Zeitschrift: Eclogae Geologicae Helvetiae

Herausgeber: Schweizerische Geologische Gesellschaft

Band: 84 (1991)

Heft: 3: [Emile Argand 1879-1940]

Artikel: Upper Jurassic calcareous nannofossils from the DSDP Site 534 in the Blake Bahama Basin, western North Atlantic

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DOI: https://doi.org/10.5169/seals-166797

Eclogae geol. Helv. 84/3: 765–789 (1991)

0012-9402/91/030765-25 $ 1.50 + 0.20/0
Birkhäuser Verlag, Basel

Upper Jurassic calcareous nannofossils from the DSDP Site 534 in the Blake Bahama Basin, western North Atlantic

By Atiur Rahman[1,2]) and Peter H. Roth[1])

ABSTRACT

One new genus *Bibreviconus* and three new species of upper Jurassic calcareous nannofossils *(Bibreviconus atlanticus, Ansulosphaera bownii, Stradnerlithus braloweri)* have been recognized. In addition, the diagnosis of one genus and one species *(Mitosia, Watznaueria coronata)* have been emended, and two new combinations *(Stradnerlithus silvaradius, Vagalapilla dibrachiata)* are proposed. All result from a study of nannofossils in cores from Deep Sea Drilling Project Site 534.

ZUSAMMENFASSUNG

Eine neue Gattung *Bibreviconus* und drei Arten jurassischer kalkiger Nannofossilien wurden neu beschrieben *(Bibreviconus atlanticus, Ansulosphaera bownii, Stradnerlithus braloweri)*, eine Gattung und eine Art wurden emendiert *(Mitosia, Watznaueria coronata)* und zwei neue Kombinationen wurden eingeführt *(Stradnerlithus silvaradius, Vagalapilla dibrachiata)*. Alle basieren auf einer Untersuchung von Kernen der Station 534 des «Deep Sea Drilling Projects».

1. Introduction

Jurassic and lower Cretaceous nannofossils from Deep Sea Drilling Project (DSDP) Site 534 (28° 26.6′ N, 75° 22.9′ W, water depth 4976 m) in the Blake Bahama Basin in the western North Atlantic Ocean (Figure 1) were previously studied by Roth (1983). Recently, Bralower et al. (1989) studied the upper Jurassic (Kimmeridgian and Tithonian) to Cretaceous interval at this site. Because of recent developments in nannofossil taxonomy and biostratigraphy (Bown 1987; Dockerill 1987; Bown et al. 1988; Cooper 1987; Bown & Cooper 1989), we restudied the Jurassic sedimentary rocks at Site 534. This paper describes new nannofossil taxa, emends and clarifies taxonomic concepts, and proposes new taxonomic combinations.

We studied thirty five samples from DSDP Site 534, selected from the Unnamed Unit (Cores 127 to 111) and from the lower part of the Cat Gap Formation (Cores 110 to 92) on the basis of the state of preservation of nannofossils (Roth 1983). Semiquantitative nannofossil data gathered in this study will be published later in a biostratigraphic paper (Rahman & Roth in prep.).

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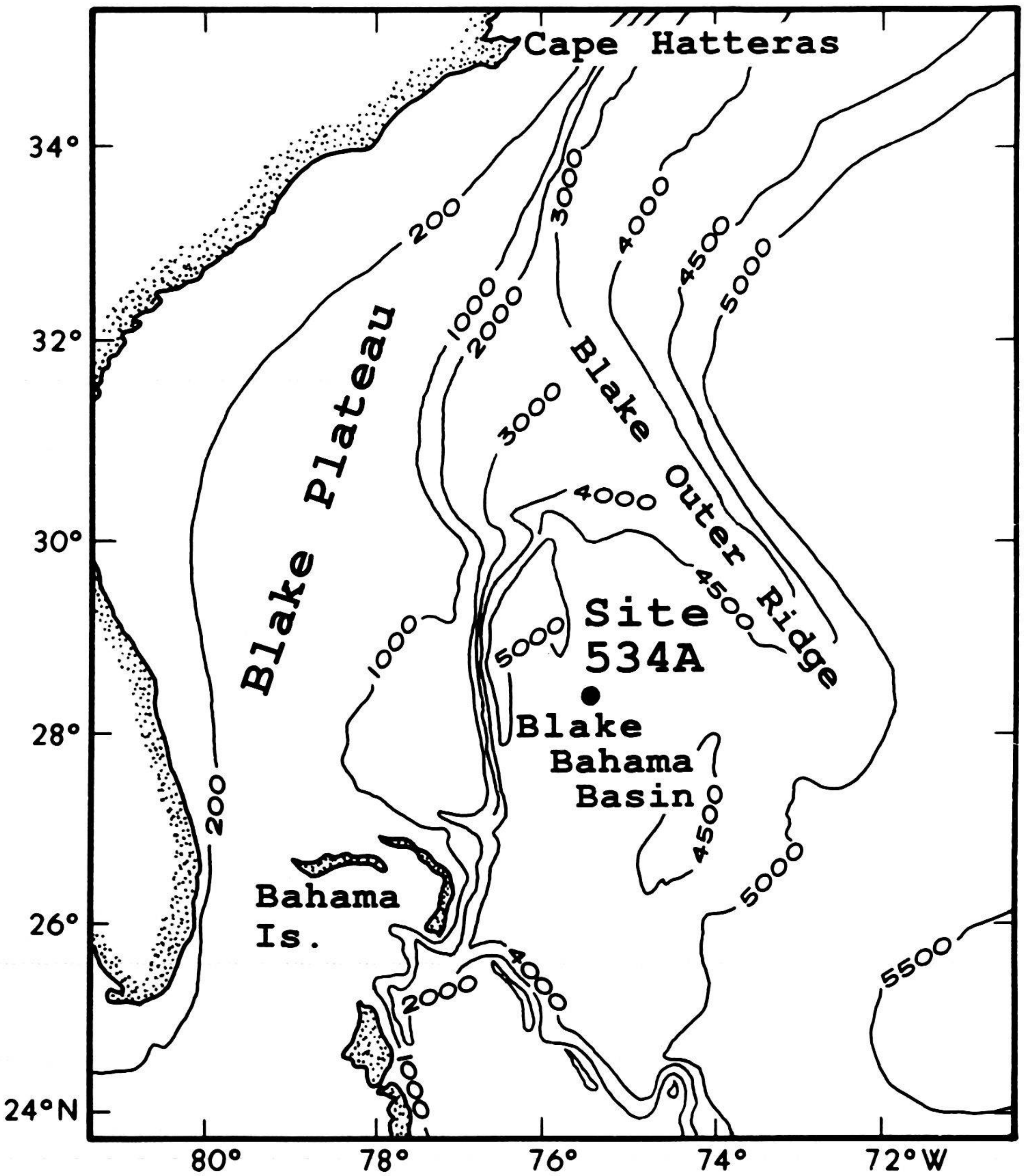

Fig. 1. Location map of the Deep Sea Drilling Project Site 534 and bathymetry of the northwestern Atlantic Ocean. Contours are in meters.

The Unnamed Unit at Site 534 is the oldest sedimentary unit that overlies pillow and brecciated basalts, which form the basement (Figure 2). This sedimentary unit is composed of greenish-black silty claystone, variegated claystone, brown silty marl, and marly limestone. The overlying Cat Gap Formation is composed of reddish-gray, green and gray calcareous claystone, micritic and bioclastic limestone, and marly limestone (Sheridan & Gradstein et al. 1983). Nannofossils are common to abundant, diversified and moderately to well preserved in the studied samples.

