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Actinocyclus ingens var. *nodus* : a New, Stratigraphically Useful Diatom of the Circum-North Pacific

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ABSTRACT

Actinocyclus ingens var. *nodus* Baldauf, n. var., is a morphologically distinct variety of the Miocene diatom *A. ingens* Rattray. The last occurrence of this new taxon approximates the top of the lower Middle Miocene *Denticula lauta* Zone in the circum-North Pacific. Its first occurrence appears to be in the lower part of the *D. lauta* zone and possibly lies close to the Lower Miocene-Middle Miocene boundary.

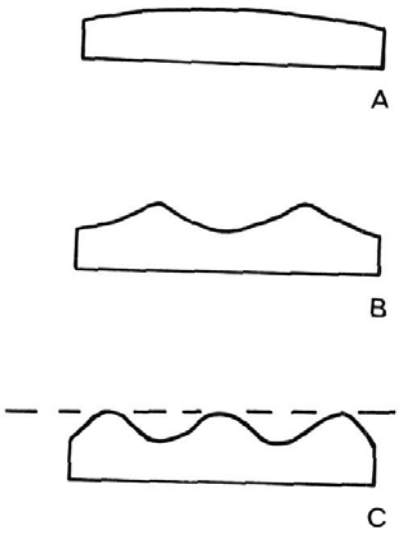
INTRODUCTION

Actinocyclus ingens Rattray (1890) is a common constituent of middle Miocene diatom assemblages throughout the world. It is recorded from broad areas of the North Pacific (Kanaya, 1971; Koizumi, 1973, 1975; Schrader, 1973, 1974; Barron, in press), from the equatorial Pacific (Gombos, 1975), from the North Atlantic (Schrader and Fenner, 1976; Bukry, 1978; Schrader, 1979), from the South Atlantic (Gombos, 1977; Fenner, 1978), and from Antarctic waters (McCollum, 1975; Schrader, 1976). The geologic range of *A. ingens* is generally considered to be late Early Miocene to Late Miocene (Barron, in press), although it occurs in Pliocene and Quaternary sediments off Antarctica, where it may be reworked (Schrader, 1976). Jousé (1977) considered the Antarctic form to be *Coscinodiscus margaritaceous* Castracane.

Rattray's (1890) type description of *A. ingens* states that the valve surface rises gradually from the center to its highest point, at about two-fifths of the radius, then slopes down toward the border. Modern diatomists, however, have adopted a broad concept for *A. ingens* and have included specimens that have both flat and undulating valve surfaces (Koizumi, 1968, 1973; Kanaya, 1971; Gombos, 1977; Fenner, 1978). Furthermore, the pseudonodule of *A. ingens* is not easily observed, and specimens lacking a pseudonodule and otherwise referable to *Coscinodiscus elegans* Greville (1866) are often grouped with *A. ingens* (Kanaya, 1971). *Coscinodiscus novazealandicus* sensu Hanna (1932) is also referable to *A. ingens*.

Kanaya (1971) observed that concentric undulating valve surfaces are generally more pronounced on larger specimens of *A. ingens*, whereas smaller specimens tend to be flat. He further pointed out that specimens that best meet Rattray's type description are found among middle-sized specimens, but "they cannot be distinguished from others because of the presence of intermediate forms which connect individuals of various sizes in a continuous chain from one extreme to another." Numerous workers including Koizumi (1973), Gombos (1977), and Fenner (1978) have recognized such variations in the morphology of *A. ingens* and have followed Kanaya's (1971) reasoning for not subdividing the species.

