Evolutionary, Biostratigraphic, and Taxonomic Study of Calcareous Nannofossils from a Continuous Paleocene-Eocene Boundary Section in New Jersey

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1554

AVAILABILITY OF BOOKS AND MAPS OF THE U.S. GEOLOGICAL SURVEY

Instructions on ordering publications of the U.S. Geological Survey, along with prices of the last offerings, are given in the current-year issues of the monthly catalog "New Publications of the U.S. Geological Survey." Prices of available U.S. Geological Survey publications released prior to the current year are listed in the most recent annual "Price and Availability List." Publications that may be listed in various U.S. Geological Survey catalogs (**see back inside cover**) but not listed in the most recent annual "Price and Availability List" may be no longer available.

Reports released through the NTIS may be obtained by writing to the National Technical Information Service, U.S. Department of Commerce, Springfield, VA 22161; please include NTIS report number with inquiry.

Order U.S. Geological Survey publications **by mail** or **over the counter** from the offices given below.

BY MAIL

Books

Professional Papers, Bulletins, Water-Supply Papers, Techniques of Water-Resources Investigations, Circulars, publications of general interest (such as leaflets, pamphlets, booklets), single copies of Earthquakes & Volcanoes, Preliminary Determination of Epicenters, and some miscellaneous reports, including some of the foregoing series that have gone out of print at the Superintendent of Documents, are obtainable by mail from

U.S. Geological Survey, Information Services
Box 25286, Federal Center, Denver, CO 80225

Subscriptions to periodicals (Earthquakes & Volcanoes and Preliminary Determination of Epicenters) can be obtained ONLY from the

Superintendent of Documents
Government Printing Office
Washington, DC 20402

(Check or money order must be payable to Superintendent of Documents.)

Maps

For maps, address mail orders to

U.S. Geological Survey, Information Services
Box 25286, Federal Center, Denver, CO 80225

Residents of Alaska may order maps from

U.S. Geological Survey, Earth Science Information Center
101 Twelfth Ave. - Box 12
Fairbanks, AK 99701

OVER THE COUNTER

Books and Maps

Books and maps of the U.S. Geological Survey are available over the counter at the following U.S. Geological Survey offices, all of which are authorized agents of the Superintendent of Documents:

- **ANCHORAGE, Alaska**—Rm. 101, 4230 University Dr.
- **LAKEWOOD, Colorado**—Federal Center, Bldg. 810
- **MENLO PARK, California**—Bldg. 3, Rm. 3128, 345 Middlefield Rd.
- **RESTON, Virginia**—USGS National Center, Rm. 1C402, 12201 Sunrise Valley Dr.
- **SALT LAKE CITY, Utah**—Federal Bldg., Rm. 8105, 125 South State St.
- **SPOKANE, Washington**—U.S. Post Office Bldg., Rm. 135, West 904 Riverside Ave.
- **WASHINGTON, D.C.**—Main Interior Bldg., Rm. 2650, 18th and C Sts., NW.

Maps Only

Maps may be purchased over the counter at the following U.S. Geological Survey offices:

- **FAIRBANKS, Alaska**—New Federal Bldg., 101 Twelfth Ave.
- **ROLLA, Missouri**—1400 Independence Rd.
- **STENNIS SPACE CENTER, Mississippi**—Bldg. 3101

Evolutionary, Biostratigraphic, and Taxonomic Study of Calcareous Nannofossils from a Continuous Paleocene-Eocene Boundary Section in New Jersey

By Laurel M. Bybell and Jean M. Self-Trail

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1554

Calcareous nannofossils were examined from upper Paleocene and lower Eocene marine sediments from six coreholes that were drilled in southern New Jersey. Microfossil data from New Jersey were compared to and were found to be consistent with material examined from the Atlantic Coastal Plain of Alabama, Maryland, and Virginia. The biostratigraphic and lithostratigraphic data indicate continuous deposition across the Paleocene-Eocene boundary in this part of New Jersey

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1994

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
GORDON P. EATON, Director

For sale by U.S. Geological Survey, Information Services
Box 25286, Federal Center, Denver, CO 80225

Published in the Eastern Region, Reston, Va.
Manuscript approved for publication May 31, 1994

Library of Congress Cataloging in Publication Data

Bybell, Laurel M.
Evolutionary, biostratigraphic, and taxonomic study of calcareous nannofossils from a continuous Paleocene-Eocene boundary section in New Jersey / by Laurel M. Bybell and Jean M. Self-Trail.
p. cm.—(U.S. Geological Survey professional paper ; 1554)
Includes bibliographical references.
Supt. of Docs. no. : I 19. 16: 1554
1. Nannofossils—New Jersey. 2. Paleobotany—Paleocene. 3. Paleobotany—Eocene. 4. Plants, Fossil—New Jersey. I. Self-Trail, Jean M. II. Title. III. Series
QE955.B93 1994
561'.93—dc20 94–30440
CIP

CONTENTS

PLATES

[Plates follow references cited]

FIGURES

TABLES

Evolutionary, Biostratigraphic, and Taxonomic Study of Calcareous Nannofossils from a Continuous Paleocene-Eocene Boundary Section in New Jersey

By Laurel M. Bybell and Jean M. Self-Trail

ABSTRACT

Calcareous nannofossils were examined with the light microscope, as well as with a scanning electron microscope, from six coreholes in southern New Jersey. Based on lithologic and paleontologic evidence, four of the coreholes have what appears to be continuous deposition across the Paleocene-Eocene boundary. Calcareous nannofossil preservation generally is very good in these coreholes, and an exhaustive study of this material resulted in 1) direct evidence for evolutionary shifts within several calcareous nannofossil species, as well as the gradual evolution of individual species into different species, 2) a vastly improved understanding of calcareous nannofossil biostratigraphy across the Paleocene-Eocene boundary, and 3) clarification of the taxonomy of late Paleocene and early Eocene members of this group, which is documented verbally with detailed remarks and pictorially with 31 plates of scanning electron photomicrographs and 7 plates of light photomicrographs. Four new species are described, six new combinations are established, and several species are put into synonymy. Fossil data from New Jersey were compared to and are consistent with information obtained from similarly aged sediments in Alabama, Maryland, and Virginia.

INTRODUCTION

PURPOSE AND SCOPE

As part of a U.S. Geological Survey-New Jersey Geological Survey joint mapping program begun in 1984, calcareous nannofossils were examined from six coreholes in Camden and Gloucester Counties, southern New Jersey (figs. 1, 2; table 1). Based on lithologic and paleontologic evidence (Gibson and others, 1993), four of these coreholes contain an apparently continuous and fossiliferous sequence across the Paleocene-Eocene boundary (GL 913, GL 915, GL 917, and Clayton cores), and the remaining two coreholes contain upper Paleocene fossiliferous sediments (K 15 and GL 916 cores). In these cores, the Vincentown Formation, which is late Paleocene in age (calcareous nannofossil Zones NP 5 to NP 9 of Martini, 1971), has a transitional boundary with the overlying Manasquan Formation, which is late Paleocene and early Eocene in age (Zones NP 9 to NP 10 in these cores) (fig. 3). In the Clayton core, this transitional zone is approximately 3 ft thick. Elsewhere in New Jersey, the Manasquan Formation includes upper Paleocene and lower Eocene sediments from Zones NP 9 to NP 14 (Owens and others, 1988; Poore and Bybell, 1988). See Gibson and others (1993) for a detailed discussion of the lithologic and sedimentary characteristics of strata at the Paleocene-Eocene boundary in the New Jersey drillholes.

As part of a companion project, calcareous nannofossil samples were examined from outcrops and coreholes in New Jersey, Alabama, Maryland, and Virginia (figs. 1, 4, 5; table 2), and although these regions do not have the continuous boundary section that occurs in New Jersey, specimens from these States provided valuable taxonomic and stratigraphic comparison material. Comparable lithologic units in Maryland and Virginia include in ascending order the Aquia Formation (Zones NP 5 to NP 9), the Marlboro Clay (Zone NP 9), and the Nanjemoy Formation (Zones NP 10 to NP 13) (fig. 3). It is unclear whether the Paleocene-Eocene boundary lies at the unconformity between the Marlboro and the Nanjemoy, where it is normally placed, or within the basal Nanjemoy. Recent data from two Virginia coreholes indicate that the Zone NP 9–NP 10 boundary may occur within the lower part of the Nanjemoy Formation. In Alabama, the Paleocene-Eocene boundary is at the unconformity between the Tuscahoma Formation (Zone NP 9) and the overlying Bashi and Hatchetigbee Formations (facies equivalent formations) of Zones NP 10–11 (fig. 3). Gibson and Bybell (in press) present a detailed discussion of the lithologic, stratigraphic, and age relations in these three geographic locations.

The occurrence of calcareous nannofossils across the Paleocene-Eocene boundary has been poorly documented in the past, mainly due to a paucity of marine sections during

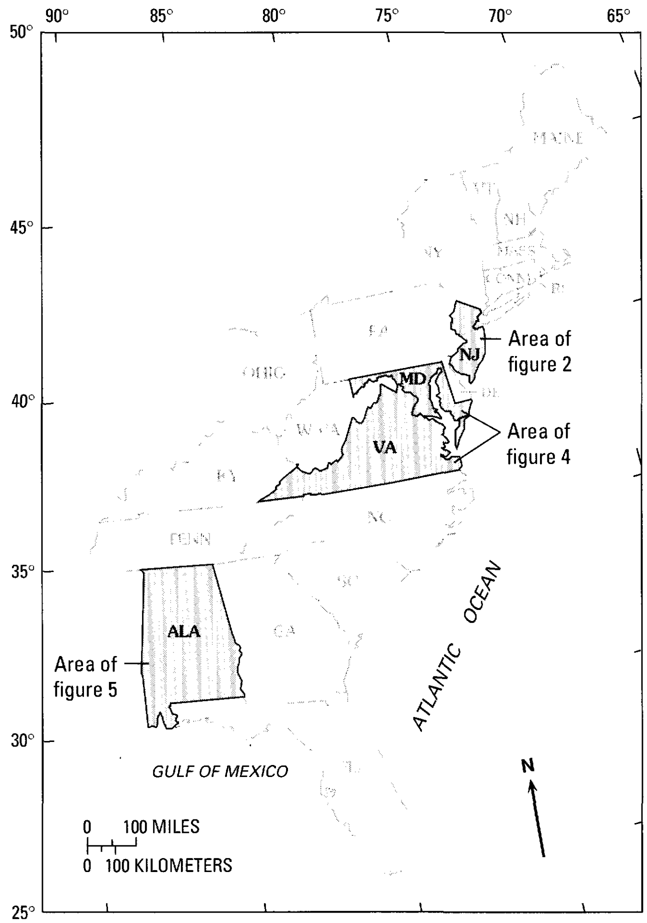


Figure 1. Locations of areas (shaded) in the Atlantic Coastal Plain of the eastern United States where samples were examined for this study.

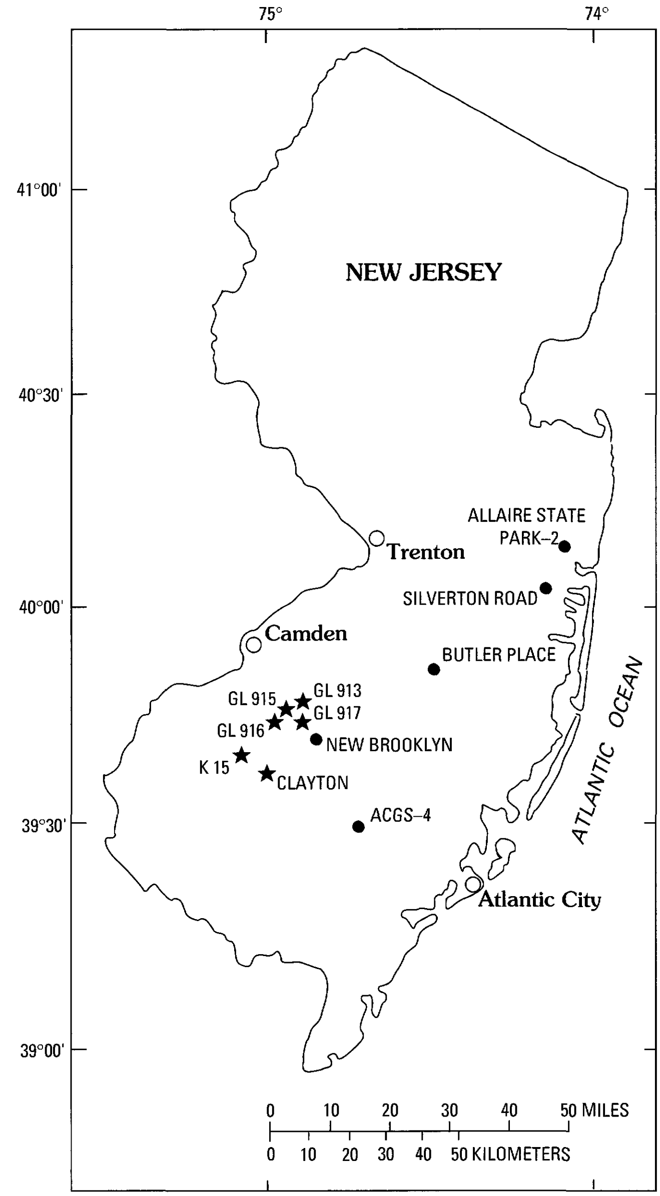


Figure 2. Locations of primary (stars) and supplementary (solid circles) coreholes in New Jersey that are discussed in text.

this period of time throughout much of the world. Preservation of the calcareous nannofossils generally is very good in much of the current study material, and an extensive study of the New Jersey cores was believed to provide an ideal opportunity to 1) document calcareous nannofossil occurrences across this important boundary, 2) study in detail the structure of the calcareous nannofossil species by means of the scanning electron microscope (SEM), 3) clarify the taxonomy of late Paleocene and early Eocene calcareous nannofossil species, and 4) document evolution within this fossil group.

ACKNOWLEDGMENTS

We wish to thank Katharina von Salis of Eidgenössische Technische Hochschule in Zurich, Switzerland, and Marie-Pierre Aubry of Laboratoire de Géologie du Quaternaire, Marseille, France, for their thoughtful reviews of this paper. We are indebted to James P. Owens of the U.S. Geological Survey and Peter J. Sugarman of the New Jersey Geological Survey, who worked with us on the New Jersey Project and who provided the core material. This paper was written as part of the International Geological Correlation Programme (IGCP) Project 308.

MATERIALS AND METHODS

Calcareous nannofossils were examined from six New Jersey drillholes (figs. 2, 6–11; table 1). The GL cores were drilled in 1984, and the K 15 core was drilled in 1987, as part of pollution studies in Gloucester and Camden Counties, N.J. At the time the cores were drilled, 2-ft-long split-

Table 1. Location information, core type, and year drilled for primary coreholes in New Jersey that were used in this study.

Corehole	Core type	Year drilled	County and State	7.5' quadrangle	Latitude and longitude
K 15	Split-spoon	1987	Gloucester County, New Jersey	Pitman West	36°43'N. 75°8'W.
GL 913	Split-spoon	1984	Camden County, New Jersey	Runnemeade	39°47'N. 75°2'W.
GL 915	Split-spoon	1984	Camden County, New Jersey	Runnemeade	39°47'N. 75°1'W.
GL 916	Split-spoon	1984	Camden County, New Jersey	Runnemeade	39°47'N. 75°2'W.
GL 917	Split-spoon	1984	Camden County, New Jersey	Runnemeade	39°47'N. 75°2'W.
Clayton	Wireline	1988	Gloucester County, New Jersey	Pitman East	39°39'N. 75°6'W.

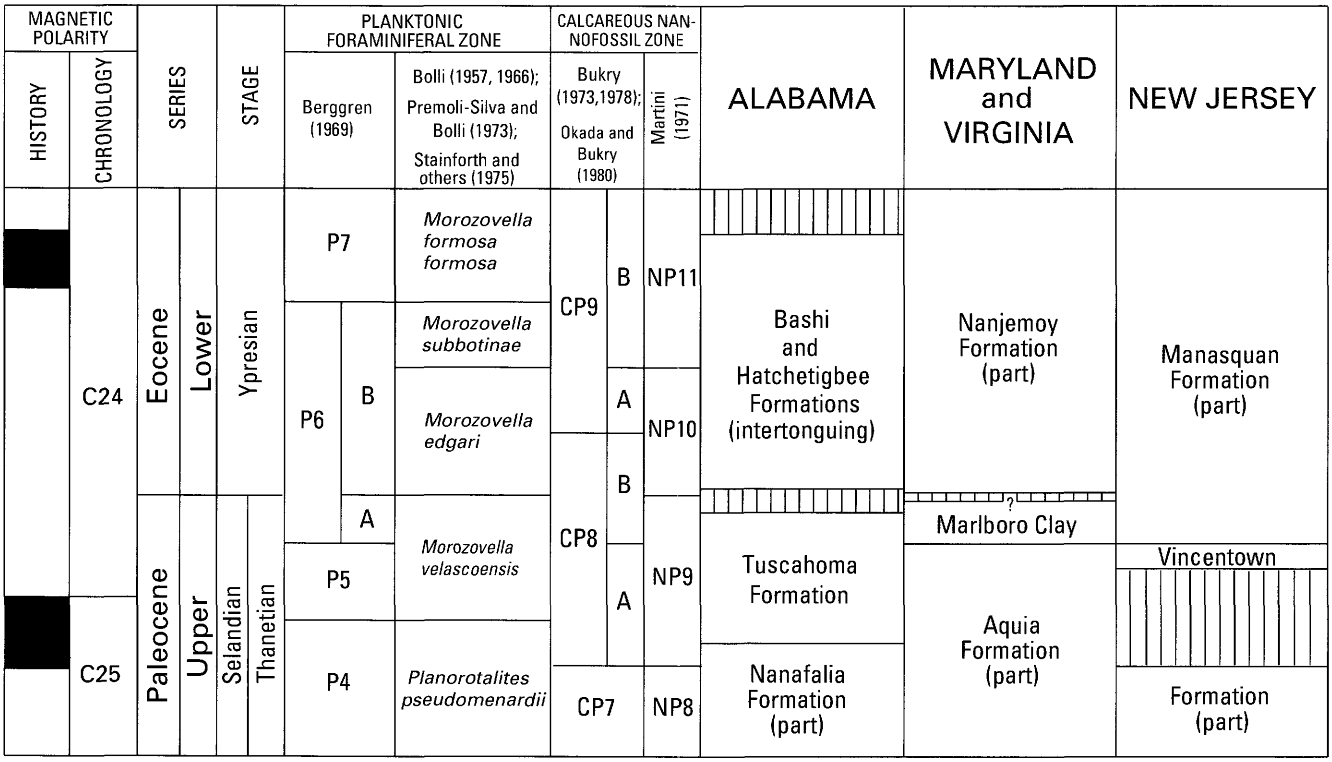


Figure 3. Correlation of fossil zones and magnetic polarity (from Berggren and others, 1985) to upper Paleocene and lower Eocene strata of Alabama, Maryland, Virginia, and New Jersey. Black rectangles indicate normal polarity. Vertical-line pattern indicates unconformity, queried where uncertain.

spoon cores were taken approximately every 5 ft, and a sample was collected from each of these cores and placed in a glass jar. In 1987, the present authors took calcareous nannofossil subsamples from each jar, which in many cases contained nearly intact core segments. The Clayton core was drilled in 1988 by the U.S. Geological Survey. In contrast to the sampling technique for the pollution study wells, the Clayton core was carefully sampled in the authors' calcareous nannofossil laboratory as soon as coring was completed and core boxes were transported to Reston, Va. Samples, which were dug out from the central portion of freshly broken, core segment surfaces, were taken at approximately 2- to 3-ft intervals. Because of close sample spacing and careful sampling procedures, the Clayton core can be considered to provide very reliable biostratigraphic data.

There is occasional minor contamination in the split-spoon cores, which probably is the result of coring and sampling procedures; however, this contamination is minimal, and the occurrence charts from the split-spoon cores agree well with the occurrence chart for the Clayton core, where there is no evidence of downhole contamination and only occasional reworking.

All of the New Jersey samples were examined with a Zeiss photomicroscope. In addition, samples with the best preservation and highest abundances of calcareous nannofossils were examined with a JEOL 135 SEM. The SEM was an extremely valuable tool for the detailed taxonomic study presented in this paper.

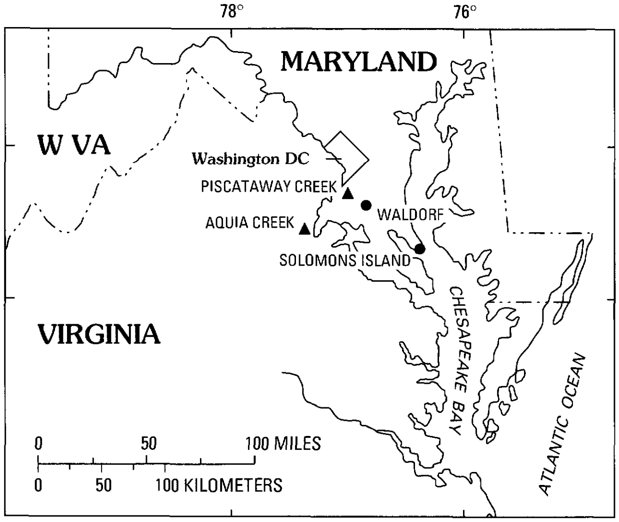


Figure 4. Locations of coreholes (solid circles) and outcrops (solid triangles) in Maryland and Virginia that are discussed in text.

