

## 15. DIATOMS FROM LEG 75, DEEP SEA DRILLING PROJECT<sup>1</sup>

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### ABSTRACT

The occurrence of slumping and reworking at Sites 530 and 532 makes precise definition of diatom biostratigraphy difficult. In addition, stratigraphic marker species appear to be ecologically excluded from this region of upwelling of the Benguela Current. At Site 530 diatoms are present only in the Pleistocene. At Site 532 a few specimens of stratigraphically useful species suggest a Plio/Pleistocene boundary above Core 22; the oldest diatoms (Core 26) are very late Pliocene in age. The fossil assemblage is variable, but there seem to be at least three assemblages—displaced benthic and neritic species (*Paralia*, *Delphineis*), pelagic species (*Coscinodiscus*, *Hemidiscus*), and “upwelling” species (*Stephanopyxis*, *Chaetoceros*). Study of a few specimens with the scanning electron microscope (SEM) allows accurate identification of a problem group (*Thalassiosira eccentrica*), suggests a possible evolutionary relationship for another (*Rhizosolenia barboi*), and provides morphologic detail on some genera of uncertain taxonomic position (*Stephanopyxis*, *Actinoptychus*).

### INTRODUCTION

Most of the stratigraphic section cored on Leg 75 does not contain diatoms; those intervals which are diatomaceous (Pliocene and Pleistocene) are completely dominated by forms adapted to the unusual upwelling conditions, so that both the tropical and high-latitude stratigraphic marker species are essentially excluded from the area. The marker species appear sporadically, perhaps in intervals representing a decrease in upwelling, so that it is very difficult to locate the true levels of extinction and first appearance. Reworking is also common, further confusing the picture.

Those stratigraphic markers that are present are also recognized in the Pacific Ocean, and I have interpreted the stratigraphy using the species ranges of Burckle (1977) and Koizumi (1977). Both of these workers have correlated species events with the paleomagnetic record, which provides an absolute time scale. The results discussed here must be treated with caution, however, since the ranges of these species in the Atlantic have not been adequately confirmed. The sequence of events from Leg 75 is the same as that in the Pacific, but the absolute ages may prove to be different.

### BIOSTRATIGRAPHY

#### Site 530

Shipboard lithologic study indicated that only Units 1a and 1b of Hole 530B contain significant numbers of diatoms (Cores 1 through 27; 0-110 m). I examined the core catchers for this interval. Biostratigraphic markers are very rare, the assemblage being dominated by *Thalassionema*, *Thalassiothrix*, and *Stephanopyxis* species. Samples from debris flows include common *Delphineis*, *Chaetoceros* spores, and *Paralia*—all displaced from shelf depths.

*Pseudoeunotia doliolus*, which ranges through the Pleistocene in the Pacific, is sporadically present throughout the interval. Below Core 20 (85 m) the ancestor *Nitzschia fossilis* is also present and it becomes difficult to distinguish the two species, which are usually in fragments. The top of *N. reinholdii* occurs in Section 10,CC (41 m), within or between debris flows—this occurrence may be an effect of displacement. In the tropical Pacific the extinction of *N. reinholdii* occurs in the lowermost Brunhes (Burckle, 1977) or uppermost Matuyama (Sancetta, 1982a).

The acme of *Mesocena quadrangula*, which Burckle (1977) has found to be a good marker for the Jaramillo in the Pacific, was not seen in any samples—this acme may have occurred during the interval covered by the debris flow. The top of *Rhizosolenia barboi* occurs in Section 21,CC. This event may be time-transgressive; Koizumi (1977) locates it in the mid-Matuyama, above the Olduvai event.

Diatoms are essentially absent below Core 27, in which Pleistocene species are present. The Plio/Pleistocene boundary must thus be below Core 27.

#### Site 532

Diatoms are only present between Cores 6 and 27 in Hole 532, and are only common from Cores 9 to 20 (35-88 m). Even within this interval their abundance and preservation vary depending on the proportion of calcium carbonate and clay present. The pelagic assemblage is similar to that at Site 530; neritic and benthic species are rare in most samples.

