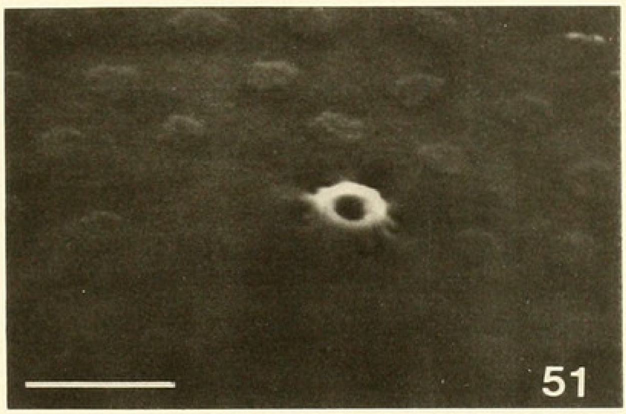
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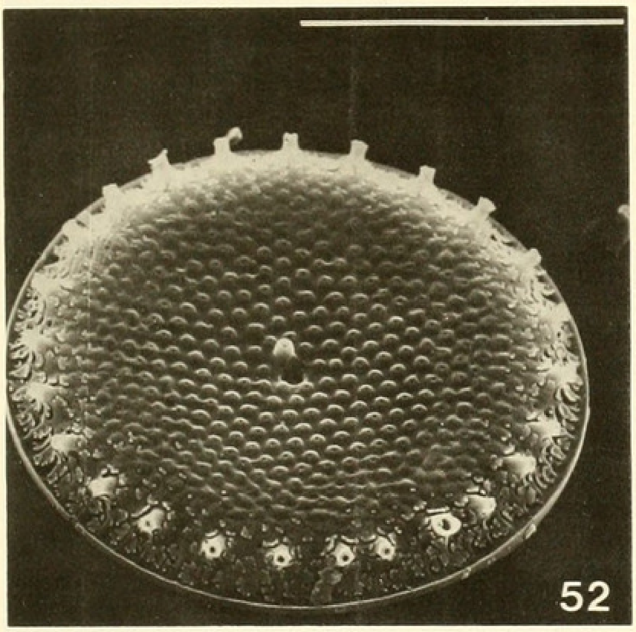
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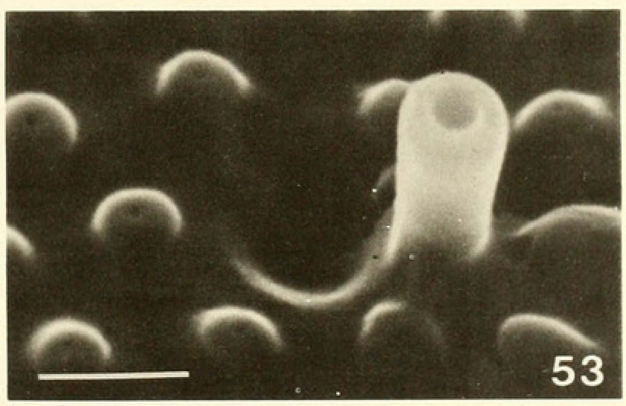
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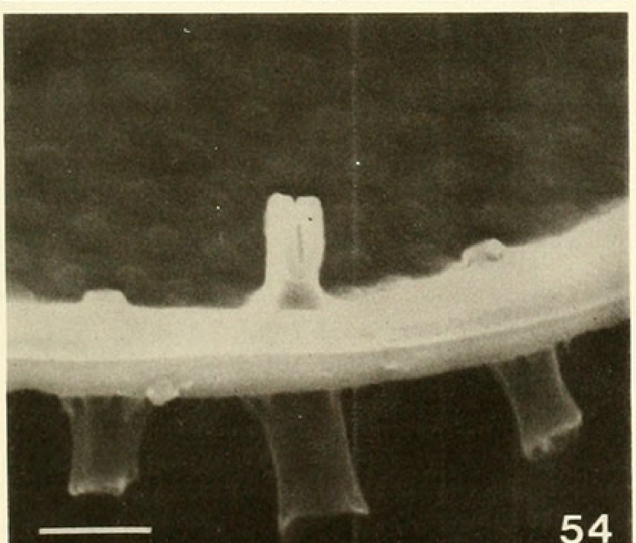
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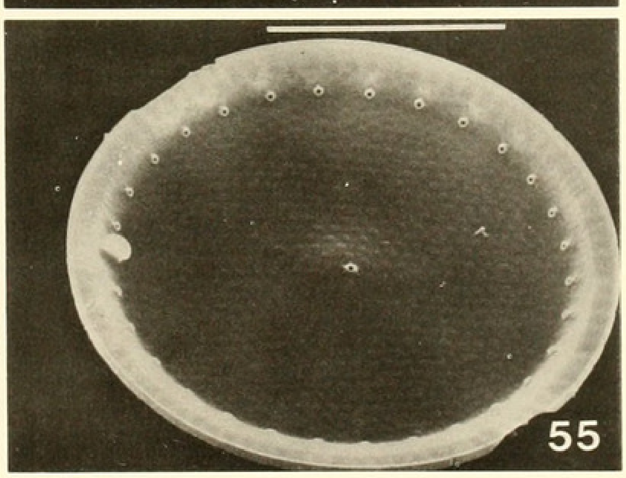
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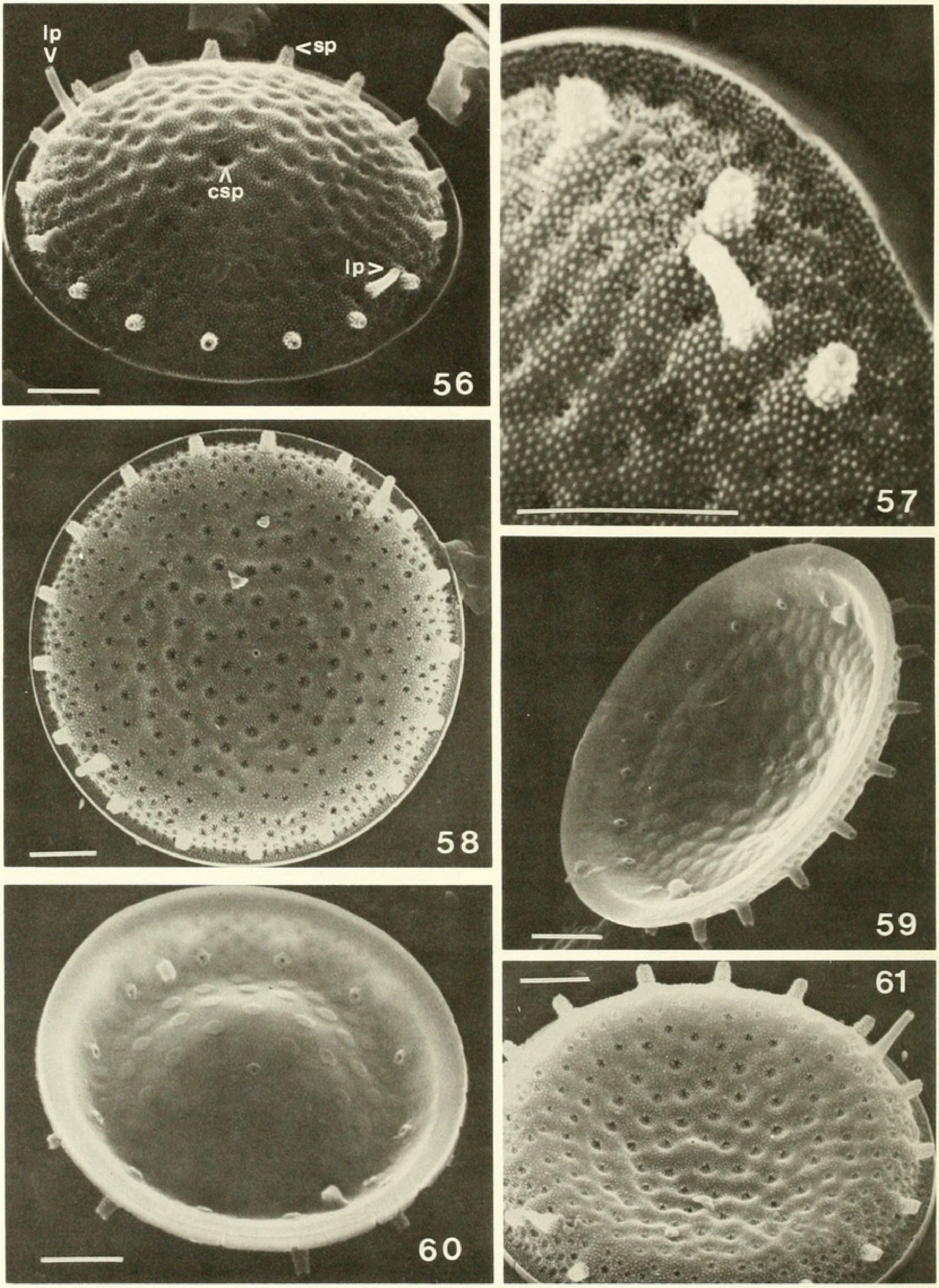
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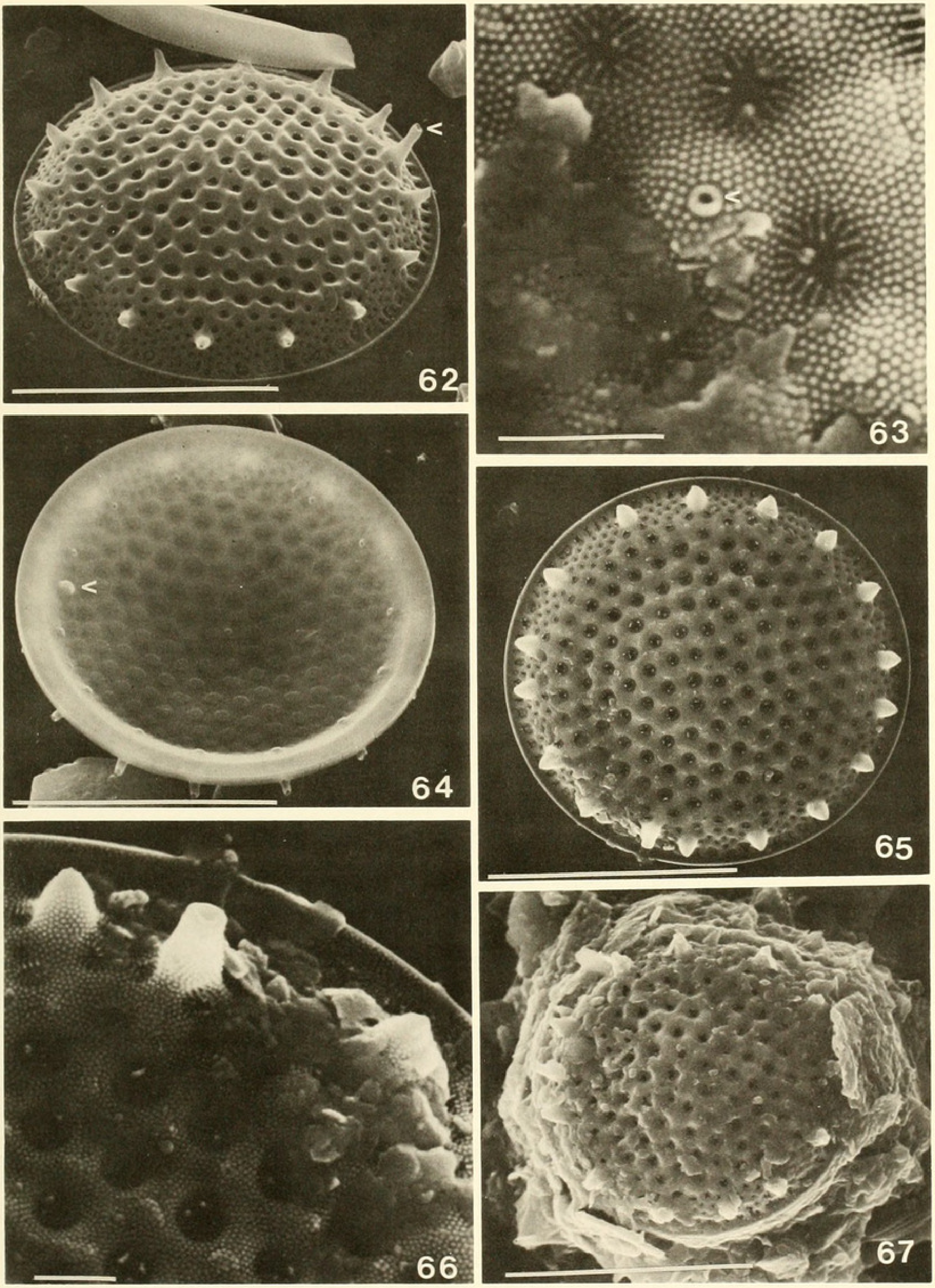
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logical studies of San Francisco Bay (Arthur and Ball 1980) is in reality a complex of *T. decipiens* and *T. visurgis,* two species usually found in the entrapment zone in Suisun Bay. Freshwater from the Sacramento and San Joaquin rivers flows westward to meet the tidal wedge moving eastward in Suisun Bay. This mixing area produces vertical and horizontal circulation that tends to concentrate populations of phytoplankton (Arthur and Ball 1980). The average salinity is low (0.1–5‰, Arthur and Ball 1980; Sitts and Knight 1979) and well within the range established for *T. decipiens, T. visurgis,* and *T. incerta.*