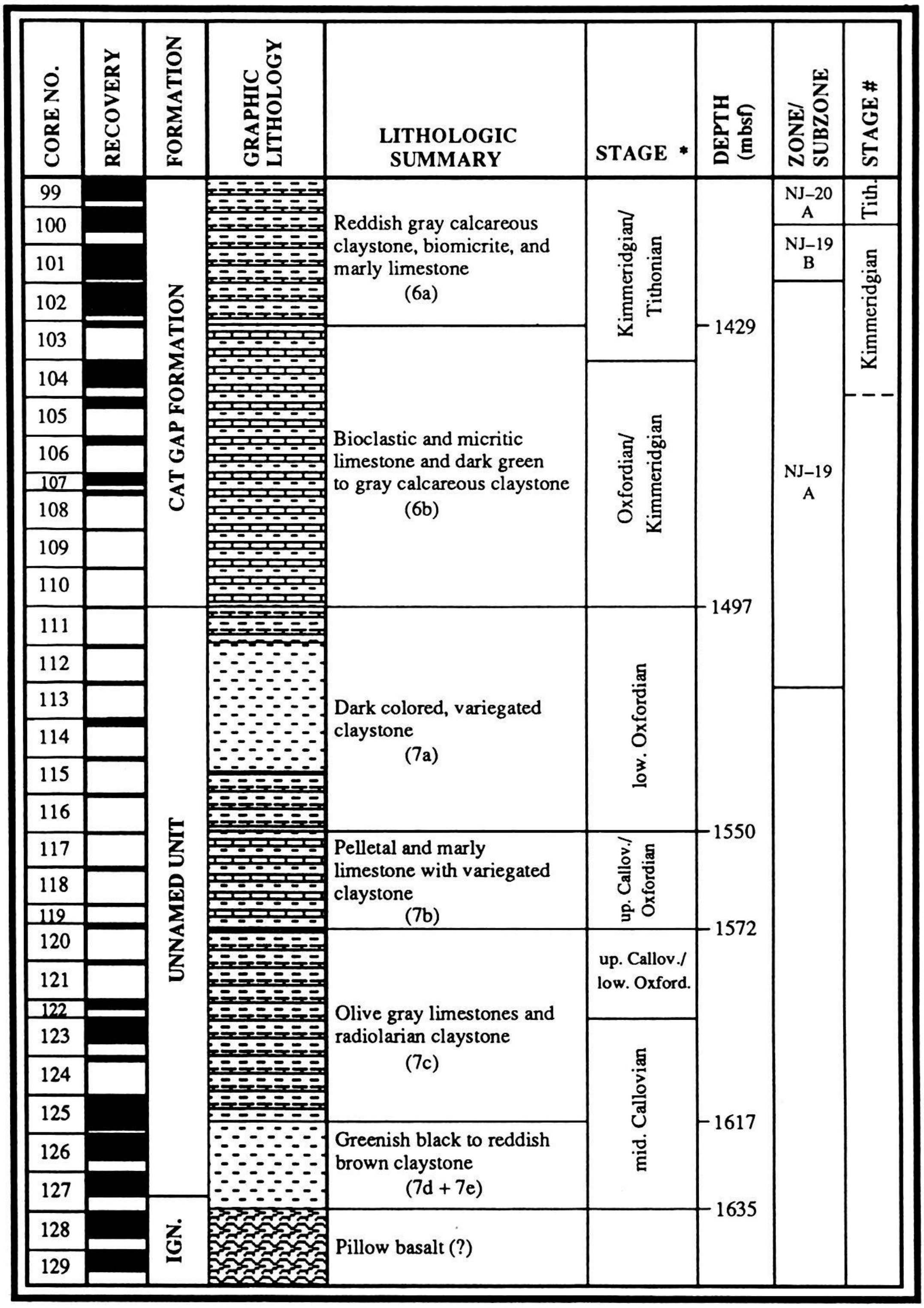

Fig. 2. Graphic lithology and major characteristics of the cores between 534A-129 and 534A-99 at Site 534. Recovery of the cores are shown in black pattern. Formational and lithologic boundaries from pillow basalt to 6a, and the stage boundaries marked by "*" are based on Sheridan & Gradstein et al. (1983). Nannofossil zones and subzones and the stage boundary marked by "#" and are based on Bralower et al. (1989), and the broken line under Kimmeridgian indicates the level of the lowermost sample studied by these authors. Kimmeridgian-Tithonian boundary is marked by the FO of *Conusphaera mexicana minor.* The base of NJ-19A is placed at the FO of *V. stradneri* recognized in this study. Depth is expressed in meters below seafloor (mbsf).

1.1 Methods

Smear slides were prepared following PERCH-NIELSEN (1985). Each slide was examined under the light microscope at a magnification of about 1560X, using phase contrast illumination and crossed nicols. A gypsum plate was used with crossed nicols whenever necessary to observe the finer details of nannofossils. Selected samples were studied in the scanning electron microscope (SEM) to describe new taxa and to investigate the ultrastructure of known taxa.

To prepare samples for SEM observation, about 0.5 g sample was put in a test tube with distilled water. One milliliter of calgon (sodium hexametaphosphate) solution (1%) was added, the test tube was shaken to disperse the sediment in water, and then treated in an ultrasonic vibrator at medium intensity for 20 seconds, and centrifuged at 600 revolutions per minute for 6 minutes. The water with the suspended clays was decanted, and distilled water and 1 milliliter calgon (1%) were added. After shaking, the sample was centrifuged again at the same speed for the same period of time. Centrifuging and decantation were repeated a few times until the supernatant liquid was clear. The final residue of water, sediment, and calgon was stirred, and one drop was transferred, smeared and allowed to dry on a broken piece of coverslip attached to a SEM stub by a piece of double-sided scotch tape. Liquid graphite was used to coat the areas of the stub, not occupied by the coverslip. The sample was then coated with gold (125 Å thick) in a sputter coater.

Nannofossils cited in this report are listed alphabetically and successively according to their family, genus and species epithets. We have not attempted to make a complete synonymy list of each species. We have selected the references to illustrations that most closely approximate the species concepts used in this study and the references necessary to clarify a particular taxonomic concept. We follow the terminology of BOWN (1987) for rim shape and structure. The ages of the samples above Core 534A-105 are based on nannofossil zones of BRALOWER et al. (1989), and the ages below this core are based on SHERIDAN & GRADSTEIN et al. (1983) (Figure 2).

All the type materials (unprocessed sample and smear slide) and photographic negatives of the holotype and the paratype are numbered (USNM) and deposited in the micropaleontological collections of the Smithsonian Institution, Washington, D.C. Same USNM number is used, but with "a" and "b" to designate the unprocessed sample and its smear slide, respectively.

2. Systematic paleontology

Family **Ahmuelleraceae** REINHARDT 1965

Genus *Vagalapilla* BUKRY 1969

Type species: Vekshinella imbricata GARTNER 1968.
Synonym: Staurorhabdus NOËL 1973.

Remarks. – There are disagreements among authors about the use of *Vekshinella* and *Vagalapilla*. LOEBLICH & TAPAN (1963) introduced *Vekshinella* to substitute *Ephippium* VEKSHINA, which was preoccupied. *Ephippium* was defined as "stephanoliths with a central projection-spine" (VEKSHINA 1959). This broad definition was emended by GARTNER (1968, p. 29), who characterized the genus by having a basal disc of a single cycle of imbricated elements and a central cross aligned parallel to the major axes. This author also stated that the central cross bars may or may not have a spine or hollow stem. We use *Vagalapilla* instead of *Vekshinella* LOEBLICH & TAPAN emend. GARTNER (1968) for the following reasons: (1) the ultrastructure of the type species of *Vekshinella (Ephippium acutifera* VEKSHINA 1959) is unknown because of the lack of electron microscopic observation; (2) none of the specimens assigned to *Vekshinella* by GARTNER (1968) indicates the presence of a proximal extension of the spine, that would be required by the original monotypic definition of the genus (BUKRY 1969); and (3) the definition of *Vagalapilla* is precise, and excludes the type species of *Vekshinella* LOEBLICH & TAPAN which has a stem extending from the proximal side of the cross.

Vagalapilla dibrachiata (Gartner 1968) n. comb.

Pl. 1, Figs. 1–3; Pl. 4, Fig. 7

1968 *Vekshinella dibrachiata* Gartner, p. 30, Pl. 5, Figs. 23–24, Pl. 7, Figs. 8a–8b; Pl. 22, Fig. 8.
1979 *Zeugrhabdotus salillum* (Noël) Rood et al. (1971); Medd, Pl. 9, Fig. 12.
1980 *Vekshinella dibrachiata* Gartner; Grün & Zweili, p. 291–294, Text-fig. 41, Pl. 15, 1–5.

Remarks. – We transferred this species from *Vekshinella* to *Vagalapilla* for the reasons stated before. The shape and width of the central cross of *V. dibrachiata* varies. The cross-arms are flaring or nearly parallel-sided, except near the small and rounded central opening. The width of the cross is one-sixth to one-third the short axis of the coccolith. In proximal view, each arm of the cross is divided into two by longitudinal furrows, which run from outer margin to the central opening (Pl. 1, Fig. 1; Pl. 4, Fig. 7). The central cross is birefringent (Pl. 1, Fig. 3) when viewed with its axis parallel to the axis of the analyzer or polarizer in cross-polarized light.

Differential diagnosis. – *V. dibrachiata* differs from *Vagalapilla stradneri* (Rood et al.) Thierstein (1973) by having wider cross bars with longitudinal furrows, and a circular opening at the center. This species is distinguished from *Crucirhabdus primulus* (Prins) ex Rood et al. (1971) by having a loxolith rim structure, lack of lateral bars, and by the birefringence of both arms of the central cross. Only the transverse bars of *C. primulus* are birefringent. *Vagalapilla quadriarculla* (Noël) Roth (1983) displays strong tapering of the arms and proximal furrows of the central cross from the center to the inner margin of the rim.

Geologic range. – Oxfordian to Maastrichtian (Grün & Zweili 1980).

Family **Biscutaceae** Black 1971, emend. Bown 1987

Genus *Discorhabdus* Noël 1965

Type species: Rhabdolithus patulus Deflandre in Deflandre & Fert 1954.