*Pseudoeunotia doliolus*, the Pleistocene marker, is not present in many samples, so that its range is rather unreliable. The upper limit of *Nitzschia reinholdii* occurs in Core 6,CC (26 m), but as this is also the upper limit of diatoms in the section, the event is probably not diagnostic of age. *Mesocena quadrangula*, whose acme ranges across the Jaramillo in the Pacific, occurs from Sections 6,CC to 8,CC (26-34.8 m).

A few specimens similar to *Rhizosolenia matuyamai* occur in Sample 532-9-1, 100 cm (35.8 m); in the North

<sup>1</sup> Hay, W. W., Sibuet, J.-C., et al., *Init. Repts. DSDP, 75*: Washington (U.S. Govt. Printing Office).

Pacific this species has a range just below the Jaramillo (Burckle et al., 1977). The top of *R. barboi* (mid-Olduvai?) is in Section 13, CC (56.8 m).

The first and only occurrence of *R. praebergonii* is in Section 22, CC (96.4 m). In the equatorial Pacific this extinction occurs at the top of the Olduvai, coincident with the Plio/Pleistocene boundary. Nannofossil stratigraphy places the Plio/Pleistocene boundary at 17, CC (74.4 m; Steinmetz and Stradner, this volume)—a difference of 22 m. There are two possible explanations for this discrepancy:

1) The range of *R. praebergonii* is shorter in the Atlantic than in the Pacific. In this case, the Atlantic extinction of *R. praebergonii* occurred in the late Pliocene, rather than at the Plio/Pleistocene boundary.

2) The range of *R. praebergonii* is the same in both oceans (extinction at the top of the Olduvai), but the species did not thrive in the upwelling regime, and its occurrence in Section 22, CC represents a rare period when it was able to survive in the area. In this case the absence of *R. praebergonii* above (and below) Section 22, CC results from ecologic exclusion rather than regional extinction.

Similar alternatives exist for *Thalassiosira convexa*, which occurs in Core 26 (114 m)—the lowest sample in which diatoms are common. The extinction of *T. convexa* occurs in the lower Matuyama in the Pacific (Burckle, 1977), while at Site 532 it occurs during a normal interval (probably the Gauss).

In view of the general appearance of the assemblage (lack of tropical species, dominance by cool-water upwelling forms), the latter alternative is probably the best explanation for both species.

#### PALEOCEANOGRAPHY

If the general presence of diatoms is used as a measure of productivity, Sites 530 and 532 indicate that regional productivity was highest in the early Pleistocene, extending into the late Pliocene at Site 532 and into the late Pleistocene at Site 530.

Species assemblages are variable from sample to sample, and a quantitative population analysis of rather closely spaced samples would be necessary to work out any regular patterns or sequence. The *Thalassionema* group (*Thalassionema* and *Thalassiothrix*), *Coscinodiscus nodulifer*, *C. radiatus*, and *Stephanopyxis* species are consistently present, but even these groups show some fluctuation. All of these species are robust, so that differential preservation can probably be ruled out. In the Pacific, the *Coscinodiscus* species appear to be more representative of pelagic non-upwelling conditions (Burckle, personal communication). The *Thalassionema* group is cosmopolitan, but appears to thrive in regions of upwelling (Hasle and de Mendiola, 1967), and *Stephanopyxis* species are usually reported from sediments of continental margins, more commonly from mid- and high-latitudes (e.g., Japan, Franz-Josephs Land) than from tropical latitudes. *Actinopteryx senarius*, *Chaetoceros* spores, *Delphineis*, and *Paralia* also occur in some samples—these groups are commonly considered to be neritic (the two latter are benthic genera).

The varying abundances of these species suggest that hydrographic changes in the area are more complex than a simple upwelling/no-upwelling system. The main core of the Benguela Current has probably moved offshore and onshore, as well as changing in intensity.

It would be interesting to investigate in detail species abundances through one or more of the light-dark lithologic cycles. There are no obvious changes in species dominance from smear slide examination. Diatoms are usually rare and fragmented in light (carbonate-rich) and dark (clay-rich) intervals, and most common in lithologies between these extremes. In the two cycles I examined (one in Core 12 and one in Core 25, Site 532), the assemblage seemed to be composed of the more pelagic forms (*Coscinodiscus* species and the *Thalassionema* group). This implies that the extremes represented by the cycles are not related to the degree of upwelling and surface productivity, but to some change in bottom-water chemistry, affecting the calcite-to-clay ratio. This is very tentative, however, and population counts should be done over a few test intervals before any firm conclusions are drawn.