GROUP 4.—*Thalassiosira* species with no central strutted process but a modified ring of processes on the face of the valve.

Thalassiosira stellaris Hasle and Guillard, 1977

(Not figured)

DETAILED DESCRIPTION. Fryxell and Hasle (1977).—Cell diameter 6–20 μm; areolae elongate, fasciculated, 30 in 10 μm; marginal strutted processes three to five (sometimes six) in 10 μm; a ring of two to seven strutted processes ½ the distance between the center and the margin.

DISTRIBUTION.—Marine (Fryxell and Hasle 1977), San Francisco Bay samples described from cultures (F226) developed at Texas A&M University and maintained at ca. 30‰ salinity.

Thalassiosira lacustris (Grunow) Hasle and Fryxell, 1977

(Figures 68–73, 88)

DETAILED DESCRIPTION. As *Coscinodiscus lacustris,* Hustedt (1930).—Cell diameter 20–75 μm; areolae 10–14 in 10 μm in central area; valve face tangentially undulated (Fig. 68, 88); areolae fine (Fig. 71), arranged in dichotomous branching radiating rows (Fig. 71); five to seven strutted processes in ring ca. ⅓ radius from center of valve (Fig. 68, external; Fig. 69, internal); also ring on edge of mantle (Fig. 69). Labiate process large, with slit parallel to the margin (Fig. 72). This species marked by tangentially undulated structure of the valve face (Fig. 68, 69) and areolar pattern. Other tangentially undulated centric species usually in San Francisco Bay include members of the genus *Cyclotella.*

DISTRIBUTION.—Specimens in our samples from Suisun Slough indicate a brackish preference.

Thalassiosira endoseriata Hasle and G. Fryxell, 1977

(Figure 91)

DETAILED DESCRIPTION. Hasle and Fryxell (1977).—Cell diameter 20–60 μm; areolae 11–18 in 10 μm; one labiate process, located ¼ distance from margin to center; marginal strutted process projecting internally 5–6 in 10 μm; central irregular ring of 4–14 strutted processes. Areolae fasciculated with rows of areolae parallel to the radius (Fig. 91).

DISTRIBUTION.—The number of specimens from samples was too small to draw positive conclusion concerning the distribution of this species, but it apparently lives at ca. 20‰ salinity.

Thalassiosira anguste-lineata (A. Schmidt) G. Fryxell and Hasle, 1977

(Figures 74–79, 93)

DETAILED DESCRIPTION. Fryxell and Hasle (1977).—Cell diameter 17–78 μm; areolae fasciculated 8–18 in 10 μm; one