Remarks. – *Discorhabdus* is characterized by a wide circular rim of radial elements and a well developed central stem. The different species of *Discorhabdus* are largely defined by the shape of the central stem (Noël 1965). *Discorhabdus* differs from *Bidiscus* Bukry (1969) by having a well developed central stem, from *Biscutum* Black (in Black & Barnes 1959) by having a circular rim, and from *Podorhabdus* Noël (1965) by having a circular rim, smaller central area, and the lack of perforations at the base of the central stem.

Discorhabdus corollatus Noël 1965, emend. Rahman & Roth, in press

Pl. 1, Figs. 4–8

non 1954 *Rhabdolithus patulus* Deflandre in Deflandre & Fert, p. 39, Pl. 15, Figs. 40, 45, Text-figs. 97–98.
1965 *Discorhabdus corollatus* Noël, p. 147, Pl. 22, Fig. 6.
1965 *Discorhabdus gibbosus* Noël, p. 146–147, Text-fig. 58, Pl. 22, Figs. 3–4.
1965 *Discorhabdus* sp. Noël, Text-fig. 53, Pl. 21, Figs. 1, 5, 12–13.
1965 *Discorhabdus patulus* (Deflandre) Noël; Noël, p. 141–144, Pl. 21, Figs. 6–8, 10–11; Pl. 22, Figs. 1–2, 9–10.
1974 *Discorhabdus patulus* (Deflandre) Noël; Barnard & Hay, Pl. 3–12, Pl. 4–11.
1979 *Discorhabdus tubus Noël; Medd,* Pl. 1, Fig. 9.
1982 *Discorhabdus patulus* (Deflandre) Noël; Hamilton, Pl. 3.2, Fig. 13; Pl. 3.4, Fig. 29.
in press *Discorhabdus corollatus* (Deflandre) Noël emend. Rahman & Roth; Rahman & Roth, Figs. 1.1–1.5.

Remarks. – This is a small species of *Discorhabdus* consisting of two closely appressed circular shields of equal size having a diameter less than 5 µm. Each shield is composed of 16 to 20 wedge-shaped elements, joined along straight radial sutures. A narrow stem of fibrous crystallites oriented parallel to the axis of the stem covers the central area of the coccolith. This stem is parallel-sided except near the distal end, where it expands to form a small cone. The stem has a narrow canal, which is difficult to see in axial views under the SEM. The canal and the distal cone of the stem are visible in side views under the light microscope (RAHMAN & ROTH in press). Occasionally, the upper part of the stem is broken and in these cases the distal cone of the stem may be absent.

The rim of *D. corollatus* is slightly birefringent in axial views between crossed nicols. In most of the specimens the inner margin of the coccolith is strongly birefringent. The sutures of the rim are usually visible in phase contrast illumination. In overgrown specimens, some of the sutures may appear non-radial because of differential overgrowth of elements from the center to the outer margin (Pl. 1, Figs. 4, 7).

The relation of *D. corollatus* to *Tremalithus ignotus* GÓRKA (1957) is unclear, because GÓRKA (1957) showed a small proximal shield of non-radial elements without any indication of the central stem in her hand drawn figure of *T. ignotus*. Restudy of the type material of *T. ignotus* by REINHARDT & GÓRKA (1967) did not indicate the presence of a well developed central stem, neither is it visible in the holotype. The radially arranged elements and a well developed central stem are important generic characters of *Discorhabdus* NOËL (1965). We consider *T. ignotus* a dubious taxon.

Geologic range. – *D. corollatus* first occurs in the lower Callovian (BARNARD & HAY 1974). We found this species sporadically from Sample 534A-127-CC of middle Callovian age to Sample 534A-99-4, 12–13 cm of early Tithonian age.

Family **Parhabdolithaceae** BOWN 1987

Genus *Bibreviconus* n. gen.

Type species: Bibreviconus atlanticus n. sp.

Diagnosis. – A nannofossil with a rim composed of two short coaxial cones of unequal diameter, and the distal cone is fitted inside the proximal cone.

Description. – *Bibreviconus* has two short cones flaring in the distal direction. Distal cone has smaller diameter and fits into the inner side of the proximal cone, which is of larger diameter. Each cone is composed of rectangular elements which are vertically to subvertically oriented.

Differential diagnosis. – *Bibreviconus* differs from *Mitrolithus* DEFLANDRE emend. BOWN & YOUNG in YOUNG et al. (1986), and *Nannoconus* KAMPTNER (1931) by having a rim of two short cones, and from *Ansulosphaera* GRÜN & ZWEILI (1980) by the lack of a distal shield that resembles *Watznaueria.*

Remark. – Because of the presence of a distally extended rim of vertical to subvertical elements we assign *Bibreviconus* to the Parhabdolithaceae.

Derivation of name. – This genus is named after three Latin words, "bi" for two, "brevis" for short, and "conus" for cone, referring to the rim structure of two short cones.

Bibreviconus atlanticus n. sp.

Pl. 2, Figs. 6–10; Pl. 4, Figs. 3, 5, 8

Diagnosis. – A circular to broadly elliptical species of *Bibreviconus* in which the central area is traversed by a number of radial bars.

Description. – The rim is composed of two short coaxial cones, each composed of about 20 rectangular elements joined laterally along straight sutures. Both these cones slightly expand in the distal direction. The height of the proximal cone is about twice the width of its elements. In the proximal side, the central area is covered by closely-spaced bars which are radially oriented and raised in the distal direction (Pl. 4, Fig. 5). Some of the bars are short and do not continue toward the center of the coccolith. Other bars are longer and run close to the center, where a narrow central canal is situated (Pl. 4, Fig. 8). In axial view, *B. atlanticus* has an outline varying from circular to broadly elliptical.

Remarks. – In side views under the light microscope, the distal cone is strongly birefringent along two sides, and there is a dark band along the axis perhaps representing the central canal (Pl. 2, Fig. 7, 10). The proximal cone and the central stem are optically continuous, and are moderately birefringent. In axial view under phase contrast illumination, the radial bars are not discernable (Pl. 2, Fig. 8). Same view between crossed nicols shows strong birefringence and a faint radial extinction pattern (Pl. 2, Fig. 9).

Differential diagnosis. – The central structure of *B. atlanticus* and *Mitrolithus jansae* (WIEGAND) BOWN & YOUNG (in YOUNG et al. 1986) is considerably similar, but the latter species has only one relatively high cone.

Derivation of name. – This species is named after its type locality in the Atlantic Ocean.

Holotype. – USNM 458819 [Pl. 4, Fig. 5, Sample 534A-101-1, 64–65 cm (USNM 458820)].

Paratype. – USNM 458821 [Pl. 4, Fig. 3, Sample 534A-101-2, 35–36 cm (USNM 458822)].

Dimensions. – Most of the specimens of *B. atlanticus* range in size from 2.5 to 4.5 µm in diameter (proximal cone) and 2.0 to 3.8 µm in height. The holotype has a diameter of 3 µm.

Type level. – Sample 534A-101-1, 64–65 cm, lower Tithonian.

Geologic range. – *B. atlanticus* was found within a short interval from Sample 534A-101-4, 83–84 cm to Sample 534A-99-4, 12–13 cm, apparently ranging in the early Tithonian.

Family **Stephanolithionaceae** BLACK 1968

Genus *Stradnerlithus* BLACK 1971

Type species: Stradnerlithus comptus BLACK 1971.

Remarks. – *Stradnerlithus* differs from *Rotelapillus* NOËL emend. RAHMAN & ROTH (in press) by the presence of a short rim, which may be elliptical, rhomboidal or biconvex in axial view. In *Stradnerlithus*, each distal element is shorter than or equal to two times its width. The type species of *Rotelapillus (Rotelapillus radians* NOËL 1973) may have a broadly elliptical rim, which is always higher than the rim of *Stradnerlithus*.

Both *Stradnerlithus* and *Rotelapillus* have a number of central bars supporting a spine. These bars are radial in *Rotelapillus,* but range from radial to non-radial in *Stradnerlithus. Stradnerlithus* differs from *Corollithion* STRADNER (1961) by the lack of a hexagonal rim.

As GOY (in GOY et al. 1979) has pointed out, the generotype of *Nodosella (Nodosella clatriata* PRINS ex ROOD et al. 1973) can easily be assigned to *Stradnerlithus* NOËL (1973), making the rather ill-defined genus *Nodosella* superfluous.

Stradnerlithus braloweri n. sp.

Pl. 2, Figs. 11–13

Diagnosis. – A *Stradnerlithus* characterized by a broadly elliptical narrow rim, which is shorter than twice the width of the elements and has an axial ratio ("short axis/long axis" of the the coccolith) of 0.8 and above, and a central spine supported by eight bars. The angle between two adjacent bars close to the long axis of the coccolith ranges from 45° to 55°.