#### TAXONOMIC AND MORPHOLOGIC REMARKS

During the course of this investigation, I had the opportunity to use several scanning electron microscopes (Cambridge and Jeol models) for short periods. The sample examined was Sample 532-26-2, 146–147 cm, a diatom-rich interval in the late Pliocene. Time did not permit a complete study of all species, but a few observations are of enough interest to be mentioned here.

#### *Thalassiosira eccentrica* (Ehrenberg) Cleve

*T. eccentrica* (sometimes misspelled “*excentrica*”) has been reported as a minor but consistent member of Neogene fossil assemblages, especially from tropical and temperate areas (e.g., Schrader, 1973, 1974; Sancetta, 1982a). This name has usually been given to any specimens which possess the characteristic “eccentric” structure and a central process—preservation in the sediments and light microscope (LM) resolution usually do not permit a closer study. The work of Fryxell and Hasle (1972) and Simonsen (1974) has shown that several species possess these characteristics; as a result, micropaleontologists have privately expressed some confusion as to which species is/are present in samples and have begun to use the phrase “*T. eccentrica* group.”

This form is relatively rare in samples from Site 532 (usually about 5%), but very distinctive. The specimens examined in SEM can be identified as *T. eccentrica* (Plate 1, Fig. 1) by the following characteristics: (1) eccentric, rather than fasciculate, arrangement of areolae; (2) one central tubulus interrupting the heptagonal areole pattern; (3) scattered tubuli in concentric heptagons over the valve face; (4) one marginal labiate process; (5) marginal spines; (6) two to three rings of marginal tubuli. In comparison, *T. mendiolana* has a fasciculate structure, *T. symmetrica* lacks a central tubulus and has two marginal labiate processes, and *Planktoniella sol* lacks the scattered tubuli and marginal spines (Fryxell and Hasle, 1972); *T. punctifera* has one ring of marginal

tubuli and a protruding central tubulus, and *T. spinosa* has spines scattered over the central part of the valve (Simonsen, 1974). Simonsen has pointed out the concentric heptagonal arrangement of the "scattered" tubuli in several of these species, a point missed by Fryxell and Hasle (1972) in their study of *T. eccentrica* but subsequently confirmed by Fryxell (personal communication).

In other samples, under LM, I have seen specimens with similar arrangement of areolae, but without visible tubuli on the valve face. In SEM such specimens proved to lack a central tubulus, but to have very small ones present in concentric heptagons on the valve face. These are probably *T. symmetrica*; I suspect that this form has been called *Coscinodiscus eccentricus* by other micropaleontologists who, working only with LM, could not see the valve-surface tubuli.

Thus, *T. eccentrica* and *T. symmetrica* both occur in the sediment and can be distinguished in LM only by the presence (*T. eccentrica*) or absence (*T. symmetrica*) of a central tubulus.

#### *Rhizosolenia barboi* Brun

This species, synonymous with *R. curvirostris* var. *inermis* Jousé, has been reported from temperate and boreal/austral sediments from the early Pleistocene to middle Miocene (e.g., Koizumi, 1977; Gombos, 1977). It has been distinguished from *R. curvirostris* by its lack of the broad spine near the bend or "elbow" possessed by *R. curvirostris*. Curvature is variable. Specimens are usually too poorly preserved to resolve fine structure under LM.

Most specimens from Site 532 were affected by dissolution as revealed by SEM microscopy. However, a few specimens were complete enough to show some structure (Plate 1, Fig. 2). The surface is smooth and featureless along most of the length, but near the apex a few striae appear, oriented along the long axis. It is possible that these "striae" are simply the result of incipient dissolution, but I believe them to be real structures, because of their regular arrangement and uniform penetration through the siliceous layer—*R. alata* has similar, but more common, striae (loculi) according to Hasle (1975). The distal end of the valve shows the characteristic "barb" to one side; the main part is ovate in cross section and dentate, with the larger spinules at the two ends of the oval and smaller ones around the rest of the periphery (Plate 1, Fig. 2).