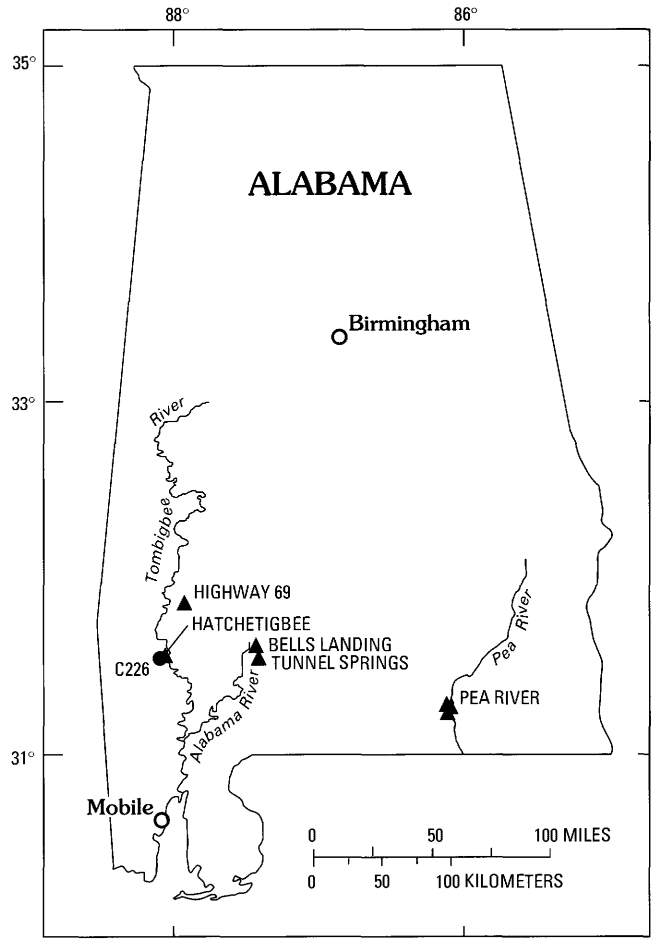


Figure 5. Locations of coreholes (solid circles) and outcrops (solid triangles) in Alabama that are discussed in text.

ZONATION OF THE PALEOCENE-EOCENE BOUNDARY

Okada and Bukry (1980), Berggren and others (1985), Perch-Nielsen (1985), and most calcareous nannofossil specialists have placed the Paleocene-Eocene boundary at the base of Martini's (1971) Zone NP 10, which they considered to be equivalent to the base of Bukry's Zone CP9 (Bukry, 1973, 1978; Okada and Bukry, 1980). Aubry and others (1988, fig. 7) recommended moving the Paleocene-Eocene boundary up to within Zone NP 10. At the present time, this mid-Zone NP 10 horizon is not commonly used; in addition, there is no specific calcareous nannofossil datum at this horizon. Therefore, in this calcareous nannofossil paper, the placement of the Paleocene-Eocene boundary still is considered to occur at the Zone NP 9–NP 10 boundary (fig. 3).

The base of Martini's Zone NP 10 is defined by the FAD (first appearance datum) of *Rhomboaster bramlettei* n. comb. (was *Tribrachiatus bramlettei*; see Taxonomic Notes section; fig. 18), while the base of Bukry's Zone CP 9 is defined by the simultaneous FAD's of *Rhomboaster contortus* n. comb. (was *Tribrachiatus contortus*; see Taxonomic Notes section) and *Discoaster diastypus*. The FAD of *Rhomboaster bramlettei* n. comb. is now known to occur before the FAD of *Rhomboaster contortus* n. comb. (Perch-Nielsen, 1985, fig. 89). This is confirmed by the present authors' work in New Jersey, Alabama, Maryland, and Virginia. Therefore, the base of Bukry's Zone CP 9 cannot be considered equivalent to the base of Zone NP 10 on the basis of the FAD of *Rhomboaster contortus* n. comb. *Discoaster diastypus* still is generally considered to have its first occurrence near the base of Zone NP 10 (Perch-Nielsen, 1985, fig. 30). Martini (1971, table 2), however, indicated that the FAD of *D. diastypus* occurs in the middle of his Zone NP 10, slightly above the FAD of *Rhomboaster contortus* n. comb. Based on our studies in the Atlantic Coastal Plain, we also place the FAD of *D. diastypus* above the FAD of *Rhomboaster bramlettei* n. comb. and near the FAD of *Rhomboaster contortus* n. comb. (see Taxonomic Notes section for additional discussion of *D. diastypus*). Considering these data, the base of Zone CP 9 can no longer be equated with the base of NP 10 and is more accurately placed in the middle part of Zone NP 10 (fig. 3). This placement agrees with Aubry and others (1988), who also placed the base of Zone CP 9 in the middle portion of Zone NP 10.

Only the lower portion of Zone NP 10 is present in the six New Jersey coreholes, and *Rhomboaster bramlettei* n. comb. and *Rhomboaster spineus* are the only members of the genus *Rhomboaster* (now includes several species previously placed in the genus *Tribrachiatus*) that are present in these sediments. *Rhomboaster contortus* n. comb. and *Rhomboaster orthostylus* n. comb. (was *Tribrachiatus orthostylus*; see Taxonomic Notes section) do occur farther to the north in New Jersey in the Allaire State Park–2 and

Table 2. Location information, core type or outcrop, and year drilled or collected for supplementary coreholes and outcrops in the Atlantic Coastal Plain that were used in this study.

Name	Sample type	Year drilled or collected	County and State	7.5' quadrangle	Latitude and longitude
ACGS-4	Wireline	1984	Atlantic County, New Jersey.	Dorothy	39°29'N. 74°46'W.
New Brooklyn	Wireline	1987	Camden County, New Jersey.	Williamstown	39°42'N. 75°57'W.
Silverton Rd.	Wireline	1989	Ocean County, New Jersey.	Lakewood	40°1°N. 74°12'W.
Allaire State Park-2	Wireline	1988	Monmouth County, New Jersey.	Farmingdale	48°8'N. 74°7'W.
Waldorf	Wireline	1984	Charles County, Maryland.	Piscataway	38°39'N. 76°52'45"W.
Solomons Island	Wireline	1986	Calvert County, Maryland.	Solomons Island	38°19'49"N. 76°27'52"W.
Aquia Creek	Outcrop	1980–90	Stafford County, Virginia.	Passapatanzy	38°22'13"N. 77°18'45"W.
Pea River Localities	Outcrop	1982–90	Coffee County, Alabama.	Ino	31°21'40"N. 86°05'45"W. to 31°18'40"N. 86°06'19"W.
Highway 69	Outcrop	1982	Clarke County, Alabama.	Morvin	31°56'33"N. 87°58'51"W.
Hatchetigbee	Outcrop	1979–82	Washington County, Alabama.	Tattlersville	31°39'18"N. 88°05'26"W.
C226	Wireline	1986	Washington County, Alabama.	Bladon Springs	31°38'20"N. 88°07'41"W.
Bells Landing	Outcrop	1982	Monroe County, Alabama.	Hybart	31°47'27"N. 87°25'13"W.
Tunnel Springs	Outcrop	1979–81	Monroe County, Alabama.	Beatric	31°40'01"N. 87°13'34"W.

Silverton Road coreholes (fig. 2), which contain younger sediments. Using a light microscope, *D. diastypus* was not apparent in these younger Zone NP 10 samples from New Jersey, and few samples from this material have been examined with the SEM. However, additional study of this younger New Jersey material should reveal the presence of *D. diastypus*. At Tunnel Springs and along the Pea River in Alabama (fig. 5), *Discoaster diastypus* was found only in the upper part of Zone NP 10 in samples that also contained *Rhomboaster contortus* n. comb.

EVENTS SURROUNDING THE PALEOCENE-EOCENE BOUNDARY

Calcareous nannofossil occurrence charts covering Zones NP 9 and NP 10 are given for each of the six cores (figs. 12–17). Although older Paleocene material also was examined in these cores, nannofossil occurrences are not plotted on the figures and will not be discussed in detail in this paper. These data will be presented in future publications. After comparing the calcareous nannofossil occurrence data from the six New Jersey cores with data from Alabama, Maryland, and Virginia, it was possible to obtain a reasonably accurate idea of the calcareous nannofossil events occurring in upper Zone NP 9 and lower Zone NP 10 in the Atlantic Coastal Plain.

In New Jersey, there appears to be an unconformity within the Vincentown Formation between Zone NP 8 and Zone NP 9, and only the upper part of Zone NP 9 is present (fig. 3). *Discoaster multiradiatus* (FAD defines the base of Zone NP 9), *Campylosphaera dela* (includes *Campylosphaera eodela* Bukry & Percival, 1971, which has its FAD in the middle of Zone NP 9 according to Bukry, 1973; Romein, 1979; and Perch-Nielsen, 1985), and *Lophodolithus nascens* (FAD in the upper fourth of Zone NP 9 according to Perch-Nielsen, 1985) all first appear in the lowest Zone NP 9 sample (for example, at 348.5 ft in the Clayton core) (figs. 17, 18). Based on the presence of *L. nascens* in this sample, it appears that no more than the upper fourth of Zone NP 9 is preserved in the New Jersey material examined in this study; the older portion of Zone NP 9 is missing in southern New Jersey. This contrasts with Virginia, where older Zone NP 9 (below the FAD of *C. dela*) sediments probably are present.

There is an increased number of FAD's and LAD's (last appearance datums) in the interval of Zone NP 9 that begins just below the Vincentown-Manasquan boundary and continues into the lower part of the Manasquan (fig. 18). It is within a 3-ft-thick transition zone from the Vincentown Formation lithology to the Manasquan Formation lithology in upper Zone NP 9 (320–317 ft in the Clayton core, fig. 11) that there is 1) a change in the clay mineral composition from smectite/illite to kaolinite, 2) an appearance of low-oxygen foraminifers, 3) a marked increase in the abundance of planktonic foraminifers, and 4) a disappearance of glauconite (Gibson and Bybell, in press; Gibson and others, 1993). These new conditions, which first occur in the transition zone, persist up into lower Zone NP 10 and indicate significant climatic warming. This change in the climate, along with its accompanying ecological stresses, resulted in the occurrence of several significant calcareous nannofossil events at this time.

Events within the transition zone include the FAD of *Transversopontis pulcher* near the very top of the Vincentown Formation and the LAD of *Scapholithus apertus* just above the base of the Manasquan Formation (fig. 19). Although the LAD of the genus *Fasciculithus* has been used to approximate the top of the Paleocene, both Perch-Nielsen

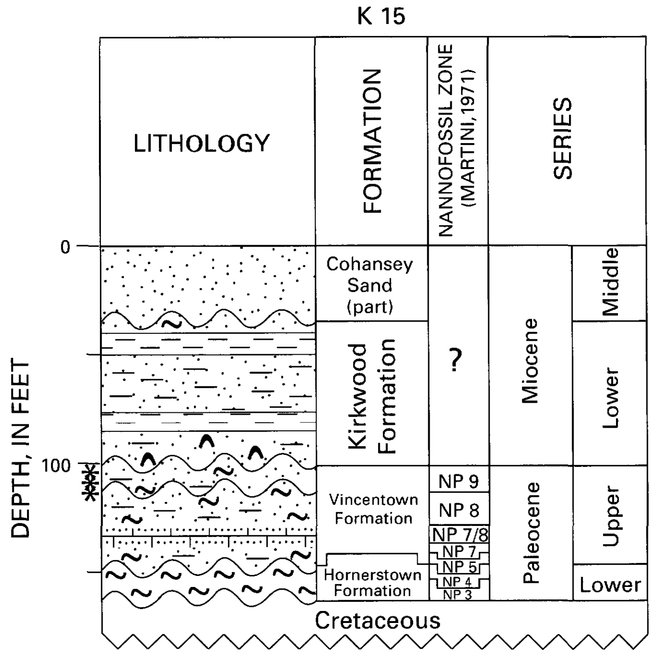


Figure 6. Stratigraphic section for Cenozoic part of K 15 core, New Jersey. See figure 2 for location of corehole.

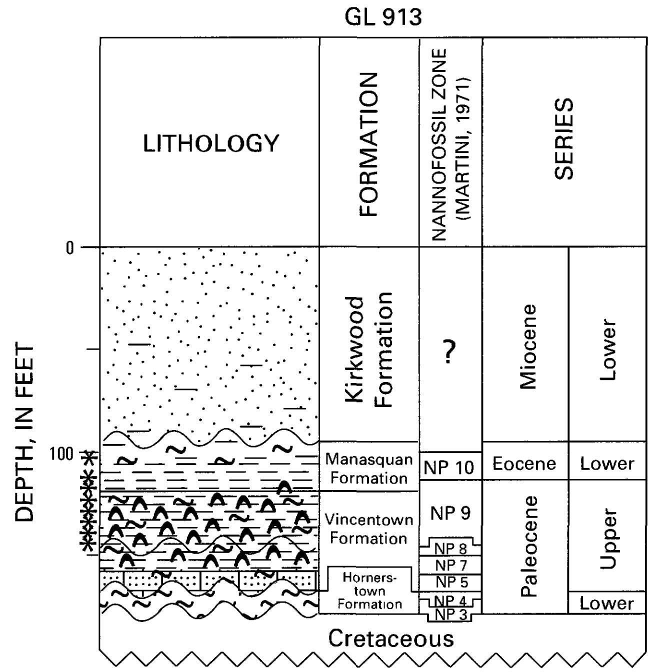


Figure 7. Stratigraphic section for Cenozoic part of GL 913 core, New Jersey. See figure 2 for location of corehole.

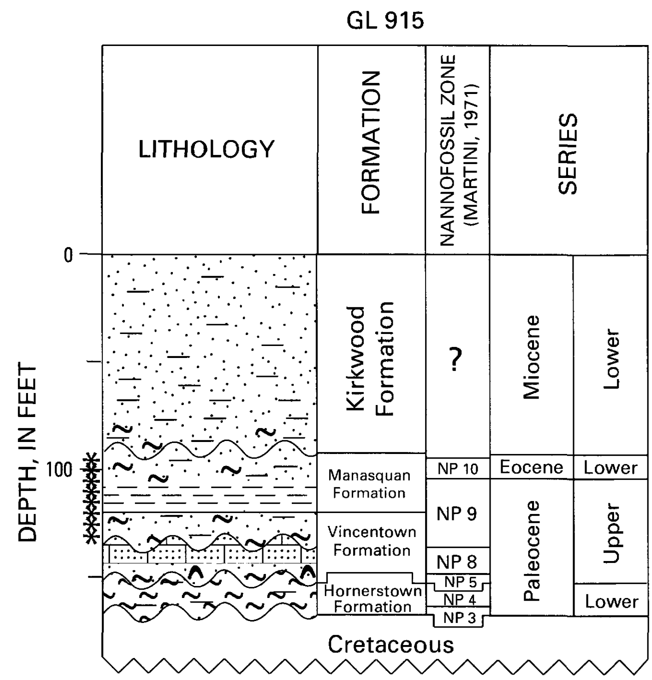


Figure 8. Stratigraphic section for Cenozoic part of GL 915 core, New Jersey. See figure 2 for location of corehole.

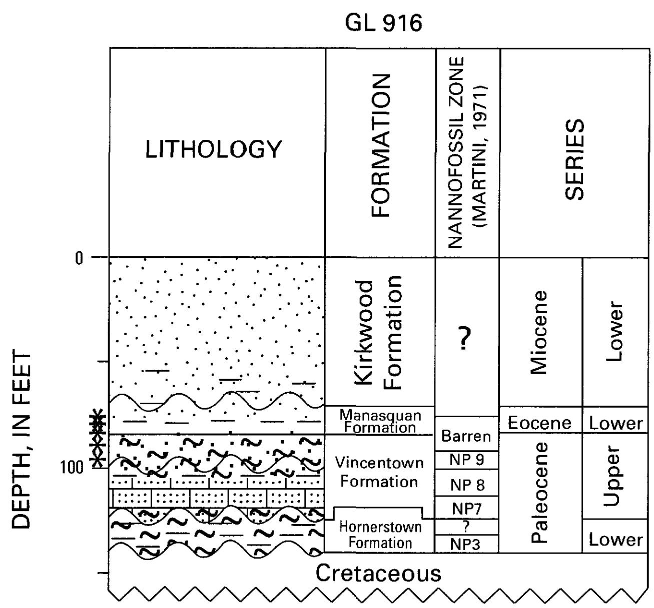


Figure 9. Stratigraphic section for Cenozoic part of GL 916 core, New Jersey. See figure 2 for location of corehole.

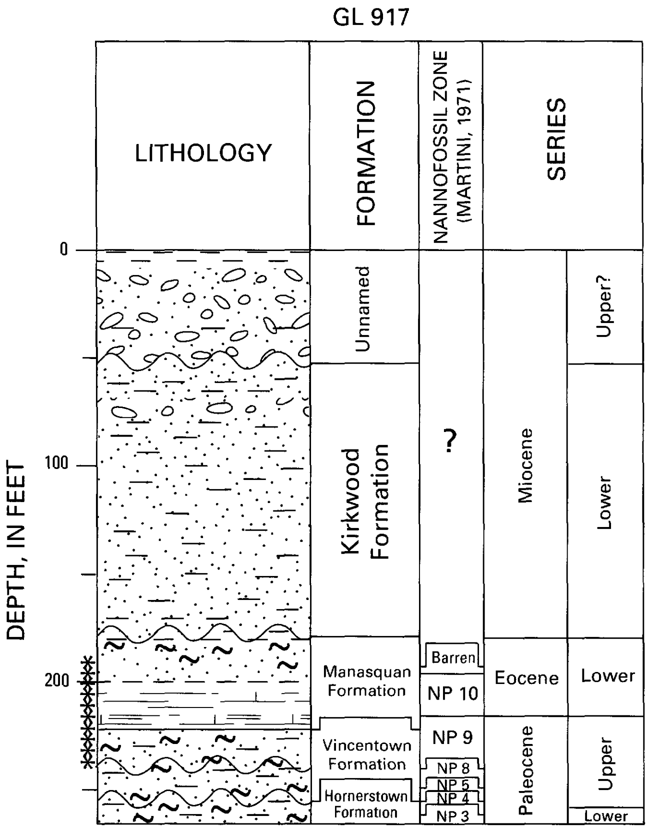


Figure 10. Stratigraphic section for Cenozoic part of GL 917 core, New Jersey. See figure 2 for location of corehole.

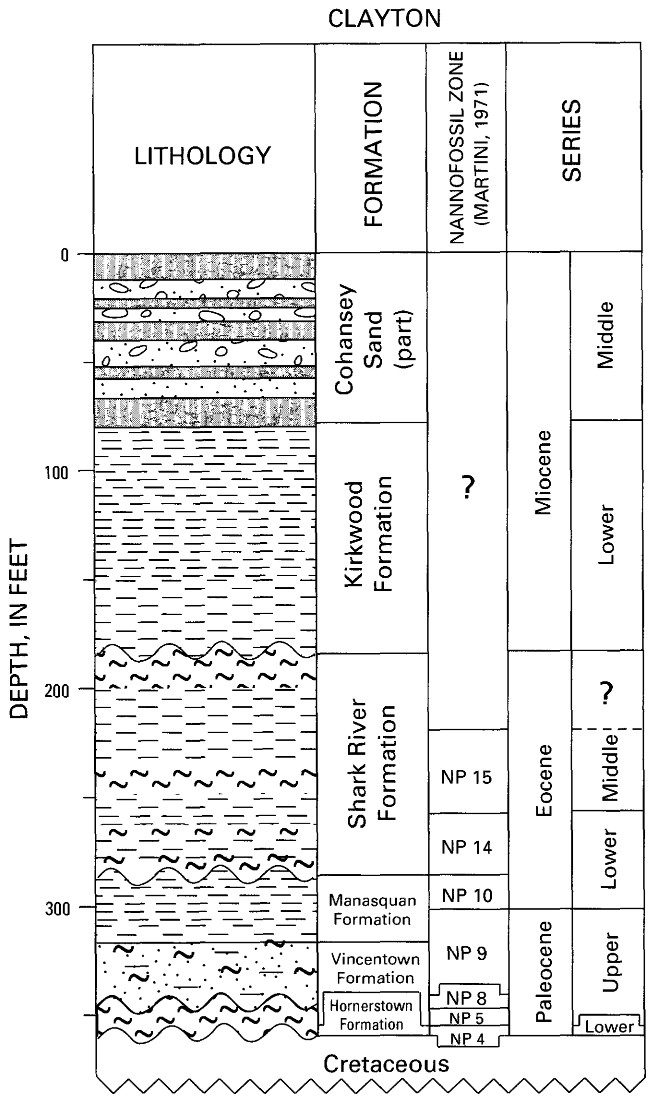
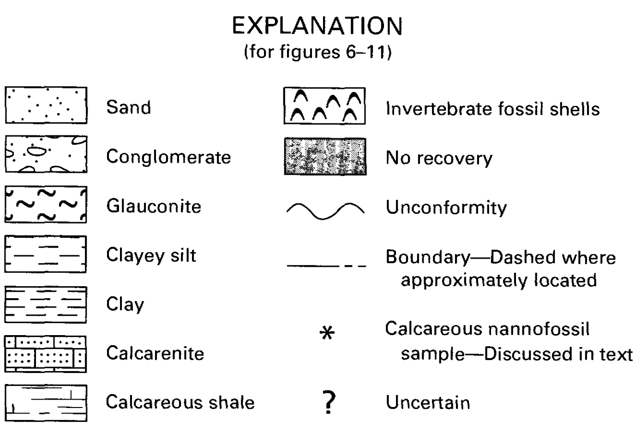


Figure 11. Stratigraphic section for Cenozoic part of Clayton core, New Jersey. Calcareous nannofossil sample locations are too numerous to plot (see fig. 18). See figure 2 for location of corehole.