Description. – *S. braloweri* has a broadly elliptical rim, with a distal shield of 24–30 tabular vertical elements attached laterally. There are eight parallel-sided bars, each composed of long prismatic microcrystals oriented parallel to the bars (Pl. 2, Fig. 12). The bars are attached to the proximal part of the inner side of the narrow rim, and join at the center to support a spine.

Remarks. – The rim of *S. braloweri* has low relief. It is dark or only slightly birefringent between crossed nicols. The bars are non-birefringent, and are only visible in phase contrast illumination.

S. braloweri marks the evolutionary transition from *Stradnerlithus* to *Rotelapillus,* which first occurs in the upper Kimmeridgian at Site 534. *Stradnerlithus* probably evolved to *Rotelapillus* by an increase in the height of the distal elements and a change in outline of the rim, from broadly elliptical to circular. The original concept of *Rotelapillus* NOËL (1973) would have included this species based on the presence of a broadly elliptical rim. Electron microscopic observation of *S. braloweri,* however, revealed the presence of a low rim typical of *Stradnerlithus,* which is also supported by light microscopic observations.

Differential diagnosis. – Among all the species of *Stradnerlithus* presently known, *S. braloweri* has the closest resemblance to *Stradnerlithus fragilis* (ROOD & BARNARD) PERCH-NIELSEN (1984), but differs by having a broadly elliptical, instead of a biconvex rim in axial view (Pl. 4, Figs. 1–2), and a larger spacing between the central bars, which are situated near the long axis of the coccolith. *S. braloweri* differs from *Stradnerlithus escovillensis* (ROOD & BARNARD) MEDD (1979) and *Stradnerlithus asymmetricus* (ROOD et al.) MEDD (1979) by a greater axial ratio, which is equal to or greater than 0.8, based on eleven measurements under the light microscope and the measurement of the holotype. The axial ratios are 0.69 and 0.72 in the holotype of *S. escovillensis* and *S. asymmetricus,* respectively.

S. braloweri differs from *Stradnerlithus geometricus* (GÓRKA) BOWN & COOPER (1989) and *Stradnerlithus callomonii* (ROOD et al.) PERCH-NIELSEN (1984) by having eight, instead of six or ten central bars. The rim of *Rotelapillus radians* NOËL (1973) and *Rotelapillus hexaradiatus* RAHMAN & ROTH (in press) is much higher than in *S. bra-*

loweri, and possess short lateral spines on the distal part of the outer side of the rim (Pl. 2, Figs. 5, 14).

Derivation of name. – This species is named after Dr. Timothy J. Bralower of the University of North Carolina, for his contribution to Jurassic and Cretaceous nannofossil biostratigraphy.

Holotype. – USNM 458823 [Pl. 2, Fig. 12, Sample 534A-99-4, 12–13 cm (USNM 458824)].

Paratype. – USNM 458825 [Pl. 2, Fig. 11, Sample 534A-102-3, 76–77 cm (USNM 458826)].

Dimension. – Holotype is 2.26 µm long and 1.85 µm wide, with an axial ratio of 0.82.

Type level. – Sample 534A-99-4, 12–13 cm, lower Tithonian.

Geologic range. – *S. braloweri* occurs in samples from 534A-102-1, 84–85 cm to 534A-99-4, 12–13 cm, ranging from latest Kimmeridgian to early Tithonian.

Stradnerlithus silvaradius (FILEWICH et al. in WISE & WIND 1977) n. comb.

Pl. 1, Figs. 14–16

1977 *Corollithion silvaradion* FILEWICZ et al. in WISE & WIND, p. 310, Pl. 62, Figs. 2–6; Pl. 63, Figs. 5–6.
1984 *Nodosella silvaradion* (FILEWICZ et al. in WISE & WIND) PERCH-NIELSEN, p. 43.
1988 *Nodosella silvaradion* (FILEWICZ et al. in WISE & WIND) PERCH-NIELSEN; APPLEGATE & BERGEN, Pl. 17, Fig. 1.
1989 *Corollithion silvaradion* FILEWICZ et al. in WISE & WIND; CRUX, Pl. 8.5, Fig. 10; Pl. 8.13, Figs. 23–24.

Remarks. – A *Stradnerlithus* with a normally elliptical rim composed of 20 to 28 subvertical elements. The rim surrounds a central area traversed by radiating bars supporting a hollow spine at the center. The outer margin of the coccolith is crenulated, each crenulation marks the position of a distal element (Pl. 1, Fig. 16). The radial bars cover the central area completely or almost completely, and connect the central stem to the proximal part of the inner side of the rim. There is no sign of the presence of a central cross of any kind. The radial bars are slightly birefringent but inseparable between crossed nicols, and are visible, but not all of them in a single view, in phase contrast.

Differential diagnosis. – *S. silvaradius* differs from *Diductius clatratus* (GRÜN & ZWEILI) RAHMAN & ROTH (in press) (Pl. 1, Fig. 17) by having a radial arrangement of the central bars, and from *Diductius constans* GOY (in GOY et al. 1979) by the lack of a regular grid pattern in the central area. *S. comptus* and *S. callomonii* have a normally elliptical to narrowly elliptical rim, and fewer lateral bars, most of which are non-radial.

Geologic range. – APPLEGATE & BERGEN (1988) reported a range from Tithonian to Hauterivian. *S. silvaradius* occurs sporadically and rarely in samples between 534A-103-CC and 534A-99-1, 10–11 cm, ranging from late Kimmeridgian to early Tithonian.

Family **Watznaueriaceae** ROOD, HAY & BARNARD 1971

Genus *Ansulosphaera* GRÜN & ZWEILI 1980

Type species: Ansulosphaera helvetica GRÜN & ZWEILI 1980.

Remarks. – *Ansulosphaera* is characterized by a broadly elliptical to circular rim of two shields. The distal shield is composed of sinistrally imbricated elements typical of the Watznaueriacean coccoliths. The proximal shield is high, and may form a tube or a wide cone.

Differential diagnosis. – *Ansulosphaera* differs from *Watznaueria* REINHARDT (1964) by having a high proximal shield, and from *Diazomatolithus* NOËL (1965) by having a distal shield of strongly imbricated elements. Two shields are closely appressed in *Watznaueria.*

Ansulosphaera bownii n. sp.

Pl. 1, Figs. 9–13; Pl. 2, Fig. 1; Pl. 4, Fig. 4

Diagnosis. – A circular to broadly elliptical *Ansulosphaera* with a relatively large central opening and a relatively high proximal shield in which the elements are sloping toward the inner part of the coccolith.

Description. – The rim of *A. bownii* consists of two unequal shields of circular to broadly elliptical shape with a central opening ranging in diameter from one-third to one-half the diameter of the coccolith. The distal shield has a crenulated outer margin, and is composed of a wide cycle of 24 to 28 elongated elements, inclined sinistrally (in distal view). The elements of the distal shield have straight sutures in most of the outer part of the shield (Pl. 1, Fig. 9). The proximal shield is smaller than the distal shield, and is composed of a single cycle of elements, equal in number to the distal shield. The sutures of the proximal shield are sinistrally inclined (Pl. 1, Fig. 10), and the elements slope steeply toward the central area in proximal view (Pl. 1, Fig. 13; Pl. 4, Fig. 4). The outer margin of the proximal shield appears irregular.

Remarks. – In axial view, *A. bownii* shows a high relief under phase contrast illumination. Between crossed nicols, the rim is birefringent with four extinction bands, each at 10 to 15° angle to the vibration plane of the polarizer or analyzer.

The morphological characteristics of *A. bownii* is in between *A. helvetica* and *Watznaueria barnesae.* The generic assignment of *A. bownii,* however, is based on the high proximal shield, which is not found in *Watznaueria.*

Differential diagnosis. – *A. bownii* differs from *A. helvetica* by a shorter proximal shield which does not form a tube, and by having a smaller number of cycles in the distal shield. Beside the inner cycle, there are two cycles in the distal shield of *A. helvetica.* In case of *A. bownii,* the distal shield is composed of a single cycle with some indications of the presence of a narrow cycle at the innermost part (Pl. 1, Fig. 9).

Derivation of name. – This species is named after Dr. Paul R. Bown of the University College London, for his contribution to Jurassic nannofossil taxonomy.

Holotype. – USNM 458827 [Pl. 1, Fig. 9, Sample 534A-102-3, 76–77 cm (USNM 458826)].

Paratypes. – USNM 458828 [Pl. 1, Fig. 10, Sample 534A-102-3, 76–77 cm (USNM 458826)]; USNM 458829 [Pl. 1, Fig. 13, Sample 534A-100-3, 6–7 cm (USNM 458830)]; USNM 458831 [Pl. 2, Fig. 1, Sample 534A-102-3, 76–77 cm (USNM 458826)].

Dimensions. – Rim is 3.3 to 5.25 μm long and 3.0 to 5.0 μm wide, and the central area is 1.2 to 2.4 μm wide and 1.2 to 2.6 μm long. The holotype is subcircular with a rim 3.4 μm long and 3.0 μm wide, and a central opening 1.5 μm long and 1.2 μm wide.