These traits are similar to those of *R. alata* (Hasle, 1975) and suggest that the two species are closely related. *R. alata* is unique among living species in that it does not possess a true terminal process; instead, the valve itself is elongate conically and terminates as the distal dentate end. Brun (1894) found the same condition in *R. barboi*, which caused him to question his generic assignment. However, as Hasle (1975) says, "it seems better to retain *R. alata* in its present genus than to establish a new genus. . . . At present, no other genus. . . is more appropriate for this species. . . ." This would apply to *R. barboi*, *R. praebarboi*, and *R. curvirostris* as well, although it might be desirable to reinstate Hustedt's (1930) section *Alatae* for these species. *R.*

*alata* would then appear to be the last surviving member of this fossil section. *R. barboi* appears to lack the longitudinal slit seen in *R. alata* by Hasle—it is possible that the barb is actually homologous to the slit.

Brun is the only author to have reported seeing the main part of the valve (his "connective zone") in *R. barboi*; other micropaleontologists have seen only these elongate ends ("calyptrae") in the sediment and have assumed that these ends are the terminal process. By analogy with *R. alata*, it would appear that these "processes" of the fossil species are in fact simply the distal extension of the elongated valves, as shown by Brun (1894).

#### *Stephanopyxis apiculata* (Ehrenberg) Grunow

The genus *Stephanopyxis*, and its numerous species, have been a source of confusion for over a century. Grunow (1884), Hustedt (1930), and others have remarked on the difficulty of distinguishing the species, and taxonomists (Ross and Sims, 1974; Simonsen, 1974) express doubts as to the familial placement of the genus. In these circumstances, I can only note a few points, which may be useful to others.

*S. apiculata* has not been reported by most micropaleontologists; I suspect that it is usually identified with *S. turris*, a closely related species. Both species are highly variable as to valve size and convexity, size of areolae, and length of processes; frustules are frequently dimorphic. *S. turris*, however, has the processes arranged in a circle ("crown") at the boundary between valve-face and mantle, while *S. apiculata* has a small number of processes (0 to 4, according to Grunow, 1884), more or less in the center of the valve.

In the sample from Site 532, *S. apiculata* is quite common, and ranges from gently convex (Plate 1, Figs. 3–5) to cylindrical. Two valves of a frustule may be of different convexity. This trait is common in semi-endogenous spores, which suggests that some or all of these specimens—perhaps the entire species—may be resting spores. Grunow (1884) also noted that external length of processes varies with degree of curvature; in this sample the processes are usually broken, but his observation seems to apply (compare Plate 1, Fig. 3 and Plate 1, Fig. 4).

It is difficult to determine the nature of the basal siliceous layer, since it may not be completely preserved. The areolae appear to be poroid, rather than loculate (i.e., without constriction at one surface relative to the other) and to possess an internal cribrum (Plate 1, Figs. 6, 7; Plate 2, Fig. 1). Perforations of the cribrum are in parallel rows of irregular length, which are oriented in the direction of valve curvature. Labiate processes are scattered across the valve in no obvious order (Plate 1, Fig. 6—note one labiate process is at the valve margin). The processes are frequently centered in an areole, or marginal to one (Plate 1, Fig. 7), but some of them also appear in the interval between two areolae. No outer velum is visible in any of these specimens, but it may have been dissolved. There is no structure on the margin.

Time was too limited to make a thorough study of the structure of the external processes, but it appears to be quite complex. Most of the labiate processes have no ex-

ternal tube, so that they look like smaller areolae in LM and from external view (e.g., at the margin in Plate 1, Fig. 5). Others project very slightly beyond the valve surface (Plate 1, Fig. 5), while those near the center of the valve may be elongated, together with the walls of the associated areolae, into the distinctive "prongs" of the genus. The external processes thus appear to originate from single areolae, by outward growth of the chamber walls, and are always associated with one (or more?) labiate processes. Plate 2, Figures 2 and 4 show the most simple case; in Plate 2, Figure 3 one can see the external openings of several labiate processes associated with elongated areolae—one such opening is actually inside a chamber wall, as though it were a passage pore.