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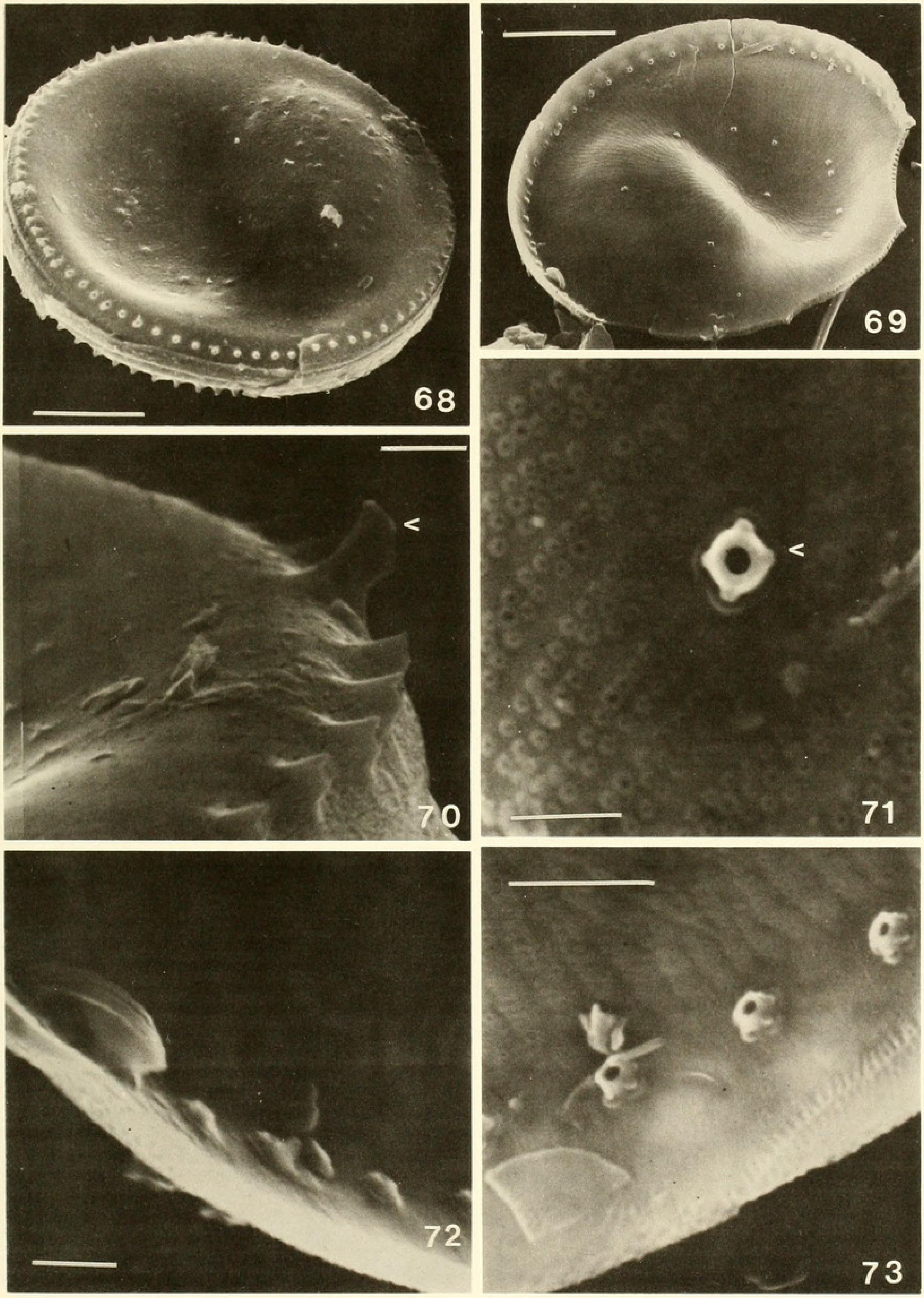
FIGURES 68–73. *Thalassiosira lacustris* (Grunow) Hasle. SEM. Figure 68. Scale = 10 μm; external view of valve; tangentially undulated, marginal strutted processes. Figure 69. Scale = 1 μm; internal view of valve; ring of valve strutted processes, pronounced tangential undulation. Figure 70. Scale = 1 μm; external view of margin, labiate process (arrow) between marginal strutted processes. Figure 71 (arrow). Scale = 1 μm; internal view of valve strutted process, areolae in dichotomous branching rows. Figure 72. Scale = 1 μm, internal view of labia and marginal strutted process. Figure 73. Scale = 10 μm; internal view of marginal strutted processes, dichotomous branching rows of areolae.

FIGURES 74–79. *Thalassiosira anguste-lineata* (A. Schmidt) G. Fryxell and Hasle. SEM. Figure 74. Scale = 20 μm; external valve view; areolae fasciculated, regular marginal strutted processes, arc of valve strutted processes in each fascicle (arrow). Figure 75. Scale = 1 μm, external view of valve strutted processes. Figure 76. Scale = 2 μm, marginal strutted processes. Figure 77. Scale = 2 μm; single labiate process (arrow) between two marginal strutted processes, small processes above each strutted process. Figure 78. Scale = 2 μm, internal view of labia. Figure 79. Scale = 2 μm, internal view of valve strutted processes.