In our studies of Miocene diatoms from the North Pacific area, we have also observed this wide variation in the morphology of *A. ingens*. We agree with Kanaya (1971) that specimens with an undulating valve surface and a depressed center show a gradation to flatter forms (pl. 1, figs. 1-4). We have also noted, however, that in some undulated specimens, the center of the valve rises to an equal elevation as the submarginal ring (pl. 1, figs. 5–9). This latter form of *A. ingens* probably



TEXT-FIGURE 1
Schematic cross-section of various forms of *Actinocyclus ingens* Rattray. A, flat form; B, form with undulating valve surface and depressed center. Type concept of Rattray (1890), included in this form. Continuous gradation exists between this form and flat form; C. *Actinocyclus ingens* var. *nodus* Baldauf, n. var. Valve surface undulating, with center raised to equal elevation with submarginal ring.

develops from other undulated forms; however, it is morphologically distinct and can easily be separated from them (text-fig. 1). Barron (in press) reported that this undulated form of *A. ingens* with a raised center may have stratigraphic utility in Miocene sediments off northeastern Japan. Consequently, this form is proposed below as a new variety of *A. ingens*, *A. ingens* var. *nodus* Baldauf, and its stratigraphic occurrence is documented in the Middle Miocene and Upper Miocene section exposed around Upper Newport Bay in Newport Beach, California.

TABLE 1
Occurrence of *Actinocyclus ingens* var. *ingens* and *A. ingens* var. *nodus*, n. var., in samples from Upper Newport Bay section (A = abundant, C = common, F = few, R = rare). Samples are those of Barron (1976).

Stratigraphic Interval (m)	Sample	*Actinocyclus ingens* var. *ingens*.	*Actinocyclus ingens* var. *nodus*
195	NEW 61	F	
195	UM	R	
192	NE 20	F	
185	NE 19	R	
184	NEW 57	A	
177	NE 18	R	
171	NE 17	R	
169	"NEW 51"	C	
168	NE 16	F	
160	"NEW 48"	F	
158	NE 15	C	
151	NE 14	F	
149	NEW 42	F	
140	Tm 19	F	
122	NE 13	R	
115	Tm 18	R	
99	NE 12	F	
95	Tm 17	F	
91	NE 11	F	
78	NE 10	C	
75	Tm 14	A	
66	Tm 9	C	R
55	NE 9	A	F
49	NE 8	A	F
32	NE 7	F	F
27	NE 6	F	F
21	NE 5	C	C
12	NE 4	C	C
9	NE 3	A	F
3	NE 2	C	R
0	NE 1	A	R
0	NEW 5	A	R

TAXONOMY

Actinocyclus ingens var. ***nodus*** Baldauf, **n. var.**
Plate 1, figures 5–9

Actinocyclus ingens RATTRAY, in Jousé, 1977, pl. 53, fig. 1.
Actinocyclus ingens variety 1.—BARRON, in press, pl. 5, figs. 8, 12.

Description: Valve circular, 35 to 65 μm in diameter, concentrically undulated, with raised central and submarginal ring areas separated by a continuous depression. The central area is an areolated node covering approximately 1/5 of the diameter. The width of the adjacent depression varies among specimens. The submarginal raised ring is distinct and is the same height as the central area.

Areolae are subrounded and arranged in radially lineate rows. Primary rows extend the length of the radius, whereas secondary rows extend from the depression region to the margin. Areolae are larger (5 in 10 μm) in the central and submarginal ring zones and are surrounded by hyaline areas. Areolae decrease in size (9 in 10 μm) in the submarginal area, where they are indistinctly separated.

