

# The Diatom Genus *Actinocyclus* in the Western United States

A. *Actinocyclus* Species from Lacustrine Miocene Deposits of the Western United States

B. Geologic Ranges of Lacustrine Species, Western United States

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J. Platt Bradbury and William N. Krebs, Editors

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By J. Platt Bradbury *and* William N. Krebs

B. Geologic Ranges of Lacustrine *Actinocyclus* Species, Western United States

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- (A) *Actinocyclus* (Bacillariophyta) species from lacustrine Miocene deposits of the Western United States, by J. Platt Bradbury and William N. Krebs
- (B) Geologic ranges of lacustrine *Actinocyclus* species, Western United States, by William N. Krebs and J. Platt Bradbury

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THE DIATOM GENUS *ACTINOCYCLUS* IN THE WESTERN UNITED STATES

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# ACTINOCYCLUS (BACILLARIOPHYTA) SPECIES FROM LACUSTRINE MIOCENE DEPOSITS OF THE WESTERN UNITED STATES

By J. PLATT BRADBURY and WILLIAM N. KREBS

## ABSTRACT

Species of the diatom genus *Actinocyclus* Ehrenberg were important constituents of lacustrine phytoplankton in the Western United States during much of the early and middle Miocene (19–10 Ma). Similar and (or) identical fossil *Actinocyclus* species are found elsewhere in the world, particularly in Eurasia, in Neogene lacustrine diatomaceous rocks. Ten new species of fossil lacustrine *Actinocyclus* (*A. acanthus*, *A. cedrus*, *A. claviolus*, *A. cupreus*, *A. motilis*, *A. nebulosus*, *A. pinnulus*, *A. theleus*, *A. venenosus*, and *Actinocyclus gorbunovii* var. *fossa*) are described and a new name (*A. krasskei*) is proposed based on the study of samples from 115 localities in the Western United States that range in age from the early Miocene to Pleistocene. Seventy of these localities contain *Actinocyclus*. Diagnostic characteristics include degree and nature of fasciculation, size of pseudonodule, areolae density, disposition and shape of hyaline stripes on the valve disk and mantle, degree of undulation, diameter, presence and nature of marginal tubular processes and spines, size and shape of areolae, and character of labiate processes.

## INTRODUCTION

The diatom genus *Actinocyclus* characterized open-water lacustrine environments in the Western United States during much of the early and middle Miocene (19–10 Ma). Fossil localities containing *Actinocyclus* are found in diatomites and diatomaceous shales deposited in paleolake systems of Nevada, Idaho, California, Oregon, and Washington (Krebs and others, 1987). The forms of *Actinocyclus* found in these deposits resemble those from other parts of the world (for example, Bradbury and Krebs, 1982; Bradbury, 1984; Bradbury and others, 1985), particularly from Eurasia, where a number of distinct taxa have been described. Radiometric dates associated with *Actinocyclus* occurrences in the

United States suggest that some of the forms have biochronologic value. Preliminary information about the geologic distribution of related taxa in other parts of the world indicates that this group may have potential for use in a worldwide lacustrine diatom biochronology.

This report describes and presents light and scanning electron microscope photographs of several distinctive *Actinocyclus* species from the Western United States. An artificial key based on characters observable in the light microscope assists separation of these morphologically variable taxa. The key includes a few European taxa, some of which also appear in the United States, and two modern nearshore marine species that can live in limnic environments. One of these species, *Actinocyclus normanii* f. *subsalsa* (pl. 12, figs. 2-5), lives today in the Great Lakes and has been recovered from late Holocene sediments of Lake Ontario (Stoermer and others, 1985).

The appropriate morphological characters for taxonomic separation of *Actinocyclus* are still largely unknown. The variability of surface areolae patterns (for example, fasciculation), degree of undulation, and mantle characteristics is great in these centric diatoms, and may be environmentally controlled to some degree (Theriot and Stoermer, 1984). Study of smaller structures, such as labiate processes, external processes and pseudonodules, and their morphometric relationships may be required to understand the natural classification of these diatoms. We do not resolve these questions, but we do present guidelines for the consistent description and identification of *Actinocyclus* species applicable to biostratigraphy and paleoecology.

## ACKNOWLEDGMENTS

We particularly acknowledge the efforts of Kathryn Dieterich-Rurup in securing scanning electron microscope photographs of the *Actinocyclus* species illustrated in the accompanying plates. Horst Lange-Bertalot photographed

Krasske's type material of *Coscinodiscus* (*Actinocyclus*) *miocenicus* and *C. (=A.) variabilis*. E.C. Theriot, Reimer Simonsen, Simone Servant-Vildary, and G.K. Khursevich have all provided many helpful discussions and insights into the morphological variations and taxonomic-descriptive problems with *Actinocyclus*. Simone Servant-Vildary, Rainer Gersonde, S.W. Starratt, L.H. Burckle, and Fumio Akiba kindly supplied comparative material. J.A. Barron and Elisabeth Fourtanier reviewed the manuscript and provided many useful suggestions. We thank all these individuals for their interest in this study.

## MATERIALS AND METHODS

Diatomites, diatomaceous tuffs, and lacustrine shales have been sampled from outcrops and wells in the Western United States. The locality numbers referred to in the text refer to these sites whose age (if known) and locations are given in Appendix 1 and figure 2 of Krebs and Bradbury (Chapter B).

To minimize contamination by water and airborne diatoms (Sovereign, 1963), outcrops were cleaned in the field to a depth of about 5 cm during sampling, and material representing 1–5 cm of stratigraphic thickness was removed and placed in air-tight plastic bags. About 1 cc of diatomaceous sediment, with all surfaces cleaned a second time, was disaggregated in distilled water and boiled in concentrated nitric acid. The samples, once rinsed of all traces of acid, were mounted in Hyrax ( $n=1.60$ ). Observations for species descriptions were made with a compound microscope (LM) at appropriate magnifications.

An aliquot of the diatom preparation was settled on a scanning electron microscope (SEM) stub and sputter-coated with gold/palladium. SEM photographs of selected specimens were taken with a JEOL 35 C scanning electron microscope. In general, internal surfaces of diatoms are better preserved than external surfaces (Bradbury, 1984), but where appropriate, SEM documentation of both sides of the diatom was made to illustrate external characteristics necessary for identification. Type and LM-figured specimens are located on designated 2.54×7.62 cm microscope slides by England Finder (E.F.) coordinates.

## CHOICE OF GENERIC EPITHET

*Coscinodiscus*, *Cestodiscus*, *Stephanodiscus*, *Pontodiscus*, and *Actinocyclus* have all been used as generic epithets for fossil lacustrine centric diatoms that possess a marginal ring of laterally expanded (fan-shaped) labiate processes and radial-fasciculate areolation (for example, Krasske, 1934; Lohman, 1957; Hajós, 1970; Temniskova-Topalova and

others, 1981; Bradbury, 1984). The very close similarity of *Pontodiscus* and *Cestodiscus* (Radionova, 1987) suggests that some of these names might be synonymous.

Bradbury (1984) confirmed the presence of a pseudonodule on Neogene lacustrine centric diatoms from Idaho and China supporting their inclusion in the genus *Actinocyclus* (see also, Simonsen, 1975). Nevertheless, in some marine species of *Actinocyclus*, the pseudonodule is tiny and difficult to distinguish from a normal areola (Watkins and Fryxell, 1986), and Radionova (1987) maintained that *Cestodiscus* may or may not have a pseudonodule. She distinguished this genus from *Actinocyclus* by the form of the labiate process (mushroom-shaped in *Cestodiscus* and nozzle-shaped in *Actinocyclus*) and by the character of the velum covering the areolae (star-shaped perforations in *Cestodiscus* and sieve-like openings in *Actinocyclus*) (Radionova, 1987). Marginal hyaline stripes of unadorned silica, positioned above and around the openings of the labiate processes characterize many *Cestodiscus* species (Radionova, 1987), but these structures are also present on diatoms referred to *Actinocyclus* (Simonsen, 1982).

The choice of the generic epithet for these centric diatoms clearly depends upon whether expanded or restricted generic definitions are employed. SEM examination of representatives of type species may suggest the synonymy of some genera. Labiate process morphology in nonmarine diatoms of the family Hemidiscaceae is variable and easily altered by corrosion in fossil forms. Pseudonodules may be obscured by debris or overgrowths of silica and clay minerals, further complicating the use of these structures for generic classification. At this time, there is no compelling reason to use the name *Cestodiscus* for these otherwise clearly *Actinocyclus*-like diatoms, and the latter name is retained for this study. *Coscinodiscus* appears to be genuinely different (as shown by Radionova, 1987), although it is still not properly typified, and at least some *Pontodiscus* species have been incorporated into *Actinocyclus* (Khursevich and others, 1990).

The species of *Actinocyclus* described in this report have been separated by more or less obvious, if variable, morphological differences. It can be argued (compare Mann, 1988) that each paleolake contained its own *Actinocyclus* species, particularly when such paleolake systems were temporally separated by hundreds of thousands or millions of years. Such great temporal and geographic separation with concomitant differences in climate, geology, hydrology, and ecology reduce the likelihood of potential biological interaction between individuals of *Actinocyclus* despite their morphological similarity. Nevertheless, the morphological units described here are moderately consistent and at least imply similar environmental controls on *Actinocyclus* that can be meaningful for biostratigraphic and paleoecologic ends.

## KEY FOR SEPARATION OF SOME NONMARINE SPECIES OF *ACTINOCYCLUS*

The following key organizes the characters of the non-marine species of *Actinocyclus* described in this report and a few others described elsewhere to facilitate their separation and identification. The species of *Actinocyclus* are quite variable, yet morphologically similar, and examination of a moderately large series of specimens is required to obtain an appreciation of the variation and a general sense of their structural characteristics. Even so, intermediate forms often occur that defy simple classification. Specimens at the very large and very small ends of the size spectrum may be difficult to sort out with this key.

- A. Fasciculate: clearly defined sectors of areolae rows.
- B. Fascicles marked off only by radial rows of areolae.
- C. Pseudonodule large, conspicuous; areolae on marginal  $\frac{1}{3}$  of disk in more or less regular tangential rows; often in brackish water. *Actinocyclus ehrenbergii* Ralfs, (pl. 6, fig. 3).
- C. Pseudonodule tiny, difficult or impossible to see in LM, especially in heavily silicified individuals; areolae on marginal  $\frac{1}{3}$  of disk in undulating, disorganized rows. Areolae within fascicles parallel. *Actinocyclus nebulosus*, (pl. 11, figs. 3, 4).
- C. Pseudonodule small, but generally visible in LM. Marginal areolae not in widely spaced undulating rows. Areolae within fascicles subparallel/subradial. *Actinocyclus cupreus*, (pl. 5, figs. 6, 7)
- B. Fascicles marked off by a combination of radial rows of areolae and (or) comparatively long, hyaline stripes originating at labiate process exit pore near disk/mantle juncture.
- C. Hyaline stripes extending about  $\frac{1}{3}$  the distance toward the valve center and continuing in a radial row of areolae (see Frenguelli, 1928; Krasske, 1934). *Coscinodiscus* (= *Actinocyclus*) *variabilis* (*sensu* Krasske, 1934), (pl. 14, figs. 5, 6).
- C. Fascicles marked off only by long hyaline stripes that extend nearly to the valve center (see Schauderna, 1983). *Actinocyclus kanitzii* (Pant. and Grun.) Schauderna, (pl. 8, fig. 1).
- C. Fascicles marked off by pyriform or clove-shaped hyaline stripes with narrow, pointed ends that extend a short distance towards the valve center; the remaining fascicle boundary composed of a radial row of areolae. *Actinocyclus claviolus*, (pl. 5, figs. 1, 2).
- B. Fascicles marked off only by directional incongruity between adjacent sets of subparallel areolae rows. Hyaline stripes absent (see Hasle, 1977). *Actinocyclus normanii* (Juhl.-Dannf.) Hustedt, (pl. 12, figs. 2, 3).
- A. Nonfasciculate: no clear sectors or fascicles of areolae, or fascicles irregularly formed, difficult to define or highly variable on specimens of different size. Hyaline stripes mark location of labiate processes.
- B. >12 areolae/10  $\mu\text{m}$  (usually 14–18).
- C. Marginal processes present, located on the exit pore of labiate process.
- D. Marginal processes conspicuous.
- E. Marginal processes narrow tubes with lateral, fin-like projections. *Actinocyclus pinnulus*, (pl. 13, fig. 1).
- E. Marginal processes are broad, irregularly forked tubes 1–2  $\mu\text{m}$  long. *Actinocyclus nordlingensis* Schauderna, (not figured).
- E. Marginal process usually angled, unforked rather broad tubes, occasionally adorned with lateral spines. *Actinocyclus acanthus*, (pl. 1, fig. 3).
- D. Marginal processes inconspicuous.
- E. Marginal process is a low, small, shield-like bump or nipple; often difficult to observe, fine areolation, 13–18 areolae/10  $\mu\text{m}$ , diameter typically <30  $\mu\text{m}$ . *Actinocyclus theleus*, (pl. 14, fig. 1).
- E. Marginal processes slender, unornamented tubes on hyaline stripes. *Actinocyclus tubulosus* (pl. 8, fig. 7) Khursevich (Khursevich and others, 1990).
- C. Marginal processes at labiate process exit pore absent.
- D. Diameter 20–70  $\mu\text{m}$ , valve conspicuously undulate, weakly undulate, or flat, areolae generally 12–13/10  $\mu\text{m}$ . *Actinocyclus krasskei* (Krasske), (pl. 8, figs. 2–8).
- E. Valve conspicuously undulate, often >50  $\mu\text{m}$  in diameter. *Actinocyclus krasskei* (undulate form), (pl. 8, fig. 5).
- E. Valve flat or weakly undulate, diameter typically <50  $\mu\text{m}$ . *Actinocyclus krasskei* (pl. 8, fig. 2).
- D. Diameter 30–70  $\mu\text{m}$ , valve conspicuously undulate, areolae 14–18/10  $\mu\text{m}$ . A “moat” surrounds the pseudonodule. *Actinocyclus gorbunovii* var. *fossa*, (pl. 7, fig. 3).
- B. <12 areolae/10  $\mu\text{m}$
- C. Areolae large (1+  $\mu\text{m}$ ), closely packed, typically 7–10/10  $\mu\text{m}$ , polygonal in outline.

- D. Conspicuous, generally pointed hyaline stripes enclosing exit pore and extending onto the valve disk. *Actinocyclus venenosus*, (pl. 15, fig. 1).
- D. Generally inconspicuous hyaline stripes that end near the valve/mantle juncture. Spines may or may not be present at disk/mantle junction. *Actinocyclus cedrus* (pl. 2, fig. 1) and *A. cedrus* spinose form (pl. 4, fig. 4).
- C. Areolae smaller, circular in outline and typically loosely packed. Marginal areolae rows sinuous and interdigitating. *Actinocyclus motilis*, (pl. 9, figs. 4–6).

## SYSTEMATIC DESCRIPTIONS

### *ACTINOCYCLUS ACANTHUS*

Bradbury & Krebs sp. nov.

Plate 1, figures 1–9

**Description.**—Valve circular, shallowly concave with slightly raised margin. Diameter typically ranging from 30 to 100  $\mu\text{m}$ . Disk with round areolae arranged in non-fasciculate, radial rows; 9–14 areolae/10  $\mu\text{m}$ . Valve center of larger specimens sometimes hyaline, containing only scattered areolae. Small, often obscure, radial, marginal hyaline stripes at disk-mantle juncture mark positions of labiate processes and are adorned with stout, hollow tubules up to 2  $\mu\text{m}$  in length that may bear terminal lateral spines. Tubule stems either rounded or angled (often triangular) in cross-section (pl. 1, fig. 7). Because of breakage, morphological characteristics of tubule ends seldom visible. Valve mantle finely areolate (20/10  $\mu\text{m}$ ) and steeply sloping away from disk margin. Labiate processes short, narrow-stemmed, with broad, spade-shaped labiae. Pseudonodule small, about 1  $\mu\text{m}$  in diameter, and variably located between labiate processes near valve margin.

**Variability.**—The length of hyaline stripes appears to vary among individuals both within and between localities. In an unnamed unit at New Pass, Lander County, Nevada (loc. 42) and in the Esmeralda Formation (Miocene) at Cedar Mountain, Nye County, Nevada (loc. 74), the hyaline stripes are often very small and obscure (pl. 1, fig. 6). Specimens from the Bully Creek Formation (Miocene), Malheur County, Oregon (loc. 7) have longer hyaline stripes (2–3  $\mu\text{m}$  or longer), as do occasional specimens from the Cedar Mountain section (Lohman, 1957).

The hyaline central area is largest and best developed in specimens from the Cedar Mountain section, while in material from New Pass it is smaller or absent. Pseudonodule position also seems to vary. In New Pass and Cedar Mountain (Esmeralda Formation) specimens, it is small and closely adjacent to a labiate process, while in the Bully Creek Formation material, it is located about  $\frac{1}{3}$  the distance between two labiate processes.

Because of their susceptibility to abrasion and

corrosion, the external tubules of this species are often poorly preserved or incomplete. In material from New Pass, some appear to bifurcate or are adorned with short lateral spines or flanges, suggesting that the typically short, blunt tubes often seen in LM may be artifacts of preservation. Tubules vary in cross section, being either round, triangular, or elliptical, but it is not known how constant tubules are on a single specimen from our available material.

The apiculate species of *Actinocyclus* from other localities are close to the type in appearance, but not identical. Detailed study, including morphometric analysis, may require splitting this apiculate *Actinocyclus* group into several species.

**Diagnosis.**—*Actinocyclus acanthus* can be distinguished from other lacustrine members of the genus by the presence of robust, often angled, hollow thorn-like tubes on the hyaline stripes that mark the exit pores of labiate processes. *A. gorbunovii* is more finely areolate, and external tubules are absent. *Actinocyclus nordlingensis* Schauderna has forked tubes and is more finely areolate (14–20/10  $\mu\text{m}$ ). Its labiate processes are narrow-stemmed but comparatively long (>2  $\mu\text{m}$ ). The pseudonodule location in *A. nordlingensis* is located about  $\frac{1}{3}$  the distance between adjacent labiate processes (Schauderna, 1983). Carina-like spines may be present on *Actinocyclus cedrus*, but they are irregularly placed, apparently solid, and not necessarily located on the hyaline stripes. *Actinocyclus tubulosus* Khursevich is smaller (16–34  $\mu\text{m}$  diameter), has more densely packed areolae (16–22/10  $\mu\text{m}$ ), and external tubes with a rounded cross section. *A. cedrus* has coarse, polygonal areolae. *Actinocyclus pinnulus* is similar to *A. acanthus*, but has distinctly finned tubules, is clearly fasciculate, and has long, narrow hyaline stripes.

**Types.**—Holotype: Strew slide United States National Museum (USNM) #465534. specimen located at E.F. (England Finder) H46.

Isotypes: Strew slides in the following institutions: Academy of Natural Sciences of Philadelphia (ANSP) A–G.C. #64465; U.S. Geological Survey, Denver (USGS–D) #14 VII 85–4; California Academy of Sciences (CAS) #216051.

**Type Locality.**—Because the diatom is best preserved and most abundant in unnamed deposits near New Pass, Lander County, Nevada (loc. 42 = USGS Denver 14 VII 85–4), this site has been selected as the type locality.

**Remarks.**—The specific epithet “*acanthus*” (L. thorn) refers to the presence of hollow, thorn-like tubes at the labiate process exit pores.

*Actinocyclus acanthus* has also been found in the Bully Creek Formation, Harper Basin, Malheur County, Oregon, and in the Esmeralda Formation near Cedar Mountain, Nye County, Nevada (loc. 74). Here the taxon was originally described by Lohman (1957) as *Cestodiscus apiculatus* nomen nudum. At the Cedar Mountain section, *Actinocyclus acanthus* is associated with species of *Surirella*, *Anomoeoneis*, and *Pinnularia* (Lohman, 1957), whose modern

relatives suggest deposition in moderately saline, alkaline water. At some levels in the New Pass locality, it is associated with *Chaetoceros*, also suggesting saline water, but elsewhere at New Pass, and at Bully Creek, freshwater species of *Aulacoseira* dominate the samples. At Silvies Valley, Grant County, Oregon (loc. 75), *Actinocyclus acanthus* is associated with large numbers of *Fragilaria* sp. cf. *F. virescens*. Other diatoms present include *Aulacoseira*, *Tetracyclus*, *Tabellaria*, *Eunotia*, and *Achnanthes*. Perhaps the morphological differences seen in *Actinocyclus acanthus* reflect salinity or other environmental characteristics.

### *ACTINOCYCLUS CEDRUS* Bradbury & Krebs sp. nov.

Plate 2, figures 1–7; plate 3, figures 1–8; plate 4, figures 1–6

**Description.**—Valve circular, with slightly raised margin. Diameter typically 50–100  $\mu\text{m}$ , but ranging from 20 to >150  $\mu\text{m}$ . Valve face shallowly concave to weakly concentrically undulate with radial rows of large (1  $\mu\text{m}$  diameter), polygonal-shaped areolae, ranging from 6–10/10  $\mu\text{m}$ . Vague fasciculation of valve disk caused by bundles of mutually parallel areolae rows that extend variable distances towards the valve center progressively truncating one another (pl. 3, fig. 2). Valve center typically densely packed with areolae. Small, generally short, hyaline stripes at valve mantle junction barely extend over mantle to enclose large (1  $\mu\text{m}$  diameter) exit pores of labiate processes. Labiate processes 3–5  $\mu\text{m}$  tall, with narrow, round or oval stems and relatively broad, spade-shaped labiae. Disk/mantle margin often hyaline and irregularly areolate and (or) variably ornamented with solid, granule-, keel-, or spine-like protuberances. Mantle variably high (10–15  $\mu\text{m}$ ), and nearly perpendicular to valve face plane, with vertical areolae rows, 16 areolae/10  $\mu\text{m}$ . Pseudonodule small and variably located between labiate processes, generally closer to one.

**Variability.**—The disk/mantle juncture may or may not be hyaline and irregularly areolate, or ornamented with spine- or granule-like protuberances. Such ornamentation is more typical in specimens from the Turner Creek (Pit River) locality in Modoc County, California (loc. 17) (pl. 4, figs. 4–6), and less common at the type locality in Stewart Valley, Mineral County, Nevada (loc. 20). Areolae near the valve disk center are sometimes sparse and surrounded by hyaline silica. Fasciculation is more apparent in some specimens than others. For example, specimens from the Virginia Range, 16 km north of Virginia City, Storey County, Nevada (loc. 68), are not clearly fasciculate, although they conform to the species in other features. Size of the hyaline stripes varies to some degree among specimens from different sites and may represent temporal or environmental gradations within this species. Forms of this species from deposits correlated to the Aldrich Station Formation (Miocene), Lyon County, Nevada (loc. 1), and from deposits near Drewsey, Harney County, Oregon (loc. 63),

tend to be less fasciculate than the type and are typically spinose. The labiate processes are taller and thinner in specimens from Goose Creek, Baker County, Oregon (loc. 27).

**Diagnosis.**—*Actinocyclus cedrus* is very similar to *A. venenosus*, another nonmarine, fossil *Actinocyclus* species with coarse, polygonal areolation on the valve face. *Actinocyclus venenosus* is characterized by generally longer and more prominent hyaline stripes that extend well onto the valve disk. *A. cedrus* tends to be more obviously, if irregularly, fasciculate than *A. venenosus*, and concentric undulation is usually poorly developed in *A. cedrus*.

**Types.**—Holotype: Strew slide USNM #465535, specimen located at E.F. L38/1.

Isotypes: Strew slides ANSP A–G.C. #64466; CAS #216052; USGS–D #31:I:88–1(65).

**Type Locality.**—“Diatomite Ridge” in Stewart Valley, northwest of Cedar Mountain, Mineral County, Nevada (loc. 20 = USGS Denver 31 I 88–1 [65]) has been selected as the type locality for *Actinocyclus cedrus*. The collection site is located at 38.62° N., 117.94° W., about 8 m below the top of a 40-m section of buff, thin-bedded to laminated diatomaceous shales, and about 28 m above a volcanic ash dated at 15.1 Ma (S.W. Starratt, written commun., 1986). The section has been assigned to the Esmeralda Formation.

**Remarks.**—The specific epithet “cedrus” (L. cedar) refers to the type locality of this species near Cedar Mountain. The type material was collected by S.W. Starratt and represents his sample DR–65. Lohman (1957) identified this diatom by the name *Cestodiscus cedarensis* nomen nudum at a nearby locality on the southeast flank of Cedar Mountain. The same (or very similar) species is reported from the Otis Basin, Harney County, Oregon (VanLandingham, 1967) under the name *Coscinodiscus subtilis*.

Associated diatoms at the type locality include freshwater, benthic *Fragilaria* species, *Ellerbeckia arenaria* v. *teres*, *Tetracyclus* sp., and a dominance of planktonic *Aulacoseira* spp.

### *ACTINOCYCLUS CLAVIOLUS*

Bradbury & Krebs sp. nov.

Plate 4, figure 7; plate 5, figures 1–5

**Description.**—Valve circular, nearly flat with a slightly raised or depressed center. Diameter ranging between 17 and about 60  $\mu\text{m}$ , typically about 27–30  $\mu\text{m}$ . Areolae about 13–14/10  $\mu\text{m}$ , small, round and in subparallel to radial rows. Areolae rows grouped into fascicles set off by continuous rows of areolae originating from hyaline stripe of each labiate process and running to valve center. Valve center sometimes a small, irregular hyaline area. Hyaline stripes marking locations of labiate processes comparatively long (3–7  $\mu\text{m}$ ), narrowed, or pointed proximally and expanded distally to form irregular, somewhat triangular-, cross- or clove-shaped areas (pl. 5, figs. 1–3). External

expression of labiate process is a short, blunt, rather thick-walled tube with a narrow opening rising 1–2  $\mu\text{m}$  above disk/mantle junction (pl. 5, fig. 3). Valve mantle steeply sloping away from disk, finely areolate (about 26/10  $\mu\text{m}$ ) and fairly short. Labiate processes not observed, but presumably with narrow, round stems. Pseudonodule of medium size (1–2  $\mu\text{m}$  in diameter) and often easily visible between hyaline stripes (pl. 5, figs. 2, 4, 5).