Type level. – Sample 534A-102-3, 76–77 cm, upper Kimmeridgian.

Geologic range. – *A. bownii* first occurs in Sample 534A-114-1, 49–50 cm, and was last observed in Sample 534A-99-4, 12–13 cm. The observed geologic range is early Oxfordian to early Tithonian.

Genus *Watznaueria* REINHARDT 1964

Type species: Tremalithus barnesae BLACK in BLACK & BARNES 1959.
Synonyms: Ellipsagelosphaera NOËL (1965), *Calolithus* NOËL (1965), *Actinosphaera* NOËL (1965).

Remarks. – The construction of the rim of *Watznaueria* is similar to *Lotharingus* NOËL (1973) emend. GOY (in GOY et al. 1979). The differentiation of these two genera is based on the central structure. The central area of *Watznaueria* may be open, closed, traversed by a bridge or several lateral bars, or may be covered by a delicate floor. *Watznaueria* lacks a spine-supported central cross. We follow GOY (in GOY et al. 1979) who emended the definition of *Lotharingus* and stated a spine-supported central cross characterize this genus.

Watznaueria coronata (GARTNER 1968) BUKRY 1969 emend.

Pl. 2, Figs. 15–17; Pl. 3, Figs. 1–2, 6; Pl. 4, Fig. 6

1968 *Coccolithus coronatus* GARTNER, p. 17, Pl. 23, Figs. 26–28.
1969 *Watznaueria coronata* (GARTNER) BUKRY, p. 32, Pl. 10, Figs. 11–12; Pl. 11, Figs. 1–2.
?1971 *Ellipsagelosphaera coronata* (GARTNER) BLACK, p. 398, Pl. 30, Fig. 6.
1971 *Ellipsagelosphaera forbesii* BLACK, p. 398–399, Pl. 30, Fig. 9.
1973 *Ellipsagelosphaera coronata* (GARTNER) BLACK; BLACK, Pl. 26, Figs. 5, 8–9, 13.
1973 *Ellipsagelosphaera forbesii* BLACK; BLACK, Pl. 26, Figs. 3, 6, 7.
1977 *Ellipsagelosphaera coronata* (GARTNER) BLACK; BARRIER, Pl. 5, Figs. 5–6.

Original diagnosis. – "Elliptical placolith with small notch developed in each element of proximal shield" (GARTNER 1968, p. 17).

Emended diagnosis. – A species of *Watznaueria* having a broadly elliptical rim of two unequal shields and a central area closed by a floor of closely attached narrow elongated elements, which are the central extensions of the elements of proximal shield.

Description. – *W. coronata* has two unequal, broadly elliptical shields with a subcircular to elliptical central area of width about one-third of the width of the coccolith. The distal shield is composed of two cycles. The outer cycle is wide and consists of 26 to 32 wedge-shaped crystals, separated by straight or slightly curved sutures. The elements of this cycle are imbricated counter-clockwise and slopes gently from the inner to peripheral side of the coccolith, when observed in distal view. The inner cycle of the distal shield is narrow and is composed of radially oriented tabular crystals. This inner cycle is often dissolved, in which case the distal shield shows only one cycle (Pl. 3, Fig. 6). The central floor is relatively flat, and is composed of the inward extensions of proximal elements, which join along a median line parallel to the long axis of the coccolith.

Remarks. – The rim of *W. coronata* is birefringent and shows nearly straight extinction bands, which are at an angle about 15° to the plane of vibration of the polarizer or analyzer. The central area is either non-birefringent or only slightly birefringent. The specimens of *W. coronata* photographed in the light microscope (Pl. 2, Figs. 15–16; Pl. 3, Figs. 1–2) are etched and overgrown, thus making it difficult to relate with SEM photomicrograph of a well preserved specimen (Pl. 2, Fig. 17).

We consider *E. forbesii* as a subjective junior synonym of *W. coronata*, because both have a similar central structure. Black (1971) used the presence of an elliptical perforation at the center as one of the distinguishing criterion of *W. coronata*. The type specimen of *W. coronata* Gartner (1968, Pl. 23, Fig. 27) has a narrow nearly parallel-sided central opening at an angle to the long axis of the coccolith, which appears to be the result of dissolution and not a characteristic of this species, as shown by the paratype (Gartner 1968, Pl. 23, Fig. 28), which lacks such an opening.

Differential diagnosis. – *W. coronata* differs from *Lotharingus sigillatus* (Pl. 3, Fig. 7) and *Lotharingus barozii* by the lack of a central cross, and from *Lotharingus velatus* Bown & Cooper (1989) by the presence of elongated, instead of granular, crystallites in the central floor.

W. coronata differs from *W. barnesae* by having a larger and wider central area. Between crossed nicols, the inner cycle of the distal shield of *W. coronata* has similar birefringence and is difficult to distinguish from the outer cycle. In contrast, the inner cycle of the distal shield of *W. barnesae* and *Watznaueria variabilis* Rahman & Roth (in press) is separable from the outer cycle by its distinctive birefringence and extinction patterns (Pl. 3, Figs. 3–4). *W. coronata* differs from *Watznaueria ovata* Bukry (1969) (Pl. 3, Fig. 5) by having a central floor, and from *Watznaueria manivitae* Bukry (1973) by having a smaller size and the lack of a strongly birefringent and central area (Pl. 3, Figs. 8–9).

Geologic range. – Previous workers reported *W. coronata* in the Cretaceous from Berriasian to Cenomanian (Bukry 1969; Gartner 1968; Barrier 1977). This species occurs sporadically in samples from 534A-104-1, 52–53 cm to 534A-99-1, 10–11 cm, ranging from Kimmeridgian to early Tithonian.

Family **Zygodiscaceae** Hay & Mohler 1967

Genus *Mitosia* Worsley 1971 emend.

Type species: Mitosia infinitiae Worsley 1971.

Original description. – "Elliptical plates having distinct elevated rims composed of radial elements showing no evident suturing, and a central area composed of randomly to sub-radially oriented granular calcite" (Worsley 1971, p. 1311).

Emended diagnosis. – *Mitosia* includes coccoliths having an elliptical loxolith rim, and a central area covered by granular crystallites forming a circular, elliptical or lemniscate-shaped structure in the distal side and two elliptical openings along the long axis of the coccolith.

Remarks. – Worsley (1971) created *Mitosia*, a monospecific genus, based on the light microscopic observation of the generotype *Mitosia infinita (= Mitosia infinitiae)*, which was photographed with SEM by Roth & Thierstein (1972) and Covington & Wise (1987). From some of these photographs and also from those taken in this study (Pl. 3, Fig. 14), it is clear that the type species of *Mitosia* has a loxolith rim of steeply inclined elements, similar to the genus *Zeugrhabdotus* Reinhardt (1964), instead of a rim of radial elements as Worsley (1971) mentioned. This observation warrants an amendment of the original description. Neither *Parhabdolithus* nor *Rhagodiscus* conform with the generic characteristics of the type species, because *Parhabdolithus* has a high rim of vertical to subvertical elements, and *Rhagodiscus* has a floor of granular crystallites. Thus we consider *Mitosia* Worsley emend. a separate genus.

Hay (1977) included *Mitosia* under the family Stephanolithionaceae Black (1968). We assign *Mitosia* to the Zygodiscaceae, because of the loxolith rim structure.

Mitosia infinita Worsley 1971

Pl. 3, Figs. 10–14

1971 *Mitosia infinitiae* Worsley, p. 1311, Pl. 1, Figs. 48–50.
1972 *Parhabdolithus infinitus* (Worsley) Thierstein in Roth & Thierstein, p. 437, Pl. 9, Figs. 7–16.
1979 *Parhabdolithus infinitus* (Worsley) Thierstein in Roth & Thierstein; Wind & Cepek, Pl. 5, Figs. 1–3.
1987 *Rhagodiscus infinitus* (Worsley) Applegate, Covington & Wise in Covington & Wise, p. 632, Pl. 8, Fig. 1.

Description. – The rim is broadly elliptical, relatively narrow, and composed of about 26 elements, which are steeply inclined and dextrally imbricated in distal view (Pl. 3, Fig. 14). The central structure is composed of granular crystallites and varies widely in distal views. One specimen photographed by Roth & Thierstein (1972, Pl. 9, Figs. 7–9) and another photographed by Wind & Cepek (1979, Pl. 5, Fig. 1) show a hollow stem of circular cross section. The specimen we photographed does not show a stem, but a central structure which has a lemniscate shape (like "8"). Specimens with a central structure intermediate between these two are shown in Roth & Thierstein (1972, Pl. 9, Figs. 11–12), and Covington & Wise (1987, Pl. 8, Fig. 1). In distal view, the appearance of the shape of the central structure is perhaps related to the extent of its development.