K 15

Vincentown Formation			FORMATION
Paleocene			SERIES
NP 9			CALCAREOUS NANNOFOSSIL ZONE (MARTINI, 1971)
115	110	105	DEPTH (FT) / SPECIES
●	●	●	*Biantholithus astralis*
	●	●	*Biscutum* spp.
		●	*Campylosphaera dela*
●	●	●	*Chiasmolithus bidens*
●		●	*Chiasmolithus consuetus* s. ampl.
●	●	●	*Coccolithus pelagicus*
	●	●	*Cyclagelosphaera prima* n. comb.
●		●	*Discoaster falcatus*
●	●	●	*Discoaster lenticularis*
		1	*Discoaster limbatus*
●	●	●	*Discoaster multiradiatus*
●	●	●	*Discoaster salisburgensis*
●	●	●	*Discoaster splendidus*
●	●	●	*Ellipsolithus distichus*
	●		*Ellipsolithus macellus*
●			*Fasciculithus alanii*
●	●	●	*Fasciculithus involutus*
	●	●	*Fasciculithus schaubii*
●	●	●	*Fasciculithus thomasii*
●	●	●	*Fasciculithus tympaniformis*
1			*Heliolithus riedelii*
●		●	*Lophodolithus nascens*
●	●	●	*Markalius apertus*
●	●	●	*Markalius inversus*
●			*Neochiastozygus concinnus* s. ampl.
●		●	*Placozygus sigmoides*
●			*Pontosphaera* spp.
●		●	*Scapholithus apertus*
●		●	*Toweius callosus*
●	●	●	*Toweius eminens* var. *eminens* autonym
●	●	●	*Toweius eminens* var. *tovae* stat. nov.
●	●	●	*Toweius pertusus*
●	●	●	*Zygodiscus herlyni*
C	C	A	Abundance
G	P	F	Preservation

(1985, fig. 37) and Aubry (1989, fig. 3) showed that the ranges of *Fasciculithus involutus* and *Fasciculithus thomasii* extend into the lower part of Zone NP 10. In New Jersey, five species of the genus *Fasciculithus* extend up into Zone NP 10 (fig. 18). *Transversopontis pulcher* is a commonly occurring species, which in the absence of the genus *Rhomboaster* (includes forms previously placed in *Tribrachiatus*) also can be used as an approximation of the Zone NP 9–NP 10 boundary (fig. 18). For example, in the Clayton core the FAD of *T. pulcher* is at 322 ft, the basal Zone NP 10 sample is at 306.5 ft, and the range of the genus *Fasciculithus* extends at least up to 292 ft where its occurrence is terminated by an unconformity (figs. 11, 17). Very close to or within the transition zone (320–317 ft in the Clayton core), two other species have their FAD's (*Discoaster mediosus* s. ampl. and *Fasciculithus sidereus* n. sp.); there are LAD's of two additional species (*Biantholithus astralis* and *Fasciculithus alanii*), *Toweius eminens* var. *eminens* autonym evolves into *Toweius occultatus*, and *Toweius eminens* var. *tovae* stat. nov. probably evolves into *Toweius serotinus* n. sp. See the Evolution of Calcareous Nannofossils and Taxonomic Notes sections for more details.

There are few calcareous nannofossil events close to the NP 9–NP 10 zonal boundary (fig. 18), and the FAD of *Rhomboaster bramlettei* n. comb., which defines this boundary, is the only datum exactly at the boundary. There is no lithologic change present at the Zone NP 9–NP 10 boundary, and deposition is presumed to have been continuous across this interval. The LAD of *Fasciculithus schaubii* occurs slightly below the Zone NP 9–NP 10 boundary, while the LAD of *Discoaster* sp. aff. *D. mohleri* probably occurs a short distance above it. Neither of these species is very common in New Jersey.

Although only one calcareous nannofossil event occurs precisely at the NP 9–NP 10 zonal boundary, the significant increase in the number of FAD's and LAD's in the interval from upper Zone NP 9 to lower Zone NP 10, particularly within Zone NP 9 near the Vincentown-Manasquan boundary (fig. 18), appears to correlate with the climatic events listed above (see Gibson and Bybell, in press; Gibson and others, 1993, figs. 3, 4).

←**Figure 12.** Calcareous nannofossil occurrences in K 15 core, New Jersey. For figures 12 through 17, the following symbols are used. Abundance: A, abundant or greater than 10 specimens per field of view at X500; C, common or 1 to 10 specimens per field of view at X500; F, frequent or 1 specimen per 1 to 10 fields of view at X500. Preservation: G, good; F, fair; P, poor. Other symbols: B, sample barren of calcareous nannofossils; 1, only one specimen observed in entire sample; R, specimens likely reworked; ?, possible occurrence.

EVOLUTION OF CALCAREOUS NANNOFOSSILS

During the detailed SEM study of closely spaced samples from the Atlantic Coastal Plain, several species exhibited obvious evolution in the late Paleocene or early Eocene. We presume that these changes are representative of worldwide events and that they can be used as biostratigraphic indicators, as well as to better understand evolution within this complex group of organisms. One type of evolution that we noted involves morphologic changes within one species, for example *Scapholithus apertus* (see below). Another type of evolution that we observed raises quite a few questions about the species concept for calcareous nannofossils. If one already established calcareous nannofossil species gradually evolves into a second already established species, do you put the two species into synonymy, since they are part of a continuum, or do you keep them as separate species and set up a mutually agreed upon point in time at which one species shifts to another. The primary concern as we see it is to maintain biostratigraphic usefulness. Statistical studies would be beneficial, but as an interim measure, we suggest that, as required, at International Nannoplankton Association conventions a committee could meet to examine new evolutionary data, make recommendations about the best nomenclatural placement, and publish these recommendations in the Journal of Nannoplankton Research. We also would urge that these decisions be made primarily upon the basis of SEM data where morphologic details can be more accurately observed.

1. ***Campylosphaera dela*** (pl. 2). This species, which includes *Campylosphaera eodela*, first appears in mid-Zone NP 9 (Bukry, 1973; Perch-Nielsen, 1985). Specimens from the upper part of Zone NP 9 in New Jersey are approximately 6–7 µm in length (pl. 2, figs. 1–3). There is a gradual evolutionary increase in size from upper Zone NP 9 to Zone NP 14 (fig. 19), and within lower Zone NP 14 specimens are approximately 8–9 µm in length (pl. 2, fig. 11). There is no change in the basic shape and structure of specimens during this interval, and as mentioned in the Taxonomic Notes section, the authors have placed *Campylosphaera eodela* in synonymy with *C. dela*. Thus, *C. dela* represents a species that undergoes a gradual increase in size from the late Paleocene into the early Eocene.

2. ***Chiasmolithus bidens*** (pl. 3). *Chiasmolithus edentulus* and *Chiasmolithus solitus* are put into synonymy with *C. bidens* because the morphologic differences among the three species are based entirely upon size. See the

GL 913

Vincentown Formation				Manasquan Formation				FORMATION
Paleocene						Eocene		SERIES
NP 9						NP 10		CALCAREOUS NANNOFOSSIL ZONE (MARTINI, 1971)
140	135	130	125	120	115	110	102	DEPTH (FT) / SPECIES
•	•	•	•					*Biantholithus astralis*
•			•					*Biantholithus sparsus?*
•	•	•	•	•		•	•	*Biscutum* spp.
•	•		•	•	•		•	*Campylosphaera dela*
•	•	•	•			•	•	*Chiasmolithus bidens*
•	•		•	•	•	•	•	*Chiasmolithus consuetus* s. ampl.
•	•	•	•	•	•	•	•	*Coccolithus pelagicus*
	•				•			*Cruciplacolithus* spp.
•	•		•				•	*Cyclagelosphaera prima* n. comb.
•			•	•	•		•	*Cyclococcolithus* spp.
				•		•		*Discoaster anartios* n. sp.
•	•		•	•	•	•		*Discoaster falcatus*
•	•	•	•	•	•	•	•	*Discoaster lenticularis*
	1						•	*Discoaster limbatus*
1			•	•	•	•	•	*Discoaster mediosus* s. ampl.
	•		•	•	•		•	*Discoaster* sp. aff. *D. mohleri*
•	•	•	•	•	•	•	•	*Discoaster multiradiatus*
•	•	•	•	•	•	•	•	*Discoaster salisburgensis*
•	•	•	•	•	•	•		*Discoaster splendidus*
•	•		•	•	•	•	•	*Ellipsolithus distichus*
•	•						•	*Ellipsolithus macellus*
•	•			•				*Ericsonia subpertusa*
	•	•						*Fasciculithus alanii*
	•	•	•	•	•	•		*Fasciculithus aubertae*
•	•	•	•	•	•	•	•	*Fasciculithus involutus*
	•	•	•					*Fasciculithus schaubii*
	•	•	•	•	•	•		*Fasciculithus sidereus* n. sp.
•	•	•	•	•	•	•		*Fasciculithus thomasii*
•	•		•	•	•	•	•	*Fasciculithus tympaniformis*
•			•					*Goniolithus fluckigeri*
R			1					*Heliolithus riedelii*
?								*Heliolithus universus*
•			•	•	•		•	*Hornibrookina arca* n. sp.
•	•		•	•	•	•	•	*Lophodolithus nascens*
•	•	•	•	•	•	•	•	*Markalius apertus*
•	•	•	•		•	•	•	*Markalius inversus*
•	•		•	•	•	•	•	*Neochiastozygus concinnus* s. ampl.
?							•	*Neococcolithes dubius*
•	•		•	•				*Neococcolithes* sp. aff. *N. protenus*
•				•			•	*Neocrepidolithus* spp.
•	•		•	•	•	•	•	*Placozygus sigmoides*
•	•		•	•			•	*Pontosphaera* spp.
						•	•	*Rhomboaster bramlettei* n. comb.
•	•	•	•					*Scapholithus apertus*
1							1	*Sphenolithus anarrhopus*
•	•						•	*Sphenolithus primus*
•	•	•		•	•	•	•	*Thoracosphaera* spp.
•	•	•	•	•		•	•	*Toweius callosus*
•	•	•	•					*Toweius eminens* var. *eminens* autonym
•	•	•	•					*Toweius eminens* var. *tovae* stat. nov.
				•	•	•	•	*Toweius occultatus*
•	•	•	•	•	•	•	•	*Toweius pertusus*
			•	•	•	•	•	*Transversopontis pulcher*
•	•		•	•	•	•	•	*Zygodiscus herlyni*
•	•		•					*Zygrhablithus bijugatus*
C	C	F	A	C	A	F	A	Abundance
F	F	P	G	G	F	P	P	Preservation

Figure 13. Calcareous nannofossil occurrences in GL 913 → core, New Jersey. See figure 2 for location of corehole and figure 12 for explanation of abundance, preservation, and other symbols. Dashed vertical line represents boundary between Vincentown Formation and Manasquan Formation.

GL 915

Vincentown Formation			Manasquan Formation					FORMATION
Paleocene						Eocene		SERIES
NP 9						NP 10		CALCAREOUS NANNOFOSSIL ZONE (MARTINI, 1971)
130	125	120	115	110	105	100	95	DEPTH (FT) / SPECIES
●	●	●						*Biantholithus astralis*
	●							*Biantholithus sparsus?*
●	●	●					●	*Biscutum* spp.
●	●			●		●	●	*Campylosphaera dela*
●	●	●	●			●	●	*Chiasmolithus bidens*
●	●	●		●			●	*Chiasmolithus consuetus* s. ampl.
●	●	●	●	●		●	●	*Coccolithus pelagicus*
●								*Cruciplacolithus* spp.
●		●	●				●	*Cyclagelosphaera prima* n. comb.
●				●			●	*Cyclococcolithus* spp.
●	●	●	●	●		●		*Discoaster falcatus*
●	●	●	●	●		●	●	*Discoaster lenticularis*
1						●	●	*Discoaster limbatus*
			●	●		●	●	*Discoaster mediosus* s. ampl.
		●	●	●		●	●	*Discoaster* sp. aff. *D. mohleri*
●	●	●	●	●	●	●	●	*Discoaster multiradiatus*
●	●	●	●	●	●	●	●	*Discoaster salisburgensis*
●	●	●	●	●	●	●		*Discoaster splendidus*
●	●	●	●	●		●	●	*Ellipsolithus distichus*
●		●					●	*Ellipsolithus macellus*
●	●		●	●	●	●	●	*Ericsonia subpertusa*
●	●			●				*Fasciculithus alanii*
●	●	●	●	●	●	●		*Fasciculithus aubertae*
●	●	●	●	●	●	●	●	*Fasciculithus involutus*
●	●	●	●					*Fasciculithus schaubii*
	●	●	●	●				*Fasciculithus sidereus* n. sp.
●	●	●	●	●				*Fasciculithus thomasii*
●	●	●		●			●	*Fasciculithus tympaniformis*
						●		*Goniolithus fluckigeri*
●	●		●	●		●	●	*Hornibrookina arca* n. sp.
●		●		●		●	●	*Lophodolithus nascens*
●	●	●	●	●		●		*Markalius apertus*
●	●	●					●	*Markalius inversus*
●		●	●	●		●	●	*Neochiastozygus concinnus* s. ampl.
?								*Neochiastozygus imbriei*
							●	*Neococcolithes dubius*
●				●		●		*Neococcolithes* sp. aff. *N. protenus*
●								*Neocrepidolithus* spp.
●		●	●	●		●	●	*Placozygus sigmoides*
		●			●		●	*Pontosphaera* spp.
						●	●	*Rhomboaster bramlettei* n. comb.
●		●		●				*Scapholithus apertus*
						●	●	*Sphenolithus anarrhopus*
●						●	●	*Sphenolithus primus*
●				●	●	●	●	*Thoracosphaera* spp.
●	●	●	●	●		●	●	*Toweius callosus*
●	●	●						*Toweius eminens* var. *eminens* autonym
●	●	●	●					*Toweius eminens* var. *tovae* stat. nov.
			●	●	●	●	●	*Toweius occultatus*
●	●	●	●	●	●	●	●	*Toweius pertusus*
				●		●	●	*Transversopontis pulcher*
●	●	●	●	●		●	●	*Zygodiscus herlyni*
●								*Zygrhablithus bijugatus*
A	F	C	F	C	F	C	C	Abundance
F	P	P	P	F	T	F	F	Preservation

←**Figure 14.** Calcareous nannofossil occurrences in GL 915 core, New Jersey. See figure 2 for location of corehole and figure 12 for explanation of abundance, preservation, and other symbols. Dashed vertical line represents boundary between Vincentown Formation and Manasquan Formation.

Taxonomic Notes section for additional information. *Chiasmolithus bidens*, when it first appears in Zone NP 5, is fairly small and has no toothlike projections into the central region; these specimens would previously have been placed in *C. edentulus*. From Zone NP 8 to Zone NP 12, small specimens continue to occur, but increasingly larger specimens are also part of the *C. bidens* population. Larger specimens have toothlike projections in the central area, a broader crossbar, and a greater number of shield segments (fig. 20). In Zone NP 11, for example, a specimen that is 9.5 µm long has no teeth, 60 shield segments, and a typical crossbar (pl. 3, fig. 7). A specimen 12.5 µm long has teeth, 70 segments, and a slightly broader crossbar (pl. 3, fig. 8). A specimen 15.8 µm long, which has teeth and an even broader crossbar (pl. 3, fig. 9), and a specimen that is 16.7 µm long are placed in the species *Chiasmolithus eograndis* Perch-Nielsen, 1971 (pl. 3, fig. 10). These large specimens appear to occur only in Zones NP 10–13 (Perch-Nielsen, 1985, fig. 19). Forms that could be assigned to *C. eograndis* do not occur above Zone NP 13 because there appear to be no specimens larger than 13 µm in material of this age. The present authors still are undecided whether *C. eograndis* specimens should also be placed in synonymy with *C. bidens*.

In either Zone NP 15 or NP 16, *C. bidens* changes again, and the distal collar broadens to cover more of the shield segments, while the individual pores in the grid get smaller (pl. 3, fig. 12).

3. ***Lophodolithus nascens*** (pl. 19). Bramlette and Sullivan (1961, p. 145) stated that early forms of *L. nascens* are more symmetrical in the rim height and in the width of the flange than are later forms. One of these early specimens is the holotype (Bramlette and Sullivan, 1961, figs. 8a–c). Our studies confirm that early forms of *L. nascens* from upper Zone NP 9 and Zone NP 10 have a nearly symmetrically shaped rim outline and uniform rim height. In contrast, by Zone NP 11, specimens have evolved so that there is a broader and higher rim at one end (fig. 21). *Lophodolithus nascens* does not change in size or in the structure of the basal plate from Zones NP 9 to NP 11.

4. ***Neochiastozygus concinnus*** s. ampl. (pl. 20). Specimens included in this species exhibit a significant variation in the shape of the crossbar. The present authors were unable to separate these forms from the Atlantic Coastal Plain into distinct species. There is a gradual increase in the size of *N. concinnus* from approximately 5.5 µm when this species first appears in Zone NP 4 to approximately 8.5 µm

GL 916

Vincentown Formation					FORMATION
Paleocene					SERIES
NP 9					CALCAREOUS NANNOFOSSIL ZONE (MARTINI, 1971)
95	90	85	80	75	DEPTH (FT) / SPECIES
	B	B	B	B	BARREN
●					*Biantholithus astralis*
●					*Biantholithus sparsus?*
●					*Biscutum* spp.
●					*Campylosphaera dela*
●					*Chiasmolithus bidens*
●					*Chiasmolithus consuetus* s. ampl.
●					*Coccolithus pelagicus*
●					*Cruciplacolithus* spp.
●					*Cyclagelosphaera prima* n. comb.
●					*Cyclococcolithus* spp.
●					*Discoaster lenticularis*
●					*Discoaster multiradiatus*
●					*Discoaster salisburgensis*
●					*Discoaster splendidus*
●					*Ellipsolithus distichus*
●					*Ellipsolithus macellus*
●					*Ericsonia subpertusa*
●					*Fasciculithus involutus*
●					*Fasciculithus schaubii*
●					*Fasciculithus thomasii*
●					*Fasciculithus tympaniformis*
●					*Goniolithus fluckigeri*
●					*Hornibrookina arca* n. sp.
●					*Lophodolithus nascens*
●					*Markalius apertus*
●					*Markalius inversus*
●					*Neochiastozygus concinnus* s. ampl.
?					*Neochiastozygus imbriei*
●					*Neococcolithes* sp. aff. *N. protenus*
●					*Placozygus sigmoides*
●					*Pontosphaera* spp.
●					*Scapholithus apertus*
●					*Thoracosphaera* spp.
●					*Toweius callosus*
●					*Toweius eminens* var. *eminens* autonym
●					*Toweius eminens* var. *tovae* stat. nov.
●					*Toweius pertusus*
●					*Zygodiscus herlyni*
A					Abundance
F					Preservation

Figure 15. Calcareous nannofossil occurrences in GL 916 core, New Jersey. See figure 2 for location of corehole and figure 12 for explanation of abundance, preservation, and other symbols.

in Zone NP 11. The structure of the rim and the structure of the crossbar do not change with time. However, in upper Zone NP 9, Zone NP 10, and NP 11, there is a change in the crossbar shape, and the majority of *Neochiastozygus concinnus* specimens have a narrower crossbar than older specimens. See the Taxonomic Notes section for additional data.

5. ***Scapholithus apertus*** (pl. 24). When *S. apertus* first appears in Zone NP 5, the length of the long axis divided by the length of the short axis is approximately 1.6. In either Zone NP 6 or NP 7, the short axis increases in size, with a resultant broadening of specimens, and by Zone NP 9 the long axis/short axis proportion is reduced to approximately 1.3. This evolutionary change can be used to distinguish Zone NP 5 samples from Zone NP 7 or younger samples (fig. 22). There is no corresponding change in the size of *S. apertus*.

6. ***Toweius eminens*** var. ***eminens*** autonym and ***Toweius eminens*** var. ***tovae*** stat. nov. (pls. 26 and 27). The present authors agree with Romein's (1979) placement of *Toweius eminens* and *Toweius tovae* in synonymy. However, we have chosen to establish two varieties for *T. eminens* in order to better understand the evolution that this species undergoes during upper Zone NP 9. *Toweius eminens* var. *eminens* autonym evolves into *Toweius occultatus* in upper Zone NP 9 through changes in the central structure (fig. 23). The four perforations in *T. eminens* var. *eminens* autonym are the result of two sets of extensions that occur at right angles to each other and which normally intersect at the center of each specimen (pl. 26, fig. 1). By the upper part of the Vincentown Formation, the longitudinal extensions have changed and are usually narrower than the lateral extensions (pl. 26, fig. 6), and occasionally they do not reach the central area. Just below the transition zone between the Vincentown and Manasquan Formations, specimens commonly have discontinuous longitudinal extensions and continuous or nearly continuous lateral extensions (pl. 26, fig. 8). Within the transition zone (320–317 ft in the Clayton core, fig. 11), evolution has proceeded to the point that the lateral extensions no longer touch in most specimens, and the longitudinal extensions usually are vestigial (pl. 27, fig. 6) but may be absent entirely. These specimens are placed within *T. occultatus*. Above the transition zone, the majority of specimens are now typical of *T. occultatus* in the strictest sense in that they have no longitudinal extensions, and the lateral extensions rarely touch (pl. 27, fig. 10). The change from *T. eminens* var. *eminens* autonym to *Toweius occultatus* thus occurs in the Vincentown-Manasquan transition zone (upper Zone NP 9) at the point where most specimens in the population have discontinuous lateral extensions and vestigial longitudinal extensions (319.4 ft in the Clayton core, fig. 11).