*Variability*.—*Actinocyclus claviolus* is known only from Jungle Point, Idaho County, Idaho (loc. 33). At this locality, large specimens have fascicles with radial areolae rows. Consequently, the radial row associated with the hyaline stripe is less distinctive. Small specimens have fascicles in which the areolae rows are parallel to the central areolae row or in irregular groups of subparallel rows. The hyaline stripes are irregular but always somewhat pyriform or cross-shaped. Larger specimens have proportionally longer stripes. The central hyaline area is typically irregular, but always small.

*Diagnosis*.—*Actinocyclus claviolus* is morphologically similar to *A. cupreus*, but it can be distinguished by its thick, prominent hyaline stripes, generally smaller size, and the presence of thick external tubes over the labiate process pore. Like *A. cupreus*, *A. claviolus* is also morphologically close to *Coscinodiscus* (= *Actinocyclus*) *variabilis* (*sensu* Krasske 1934) (pl. 14, figs. 5, 6), but that species does not have laterally expanded hyaline stripes and is more coarsely areolate than *A. claviolus*. In addition, the hyaline stripes of *Coscinodiscus variabilis* (*sensu* Krasske) are typically longer, extending to about  $\frac{1}{3}$  of the disk radius.

*Types*.—Holotype: Strew slide USNM #465536, specimen at E.F. R28/2.

Isotypes: Strew slides ANSP A–G.C. #64467; USGS–D #5 XII 80–7; CAS #216053.

*Type Locality*.—The type locality of *Actinocyclus claviolus* is an unnamed lacustrine deposit at Jungle Point, northwest of the town of Lowell, Idaho County, Idaho; SE  $\frac{1}{4}$ , SE  $\frac{1}{4}$  sec. 15, T. 33 N., R. 6 E. (loc. 33 = USGS Denver 5 XII 80–7). The diatoms at this locality show some corrosion and breakage.

*Remarks*.—The specific epithet “claviolus” (L. diminutive for nail or clove) refers to the small clove-like shape of the hyaline stripes of this species. *Aulacoseira* sp. cf. *A. praeislandica* is the dominant diatom associated with *Actinocyclus claviolus*.

### *ACTINOCYCLUS CUPREUS*

Bradbury & Krebs sp. nov.

Plate 5, figures 6–9

*Description*.—Valve circular, shallowly concave with a broadly raised margin. Diameter typically around 50  $\mu\text{m}$  and ranging between 20 and 76  $\mu\text{m}$ . Areolae round-polygonal, in roughly radial to parallel rows. Areolae rows

grouped in broad fascicles set off by continuous rows of areolae originating from hyaline stripe of each labiate process and running to valve center. Areolae about 13/10  $\mu\text{m}$ , generally loosely packed near valve center. Comparatively long (2–5  $\mu\text{m}$ ), prominent hyaline stripes extend from exit pore of labiate processes over disk/mantle junction and onto disk. Valve mantle finely areolate (about 20/10  $\mu\text{m}$ ) and gently sloping away from valve disk. Labiate processes with narrow, round stems and rather broad, spade-like labiae. Pseudonodule small, but usually clearly visible; located at a variable distance between labiate processes on disk-mantle junction.

*Variability*.—To date, *Actinocyclus cupreus* has been found at four localities in the Western United States. At Copper Kettle Canyon, Churchill County, Nevada (loc. 16), evident variability has been found in the degree of fasciculation. Small specimens, probably referable to this species, tend to be more coarsely areolate and do not clearly show the radial areolae rows running between the hyaline stripes and the valve center that separate the areolae fascicles. In large specimens, strong valve undulation may obscure the radial areolae rows that border fascicles. Between labiate processes, areolae rows become more radial than mutually parallel in small individuals. Hyaline stripes show some variation in length, with relatively longer stripes on larger specimens. At Juliaetta, Nez Perce County, Idaho (loc. 32), and at Jungle Point, Idaho County, Idaho (loc. 33), diatoms referable to *A. cupreus* are comparatively small and resemble *A. claviolus* and *A. krasskei*, respectively, although the distinctive fasciculation is evident. In the Miocene Humboldt Formation, Eureka County, Nevada (loc. 30), comparatively large forms are present that closely resemble the Copper Kettle Canyon material.

*Diagnosis*.—*Actinocyclus cupreus* is distinguished from *A. ehrenbergii* (which also has single, radial areolae rows between hyaline stripes and the valve center) by its inconspicuous small pseudonodule, finer areolation, and generally smaller size. See also diagnosis under *A. nebulosus* and *A. claviolus*.

*Actinocyclus cupreus* is also similar to an *Actinocyclus* species identified as *Coscinodiscus variabilis* Frenguelli by Krasske (1934) from Miocene freshwater deposits near the town of Ruckers on the southeast margin of the Vogelsberg Range at the northern end of the Rhine graben in central Germany. The Ruckers material tends to have slightly coarser areolation (9–12 areolae/10  $\mu\text{m}$ ) than do specimens from Copper Kettle Canyon, and the hyaline stripes are longer, often extending to one half the valve radius. Also, *C. variabilis* appears to have an external extension associated with each pore of the labiate process, unlike *A. cupreus*. Pseudonodules are visible on well-preserved valves of the Ruckers material indicating their probable affiliation with *Actinocyclus*.

*Types*.—Holotype: Strew slide USNM #465537, E.F. F46/4.

Isotypes: Strew slides ANSP A-G.C. #64468; USGS-D #15 XII 88-1F; CAS #216054.

*Type Locality.*—The type locality of *Actinocyclus cupreus* is an unnamed formation at Copper Kettle Canyon in the northern Stillwater Mountains, sec. 26, T. 24 N., R. 34 E., Churchill County, Nevada (loc. 16 = USGS Denver 15 XII 88-1F). Specimens of *A. cupreus* are uncommon and poorly preserved.

*Remarks.*—The specific epithet “cupreus” (L. of copper) refers to the type locality in Copper Kettle Canyon. A similar, perhaps closely related species of *Actinocyclus* has been found in Miocene freshwater sediments now covered by the Sea of Japan in the region of Yamato Bank (pl. 6, figs. 1, 2) (Burckle and Akiba, 1978; Tsoy and others, 1985), and from Japan (Koizumi, 1988). Specimens from Yamato Bank have hyaline stripes that can be very long, in some cases extending more than halfway towards the valve center in large individuals. The valve disk of this diatom is flatter than in *A. cupreus*, and the parallel-rowed fasciculation pattern is more regular and distinct. Further studies may confirm that all these diatoms are closely related.

Freshwater, planktonic species of *Aulacoseira* dominate the type material containing *Actinocyclus cupreus*; *Pinnularia*, *Tetracyclus*, and *Fragilaria* are present in smaller numbers.

### ACTINOCYCLUS EHRENBURGII

Ralfs in Pritchard (1861)

Plate 6, figures 3-9; plate 7, figures. 1, 2

*Description.*—Descriptions, figures, and diagnoses of *Actinocyclus ehrenbergii* from nearshore marine localities (such as in Hustedt, 1930) suffice to identify and separate this distinctive diatom from nonmarine species of *Actinocyclus*. The chief characteristic is the large, well defined, annulate-operculate pseudonodule of *A. ehrenbergii*. In addition, marine examples of this species have numerous, close-spaced, short-stemmed labiate processes. In contrast, nonmarine *Actinocyclus* species appear to have small, non-annulate (but perhaps also operculate?) pseudonodules and typically few and wide-spaced labiate processes with relatively longer stems.

*Remarks.*—*Actinocyclus ehrenbergii* (pl. 6, figs. 3-5) is present in upper Miocene continental deposits of the Quiburis Formation, Edgar Canyon, Pima County, Arizona (loc. 92), where it is associated with brackish-water diatoms, such as *Hyalodiscus* sp. cf. *H. laevis*, *Melosira moniliformis*, *Diploneis interrupta*, *D. ovalis*, *Mastogloia braunii*, *M. elliptica*, *Frustulia interposita*, species of *Amphora*, *Nitzschia*, *Achnanthes*, *Navicula*, and many others. Benthic alkaline-water diatoms, such as *Fragilaria brevistriata*, *Denticula elegans*, and *Caloneis silicula*, are also abundant and indicate a transitional brackish, perhaps estuarine (Blake, 1902), to freshwater environment. *A. ehrenbergii* is

also present in the uppermost Miocene to lowermost Pliocene Furnace Creek Formation of Death Valley, Inyo County, California (loc. 113).

### ACTINOCYCLUS GORBUNOVII var. FOSSA

Bradbury & Krebs var. nov.

Plate 7, figures 3-8

*Description.*—Valve face characterized by comparatively small, round areolae (14-18/10  $\mu$ m) arranged in a radial, generally non-fasciculate pattern. Valve diameter averages about 30  $\mu$ m but varies between 15 and 48  $\mu$ m. Valve disks typically strongly undulate. Labiate processes with narrow, long stems and circular cross sections. Short (4  $\mu$ m) hyaline stripes extend from external opening of labiate process at valve margin towards valve center. Pseudonodule comparatively distinct, located between labiate processes, and usually closer to one. A tiny, moat-like structure surrounds external opening of pseudonodule (pl. 7, figs. 5-6). In favorable cases, this structure can be seen by LM as a small ring of hyaline silica around pseudonodule pore.

*Variability.*—*Actinocyclus gorbunovii* var. *fossa* is known from only one locality. Some variation in the degree of areolation is present in the center of the valve disk. In large individuals, areolae may be loosely scattered about the valve center. Large valves tend to be more conspicuously undulate than small valves. Not enough SEM observations have been made to determine the constancy of the moat-like structure surrounding the external opening of the pseudonodule. From light microscope observations, it appears to be better developed in some valves than in others.

*Diagnosis.*—*Actinocyclus gorbunovii* var. *fossa* is distinguished from *A. gorbunovii* by the presence of a small moat-like structure of hyaline silica that surrounds the external opening of the pseudonodule. This structure is not present in type material of *Actinocyclus gorbunovii* (G.K. Khursevich, written commun., 1990). The closely spaced areolae (14-18/10  $\mu$ m) and the strongly undulate valve disk, however, suggest a varietal affinity with *Actinocyclus gorbunovii*.

*Actinocyclus krasskei* is generally more coarsely areolate (12-13/10  $\mu$ m, although finer forms are reported), smaller, and flatter than *A. gorbunovii* var. *fossa*. Nevertheless, considerable variation exists, and some overlap is found in all these characters. Separation of these species is not likely to be consistent in mixed assemblages, and it may turn out that they all belong to the same variable taxon.

*Types.*—Holotype: Strew slide USNM #465538, E.F. N33/1.

Isotypes: Strew slides ANSP A-G.C. #64775; USGS-D #2 IX 87-3B; CAS #216081.

*Type Locality.*—*Actinocyclus gorbunovii* var. *fossa* is common in the early middle Miocene leaf-bearing

diatomites at Forty-nine Camp, Washoe County, Nevada (loc. 69). Preservation is variable, and valves are often broken.

*Remarks.*—The varietal epithet “fossa” (L. “ditch”) refers to the small ditch or moat surrounding the pseudonodule of this taxon. In the upper Cedarville Formation at Forty-nine Camp, Washoe County, Nevada, *Actinocyclus gorbunovii* var. *fossa* is associated with abundant *Aulacoseira* sp. cf. *A. islandica*, *Tetracyclus ellipticus*, *Ellerbeckia arenaria* v. *teres*, and several other freshwater diatoms are present in smaller numbers.

Bradbury (1984) suggested that *Coscinodiscus gorbunovii* (Sheshukova-Poretzkaja and Moissejeva, 1964), belonged in the genus *Actinocyclus* according to its general morphology and the presence of a pseudonodule in a related species from the Poison Creek Formation (Miocene) in the Snake River Plain, Idaho. Khursevich and others (1990) formally transferred *C. gorbunovii* to *Actinocyclus*. The Poison Creek Formation taxon is now regarded as distinct from *A. gorbunovii* and has herein been described as *Actinocyclus venenosus*. In view of the biostratigraphic importance of *A. gorbunovii* in Eurasia and of closely related taxa in the Western United States, it is appropriate to evaluate the original description of *Coscinodiscus gorbunovii* Shesh. and its varieties.

The following description of *Coscinodiscus gorbunovii* represents an approximate translation from Russian (Sheshukova-Poretzkaja and Moissejeva, 1964). The original description includes two varieties, *Coscinodiscus gorbunovii* v. *gorbunovii* Shesh. and *C. gorbunovii* v. *ethmodiscoides* Moiss.

***COSCINODISCUS GORBUNOVII* SHESHUKOVA**

In Sheshukova-Poretzkaja & Moissejeva 1964,

P. 94, pl. 2, figs. 1–5.

*Description.*—Cells of yellow-brown color, short cylindrical or disk-shaped, with or without intercalary bands, 30–70  $\mu\text{m}$  in diameter, 2–20  $\mu\text{m}$  tall. Valves concentrically undulate with a single concave zone and concave center. Valve structure of small, dense areolae in radial rows, 12–18/10  $\mu\text{m}$ , not forming fascicles. Central area small, round or of irregular shape with one or several isolated areolae, or occasionally absent. Distinct undulating rows of areolae occur at the valve margin, and a ring of 7–14 short, blunt spines (=tubules) from which short, radial, hyaline rays emanate towards the valve center. Valve mantle edge narrow, delicately crosshatched (23–24 striae/10  $\mu\text{m}$  or not visible). Short-cylindrical cells have valves with clearly expressed mantles of moderate height (3–4  $\mu\text{m}$ ) and with small areolae in radial and obliquely intersecting rows, 23–24/10  $\mu\text{m}$ .

***COSCINODISCUS GORBUNOVII* v. *GORBUNOVII* SHESHUKOVA**

In Sheshukova-Poretzkaja & Moissejeva 1964,

P. 96, pl. 2, figs. 1–5.

*Description.*—Frustules disk-shaped, height 2–3  $\mu\text{m}$ , without intercalary bands. Diameter of the valves 35–70  $\mu\text{m}$ . On the frustule, 13–18 rows of areolae/10  $\mu\text{m}$ , central zone present, marginal zone narrow, delicately crosshatched. Mantle not developed.

***COSCINODISCUS GORBUNOVII* v. *ETHMODISCOIDUS***

MOISSEJEVA in Sheshukova-Poretzkaja & Moissejeva 1964,

P. 96, pl. 3, figs. 1–7.

*Description.*—Frustules short-cylindrical with small collar-shaped, structureless intercalary bands, 30–50  $\mu\text{m}$  diameter, and up to 20  $\mu\text{m}$  high. 12 areolae rows/10  $\mu\text{m}$  on the frustule, central zone absent, marginal zone inconspicuous. Mantle of the frustule 3–4  $\mu\text{m}$  high with small areolae in radial and obliquely intersecting rows, 23–24/10  $\mu\text{m}$ .

*Variability and Comments on the Descriptions.*—For the most part, the description of *Coscinodiscus gorbunovii* and varieties is straight forward. Some points however, require discussion and revision.

1. It is not quite clear what is meant by the undulating areolae rows on the valve margin. In direct translation this passage reads, “In the area by the edge are distinct concentric-undulating rows of the same kind of areolae and \* \* \*”. Published figures of this species (Sheshukova-Poretzkaja and Moissejeva, 1964; Cheremisinova, 1968; Moissejeva, 1971; and Temniskova-Topalova and others, 1981) do not clearly illustrate what might be meant by this remark. It is possible that it refers to a wavy pattern of short, interdigitated, and truncated radial areolae rows sometimes visible near the margin of this diatom. Alternatively, it could refer to a looser and somewhat undulate pattern of areolae distributed tangentially along the valve margin and visible in some specimens. The revised description of *A. gorbunovii* (Khursevich and others, 1990) does not mention this feature. Such patterns are evident on other freshwater *Actinocyclus* species, however, and are of unknown taxonomic significance.

2. The description of valve disk undulation sounds equivalent to the “shallowly concave” terminology used in this report. Both light and SEM photographs of *Coscinodiscus gorbunovii* from the literature show individuals that have raised central areas (truly “concentrically undulate”) (for example, Temniskova-Topalova and others, 1981 pl. 3, fig. 3) among specimens that are shallowly (or deeply) concave. This probably represents normal variation within the species. It appears that undulation consisting of a raised margin and center (for example, in Khursevich and others, 1990) characterizes larger individuals of this species.

3. The reference to the yellow-brown color of *Coscinodiscus gorbunovii* is taken to be taxonomically important by Moissejeva (1971). The color of *Coscinodiscus gorbunovii* or any other diatom for that matter, partly relates to the density of its structural elements, but also to its magnification, the refractive index of the mounting medium, and related optical properties that have nothing to do with the biological characters required for taxonomic separation (Bradbury, 1984).

4. The comment about the presence or absence of "intercalary bands" probably reflects preservation and also seems irrelevant to the description of *Coscinodiscus gorbunovii*.

5. The "lack of mantle development" suggested for *Coscinodiscus gorbunovii* v. *gorbunovii* presumably means that the mantle of this species is short in comparison to that of *Coscinodiscus gorbunovii* v. *ethmodiscoidus*.

6. The presence of short, blunt spines associated with the hyaline rays is difficult to confirm by most illustrations of *Coscinodiscus gorbunovii*. Typically, no spines of any kind are shown, and the only figure that clearly illustrates spines (Temniskova-Topalova and others, 1981, pl. 3, fig. 3), shows a number of irregular, spine-like protrusions along the disk/mantle junction and without clear relation to the hyaline rays. The description of the spines in this case states that they are between the hyaline rays (Temniskova-Topalova and others, 1981). Such spine-like projections (see also Khursevich and others, 1990) may represent an ecotypical variant of this species.

The description of the synonym, *Pontodiscus gorbunovii* (Shesh.) Shesh. et Moiss. (Temniskova-Topalova and others, 1981), also indicates the presence of external tubules at the openings of the labiate processes, although these are not illustrated. Furthermore, Moissejeva in an oral communication to G.K. Khursevich (written commun., 1989) stated that the labiate processes of *Coscinodiscus gorbunovii* were mistaken as short spines in the original description of this species.

7. Khursevich and others (1990) gave 16-18 areolae rows/10  $\mu$ m and 14-18 areolae/10  $\mu$ m (presumably along a radial row) for *A. gorbunovii*. According to Khursevich and others (1990), the coarser *Coscinodiscus gorbunovii* v. *ethmodiscoidus* is no longer considered a variety of *A. gorbunovii*. In this report, we follow the revised description with regard to areolar density of *A. gorbunovii*.

### ACTINOCYCLUS KRASSKEI (KRASSKE)

Bradbury & Krebs nom. nov.

Plate 8, figures 2-6, 8-11; plate 9, figures 1-3

Syn. *Coscinodiscus miocenicus* Krasske 1934, p. 23, figs. 5-7.

A nomenclatural problem exists with *Coscinodiscus miocenicus* Krasske. Unmounted type material of this taxon has not been found, precluding SEM investigations to

precisely document micromorphological characters of this species. Nevertheless, pseudonodules can be seen by light microscopy in well-preserved specimens of type material (pl. 8, fig. 3). By this and other criteria (see Simonsen, 1982), *Coscinodiscus miocenicus* can be confidently transferred to *Actinocyclus*. Because the name *Actinocyclus miocenicus* Jousé (Jousé, 1973) has preempted the logical new combination, we propose that *Actinocyclus krasskei* be used to designate this taxon.

*Description* (From Krasske, 1934).—Valve circular, rather flat, 11-47  $\mu$ m in diameter. Large areolae in radial rows, at the margin about 13/10  $\mu$ m, organized in unclear fascicles. Secondary rows in clear spirals. Mantle ornamented with delicate areolae organized in three self-crossing linear systems (quincunx), about 20 striae in 10  $\mu$ m. Central area lacking. Small individuals show irregular areolation.

Observations of the type material [Beuern (Vogelsberg) Hessen Kieselgur O. Miocene No. 3004 and 3005, No. 24/25] by LM indicate the presence of a comparatively distinct pseudonodule, located between short to medium-length, hyaline stripes that mark the position of narrow, long-stemmed labiate processes. In addition, concentrically undulate valve disks are common in the material. Areolae along radial rows are about 12-13/10  $\mu$ m in type material, although densities of 15-22/10  $\mu$ m had been stated for this species (Moissejeva, 1971; Temniskova-Topalova and others, 1981). No external tubes are visible at the labiate process exit pores.

*Variability*.—As stated by Krasske (1934), small individuals have irregular areolation. The shape of the valve disk varies from flat to concentrically undulate. In the Western United States, diatoms that otherwise conform to *Actinocyclus krasskei* have somewhat undulate disks and diameters as large as 70  $\mu$ m. The large, undulate forms of *A. krasskei* may actually be synonymous with *Coscinodiscus gorbunovii*, although they tend to be coarser than most Asian examples of *A. gorbunovii*.

*Diagnosis*.—Moissejeva (1971) stated that the marginal zone of *Coscinodiscus gorbunovii* is similar to that of *Coscinodiscus miocenicus* Krasske, but that *C. gorbunovii* is larger, yellow-brown, and concentrically undulate. Type material of *Coscinodiscus miocenicus* (light yellow or colorless) includes undulate valves whose diameter (11-47  $\mu$ m; Krasske, 1934) overlaps with the lower end of the size range reported for *Actinocyclus gorbunovii*. The color of these diatoms is not taxonomically relevant, and in most other respects *A. gorbunovii* and *A. krasskei* are quite similar. In the type material and in examples of *A. krasskei* from the Western United States, areolae density does not exceed 13/10  $\mu$ m along radial areolae rows.

*Remarks*.—The specific epithet of *Actinocyclus krasskei* acknowledges the original author of this taxon (Krasske, 1934).

Krasske (1934) reported large quantities of freshwater *Aulacoseira* and *Fragilaria* species in association with

*Coscinodiscus miocenicus*. The identification of *Stephanodiscus astraea* (Krasske, 1934) could not be confirmed by close re-inspection of the type material (Reimer Simonsen, written commun., 1984).

*Actinocyclus krasskei* has been reported as *Coscinodiscus miocenicus* from the Harper Basin, Malheur County, Oregon (Abbott and VanLandingham, 1972), and from the Squaw Creek Member of the Ellensburg Formation (Miocene) in Yakima County, Washington (VanLandingham, 1964). At both localities, fresh water *Aulacoseira* species are dominant. At Vinegar Creek, in the Mascall Formation in Grant County, Oregon (loc. 88), and at Juliaetta, Nez Perce County, Idaho (loc. 32), undulate *A. krasskei* occur with coarsely structured *Aulacoseira* sp., possibly related to *A. islandica* or *A. granulata*. Flat forms of *Actinocyclus krasskei* are present in the Latah Formation (Miocene), Spokane County, Washington (loc. 77), and in unnamed Miocene units at Oviatt Creek, Clearwater County, Idaho (loc. 43), and Arrow Junction, Nez Perce County, Idaho (loc. 72). At these localities, *Aulacoseira* species related to *A. distans* and *A. praeislandica* dominate along with *Ellerbeckia arenaria* v. *teres*, *Melosira undulata*, and species of *Eunotia*, *Tetracyclus*, and *Tabellaria*.

Some diatoms from Siberia, identified as *Pontodiscus* (= *Coscinodiscus*) *miocenicus*, have SEM illustrations of external tubules placed at the hyaline stripes (for example, Temniskova-Topalova and others, 1981, pl. 4, figs. 2, 3, and 8). Khursevich and others (1990) have renamed such diatoms *Actinocyclus tubulosus*, but this name probably should not be applied to Krasske's (1934) material nor to forms in the Western United States without tubules. Nevertheless, *A. tubulosus* is also present in the Squaw Creek Member (loc. 49). When the tubules of this diatom are missing because of breakage or corrosion, it cannot be effectively separated from *A. krasskei* by light microscopy (like that of pl. 8, fig. 7).

### *ACTINOCYCLUS MOTILIS* Bradbury and Krebs

sp. nov.

Plate 9, figures 4–6; plate 10, figures 1–12; plate 11, figure 1

**Description.**—Valve circular, disk slightly concave to weakly concentrically undulate with broadly raised margin. Diameter 20–90  $\mu\text{m}$ . Disk with spaced, round areolae in slightly sinuous radial rows (especially near margin). Areolae rows of variable length, interdigitating with one another near margin of disk. Areolae density of type material 11–13/10  $\mu\text{m}$ . Areolae near disk margin noticeably smaller and more crowded (to 16/10  $\mu\text{m}$ ) than those closer to valve center (10/10  $\mu\text{m}$ ). Fasciculation not apparent. Valve center small and irregularly hyaline with loosely packed areolae. Hyaline rays at disk/mantle junction short, radial, and distinct. Valve/mantle junction typically abrupt, with a steeply sloping mantle. Mantle finely areolate (about 18/10  $\mu\text{m}$ )

with vertical-quincunx arrangement. Pseudonodule very small (often not visible in LM), located between labiate processes, usually closer to one. Externally, pseudonodule appears on a slightly elevated platform or mound (pl. 11, fig. 1). Internally, it is represented by a small field of several irregular areolae or pores (pl. 10, figs. 4 and 6). Internal expression of pseudonodule on specimens of *Actinocyclus motilis* from Ellensburg Formation (Squaw Creek Member) is very difficult to differentiate from normal areolation pattern. Labiate processes have long, narrow, circular stems with narrow, flanged labiae.