FIGURES 80–85. *Thalassiosira rotula* Meunier. SEM. Figure 80. Scale = 2 μm, external view of central area strutted processes. Figure 81. Scale = 2 μm, internal view of central area strutted processes and scattered strutted processes on valve. Figure 82. Scale = 10 μm; external view of center and margin; weakly silicified valve, many marginal and valve strutted processes. Figure 83. Scale = 10 μm, internal view of valve, central and valve strutted processes. Figure 84. Scale = 10 μm, external view of valve, single labiate process (arrow), radial arrangement of areolae. Figure 85. Scale = 2 μm, external labiate process (arrow).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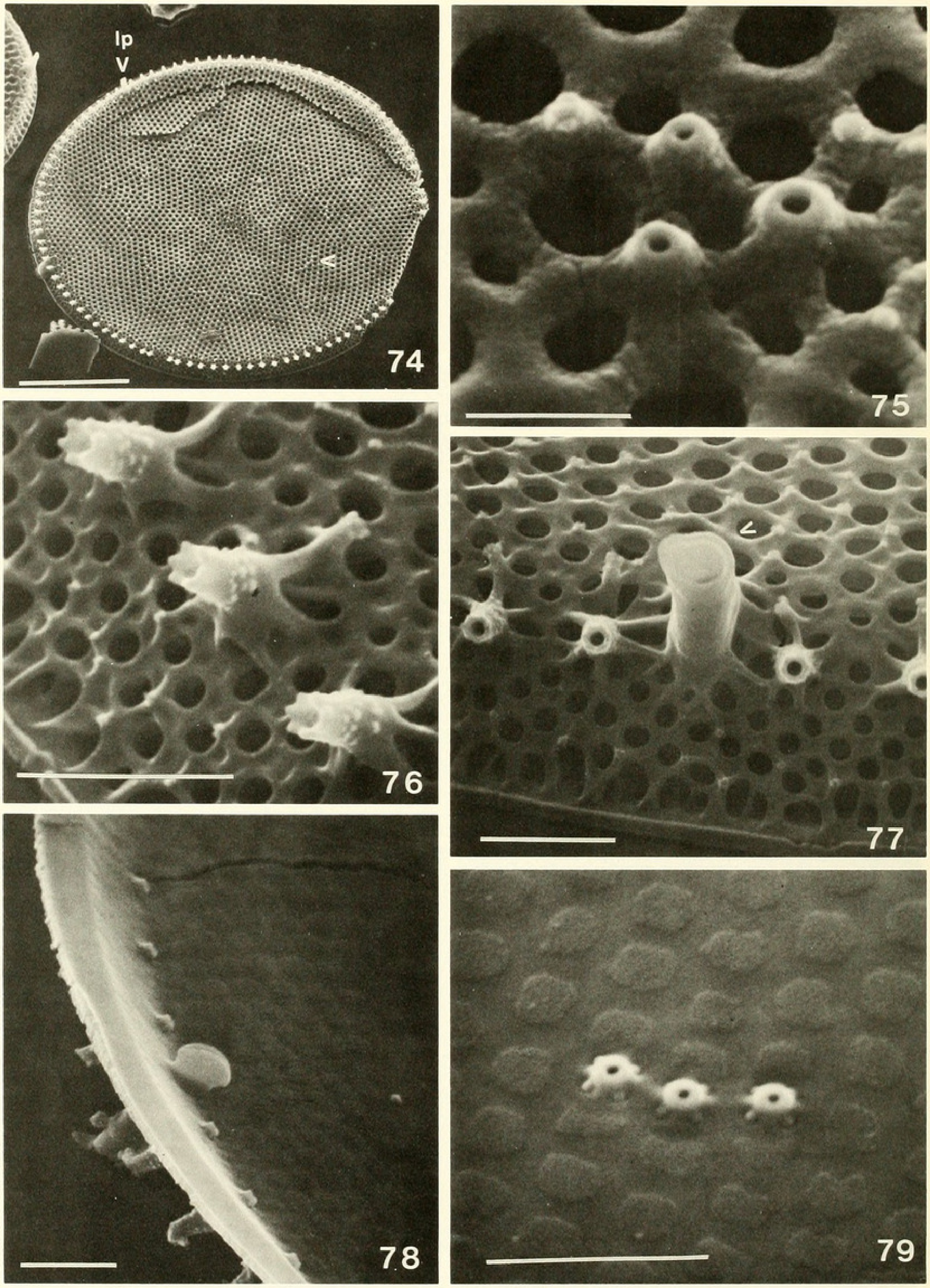
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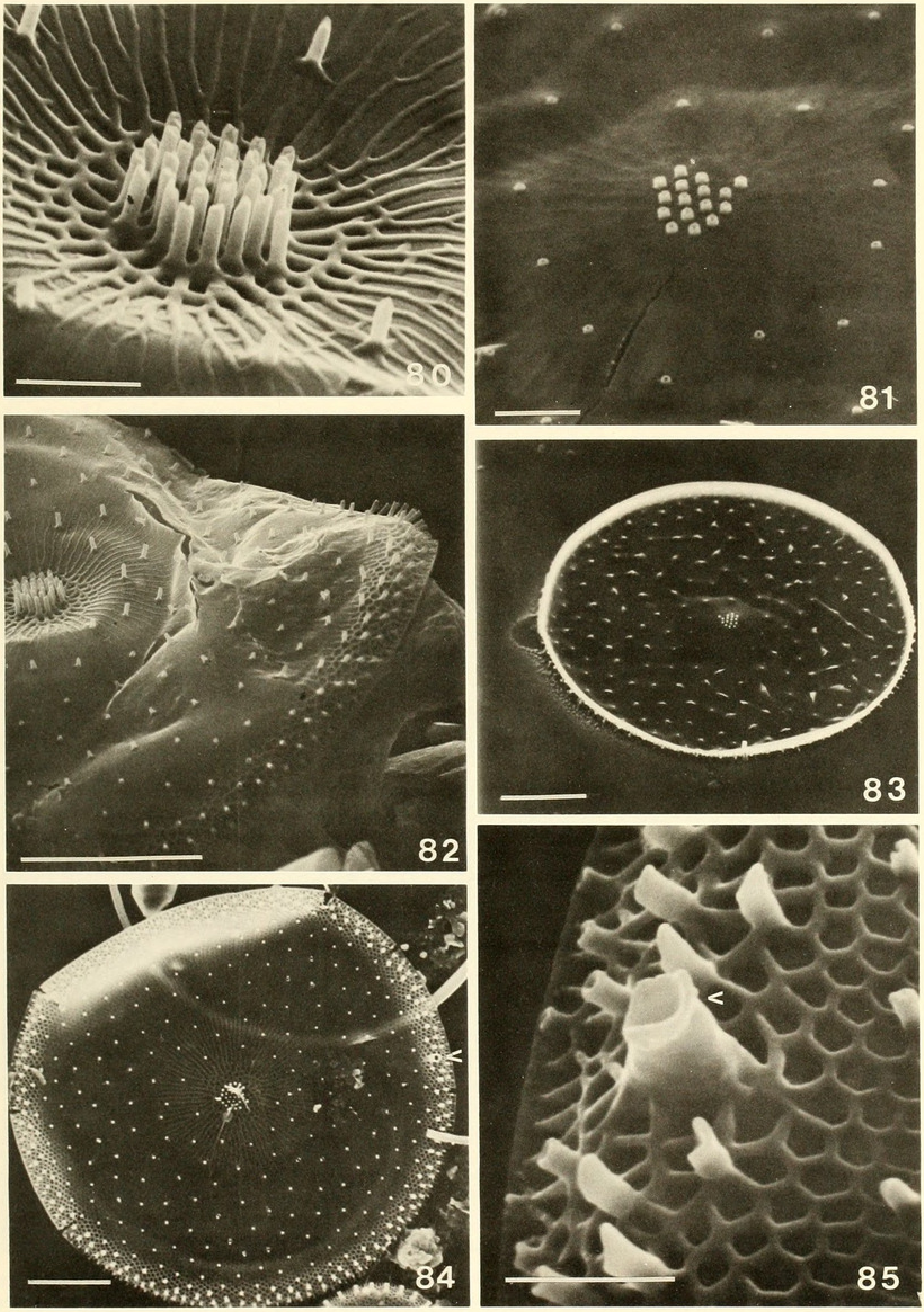
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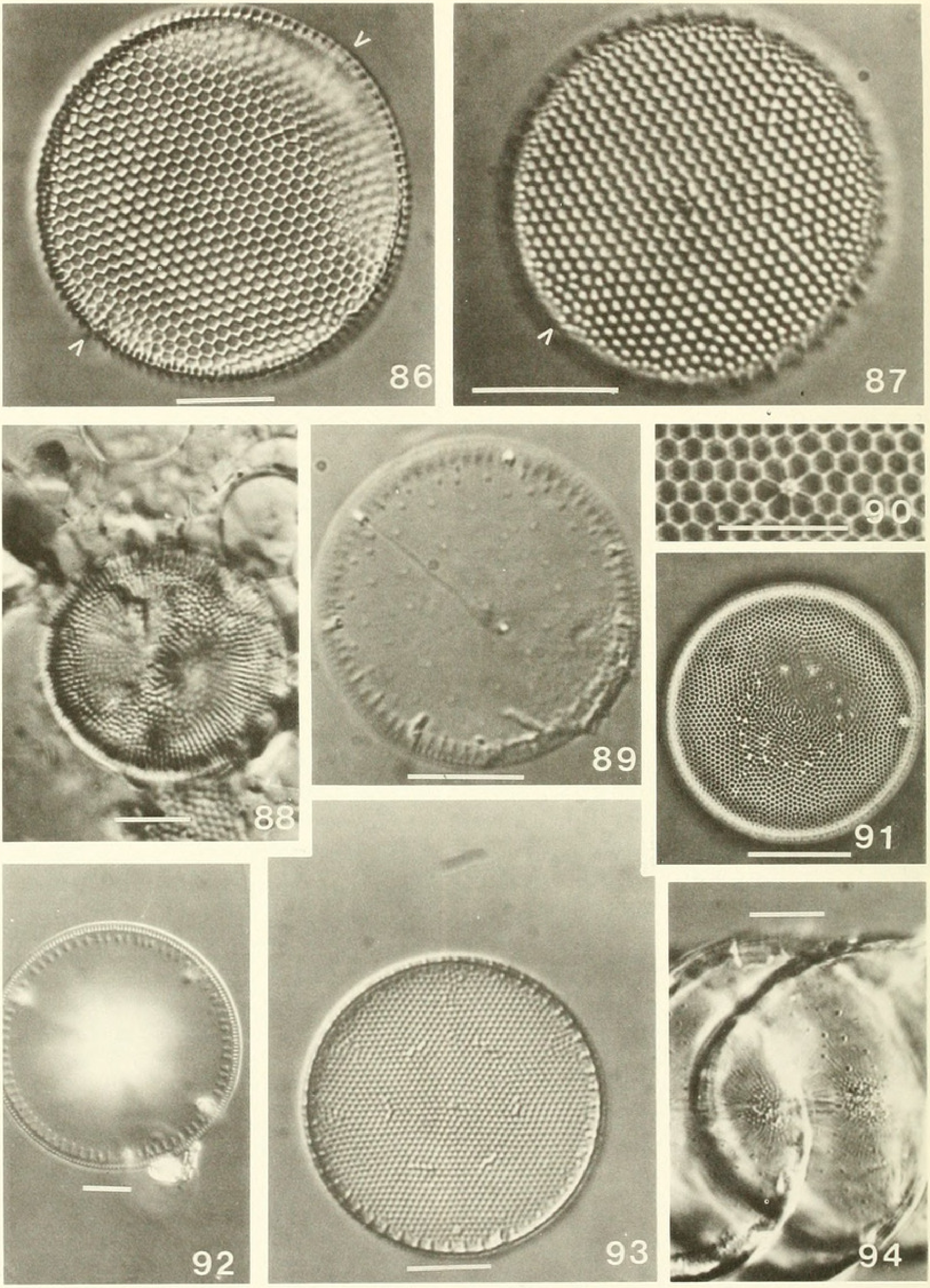