Toweius eminens var. *tovae* stat. nov. is used for specimens that have five to nine perforations (see the Taxonomic Notes section for additional discussion), and this variety appears to evolve into *Toweius serotinus* n. sp. (pl. 28, figs. 6 and 10) within the transition zone between the Vincentown and Manasquan Formations. This species' shift occurs

GL 917

Vincentown Formation			Manasquan Formation							FORMATION
Paleocene						Eocene				SERIES
NP 9						NP 10				CALCAREOUS NANNOFOSSIL ZONE (MARTINI, 1971)
235	230	225	220	215	210	205	200	195	190	DEPTH (FT) / SPECIES
									B	BARREN
•	•	•								*Biantholithus astralis*
•		•								*Biscutum* spp.
		•	•	•	•	•	•	•		*Campylosphaera dela*
•	•	•		•				•		*Chiasmolithus bidens*
•		•	•	•	•	•	•	•		*Chiasmolithus consuetus* s. ampl.
•	•	•	•	•	•	•	•	•		*Coccolithus pelagicus*
•										*Cruciplacolithus* spp.
•		•			•	•		•		*Cyclagelosphaera prima* n. comb.
	•	•	•	•	•	•	•	•		*Cyclococcolithus* spp.
					•	•	•	•		*Discoaster anartios* n. sp.
•	•	•	•	•	•	•	•	•		*Discoaster falcatus*
•	•	•	•	•	•	•	•	•		*Discoaster lenticularis*
		1		•	•	•	•			*Discoaster limbatus*
	•	•	•	•	•		•	•		*Discoaster mediosus* s. ampl.
		•	•	•		•	•	•		*Discoaster* sp. aff. *D. mohleri*
•	•	•	•	•	•	•	•	•		*Discoaster multiradiatus*
•	•	•		•	•	•	•	•		*Discoaster salisburgensis*
•		•	•	•	•	•	•	•		*Discoaster splendidus*
•	•	•	•	•	•	•	•	•		*Ellipsolithus distichus*
•		•								*Ellipsolithus macellus*
•			•	•				•		*Ericsonia subpertusa*
•	•	•								*Fasciculithus alanii*
•	•	•	•	•	•	•	•	•		*Fasciculithus aubertae*
•	•	•	•	•	•	•	•	•		*Fasciculithus involutus*
•	•	•			•					*Fasciculithus schaubii*
•		•	•	•	•	•	•	•		*Fasciculithus sidereus* n. sp.
•	•	•	•	•	•	•	•	•		*Fasciculithus thomasii*
•		•	•	•	•	•	•	•		*Fasciculithus tympaniformis*
		•								*Goniolithus fluckigeri*
1										*Heliolithus riedelii*
		•	•	•				•		*Hornibrookina arca* n. sp.
•		•	•	•	•	•	•	•		*Lophodolithus nascens*
•	•	•	•	•	•	•	•			*Markalius apertus*
•	•	•		•	•	•	•	•		*Markalius inversus*
•		•	•	•	•	•	•	•		*Neochiastozygus concinnus* s. ampl.
				?	?					*Neochiastozygus imbriei*
		1		1						*Neococcolithes dubius*
		•	•	•	•	•	•	•		*Neococcolithes* sp. aff. *N. protenus*
•		•								*Neocrepidolithus* spp.
•		•	•	•	•	•	•	•		*Placozygus sigmoides*
		•	•	•	•		•			*Pontosphaera* spp.
						•	•	•		*Rhomboaster bramlettei* n. comb.
					•		•			*Rhomboaster spineus*
•		•								*Scapholithus apertus*
			•							*Sphenolithus primus*
	•	•	•	•	•	•	•	•		*Thoracosphaera* spp.
•		•	•	•	•	•	•	•		*Toweius callosus*
•	•	•								*Toweius eminens* var. *eminens* autonym
•	•	•	•							*Toweius eminens* var. *tovae* stat. nov.
			•	•	•	•	•	•		*Toweius occultatus*
•	•	•	•	•	•	•	•	•		*Toweius pertusus*
							•	•		*Toweius serotinus* n. sp.
			•	•	•	•	•	•		*Transversopontis pulcher*
•		•	•	•	•	•	•	•		*Zygodiscus herlyni*
C	F	C	C	A	A	C	C	A		Abundance
P	P	F	F	F	F	F	F	F		Preservation

←**Figure 16.** Calcareous nannofossil occurrences in GL 917 core, New Jersey. See figure 2 for location of corehole and figure 12 for explanation of abundance, preservation, and other symbols. Dashed vertical line represents boundary between Vincentown Formation and Manasquan Formation.

Figure 17. Calcareous nannofossil occurrences in the → Clayton core, New Jersey. See figure 2 for location of corehole and figure 12 for explanation of abundance, preservation, and other symbols. Dashed vertical line represents boundary between Vincentown Formation and Manasquan Formation

CLAYTON

Depth (ft) / Species	348.5	347	345.2	344	342	339	337	335.5	334	331	329	327	324.4	324.1	322	321.4	319.4	318.5	317.4	317	314	313.3	311	310.8	310.3	309.6	309	308.7	308.3	307.9	307.2	306.9	306.5	302.5	300.5	298.5	296.5	294.5	292
Formation	Vincentown Formation															Manasquan Formation																						
Series	Paleocene																															Eocene						
Calcareous nannofossil zone (Martini, 1971)	NP 9																															NP 10						
Biantholithus astralis	•	•			•						•		•	•		•																		R									
Biantholithus sparsus?	•															•																							?					
Biscutum spp.		•			•		•			•		•	•	•	•	•	•			•			•	•	•		•		•				•	•				•	•
Braarudosphaera bigelowii																					•																				
Campylosphaera dela	•											•			•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•
Chiasmolithus bidens	•	•	•	•	•	•				•		•	•	•	•	•	•	•	•	•			•		•				•									•	•	•	•
Chiasmolithus consuetus s. ampl.	•	•										•	•		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Coccolithus pelagicus	•	•	•	•	•	•				•		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Cruciplacolithus spp.													•			•			•												•			•					
Cruciplacolithus tenuis	?																																						
Cyclagelosphaera prima n. comb.	•	•		•								•	•		•	•			•					•		•				•								•		
Cyclococcolithus spp.	•		•												•	•	•		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•			
Discoaster anartios n. sp.																				•		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Discoaster falcatus					•								•	•	•		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Discoaster lenticularis	•	•	•	•	•	•	•			•	•	•	•		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Discoaster limbatus																			•		•			•	•	•				•	•								
Discoaster mediosus s. ampl.															•	•		•	•	•	•	•	•	•	•	•	•		•	•	•	•		•	•	•	•		
Discoaster sp. aff. *D. mohleri*													•	•	•	•	•		•	•	•		•	•	•	•	•	•	•	•	•	•							
Discoaster multiradiatus	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Discoaster salisburgensis	•	•	•	•	•	•			•	•	•	•	•	•	•	•		•	•	•	•	•		•	•	•	•	•		•	•	•	•	•	•	•		•	•
Discoaster splendidus	•	•	•								•		•	•		•				•					•		•	•		•	•	•	•		•	•	•	•		•
Ellipsolithus distichus	•	•										•	•		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Ellipsolithus macellus	•	•	•											•		•	•	•				•								•				•					
Ericsonia subpertusa													•				•		•		•	•	•	•	•		•	•	•	•			•	•	•			•	•
Fasciculithus alanii												•				•																						
Fasciculithus aubertae	•	•	•	•						•		•		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Fasciculithus involutus	•	•	•	•	•	•				•	•	•	•	•	•	•			•		•	•	•	•		•	•	•	•	•	•	•	•	•		•	•	•	•
Fasciculithus schaubii			•							•		•	•	•	•	•				•				•							•								
Fasciculithus sidereus n. sp.															•			•	•	•		•		•	•	•		•				•	•	•	•	•			
Fasciculithus thomasii	•	•	•	•						•		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•
Fasciculithus tympaniformis	•	•	•		•				•		•	•		•	•	•		•	•	•	•	•	•	•	•	•		•		•	•	•	•	•	•	•		
Goniolithus fluckigeri	•														•	•																						
Hornibrookina arca n. sp.	•	•														•	•	•	•	•	•	•	•			•	•		•	•	•	•		•	•				
Lophodolithus nascens	•														•	•			•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		
Markalius apertus	•	•	•					•	•	•		•	•		•	•	•	•	•	•	•	•	•		•	•	•	•	•	•	•	•	•	•	•	•	•		
Markalius inversus	•	•		•	•				•	•		•	•		•				•	•			•	•	•	•		•	•	•	•	•	•	•	•	•	•	•	•
Neochiastozygus concinnus s. ampl.	•	•										•		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Neochiastozygus imbriei	?																			?	?	?	?	?	?	?	?	?		?	?	?		?	?	?				
Neococcolithes dubius																																	•						
Neococcolithes spp. aff. *N. protenus*	•	•													•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•			
Neocrepidolithus spp.		•											•		•	•			•																			
Placozygus sigmoides	•	•										•		•	•		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•
Pontosphaera spp.																				•	•					•	•							•					
Rhomboaster bramlettei n. comb.																																	•	•	•	•	•	•	•
Rhomboaster spineus																									•	•	•			•	•	•	•	•	•	•			
Scapholithus apertus	•											•		•	•	•															R		R						
Sphenolithus primus	•				•										•				•													•				•	•		
Thoracosphaera spp.	•										•				•	•	•	•	•	•		•	•	•	•	•				•	•		•	•	•	•	•	•
Toweius callosus	•	•	•	•	•						•	•	•	•	•		•	•	•	•	•	•		•			•	•	•	•	•		•	•	•	•		•
Toweius eminens var. *eminens* autonym	•	•	•	•	•		•		•			•	•		•	•																						
Toweius eminens var. *tovae* stat. nov.	•	•	•						•		•	•	•	•	•	•																					
Toweius occultatus																•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•
Toweius pertusus	•	•	•	•	•					•		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Toweius serotinus n. sp.																		•	•	•	•			•		•				•				•		•	•	•
Transversopontis pulcher															•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•
Zygodiscus herlyni	•	•										•		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•	•	•	•	•	•			
Zygrhablithus bijugatus			•																																			
Abundance	C	F	F	F	F	F	F	F	F	C	F	F	C	C	C	A	F	C	C	C	A	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	F	C
Preservation	F	P	P	P	P	P	P	P	P	P	P	P	F	P	F	F	F	F	F	F	F	F	F	F	F	G	F	F	F	F	G	F	F	F	F	G	F	P	F

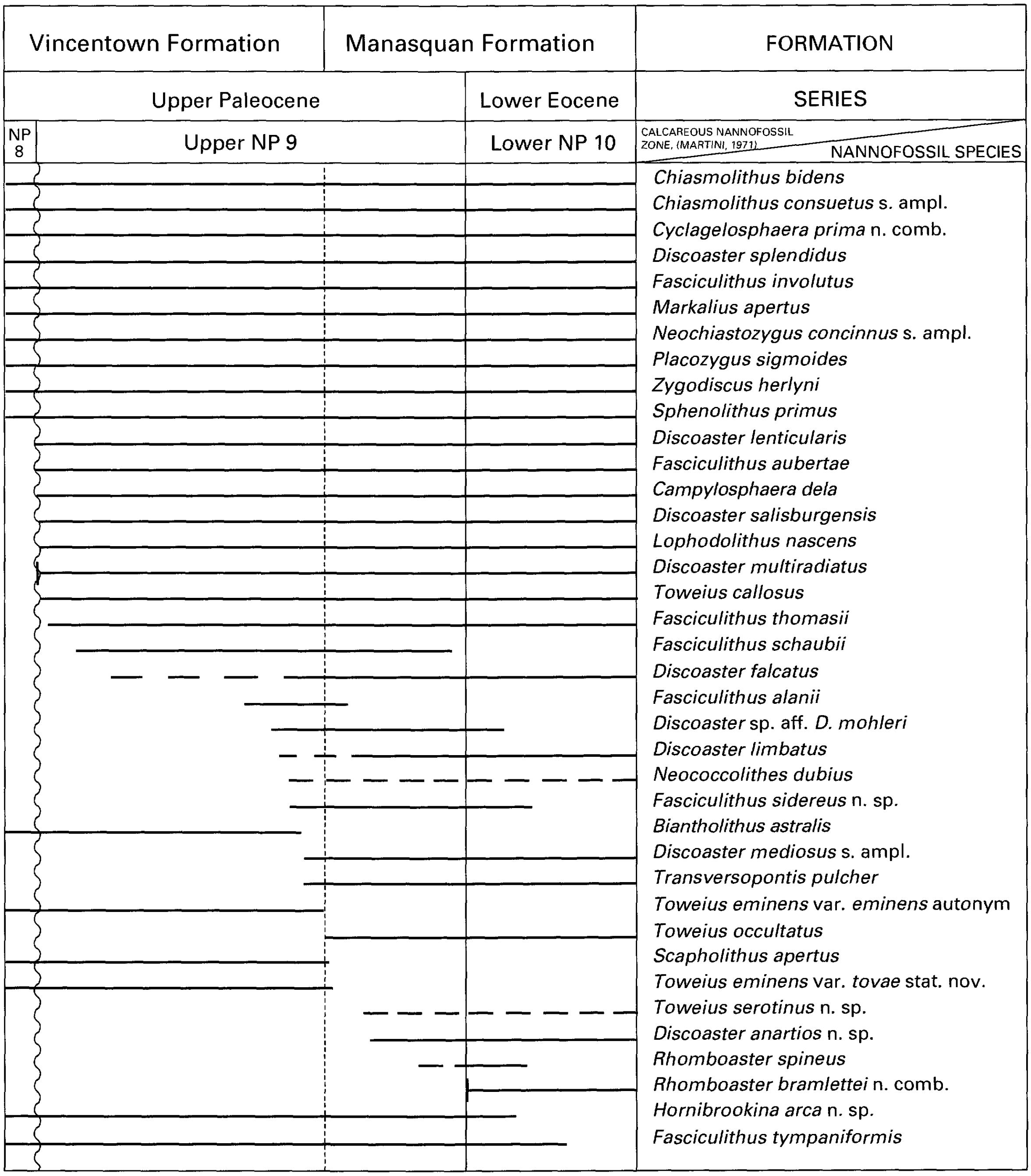


Figure 18. Stratigraphically useful calcareous nannofossil species near the Paleocene-Eocene boundary in New Jersey. Wavy vertical line indicates unconformity. Dashed vertical line represents boundary between Vincentown Formation and Manasquan Formation. Dashed horizontal line indicates sporadic occurrence. Horizontal line with vertical end bar represents occurrence of zonal marker species.

by means of an increase in the number of perforations (13–19 for *T. serotinus* n. sp.), a decrease in the perforation size, and replacement of the small pores in the central area with fewer, larger pores. *T. serotinus* n. sp. first appears shortly after the evolution of *T. eminens* var. *eminens* autonym into *T. occultatus*, and although we have observed no intermediate specimens with the SEM, it seems likely that *T. eminens* var. *tovae* stat. nov. is the predecessor to *T. serotinus* n. sp. See the Taxonomic Notes section for additional data.

7. ***Toweius pertusus*** (pl. 29). When *T. pertusus* first appears in Zone NP 4, its central perforate region is continuous with the surrounding collar. In upper Zone NP 9 near

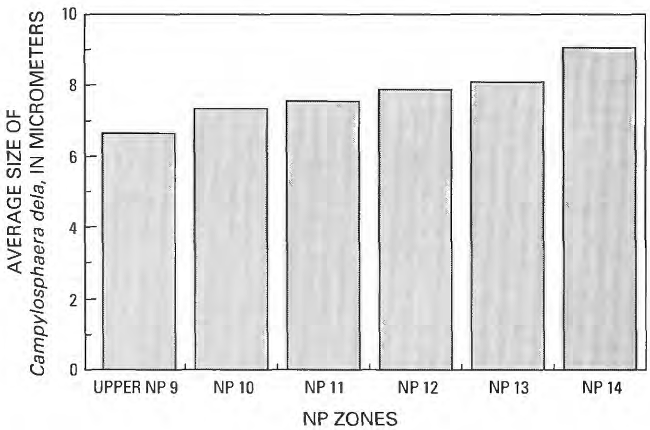


Figure 19. Gradual increase in average size of *Campylosphaera dela* from upper Zone NP 9 through Zone NP 14.

the Vincentown-Manasquan transitional boundary, the central perforate area becomes recessed below the distal surface (fig. 24) and remains recessed in Zone NP 10 (pl. 29, figs. 1–3). Plate 29, figure 7, illustrates a typical form from Zone NP 8 in which the outer edge that surrounds the pores is not recessed. Intermediary specimens are illustrated on plate 29, figures 4–6. The number of central perforations increases in Zone NP 9 and continues to increase until Zone NP 11 (fig. 25). There is no apparent size change in *T. pertusus* throughout its occurrence. Late forms of *Toweius*, which have recessed pores, may evolve into the genus *Reticulofenestra* in Zone NP 13.

8. ***Transversopontis pulcher*** (pl. 30). Early forms of *T. pulcher* from upper Zone NP 9 are similar in several respects to typical specimens of this species that commonly occur in Zone NP 12: there are two, large, central, rounded perforations and rim. The floor of specimens from upper Zone NP 9, however, is much more irregular than in younger forms; this rough surface is due to the presence of small chunks of calcite on the floor that are oriented parallel to the rim (pl. 30, figs. 1–3). In lower Zone NP 10, *T. pulcher* has evolved somewhat, and specimens have a wider, taller rim and a somewhat smoother floor (fig. 26). In upper Zone NP 10 (pl. 30, figs. 4, 5) and Zone NP 11 (pl. 30, fig. 6a, b), the rim continues to thicken, the floor becomes fairly smooth, crenulations appear around the edge of the base, and the size increases (fig. 26). By Zone NP 12, typical specimens of *T. pulcher* have a broad rim, smooth floor, and crenulations around the edge of the base (pl. 30, fig. 7; fig. 26).

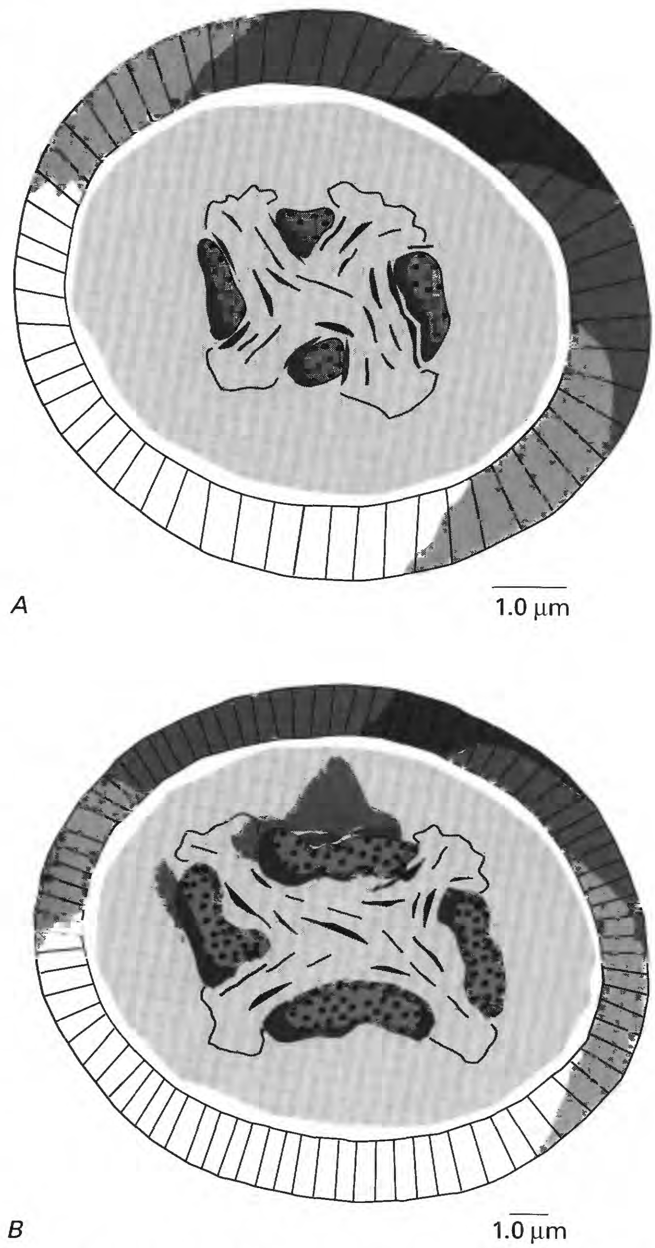


Figure 20. Variation in *Chiasmolithus bidens* with size. Distal view. *A*, typical specimen that is approximately 8 μm long, which has no teeth, approximately 60 shield segments, and a typical crossbar. *B*, specimen that is approximately 12 μm long, which has toothlike projections, approximately 80 segments, and a broader crossbar.

CONCLUSIONS

Paleocene and Eocene material was examined for calcareous nannofossil occurrences from six coreholes in southern New Jersey. A detailed study shows the following conclusions:

1. Four of these coreholes (GL 913, GL 915, GL 917, and Clayton) have an apparently continuous fossiliferous sequence across the NP 9–NP 10 zonal boundary (Paleocene-Eocene boundary). The two remaining coreholes (GL 916 and K 15) contain only late Paleocene fossiliferous material.