**Variability.**—Some variability can be seen in the character of the disk/mantle junction. Typically it is abrupt, but in some specimens it tends to become more gradual and gently sloping. A stellate pattern, caused by the termination of areolae rows, is distinctive in large specimens of this species but absent in smaller ones. As with most species of *Actinocyclus*, the hyaline central area is quite variable and sometimes absent. Specimens from some localities have hyaline rays that are very small and obscure. Large specimens of *Actinocyclus motilis* appear to grade into *A. cedrus* at Goose Creek, Baker County, Oregon (loc. 27), and at the Ellensburg Formation localities in Washington (locs. 49, 59). These forms have coarser, crowded, and somewhat polygonal areolation, especially near the valve center.

**Diagnosis.**—*Actinocyclus motilis* is best distinguished by its sinuous, interdigitating rows of round, spaced areolae. This pattern is also visible in *A. cedrus* and *A. venosus*, but the areolae in these species tend to be larger, uniformly crowded and polygonal. Labiate process labiae are also narrower in *A. motilis*. Nevertheless, large forms of *A. motilis* can be confused with the former taxa. The coarseness of areolation separates *A. motilis* from large forms of *A. gorbunovii* and *A. krasskei*.

**Types.**—Holotype: Strew slide USNM #465539, E.F. Q39/2.

Isotopes: Strew slides ANSP A.–G.C. #64469; USGS–D #23 I 81–10; CAS #216055.

**Type locality.**—*Actinocyclus motilis* is abundant and well preserved in deposits of the Esmeralda Formation at the southeast end of Cedar Mountain, Mineral County, Nevada (loc. 22). This deposit (USGS Denver 23 I 81–10) is chosen as the type locality.

**Remarks.**—The specific epithet “*motilis*” (L. motion) refers to an apparent rotational movement of the valve when focusing through it in the light microscope, apparently caused by the sinuous nature of the marginal areolae rows. This species, called *Cestodiscus mobilis* Lohman (nomen nudum), was first recognized by Lohman (1957) from the Esmeralda Formation near Cedar Mountain, Nye County, Nevada, but here the species is rare, poorly preserved, and mixed with other forms of *Actinocyclus*. Similar but somewhat coarser forms are extensively figured in VanLandingham (1964) under the name *Coscinodiscus subtilis* from the

Squaw Creek Member of the Ellensburg Formation in Yakima County, Washington.

At the type locality, *Actinocyclus motilis* dominates the assemblage. Associated taxa include freshwater species of *Aulacoseira*, *Tetracyclus*, *Fragilaria*, and occasional fragments of *Actinocyclus cedrus*.

### ACTINOCYCLUS NEBULOSUS

Bradbury & Krebs sp. nov.

Plate 11, figures 2–8; plate 12, figure 1

**Description.**—Valve circular, diameter 35–100  $\mu\text{m}$ . Disk shallowly concave to slightly concentrically undulate and ornamented with fascicles of areolae. Areolae rows parallel to middle row of each fascicle. Fascicles separated by hyaline, costa-like rays enclosing a single row of wide-spaced areolae that run from disk margin to center. Areolae in fascicles irregularly spaced on distal third of valve and forming irregularly undulating rows tangential to valve circumference. Areolae small and widely separated (9–12/10  $\mu\text{m}$ ), and apparently with large and irregularly shaped internal loculae, especially on distal third of disk. Central area of disk variable. Marginal hyaline stripes comparatively long (about 10  $\mu\text{m}$ ) and with irregular edges. Stripes merge proximally into hyaline rays and corresponding radial rows of areolae marking fascicle. Disk/mantle junction sharp and mantle steep, finely areolate (16–20/10  $\mu\text{m}$ ) with vertical, slightly quincunx pattern. Labiate processes with broad, recurved flanges and comparatively narrow, circular stems. Pseudonodule small, generally close to labiate process.

**Variability.**—On some valves, the labiate process stems appear to be shorter and broader than the typical condition. The areolae, especially what are presumed to be their locules, are highly irregular in shape and apparently expanded internally so that the integrity of the areola disappears when focusing through the comparatively thin disk wall. This may be a partial artifact of preservation. The hyaline central area of the valve is highly variable, sometimes discrete and large, other times irregular or absent. Hyaline stripes, because of the irregularity of surrounding areolae, are also variable in shape, length, and clarity.

**Diagnosis.**—*Actinocyclus nebulosus* is close to *A. ehrenbergii* in character of fasciculation, but it can be separated from that species by its small, obscure pseudonodule and the irregular, disorganized arrangement of areolae around the disk margin. *A. cupreus* is also similar but does not have disorganized areolae on the disk margin, and areolae rows within fascicles are not clearly parallel to the central areolae row.

**Types.**—Holotype: Strew slide USNM #465540, E.F. K41.

Isotypes: Strew slides ANSP A.–G.C. #64479; USGS–D #26 XII 86-2A; CAS #216056.

**Type Locality.**—We designate outcrops of the Esmeralda Formation near Black Spring, Nye County, Nevada (loc. 93 = USGS Denver 26 XII 86–2A), as the type locality of this species.

**Remarks.**—The specific epithet “nebulosus” (L. cloudy or obscure) refers to the poorly defined marginal region of the valve apparently caused by irregular loculae beneath areoles.

Smedman (1969) described and illustrated this species as *Coscinodiscus nevadensis* (nomen nudum) from an unnamed formation in Buffalo Canyon, southeast of Eastgate, Churchill County, Nevada (loc. 6), but she failed to designate a type specimen, slide, or a repository. The species is also common near the base of the Cedar Mountain section in Nye County, Nevada (loc. 74), and was described and figured (Lohman, 1957) as *Cestodiscus fasciculatus* Lohman (nomen nudum).

*Aulacoseira* sp. cf. *A. distans* dominates in a sample containing abundant *Actinocyclus nebulosus* from near Buffalo Canyon, Nevada. Smedman (1969) listed several species of *Melosira* (*Aulacoseira*), *Cymbella*, *Pinnularia*, *Navicula*, and *Gomphonema* in the type assemblage. *A. nebulosus* is also present in the Mascall Formation near Aldrich Mountain, Grant County, Oregon (loc. 85), where it associates with freshwater *Aulacoseira* species related to *A. distans*, *A. agassizii*, and *A. islandica*. At the type locality, *Actinocyclus nebulosus* codominates with *Aulacoseira* spp.

### ACTINOCYCLUS PINNULUS

Bradbury & Krebs sp. nov.

Plate 12, figures 6, 7; plate 13, figures 1–5

**Description.**—Valve circular, with raised rim and shallowly concave center. Diameter ranging between 47 and 76  $\mu\text{m}$ , typically between 65 and 70  $\mu\text{m}$ . Disk with small, round areolae, about 13/10  $\mu\text{m}$ . Near center of disk, areolae smaller and somewhat loosely packed. On disk margin, areolae larger, closely packed and slightly polygonal in shape. Areolae pattern obscurely fasciculate with two wedge-shaped fascicles of subparallel areolae rows between each pair of labiate processes. Intersection of adjacent sets of subparallel areolae rows evident near the disk margin and less so towards valve center. Valve center generally, but not necessarily, with loosely packed areolae forming irregular hyaline space. Disk/mantle juncture sharp, with mantle perpendicular to disk plane. Mantle 8–10  $\mu\text{m}$  high with tiny areolae in a quincunx pattern, about 18/10  $\mu\text{m}$ . Marginal, hyaline stripes narrow, about 5  $\mu\text{m}$  long and extending from disk-mantle juncture onto valve disk. External tubules of labiate processes with a narrow stem, ornamented with two or more fin-like projections resembling pinnae or small leaflets attached parallel to tubule axis. Labiate processes long stemmed, with comparatively small, recurved and flexed

labiae. Pseudonodule small to medium, often obscurely visible between two labiate processes.

*Variability.*—*Actinocyclus pinnulus* is known only from three localities in the Western United States (locs. 81, 90, 91). Different collections of *A. pinnulus* from the Hole-in-the-Wall diatomite quarry (Miocene), Gooding County, Idaho (locs. 90, 91), show variations in the degree of central area development; in some populations the central areas are mostly absent or very small, while in others they are typically large and irregular. The pseudonodule is larger and more visible in some specimens than others, and the fins on the external tubules of the labiate processes exhibit some variation apart from differences in preservation. Generally, each tubule has two opposite fins that lie in a plane tangential to the valve circumference. Rarely, individual tubules will have three or even four fins irregularly placed along the tubule axis. Fasciculation and diameter of *A. pinnulus* appear comparatively uniform.

At 986 m depth in the AMOCO Becharof No. 1 well, Alaska (loc. 112), a nonmarine species of *Actinocyclus* related to *A. pinnulus* is rare (pl. 13, fig. 6). It resembles *A. pinnulus* by the presence of flanged marginal apiculae and general pattern of fasciculation, although the areolae are smaller and less polygonal than in the species. It also differs from the species in having a sloping mantle with vertical (not a quincunx pattern) areolae rows.

*Diagnosis.*—*Actinocyclus pinnulus* is closest to *A. acanthus*. *A. acanthus* does not, however, have tubules with fins, is non-fasciculate, and has only tiny, obscure hyaline stripes in contrast to *A. pinnulus*. *A. nordlingensis* has forked, not finned tubules, and *Coscinodiscus* (= *Actinocyclus*) *gorbunovii* apparently lacks tubules.

*Types.*—Holotype: Strew slide USNM #465541, E.F. L34/2.

Isotypes: Strew slides ANSP A–G.C. #64471; USGS–D #21 VI 88–1; CAS #216057.

*Type Locality.*—The type locality for *Actinocyclus pinnulus* is the Hole-in-the-Wall diatomite quarry, NW  $\frac{1}{4}$  sec. 12, T. 4 S., R. 13 E., Gooding County, Idaho (loc. 90), along the drainage of Clover Creek.

*Remarks.*—The specific epithet “pinnulus” (L. small fin or pinna) refers to the fin-like projections on the external tubes of the labiate processes of this diatom.

The species has also been collected from the same unit exposed in the NE  $\frac{1}{4}$  of sec. 19, T. 3 S., R. 13 E. (loc. 91 = USGS Denver 21 VI 88–1). *Aulacoseira* sp. cf. *A. praeislandica* is the dominant associate of *Actinocyclus pinnulus*, and a species of *Mesodictyon* Theriot and Bradbury (Thalassiosiraceae) is present in smaller numbers. *Mesodictyon* also occurs with *A. pinnulus* in the unnamed lacustrine beds at Durkee, Baker County, Oregon (loc. 81).

## *ACTINOCYCLUS THELEUS*

Bradbury & Krebs sp. nov.

Plate 13, figure 7; plate 14, figures 1–4

*Description.*—Valve circular, concentrically undulate with broadly raised margin and shallowly raised or depressed center. Diameter 11–35  $\mu\text{m}$ , typically around 20  $\mu\text{m}$ . Areolae small, round, loosely packed, about 13–18/10  $\mu\text{m}$  and not forming clear fascicles. Areolae in valve center often scattered, but not always. Hyaline stripes inconspicuous, narrow, and extending onto disk edge. Exit pores of labiate processes with a low, shield-shaped or nipple-like protrusion rising about 1  $\mu\text{m}$  above valve surface. Valve mantle perpendicular, with vertical rows of fine areolae, about 25/10  $\mu\text{m}$ . Labiate processes with narrow, round stems and spade-shaped labiae with curved, slit-like openings. Pseudonodule generally small but prominent and variably located between labiate processes at valve-disk margin.

*Variability.*—The nipple-like protrusions at the exit pores of the labiate processes and associated hyaline stripes may be more or less prominent, perhaps as a result of preservation. At Emerald Creek, Benewah County, Idaho (loc. 21), degree of undulation and density of areolae vary considerably. Generally poor preservation of the species at Oviatt Creek, Clearwater County, Idaho (loc. 43), complicates comparison of these forms, but in general they appear flatter than the Emerald Creek forms, and with reduced shield-like processes. At Juliaetta, Nez Perce County, Idaho (loc. 32), and at the White Hills (Mascal Formation), Grant County, Oregon (loc. 87), *A. theleus* tends to be coarser and more heavily silicified than at Emerald Creek. Perhaps the larger and coarser members of this complex merit separation.

*Diagnosis.*—*Actinocyclus theleus* is characterized by the presence of nipple-like tubules external to the labiate processes and by its typically undulate shape and fine areolation. It can be distinguished from small forms of *A. gorbunovii* and *A. krasskei* by the presence of the shield-like platforms that subtend the small external processes. The external processes of *Actinocyclus acanthus* are heavier, larger, and longer than those of *A. theleus*.

*Types.*—Holotype: Strew slide USNM #465542, E.F. M34/4.

Isotypes: Strew slides ANSP A–G.C. #64472; USGS–D #5 XII 80–4; CAS #216058.

*Type Locality.*—Finely laminated lacustrine siltstone from the “Clarkia Lake deposits” of Miocene age from Emerald Creek, near Clarkia, Idaho (loc. 21 = USGS Denver 5 XII 80–4) represents the type locality of *Actinocyclus theleus*. The sample location is in the NW  $\frac{1}{4}$ , NE  $\frac{1}{4}$ , sec. 33, T. 43 N., R. 1 E., Benewah County, Idaho (= locality UIMM P–37, Smiley and Rember, 1985, at Emerald Creek; loc. 21).

*Remarks.*—The specific epithet “theleus” (G. nipple) refers to the character of the external tubes of the labiate processes.

The species is figured as *Actinocyclus* sp. in Bradbury and others (1985), and at both Emerald Creek and at Oviatt Creek, Clearwater County, Idaho (loc. 43), it co-occurs with abundant *Aulacoseira* species related to *A. lirata* and *A. distans*, and a large variety of benthic diatoms indicative of soft, fresh, humic-rich, slightly acid water. *Actinocyclus theleus* is not widely distributed, and it may be that this form is characteristic of softwater, slightly acid environments. The coarser and larger forms at Juliaetta (loc. 32) and the White Hills (Mascall Formation), Grant County, Oregon (loc. 87) are associated with heavily silicified *Aulacoseira* sp. (cf. *A. praeislandica*) that may indicate more silicon-rich, eutrophic environments.

**ACTINOCYCLUS TUBULOSUS** Khursevich  
(Khursevich and others, 1990)

Plate 8, figure 7

*Remarks.*—This small, fine *Actinocyclus* species with short external tubules of circular cross section occurs rarely in the Squaw Creek Member of the Ellensburg Formation in central Washington. Poorly preserved specimens (lacking external tubules) may be misidentified as *Actinocyclus krasskei* that is otherwise similar (for example, Temniskova-Topalova and others, 1981). The specimen figured (pl. 8, fig. 7), has external tubules that appear above the focal plane in light microscopy. The type locality is in western Siberia along the Tim River (Khursevich and others, 1990).

**ACTINOCYCLUS VENENOSUS**  
Bradbury & Krebs sp. nov.

Plate 14, figures 7, 8; plate 15, figures 1–6

*Description.*—Valve circular, with broadly raised rim and shallowly concave to concentrically undulate valve disk. Diameter 35 to >160  $\mu\text{m}$ , but typically around 70 to 100  $\mu\text{m}$  in type material. Disk with coarse (about 1  $\mu\text{m}$  diameter) polygonal areolae arranged in approximately radial rows, 6–10 in 10  $\mu\text{m}$ . Areolae pattern non-fasciculate or vaguely fasciculate. In medium to large specimens, shorter areolae rows interspersed between longer rows terminate in narrow triangles of hyaline silica at variable distances from valve margin. Valve center either tightly or loosely packed with areolae. Disk/mantle juncture often loosely and irregularly areolate and typically unornamented. Occasionally, closely spaced, keel-like spines present along the disk/mantle junction. Marginal hyaline stripes prominent (often 2–3  $\mu\text{m}$  in length) and proximally pointed or tapered. Stripes usually extend across valve mantle and onto valve disk. On mantle, marginal hyaline stripes enclose comparatively large and often elliptical

exit pores of labiate processes. Labiate processes typically short, broad-stemmed, and with broad, recurved, crescentic, spade-like labium. Pseudonodule small, at disk/mantle junction, and typically closer to one labiate process.

*Variability.*—Like other species of *Actinocyclus*, *A. venenosus* varies morphologically. The hyaline stripes are usually rather long and prominent but may be comparatively small; some variation is seen on single valves. They are generally easily seen at low magnifications. Typically, the disk/mantle junction is broad, and the mantle gently slopes away from the plane of the disk. In some specimens, however, the junction is sharper and the mantle more steeply sloping. Labiate processes usually have short, elliptical stems and broad, recurved, crescent-shaped labiae, but occasionally, relatively taller, more circular-stemmed labiate processes occur. Fasciculation is occasionally evident. It is not certain whether these variations, which tend to co-occur (fasciculation, steep, sharp mantles, and sometimes longer labiate processes), represent intraspecific variation or characters of *Actinocyclus cedrus*. More fasciculate forms of this species occur in the Coal Valley Formation (Miocene), Lyon County, Nevada (loc. 15).

*Diagnosis.*—*Actinocyclus venenosus* is best recognized by its prominent hyaline stripes, broad disk/mantle junction, gradually sloping mantle, radial, non-fasciculate areolation, and concentric undulation of the valve disk. It is closest to *A. cedrus*, and type material can usually be separated from this species that typically has a sharp disk/mantle junction, a steep, tall mantle, more evident and consistent fasciculation, and minute, blunt hyaline stripes. Nevertheless, intergradations occur at other sites that frustrate simple separation, and broken valves may be impossible to identify.

*Actinocyclus cupreus* is distinguished from *A. venenosus* by the presence in the former of continuous radial areolae rows that extend from each labiate process to the valve center. *Actinocyclus cupreus* is also somewhat more finely structured (13 rounded-polygonal areolae/10  $\mu\text{m}$ ) and has labiate processes with comparatively long stems.

*Types.*—Holotype: Strew slide USNM #465543, E.F. E39.

Isotypes: Strew slides ANSP A–G.C. #64473; USGS–D #11 VI 78–1A; CAS #216059.

*Type Locality.*—The type locality is at Reynolds Creek, Owyhee County, Idaho (NW1/4 sec. 2, T. 2 S., R. 3 W.) (loc. 44 = USGS Denver 11 VI 78–1A).

*Remarks.*—The specific epithet “venenosus” (L. very poisonous) refers to its abundance in the Poison Creek Formation of the Idaho Group, western Snake River Plain, Idaho.

This species, labeled *Actinocyclus* sp. cf. *A. gorbunovii* from the Poison Creek Formation and from diatomaceous deposits in the Xian Feng Basin near Kunming, China is figured in Bradbury (1984). *Actinocyclus* sp. (Khursevich and others, 1990) from the Primor region of western Siberia appears to be closely related to *A. venenosus*. Associated

diatoms at the type locality are dominated by *Aulacoseira* species. *Navicula*, *Diploneis*, *Tetracyclus*, *Cymbella*, *Stauroneis*, and several other genera are present in smaller numbers.

## PALEOECOLOGY OF MIOCENE LACUSTRINE *ACTINOCYCLUS*

Between 20 and 10 Ma, species of *Actinocyclus* were the dominant planktonic discoid diatoms of temperate lake systems in the Northern Hemisphere. With the clear exception of *Actinocyclus ehrenbergii*, and possibly of *A. acanthus*, the *Actinocyclus* species from Miocene lacustrine deposits in the Western United States are freshwater planktonic diatoms. *Actinocyclus krasskei* and *A. theleus* seem to have dominated in smaller, neutral to slightly acidic lake systems (for example, Bradbury and others, 1985), while the larger and more coarsely structured forms, *A. motilis*, *A. cedrus*, and *A. venenosus*, appear to have been characteristic of larger, more eutrophic, slightly alkaline environments.

Little is known about the limnology of the lakes inhabited by *Actinocyclus*. It is reasonable to assume that large Miocene lakes in the Western United States were warm monomictic; that is, circulating in the winter at temperatures above 4°C because Miocene climates were less seasonal and winters milder. By analogy to modern lake systems, *Aulacoseira* species would dominate the diatom plankton during times of circulation where turbulence could suspend the heavy cells and supply nutrients to the photic zone. *Actinocyclus normanii* f. *subsalsa* is the only known extant *Actinocyclus* species living in freshwater. Its ecology is not well known, although in Lake Ontario it prefers nutrient-enriched water and reaches maximum populations in late summer (Stoermer and others, 1974). In contrast, *Aulacoseira islandica* blooms in late spring and early summer in Lake Ontario (Stoermer and others, 1974), during or shortly following spring circulation in less contaminated parts of the lake.

The common association of *Actinocyclus* and *Aulacoseira* species in Miocene lakes suggests that perhaps the two diatoms occupied limnological niches similar to their counterparts in Laurentian Great Lakes. Nonetheless, extrapolation from the modern distribution of *Actinocyclus normanii* f. *subsalsa* may be compromised by the fact that this species has significant morphological differences compared to Miocene *Actinocyclus* species (for example, lack of hyaline stripes and apparently a structurally more complicated pseudonodule).

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## PLATES 1–15

Contact photographs of the plates in this report are available, at cost, from the U.S. Geological Survey Photographic Library  
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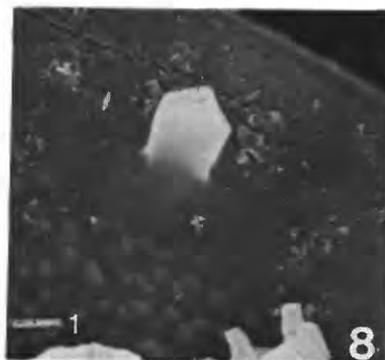
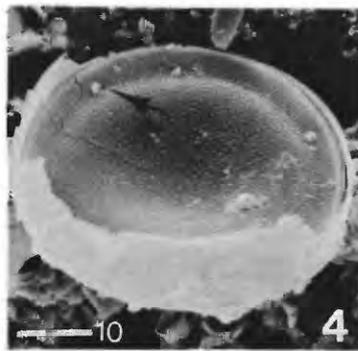
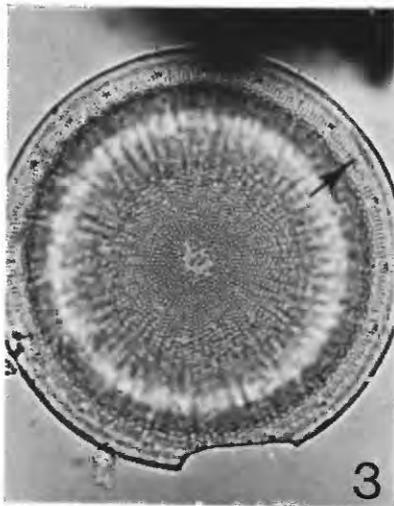
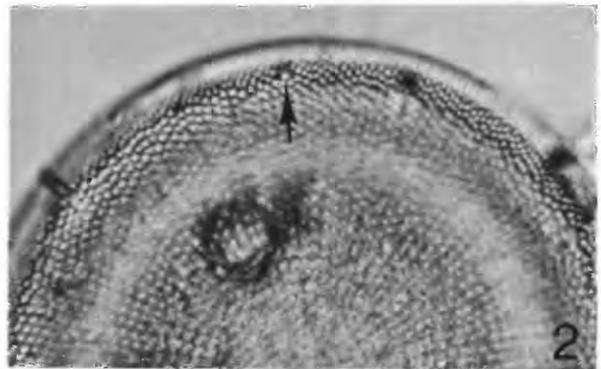
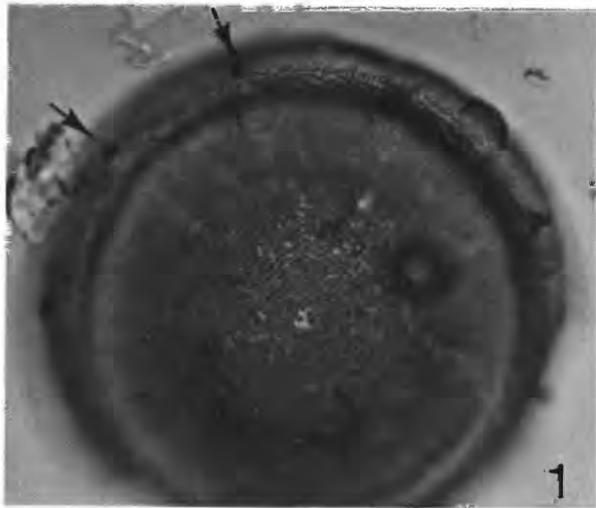
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## PLATE 1

Figures 1–9. *Actinocyclus acanthus* Bradbury & Krebs, sp. nov. (p. 4). Scale bars in  $\mu\text{m}$ .

1. Unnamed Miocene unit, New Pass, Lander County, Nevada (loc. 42). Arrows mark marginal tubular processes at disk/mantle junction and concentric undulation of valve. Diameter 65  $\mu\text{m}$ . Slide USGS–D 14 VII 85–4 (2), E.F. G32/1.
2. New Pass, Lander County, Nevada (loc. 42). Internal view showing pseudonodule (arrow). Diameter 55  $\mu\text{m}$ . Slide USGS–D 14 VII 85–4 (2), E.F. L45/3.
3. Bully Creek Formation, Harper Basin, Malheur County, Oregon (loc. 7). Valve view of exterior surface showing obscure pseudonodule (arrow). Diameter 69  $\mu\text{m}$ . Slide AMOCO: OM–29–1(+), E.F. K4/4.
- 4–6. New Pass, Lander County, Nevada (loc. 42). Internal views showing pseudonodule (arrows in figs. 4, 5) and labiate process (fig. 6).
- 7, 8. New Pass, Lander County, Nevada (loc. 42). Detail of marginal tubular processes.
9. New Pass, Lander County, Nevada (loc. 42). Base of broken marginal tubular process.