The two opposite sides of the base of the central structure are attached to the inner side of the rim along the short axis of the coccolith. The base of the central structure may partly or completely surround two openings, which are elongated parallel to the long axis of the coccolith (see Roth & Thierstein 1972).

The rim of *M. infinita* is moderately birefringent, similar to *Zeugrhabdotus erectus* (Deflandre) Reinhardt (1965) under the light microscope. The central structure is slightly birefringent, and overlaps the inner side of the rim. Under phase contrast illumination, the shape of the central structure looks like an "8".

Differential diagnosis. – *M. infinita* differs from all known species of *Zeugrhabdotus* by the complicated shape of the transverse bar. *Zeugrhabdotus fissus* Grün & Zweili (1980) has a transverse bar which splits into two with the widest separation at the center.

Geologic range. – Worsley (1971) reported this species from Portlandian to Hauterivian in the Atlantic Ocean. At Hole 534A, Bralower et al. (1989) found this species (as *Parhabdolithus infinitus)* from near the Tithonian-Berriasian boundary to the Valanginian. We found *M. infinita* in samples from 534A-103-CC to 534A-99-CC, ranging from late Kimmeridgian to the early Tithonian.

Genus *Tranolithus* Stover 1966

Type species: Tranolithus manifestus Stover 1966.

Remarks. – *Tranolithus* is characterized by an elliptical rim surrounding a central area partly or almost completely covered by 2 or 4 blocky crystals (Perch-Nielsen

1985). Stover (1966) mentioned that in *Tranolithus* the transverse bars are divided longitudinally, each half of which has the same optical orientation as the adjacent parts of the rim.

Tranolithus ? *minimus* (Bukry 1969) Perch-Nielsen 1984

Pl. 2, Figs. 2–4

1969 *Zygodiscus minimus* Bukry, p. 61, Pl. 35, Figs. 9–11.
1982 *Zygodiscus minimus* Bukry; Crux, Pl. 5.1, Figs. 19–20; Pl. 5.8, Figs. 19–20.
1984 *Tranolithus minimus* (Bukry) Perch-Nielsen, p. 44.
1985 *Tranolithus minimus* (Bukry) Perch-Nielsen; Perch-Nielsen, Figs. 83/16.

Remarks. – It is difficult to assign this species to either of *Zeugrhabdotus* or *Tranolithus*. The absence of the floor of microcrystals, however, suggests that the specimens photographed in Plate 2, Figure 2 and in Bukry (1969) do not belong to *Zeugrhabdotus*.

T. ? *minimus* has a small, narrowly elliptical rim composed of about 20 steeply inclined distal elements, at the base of which about 16 tabular proximal elements are attached. There are the two blocky crystals filling the two sides of the central area. The description of *Z. minimus* was based only on distal views, which show the presence of a hollow and circular central stem of granular crystals (Bukry 1969). Specimens examined in this study showed a rhombic central opening in proximal view. Light microscopic observation suggests that there may be variations in the shape of the central opening, however, because of the very small size, none of our attempts to photograph these variations were successful. Between crossed nicols the central structure is slightly birefringent, and has a granular appearance. Neither this structure nor the two blocky crystals in the center are in optical continuity with the rim, as observed with the gypsum plate. Thus our generic assignment is unsatisfactory, and should be treated as tentative.

Differential diagnosis. – *T.* ? *minimus* differs from *Zeugrhabdotus fissus* (Grün & Zweili) Roth (1983) by the presence of two large crystals along the two opposite sides of the long axis of the coccolith, and by the lack of a floor of granular crystals, and from *Tranolithus macleodiae* Bukry (1969) by the lack of opening at the middle of each blocky crystal.

Geologic range. – Bukry (1969) reported *T.* ? *minimus* from Santonian. We found it in samples from 534A-104-1, 52–53 cm to 534A-99-1, 10–11 cm, apparently ranging from Kimmeridgian to early Tithonian.

Acknowledgments

Drs. Francis H. Brown, Katharina v. Salis Perch-Nielsen, Paul R. Bown, and one anonymous reviewer read this manuscript, their comments and criticisms are appreciated. Mr. Quintin Sahratian helped us in preparing samples for SEM observation. The samples were supplied through the assistance of the Deep Sea Drilling Project of the US National Science Foundation. This study was supported by US National Science Foundation Grant No. OCE 5382502 awarded to P.H.R.

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Manuscript received 26 April 1991
Revision accepted 2 October 1991

Plate 1

Length of the bar in the scanning electron microscope photographs represents 2 μm. PC = phase contrast, CN = crossed nicols.

Figs. 1–3. *Vagalapilla dibrachiata* (GARTNER 1968) n. comb.
1. Proximal view (Sample 534A-100-3, 67–68 cm).
2–3. Light micrograph under PC and CN (Sample 534A-101-CC), 6000X.

Figs. 4–8. *Discorhabdus corollatus* NOËL (1965) emend. RAHMAN & ROTH (in press).
4. Oblique distal view (Sample 534A-101-CC).
5–6. Light micrograph under PC and CN (Sample 534A-103-CC), 4660X.
7. Distal view (Sample 534A-102-3, 76–77 cm).
8. Side view (Sample 534A-100-3, 6–7 cm).

Figs. 9–13. *Ansulosphaera bownii* n. sp.
9. USNM 458827, distal view of the holotype [Sample 534A-102-3, 76–77 cm (USNM 458826)].
10. USNM 458828, proximal view of the paratype [Sample 534A-102-3, 76–77 cm (USNM 458826)].
11–12. Light micrograph under PC and CN (Sample 534A-99-4, 12–13 cm), 4200X.
13. USNM 458829, oblique proximal view of the paratype [Sample 534A-100-3, 6–7 cm (USNM 458830)].

Figs. 14–16. *Stradnerlithus silvaradius* (FILEWICH et al. in WISE & WIND 1977) n. comb.
14–15. Light micrograph under PC and CN (Sample 534A-102-5, 57–58 cm), 4250X.
16. Distal view (Sample 534A-102-3, 76–77 cm).

Fig. 17. *Diductius clatratus* (GRÜN & ZWEILI 1980) RAHMAN & ROTH (in press). Distal view [Sample Vi-17, from the Lower Oxfordian of northern France (for more information about the sample see KEUPP & ILG 1989)].

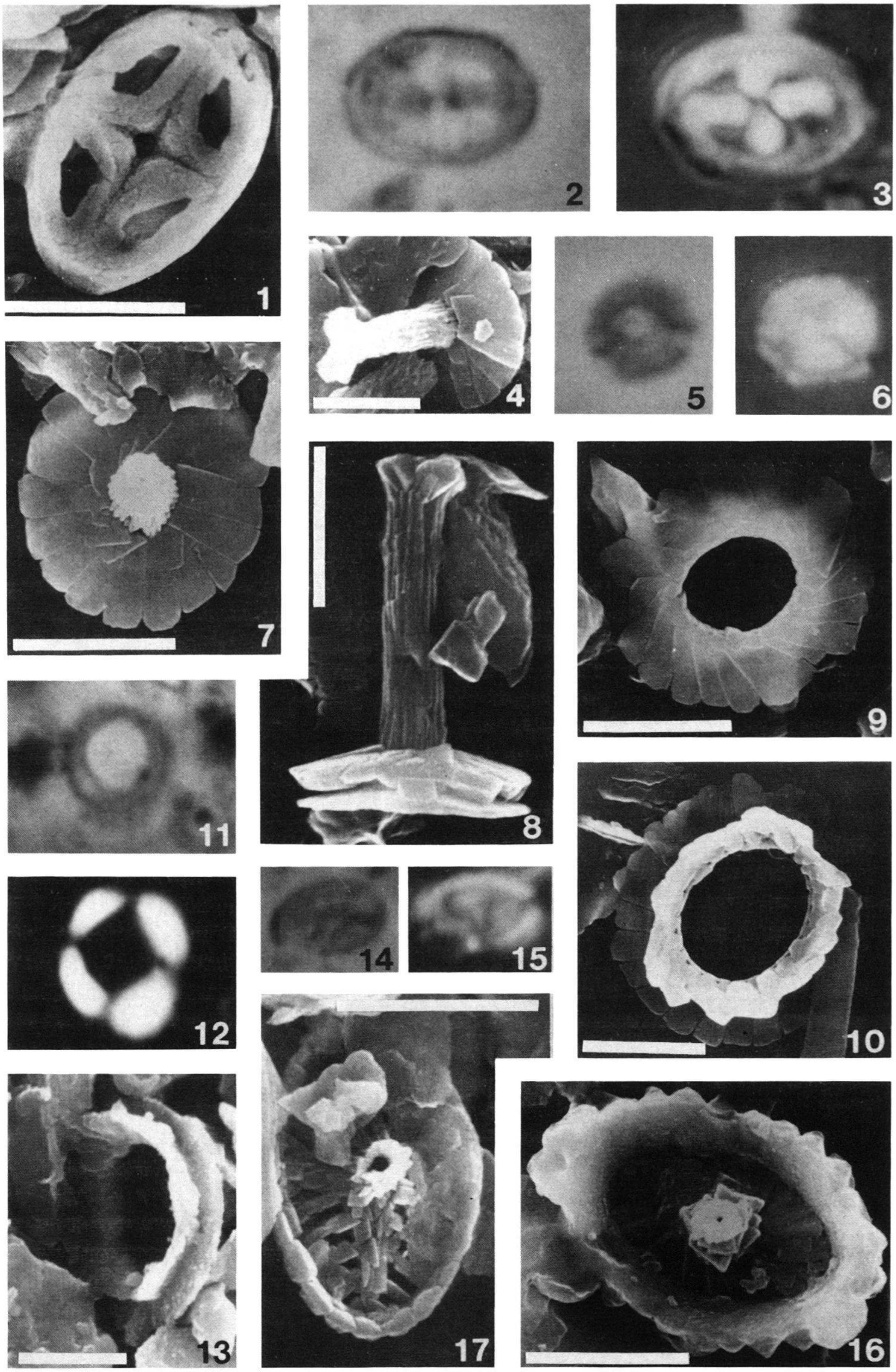
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Plate 2

Length of the bar in the scanning electron microscope photographs represents 2 μm. PC = phase contrast, CN = crossed nicols.