2. Two formations were examined in New Jersey: the Vincentown Formation (Zones NP 5 to NP 9), which ranges

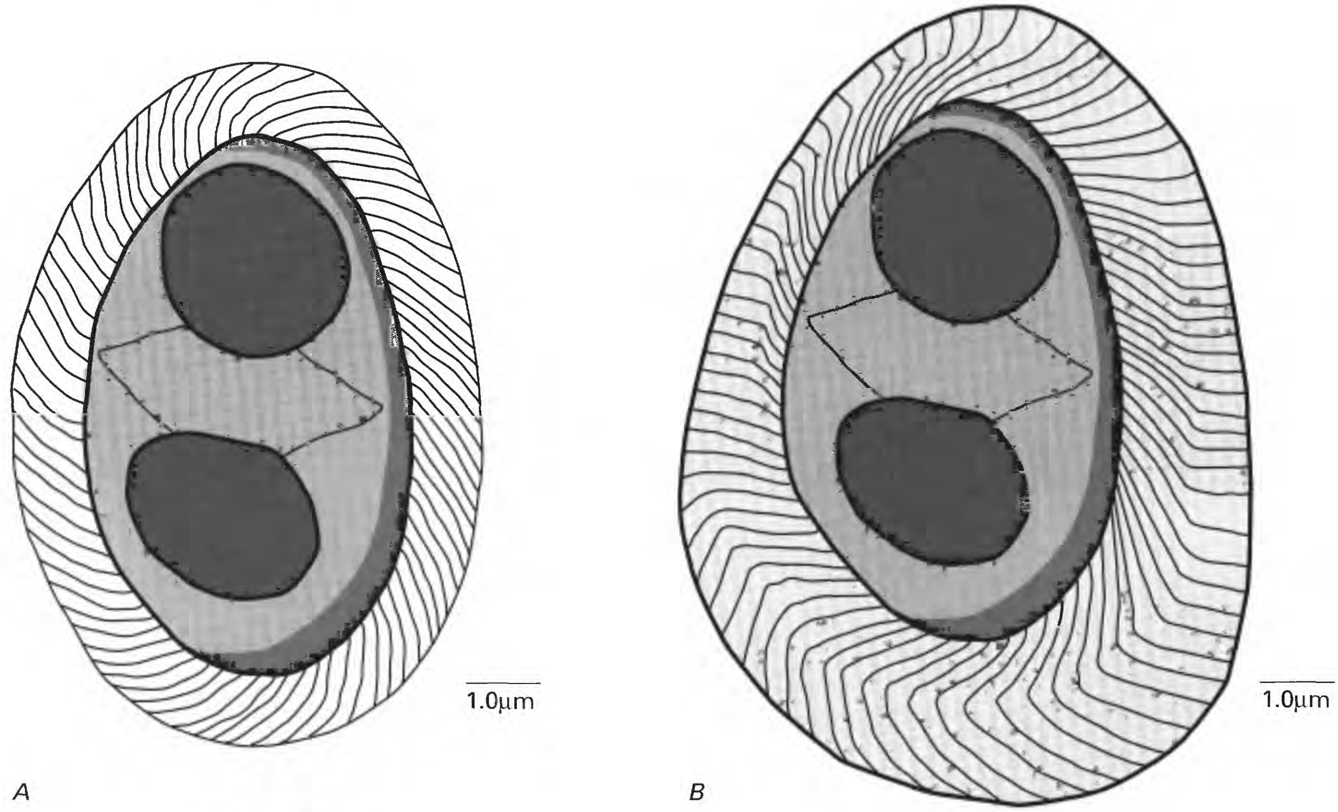


Figure 21. Evolutionary changes in *Lophodolithus nascens*. Proximal view. *A*, specimen typical of lower Zone NP 10 that has a nearly symmetrical outline and uniform rim height. *B*, specimen typical of Zone NP 11 that has a broader and higher rim at one end.

into the upper fourth of the upper Paleocene, and the Manasquan Formation (Zones NP 9 to NP 14), which extends from the upper Paleocene into the lower Eocene and contains the Paleocene-Eocene boundary.

3. Based on the calcareous nannofossil data, it appears that only the uppermost portion of Zone NP 9 and the lower portion of Zone NP 10 are present in the New Jersey coreholes.

4. Several evolutionary trends were documented during the late Paleocene and early Eocene. *Campylosphaera dela, Chiasmolithus bidens*, and *Neochiastozygus concinnus* increased in size. Two varieties of *Toweius eminens* are established, *Toweius eminens* var. *eminens* autonym and *Toweius eminens* var. *tovae* stat. nov., in order to clarify the evolution this species underwent in Zone NP 9. Changes in the width and length of lateral and longitudinal extensions of *T. eminens* var. *eminens* autonym resulted in the evolution of this species into *Toweius occultatus*. *Toweius eminens* var. *tovae* stat. nov. probably evolved into *Toweius serotinus* n. sp. in upper Zone NP 9 by means of changes in pore number, pore size, and the central structure. In upper Zone NP 9, the central perforate region of *T. pertusus* became recessed, and the number of perforations increased. Early forms of *Transversopontis pulcher* evolved during the early Eocene into forms with a wider and taller rim structure, a smoothed floor, increased size, and crenulations around the edge of the base. In the early Eocene, the outline of *Lophodolithus nascens* became less symmetrical as the rim became broader and higher at one end. In the late Paleocene, the short axis of *Scapholithus apertus* increased in size, and younger specimens have a distinctly broader appearance.

5. These evolutionary events, which are thought to be a result of worldwide climatic changes that occurred at this time, can be used for greater biostratigraphic subdivision of upper Paleocene and lower Eocene sediments.

6. The genus *Tribrachiatus* is placed in synonymy with the genus *Rhomboaster*.

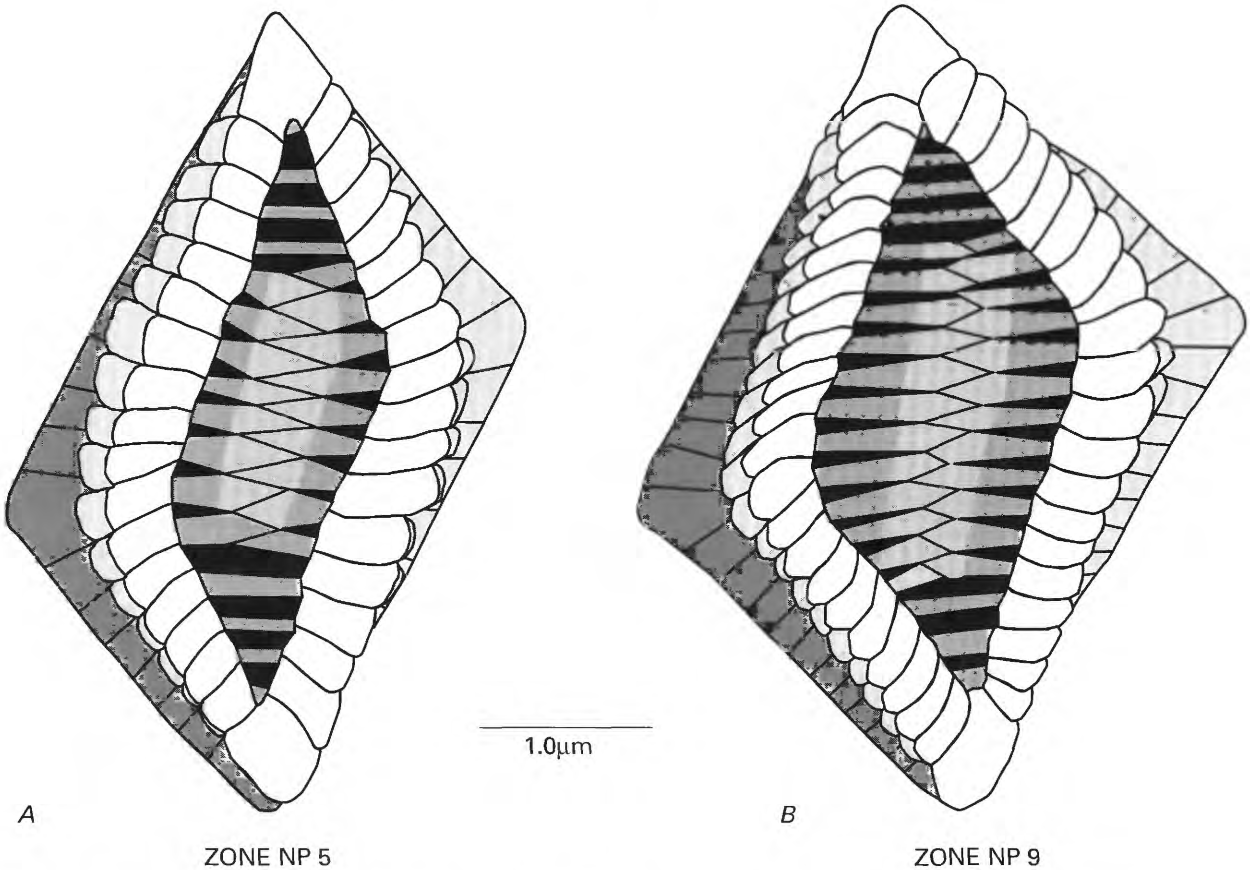


Figure 22. Evolutionary changes in *Scapholithus apertus*. Typical specimen occurring in Zone NP 5 (*A*) is noticeably narrower than typical specimen occurring in Zone NP 9 (*B*).

TAXONOMIC NOTES ON SELECTED TAXA

Biantholithus astralis Steinmetz & Stradner, 1984

Plate 1, figures 1–7; plate 32, figures 1–3

Remarks.— The original description by Steinmetz and Stradner (1984) mentioned only the presence of a distal shield. A proximal shield, however, is easily apparent in their original illustrations, particularly in figure 2. Specimens from New Jersey reveal that the proximal shield is larger than the distal shield, and each shield has 7–10 segments. On an individual specimen, both shields have the same number of segments, and segments are in alignment between the two shields. The segments of the distal shield overlap slightly for the inner two-thirds of their length, and the outer third of each segment is free. The segments of the proximal shield do not overlap and appear to be joined throughout most of their length. In well-preserved specimens, the outer edges of the segments on both shields are straight (pl. 1, figs. 3a, 4a); however, dissolution tends to round the terminations, particularly on the distal shield (pl. 1, fig. 1a). There is a small, central, cup-shaped structure on the bottom of the proximal shield (pl. 1, fig. 4a), and a central perforation extends through this cup, as well as through the entire specimen. This perforation is visible on both the distal and proximal surfaces of well-preserved specimens, but it becomes smaller (pl. 1, fig. 2a) or is obliterated (pl. 1, fig. 3a) if there is recrystallization.

Occurrence.—This species originally was described from Zone NP 2, a zone that is rarely present in New Jersey and is absent in Virginia and Maryland. In the Atlantic Coastal Plain, *B. astralis* consistently occurs from Zone NP 3 to upper Zone NP 9. This species occurs most abundantly within Zone NP 9 in New Jersey, Maryland, and Virginia. In New Jersey, *B. astralis* probably has its last occurrence in the upper part of Zone NP 9 (just below the Vincentown Formation-Manasquan Formation transitional boundary). In the Clayton core, there is one occurrence of this species in the Manasquan Formation within the uppermost part of Zone NP 9 (307.2 ft), but this is 15 ft above the next occurrence and probably is a result of reworking. In Virginia and Maryland, *Biantholithus astralis* does not occur in material younger than the Zone NP 9 sediments of the Aquia Formation.

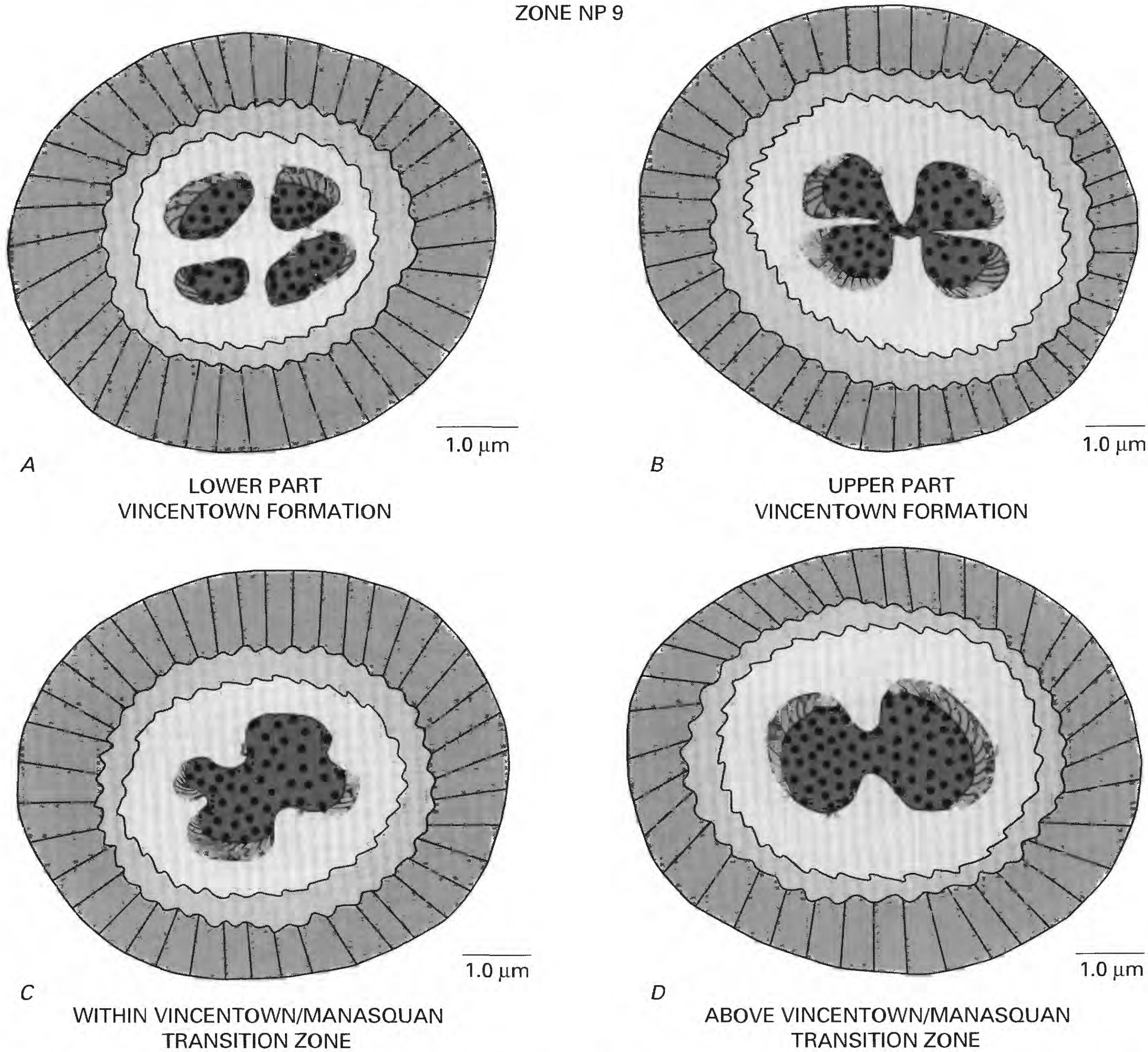


Figure 23. Evolution of *Toweius eminens* var. *eminens* autonym into *Toweius occultatus* within Zone NP 9. All views are of distal surface. *A*, typical specimen of *T. eminens* var. *eminens* autonym that has two sets of intersecting extensions at right angles to each other. *B*, typical specimen from the upper part of the Vincentown Formation that has narrowed longitudinal extensions and lateral extensions that often do not touch. *C*, typical specimen from the Vincentown/Manasquan Formation transition zone that has vestigial longitudinal extensions and usually more widely separated lateral extensions. *D*, typical specimen of *Toweius occultatus*, which is from the lower part of the Manasquan Formation just above the transition zone, that has no longitudinal extensions and lateral extensions that rarely touch.

Biantholithus sparsus? Bramlette & Martini, 1964

Plate 1, figure 8; plate 32, figure 4

Remarks.—In this study, only one questionable specimen of *B. sparsus* was observed with the SEM, and this specimen from New Jersey can be placed in Zone NP 9. The bottom of this specimen has a small, central, cup-shaped structure (pl. 1, fig. 8), much like that found in *Biantholithus astralis*. Unfortunately, this specimen was not tilted in order to determine the presence or absence of two shields. Specimens illustrated by Steinmetz and Stradner (1984, pl. 53, figs. 3, 4), however, have both a proximal and distal shield. Sinistrally curved sutures on the proximal surface of *B. sparsus*, as compared to straight sutures on both surfaces of *B. astralis*, form the major distinguishing characteristic between the two species.

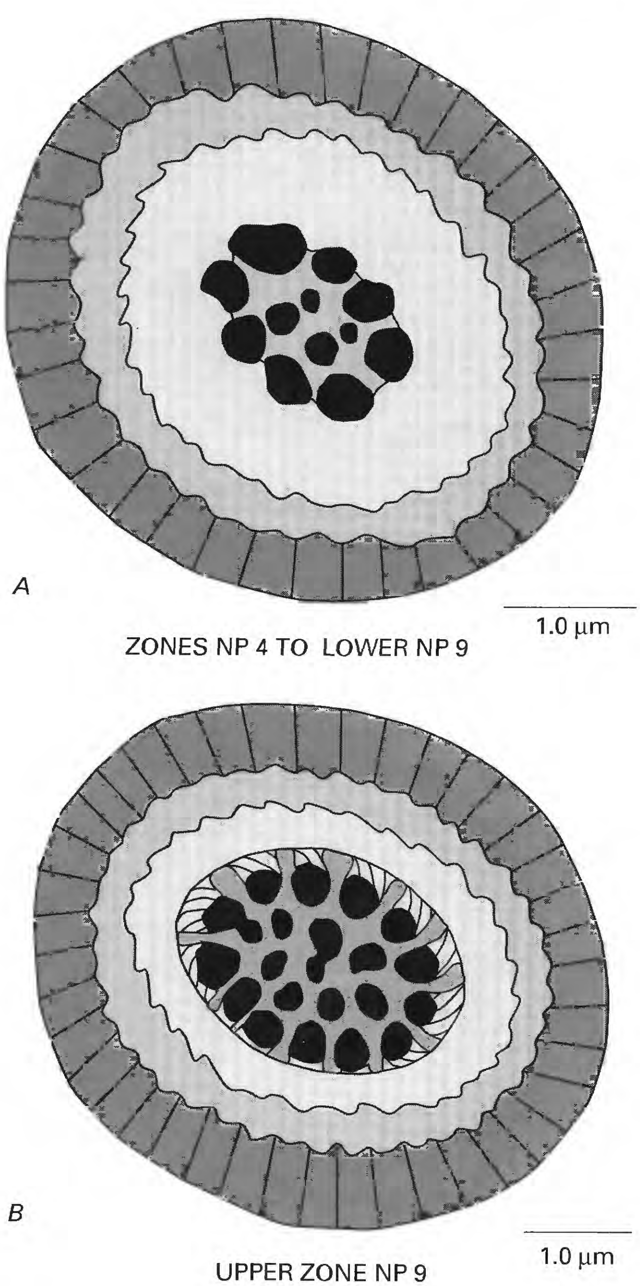


Figure 24. Evolutionary changes in *Toweius pertusus*. Distal view. *A*, typical specimen from Zones NP 4 to lower NP 9 that has surface of central perforate region continuous with surrounding collar. *B*, typical specimen from upper Zone NP 9 where central perforate region has become recessed and number of pores has increased.

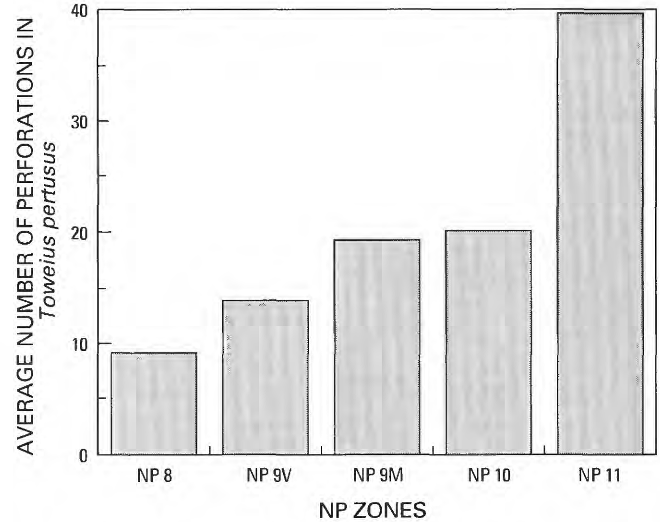


Figure 25. Increase in average number of central perforations in *Toweius pertusus* from Zones NP 8 to NP 11. For Zone NP 9, data from the Vincentown Formation are labeled NP 9V, and data from the overlying Manasquan Formation are labeled NP 9M.

Occurrence.—*B. sparsus* is present only sporadically in Zones NP 3 to NP 9 in New Jersey sediments.

Biscutum spp.

Plate 32, figures 5, 10

Remarks.—Species in the genus *Biscutum* contain distal and proximal shields that show little birefringence with crossed nicols and a small, central area that has strong birefringence. It is probable that there are several representatives of this genus in the New Jersey sediments. *Biscutum* species are very difficult to differentiate in the light microscope, and they rarely were observed with the SEM. Additional study, especially with the SEM, will be necessary to distinguish individual species and determine their biostratigraphic importance.

Occurrence.—The genus *Biscutum* occurs in Zones NP 3 to lower NP 10 in New Jersey.

Braarudosphaera bigelowii (Gran & Braarud, 1935) Deflandre, 1947

Occurrence.—*Braarudosphaera bigelowii* occurs intermittently and never in great abundance in upper Zone NP 9 and lower Zone NP 10 in New Jersey, Alabama, Maryland, and Virginia.

Campylosphaera dela (Bramlette & Sullivan, 1961) Hay & Mohler, 1967

Plate 2, figures 1–11; plate 32, figures 8, 9

Campylosphaera eodela Bukry & Percival, 1971, p. 125, pl. 1, figs. 1–4.