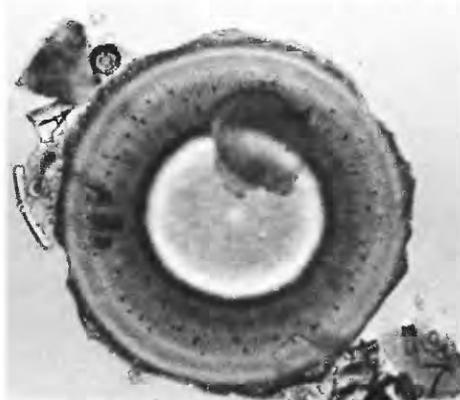
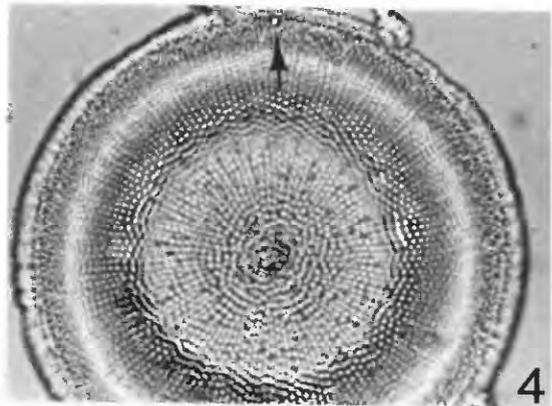
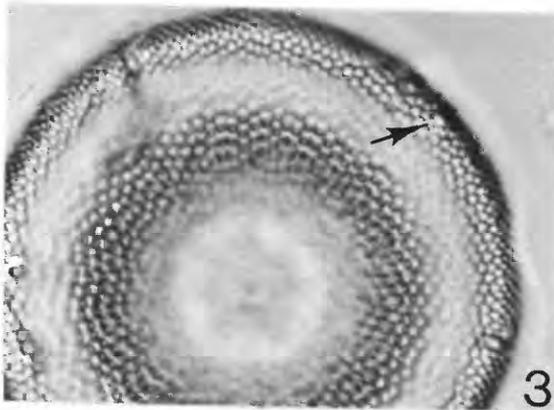
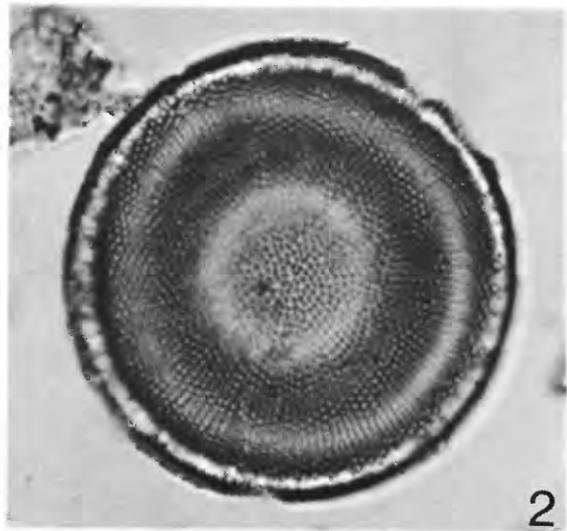
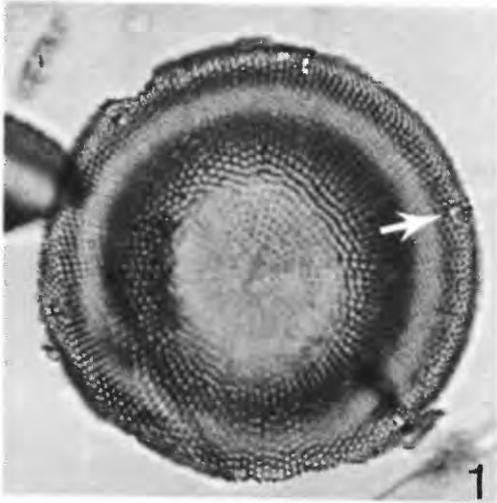


*ACTINOCYCLUS ACANTHUS*

## PLATE 2

Figures 1–7. *Actinocyclus cedrus* Bradbury & Krebs, sp. nov. (p. 5).

1. Esmeralda Formation, Diatomite Ridge, Mineral County, Nevada (loc. 20). Note short, blunt hyaline stripe at the disk/mantle junction (arrow) and polygonal areolae. Diameter 53  $\mu\text{m}$ . Slide USGS–D 31 I 88–1 (65), E.F. P41/1.
2. Esmeralda Formation, Diatomite Ridge, Mineral County, Nevada (loc. 20). Valve with hyaline rim. Diameter 56  $\mu\text{m}$ . Slide USGS–D 31 I 88–1 (65), E.F. L41/4.
3. Esmeralda Formation, Diatomite Ridge, Mineral County, Nevada (loc. 20). Arrow marks pseudonodule. Diameter 45  $\mu\text{m}$ . Slide USGS–D 31 I 88–1 (65), E.F. M32.
4. Poison Creek Formation, Reynolds Creek, Owyhee County, Idaho (loc. 44). Detail of valve surface showing pseudonodule (arrow). Diameter 85  $\mu\text{m}$ . Slide AMOCO: IO–24–5(+), E.F. O9/2.
5. Unnamed Miocene unit, southern Stillwater Mountains, Churchill County, Nevada (loc. 48). Detail of disk and mantle under different focus (a, mantle; b, disk center). Diameter is 67  $\mu\text{m}$ . Slide USGS–D 29 I 81–3B, E.F. N38
6. Juntura (?) Formation, Otis Creek, Harney County, Oregon (loc. 34). Diameter 68  $\mu\text{m}$ . Slide USGS–D 14 VI 78–4B (3), E.F. O34/4.
7. Juntura (?) Formation, Otis Creek, Harney County, Oregon (loc. 34). Large valve with triangular hyaline patches between rows of areolae producing stellate pattern. Diameter 157  $\mu\text{m}$ . Slide USGS–D 14 VI 78–4B (3), E.F. O32/1.

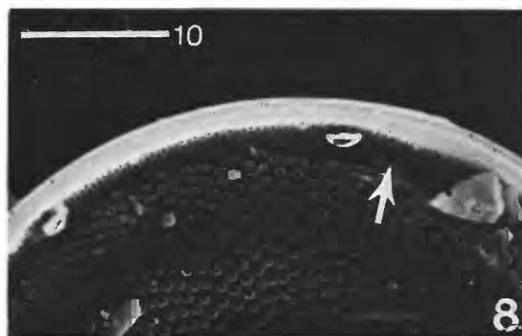
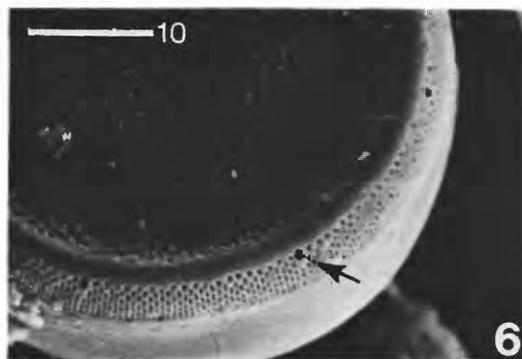
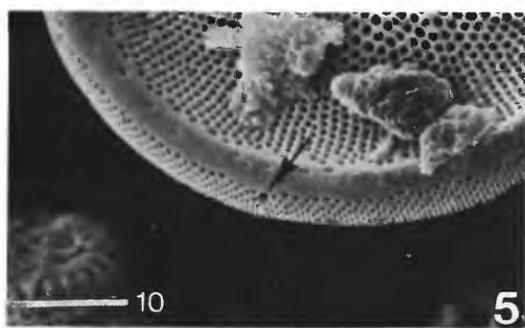
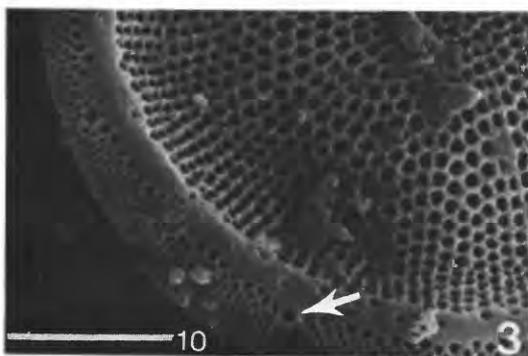
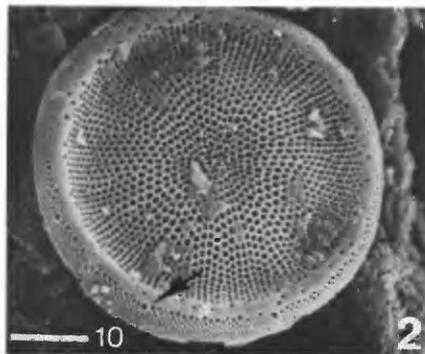


*ACTINOCYCLUS CEDRUS*

### PLATE 3

Figures 1–8. *Actinocyclus cedrus* Bradbury & Krebs, sp. nov. (p. 5). Scale bars in  $\mu\text{m}$ .

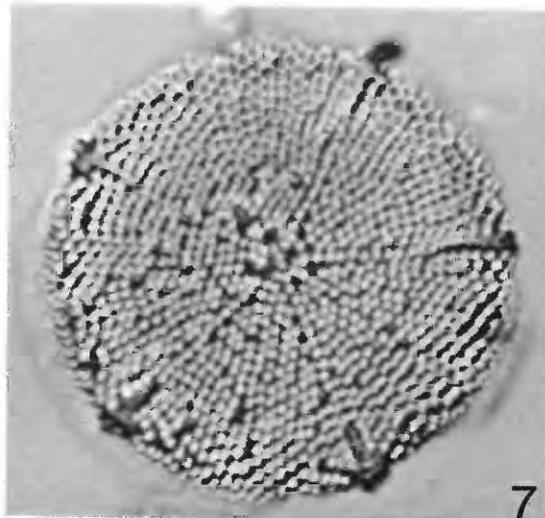
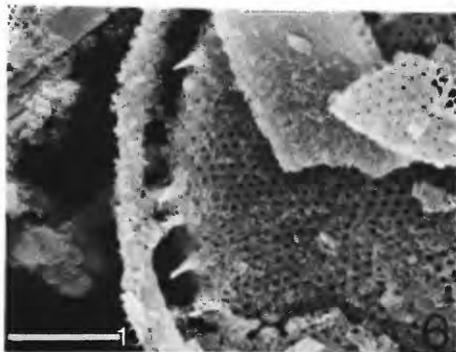
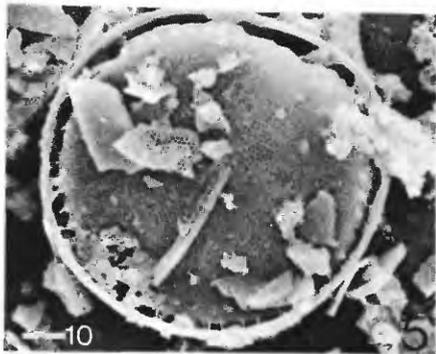
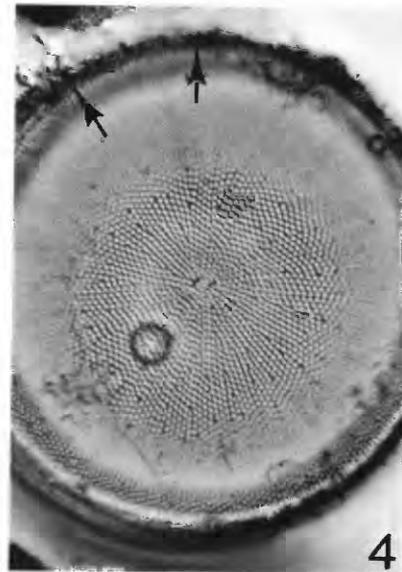
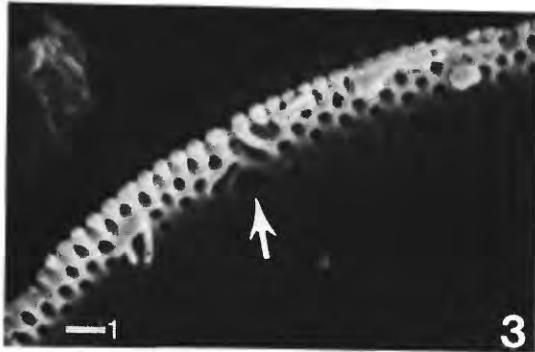
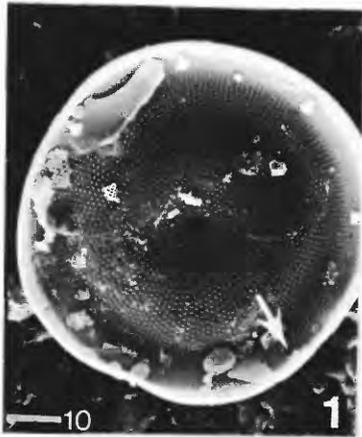
1. Unnamed Miocene unit, southern Stillwater Mountains, Churchill County, Nevada (loc. 48). Valve with hyaline rim. Diameter 49  $\mu\text{m}$ . Slide AMOCO: S.E. Carson Sink-low (-), E.F. Q4/3.
- 2, 3. Esmeralda Formation, Diatomite Ridge, Mineral County, Nevada (loc. 20). Valve exterior with hyaline rim and exit pores of labiate processes (arrows).
- 4, 5. Esmeralda Formation, Diatomite Ridge, Mineral County, Nevada (loc. 20). Exit pores of labiate processes indicated by arrows.
6. Esmeralda Formation, Diatomite Ridge, Mineral County, Nevada (loc. 20). Detail of valve margin and mantle. The arrow pinpoints an exit pore.
- 7, 8. Esmeralda Formation, Diatomite Ridge, Mineral County, Nevada (loc. 20). Overview of valve interior (fig. 7) and detail of disk/mantle junction showing labiate process and position of pseudonodule (arrow) (fig. 8).



*ACTINOCYCLUS CEDRUS*

## PLATE 4

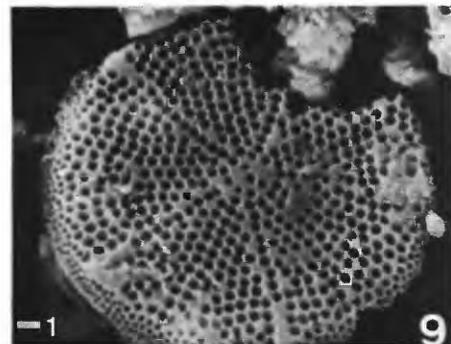
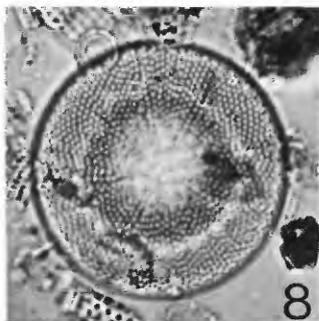
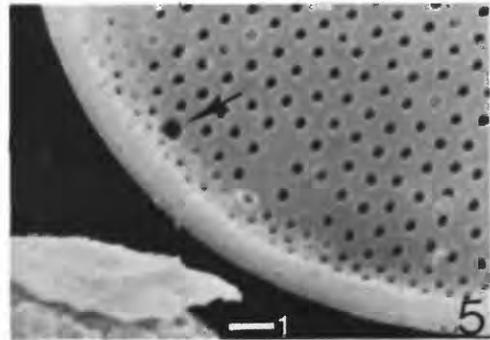
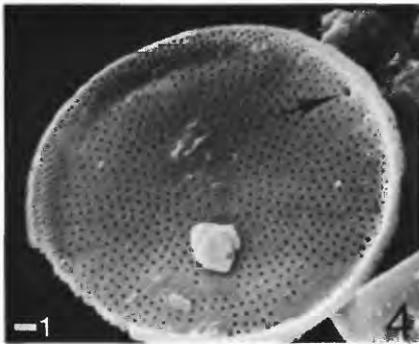
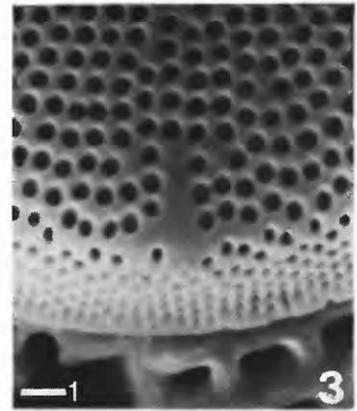
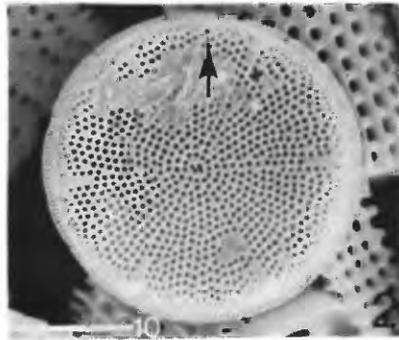
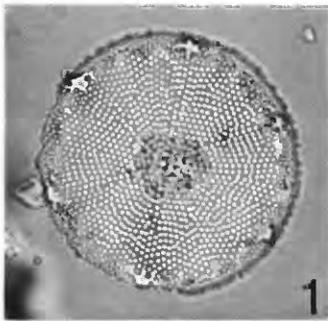
- Figures 1–3. *Actinocyclus cedrus* Bradbury & Krebs, sp. nov. (p. 5). Esmeralda Formation, Diatomite Ridge, Mineral County, Nevada (loc. 20). Scale bars in  $\mu\text{m}$ .
1. Overview of valve interior showing ring of labiate processes. Arrow marks location of pseudonodule.
  2. Closeup of labiate processes.
  3. Internal view of pseudonodule (arrow).
- 4–6. *Actinocyclus cedrus* (spinose form) (p. 5). Unnamed Miocene unit, Turner Creek, Modoc County, California (loc. 17). Scale bars in  $\mu\text{m}$ .
4. Valve view; arrows highlight marginal spines. Diameter is 91  $\mu\text{m}$ . Slide AMOCO: Pit River (+30), E.F. T72.
- 5, 6. Views of marginal spines.
7. *Actinocyclus claviolus* Bradbury & Krebs, sp. nov. (p. 5). Unnamed middle Miocene unit, Jungle Point, Idaho County, Idaho (loc. 33). Note clove-shaped hyaline stripes on disk/mantle junction. Diameter 21  $\mu\text{m}$ . Slide USGS–D 5 XII 80–7 (1), E.F. S37/1.



*ACTINOCYCLUS CEDRUS* AND *ACTINOCYCLUS CLAVIOLUS*

## PLATE 5

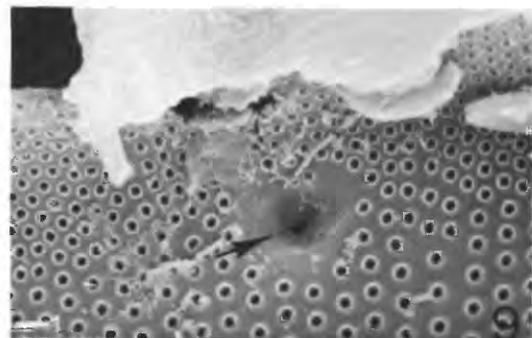
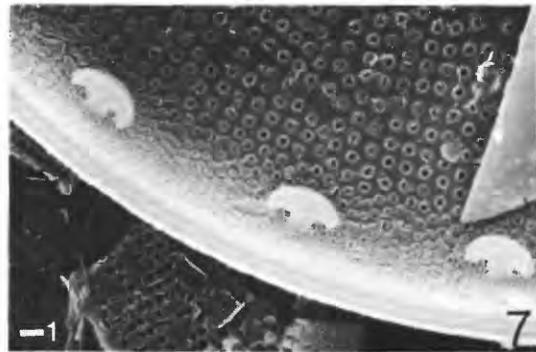
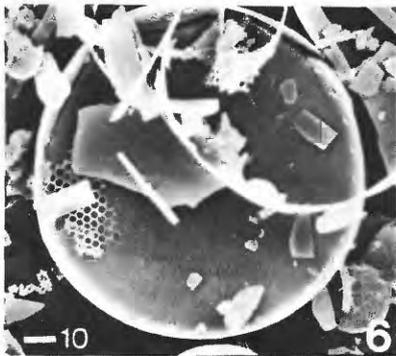
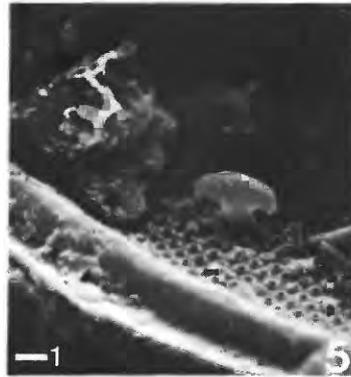
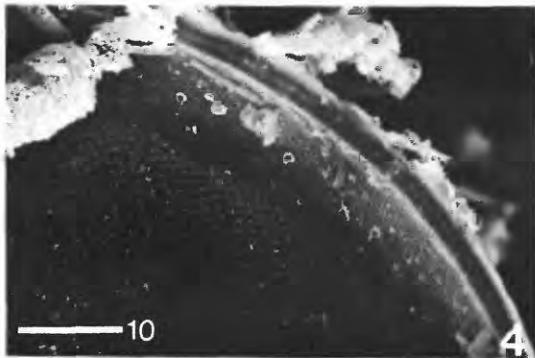
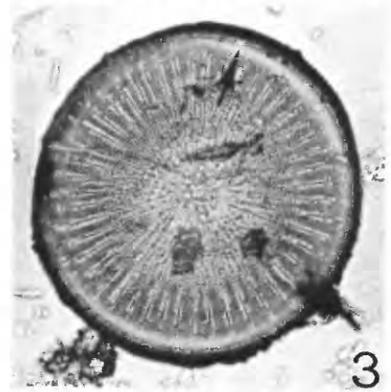
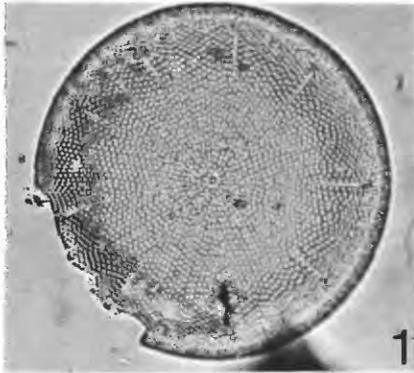
- Figures 1–5. *Actinocyclus claviolus* Bradbury & Krebs, sp. nov. (p. 5). Unnamed middle Miocene unit, Jungle Point, Idaho County, Idaho (loc. 33). Scale bars in  $\mu\text{m}$ .
1. Valve view. Diameter 30  $\mu\text{m}$ . Slide USGS–D 5 XII 80–7 (3), E.F. J33/2.
  2. Valve view. Arrow marks probable pseudonodule.
  3. Detail of marginal clove-shaped hyaline stripe.
  4. Valve interior showing position of pseudonodule (arrow).
  5. Internal view of pseudonodule (arrow).
- 6–9. *Actinocyclus cupreus* Bradbury & Krebs, sp. nov. (p. 6).
6. Unnamed lower Miocene unit, Copper Kettle Canyon, Churchill County, Nevada (loc. 16). Note the pattern of fasciculation and the simple hyaline marginal stripes that delimit each fascicle. Diameter 37  $\mu\text{m}$ . Slide AMOCO: NSD–6 (-), E.F. U9/1.
  7. Humboldt Formation, Eureka County, Nevada (loc. 30). Valve view. Diameter 43  $\mu\text{m}$ . Slide AMOCO: PC–3–79 (+), E.F. H15/4.
  8. Unnamed middle Miocene unit, Juliaetta, Nez Perce County, Idaho (loc. 32). Valve view. Diameter 29  $\mu\text{m}$ . Slide USGS–D 5 XII 80–3 (2), E.F. K30/4.
  9. Juliaetta, Nez Perce County, Idaho (loc. 32). Valve view. Scale bar in  $\mu\text{m}$ .



*ACTINOCYCLUS CLAVIOLUS* AND *ACTINOCYCLUS CUPREUS*

## PLATE 6

- Figures 1, 2. *Actinocyclus* cf. *A. cupreus* (p. 7). Freshwater Miocene deposits, Yamato Bank, Sea of Japan. Valve views. Note the flat disk and long marginal hyaline stripes.
1. Core RC 12-394 (600 cm). Diameter 62  $\mu\text{m}$ . Slide AMOCO: RC12-394 600 cm (+), E.F. E33/4.
  2. Core RC 12-394 (600 cm). Diameter 54  $\mu\text{m}$ . Slide AMOCO: RC12-394 600 cm (+), E.F. V10/2.
- 3-9. *Actinocyclus ehrenbergii* Ralfs in Pritchard (p. 7).
- 3-5. Quiburis Formation, Edgar Canyon, Pima County, Arizona (loc. 92). Scale bars in  $\mu\text{m}$ .
    3. Valve view showing large pseudonodule (arrow). Diameter 146  $\mu\text{m}$ . Slide USGS-D 19 IV 80-3A (2), E.F. H36/3.
    4. Internal detail of disk/mantle junction showing the closely spaced pores of labiate processes. Labiate processes are missing.
    5. Closeup of labiate process.
  - 6-9. *Actinocyclus ehrenbergii* Ralfs in Pritchard. Holocene marine sediment, Walvis Bay, Namibia. Scale bars in  $\mu\text{m}$ .
    6. Overview of valve interior showing marginal ring of labiate processes.
    - 7, 8. Closeup of labiate processes.
    9. Internal view of pseudonodule (arrow).