FIGURES 86–94. LM. Scale = 10 μm. Figure 86. *Thalassiosira hendeyi* Hasle and G. Fryxell. Linear arranged areolae, two labiate processes (arrow), wavy margin. Figure 87. *T. nodulolineata* (Hendey) Hasle and G. Fryxell. Linear arranged areolae, six symmetrical areolae surrounding central area, marginal strutted processes, single labiate process (arrow). Figure 88. *T.*

labiate process (Fig. 77, arrow; Fig. 78); ring of strutted processes in small arcs (Fig. 74, 75, 79) in each fascicle located ca. ½ the distance between the margin and the central areolae (Fig. 74). Characteristic arc-shaped grouping of strutted processes regularly arranged in each fascicle diagnostic for this species.

DISTRIBUTION.—Coastal, prefers cold to temperate waters, usually associated with other marine forms. Central San Francisco Bay to Golden Gate.

DISCUSSION.—*Thalassiosira stellaris,* a lightly silicified species, was found in culture from a sample taken north of Golden Gate Bridge. *Thalassiosira endoseriata* was found only once. As previously mentioned, *Thalassiosira lacustris* displays a tangentially undulated valve face (Fig. 68), an aid in identification. The largest concentration of viable cells of *T. lacustris* was found in the brackish waters of Suisun Slough (Mahood 1981). *Thalassiosira anguste-lineata,* with its fasciculated areolar pattern and distinguishing arrangement of strutted processes in each fascicle (Fig. 74, 79, 93) is easily distinguished from other fasciculated species seen within the Bay in cleaned material in permanent mounts. However, the strutted processes on the valve face are not always easily seen in an uncleaned sample, and lack of resolution may result in some confusion. When cells are united in chains, however, several threads can be seen to extend from one cell to the next, one from each cluster of strutted processes instead of the single central thread commonly seen in the genus.