Remarks.—*Campylosphaera eodela* is herein placed in synonymy with *C. dela*. Older, smaller specimens of this species (mid-Zone NP 9 to mid-Zone NP 10) were originally placed in *C. eodela*, and younger, larger specimens (mid-Zone NP 10 to Zone NP 15) originally were placed in

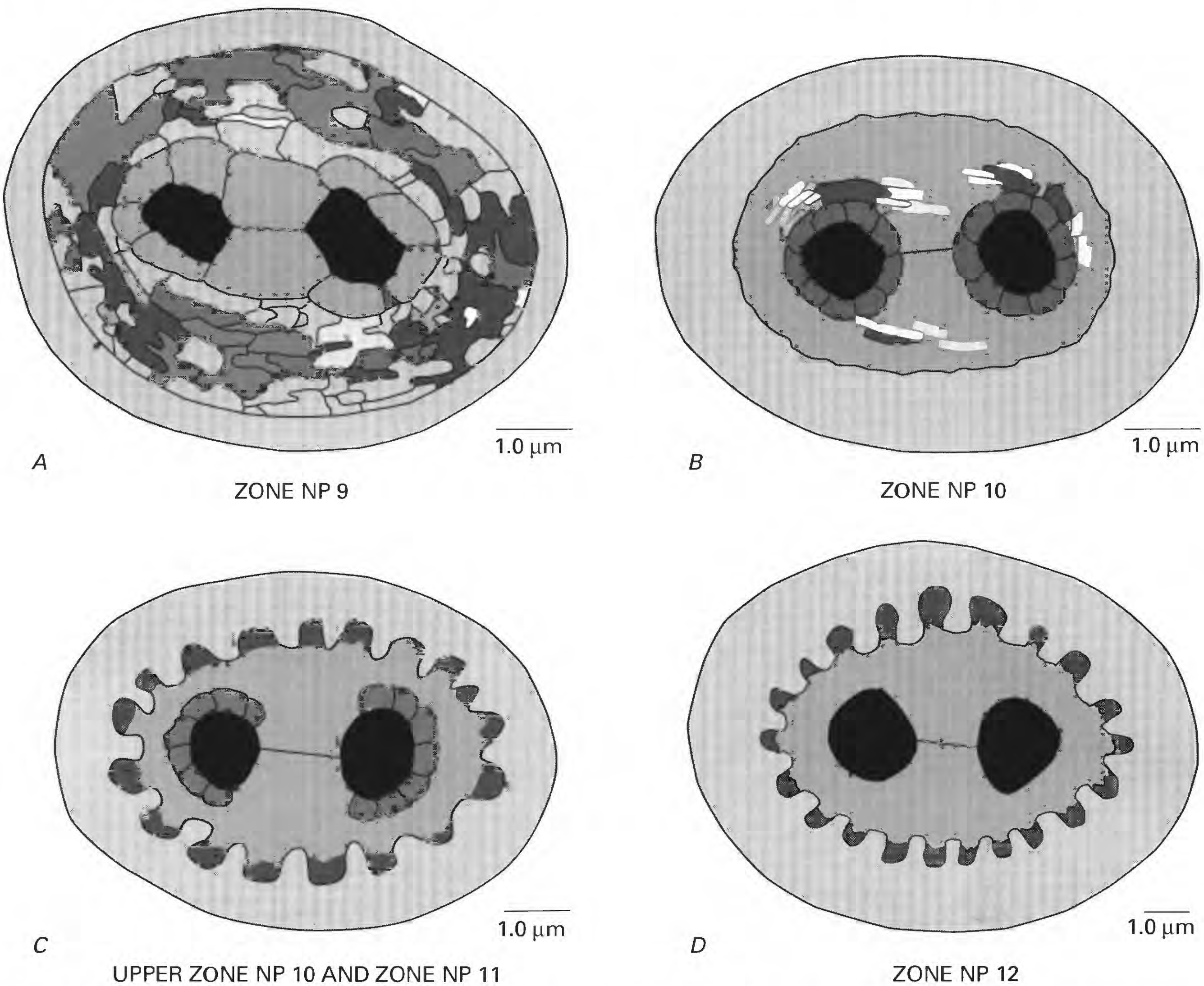


Figure 26. Evolution of *Transversopontis pulcher*. Distal view. Early specimens from upper Zone NP 9 (*A*) have an irregular floor and narrow rim. By lower Zone NP 10 (*B*), specimens now have a wider, taller rim and somewhat smoother floor. Specimens typical of upper Zone NP 10 and Zone NP 11 (*C*) have continued thickening of the rim, smoothing of the floor, and the appearance of small perforations around the edge of the floor. By Zone NP 12 (*D*), specimens of typical *T. pulcher* have a broad rim, smooth floor, and crenulations around the edge of the base.

C. dela. *Campylosphaera dela* and *C. eodela* are indistinguishable except for size (compare the specimen on pl. 2, fig. 1 from upper Zone NP 9 at 6.9 µm with the specimen on pl. 2, fig. 11 from Zone NP 14 at 8.7 µm). The difference in shape and size of the central area between *C. eodela* and *C. dela* that was described by Bukry and Percival (1971) was not observed in specimens from New Jersey, Alabama, and Maryland. The present authors consider the gradual evolution in time from smaller to larger forms to be consistent with placement within one species. See the Evolution of Calcareous Nannofossils section for more details.

Occurrence.—The combined range for *C. dela* and *C. eodela* is from upper Zone NP 9 to the late Eocene. In New Jersey, small forms of this species first appear in the upper part of Zone NP 9, and the size of these specimens increases gradually in Zones NP 9 through NP 14 (fig. 19).

Chiasmolithus bidens (Bramlette & Sullivan, 1961) Hay & Mohler, 1967

Plate 3, figures 1–12; plate 32, figures 6, 7, 11, 12

Coccolithus solitus Bramlette & Sullivan, 1961, p. 139, pl. 2, fig. 4a–c.
Chiasmolithus solitus (Bramlette & Sullivan, 1961) Hay & Mohler, 1967, p. 1526.
Chiasmolithus edentulus van Heck & Prins, 1987, p. 288, pl. 1, figs. 13, 14, text-fig. 5.

Remarks.—*Chiasmolithus bidens* is a medium-sized chiasmolith with a split crossbar and a thin, distinctive, central grid, which is easily dissolved. Elements of the collar are raised relative to the outer shield segments. Early forms of this species (from Zones NP 5 to NP 7) are fairly consistent in size and lack the two toothlike projections into the central area; these include specimens placed in *Chiasmolithus edentulus*. However, beginning in Zone NP 8 (and continuing at least into Zone NP 12), there is increased variation in specimen size (fig. 20); this is due to the appearance of larger forms that have a broader crossbar, small toothlike projections that extend into the central area, and an increased number of shield segments.

The differences among *C. bidens*, *C. edentulus*, and *Chiasmolithus solitus* are gradational, and these three species are herein placed in synonymy. *Chiasmolithus solitus* has been used for specimens from Zones NP 10 to NP 16, and *C. bidens* has been used for specimens from Zones NP 5 to NP 10. *Chiasmolithus edentulus* was used for specimens without the toothlike projections. Plate 3, figure 6, illustrates a specimen from Zone NP 5 in New Jersey, and plate 3, figure 11, illustrates a nearly identical specimen from Zone NP 14 in New Jersey. *Chiasmolithus bidens* (p. 139 in Bramlette and Sullivan, 1961) has priority over *C. solitus* (p. 140 in Bramlette and Sullivan, 1961). *Chiasmolithus eograndis*, which also appears in Zone NP 10, is even larger and has a broader crossbar than *C. bidens*. As mentioned in the Evolution of Calcareous Nannofossils section, *Chiasmolithus eograndis* probably is another morphological variant and could be placed in synonymy with *C. bidens*.

Occurrence.—The range for *C. bidens* (including *C. edentulus* and *C. solitus*) is from the upper part of Zone NP 5 to the top of Zone NP 16 (Martini, 1971; Perch-Nielsen, 1985, fig. 19). Studies in New Jersey support this range. There is a significant decrease in the abundance of *C. bidens* in the 10 ft of sediments immediately surrounding the Paleocene-Eocene boundary. This decrease occurs in all four New Jersey cores that contain this boundary. Because of the unconformity at the Zone NP 9–NP 10 boundary in Alabama, Maryland, and Virginia, it was not possible to confirm a reduction in abundance in these regions.

***Chiasmolithus consuetus* s. ampl. (Bramlette & Sullivan, 1961) Hay & Mohler, 1967**

Plate 4, figures 1–4; plate 32, figures 13–15

Remarks.—*Chiasmolithus consuetus* has an unsplit central crossbar, and the elements of the collar area are depressed relative to the outer ring of segments. Specimens in Zones NP 3 and NP 4 have a larger collar and a less marked depression than specimens from younger sediments. There is no grid present in the central area, and there is significant variation in specimen size. *Chiasmolithus danicus* differs from *C. consuetus* in that it has a collar that is raised rather than depressed. *Chiasmolithus consuetus* is difficult to distinguish from other similar chiasmoliths in the light microscope, and because of this, many occurrences of *C. consuetus* that are reported in the literature are believed by the present authors to be unreliable and are best placed in *C. consuetus* s. ampl. Reported occurrences of *Chiasmolithus californicus* (Sullivan, 1964) Hay & Mohler, 1967 in the Paleocene probably should be attributed to larger specimens of *C. consuetus*.

Occurrence.—Based on SEM identifications, this species ranges from Zones NP 4 to at least Zone NP 11 in New Jersey, and light microscope identification indicates possible placement in Zone NP 3. Perch-Nielsen (1985, fig. 19) reported a range for *C. consuetus* from Zone NP 5 to Zone NP 19.

***Coccolithus pelagicus* (Wallich, 1877) Schiller, 1930**

Plate 4, figures 6–8; plate 32, figures 16, 17

Remarks.—The present authors consider *Coccolithus pelagicus* to include *Coccolithus cavus* Hay & Mohler, 1967 and *Ericsonia ovalis* Black, 1964. In well-preserved Paleocene and early Eocene specimens, the distal shield of *C. pelagicus* has a narrow gap between the inner edge of the shield segments and the outer edge of the collar. In much of the Paleocene, the outer portion of the collar is recessed below or at approximately the same level as the shield segments. In upper Zone NP 9, however, the collar becomes thicker, and its outer portion is elevated somewhat above the level of the shield segments (pl. 4, fig. 8a). The collar of *Ericsonia subpertusa* always is noticeably higher than the shield segments, the outer edge of the collar actually rests upon the inner edge of the shield segments, and there is no gap present. The central perforation is generally more elliptical in *C. pelagicus* than in *E. subpertusa*.

Occurrence.—In New Jersey, this species first occurs in sediments from Zone NP 5. A broad taxonomic interpretation for this species extends its range into the Quaternary (Perch-Nielsen, 1985, fig. 23).

***Cruciplacolithus tenuis* (Stradner, 1961) Hay & Mohler *in* Hay and others, 1967**

Remarks.—There is one questionable occurrence of *Cruciplacolithus tenuis* in upper Zone NP 9 in the Clayton core. This species was not observed in either Zone NP 9 or NP 10 in the other New Jersey cores examined for this study or in Alabama, Maryland, or Virginia. Perch-Nielsen (1985, fig. 19) indicated that *C. tenuis* does not occur above the lower part of Zone NP 9. It is the present authors' opinion that the presence of *C. tenuis* in Zone NP 9 or NP 10 is equivocal.

Cruciplacolithus spp.

Plate 4, figure 5; plate 32, figure 18

Remarks.—In this study, several small nondescript representatives of the genus *Cruciplacolithus* occasionally were observed in the light microscope, and these specimens appear to represent several different species. Only one probable *Cruciplacolithus* specimen was observed with the SEM from either Zone NP 9 or NP 10 in New Jersey (pl. 4, fig. 5); this specimen resembles *Ericsonia insolita*, which Perch-Nielsen (1971b, pl. 14, fig. 9) originally described from the late Eocene of Denmark. Additional investigation of this material with the SEM is necessary before any taxonomic decisions are made.

Occurrence.—Members of this genus occur sporadically in Zones NP 9 and NP 10 in New Jersey, Alabama, Maryland, and Virginia.

Cyclagelosphaera prima (Bukry, 1969) n. comb.

Plate 5, figures 1–3; plate 32, figures 19, 20

Similicoronilithus primus Bukry 1969, p. 31, pl. 19, fig. 11.
Tergestiella barnesae (Black *in* Black & Barnes, 1959) Reinhardt, 1964; in Reinhardt 1966, pl. 1, figs. 1, 2.
Cyclagelosphaera reinhardtii (Perch-Nielsen, 1968) Romein, 1977; Perch-Nielsen, 1981, pl. 3, fig. 8.

Remarks.—Specimens found in New Jersey match those illustrated and described by Bukry (1969) as *Similicoronilithus primus*. Bukry (1969, p. 31) described the small central knob as being fairly low, based on lack of shadowing on the TEM (transmission electron microscope). However, well-preserved specimens from New Jersey and Maryland, which have been tilted in the SEM, indicate a higher central structure (pl. 5, figs. 1b, 2b). The proximal and distal shields are the same size, and there are 30–35 segments on each shield. Elements of the distal shield imbricate clockwise; this is the opposite of the segments in the proximal shield. There are approximately 24 segments in the stem, which imbricate counterclockwise. The top of the stem is flat in well-preserved specimens (pl. 5, fig. 1b), but the center becomes depressed with dissolution (pl. 5, fig. 2b).

Cyclagelosphaera prima n. comb. can be distinguished from other members of this genus primarily on the basis of the central structure on the distal shield. Apart from the central structure, the distal shields on all species in the genus *Cyclagelosphaera* are very similar. *Cyclagelosphaera prima* n. comb. has a central structure or stem with a round outline, while the central structures on *Cyclagelosphaera reinhardtii* (Perch-Nielsen, 1968) Romein, 1977 and *Cyclagelosphaera alta* Perch-Nielsen, 1979 are broader and have irregular outlines. These differences also are visible with the light microscope.

Occurrence.—*Cyclagelosphaera prima* n. comb. originally was described from mid-Campanian sediments (Bukry, 1969). A specimen resembling this species also was reported in Maastrichtian sediments (Reinhardt, 1966). In New Jersey, this species definitely occurs in Zones NP 2 to NP 10, and may occur in Zone NP 11. This appears to be one of the few species that crosses the Cretaceous-Tertiary boundary.

Discoaster anartios Bybell & Self-Trail n. sp.

Plate 5, figures 4–8; plate 32, figures 21–23; plate 33, figure 1

Diagnosis.—A fairly large discoaster with 15–20 irregularly shaped curving rays and a tall narrow stem on one side.

Description.—*Discoaster anartios* n. sp. ranges from 13–18 µm in size. One side (side 1) is slightly concave and has a tall narrow stem (pl. 5, figs. 4, 5). There is no distinct stem on the opposite, slightly convex side (side 2, pl. 5, figs. 6–8), although there is a central area that is raised somewhat above the level of the rays (pl. 5, fig. 6b). The rays curve sinistrally on the side without a stem and curve dextrally on the concave side with a stem. The most diagnostic feature for *D. anartios* n. sp. is the irregularity in the shape of the rays. This irregularity is the result of a large variation both in ray width and in the amount of indentation between each ray; the latter may be partially a result of dissolution. On an individual specimen, the distance between rays can vary considerably (pl. 5, fig. 4). On well-preserved specimens, the sutures on the concave side (side 1) are thickened slightly (pl. 5, fig. 5b). On the convex side (side 2), the sutures are depressed (pl. 5, fig. 7). The outer third of the rays are free, and on well-preserved specimens the rays terminate in fairly sharp points.

Remarks.—*Discoaster anartios* n. sp. most closely resembles *D. araneus* Bukry, 1971, which also has irregularly shaped rays and a prominent stem. However, *D. araneus* has fewer rays (7–10), and one-third to two-thirds of the total ray length is free.

Holotype.—Plate 5, figures 5a, 5b, SEM photomicrograph numbers 447–1A, 447–1B.

Paratypes.—Plate 5, figures 4, 8, SEM photomicrograph numbers 464–23, 464–15.

Type locality.—Holotype: New Jersey, Clayton core, 307.2 ft, Zone NP 9, Manasquan Formation. Paratypes: New Jersey, Clayton core, 298.5 ft, Zone NP 10, Manasquan Formation.

Occurrence.—Late Paleocene into early Eocene. This species was observed only in the upper part of Zone NP 9 and the lower part of Zone NP 10 in New Jersey.

Depository.—The original scanning electron photomicrographs and negatives are stored at the U.S. Geological Survey in Reston, Va.

Discoaster diastypus Bramlette & Sullivan, 1961

Plate 6, figures 1–5

Remarks.—Although this species does not occur in the present study material, it is discussed here because of its previously placed FAD at the base of the Eocene (Bukry, 1973). The illustrations on plate 6 are from the upper part of Zone NP 10 in Alabama, in a sample that also contains *Rhomboaster contortus* n. comb.

Discoaster diastypus is distinguished from other discoasters by the presence of two stems and 14 to 20 curving rays. There is no significant difference between the height and the diameter of the two different stems. The side with the sinistrally curving rays (side 2, pl. 6, figs. 2–5) has a raised rib or ridge between the rays, which extends from the center of the discoaster towards the outer edge (pl. 6, fig. 5). This rib curves to the left and forms a thickening around the outside of one half of each ray tip. In contrast, on the dextrally curving side (side 1), the ribs extend down the center of the rays, ending just before the ray tip (pl. 6, fig. 1). This large species ranges in size from 16 to 20 μm. Somewhat smaller, similarly shaped specimens having fewer than 14 rays, only one stem, and parallel rows of small nodules on one surface are placed in the species *Discoaster falcatus*. Plate 11, figure 6, of Bramlette and Sullivan (1961), which was labeled as *D. diastypus*, should more properly be placed in *D. falcatus*, as should the specimens illustrated by Bramlette and Sullivan (1961) on plate 11, figures 9–10, which were named *D.* aff. *diastypus*.

Occurrence.—*Discoaster diastypus* is not present in the lower Zone NP 10 sediments in the Clayton core or in any of the cores crossing the Paleocene-Eocene boundary in New Jersey. In Alabama, *D. diastypus* does occur within Zone NP 10; however, this occurrence is well above the FAD of *Rhomboaster bramlettei* n. comb. and only is in samples that also contain *Rhomboaster contortus* n. comb. *Discoaster diastypus* was not viewed with the SEM in New Jersey, Maryland, or Virginia. Although the first occurrence of *Rhomboaster contortus* n. comb. was used by Bukry (1973, 1978) to define the base of the Eocene, it is now known to first occur higher in the Eocene within mid-Zone NP 10 (Perch-Nielsen, 1985, fig. 89).

Discoaster falcatus Bramlette & Sullivan, 1961

Plate 6, figures 6–11; plate 7, figures 1–11; plate 33, figures 2, 3, 8

Remarks.—On one side (side 2), *D. falcatus* is similar to *D. splendidus*, but on the opposite side (side 1), *D. falcatus* has a central, flaring stem with a diameter only two-thirds as wide as the stem in *D. splendidus* (fig. 27). There is a depression in the middle of each ray (side 1), and the resulting raised suture lines curve to the left along the outer edge of the right side of each ray tip (pl. 6, fig. 8).

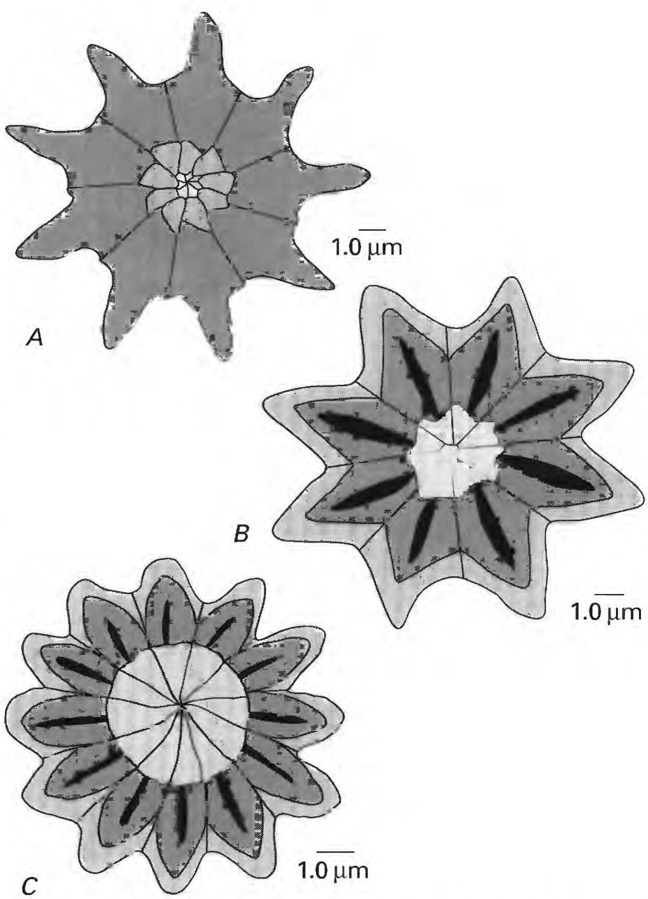


Figure 27. Morphologic distinctions on side 1 among *Discoaster mediosus* (*A*), *Discoaster falcatus* (*B*), and *Discoaster splendidus* (*C*). Specimens typical of *D. falcatus* resemble *D. splendidus* in basic structure, but *D. falcatus* has a narrower stem and fewer rays. *Discoaster mediosus* can be similar in shape to *D. falcatus* but lacks the central ray depression and corresponding sutural thickening that are present in both *D. falcatus* and *D. splendidus*. *Discoaster mediosus* resembles a large central disk with rays extending outward; neither *D. falcatus* nor *D. splendidus* have this feature.

The ray tips vary from somewhat rounded to slightly pointed, and in some specimens the tips seem to curve slightly. This curvature appears to be a dissolution feature (pl. 6, fig. 6). On the opposite side of this species (side 2), there is a shallow, central raised area, and there are three parallel rows of small nodules, which extend down the length of each ray (pl. 7, fig. 8). The central line of nodules, which often is less distinct than the other two rows, may be absent entirely. These nodules, which can be difficult to detect in the SEM if there is a moderate amount of dissolution or recrystallization, are not visible with the light microscope. *Discoaster mediosus* also has nodules on its lower surface (side 2). However, the opposite side (side 1) is significantly different between these two species: the depressions that occur in the middle of each ray on *D. falcatus* are absent in *D. mediosus* (fig. 27). The highest part of each specimen is at the suture line in *D. falcatus*, and in *D. mediosus* specimens are generally flat on side one but are thickened slightly along the center of each ray.