*ACTINOCYCLUS* sp.cf. *A. CUPREUS* AND *ACTINOCYCLUS EHRENBERGII*

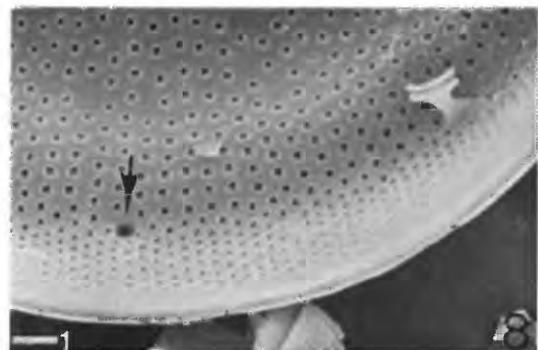
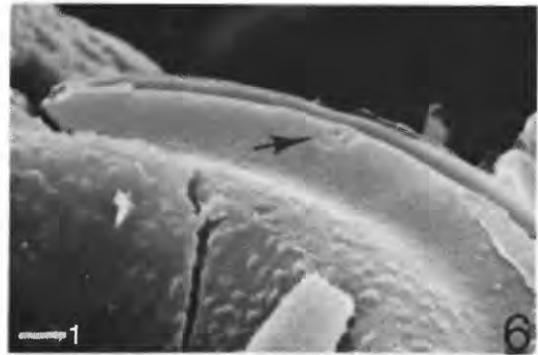
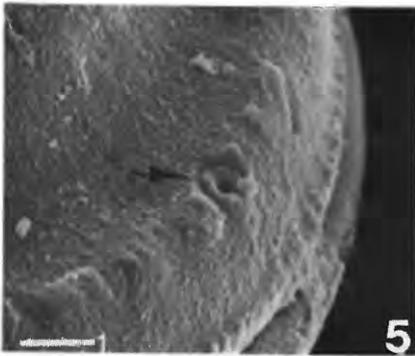
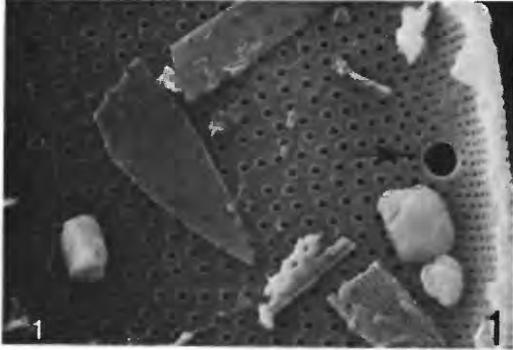
## PLATE 7

Figures 1, 2. *Actinocyclus ehrenbergii* Ralfs in Pritchard (p. 7). Holocene marine sediment, Walvis Bay, Namibia. Scale bars in  $\mu\text{m}$ .

1. Internal view of corroded pseudonodule (arrow).
2. External view of annulate pseudonodule (arrow) and exit pores of labiate processes.

3–8. *Actinocyclus gorbunovii* (Sheshukova) var. *fossa* Bradbury & Krebs, var. nov. (p. 7). Cedarville Formation, Forty-nine Camp, Washoe County, Nevada (loc. 69). Scale bars in  $\mu\text{m}$ .

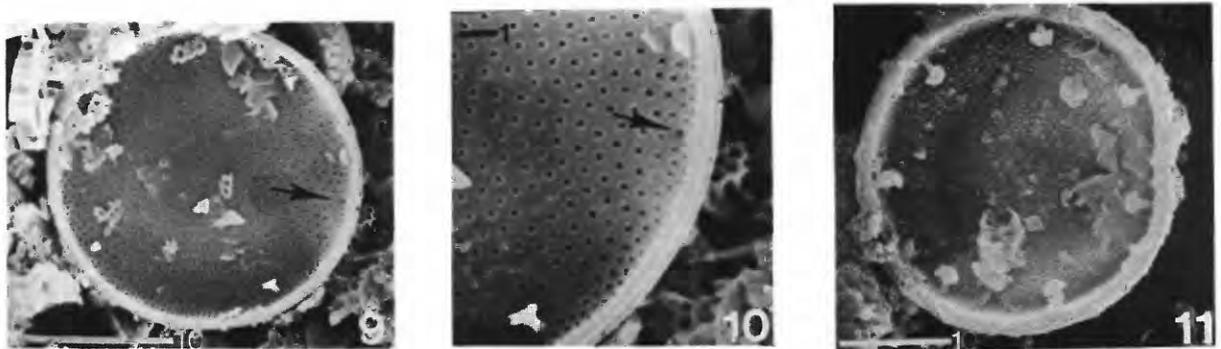
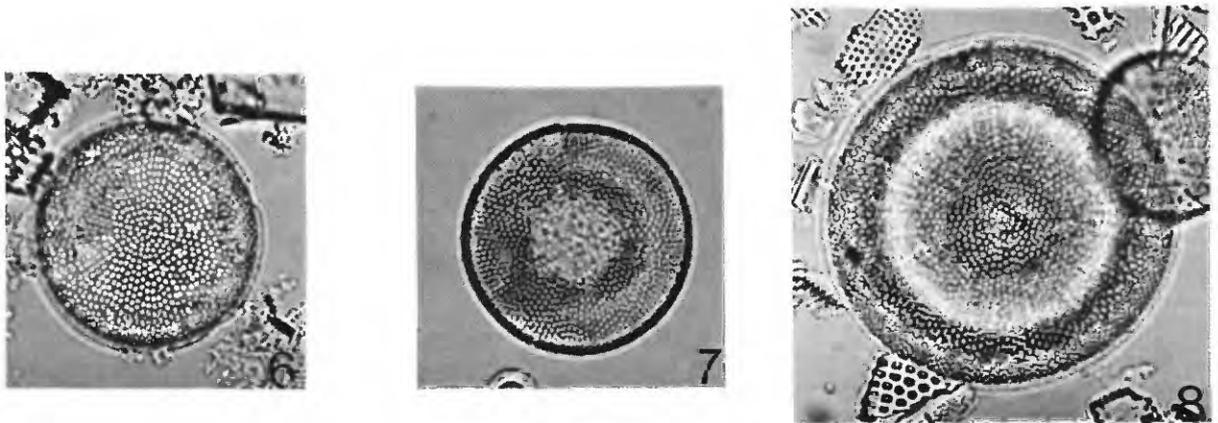
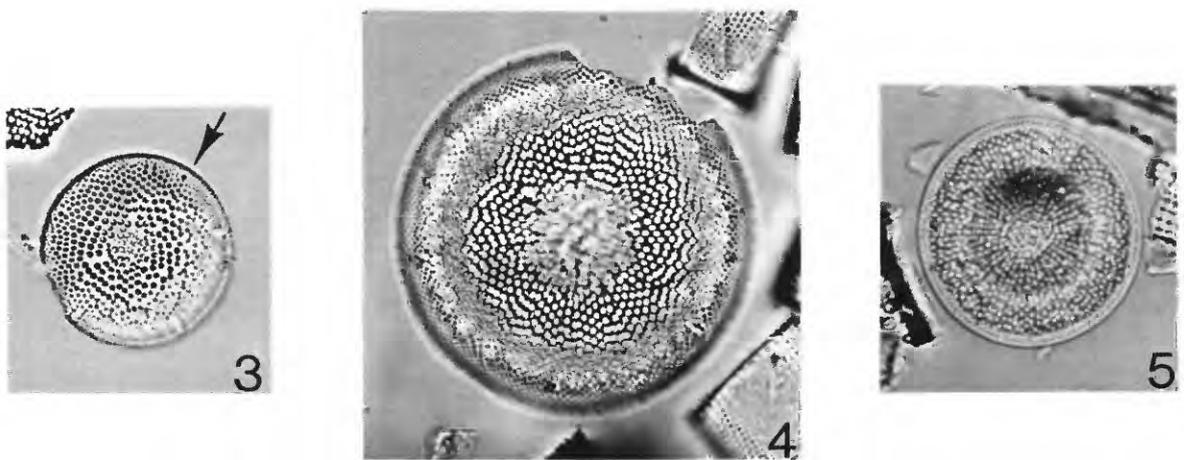
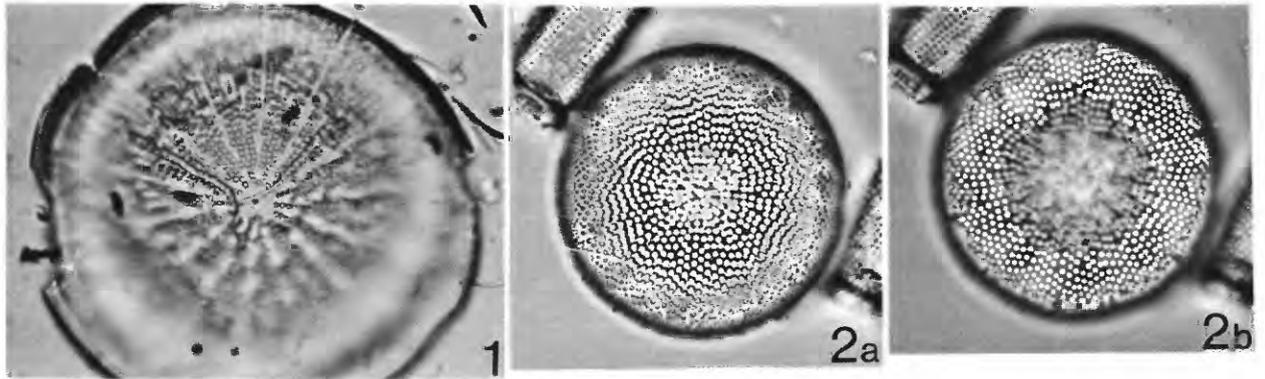
3. Valve view; note the pseudonodule (arrow), the lack of marginal tubular processes, and the concentric undulation of valve. Diameter 35  $\mu\text{m}$ . Slide USGS–D 2 IX 87–3B (1), E.F. P35.
4. Overview of frustule showing steep mantle, concentric undulation, and position of pseudonodule (arrow).
5. Detail of pseudonodule (arrow).
6. View of disk/mantle junction and pseudonodule (arrow). Note the circular moat-like structure that surrounds the pseudonodule.
7. Overview of valve interior showing labiate processes and pseudonodule (arrow).
8. Interior closeup of disk/mantle junction with labiate process and pseudonodule (arrow).



*ACTINOCYCLUS EHRENBURGII* AND *ACTINOCYCLUS GROBUNOVII*

## PLATE 8

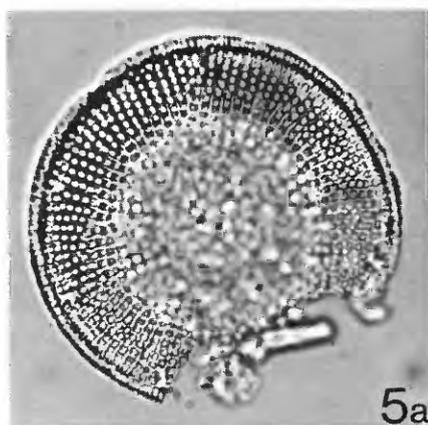
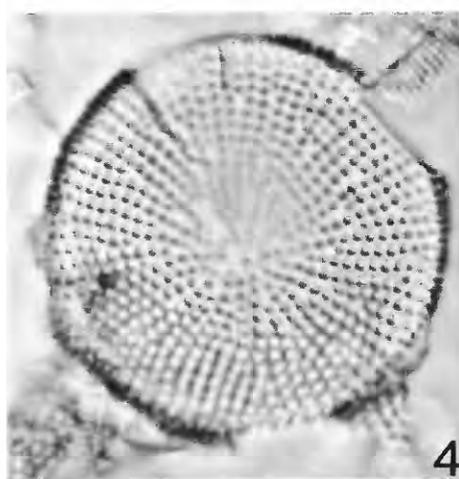
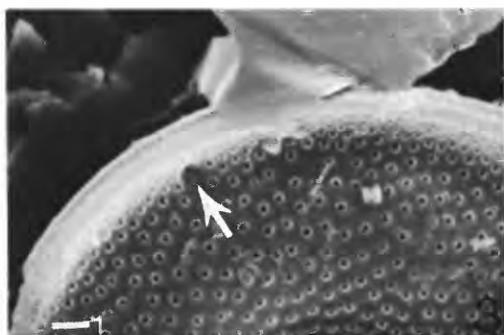
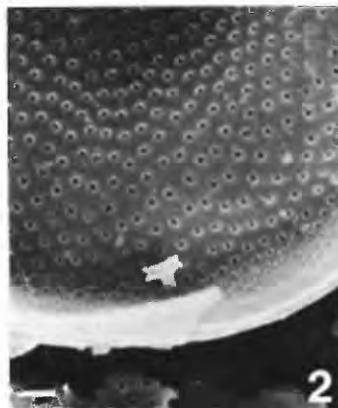
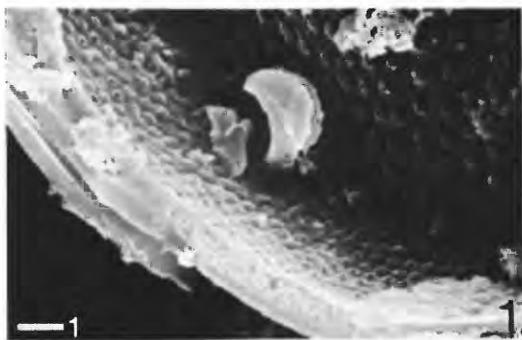
- Figure 1. *Actinocyclus kanitzii* (Pant. & Grun.) Schauderna (p. 3). Middle Miocene lacustrine and brackish water deposits, Szurdokpuszoki, Matra Mountains, Hungary. The fascicles are separated by hyaline stripes that run from the disk/mantle junction to the center of the disk. Diameter 74  $\mu\text{m}$ . Slide USGS-D 3 IX 80-1B, E.F. F43/3.
- 2-6, 8-11. *Actinocyclus krasskei* (Krasske) Bradbury & Krebs, nom. nov. (p. 9).
2. "Kieselgur" (diatomite) deposits of Miocene? age in Vogelsberg Range, Beuern, Germany. Different focus showing detail of slightly undulate valve center (a) and margin (b). Diameter 31  $\mu\text{m}$ . Slide Krasske Collection, Natural History Museum, Kassel, Germany, Beuern #3004.
  3. Beuern, Germany. Valve view showing hyaline stripes and pseudonodule (arrow). Diameter 21  $\mu\text{m}$ . Slide Krasske Collection, Natural History Museum, Kassel, Germany, Beuern #3004.
  4. Beuern, Germany. View of undulate valve showing disk/mantle junction and areolae on mantle arranged in quincunx pattern. Diameter 40  $\mu\text{m}$ . Slide Krasske Collection, Natural History Museum, Kassel, Germany, Beuern #3004.
  5. Unnamed middle Miocene unit, Juliaetta, Nez Perce County, Idaho (loc. 32). Valve view. Diameter 29  $\mu\text{m}$ . Slide USGS-D 5 XII 80-3 (2), E.F. D32/1.
  6. Unnamed Miocene? unit, Arrow Junction, Nez Perce County, Idaho (loc. 72). Valve view. Diameter 27  $\mu\text{m}$ . Slide AMOCO: USGS-DC#2289, E.F. H30/1.
  8. Juliaetta, Nez Perce County, Idaho (loc. 32). View of undulate valve. Diameter 40  $\mu\text{m}$ . Slide USGS-D 5 XII 80-3 (2). E.F. Q38.
  - 9, 10. Squaw Creek Member, Ellensburg Formation, Yakima County, Washington (loc. 49). Interior of valve showing long-stemmed labiate processes and pseudonodule (arrow). Scale bars in  $\mu\text{m}$ .
  11. Mascall Formation, Vinegar Creek, Grant County, Oregon (loc. 88). Interior of valve showing ring of long-stemmed labiate processes. Scale bars in  $\mu\text{m}$ .
7. *Actinocyclus tubulosus* Khursevich. (p. 13). Squaw Creek Member, Ellensburg Formation, Yakima County, Washington (loc. 49). Valve view. Diameter 27  $\mu\text{m}$ . Slide USGS-D 26 II 79-2A (3), E.F. N47/4.



*ACTINOCYCLUS KANTIZII*, *ACTINOCYCLUS KRASSKEI*, AND *ACTINOCYCLUS TUBULOSUS*

## PLATE 9

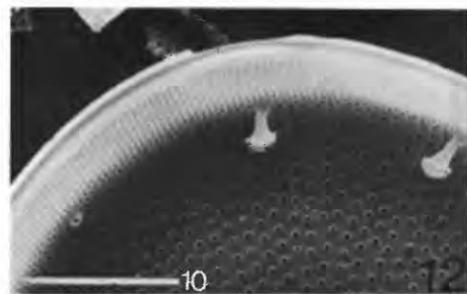
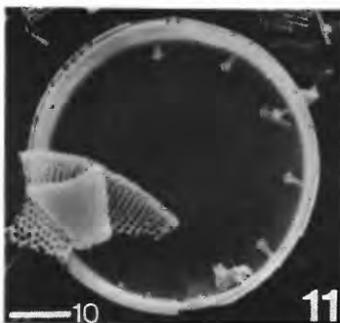
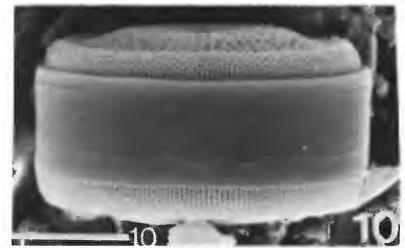
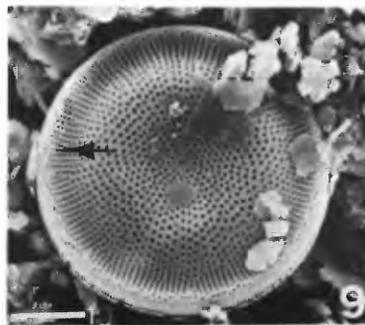
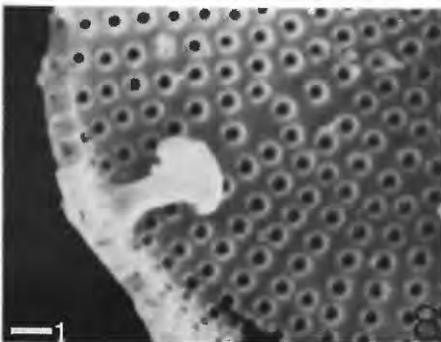
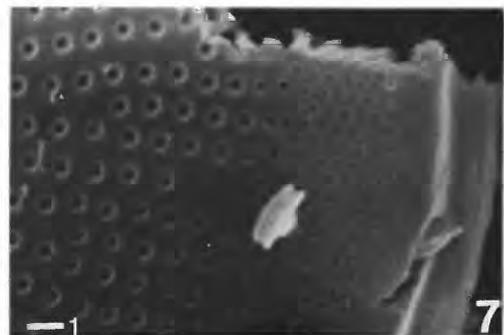
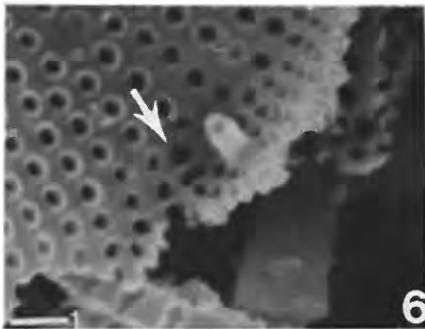
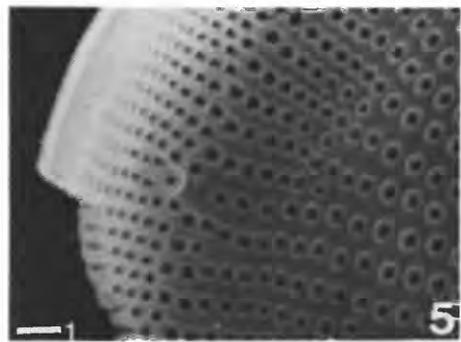
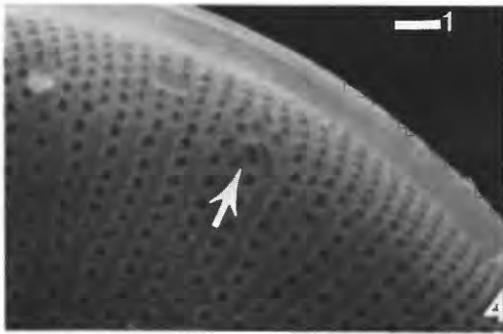
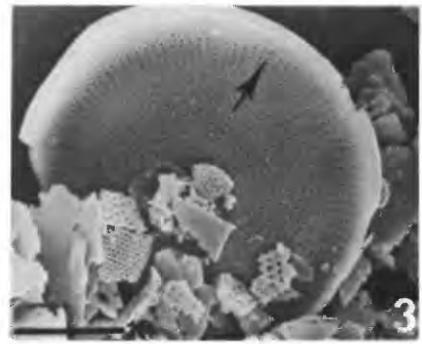
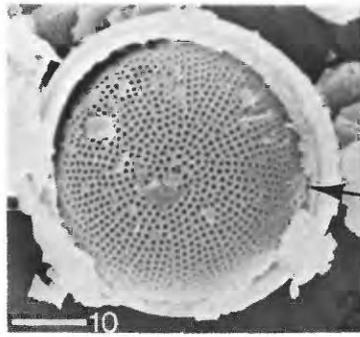
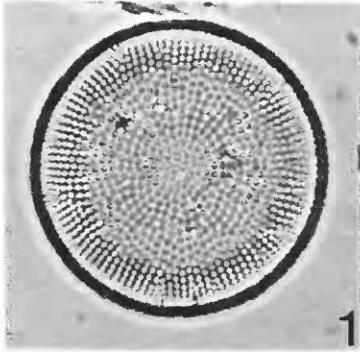
- Figure 1. Flat forms of *Actinocyclus krasskei* (Krasske) Bradbury & Krebs, nom. nov. (p. 9). Mascall Formation, Vinegar Creek, Grant County, Oregon (loc. 88). Closeup of labiate process. Scale bars in  $\mu\text{m}$ .
- 2, 3. Undulate forms of *Actinocyclus krasskei* (Krasske) Bradbury & Krebs, nom. nov. (p. 9). Squaw Creek Member, Ellensburg Formation, Yakima County, Washington (loc. 49). Scale bars in  $\mu\text{m}$ .
2. Closeup of labiate process.
3. Valve interior showing position of pseudonodule (arrow).
- 4–6. *Actinocyclus motilis* Bradbury & Krebs, sp. nov. (p. 10).
4. Esmeralda Formation, Cedar Mountain, Mineral County, Nevada (loc. 22). Note the truncation of sinuous rows of areolae by other rows. Diameter 23  $\mu\text{m}$ . Slide USGS–D 23 I 81–10 (1), E.F. L34/2.
5. Unnamed middle Miocene unit, Augusta Mountains, Churchill County, Nevada (loc. 4). Focus on valve margin (a) and center (b). Diameter 42  $\mu\text{m}$ . Slide AMOCO: AMS–1–1(-), E.F. M34/2.
6. Unnamed middle Miocene unit, Goose Creek, Baker County, Oregon (loc. 27). Focus on valve margin (a) and center (b). Diameter 46  $\mu\text{m}$ . Slide USGS–D 10 VI 78–2B (3), E.F. L24/4.



*ACTINOCYCLUS KRASSKEI* AND *ACTINOCYCLUS MOTILIS*

## PLATE 10

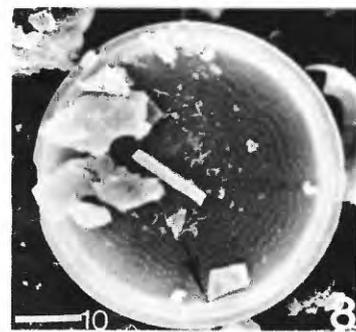
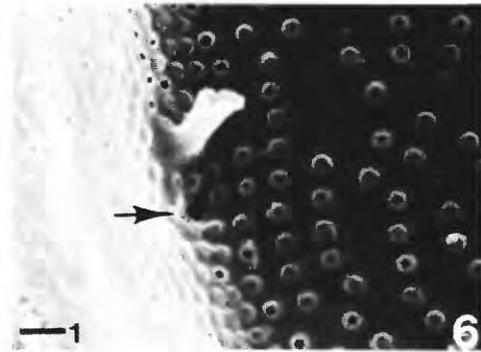
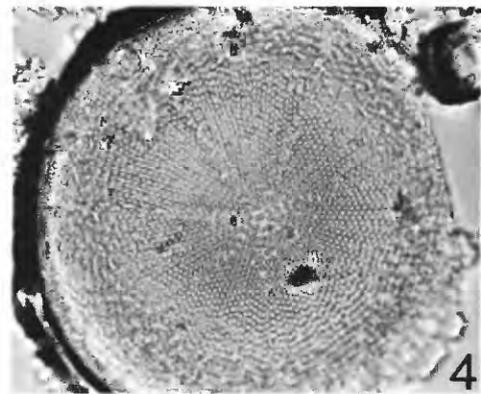
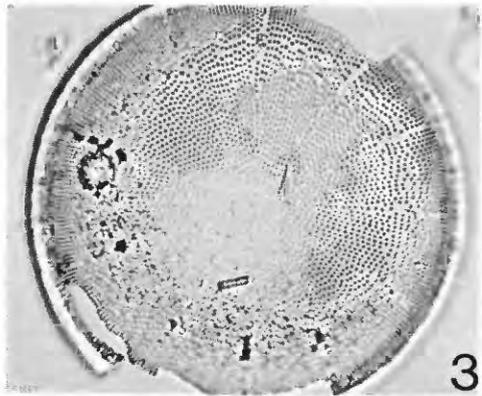
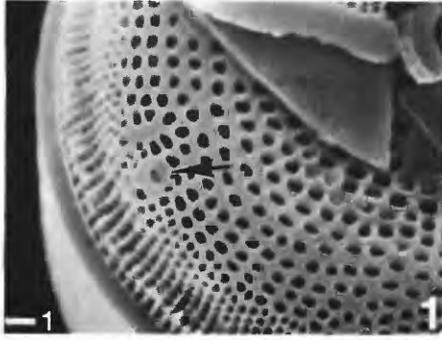
- Figure 1–12. *Actinocyclus motilis* Bradbury & Krebs, sp. nov. (p. 10). Scale bars in  $\mu\text{m}$ .
1. Squaw Creek Member, Ellensburg Formation, Yakima County, Washington (loc. 49). Diameter 34  $\mu\text{m}$ . Slide USGS–D 27 II 79–1, E.F. R31/4.
  - 2–8. Esmeralda Formation, Cedar Mountain, Mineral County, Nevada (loc. 22).
    2. Valve view showing separation of valve from intercalary bands. Arrow marks probable pseudonodule.
    3. Valve interior showing position of pseudonodule (arrow).
    4. Detail of pseudonodule (arrow) showing pore structure.
    - 5, 6. Broken stumps of labiate processes. Arrow marks location of probable pseudonodule in figure 6.
  - 7, 8. Closeups of long-stemmed labiate processes.
  - 9–12. Squaw Creek Member, Ellensburg Formation, Yakima County, Washington (loc. 49).
    9. Exterior of valve showing concentric undulation and interdigitation of rows of areolae at the valve margin. Arrow marks probable pseudonodule.
    10. Girdle view of frustule.
    11. View of valve interior showing a marginal ring of long-stemmed labiate processes.
    12. Closeup of labiate processes.