Fig. 1. *Ansulosphaera bownii* n. sp. USNM 458831, distal view of the paratype [Sample 534A-102-3, 76–77 cm (USNM 458826)].

Figs. 2–4. *Tranolithus*? *minimus* (Bukry 1969) Perch-Nielsen (1984).
2. Proximal view (Sample 534A-102-3, 76–77 cm).
3–4. Light micrograph under PC and CN (Sample 534A-102-5, 57–58 cm), 6400X.

Fig. 5. *Rotelapillus radians* Noël 1973. Proximal view (Sample 534A-101-6, 33–34 cm).

Figs. 6–10. *Bibreviconus atlanticus* n. sp.
6–7. Light micrograph under PC and CN, side view (Sample 534A-101-1, 64–65 cm), 4570X.
8–9. Light micrograph under PC and CN, top view (Sample 534A-99-4, 12–13 cm), 4200X.
10. Light micrograph between CN, side view (Sample 534A-102-3, 76–77 cm), 4530X.

Figs. 11–13. *Stradnerlithus braloweri* n. sp.
11. USNM 458825, oblique proximal view of the paratype [534A-102-3, 76–77 cm (USNM 458826)].
12. USNM 458823, distal view of the holotype [Sample 534A-99-4, 12–13 cm (USNM 458824)].
13. Light micrograph under PC (Sample 534A-101-1, 64–65 cm), 4550X.

Fig. 14. *Rotelapillus hexaradiatus* Rahman & Roth (in press). Oblique proximal view [Sample 84-17, from Ryazanian of the Oka River Valley, Russia (see Rahman & Roth in press)].

Figs. 15–17. *Watznaueria coronata* (Gartner 1968) Bukry (1969) emend. Rahman & Roth.
15–16. Light micrograph under PC and CN (Sample 534A-102-5, 57–58 cm), specimen is etched and overgrown, 4550X.
17. Distal view (Sample 534A-100-3, 6–7 cm).

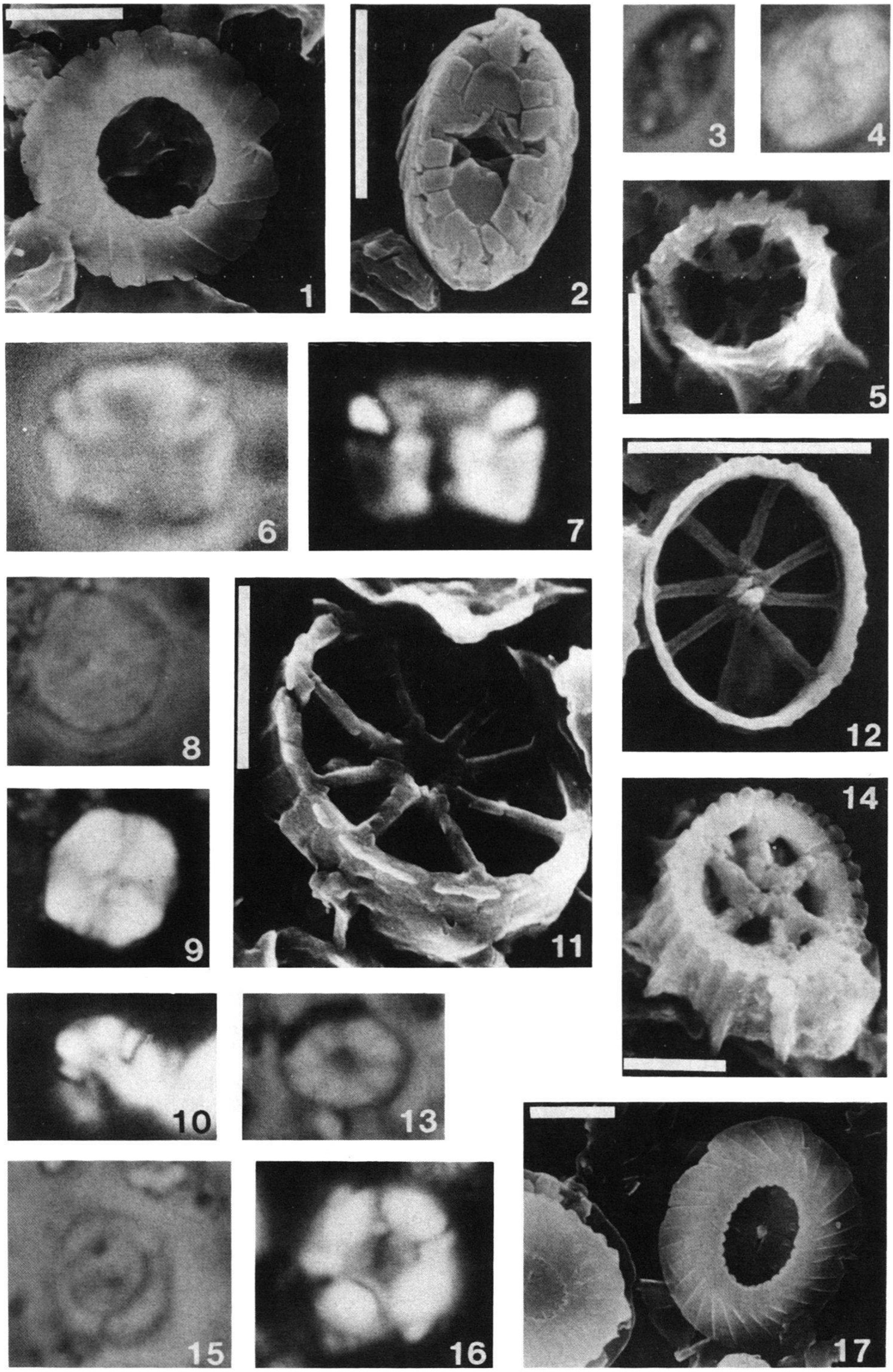

Plate 3

Length of the bar in the scanning electron microscope photographs represents 2 μm. PC = phase contrast, CN = crossed nicols.

Figs. 1–2, 6. *Watznaueria coronata* (GARTNER 1968) BUKRY (1969) emend. RAHMAN & ROTH.
1–2. Light micrograph under PC and CN (Sample 534A-102-5, 57–58 cm), specimen is etched and overgrown, 5180X.
6. Distal view (Sample 534A-100-4, 53–54 cm), inner cycle of the distal shield is completely dissolved.

Fig. 3. *Watznaueria barnesae* (BLACK in BLACK & BARNES 1959) PERCH-NIELSEN (1968). Light micrograph between CN (Sample 534A-102-3, 76–77 cm), 4650X.

Fig. 4. *Watznaueria variabilis* RAHMAN & ROTH (in press). Light micrograph between CN [Sample 84-23, early Oxfordian age, from the Oka River Section on the European Platform (see RAHMAN & ROTH in press)], 3000X.

Fig. 5. *Watznaueria ovata* BUKRY (1969). Distal view (Sample 534A-100-3, 6–7 cm).

Fig. 7. *Lotharingus sigillatus* (STRADNER 1961) PRINS in GRÜN et al. (1974). Distal view [Sample Vi-17, from the Lower Oxfordian of northern France (see KEUPP & ILG 1989)].

Figs. 8–9. *Watznaueria manivitae* BUKRY (1973). Light micrograph under PC and CN (Sample 534A-99-CC), 1450X.

Figs. 10–14. *Mitosia infinita* WORSLEY (1971).
10–11. Light micrograph under PC and CN (Sample 534A-99-CC), 4700X.
12–13. Light micrograph under PC and CN (Sample 534A-100-6, 53–54 cm), 4700X.
14. Sample 534A-100-4, 53–54 cm, distal view.