Discoaster falcatus has 8–12 rays. Due to the large amount of variability in the ray terminations and the inability to distinguish the rows of nodules with the light microscope, *D. falcatus* was particularly confusing and difficult to identify during the early stages of this study. Once numerous SEM photomicrographs were available for comparison, the species could be more clearly defined, and it then became much easier to identify *D. falcatus* in the light microscope.

Occurrence.—Based on confirmation with the SEM, *D. falcatus* occurs in upper Zone NP 9 and Zone NP 10 in New Jersey. Specimens also were found in Zones NP 9 and NP 10 in Alabama and Virginia. *Discoaster falcatus* occurs sporadically in the lower portion of its range in Zone NP 9, and there is the possibility that it may extend lower.

Discoaster lenticularis Bramlette & Sullivan, 1961

Plate 8, figures 1–9; plate 33, figures 5–7

Discoaster multiradiatus Bramlette & Riedel, 1954, *in* Romein, 1979, in part, pl. 6, fig. 3.

Discoaster sp., Pospichal and Wise, 1990, pl. 3, fig. 2.

Remarks.—*D. lenticularis* is a small, robust biconvex discoaster having 18–26 rays that are joined throughout most of their length. There is no distinct stem, and specimens are 5–12 µm in size. This extends the original description of Bramlette & Sullivan (1961, p. 160), which described 20–26 rays and a diameter of 8–12 µm. Both sides of *D. lenticularis* are convex, one side more strongly arched than the other. On the flatter side, the rays overlap each other sinistrally and curve dextrally, and there is a middle cycle of elements, which curves in the opposite direction from the outer cycle and is only slightly raised (pl. 8, figs. 1a, 2a, 3a, 4, 7). The inner area is covered with a third cycle of very small segments; these segments curve in the same direction as the middle cycle and are depressed. The elements of the third cycle often are dissolved partially or completely away. On the more convex side, the rays do not overlap, and the central area, which is narrower than on the less convex side, is raised up as a shallow stem (pl. 8, figs. 5, 6, 8, 9). There is a central perforation that appears to penetrate the entire specimen.

Discoaster lenticularis with 18–25 rays is similar to *D. multiradiatus*, which has from 18–28 rays, but *D. lenticularis* is much smaller (approximately one-half the size of *D. multiradiatus*) and has a very different type of central area, which is much broader and more complex than found in *D. multiradiatus*. *Discoaster lenticularis* is more robust than *D. multiradiatus* and has no concentric rings.

Occurrence.—*Discoaster lenticularis* occurs in upper Paleocene and lower Eocene sediments (Zone NP 9 and Zone NP 10) in New Jersey, Alabama, Maryland, and Virginia. Perch-Nielsen (1985, fig. 30) reported this species from Zones NP 9 and NP 10. In New Jersey, Alabama, and Maryland, *D. lenticularis* and *D. multiradiatus* first occur in the same samples. In Virginia, where there appears to be older Zone NP 9 sediments than at the other locations, *D. lenticularis* first appears a few feet above the first appearance of *D. multiradiatus*.

Discoaster limbatus Bramlette & Sullivan, 1961

Plate 9, figures 1–12; plate 33, figure 9

Remarks.—Most specimens found in New Jersey can easily be assigned to this species based on distinctive ray terminations. In well-preserved specimens, the ray tips resemble arrowheads (pl. 9, fig. 1). With dissolution, the arrowheads become rounded, and eventually the ray terminations are reduced to rounded knobs (pl. 9, fig. 6). This species has 9–14 rays. On one side (side 1), *D. limbatus* has thickened sutures and a shallow stem, which is depressed in the center (pl. 9, figs. 8–12). On the opposite side (side 2) there are two parallel rows of small nodules running the length of each ray (pl. 9, figs. 1–7); the stem is smaller in diameter on the side with nodules, and it has no central depression. In its basic structure, *D. limbatus* closely resembles *D. falcatus*. The most significant difference is the ray shape; unfortunately, dissolved specimens of *D. limbatus* (pl. 9, fig. 9) may closely resemble *D. falcatus*. *Discoaster mediosus* has similar nodules on one side (side 2), but the opposite side (side 1) differs significantly (fig. 27). Instead of the thickened sutures typical of *D. limbatus*, *D. mediosus* is relatively flat, and the thickest part of each specimen occurs at the center of each ray.

Occurrence.—In New Jersey, *D. limbatus* occurs only sporadically in upper Zone NP 9, Zone NP 10, and Zone NP 11. It is also present in Zone NP 10 in Alabama and Maryland.

Discoaster mediosus s. ampl. Bramlette & Sullivan, 1961

Plate 10, figures 1–12; plate 34, figures 1, 2

Remarks.—This species has a large central area, 8–10 relatively flat rays, and a narrow shallow stem on each side. There is a large amount of variation in the length of ray that is free, the width of the rays, and the shape of the ray terminations. For example, specimens with long, slender rays (pl. 10, fig. 4) can be found along with specimens having shorter, stubbier rays (pl. 10, fig. 10). This variation does not appear to be due to dissolution. Because of the similarity of the central area and stem, the authors have chosen at this time to keep all these forms within one species. One side (side 1) of this species has no apparent ornamentation (pl. 10, fig. 5), whereas the opposite side (side 2) has two or three parallel rows of small nodules, which extend down the length of each ray (pl. 10, figs. 7, 9–12). With dissolution or recrystallization, these nodules become increasingly difficult to detect. Similar nodules are found on the lower surface (side 2) of *Discoaster falcatus* and *Discoaster limbatus*. Heavily dissolved specimens of *D. limbatus* may resemble *D. mediosus* in outline; however, on side 2, *D. mediosus* (pl. 10, fig. 10) lacks the sutural thinning typical of *D. limbatus* (pl. 9, fig. 4) and *D. falcatus* (pl. 8, fig. 7a). On side 1, *D. falcatus*, *D. limbatus*, and *D. splendidus* have thickened sutures and recessed ray centers. On the same side, *D. mediosus* is flatter and does not have recessed ray centers and thickened sutures (fig. 27). In outline, *D. mediosus* resembles a large central disk with rays extending out from it. There is no impression of a central disk for *D. falcatus*, *D. limbatus*, or *D. splendidus*.

Occurrence.—This species occurs only in upper Zone NP 9 and lower Zone NP 10 in New Jersey, Alabama, Maryland, and Virginia.

Discoaster sp. aff. *D. mohleri* Bukry & Percival, 1971

Plate 11, figures 1–4, 8; plate 34, figures 3, 4, 6

Remarks.—It is likely that this category includes several species. These forms resemble *Discoaster mohleri* in size, shape, and the presence of 8–10 rays. However, unlike *D. mohleri*, specimens included in *D.* aff. *mohleri* have a distinct stem. Some specimens appear to have no overlap of rays (pl. 11, fig. 2a), while in other specimens the rays overlap slightly (pl. 11, fig. 3). It is probable that these forms represent two separate species. Several specimens have small nodules on the ray surface that are visible with the SEM (pl. 11, figs. 4, 8); it is unclear whether these nodules occur in rows as in *D. falcatus*, *D. limbatus*, *D. mediosus*, and *D. splendidus*, or whether they are scattered on the ray surface. Additional study is necessary before any new species are described.

Occurrence.—Discoaster sp. aff. *D. mohleri* occurs in Zones NP 9 to NP 10 in New Jersey.

Discoaster multiradiatus Bramlette & Riedel, 1954

Plate 12, figures 1–11; plate 34, figures 5, 7

Discoaster perpolitus Martini, 1961, p. 9, pl. 2, fig. 20; pl. 5, fig. 50.

Remarks.—This large discoaster has 17–28 rays and a narrow, circular, shallow stem on one side (side 1); the side with the stem is slightly concave and has several, raised, concentric lines. These lines are most noticeable where they cross the raised suture lines (pl. 12, fig. 1b). *Discoaster perpolitus*, a similarly shaped form that originally was described with concentric lines, is placed in synonymy with *D. multiradiatus*. In poorly preserved specimens, calcitic overgrowth masks or obliterates the concentric lines (pl. 12, fig. 7). In well-preserved specimens, the suture lines and the tips of the rays are thickened, which leaves a depressed area in the center of each ray. Bramlette and Sullivan (1961, p. 162) described some specimens with thicker borders than normally observed on *D. multiradiatus*, and they also described specimens with faint concentric ornamentation. They attributed these forms to less calcified specimens and called them *D. multiradiatus* variety. We do not recognize that the amount of calcification warrants separation into varieties and therefore place both the noncalcified and calcified forms within *D. multiradiatus*.

The underside of this species (side 2) has a slightly raised central area (pl. 12, figs. 8–11) that may be somewhat larger in diameter than the more pronounced stem on the opposite side. On the underside, the rays appear to overlap slightly, and there is a thickened rib running down each ray, somewhat off center in position (pl. 12, fig. 9). The sutures on this surface are depressed. There also are several concentric lines on this surface, which are most pronounced where they cross the thickened rib. The average number of rays does not change from the upper part of Zone NP 9 to the lower part of Zone NP 10, while the average size does appear to increase somewhat within Zone NP 9 (table 3). Faris (1992) and Wei (1992) reported that the mean number of rays in *D. multiradiatus* decreased through time, and Wei found that the most significant change occurred in the lower part of Zone CP8 (equivalent to the lower part of Zone NP 9), which is missing in the New Jersey material. Specimens of *D. multiradiatus* occur in upper Zone NP 10 and Zone NP 11 elsewhere in New Jersey, but there was no detailed examination of this material with the SEM. Thus, the lower part of Zone NP 9, the upper Zone NP 10, and NP 11 are missing or poorly represented in New Jersey, and more complete sections in the Atlantic Coastal Plain may reveal a similar trend in ray reduction.

Occurrence.—Discoaster multiradiatus occurs throughout Zones NP 9 and NP 10 in New Jersey, Alabama, Maryland, and Virginia. It is also present sporadically in Zone NP 11 in New Jersey.

Discoaster salisburgensis Stradner, 1961

Plate 13, figures 1–8; plate 35, figures 1–2

Remarks.—This relatively flat, fairly large discoaster has 13–26 rays that do not overlap; this ray number is similar to that of *Discoaster multiradiatus*, but *D. salisburgensis* is somewhat smaller (table 3). From Zone NP 9 into Zone

Table 3. Comparison of size (in micrometers) and number of rays between *Discoaster multiradiatus* and *Discoaster salisburgensis* in Zones NP 9 and NP 10. Zone NP 9 specimens from the Vincentown Formation are NP 9V, and Zone NP 9 specimens from the overlying Manasquan Formation are NP 9M.

Species	NP 9 V		NP 9 M		NP 10	
	Size	Rays	Size	Rays	Size	Rays
Discoaster salisburgensis	10.4	23	11.5	26	14.5	20
	9.7	20	10.0	15	15.7	22
	12.7	25	10.2	21	8.2	16
	7.9	23		22	10.7	17
	9.1	19			14.1	15
	10.2	24			13.1	16
	14.1	20			14.8	19
	9.8	23			9.5	13
	10.1	23			9.8	13
	10.9	22			13.4	19
	10.5	20			13.0	15
	8.9	19				23
	11.6	19				
	8.4	18				
	11.0	24				
	10.4					
	7.8					
Average	10.2	22	10.6	21	12.4	17
Discoaster multiradiatus	16.1	23	18.7	19	12.5	21
	15.8	25	12.3	20	13.9	21
	12.5	22	15.3	22	15.3	22
	14.5	23	15.6	22	12.5	22
	14.4	28	16.1	24	15.3	24
	12.3	26	16.9	24	18.3	20
	12.7	21	17.5	24	13.6	22
	8.8	18	16.7	24	16.2	23
	15.2	28	16.9	25	20.3	21
	9.2	19	17.8	27	13.7	23
	14.0	25	15.0	22	13.2	23
	16.1	19	17.2	22	14.2	22
	16.7	27	15.0	23	14.2	20
			7.2	21	14.2	21
					13.9	21
					15.0	25
					17.8	24
					17.5	23
					15.0	26
Average	13.7	23	15.6	23	15.0	23

NP 10, the number of rays decreases, and the ray tips become more pointed. This species has a central, broad, fairly tall stem that is depressed slightly in the center (side 1, pl. 13, figs. 1a,b). Segments that form the top of the stem overlap sinistrally. As in *D. multiradiatus*, the suture lines and the ray terminations are thickened, which leaves a depressed area in the center of each ray. With dissolution and recalcification, there is infilling of the ray depressions, and the stem becomes shorter (pl. 13, figs. 3a,b). This infilling may explain the original figure drawing of Stradner (1961, fig. 78), which indicates a wedge-shaped side view for *D. salisburgensis*. The depressed area between the sutures contains slightly raised, concentric lines that are most noticeable on the outer part of each ray (pl. 13, figs. 1a,b). These concentric lines dissolve much more readily than those on *D. multiradiatus*, and they are present only on very well-preserved specimens of *D. salisburgensis* (pl. 13, figs. 1a,b). The underside of this species (side 2) is fairly flat, and there is a slightly raised central cycle (pl. 13, fig. 5). There are concentric lines on the underside, which are most noticeable at the raised median line of each ray; the sutures are depressed (pl. 13, fig. 5). The underside of *D. salisburgensis* is very similar to the underside of *D. multiradiatus*, differing mainly in size, and it is apparent that these two species are very closely related. Whether they should be put in synonymy is unresolved at this time.

Occurrence.—*Discoaster salisburgensis* occurs in Zones NP 9 and NP 10 in New Jersey, Alabama, Maryland, and Virginia. This species may occur in Zone NP 8, but this needs to be confirmed with the SEM.

Discoaster splendidus Martini, 1960

Plate 11, figures 5–7, 9; plate 35, figures 3, 5

Remarks.—We concur with Romein's (1979) placement of *Discoaster helianthus* Bramlette & Sullivan, 1961 in synonymy with *D. splendidus*. *Discoaster splendidus* is a flat discoaster with a broad low stem that covers more than one-third of the ray length (side 1, pl. 11, figs. 5a,b). Specimens from New Jersey, which were observed with the SEM, have either 12 or 13 rays. Each ray has a thickening along both sides and around the end, which results in a depressed central region. *Discoaster splendidus* appears to be closely related to *D. falcatus* and differs in that *D. splendidus* has more rays and a broader stem (fig. 27). Plate 11, figure 9, is a specimen that the authors believe may be the opposite side (side 2) of *D. splendidus*. On this side there is a somewhat narrower, low central stem and two rows of small nodules running down each ray.

Occurrence.—*Discoaster splendidus* appears to be confined to Zones NP 8 to NP 10 in New Jersey. Perch-Nielsen (1985) reported that this species occurred in Zones NP 8 and NP 9.

Ellipsolithus distichus (Bramlette & Sullivan, 1961) Sullivan, 1964

Plate 14, figures 1–5; plate 35, figures 8, 9

Remarks.—On the distal surface, *E. distichus* has several large perforations and a thickened longitudinal bar that bisects the central area. When viewed from the proximal side, each perforation is covered with a net that consists of a circular pattern of oval holes with the long axes of the holes parallel to one another (pl. 14, fig. 5). In poorly preserved specimens, the net is dissolved away either partially or completely and only the large perforations are present. The thin outer rim of the proximal shield dissolves easily and rarely is found to be intact.

Occurrence.—This species ranges from Zones NP 4 to NP 12.

Ellipsolithus macellus (Bramlette & Sullivan, 1961) Sullivan, 1964

Plate 14, figures 6–10; plate 35, figures 4, 6, 7

Occurrence.—Forms resembling *E. macellus* in the light microscope occur in Zones NP 4 to NP 12 in New Jersey. With the SEM, this species was most commonly observed in Zone NP 11, and no specimens were observed with the SEM from Zones NP 9 or NP 10. The illustrations on plate 14 are all from Zone NP 11 in New Jersey.

Ericsonia subpertusa Hay & Mohler, 1967

Plate 15, figures 1, 2; plate 35, figures 10, 11

Remarks.—In the Paleocene and early Eocene, this species differs from *Coccolithus pelagicus* in that it does not have a gap between the distal shield and the collar. Instead, the outer part of the collar actually rests on top of the shield segments, forming an upraised ridge.

Occurrence.—This species first occurs in Zone NP 2. More rounded forms with larger central openings are dominant during Zones NP 5 to NP 8. Specimens resembling *E. subpertusa* in the light microscope occur in Zones NP 9 to NP 11, and SEM photomicrographs from Zone NP 10 and NP 11 (pl. 15, figs. 1, 2) indicate that these forms are more elliptical and have a narrower collar than *E. subpertusa* in Zone NP 8. Unfortunately, the authors do not have any SEM photomicrographs from Zone NP 9, which may contain intermediary forms between those found in Zone NP 8 and NP 10. Based upon its structure, it seems possible that *E. subpertusa* may evolve into *Cyclococcolithus formosus* Kamptner, 1963. Perch-Nielsen (1985, fig. 23) indicated that *E. subpertusa* only occurs within the Paleocene.

Fasciculithus alanii Perch-Nielsen, 1971

Occurrence.—*Fasciculithus alanii* is restricted to a very small portion of upper Zone NP 9 in New Jersey. Perch-Nielsen (1985, fig. 37) reported that this species only occurs in Zone NP 9. In this study, *F. alanii* was not observed with the SEM.

Fasciculithus aubertae Haq & Aubry, 1981

Plate 35, figures 12–14

Occurrence.—Forms identified as *F. aubertae* in the light microscope are present in Zone NP 9 and lower Zone NP 10 in New Jersey. However, these forms were not observed with the SEM, and, therefore, the species designation cannot be absolute. Haq and Aubry (1981, p. 301) and Perch-Nielsen (1985, fig. 37) only reported this species from Zone NP 9.

Fasciculithus involutus Bramlette & Sullivan, 1961

Plate 15, figures 3–7; plate 36, figures 1–4

Remarks.—*Fasciculithus involutus* has numerous, small-to-large depressions on the parallel-sided proximal column. These depressions, which vary in diameter from specimen to specimen, form two to three tiers. Specimens are topped with a low cone; this is a small, circular-shaped structure with blades radiating outward from the center and decreasing in height until at the outer rim they become flush with the top of the proximal column (pl. 15, fig. 4a). With dissolution, the blades on the cone are the first structure to disappear (pl. 15, fig. 5a). The base is concave and has a series of depressions that radiate outward (pl. 15, figs. 7a,b). This is the most common fasciculith in New Jersey.

Occurrence.—In the Atlantic Coastal Plain, *F. involutus* occurs sporadically in Zones NP 5–7, consistently in Zones NP 8–9, and sporadically again in lower Zone NP 10. Perch-Nielsen (1985) reported this species only from upper Zone NP 9 and lower Zone NP 10.

Fasciculithus schaubii Hay & Mohler, 1967

Plate 36, figures 5, 10

Occurrence.—*Fasciculithus schaubii*, which never is very common in New Jersey, only occurs in the upper, but not uppermost, part of Zone NP 9. Perch-Nielsen (1985, fig. 37) also reported that this species only occurs within Zone NP 9. *Fasciculithus schaubii* was not observed with the SEM.

Fasciculithus sidereus Bybell & Self-Trail n. sp.

Plate 16, figures 1–6; plate 36, figures 6–9, 11

Diagnosis.—Fasciculith with a 5- or 6-sided proximal column with numerous depressions and a central perforation on both concave ends.

Description.—The proximal column on this distinctive fasciculith is slightly larger at its base than at its top. Well-preserved specimens, when viewed from the top or bottom, resemble a pentagon or hexagon (pl. 16, fig. 5a).

However, moderate dissolution is common, and in these specimens the central portion of each disk becomes star shaped (pl. 16, fig. 4a). In some specimens, the disks are almost completely dissolved away (pl. 16, figs. 3a,b). A vertical rib connects each of the corresponding apices between the top and bottom disks, and the proximal column is recessed in the area between the ribs. Each recessed area has a series of side-by-side depressions, which are stacked one upon the other. There are three or four tiers in each specimen.

Remarks.—The top and basal disks of *F. sidereus* n. sp. are very different from any other species, and this species is easily identified both in the light microscope and in the SEM. Under the light microscope, the star shape is very diagnostic. *Fasciculithus sidereus* n. sp. does not closely resemble any other fasciculith, except in side view, where it might be possible to confuse badly dissolved specimens with *F. involutus*.

Holotype.—Plate 16, figures 1a–c, SEM photomicrograph numbers 445–11A, 445–11B, 445–11C.

Paratypes.—Plate 16, figures 3a,b, 5a,b, SEM photomicrograph numbers 449–8A, 449–8B, 445–13A, 445–13B.

Type Locality.—Holotype: New Jersey, Clayton core, 306.9 ft, Zone NP 9, Manasquan Formation. Paratypes: pl. 16, figs. 3a,b, New Jersey, GL 917 core, 225 ft, Zone NP 9, Vincentown Formation; pl. 16, figs. 5a,b, Clayton core, 306.9 ft, Zone NP 9, Manasquan Formation.

Occurrence.—This species occurs in the upper part of Zone NP 9 and the lower part of Zone NP 10 in New Jersey.

Depository.—Original scanning electron photomicrographs and negatives are stored at the U.S. Geological Survey in Reston, Va.

Fasciculithus thomasii Perch-Nielsen, 1971

Plate 17, figures 1–5; plate 36, figures 12, 13

Remarks.—Perch-Nielsen (1985, p. 484) described this small species as "bell shaped with slightly concave sides in the lower part of the column and convex sides in the upper half." In addition, there is a distinctive, thin, slightly concave base, which extends outward from the proximal column and is visible in side view (pl. 17, fig. 3b). The proximal column is covered with both large and small depressions. The dome on top of the proximal column is a tall circular structure usually with six blades that radiate outward and taper sharply downward at their outer edge. The dome of *F. thomasii*, when viewed from the top, most closely resembles that of *Fasciculithus involutus*.