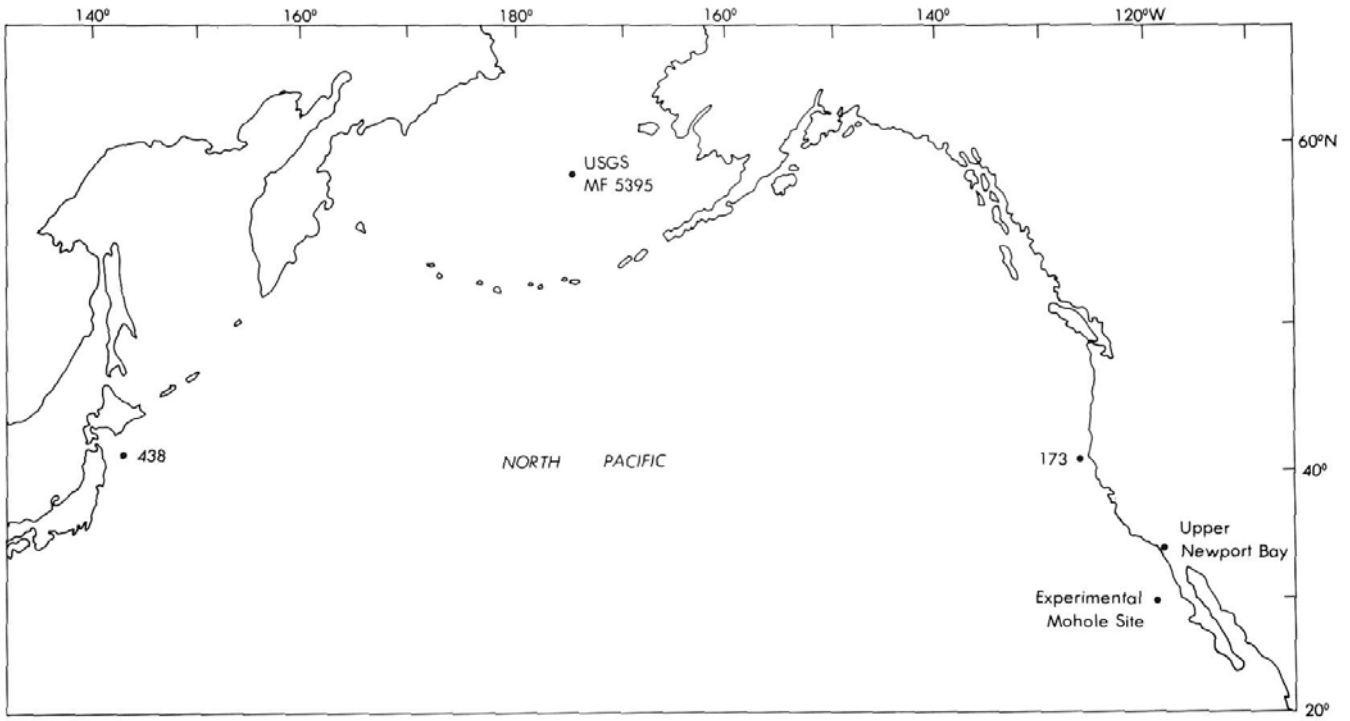
The pseudonodule near the margin is similar to that in *Actinocyclus ingens* Rattray, where it is described as obscure, sharply angular, with irregular edges (pl. 1, fig. 8).

Remarks: Actinocyclus ingens var. *nodus* Baldauf differs from *A. ingens* Rattray (1890) var. *ingens* by the presence of a raised central area, which is equal in height to the raised submarginal ring. Rattray's (1890) type concept of *A. ingens* includes specimens with depressed center and raised submarginal rings (see text-fig. 1).

Etymology: nodus (Latin), knot or swelling.

Occurrence: Presently known only from the circum-North Pacific, lower Middle Miocene, *Denticula lauta* Zone of Koizumi (1975), North Pacific diatom Zones XXIII-XXI of Schrader (1973).

Holotype: USNM 689949, sample NE 9 (of Barron, 1976) (55 m), Monterey shale, Upper Newport Bay,



TEXT-FIGURE 2
Map of high-latitude North Pacific showing location of various sections discussed.

Newport Beach, California (pl. 1, fig. 7). Size 64 μm in diameter.

Isotypes: USNM 689950 to 689952.