The high numbers of *Stephanopyxis* species at Site 532 suggest that it is associated with upwelling and production by the Benguela Current. The other species in this sample are mostly pelagic forms (no benthic diatoms are present), which suggests that *S. apiculata* is related to deep-water, rather than coastal, upwelling.

#### *Actinoptychus senarius* (Ehrenberg) Ehrenberg

This species, sometimes referred to as *A. undulatus*, appears to be a cosmopolitan neritic form, having been reported from such diverse regions as the Bering Sea (Sancetta, 1982b), the South Atlantic (Hendey, 1937) and the Gulf of California (Schrader, personal communication). Some confusion exists as to the correct specific epithet: Ehrenberg (1841) used the epithet *senarius* while Kützing (1844) introduced the epithet *undulatus* which he attributed (wrongly) to Bailey (1842). Hendey (1937) has pointed out that the epithet *senarius* has precedence and should be re-established.

The morphology and fine structure of the species has been illustrated and discussed by other workers (Worwardt, 1971; Fryxell and Hasle, 1974; Ross and Sims, 1974), so that only a few remarks need be made here.

The nature of the loculi remains unclear—from an internal view the structure is that of uniform foramina across the sectors (Fryxell and Hasle, 1974), but externally the structure is more complex. Ross and Sims (1974) call it an external velum with a network of costae, while Fryxell and Hasle (1974) call it "a developing loculus pattern," so that position of the cribrum, if any, remains uncertain. The loculi of specimens from Site 532 give the impression of an external cribrum (set of perforations) that has been depressed into each loculus (Plate 3, Figs. 1, 3). In high magnification the pattern of perforations appears to spiral downward into the loculus (Plate 3, Fig. 4), with the direction of the spiral (clockwise or the reverse) varying from one to the next. This may be only a visual effect, but it is quite consistent. At the corners of the loculi, on the costae, there are very small spinules (Plate 3, Fig. 4). Structure in the depressed sectors, where the costae are developed into a network of nodes, is more difficult to determine (Plate 3, Figs. 1, 3). There are two rows of peripheral spinules—one row along the costa of the boundary of the valve face and mantle (where the labiate processes of the raised sectors project), and one row along the margin (Plate 3, Figs. 1, 2). The mantle has simple areolae ar-

ranged in quincunx; this pattern continues to the margin as parallel rows (Plate 3, Fig. 1). There are occasional spinules toward the outer part of the mantle; these correspond to gaps in the row along the margin, and are probably displaced, rather than members of a third row.

#### *Thalassionema* and *Thalassiothrix*

Micropaleontologists have sometimes expressed uncertainty as to the distinction of these two genera in sediment samples. The diagnosis usually given is that *Thalassiothrix* is heteropolar while *Thalassionema* is homopolar. Since specimens are almost always broken, this is not very helpful. Hasle and de Mendiola (1967) and Hasle (1974) have studied species of the genera and noted that *Thalassionema nitzschioides* has a small partly hollow spine at each end, while *Thalassiothrix longissima* has two large apical spines (*T. frauenfeldii* has one). Although I was unable to get good photographs, I saw both of these forms in the sample from Site 532, suggesting that both genera are present.