*ACTINOCYCLUS MOTILIS*

## PLATE 11

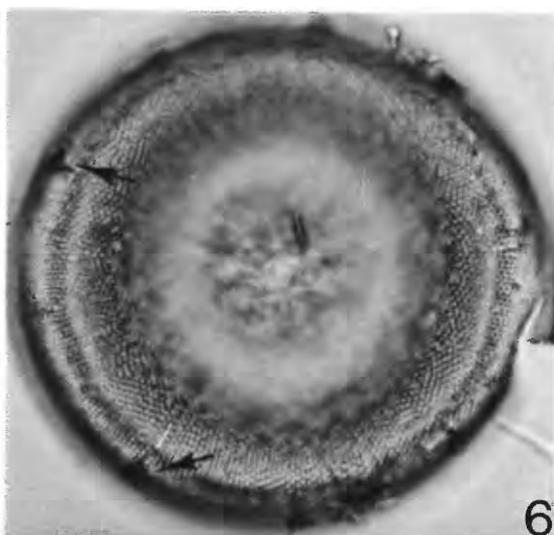
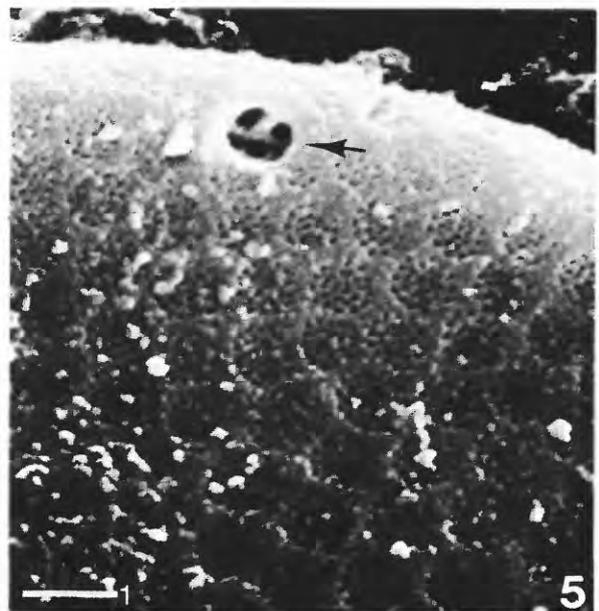
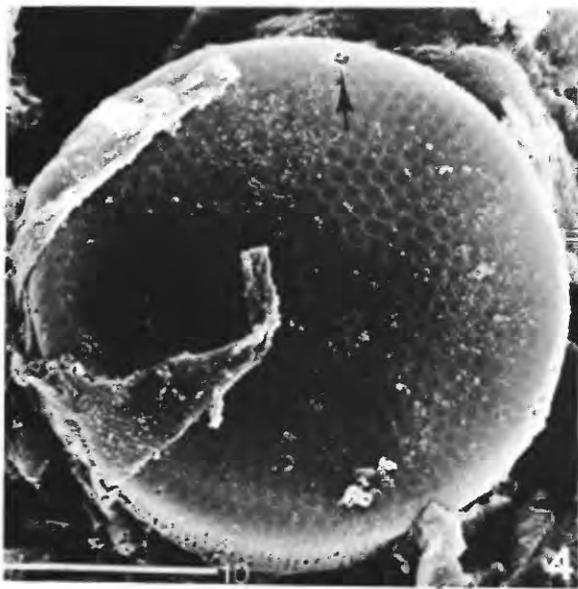
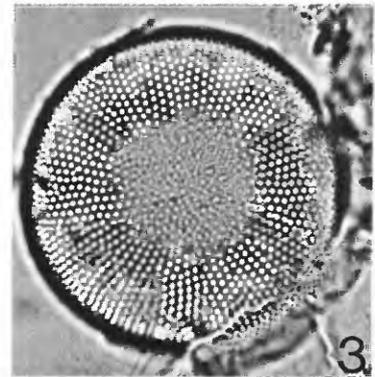
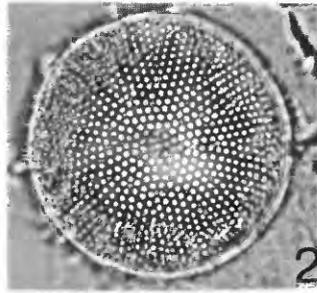
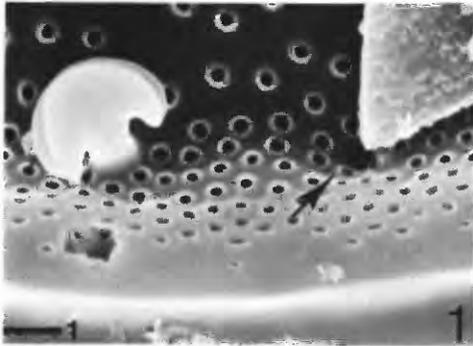
- Figure 1. *Actinocyclus motilis* Bradbury & Krebs, sp. nov. (p. 10). Squaw Creek Member, Ellensburg Formation, Yakima County, Washington (loc. 49). Detail of valve disk/mantle junction showing pseudonodule (arrow) and hyaline stripe with exit pore. Scale bar in  $\mu\text{m}$ .
- 2–8. *Actinocyclus nebulosus* Bradbury & Krebs. (p. 11). Scale bars in  $\mu\text{m}$ .
2. Esmeralda Formation, Black Spring, Nye County, Nevada (loc. 93). Valve view. Diameter 67  $\mu\text{m}$ . Slide USGS–D 26 XII 86–2A (1), E.F. H38/1.
  3. Esmeralda Formation, Black Spring, Nye County, Nevada (loc. 93). Valve view. Diameter 77  $\mu\text{m}$ . Slide USGS–D 26 XII 86–2A (1), E.F. G36/3.
  4. Buffalo Canyon Formation, Buffalo Canyon, Churchill County, Nevada (loc. 6). Valve view. Diameter 83  $\mu\text{m}$ . Slide AMOCO: Buffalo Canyon, E.F. E6/4.
  5. Esmeralda Formation, Cedar Mountain, Nye County, Nevada (loc. 74). Arrow marks probable pseudonodule. Diameter 67  $\mu\text{m}$ . AMOCO: USGS–DC #3394 (3). E.F. M42/2.
  - 6–8. Esmeralda Formation, Black Spring, Nye County, Nevada (loc. 93). Views of valve interior; arrow indicates position of pseudonodule.



*ACTINOCYCLUS MOTILIS* AND *ACTINOCYCLUS NEBULOSUS*

## PLATE 12

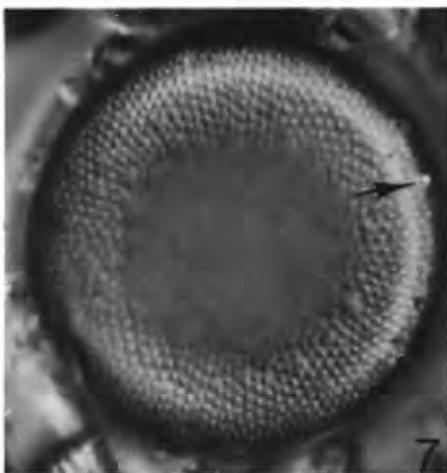
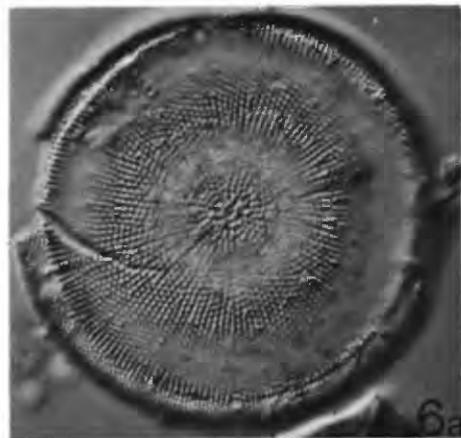
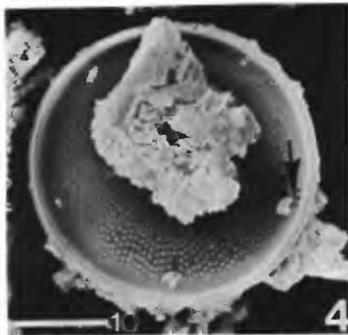
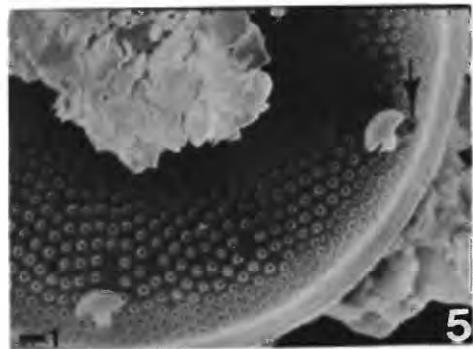
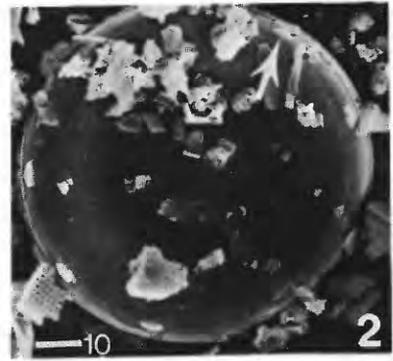
- Figure 1. *Actinocyclus nebulosus* Bradbury & Krebs, sp. nov. (p. 11). Esmeralda Formation, Black Spring, Nye County, Nevada (loc. 93). Interior detail of mantle/disk junction showing short-stemmed broad labiate process and position of pseudonodule (arrow). Scale bar in  $\mu\text{m}$ .
- 2–5. *Actinocyclus normanii* f. *subsalsa* (Juhl.-Dannf.) Hustedt. (p. 3). Holocene lake sediment, Saginaw Bay, Lake Huron, Michigan. Scale bars in  $\mu\text{m}$ .
2. Valve view. Diameter 33  $\mu\text{m}$ . Slide USGS–D 24 II 82–1 (1), E.F. P31/1.
3. Valve view. Diameter 37  $\mu\text{m}$ . Slide USGS–D 24 II 82–1 (1), E.F. N39/1–2.
- 4, 5. Valve views. Arrows indicate position of pseudonodule.
- 6, 7. *Actinocyclus pinnulus* Bradbury & Krebs, sp. nov. (p. 11). Hole-in-the-Wall Diatomite, Gooding County, Idaho (loc. 90).
6. Valve view. Arrows indicate positions of marginal flanged tubular processes. Diameter 61  $\mu\text{m}$ . Slide USGS–D 21 VI 88–1 (1), E.F. N29.
7. Valve view. Arrows highlight marginal hyaline stripes. Diameter 66  $\mu\text{m}$ . Slide USGS–D 21 VI 88–1 (1), E.F. P43.



*ACTINOCYCLUS NEBULOSUS*, *ACTINOCYCLUS NORMANII* f. *SUBSALSA*,  
AND *ACTINOCYCLUS PINNULUS*

### PLATE 13

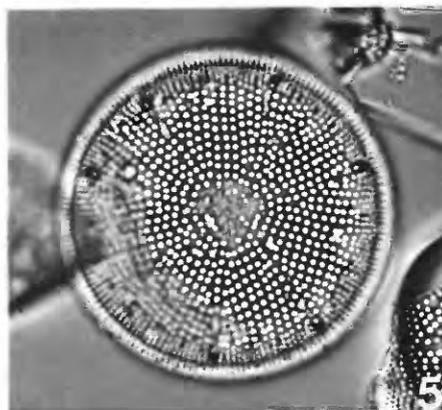
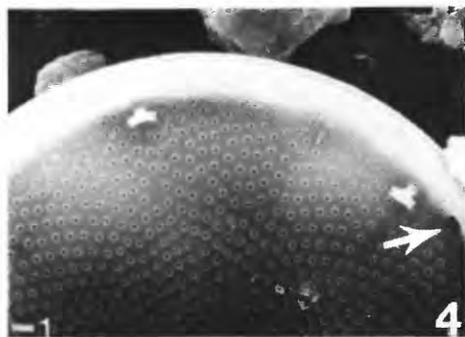
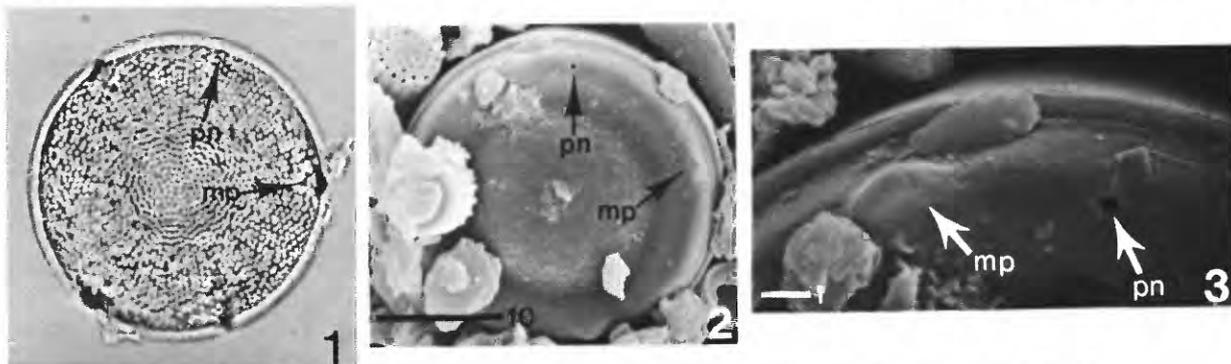
- Figures 1–5. *Actinocyclus pinnulus* Bradbury & Krebs, sp. nov. (p. 11). Hole-in-the-Wall Diatomite, quarry, Gooding County, Idaho (loc. 90). Scale bars in  $\mu\text{m}$ .
1. Valve view. Arrows highlight marginal flanged tubular processes. Diameter 66  $\mu\text{m}$ . Slide USGS–D 21 VI 88–1 (1), E.F. P43.
  - 2, 3. Valve view. Arrows indicate the position of a marginal flanged tubular process
  4. Overview of valve interior showing a ring of marginal short-stemmed labiate processes and the pseudonodule (arrow).
  5. Closeup of labiate processes and the pseudonodule (arrow).
6. *Actinocyclus* sp. cf. *A. pinnulus* (p. 12). Amoco Becharof No. 1 well, depth 3220–3250 feet, Alaska Peninsula, Alaska (loc. 112). Focus on valve margin (a) and center (b). Arrow indicates the position of the pseudonodule. Diameter 40  $\mu\text{m}$ . Slide AMOCO: Becharof 3220–3250 ft. (-), E.F. V22/3.
7. *Actinocyclus theleus* Bradbury & Krebs, sp. nov. (p. 12). “Clarkia Lake deposits,” Emerald Creek, Benewah County, Idaho (loc. 21). Valve view; pseudonodule indicated by arrow. Diameter 25  $\mu\text{m}$ . Slide USGS–D 5 XII 80–4 (2), E.F. P28/2.



*ACTINOCYCLUS PINNULUS*, *ACTINOCYCLUS* sp.cf. *A. PINNULUS*,  
AND *ACTINOCYCLUS THELEUS*

## PLATE 14

- Figures 1–4. *Actinocyclus theleus* Bradbury & Krebs, sp. nov. (p. 12). Scale bars in  $\mu\text{m}$ .
1. Unnamed middle Miocene unit, Oviatt Creek, Clearwater County, Idaho (loc. 43). Valve view. Note arrow to the nipple-like marginal process(es) (mp). Pseudonodule is indicated by other arrow (pn). Diameter 34  $\mu\text{m}$ . Slide USGS D 5 XII 80–1 (1), E.F. V39/1.
  2. “Clarkia Lake deposits,” Emerald Creek, Benewah County, Idaho (loc. 21). Valve view of exterior surface showing the pseudonodule (pn) and marginal process(es) (mp).
  3. Emerald Creek, Benewah County, Idaho (loc. 21). Closeup of disk/mantle junction showing marginal process (mp) and pseudonodule (pn).
  4. Emerald Creek, Benewah County, Idaho (loc. 21). Interior view with two labiate processes, and the pseudonodule (arrow).
- 5, 6. *Coscinodiscus* (= *Actinocyclus*) *variabilis* sensu Krasske. (p. 3). Unnamed Miocene? unit in the Vogelsberg Range, Ruckers, Germany.
5. Valve view. Diameter 37  $\mu\text{m}$ . Slide Krasske Collection, Natural History Museum, Kassel, Germany, Ruckers #2996.
  6. Focus on the valve disk (a) and mantle (b). Diameter 52  $\mu\text{m}$ . Slide Krasske Collection, Natural History Museum, Kassel, Germany, Ruckers #2996.
- 7, 8. *Actinocyclus venenosus* Bradbury & Krebs, sp. nov. (p. 13). Poison Creek Formation, Reynolds Creek, Owyhee County, Idaho (loc. 44).
7. Valve view showing long, pointed hyaline stripes. Diameter 71  $\mu\text{m}$ . Slide AMOCO: IO–23–2(+), E.F. Q22/4.
  8. Valve view of large specimen. Note the dash-like hyaline stripes. Diameter 125  $\mu\text{m}$ . Slide AMOCO: IO–23–6(+), E.F. F35/4.

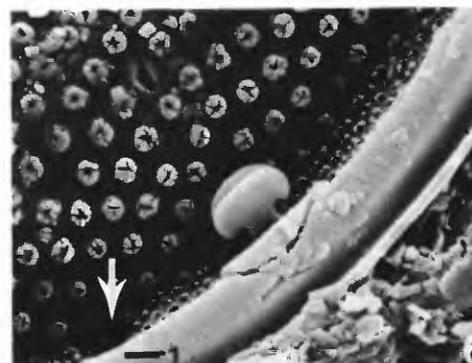
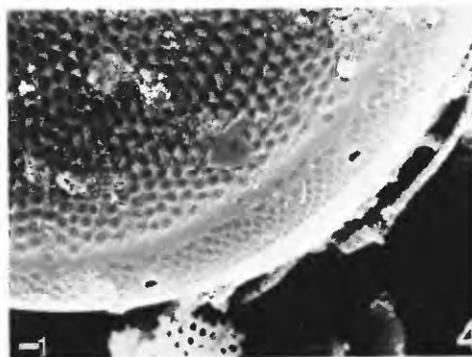
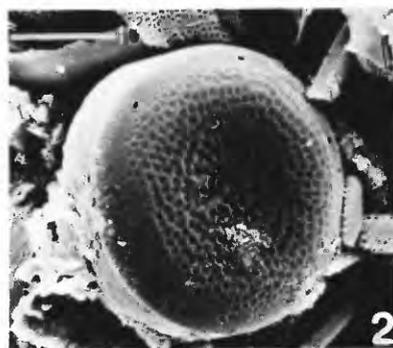


*ACTINOCYCLUS THELEUS*, *COSCINODISCUS* (= *ACTINOCYCLUS*) *VARIABILIS*,  
AND *ACTINOCYCLUS VENENOSUS*

## PLATE 15

Figures 1–6. *Actinocyclus venenosus* Bradbury & Krebs, sp. nov. (p. 13). Scale bars in  $\mu\text{m}$ .

1. Poison Creek Formation, Reynolds Creek, Owyhee County, Idaho (loc. 44). Valve view showing polygonal areolae, concentric undulation of the valve face, and pointed marginal hyaline stripes. Diameter 66  $\mu\text{m}$ . Slide USGS–D 11 VI 78–1A (2), E.F. G35.
- 2, 3. Idaho Group, Washington County, Idaho (loc. 31). View of exterior valve surface showing the exit pores of the labiate processes and marginal hyaline stripes.
4. Idaho Group, Washington County, Idaho (loc. 31). Detail of valve disk/mantle junction showing exit pores, hyaline stripes, and hyaline rim.
5. Idaho Group, Washington County, Idaho (loc. 31). View of interior surface. Note the ring of marginal short-stemmed, broadly flanged labiate processes.
6. Poison Creek Formation, Reynolds Creek, Owyhee County, Idaho (loc. 44). Closeup of labiate process. Arrow indicates the position of pseudonodule.



*ACTINOCYCLUS VENENOSUS*

# Geologic Ranges of Lacustrine *Actinocyclus* Species, Western United States

By William N. Krebs and J. Platt Bradbury

THE DIATOM GENUS *ACTINOCYCLUS* IN THE WESTERN UNITED STATES

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U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1543-B

*Preliminary geologic ranges of lacustrine species of the Western United States determined from radiometrically dated outcrops of diatomites and diatomaceous sediments from Nevada, California, Washington, Oregon, and Idaho*



UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1995

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3. Preliminary range chart of obligate lacustrine <i>Actinocyclus</i> species, Western United States .....	56

# GEOLOGIC RANGES OF LACUSTRINE *ACTINOCYCLUS* SPECIES, WESTERN UNITED STATES

By William N. Krebs<sup>1</sup> and J. Platt Bradbury<sup>2</sup>

## ABSTRACT

In the Western United States, twelve obligate freshwater species of *Actinocyclus* Ehrenberg are restricted to the early and middle Miocene. Maximum diversity (11 species) was attained during the early middle Miocene, before the appearance of obligate lacustrine genera of the family Thalassiosiraceae. Three, possibly five, species of *Actinocyclus* are restricted to the early middle Miocene; *A. pinnulus* is restricted to the late middle Miocene. *Actinocyclus ehrenbergii* Ralfs, a coastal marine species, has been found in latest Miocene to earliest Pliocene lake sediments, but because of its long geologic range in marine sediments and rarity in lacustrine rocks, it is probably not a useful biostratigraphic indicator in continental deposits. Fossil lacustrine *Actinocyclus* spp. are found elsewhere in the world and may have geologic ranges that differ in detail, but which are generally similar to those in the Western United States.

## INTRODUCTION

Interest in lacustrine diatom biochronology has greatly increased in recent years (Servant-Vildary, 1978; Gasse, 1980; Rehakova, 1980; Bradbury and Krebs, 1982; Khursevich, 1982; Loginova, 1982; Loginova and others, 1984; Bradbury, 1984, 1986; Bradbury and others, 1985; VanLandingham, 1985; Fourtanier, 1987; Krebs and others, 1987; Theriot and Bradbury, 1987; Fourtanier and Gasse, 1988; Serieyssol, 1988). In the Western United States, lacustrine diatomaceous sediments are often interbedded with volcanic rock and are thus well suited for radiometric dating. Fossil microfloras can therefore be arranged geochronologically and key diatoms can be traced through time. In this manner, Krebs and others (1987) have documented the succession of several lacustrine diatom genera through the Neogene and Quaternary of the Western

United States (fig. 1). The purpose of this study is to present the geologic ranges of species belonging to one of these genera, *Actinocyclus*. These ranges will, of course, change as additional data accumulate and as lacustrine diatomaceous sediments become better dated. We present this information as our knowledge to date and hope that it will stimulate comparative studies in the Western United States and in other regions worldwide.