STRATIGRAPHIC OCCURRENCES IN THE UPPER NEWPORT BAY SECTION

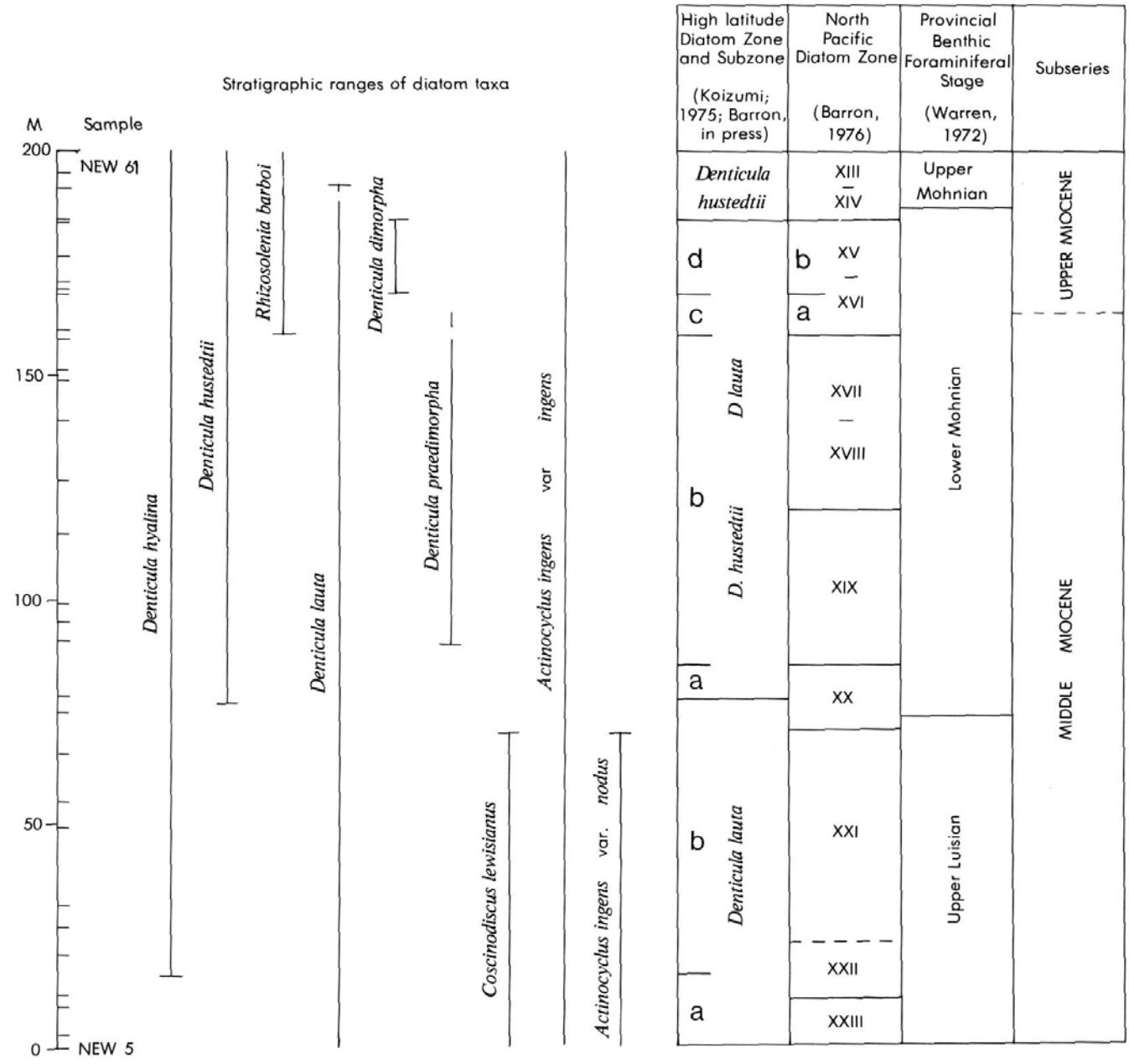
Abundant and well-preserved Middle Miocene to Early Pliocene diatoms are documented by Wornardt (1973) and Barron (1975, 1976) in exposures of the Monterey Shale around Upper Newport Bay in Newport Beach, California (text-fig. 2). Within this section, Barron (1976) recorded *Actinocyclus ingens* as most common and consistent in the lower part (middle Miocene to upper Miocene), which is exposed on the eastern side of the bay. This part of the section includes the samples from which *A. ingens* var. *nodus* has been described. In order to document the stratigraphic range of *A. ingens* var. *nodus* at Upper Newport Bay, the 32 samples of Barron (1976) were reexamined.