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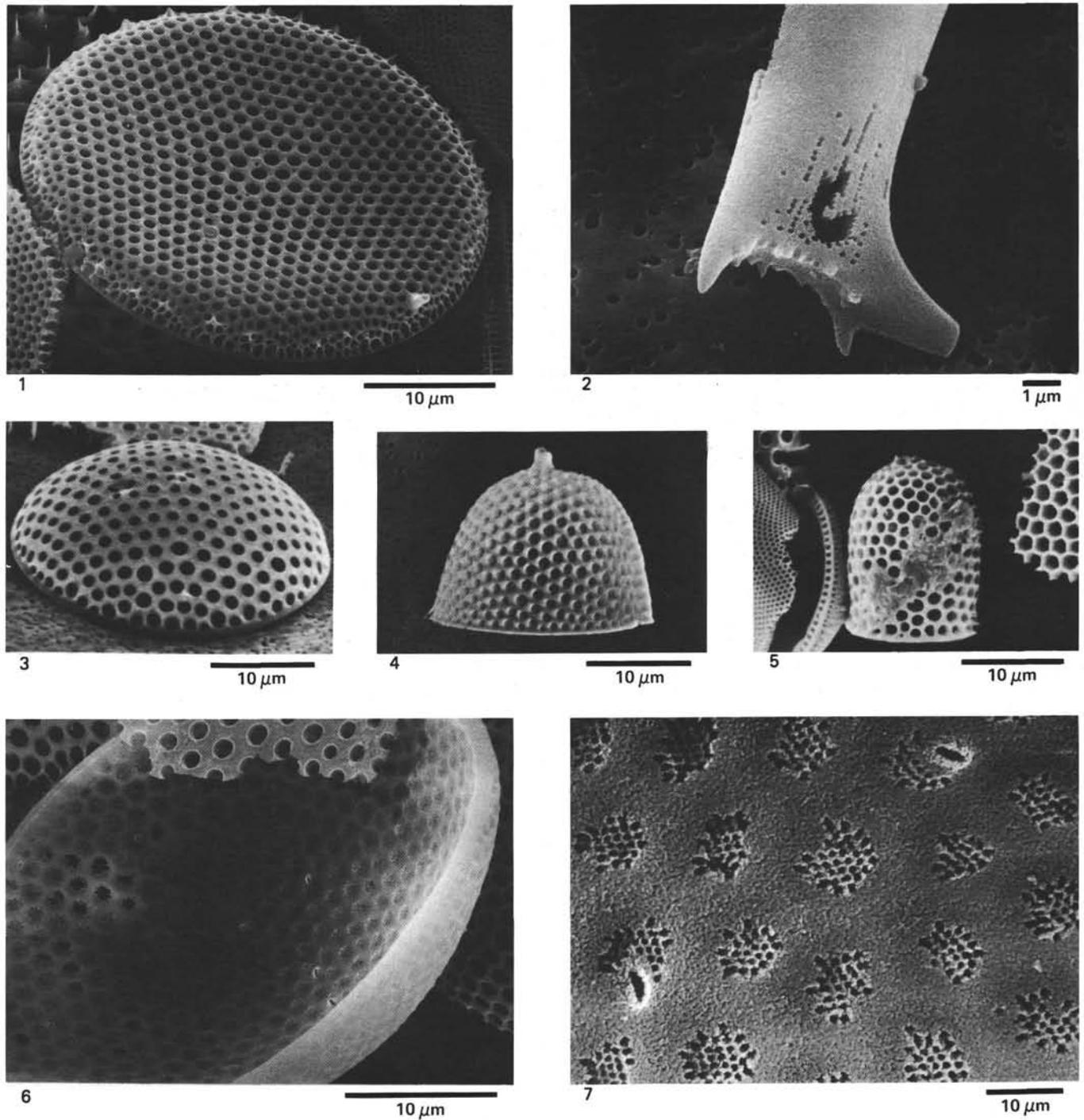
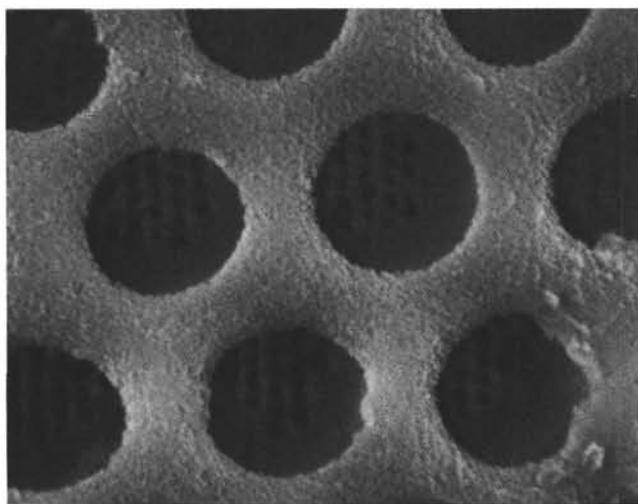
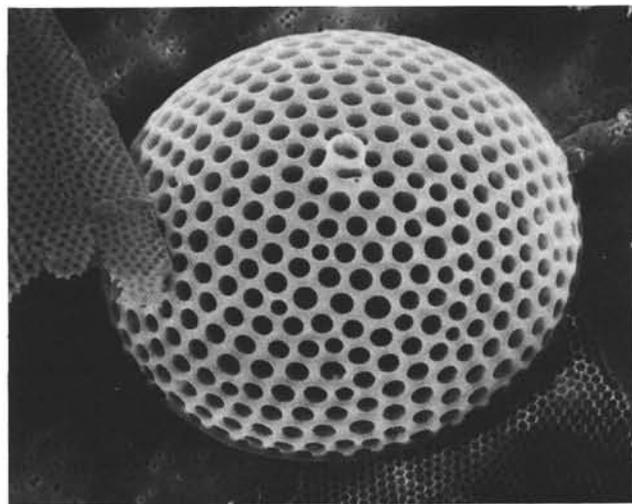