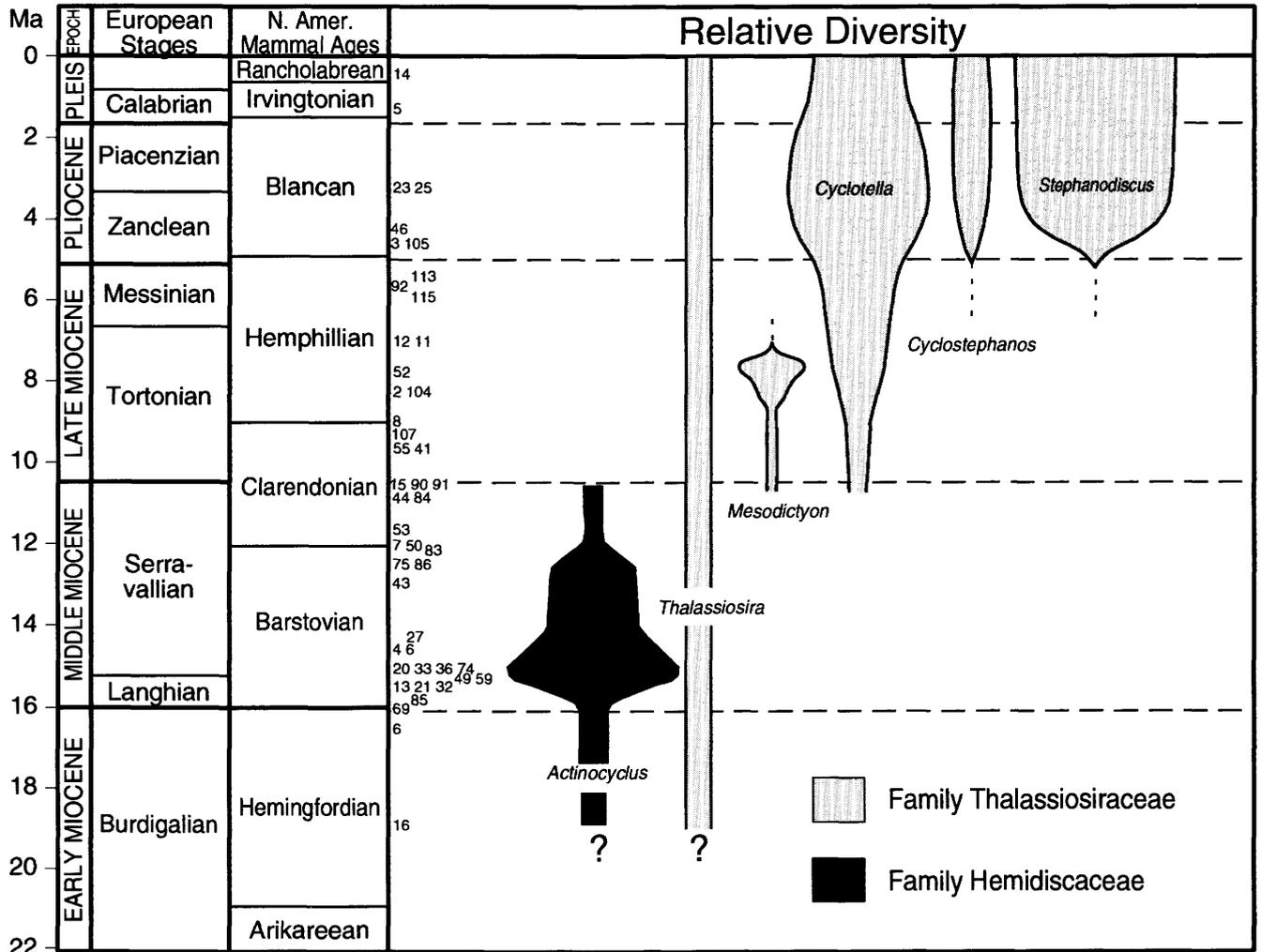
## MATERIALS AND METHODS

Our data are derived from 115 localities in the Western United States, including Alaska, mostly from the Great Basin (fig. 2 and "Appendix"). From these localities, several hundred samples were collected and analyzed for their lacustrine diatom content. Forty-nine of these sites have radiometric dates or have age estimates based on stratigraphic relationships with other dated units. Of these 49 dated localities, 28 have obligate lacustrine species of *Actinocyclus*—that is, they are found only in continental (lake) deposits and only in association with other nonmarine diatom taxa (see chapter A). Unfortunately, the exact stratigraphic and depositional relationships of diatomaceous samples to the dated volcanic rock(s) are often obscure or poorly documented. In addition, radiometric dates may be inaccurate and conflicting. We are confident, however, that the general pattern of lacustrine diatom biochronology in the Western United States presented in figure 1 is accurate and that the species ranges of *Actinocyclus* (fig. 3) reflect evolutionary and (or) environmental changes during the Miocene.

Natural reworking and the rare occurrence of whole specimens or fragments poses problems of interpretation (Krebs and others, 1987). Excluding contamination during collecting and processing, rare occurrences of poorly preserved specimens older than the oldest known occurrence are regarded as significant and merit range extension. Rare (occasionally common) occurrences and fragments younger than the youngest true occurrence may be the result of natural reworking. Clearly, large upward range extensions based on rare occurrences evoke suspicion. Also, poor preservation (abrasion and (or) corrosion) of frustules relative to those of

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**Figure 1.** Biochronology and general relative diversities of six lacustrine diatom genera, Western United States. The numbers represent localities with radiometric ages (see "Appendix" and fig. 2). Diversity patterns are qualitative and not comparable between genera. Time scale is from Berggren and others (1985) and Haq and others (1987).

other diatoms in a sample may indicate reworking. In any case, we have queried occurrences and dashed lines where there is sufficient doubt about absolute age and (or) rare occurrences. Additional localities and closer examination of questionable occurrences may resolve these uncertainties.

## RESULTS

The geologic ranges of lacustrine *Actinocyclus* species will be discussed in alphabetical order rather than by oldest first occurrence, which may change with additional information. Figure 3 is a range chart of these species.

### *Actinocyclus acanthus* Bradbury & Krebs

*Actinocyclus acanthus* was originally described as *Ces-todiscus apiculatus* by Lohman (1957) from the Esmeralda

Formation (Miocene) at Cedar Mountain, Nye County, Nevada (loc. 74). Evernden and others (1964) obtained two radiometric dates from this formation in the Cedar Mountain area whose corrected average is 11.4 Ma. These two dates were taken 61 m and 76 m, respectively, above early Clarendonian ( $\cong$  12 Ma) vertebrates. J. H. Stewart (oral commun., 1988), however, reported that the lower (diatomaceous) half of the Esmeralda Formation dates from about 14 to 12 Ma (Barstovian). Furthermore, recent field work in this area has demonstrated that there is an unconformity between the lower half of the "Esmeralda Formation" and the upper-half that yielded Clarendonian vertebrates and the dates of Evernden and others (1964) (H. E. Schorn, oral commun., 1989). Barstovian vertebrates have been found in the lower diatomaceous portion beneath the unconformity, and a radiometric date of 15.1 Ma obtained from this unit nearby (loc. 20) confirms this age. We, therefore, assign a Barstovian age to the diatomites collected by Lohman at Cedar Mountain



Figure 2. Location of sample sites (see "Appendix").

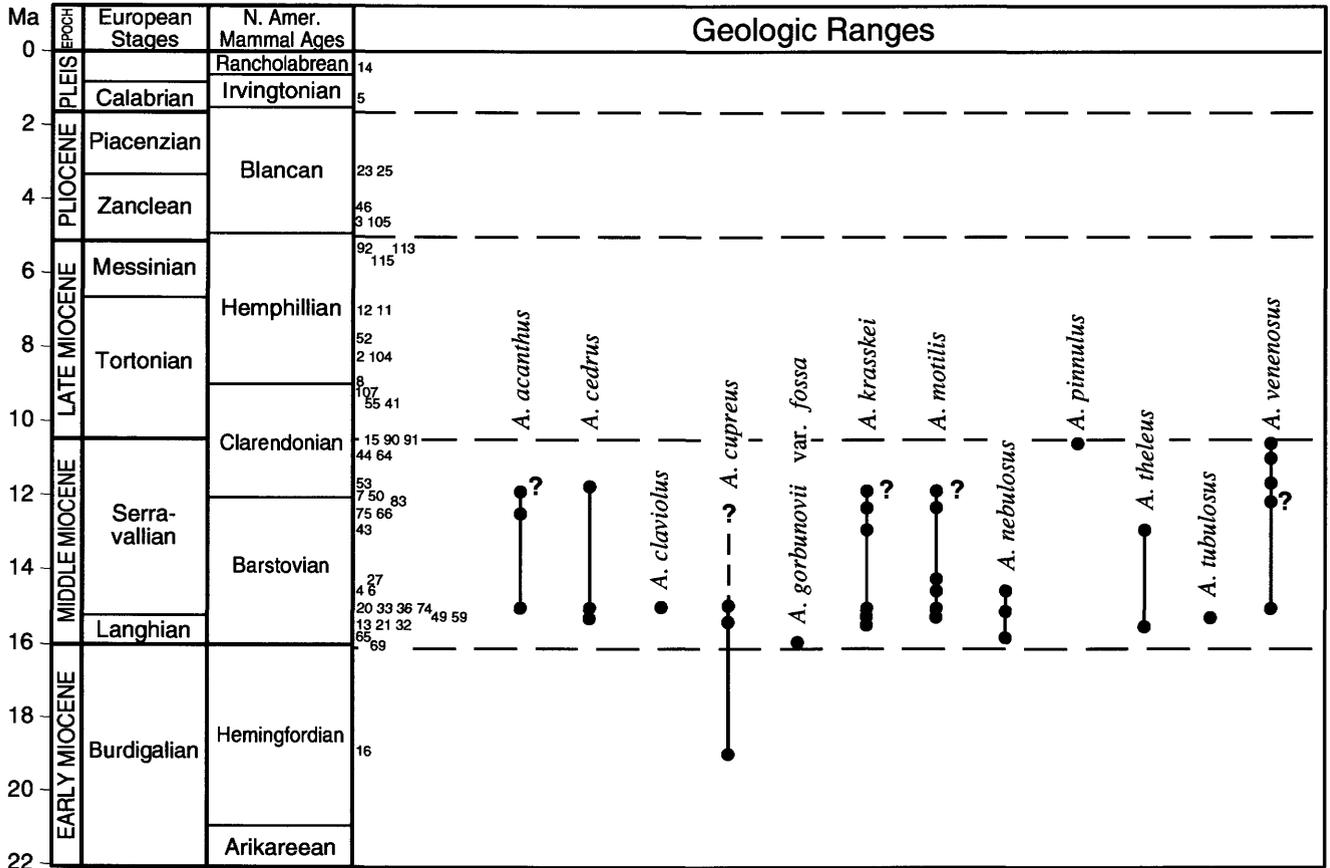


Figure 3. Preliminary range chart of obligate lacustrine *Actinocyclus* species, Western United States. The numbers represent localities with radiometric ages (see "Appendix" and fig. 2). The species ranges have been established by localities with radiometric ages.

(loc. 74), and estimate their absolute age at about 15.1 Ma. We do not know if *A. acanthus* occurs above the unconformity in this section.

The only other occurrences of *A. acanthus* are at the type locality, New Pass, Lander County, Nevada (loc. 42; undated), in Silvies Valley, Grant County, Oregon (loc. 75; about 12.5 Ma), possibly in the Latah Formation (Miocene) near Mead, Spokane County, Washington (loc. 106), and in the Bully Creek Formation (Miocene), Malheur County, Oregon (loc. 7), which has an estimated age of 12 Ma (S.L. VanLandingham, written commun., 1983). This estimate appears loosely constrained, so the Bully Creek Formation may in fact be considerably older. *Actinocyclus acanthus* occurs in the lower middle Miocene (15.1 Ma) and may range into the mid middle Miocene (about 12 Ma).

*Actinocyclus cedrus* Bradbury & Krebs

Lohman (1957) originally described this species as *Cestodiscus cedarensis* from the Esmeralda Formation at Cedar Mountain, Nye County, Nevada (loc. 74, about 15.1 Ma). *Actinocyclus cedrus* is common in many Miocene lacustrine formations of the Great Basin and can

constitute nearly the entire mass of a diatomite, for example, in the southern Stillwater Mountains, Churchill County, Nevada (loc. 48). Among our sample localities, its oldest first occurrence is at the type locality at Diatomite Ridge, Stewart Valley, Mineral County, Nevada (loc. 20; 15.1 Ma). VanLandingham (1988), however, reported the presence of this species at New Pass Summit, Nevada (E½ sec. 32, T. 20 N., R. 40 E., Churchill County) in rocks that date from about 22 Ma (Hudson and Geissman, 1988). Inasmuch as VanLandingham did not figure this species and was unclear how his sample relates stratigraphically to the dated tuff, we cannot confirm his assertion.

In addition to the above mentioned localities, *A. cedrus* has been found in the Squaw Creek Member of the Ellensburg Formation, Yakima County, Washington (loc. 49; 15.5–14.5 Ma), the Ellensburg Formation at Vantage, Grant County, Washington (loc. 59; 15.5–14.5 Ma), in the Beaverdam Formation at Trapper Creek, Cassia County, Idaho (loc. 53, estimated 12.0–11.5 Ma), in the Virginia Range north of Virginia City, Storey County, Nevada (loc. 68; undated), at Drewsey, Harney County, Oregon (loc. 63; undated), Turner Creek, Modoc County, California (loc. 17; late Barstovian-Clarendonian), Otis Creek, Harney County,

Oregon (loc. 34; undated), Esmeralda Formation, Black Spring, Nye County, Nevada (loc. 93; undated) and in the Milford Federal No. 1 Well, Lemhi County, Idaho (loc. 40; undated). In the middle member of the Truckee Formation (Miocene) at Browns Hill, Churchill County, Nevada (loc. 55; 9.8 Ma), fragments and a few whole specimens of *A. cedrus* have been noted. Redeposited *A. cedrus* occurs in the middle member of the Truckee Formation near Fernley, Churchill County, Nevada (loc. 41; 9.8 Ma), and in the basal Truckee Formation in the Hot Springs Mountains, Churchill County, Nevada (loc. 56). It has also been reworked into the diatomite of the Kate Peak Formation at the Eagle-Picher diatomite quarry near Clark Siding, Storey County, Nevada (loc. 84;  $11.2 \pm 0.3$  Ma). Deposits with abundant *A. cedrus* have been found to the southeast (for example, loc. 48) and southwest (for example, loc. 68) of Browns Hill (loc. 55). Therefore, we consider the occurrence at Browns Hill as possible reworked contamination. *Actinocyclus cedrus*, thus, has a known geologic range from 15 to about 12 Ma (middle Miocene) in the Western United States, and it also occurs in Miocene lacustrine diatomite of the Moon-To Basin near Kunming in southwestern China.

*Actinocyclus claviolus* Bradbury & Krebs

*Actinocyclus claviolus* has only been found at its type locality at Jungle Point, Idaho County, Idaho (loc. 33, 15.4–14.5 Ma). A few specimens and fragments occur in the Latah Formation (Miocene) near Mead, Spokane County, Washington (loc. 106; undated). Thus far, it is restricted to the lower middle Miocene.

*Actinocyclus cupreus* Bradbury & Krebs

This species has been found at only four localities in the Western United States—the type locality at Copper Kettle Canyon, Churchill County, Nevada (loc. 16;  $18.9 \pm 1.2$  Ma), at Juliaetta, Nez Perce County, Idaho (loc. 32; 15.3 Ma), at Jungle Point, Idaho County, Idaho (loc. 33, 15.4–14.5 Ma), and in the Humboldt Formation, Eureka County, Nevada (loc. 30; undated). Fields (1983) assigned a middle Miocene age to the Humboldt Formation. In the United States, *A. cupreus* ranges from the lower to middle Miocene  $\geq 19$  to  $\leq 15.3$  Ma). A similar species of *Actinocyclus* has been found in lower Miocene freshwater deposits beneath the Sea of Japan and on the Japanese mainland (Koizumi, 1988).

*Actinocyclus gorbunovii* var. *fossa* Bradbury & Krebs

We have found this taxon only at Forty-nine Camp, Washoe County, Nevada (loc. 69; 16 Ma). In the Western United States, its geologic age is approximately 16 Ma—earliest middle Miocene.

*Actinocyclus krasskei* (Krasske) Bradbury & Krebs

*Actinocyclus krasskei* appears to be restricted to the lower middle and mid middle Miocene (15.3 to 12.5 or 12 Ma), although VanLandingham (1988) reported it from New Pass Summit, Nevada (about 22 Ma). As previously noted with *Actinocyclus cedrus*, we cannot confirm this occurrence.

Although small and variable in form, *A. krasskei* occurs abundantly, particularly in the lower middle Miocene of Idaho. Its youngest occurrence may be in the Bully Creek Formation, Malheur County, Oregon (loc. 7; estimated at 12 Ma). The absolute age of this formation, however, is very uncertain and may well prove to be older. In addition, we have found *A. krasskei* at the following localities: Juliaetta, Nez Perce County, Idaho (loc. 32; 15.3 Ma), Latah(?) Formation, Hangman Valley, Spokane County, Washington (loc. 36; 14.9 Ma), Squaw Creek Member, Ellensburg Formation, Yakima County, Washington (loc. 49; 15.5–14.5 Ma), Oviatt Creek, Clearwater County, Idaho (loc. 43; 12.8 Ma), Arrow Junction, Nez Perce County, Idaho (loc. 72; undated), near Weiser, Washington County, and Whitebird, Idaho County, Idaho (locs. 70, 71, respectively; undated), North Fork Fitsum Creek, Valley County, Idaho (loc. 94; undated), Silvies Valley, Grant County, Oregon (loc. 75; about 12.5 Ma), the Columbia River Basalt Group (Miocene), Seven Mile Creek, Umatilla County, Oregon (loc. 38; undated), in the Humboldt Formation, Eureka County, Nevada (loc. 30; undated), and in the Mascall Formation (Miocene) at Vinegar Creek, Grant County, Oregon (loc. 88; undated). In the Latah Formation, Spokane County, Oregon (locs. 76, 106; undated), rare (reworked?) *Actinocyclus*, possibly *A. krasskei*, has been observed.

*Actinocyclus motilis* Bradbury & Krebs

Lohman (1957) first described this species as *Cestodiscus mobilis (mobilensis)* in his unpublished dissertation, and reported it from the Esmeralda Formation at Cedar Mountain, Nye County, Nevada (loc. 74; about 15.1 Ma). *Actinocyclus motilis* is widely distributed and often abundant in the Western United States. The type specimens come from locality 22 (Esmeralda Formation, Cedar Mountain, Mineral County, Nevada). This species also occurs in the Squaw Creek Member, Ellensburg Formation, Yakima County, Washington (loc. 49; 15.5–14.5 Ma), at Vantage, Grant County, Washington in the Ellensburg Formation (loc. 59; 15.5–14.5 Ma), Augusta Mountains, Churchill County, Nevada (loc. 4; 14.6 Ma), in the Juntura(?) Formation, Harney County, Oregon (loc. 86; 12.4 Ma), in the Bully Creek Formation, Harper Basin, Malheur County, Oregon (loc. 7; estimated 12 Ma), in the Esmeralda Formation, Black Spring, Nye County, Nevada (loc. 93; undated), in the Mascall Formation, White Hills, Grant County, Oregon (loc. 87; undated), and at Goose Creek, Baker County, Oregon

(loc. 27; 14.5 Ma). These dated localities indicate a geologic range for *A. motilis* of about 15 Ma to possibly 12 Ma (middle Miocene) within the Western United States.

*Actinocyclus nebulosus* Bradbury And Krebs

*Actinocyclus nebulosus*, although very distinctive and locally abundant, has been found at only a few localities. Lohman (1957) originally described it in his unpublished dissertation as *Cestodiscus fasciculatus* from the Esmeralda Formation of Cedar Mountain, Nye County, Nevada (loc. 74; about 15.1 Ma). Smedman (1969) named it *Coscinodiscus nevadensis*, and reported its occurrence at Buffalo Canyon, Churchill County, Nevada (loc. 6; 14.6 Ma). *Actinocyclus nebulosus* also occurs in the Mascall Formation at Aldrich Mountain, Grant County, Oregon (loc. 85; about 15.8 Ma), in the Latah Formation near Mead, Spokane County, Washington (loc. 106), and in the Esmeralda Formation at Black Spring (loc. 93) and Cedar Spring (loc. 95), Nye County, Nevada. It is thus far restricted to the lower middle Miocene (15.8–14.6 Ma).

*Actinocyclus pinnulus* Bradbury & Krebs

The type locality for *A. pinnulus* is the Hole-in-the-Wall diatomite (locs. 90, 91; 10.3 Ma) in Gooding County, Idaho, where it occurs in association with *Mesodictyon* Theriot & Bradbury. It is also found with *Mesodictyon* at Durkee, Baker County, Oregon (loc. 81; undated). A form of *Actinocyclus* very similar to *A. pinnulus* is present near –985 m in the AMOCO Becharof No. 1 well, Alaska (loc. 112) in deposits of unknown age. *A. pinnulus* is thus far restricted to the uppermost middle Miocene.

*Actinocyclus theleus* Bradbury & Krebs

*Actinocyclus theleus* has been found at only a few sites in the Pacific Northwest: Emerald Creek, Benewah County (loc. 21; 15.3 Ma), Juliaetta, Nez Perce County (loc. 32; 15.3 Ma), Oviatt Creek, Clearwater County (loc. 43; 12.8 Ma), Idaho, in the Mascall Formation, White Hills, Grant County, Oregon (loc. 87), and possibly reworked in the Latah Formation, Spokane County, Washington (locs. 76, 106). Its known range is, therefore, from the lower middle to mid middle Miocene (15.3–12.8 Ma).

*Actinocyclus tubulosus* Khursevich

Galina Khursevich (written commun., 1992) has confirmed the presence of *Actinocyclus tubulosus* in the Squaw Creek Member of the Ellensburg Formation, Yakima County, Washington (loc. 49, ~15 Ma). It has not been found elsewhere in the United States and is thus far restricted to the early middle Miocene. Its similarity to and possible

misidentification with *Actinocyclus krasskei* may partly account for its restricted range.

*Actinocyclus venenosus* Bradbury & Krebs

*Actinocyclus venenosus* is found abundantly and well preserved at the type locality (loc. 44, Poison Creek Formation, Reynolds Creek, Owyhee County, Idaho, 8.9 Ma). This radiometric date is from the Banbury(?) basalt stratigraphically well above the last occurrence of *A. venenosus* in that section, and probably represents the uppermost age limit of the Poison Creek Formation. Armstrong and others (1975) reported that the formation is Clarendonian in age and estimated its age at 11 Ma from dates on enclosing volcanic rocks. Fields (1983), after a thorough literature review, also centered the formation at 11 Ma. For the purposes of this study, we accept this estimate as the most accurate.

*Actinocyclus venenosus* also occurs in the Esmeralda Formation, Cedar Mountain, Nye County, Nevada (loc. 74; about 15.1 Ma), the Coal Valley Formation, Pine Grove Hills, Lyon County, Nevada (loc. 15, 11.1–9.5 Ma), the Beaverdam Formation at Trapper Creek, Cassia County, Idaho (loc. 53, estimated 12.0–11.5 Ma), an unnamed unit at Turner Creek, Modoc County, California (loc. 17), and at sites within the Poison Creek Formation (locs. 108, 109) and Idaho Group (locs. 31, 111), Washington County, Idaho. Poorly preserved, possibly reworked specimens of *A. venenosus* (?) have been observed within the Sucker Creek Formation (Miocene) at Leslie Gulch, Malheur County, Oregon (loc. 50; estimated 12 Ma). Its geologic range in the United States appears to span most of the middle Miocene (15 to about 11 Ma). *Actinocyclus* aff. *A. venenosus* has been found in Miocene lacustrine diatomites of the Xian Feng Basin of southwest China (Bradbury, 1984; chapter A).

## DISCUSSION

In the Western United States, obligate freshwater species of *Actinocyclus* range from the lower Miocene to upper middle Miocene (about 19 to 10 Ma). We have examined Oligocene and lowest Miocene lacustrine diatomaceous sediments from southwestern Montana, Eocene material from British Columbia, Idaho, and Montana, and Oligocene material from Colorado and Nevada, but we have not found *Actinocyclus*. An upper Eocene diatom assemblage from Wyoming does not contain *Actinocyclus* (Lohman and Andrews, 1968). Similarly, our extensive collection of upper Miocene and younger material has failed to produce fossil obligate lacustrine *Actinocyclus* species that are not probable contaminants reworked from older sediments. We have confirmed however, the presence of *A. ehrenbergii* in lacustrine sediments of the Quiburis Formation at Edgar Canyon near Tucson, Pima County, Arizona (loc. 92) and in the Furnace

Creek Formation of Death Valley, Inyo County, California (loc. 113). The Quiburis Formation is latest Miocene in age (6.6–5.4 Ma; Shenk, 1990) and apparently formed in a moderately saline (sodium chloride) lake. The age of the Furnace Creek Formation (7.35–5.18 Ma) (Marvin and Dobson, 1979) is late Miocene to earliest Pliocene. *Actinocyclus ehrenbergii* is a coastal marine species that can live in lagoons and saline lakes (Yezdani, 1970; Foged, 1978). Although of ecological interest, it is probably not biostratigraphically important because (1) its age range in marine rocks extends from at least the early Oligocene (Fenner, 1977) to the Holocene, and (2) it is rare in lacustrine diatomaceous sediments.

Elsewhere in the world, freshwater species of *Actinocyclus* appear to have a longer geologic range. In the former Soviet Union, for example, the genus may range from the early Miocene, or even the late Oligocene (Moisseeva and others, 1974), to early Pliocene, although its maximum diversity occurred during the middle Miocene (Khursevich, 1982). Similarly, *Actinocyclus* occurs in early Pliocene deposits in Bulgaria (Temniskova-Toplova and Ognjanova-Rumenova, 1990). Although these reported ranges are without radiometric age control, the associations of diatom genera within samples do indicate significant differences in the geologic ranges of some lacustrine diatom genera between western North America and Eurasia. Late Miocene samples from Macedonia in northern Greece (Gersonde and Velitzelos, 1977) confirms this conclusion. In these samples, *Stephanodiscus Ehrenberg* and obligate freshwater *Actinocyclus* are common and co-occur, an association never seen in the Western United States except for isolated (probably contaminated) examples (for examples, see VanLandingham, 1964, 1967). Nevertheless, Fourtanier (1987) and Serreyssol (1988) have demonstrated that there is a remarkable synchronicity of events in the evolution of lacustrine diatoms between continents—that is, the decline of *Actinocyclus* during the late Miocene, the late Miocene species diversification of *Mesodictyon* Theriot and Bradbury, and the appearance of *Stephanodiscus* and *Cyclostephanos* Round near the Miocene-Pliocene boundary.