The stratigraphic occurrences of *Actinocyclus ingens* var. *ingens* and *A. ingens* var. *nodus* in these samples are shown in table 1. An entire microscope slide (22 X 40 mm cover glass size) of unsieved acid residue was examined under the light microscope at X 500. Specimens were recorded as "abundant" if at least 1 individual was present in each field of view; "common" if 1 individual was encountered in 5 fields of view; "few" if present in each horizontal traverse (length 40 mm); and "rare" if there were sparser occurrences.

Actinocyclus ingens var. *nodus* ranges from the base of the section (sample NEW 5) to a horizon 66 m above the base (sample Tm 9). Therefore, *A. ingens* var. *nodus* ranges from North Pacific diatom Zone XXIII to the top of North Pacific diatom Zone XXI of Barron (1976). Barron (1976) assigned this interval to the lower Middle Miocene, and Warren (1972) placed the benthic foraminifers of this interval within the upper part of the provincial benthic foraminiferal Luisian Stage (text-fig. 3). Although not recorded in table 1, we observed that undulated specimens of *A. ingens*, in general, are also restricted to the lower parts of this section. This supports Kanaya's (1971) observation that undulated specimens of *A. ingens* do not occur above the Middle Miocene in the Experimental Mohole Drilling Site section off Baja California, Mexico (28°59′ N, 117°30′ W).

UPDATED DIATOM BIOSTRATIGRAPHY AT UPPER NEWPORT BAY

Barron (in press) defined biostratigraphic subzones for the high-latitude North Pacific diatom zonation of Koizumi (1975) that can be recognized throughout the middle- and high-latitude North Pacific for the Middle and Upper Miocene. In many cases the boundaries of these subzones were chosen so that they



TEXT-FIGURE 3
Stratigraphic section at Upper Newport Bay showing stratigraphic position of samples studied (Barron, 1976) and ranges of selected diatoms including *Actinocyclus ingens* var. *nodus*. Right side of figure, diatom biostratigraphy of this report (left column) listed with that of Barron (1976) and benthic foraminiferal biostratigraphy of Warren (1972).

corresponded with zonal boundaries of the North Pacific diatom zonation of Schrader (1973) and Barron (1976).

As a part of this study, samples from the lower section at Upper Newport Bay have been reexamined and correlated with Barron's (in press) refinement of Koizumi's (1975) diatom zonation (text-fig. 3). Whereas Barron (1976) recorded *Denticula hustedtii* Simonsen and Kanaya as ranging to the base of the Upper Newport Bay section, we did not observe this taxon below sample NE 10 (78 m). Specimens from below 78 m that were assigned to *D. hustedtii* by Barron (1976) are here reassigned to *D. lauta* Bailey. Another difference from the results of Barron (1976) regards the range of *Denticula dimorpha* Schrader. Akiba (1979) recently separated from this species specimens in which the crossbars are not united to the septum. He included such specimens in the new species *D. praedimorpha* Akiba (1979). Following Barron's (in press) zonation, the first occurrence of *D. praedimorpha* at 91 m in the Upper Newport Bay section marks the base of Subzone b of the *Denticula hustedtii-Denticula lauta* Zone, and the first occurrence of *D.*

dimorpha s. str. at 169 m marks the base of Subzone d of the *D. hustedtii-D. lauta* Zone (text-fig. 3). Barron (in press) places the middle Miocene-upper Miocene boundary of Ryan and others (1974) in Subzone c of the *D. hustedtii-D. lauta* Zone. The lowest part of the Upper Newport Bay section, including the entire local range of *A. ingens* var. *nodus*, is divided into Subzones a and b of the *Denticula lauta* Zone by the first occurrence of *D. hyalina* Schrader in sample NE 4 (12 m).