Plate 1. SEM photographs from Sample 532-26-2, 147-148 cm. 1. *Thalassiosira eccentrica*,  $\times 1924$ . 2. *Rhizosolenia barboi*,  $\times 6068$ . 3-7. *Stephanopyxis apiculata*, (3)  $\times 1480$ , (4)  $\times 1591$ , (5)  $\times 1480$ , (6) internal view,  $\times 2220$ , (7) detail from 6,  $\times 11,100$ .



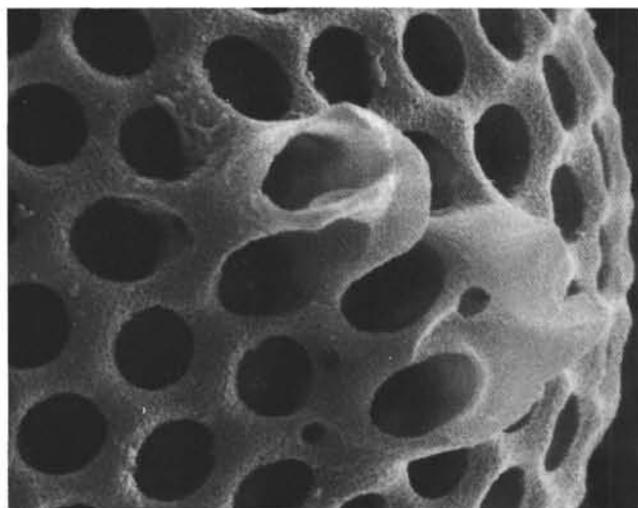
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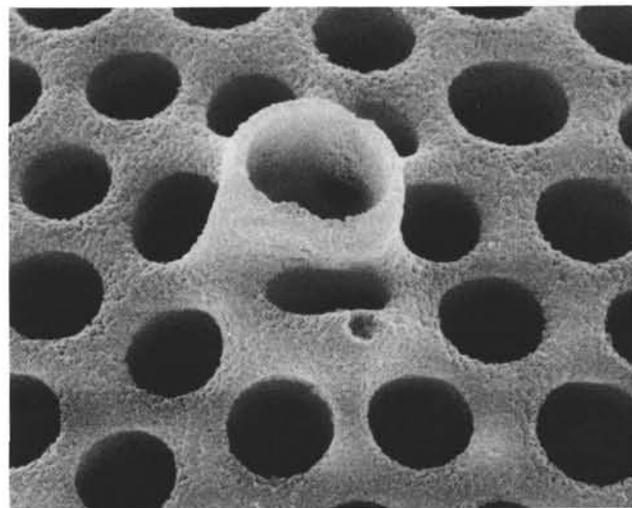
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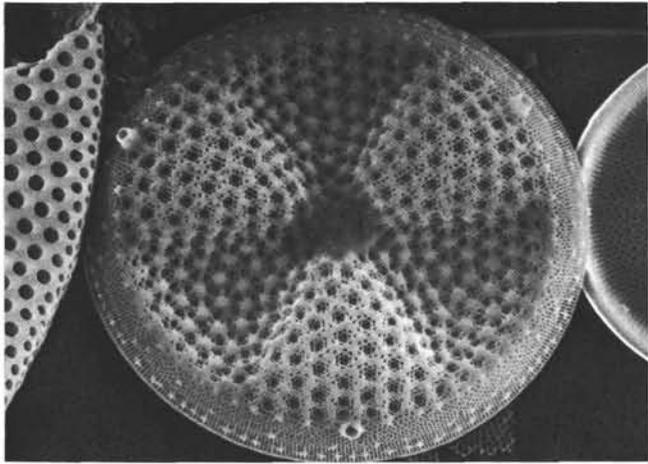
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4