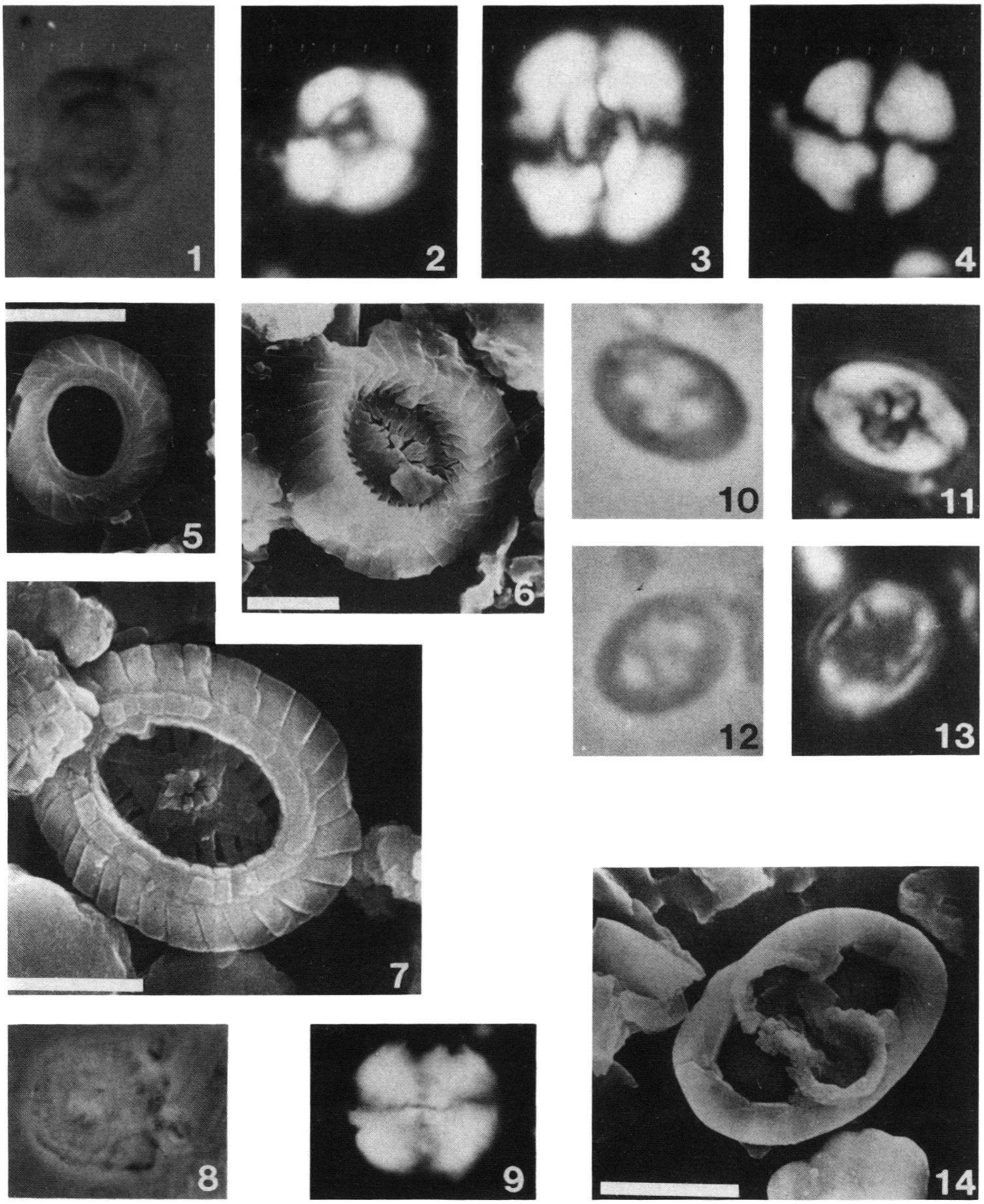
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Plate 4

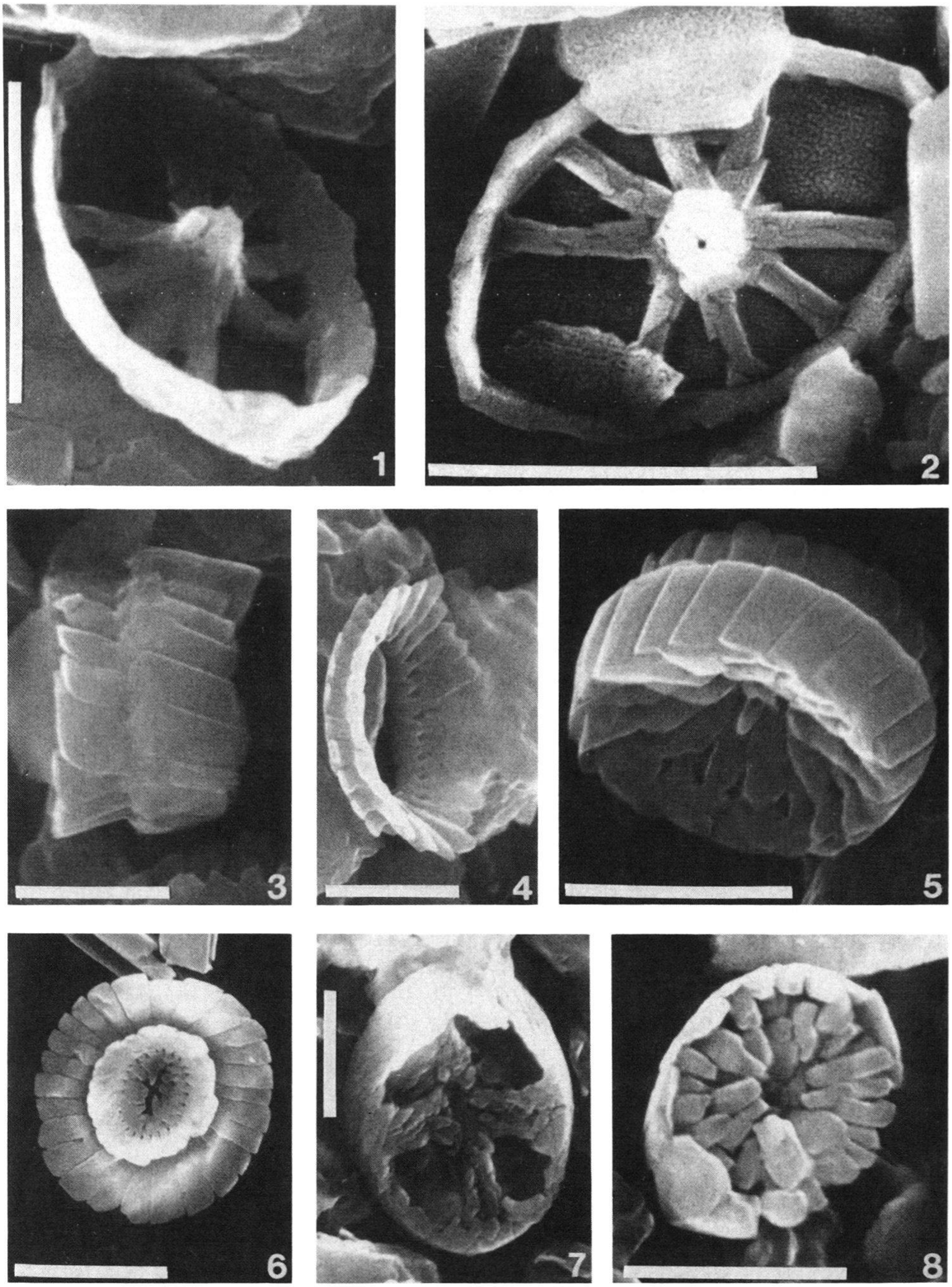
Figs. 1–2. *Stradnerlithus fragilis* (Rood & Barnard 1972) Perch-Nielsen 1984. Sample 84-41, from lower Oxfordian of the Oka River Valley, Russia (for more information about the sample see Rahman & Roth in press).
1. Oblique distal view.
2. Distal view.

Figs. 3, 5, 8. *Bibreviconus atlanticus* n. sp.
3. USNM 458821, side view of the paratype [Sample 534A-101-2, 35–36 cm (USNM 458822)].
5. USNM 458819, oblique proximal view of the holotype [Sample 534A-101-1, 64–65 cm (USNM 458820)].
8. Proximal view (Sample 534A-101-4, 83–84 cm).

Fig. 4. *Ansulosphaera bownii* n. sp. Oblique distal view (Sample 534A-101-1, 64–66 cm).

Fig. 6. *Watznaueria coronata* (Gartner 1968) Bukry (1969) emend. Proximal view (Sample 534A-100-4, 83–84 cm).

Fig. 7. *Vagalapilla dibrachiata* (Gartner 1968) n. comb. Proximal view (Sample 534A-101-4, 83–84 cm) of a etched specimen.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