OCCURRENCES ELSEWHERE IN THE CIRCUM-NORTH PACIFIC

At Deep Sea Drilling Site 438 (lat. 40°37.79′ N, long. 143°14.15′ E) (text-fig. 2), Barron (in press) recorded that specimens synonymous with *Actinocyclus ingens* var. *nodus* (*A. ingens* var. 1 of Barron, in press) range from about 821 m to 689 m in the section. The lowest occurrence is in the lower part of the *Denticula lauta* Zone (Subzone a) and probably lies close to the Lower Miocene-Middle Miocene boundary (Barron, in press), but poor to moderate preservation in that interval makes it doubtful whether this is a true first occurrence. The highest occurrence of *A. ingens* var. *nodus* is immediately below the first common occurrence of *Denticula hustedtii*, a horizon which probably correlates with the first occurrence of *D. hustedtii* at Upper Newport Bay and in the low-latitude North Pacific (DSDP Site 77). *Denticula hustedtii* first occurs at 699 m in the section at Site 438, so that the overlap of the ranges of *A. ingens* var. *nodus* and *D. hustedtii* is about 10 m.

Samples from DSDP Site 173 (lat. 39°57.71′ N, long. 125°27.12′ W) off the northern California coast (text-fig. 2) were examined briefly, and *A. ingens* var. *nodus* was observed in Cores 28 and 29 (252.0–271.5 m). This interval is assigned to North Pacific diatom zones XXIII and XXII by Schrader (1973) and to the *Denticula lauta* Zone by Koizumi (1977).

Finally, *Actinocyclus ingens* var. *nodus* has been recorded in material dredged from the Bering Sea (sample USGS Mf5395) (lat. 57°53′ N, long. 174°22.3′ W) that is correlated with the *Denticula lauta* Zone (Barron, unpublished data, 1979) (text-fig. 2).

The last occurrence of *Actinocyclus ingens* var. *nodus* thus approximates the top of the *Denticula lauta* Zone of Koizumi (1975) in the North Pacific. Relationships at Upper Newport Bay show that it is close to the boundary between the Luisian and Mohnian provincial benthic foraminiferal stages of California. Data from DSDP Site 438 imply that the first occurrence of *A. ingens* var. *nodus* is within the lower part of the *D. lauta* Zone; however, this requires further documentation.

Warren (1972) reported that the top of the *Sphenolithus heteromorphus* nannofossil zone is close to the Luisian-Mohnian boundary in the Upper Newport Bay section, and, therefore, it approximates the top of the *Denticula lauta* Zone in that section (text-fig. 3). Unpublished data acquired by Barron and David Bukry during DSDP Leg 63 off southern California and Baja California also show that the top of the *D. lauta* Zone correlates fairly closely with the top of the *Sphenolithus heteromorphus* Zone of Bukry (1973). Koizumi (1977) estimated that the absolute age of the top of the *D. lauta* Zone is about 14.0 Ma (million years before present) on the basis of a radiometric date from Japan. This is in good agreement with Bukry's (1975) estimate of 14.0 Ma for the top of the *S. heteromorphus* Zone. Relationships at Upper Newport Bay and at Site 438 consequently suggest that the last occurrence of *A. ingens* var. *nodus* is at about 14.0 Ma in the North Pacific.

Actinocyclus ingens is a fairly robust, dissolution-resistant species. It is commonly one of the few species remaining in strongly dissolved Middle Miocene assemblages (Barron, unpublished data, 1979). *Actinocyclus ingens* var. *nodus*, therefore, is likely to be a valuable taxon for correlating dissolved sequences with the *D. lauta* Zone.

In summary, *Actinocyclus ingens* var. *nodus* is morphologically distinct and is stratigraphically useful in the lower Middle Miocene of the circum-North Pacific. Whether *A. ingens* var. *nodus* is present or stratigraphically useful in areas outside the North Pacific awaits future study.

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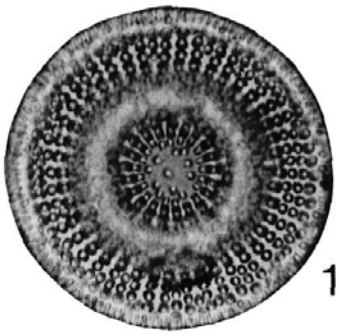
PLATE 1

1–4 *Actinocyclus ingens* Rattray var. *ingens*
Gradation from flat forms (fig. 4) through forms with increasingly undulated valve surfaces (figs. 1–3). 1, sample USGS Mf5395, Bering Sea, scale bar equals 12 μm. This specimen closely approximates the type concept of Rattray (1890); 2, sample NE9, Newport Beach, California, scale bar equals 12 μm; 3, sample Tm9, Newport Beach, California, scale bar equals 3 μm; 4, sample NE1, Newport Beach, California, scale bar equals 3 μm.