GROUP 5.—*Thalassiosira,* otherwise dissimilar species that have radial areolae patterns and multiple central processes.

Thalassiosira rotula Meunier, 1910

(Figures 80–85, 94)

DETAILED DESCRIPTION. Fryxell (1975*b*); Syvertsen (1977).—Cell diameter 8–61 μm (40–61 μm, Gran and Angst 1931); areolae very fine, only clearly seen in the central area (Fig. 84); cluster of strutted processes in center (Fig. 80, external; Fig. 81, internal), with scattered processes across entire valve face (Fig. 83, 84); single labiate process (Fig. 84, arrow; Fig. 85, arrow); valve weakly silicified (Fig. 82). Usually observed in chains (Fig. 94).

DISTRIBUTION.—In our samples *T. rotula* restricted to the more saline portion of the central bay and Golden Gate with other marine forms.

Thalassiosira incerta Makarova, 1961

(Not figured)

DETAILED DESCRIPTION. Hasle (1978*a*).—Cell diameter 13–38 μm; areolae 8–16 in 10 μm; three to four strutted processes in 10 μm at margin; four to six strutted processes surrounding central areolae.

DISTRIBUTION.—Fresh to brackish water, rare in our samples.

DISCUSSION.—Both brackish and marine members of this group show distinctive characteristics that clearly differentiate them from other *Thalassiosira* species of the bay. *Thalassiosira rotula,* first mentioned by Whedon (1939), is usually found in the central bay (Wong and Cloern 1981). This species has been reported from similar estuarine environments (Marshal 1980). Our experience has been to associate *T. rotula* with other coastal or marine forms. Its characteristic chain formation with coin-shaped cells connected by a thick central thread, narrow girdle bands, delicate structure, and scattered strutted processes on the valve face aid in the identification.

Thalassiosira incerta, T. decipiens, and *T. visurgis* are all characterized by small size, eccentric to linear areolar patterns, and an accumulation of detritus around the margin of the living cell. This group has proven to be the most difficult to differentiate by light microscopy. All three species have similar diameters and general characteristics (Table 2) and can only be differentiated after the sample has been cleaned of organic material. In cleaned material *T. incerta* possesses characteristics that distinguish it from

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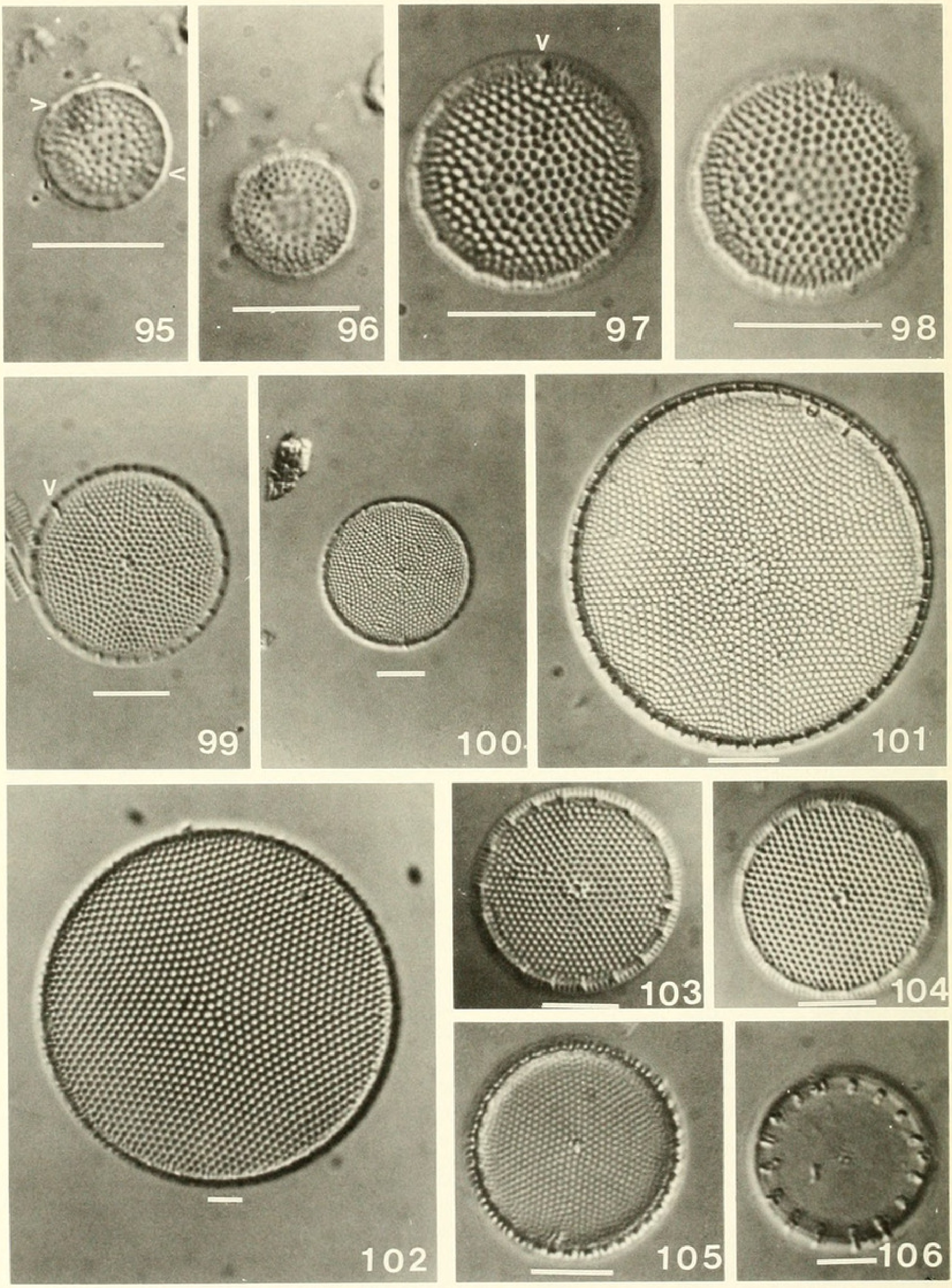
lacustris (Grunow) Hasle. Tangential undulations, radial arrangement of areolae. Figure 89. *T. lundiana* G. Fryxell. Weakly silicified, large irregular occluded processes at margin, irregularly arranged strutted processes on valve. Figure 90. *T. nodulolineata* (Hendey) Hasle and G. Fryxell. Detail of central area, strutted processes in central areola. Figure 91. *T. endoseriata* Hasle and G. Fryxell. Fasciculated areolae, ring of strutted processes near center of valve. Figure 92. *T. punctigera* (Castracane) Hasle. Regular marginal strutted processes, weakly silicified. Figure 93. *T. anguste-lineata* (A. Schmidt) G. Fryxell and Hasle. Fasciculated, arc of strutted processes in each fascicle. Figure 94. *T. rotula* Meunier. Central strutted process, random valve strutted processes, forming chains.