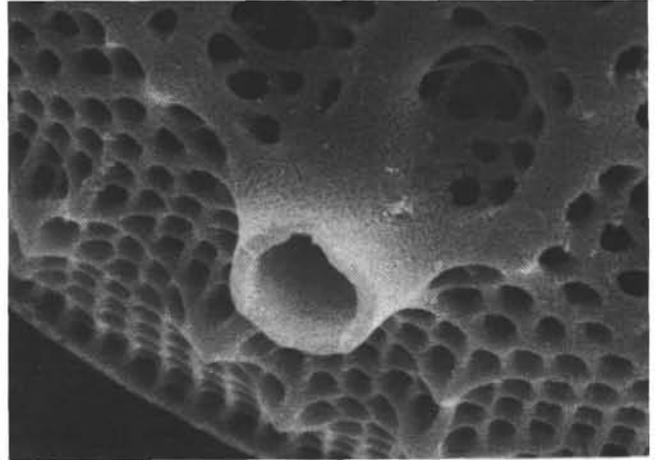
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Plate 2. SEM photographs of *S. apiculata* from Sample 532-26-2, 147–148 cm. 1. Detail of external view,  $\times 16,287$ . 2.  $\times 2,225$ . 3. Detail of outer view, valve center,  $\times 8900$ . 4. Detail of 2,  $\times 10,680$ .



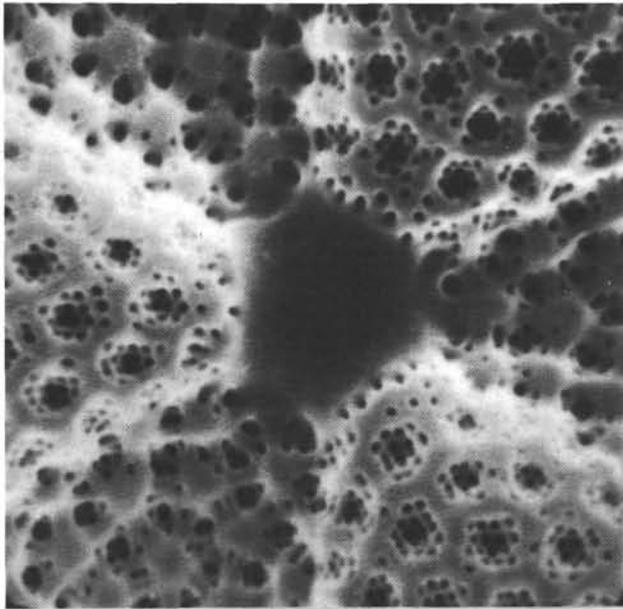
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10 μm



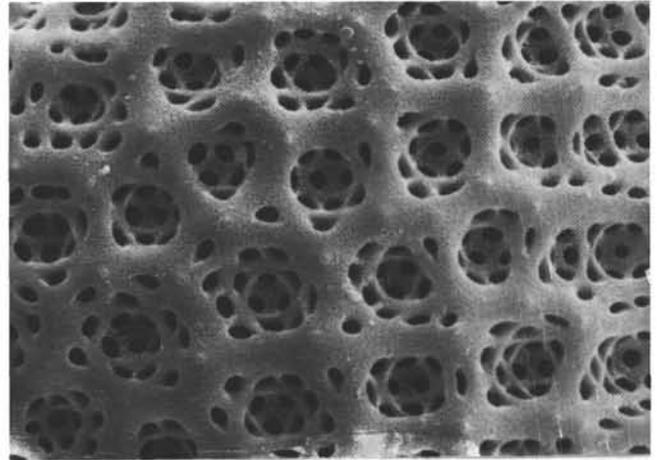
2

1 μm



3

1 μm



4

1 μm

Plate 3. SEM photographs of *Actinoptychus senarius* from Sample 532-26-2, 147-148 cm. 1.  $\times 1209$ . 2. Detail of mantle and margin with process,  $\times 15,600$ . 3. Detail of central area,  $\times 6396$ . 4. Detail of raised sector showing loculi,  $\times 7800$ .