5–7 *Actinocyclus ingens* var. *nodus* Baldauf, n. var.
5, isotype USNM 689950, sample NE9, Newport Beach, California. Scale bar equals 12 μm; 6, Deep Sea Drilling Project, sample 438A-70-5, 121–123 cm. Scale bar equals 12 μm; 7, holotype USNM 689949, sample NE9, Newport Beach, California. Diameter 64 μm.

8–9 Scanning electron micrographs of *Actinocyclus ingens* var. *nodus*.
Specimens show that center of valve is raised to same height as submarginal ring. Monterey shale, Newport Beach, California. 8, isotype USNM 689951, sample NE3. Pseudonodule near 12 o'clock position; 9, isotype USNM 689952, sample NE3.



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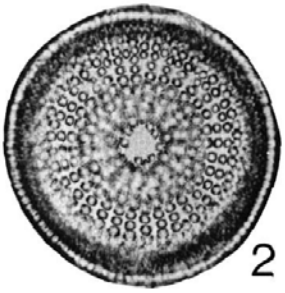

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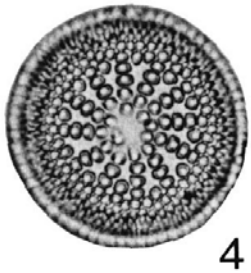

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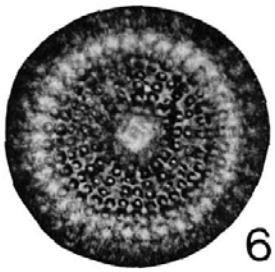

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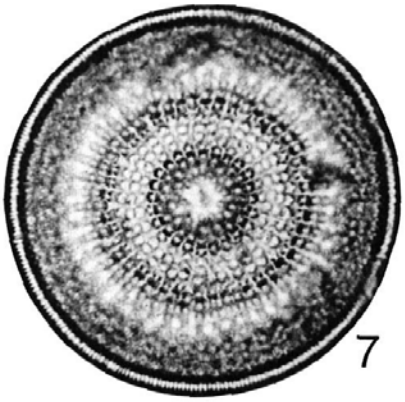

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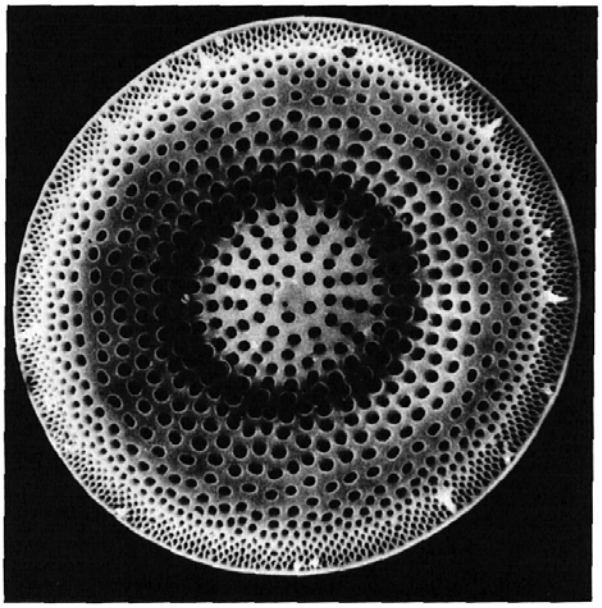

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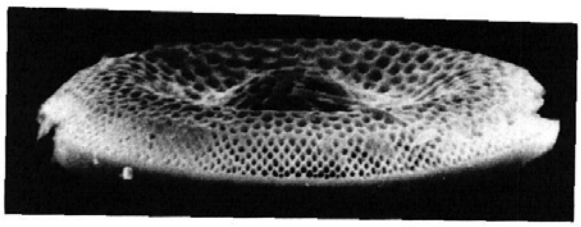

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