In conclusion, we note that the appearance of freshwater *Actinocyclus* in the Western United States coincides with the early Miocene species radiation of marine *Actinocyclus* (Radionova, 1987), high stand in sea level (Haq and others, 1987), and the initiation of extensional basin-and-range tectonics (Stewart and Carlson, 1976). Furthermore, the worldwide decline in freshwater *Actinocyclus* during the late Miocene corresponds with the origin and (or) species radiations of *Mesodictyon* and *Cyclotella* (Kützing) Brebisson, and the appearance of *Stephanodiscus* and *Cyclostephanos*. The ways in which paleoenvironmental changes and species competition influenced the course of lacustrine diatom evolution remain unknown but are worthy of study.

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# APPENDIX

## List of Diatom Sample Localities

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## LIST OF DIATOM SAMPLE LOCALITIES

Localities with absolute ages are marked with an asterisk (\*); + identifies localities with *Actinocyclus*. The location of each sample site is shown in figure 2. Locality information includes the name of the formation (if known), geographic coordinates, the name of the collector and sampling year, and age (if known), and where the information has been published. Radiometric ages have been corrected according to Dalrymple (1979). Formation names in quotes indicate that the assigned name is of dubious validity. (?) indicates that the deposit is not assignable to the formation with certainty. "UCMP" = University of California Museum of Paleontology; "P####" = plant locality number.

- 1+ Aldrich Station(?) Formation, east Walker River, 38.84°N., 119.06°W., Lyon Co., Nevada, J. H. Stewart, 1980; Miocene.
- 2\* Alturas Formation, Howards Gulch, sec. 27, T. 42 N., R. 15 E., Modoc Co., California, R. A. Laws, 1981; 8.1 Ma (Evernden and James, 1964), 8.3 Ma corrected.
- 3\* Alturas Formation, 3.5 miles west of Alturas, California Academy of Sciences locality 36805, Modoc Co., California, G. D. Hanna; 4.8 Ma (Repenning, 1987).
- 4\*+ Augusta Mountains, unnamed unit, sec. 31, T. 24 N., R. 39 E., Churchill Co., Nevada, W. N. Krebs, 1982; 14.6 Ma (Krebs and others, 1987).
- 5\* Bruneau Formation, W. Snake River Plain, sec. 27, T. 5 S., R. 4 E., Elmore Co., Idaho, J. P. Bradbury, 1978; 1.36 Ma (Evernden and others, 1964), 1.4 Ma (Armstrong and others, 1975).
- 6\*+ Buffalo Canyon Formation, Buffalo Canyon, sec. 2, T. 15 N., R. 37 E., southeast of Eastgate, Churchill Co., Nevada, D. I. Axelrod, (Smedman, 1969); 14.6±0.4 Ma (AMOCO, unpublished data, 1982), 14.5–15.0 Ma (H. E. Schorn, written commun., 1989).
- 7\*+ Bully Creek Formation, type section, Harper Basin, sec. 11, T. 19 S., R. 41 E., Malheur Co., Oregon, W. N. Krebs, 1980; middle Miocene (estimated 12 Ma) VanLandingham, written commun., 1983).
- 8\* Chalk Hills Formation, base of formation, West Browns Creek, sec. 2, T. 5 S., R. 1 W., Owyhee Co., Idaho, W. N. Krebs, 1980; about 9 Ma (Kimmel, 1979).
- 9\* Chalk Hills Formation, Castle Creek, sec. 9, T. 6 S., R. 1 E., Owyhee Co., Idaho, W. N. Krebs, 1980; 7–9 Ma (Kimmel, 1979).
- 10\* Chalk Hills Formation, Chalk Hills, sec. 20, T. 7 S., R. 4 E., Owyhee Co., Idaho, W. N. Krebs, 1980; 7–9 Ma (Kimmel, 1979).
- 11\* Chalk Hills Formation, Shoofly Creek, lower Horse Hill ash, sec. 9, T. 7 S., R. 3 E., Owyhee Co., Idaho, M. J. Evetts, 1979; 7 Ma (Kimmel, 1979).
- 12\* Chalk Hills Formation, type section, lower Horse Hill ash, sec. 25, T. 7 S., R. 4 E., Owyhee Co., Idaho, M. J. Evetts, 1979; 7 Ma (Kimmel, 1979).
- 13\*+ Clarkia Basin, unnamed unit, sec. 13, T. 42 N., R. 1 E., Shoshone Co., Idaho, C. J. Smiley; 15.3 Ma (Bradbury and others, 1985).
- 14\* Kelseyville Formation, Clear Lake, sec. 27, T. 13 N., R. 9 W., Lake Co., California, M. J. Rymer, 1978; 0.4 Ma (Rymer, 1981).
- 15\*+ Coal Valley Formation, Pine Grove Hills, sec. 2, T. 9 N., R. 26 E., Lyon Co., Nevada, J. H. Stewart, 1983; 9.3–10.8 Ma (Gilbert and Reynolds, 1973), 9.5–11.1 Ma corrected.
- 16\*+ Copper Kettle Canyon, unnamed unit, sec. 26, T. 24 N., R. 34 E., Churchill Co., Nevada, W. N. Krebs, 1982; 18.9±1.2 Ma (AMOCO, unpublished data, 1982).
- 17+ Turner Creek, unnamed unit, sec. 1, T. 41 N., R. 8 E., Modoc Co., California, J. P. Bradbury, 1985; late Barstovian-Clarendonian (J. A. Wolfe, oral commun., 1985).
- 18 Dead Camel Mountains, unnamed unit, sec. 24, T. 18 N., R. 26 E., Churchill Co., Nevada, W. N. Krebs, 1981; Miocene.
- 19 AMOCO Delta Stephan Szot No. 1 well, sec. 19, T. 14 N., R. 1 E., Cache Co., Utah, W. N. Krebs, 1983.
- 20\*+ Esmeralda Formation, Diatomite Ridge, Stewart Valley, 38°37'02"N., 117°56'35"W., Mineral Co., Nevada, S. W. Starratt, 1986, 15.1 Ma (S. W. Starratt, written commun., 1986).
- 21\*+ Clarkia Basin, Emerald Creek, unnamed unit, sec. 33, T. 43 N., R. 1 E., Benewah Co., Idaho, C. J. Smiley, 1978; 15.3 Ma (Bradbury and others, 1985).
- 22+ Esmeralda Formation, Cedar Mountain, 38.5°N., 44.75°W., Mineral Co., Nevada, J. H. Stewart, 1980; Miocene.
- 23\* Glens Ferry Formation, Hagerman Horse quarry, sec. 16, T. 7 S., R. 13 E., Twin Falls Co., Idaho, J. P. Bradbury, 1979; about 3.2 Ma (Neville and others, 1979).
- 24 Glens Ferry Formation, Malde's (1972) section no. 55, sec. 1, T. 6 S., R. 8 E., Owyhee Co., Idaho, M. J. Evetts, 1979; Pliocene.
- 25\* Glens Ferry Formation, Shoofly Creek, sec. 6, T. 7 S., R. 3 E., Owyhee Co., Idaho, M. J. Evetts, 1979; 3.0–3.3 Ma (M. L. Porter, oral commun., 1985).
- 26 Glens Ferry (?) Formation, Weiser, sec. 35, T. 15 S., R. 46 E., Washington Co., Idaho, M. J. Evetts, 1979; Pliocene(?).
- 27\*+ Goose Creek, unnamed unit, sec. 29, T. 8 S., R. 43 E., Baker Co., Oregon, J. P. Bradbury, 1978, 14.5 Ma (Fiebelkorn and others, 1983).

- 28 Michel T. Halbouty Federal No. 1 well, sec. 14, T. 17 N., R. 28 E., Churchill Co., Nevada, W. N. Krebs, 1982.
- 29 Alturas Formation, Howards Gulch, sec. 22, T. 42 N., R. 9 E., Modoc Co., California, J. P. Bradbury, 1985; Miocene.
- 30+ Humboldt Formation, sec. 31, T. 31 N., R. 52 E., Eureka Co., Nevada, Susan Laule, 1979; Miocene.
- 31+ IW-24, IW-26, Idaho Group, sec. 34, T. 12 N., R. 4 W., Washington Co., Idaho, M. J. Evetts, 1979; Neogene.
- 32\*+Juliaetta, unnamed unit, sec. 20, T. 37 N., R. 3 W., Nez Perce Co., Idaho, C. J. Smiley; 15.3 Ma (Bradbury and others, 1985).
- 33\*+Jungle Point, unnamed unit, sec. 15, T. 33 N., R. 6 E., Idaho Co., Idaho; 14.5–15.4 Ma (Smiley and Rember, 1979).
- 34+ Juntura(?) Formation, Otis Creek, sec. 32, T. 19 S., R. 36 E., Harney Co., Oregon, J. P. Bradbury, 1978; Miocene.
- 35 Lake Britton, unnamed unit, sec. 29, T. 37 N., R. 3 E., Shasta Co., California, R. A. Laws, 1981.
- 36\*+Latah(?) Formation, Hangman Valley, sec. 6, T. 24 N., R. 43 E., Spokane Co., Washington, J. P. Bradbury, 1979; 14.5 Ma (Evernden and James, 1964; 14.9 Ma corrected).
- 37 Raft River Formation, Burley, sec. 35, T. 10 S., R. 27 E., Cassia Co., Idaho, J. P. Bradbury, 1979; Pleistocene.
- 38+ Lower(?) part of the Columbia River Basalt Group, Seven Mile Creek, sec. 19, T. 2 S., R. 33 E., Umatilla Co., Oregon, M. J. Evetts, 1979; Miocene.
- 39 AMOCO Lynn Reese No. 1 well, sec. 17, T. 12 N., R. 1 E., Cache Co., Utah, W. N. Krebs, 1983.
- 40+ AMOCO Milford Federal No. 1 well, sec. 19, T. 15 N., R. 27 E., Lemhi Co., Idaho, W. N. Krebs, 1983.
- 41\*+Truckee Formation (middle member), Fernley, sec. 8, T. 19 N., R. 26 E., Churchill Co., Nevada, W. N. Krebs, 1981; 9.8 Ma (F. H. Brown, unpublished data, 1986).
- 42+ New Pass, unnamed unit, unsurveyed T. 19 N., R. 40 E., Lander Co., Nevada, J. P. Bradbury, 1985; Miocene.
- 43\*+Oviatt Creek, unnamed unit, sec. 12, T. 39 N., R. 1 E., Clearwater Co., Idaho, C. J. Smiley; 12.8 Ma (Smiley and Rember, 1979).
- 44\*+Poison Creek Formation, Reynolds Creek, NW¼ sec. 2, T. 2 S., R. 3 W., Owyhee Co., Idaho, W. N. Krebs, 1980; minimum age 8.9 Ma (Krebs and others, 1987), estimated 11 Ma (Armstrong and others, 1975).
- 45+ Poison Creek Formation, sec. 17, T. 11 N., R. 6 W., Washington Co., Idaho, M. J. Evetts, 1979; Miocene.
- 46\* Ringold Formation, White Cliffs, Columbia River, sec. 1, T. 10 N., R. 28 E., Franklin Co., Washington, J. P. Bradbury, 1978; 4.3 Ma (Repenning, 1987).
- 47 Big Smokey Valley, unnamed unit, unsurveyed T. 2 N., R. 38 E., Esmeralda Co., Nevada, J. P. Bradbury, 1984; Miocene.
- 48 + Southern Stillwater Mountains, unnamed unit, sec. 22, T. 18 N., R. 31 E., Churchill Co., Nevada; Miocene.
- 49\*+Squaw Creek Member, Ellensburg Formation, sec. 9, T. 14 N., R. 19 E., Yakima Co., Washington, J. P. Bradbury, 1979; 14.5–15.5 Ma (Beeson and others, 1985), ~15 Ma (Smith, 1988).
- 50\*+Sucker Creek Formation, Leslie Gulch, sec. 28, T. 24 S., R. 46 E., Malheur Co., Oregon, M. J. Evetts, 1979; estimated 12 Ma (Fields, 1983).
- 51 Swayze Creek, unnamed unit, sec. 6, T. 12 S., R. 44 E., Baker Co., Oregon, J. P. Bradbury, 1978.
- 52\* Thousand Creek Formation, unsurveyed T. 46 N., R. 25 E., Humboldt Co., Nevada, J. P. Bradbury, 1985; Hemphillian (Wood and others, 1941), estimated 7.8 Ma (VanLandingham, written commun., 1983).
- 53\*+Beaverdam Formation, Trapper Creek, sec. 2, T. 15 S., R. 20 E., Cassia Co., Idaho, C. J. Smiley; estimated 11.5–12.0 Ma (Wolfe, 1971).
- 54+ Truckee Formation (middle member), Bradys Hot Spring, sec. 21, T. 23 N., R. 27 E., Churchill Co., Nevada, W. N. Krebs, 1981; Miocene.
- 55\*+Truckee Formation (middle member), Browns Hill, sec. 33, T. 23 N., R. 27 E., Churchill Co., Nevada, W. N. Krebs, 1981; 9.8 Ma (Krebs and others, 1987).
- 56+ Truckee Formation (lower member), Hot Springs Mountains, sec. 36, T. 22 N., R. 27 E., Churchill Co., Nevada, W. N. Krebs, 1981; Miocene.
- 57+ Truckee Formation (middle member), Nightingale, sec. 18, T. 24 N., R. 26 E., Churchill Co., Nevada, W. N. Krebs, 1981; Miocene.
- 58 Tulare Formation, La Ceja Ridge, Kettleman Hills, secs. 26 and 35, T. 21 S., R. 17 E., Kings Co., California; Pliocene to Pleistocene.
- 59\*+Ellensburg Formation, Vantage, sec. 17, T. 18 N., R. 23 E., Grant Co., Washington, 14.5–15.5 Ma (Beeson and others, 1985).
- 60 "Yonna" Formation, Dorris, sec. 11, T. 47 N., R. 1 E., Siskiyou Co., California, J. P. Bradbury, 1978; Pliocene.
- 61 "Yonna" Formation, Klamath Falls, sec. 23, T. 38 S., R. 8 E., Klamath Co., Oregon, Maura O'Brian, 1980; Pliocene.
- 62 "Yonna" Formation, Yonna Valley, sec. 23, T. 38 S., R. 11½ E., Klamath Co., Oregon, J. P. Bradbury, 1978; Pliocene.
- 63+ Unnamed unit, USGS 1019, 1020, Drewsey, sec. 14, T. 20 S., R. 36 E., Harney Co., Oregon, B. N. Moore, 1931.

- 64+ Bully Creek Formation, USGS 1022, Westfall, Harper Basin, sec. 15, T. 18 S., R. 41 E., Malheur Co., Oregon, B. N. Moore, 1931; Miocene.
- 65+ Bully Creek Formation, USGS 1023, Harper Basin, sec. 34, T. 19 S., R. 42 E., Malheur Co., Oregon, B. N. Moore, 1931; Miocene.
- 66+ Bully Creek Formation, USGS 1024, Harper Basin, sec. 34, T. 18 S., R. 41 E., Malheur Co., Oregon, B. N. Moore, 1931; Miocene.
- 67 Lake beds of Burnt River, USGS 1030, Swayze Creek, sec. 11, T. 11 S., R. 43 E., Baker Co., Oregon, B. N. Moore, 1931.
- 68+ "Truckee" lake beds, USGS 1187, 10 miles N. of Virginia City, Virginia Range, Storey Co., Nevada, V. P. Gianella, 1932.
- 69+ USGS 1690, upper part of the Cedarville Formation, Forty-nine Camp, Washoe Co., Nevada, 17 miles E. of N. of Cedarville, California, R. S. LaMotte, 1933; 15.6 Ma (Axelrod, 1966), 16.0 Ma corrected.
- 70+ Unnamed unit, USGS 2280, 15 miles NE. of Weiser, Washington Co., Idaho, R. W. Brown, 1934.
- 71+ Unnamed unit, USGS 2281, 2.5 miles NE. of Whitebird, Idaho Co., Idaho, on road to Grangeville, R. W. Brown, 1934.
- 72+ Unnamed unit, USGS 2289, about 2.5 miles NE. of Arrow Junction, Nez Perce Co., Idaho, on road to Juliaetta, R. W. Brown, 1934.
- 73+ Unnamed unit, USGS 3707, Goose Creek, sec. 35, T. 14 S., R. 20 E., Cassia Co., Idaho, J. R. Gill, 1951.
- 74+ Esmeralda Formation, USGS 3394, Cedar Mountain, T. 8 N., R. 38 E., Nye Co., Nevada, K. E. Lohman, 1938, about 15.1 Ma (H. E. Schorn, oral commun., 1989).
- 75+ Unnamed unit, USGS 4213, Silvies Valley, sec. 36, T. 17 S., R. 31 E., Grant Co., Oregon, R. E. Wallace, 1955; about 12.5 Ma (Fiebelkorn and others, 1983).
- 76+ Latah Formation, USGS 5678, Shelly Lake, sec. 24, T. 25 N., R. 44 E., Spokane Co., Washington, J. W. Hosterman, 1963; Miocene.
- 77+ Latah Formation, USGS 5679, sec. 15, T. 24 N., R. 43 E., Spokane Co., Washington, J. W. Hosterman, 1963; Miocene.
- 78+ Latah(?) Formation, USGS 5681, Peone, sec. 27, T. 26 N., R. 44 E., Spokane Co., Washington, J. W. Hosterman, 1963.
- 79+ Unnamed unit, USGS 6007, sec. 20, T. 24 N., R. 26 E., Churchill Co., Nevada, Ronald Willden, 1966.
- 80 Unnamed unit, USGS 6035, N. Santiam River, T. 11 S., R. 7 E., Linn Co., Oregon, Harry Wheeler, 1967.
- 81+ Unnamed unit, USGS 6364, 6371, 6373, Durkee, sec. 23, T. 11 S., R. 43 E., Baker Co., Oregon, R. A. Sheppard, 1970.
- 82 Unnamed unit, USGS 6368, Durkee, sec. 20, T. 11 S., R. 43 E., Baker Co., Oregon, R. A. Sheppard, 1970.
- 83\* Aldrich Station Formation, type section, 38°29'30"N., 118° 53'21" W., Mineral Co., Nevada, J. H. Stewart, 1980; 13.0–11.4 Ma (Golia and Stewart, 1984) (13.4–1.7 Ma corrected).
- 84\*+ Kate Peak Formation, Eagle-Picher diatomite quarry, Clark Siding, Nevada, T. 20 N., R. 23 E., Storey Co., Nevada; (11.2±0.3 Ma, AMOCO, unpublished data, 1980).
- 85\*+ Mascall Formation, Aldrich Mountain, "meadow locality," Grant Co., Oregon (UCMP loc. P4123); SE ¼ sec. 14, T. 13 S., R. 28 E.; N. side of east fork of John Day River, Carlton Condit, 1941; (15.4 Ma, Evernden and others, 1964; corrected 15.8 Ma.).
- 86\*+ Juntura(?) Formation, Harney Co., Oregon, Stinking Water flora (UCMP loc. P4121); NW ¼ sec. 17, T. 21 S., R. 35 E.; Carlton Condit, 1941; (12.1 Ma, Evernden and James, 1964; corrected 12.4 Ma).
- 87+ Mascall Formation, White Hills, Belshaw Ranch locality, Grant Co., Oregon (UCMP loc. P3735); center N ½ sec. 13, T. 13 S., R. 28 E., Carlton Condit.
- 88+ Mascall Formation, Blue Mountains, Vinegar Creek, Grant Co., Oregon (UCMP loc. P5404); sec. 17, T. 10 S., R. 35 E.; 1 mile NW. of Bates on road to Susanville, R. W. Chaney, 1954.
- 89+ Unnamed unit, Thorn Creek, Boise Co., Idaho (UCMP loc. P4600); sec. 28, T. 5 N., R. 5 E., H.V. Smith, 1941.
- 90\*+ Hole-in-the-Wall diatomite quarry, Gooding Co., Idaho, along the drainage of Clover Creek; NW ¼ sec. 12, T. 4 S., R. 13 E., J. P. Bradbury, 1988; (10.0 Ma, Evernden and others, 1964; corrected 10.3 Ma).
- 91\*+ Hole-in-the-Wall diatomite quarry, Gooding Co., Idaho; NE ¼ sec. 19, T. 3 S., R. 13 E., J. P. Bradbury, 1988; (10.0 Ma, Evernden and others, 1964; corrected 10.3 Ma).
- 92\*+ Quiburis Formation, Edgar Canyon, San Pedro Valley, Pima Co., Arizona, 900 m E. and 200 m N. of SW corner, sec. 21, T. 11 S., R. 18 E.; J. P. Bradbury, 1980, (5.4–6.6 Ma, Shenk, 1990).
- 93+ Esmeralda Formation, Black Spring, Nye Co., Nevada; sec. 19, T. 8 N., R. 38 E., Douglas Bergstrom, 1986.
- 94+ Unnamed unit, N. Fork Fitusum Creek, Valley Co., Idaho; sec. 6, T. 19 N., R. 6 E., B. F. Leonard, 1986.
- 95+ Esmeralda Formation, Cedar Spring, Nye Co., Nevada; unsurveyed T. 8 N., R. 38 E., Douglas Bergstrom, 1986.
- 96 Unnamed unit, USGS 642, Baker Co., Oregon; sec. 8, T. 8 S., R. 42 E., B. N. Moore, 1930.
- 97 Unnamed unit, USGS 1013, Clover Creek District, Baker Co., Oregon; sec. 11, T. 8 S., R. 42 E., B. N. Moore, 1931.
- 98 Unnamed unit, USGS 1031, Malheur Co., Oregon; sec. 2, T. 15 S., R. 42 E., B. N. Moore, 1931.

- 99** Unnamed unit, USGS 1037, Grant Co., Washington; T. 28 N., R. 30 E., (Grand Coulee flora), T. H. Bonser, 1927.
- 100** Unnamed unit, USGS 1133, 4 miles E. of Basalt, Esmeralda Co., Nevada; T. 2 N., R. 34 E., H. G. Ferguson, 1923.
- 101** "Truckee" lake beds, USGS 1186, Chalk Bluff, 3 miles W. of Reno, Washoe Co., Nevada; T. 19 N., R. 19 E., V. P. Gianella, 1932.
- 102** Unnamed unit, USGS 2268, Wikiup Damsite, Deschutes River, Deschutes Co., Oregon; T. 22 S., R. 9 E., A. C. Spencer, 1934.
- 103** Thousand Creek Formation, USGS 3544, Humboldt Co., Nevada; unsurveyed T. 45 N., R. 26 E., K. E. Lohman, 1938.
- 104\*** Santa Fe Formation, USGS 4671, Rio Arriba Co., New Mexico; T. 21 N., R. 7 E., R. L. Smith, 1948; (~8 Ma; Manley and Mehnert, 1981).
- 105\*** Alturas Formation, USGS 4690, Modoc Co., California; sec. 7, T. 42 N., R. 12 E., Ian Campbell, 1958; (~4.8 Ma, see loc. 3).
- 106+** Latah Formation, USGS 5682, Mead, Spokane Co., Washington; sec. 14, T. 26 N., R. 43 E., J. W. Hosterman, 1963.
- 107\*** Teewinot Formation, USGS 5935, Teton Co., Wyoming; sec. 36, T. 42 N., R. 116 W., G. W. Andrews, 1966; (9.2 Ma, Evernden and others, 1964; 9.4 Ma corrected).
- 108+** Poison Creek Formation, IW-7, Washington Co., Idaho; SW  $\frac{1}{4}$ , SW  $\frac{1}{4}$  sec. 29, T. 12 N., R. 6 W., M. J. Evetts, 1979.
- 109+** Poison Creek Formation, IW-8, Washington Co., Idaho; SW  $\frac{1}{4}$ , SW  $\frac{1}{4}$  sec. 32, T. 12 N., R. 6 W., M. J. Evetts, 1979.
- 110** IW-9, Poison Creek Formation, Washington Co., Idaho; SE  $\frac{1}{4}$ , SE  $\frac{1}{4}$  sec. 19, T. 12 N., R. 6 W., M. J. Evetts, 1979.
- 111+** Idaho Group, IW-13, Washington Co., Idaho; NE  $\frac{1}{4}$ , NE  $\frac{1}{4}$  sec. 19, T. 12 N., R. 4 W., M. J. Evetts, 1979.
- 112+** AMOCO Becharof No. 1 well, depth ~985 m, 57.78°N., 157.11°W., Alaska Peninsula, Alaska, W. N. Krebs, 1985.
- 113\***+Furnace Creek Formation, USGS 4070, Inyo Co., California; 1.15 miles N. 77°W. of Travertine Point, road cut on south side of Highway 190. Hard gray limestone 3 ft below base of travertine, K. E. Lohman, 1954; (5.18±0.15 Ma, 6.05±0.18 Ma, 7.35±0.22 Ma, Marvin and Dobson, 1979).
- 114\*** Coal Valley Formation *sensu* Axelrod, 1958, Washoe Co., Nevada; roadcut along Highway 40 W. of Reno, sec. 18, T. 19 N., R. 19 E.; (<5.7 Ma, Evernden and James, 1964; <5.9 Ma corrected).
- 115\*** Coal Valley Formation *sensu* Axelrod, 1958, Washoe Co., Nevada; Verdi flora locality, sec. 16, T. 19 N., R. 18 E.; (5.7 Ma, Evernden and James, 1964; 5.9 Ma corrected).

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