FIGURES 95–106. LM. Scale = 10 μm. Figure 95. *Thalassiosira visurgis* Hustedt. Focused on center, two labiate processes (arrows), radial pattern of areolae. Figure 96. *T. visurgis* Hustedt. Same valve as Figure 95, focused on margin. Figure 97. *T. decipiens* (Grunow) Jørgensen. Focused on center, regular marginal strutted processes, one labiate process (arrow). Figure 98. *T. decipiens* (Grunow) Jørgensen. Same valve as Figure 97, focused on margin, uniform areolae across valve. Figures 99–101. *T. wongii* Mahood sp. nov. Fasciculated, two circles of strutted processes on valve, one labiate process (arrow), raised central

TABLE 2. *THALASSIOSIRA* SPECIES FROM SAN FRANCISCO BAY AREA. Measurements from the literature and our observations.

Species	Diameter (μm)	Areolae in 10 μm	Labiate processes	Marginal strutted processes in 10 μm	Central strutted processes	Distinctive characteristics
Group 1—Species with a linear areolar pattern						
T. hendeyi	38–120	5–6	2	5–6	1	wavy margin
T. nodulolineata	26–58	3.5–7.0(9.0)	1	3–5	5–6	strutted processes in central areola
T. simonsenii	30–57	4.0–5.5	2	5–6	1	two marginal rings of strutted processes
T. tenera	10–29	9–16	1	3–5	1	flattened marginal processes
Group 2—Species with eccentric patterns						
T. eccentrica	12–101	5–10	1	irregular 10–20	1	seven areolae around central areola
T. oestrupii var. *venrickae*	5.5–39.0	6–9	1	1–2	1	strutted processes project inward
T. wongii	27–51	9–11	1	3–5	4–5	fasciculated central ring of strutted processes
Group 3—Species with 1 central process and 1 marginal ring of strutted processes						
T. lundiana	7–43	24–30	1	5–10	1	fasciculated, weakly silicified
T. punctigera	43–145	15	1	4–5	1	fasciculated, regular marginal strutted processes
T. nordenskioeldii	10–50	14–18	1	3	1	radial, marginal strutted processes back from margin
T. pacifica	7–46	10–18	1	4–7	1	fasciculated, raised central process
T. minuscula	10–20	30	1	4–5		labiate process away from margin
T. visurgis	9–18	13–14	2	4–5	1	irregular radial pattern
T. decipiens	9–29	8–12	1	4–6	1	eccentric radial pattern
Group 4—Species with no central strutted processes but a modified ring of strutted processes						
T. stellaris	6–20	30	1	3–5 (6)		2–7 processes in ring, fasciculated
T. lacustris	20–75	10–14	1	5–7		tangentially undulated
T. endoseriata	20–60	11–18	1	5–6		4–14 processes in ring, fasciculated
T. anguste-lineata	17–78	8–18	1	3–4		ring of arcs on face of valve, fasciculated
Group 5—Dissimilar species with radial patterns						
T. rotula	8–61	20	1	4–7	cluster	cluster of central strutted processes
T. incerta	13–38	8–16	1	3–4	4–6	central processes around central areola radial pattern

T. decipiens and *T. visurgis.* The central areola of *T. incerta* is surrounded by five to six strutted processes similar to the arrangement seen in *T. nodulolineata* (Fig. 14). Unlike those in *T. nodulolineata,* the central strutted processes in *T. incerta* are extremely small and are just visible under the light microscope. *Thalassiosira incerta* was rare in our collections and was only found

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strutted process, pronounced and regular marginal strutted processes. Figure 102. *T. eccentrica* (Ehrenb.) Cleve. Eccentric areolar pattern, irregular marginal spines. Figures 103, 104. *T. tenera* Proschkina-Lavrenko. Linear arrangement of areolae, robust flattened marginal strutted processes, central area raised around the central areola. Figure 105. *T. pacifica* Gran and Angst. Fasciculated pronounced regular marginal strutted processes, distinctive central process. Figure 106. *T. nordenskioeldii* Cleve. Large marginal strutted processes set back from margin, raised central process.

from the Suisun Bay material. Hasle (1978*a*) has also reported *T. incerta* from waters of the San Joaquin delta.

Conclusions

The 20 species presented require additional study to delineate more clearly their ecological variables. Other than salinity, little is known of their habitat requirements. Of the species presented, *T. decipiens, T. nodulolineata, T. eccentrica, T. hendeyi,* and *T. wongii* appear to be best suited as indicators of salinity.

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