Occurrence.—*Fasciculithus thomasii* occurs sporadically in Zone NP 8 and more consistently in Zone NP 9 and lower Zone NP 10 in New Jersey. Perch-Nielsen (1985, fig. 37) reported that this species occurs in upper Zone NP 9 and lower Zone NP 10.

Fasciculithus tympaniformis Hay & Mohler *in* Hay and others, 1967

Plate 36, figures 14, 15, 19, 20

Occurrence.—Forms resembling this species in the light microscope occur from Zone NP 5 to the lower part of Zone NP 10 in New Jersey. Perch-Nielsen (1985, fig. 37) reported this species in Zones NP 5 through NP 9. *Fasciculithus tympaniformis* was not observed with the SEM in the present study. Wise and Wind (1976, p. 295–296) put *F. tympaniformis* in synonymy with *Fasciculithus involutus*, attributing *F. involutus* to etched forms of *F. tympaniformis*. The present authors, however, believe that it is unlikely that our well-preserved New Jersey specimens of *F. involutus* represent etching. In fact, all our SEM photomicrographs of the genus *Fasciculithus* indicate a similar structure that consists of numerous small-to-large depressions on the proximal column. It would appear more likely that smooth forms, such as *F. tympaniformis*, indicate recrystallization. The presence of both species in the same sample under the light microscope, but not the SEM, adds to the confusion, and the present authors are unwilling to put *F. tympaniformis* in synonymy with *F. involutus* without additional SEM studies.

Goniolithus fluckigeri Deflandre, 1957

Plate 17, figures 6, 7; plate 36, figures 17, 18

Hornibrookina arca Bybell & Self-Trail n. sp.

Plate 18, figures 1–9; plate 36, figures 16, 21, 22

Diagnosis.—A species of *Hornibrookina* in which both shields arch convexly upward; the central area contains slender laths that radiate outward from a narrow longitudinal bar.

Description.—*Hornibrookina arca* n. sp., which is 4–7 µm in size, has 21 to 26 elements both on the distal and the proximal shield. The shield elements overlap slightly on the distal surface (pl. 18, fig. 1); overgrowth is common on the proximal surface (pl. 18, fig. 6), and it is unclear whether these elements overlap or not. This species has an irregular outline on the distal surface; the central portion of one side bulges outward, there is an indentation next to the bulge, and each apex of the shield narrows somewhat (pl. 18, fig. 4). Both shields arch convexly (pl. 18, fig. 9b). There is less arching of the shields and narrowing of the apices on the oldest specimens of this species, which were found in Zone NP 3. The amount of arching increases through time and is at its maximum in Zones NP 8 and NP 9.

On the distal surface, the large central area contains slender laths that extend inward from either side of the specimen. The spacing between laths varies so that individual laths from either side may or may not be in alignment (pl. 18, fig. 1). In the central area where the laths join, they thicken to form a longitudinal bar. With recrystallization, the laths and the longitudinal bar thicken and widen somewhat. The proximal shield is smaller than the distal shield and has a more uniform outline because it lacks the lateral extension and indentation that occur on the distal shield. This species occurs in New Jersey, Alabama, Maryland, and Virginia. The holotype is from Virginia, where the preservation is significantly better than in the other areas.

Remarks.—*Hornibrookina australis* Edwards & Perch-Nielsen, 1975 also is arched convexly, but it has considerably wider laths and lacks the central longitudinal bar that is found in *H. arca* n. sp. It is possible, but unlikely, that previously illustrated specimens of *H. australis* may represent heavily overgrown specimens of *H. arca* n. sp. *Hornibrookina australis* lacks a longitudinal bar, and as mentioned above, overgrowth that was observed in *H. arca* n. sp. did not remove its distinctive longitudinal bar.

Holotype.—Plate 18, figure 1, SEM photomicrograph number 90.

Paratypes.—Plate 18, figures 2, 6, SEM photomicrograph numbers 88, 87.

Type Locality.—Holotype: Virginia, Aquia Creek locality, sample AQ 24, NP 8, Aquia Formation. Paratypes: pl. 18, fig. 2, Maryland, Piscataway Creek locality, sample PC 21, NP 8, Aquia Formation; pl. 18, fig. 6, Piscataway Creek locality, sample PC 23, NP 8, Aquia Formation.

Occurrence.—This species is present in Zones NP 3 through lower NP 10 in New Jersey, Maryland, and Virginia, and it also has been observed in lower Zone NP 10 in Alabama.

Depository.—The original scanning electron photomicrographs and negatives are stored at the U.S. Geological Survey in Reston, Va.

Lophodolithus nascens Bramlette & Sullivan, 1961

Plate 19, figures 1–5; plate 36, figures 23–25, 30

Remarks.—As mentioned in the original description of Bramlette and Sullivan (1961, p. 145), early forms of this species (from upper Zone NP 9 and Zone NP 10) are more symmetrically shaped than younger specimens (Zones NP 11 and younger; see fig. 22). At first glance, early symmetrical specimens of *L. nascens* in proximal view (pl. 19, fig. 3) resemble exceptionally large specimens of *Placozygus sigmoides* (pl. 21, fig. 4b). However, *L. nascens* is easily discernible in distal view (pl. 19, fig. 5) because it lacks a vertical structure on the crossbar, has a basket-shaped rim, and is consistently larger than any specimens of *P. sigmoides*.

Occurrence.—In New Jersey, *L. nascens* occurs in upper Zone NP 9 through Zone NP 15. Perch-Nielsen (1985, fig. 80) indicated that the range of this species is from the upper fourth of Zone NP 9 to Zone NP 15.

Markalius apertus Perch-Nielsen, 1979

Plate 19, figures 6–11; plate 36, figures 27–29

Remarks.—New Jersey specimens of *M. apertus* have a large variation in the size of the central hole, as was mentioned in the original description of Perch-Nielsen (1979, p. 128). The central hole in the distal plate is larger than the hole in the proximal plate, and part of the proximal plate is visible from the distal surface as a circular recessed area inside the ring of distal segments (pl. 19, figs. 6–10).

Occurrence.—This species occurs from Zone NP 3 to lower Zone NP 10 in New Jersey. *Markalius apertus* may occur sporadically in Zone NP 11, but this needs to be confirmed with the SEM. Perch-Nielsen (1985, fig. 23) only reported this species from the Paleocene.

Markalius inversus (Deflandre *in* Deflandre & Fert, 1954) Bramlette & Martini, 1964

Plate 20, figures 1–5; plate 36, figures 26, 31

Remarks.—Plate 20, figures 4, 5, show specimens of *M. inversus* with dissolution of the central region. They resemble *Markalius apertus* but differ in that *M. inversus* has a broad central basal disk (pl. 20, fig. 3) that is absent in *M. apertus*.

Neochiastozygus concinnus s. ampl. (Martini, 1961) Perch-Nielsen, 1971

Plate 20, figures 6–12; plate 36, figures 32–35

Remarks.—Most specimens observed in Zone NP 9 and NP 10, although they closely resemble typical specimens of *Neochiastozygus concinnus* in the structure of the rim, as well as in the structure of the crossbar, have a much narrower crossbar and are somewhat larger (pl. 20, figs. 7–11) than typical older representatives of this species. There are occasional specimens in Zones NP 9 and NP 10 that do contain the more typical, broader crossbar of this species (pl. 20, figs. 6, 12). For the present, the younger forms with a narrower crossbar are retained within *N. concinnus* as *N. concinnus* s. ampl. When viewed from the proximal surface (pl. 20, fig. 10), these narrower forms closely resemble *Neochiastozygus junctus* (Bramlette & Sullivan, 1961) Perch-Nielsen, 1971; *N. junctus*, however, is larger, and its crossbar is structurally less complex when viewed from the distal surface.

Occurrence.—Typical specimens of *N. concinnus* (pl. 20, figs. 6, 12) commonly occur from Zones NP 4 through NP 8, and they are present only occasionally above Zone NP 8. The somewhat larger specimens with a narrower crossbar first occur in Zone NP 8 and extend into Zone NP

10. It seems probable that the younger forms represent a evolutionary shift in the species.

Neochiastozygus imbriei Haq & Lohmann, 1975

Plate 37, figure 1

Occurrence.—Specimens identified as *N. imbriei* on the basis of the crossbar occasionally were observed with the light microscope in Zones NP 3 to NP 10 in New Jersey. Perch-Nielsen (1985) reported that *N. imbriei* occurred in upper Zone NP 3 and Zone NP 4. Identification of this species was not confirmed with the SEM above Zone NP 4.

Neococcolithes dubius (Deflandre *in* Deflandre & Fert, 1954) Black, 1967

Plate 21, figures 1–3

Occurrence.—This species occurs sporadically in upper Zone NP 9, Zone NP 10, and Zone NP 11, and it occurs consistently in Zones NP 12 and above. Perch-Nielsen (1985, fig. 78) reported that *N. dubius* occurred in Zones NP 12 to NP 18.

Placozygus sigmoides (Bramlette & Sullivan, 1961) Romein, 1979

Plate 21, figures 4–9; plate 37, figures 2, 3

Remarks.—Both Paleocene and Eocene specimens from New Jersey appear to be approximately the same size. Particularly well-preserved specimens of *P. sigmoides* (pl. 21, figs. 7, 8) from Zone NP 8 show a fluted upper edge on the stem. It is unclear whether this fluting is typical of the species throughout its range or whether it is only typical of specimens from Zone NP 8.

Occurrence.— This species occurs from Zone NP 3 to Zone NP 10 in New Jersey, Alabama, Maryland, and Virginia. This species was not found below Zone NP 3 because sediments older than this generally do not occur in the Atlantic Coastal Plain. Perch-Nielsen (1985, p. 532) indicated that *P. sigmoides* occurs from the Cretaceous to Zone NP 9.

Pontosphaera spp.

Occurrence.—Specimens of the genus *Pontosphaera* were observed very sporadically with the light microscope. They never were observed with the SEM.

Rhomboaster bramlettei (Brönnimann & Stradner, 1960) n. comb.

Plate 22, figures 1–4; plate 23, figures 1–4; plate 37, figures 4, 5, 7–10

Marthasterites bramlettei Brönnimann & Stradner, 1960, p. 366, figs. 17–20. 23, 24
Tribrachiatus bramlettei (Brönnimann & Stradner, 1960) Proto Decima and others, 1975, p. 49, pl. 4, figs. 17, 18.
Rhomboaster bitrifida Romein, 1979, p. 191, pl. 7, figs. 3, 4; pl. 10, figs. 10–13.
Rhomboaster calcitrapa Gartner, 1971, p. 114, pl. 4, figs. 2–6.
Rhomboaster cuspis Bramlette & Sullivan, 1961, p. 166, pl. 14, figs. 17, 18, 19a–c

Remarks.—*Rhomboaster bitrifida, R. calcitrapa,* and *R. cuspis* are herein placed in synonymy with *Rhomboaster bramlettei* n. comb., a species that was previously referred to as *Tribrachiatus bramlettei*. There are very few published scanning electron photomicrographs of *Rhomboaster cuspis*. However, Perch-Nielsen (1985, fig. 90–11) and Müller (1979, pl. 2, figs. 7–9) do have SEM illustrations of *R. cuspis*, and the four specimens cannot be distinguished from previously illustrated specimens of *"Tribrachiatus" bramlettei*. By placing *R. cuspis,* the original type species of the genus *Rhomboaster* (Bramlette and Sullivan, 1961), in synonymy with *Tribrachiatus bramlettei* (originally named as *Marthasterites bramlettei* by Brönnimann and Stradner in 1960), *Marthasterites bramlettei* by priority becomes the type species of the genus *Rhomboaster*, and *Tribrachiatus bramlettei* becomes *Rhomboaster bramlettei* n. comb. *Tribrachiatus contortus* and *Tribrachiatus orthostylus*, which belong in the same genus as *Rhomboaster bramlettei* because of their similar construction, also are transferred to the genus *Rhomboaster* and become *Rhomboaster contortus* n. comb. and *Rhomboaster orthostylus* n. comb.

In order to better understand the structure of the genera *Rhomboaster* and *Tribrachiatus*, which had several species described from upper Zone NP 9 and lower Zone NP 10, the present authors made clay models of the four species, *Rhomboaster bitrifida, Rhomboaster calcitrapa, Rhomboaster cuspis,* and *Tribrachiatus bramlettei* (now *Rhomboaster bramlettei* n. comb.), based upon examination of illustrations from many publications and from our many scanning electron photomicrographs. There was insufficient photographic detail to construct a clay model of *Rhomboaster intermedia* Romein, 1979. After constructing and examining these clay models, it became apparent that ray length is the only difference among the four species. They all have an identical central area: a rhombohedron. Each of the six rhombohedral faces is identical in that the central area is depressed, and three of the four corners of each face are extended outward to form rays that vary in length from specimen to specimen. Six of the eight apices or corners of the rhombohedron are extended into rays. A clay model of *Rhomboaster cuspis* with very short arms was turned into a model of *Rhomboaster bramlettei* n. comb. merely by lengthening the rays. As the rays were lengthened, in order to maintain symmetry within a specimen, the angles on each face of the rhombohedron were forced to change: the angle increased on the corner without a ray, and the angles decreased on the three corners containing rays.

Based on examination of the literature, it appears that in many instances 1) long-rayed specimens have been attributed to *Rhomboaster bitrifida* and *Rhomboaster calcitrapa*, 2) specimens with rays of intermediate length have been placed in *Rhomboaster bramlettei* n. comb., and 3) short-rayed specimens have been attributed to *Rhomboaster cuspis*. The present authors believe that the difference in the ray length is most likely a result of normal species variation and (or) of varying amounts of dissolution. There is a continuum in specimens from short to long-rayed forms, and there is no apparent stratigraphic significance to the ray length. Specimens from poorly preserved samples invariably have most of the ray dissolved away, leaving only the central rhombohedral structure (pl. 23, fig. 4). Specimens from well-preserved samples contain predominantly longer-rayed forms.

There is another reason why the various forms of *Rhomboaster bramlettei* n. comb. have been placed in different species in the past: *R. bramlettei* n. comb. looks significantly different when viewed from different angles. One specimen of *R. bramlettei* n. comb. from Alabama, illustrated from several views (pl. 22, figs. 1a–g), shows how, depending upon which view is presented, this specimen could have been attributed to more than one species. If you look straight down at either of the two nonextended apices, six evenly spaced rays are visible (pl. 22, fig. 1a), and specimens observed from this angle normally are placed in *R. bramlettei* n. comb. The same specimen looks very different, however, when it is viewed from directly above one of the rhombohedron faces (pl. 22, fig. 1b) and looks different again when viewed at an angle to a rhombohedron face (pl. 22, fig. 1c). Symbols were placed on the SEM photomicrographs to help the reader track the same rhombohedral face from view to view.

Occurrence.—*Rhomboaster bramlettei* n. comb. by definition cannot occur below Zone NP 10, and this species has its LAD within Zone NP 10, slightly above the FAD of *Rhomboaster contortus* n. comb. Because *R. bramlettei* n. comb. is used to define the base of Zone NP 10, samples that contain *R. bitrifida, R. calcitrapa,* and *R. cuspis*, which previously were placed in the late Paleocene Zone NP 9, must now be placed in Zone NP 10.

Rhomboaster contortus (Stradner, 1958) n. comb.

Discoaster contortus Stradner, 1958, p. 12, figs. 35, 36.
Marthasterites contortus (Stradner, 1958) Deflandre, 1959, p. 139.
Tribrachiatus contortus (Stradner, 1958) Bukry, 1972, p. 1081.

Remarks.—Placement of *Tribrachiatus bramlettei* in synonymy with *Rhomboaster cuspis* necessitates usage of the genus *Rhomboaster* by priority, and *T. bramlettei* becomes *Rhomboaster bramlettei* n. comb. *Tribrachiatus contortus*, because of its similar structure, belongs in the same genus as *R. bramlettei* n. comb. and thus becomes *Rhomboaster contortus* n. comb. See *Rhomboaster bramlettei* n. comb. in the Taxonomic Notes section for additional discussion.

Rhomboaster orthostylus (Shamrai, 1963) n. comb.

Discoaster tribrachiatus Bramlette & Riedel, 1954, p. 397, pl. 38, fig 11.
Marthasterites tribrachiatus (Bramlette & Riedel, 1954) Deflandre, 1959, p. 138, pl. 2, fig 1.
Tribrachiatus orthostylus Shamrai, 1963, p. 38, pl. 2, figs. 13, 14.

Remarks.—Placement of *Tribrachiatus bramlettei* in synonymy with *Rhomboaster cuspis* necessitates usage of the genus *Rhomboaster* by priority, and *T. bramlettei* becomes *Rhomboaster bramlettei* n. comb. *Tribrachiatus orthostylus*, because of its similar structure, belongs in the same genus as *R. bramlettei* n. comb. and thus becomes *Rhomboaster orthostylus* n. comb. See *Rhomboaster bramlettei* n. comb. in the Taxonomic Notes section for additional discussion.

Rhomboaster spineus (Shafik & Stradner, 1971) Perch-Nielsen, 1984

Plate 31, figures 1, 2; plate 37, figures 6, 11–13

Remarks.—In basic shape, *Rhomboaster spineus* resembles *Rhomboaster bramlettei* n. comb.: there is a central rhombohedron with depressed faces and arms extending from six of the rhombohedral apices; when viewed from one of the nonextending apices, six, evenly spaced arms are visible (pl. 31, fig. 1a). Each of the arms of *Rhomboaster spineus* contains single or multiple, irregularly shaped, lateral extensions along its length. These lateral ray extensions are absent in *Rhomboaster bramlettei* n. comb. The original description by Shafik and Stradner (1971, p. 93), which was based upon light microscope observations, mentioned only one set of lateral extensions. A specimen from the Clayton core, (pl. 31, figs. 1a,b) shows additional smaller lateral extensions, although these extensions would be both difficult to observe with a light microscope and prone to dissolution.

Occurrence.—This species has a very limited stratigraphic occurrence in New Jersey, where it extends from the very uppermost part of Zone NP 9 to the lower part of Zone NP 10. In the Clayton core (fig. 17), this species first occurs approximately 4 ft below the first occurrence of *Rhomboaster bramlettei* n. comb. and last occurs 6 ft above the first occurrence of *R. bramlettei* n. comb. Shafik and Stradner (1971, p. 77) also placed the first occurrence of *Rhomboaster spineus* below the first occurrence of *R. bram-*

lettei n. comb. in Egypt, although they did not report that *R. spineus* extended up into the Eocene.

Scapholithus apertus Hay & Mohler, 1967

Plate 24, figures 1–7; plate 37, figures 14, 15

Remarks.—*Scapholithus apertus* is constructed of a rhombohedron with a thickened rim on two faces. There are 14–18 slender laths that extend from either side of the rim to the center of the scapholith. One face of the rhombohedron (side 1) is wider and contains a single bar, which runs parallel to the longitudinal axis for most of the length of the specimen (pl. 24, figs. 5–7). This bar is visible on the opposite side (side 2) as an area where there is no space between the laths (pl. 24, figs. 1–4). The laths are slightly offset from one another where they meet. This species is very small in size, and the central area is easily dissolved (pl. 24, fig. 7). The present authors agree with Romein (1979, p. 188) that *S. apertus* and *Scapholithus rhombiformis*, both of which were described as new species by Hay and Mohler (1967), represent the two different sides of the same species. *Scapholithus apertus* has precedence over *S. rhombiformis* because its description comes first in Hay and Mohler (1967, p. 1534).

Occurrence.—*Scapholithus apertus* ranges from Zone NP 5 to the upper part of Zone NP 9 in New Jersey, Maryland, and Virginia. Its LAD is a useful biostratigraphic marker in the upper Paleocene (see fig. 18). *Scapholithus apertus*, when it first appears in Zone NP 5, is somewhat narrower than specimens found in Zone NP 9 (fig. 22). In Zone NP 5, the long axis divided by the short axis is approximately 1.6, while in Zone NP 9, the proportion is 1.3. This appears to be a biostratigraphically useful evolutionary change (see the Evolution of Calcareous Nannofossils section).

Sphenolithus anarrhopus Bukry & Bramlette, 1969

Plate 37, figure 16

Occurrence.—*Sphenolithus anarrhopus* was seen occasionally with the light microscope in Zones NP 8 to NP 11 in New Jersey. It was never observed with the SEM.

Sphenolithus primus Perch-Nielsen, 1971

Plate 24, figures 8–10; plate 37, figures 17, 18

Remarks.—The basal column in *S. primus* does not flare outward at the base as does the base in *Sphenolithus moriformis* (Brönnimann & Stradner, 1960) Bramlette & Wilcoxon, 1967, and the basal elements are the same height as the tiers of lateral elements overlying the basal column. This contrasts with *S. moriformis*, in which the basal elements are longer than the lateral elements of the overlying tiers. However, these two species are difficult to distinguish in the light microscope.

Occurrence.—This species was found in New Jersey in Zones NP 5 to NP 10. Perch-Nielsen (1985, fig. 69) reported that it occurs from Zones NP 4–11.

Toweius callosus Perch-Nielsen, 1971

Plate 25, figures 1–9; plate 37, figures 19, 20, 25

Remarks.—*Toweius callosus* is a member of the genus *Toweius* in which there is a thin grid on the proximal side that covers the small, central oval-shaped opening. The grid is easily dissolved, leaving only a scalloped edge around the outside of the central hole (pl. 25, fig. 7), which is also visible with a light microscope. With the SEM, the grid can be seen from the distal surface through the central opening (pl. 25, figs. 4–6). However, the size of the central opening on the distal surface appears to be smaller than on the proximal surface, and the outer edge of the grid is covered. The central opening in *T. callosus* is smaller than the opening in *Toweius pertusus* in equivalent-aged sediments and has smaller individual perforations. The grid in *T. pertusus* is thicker than in *T. callosus* and extends farther up from the proximal surface. Specimens of *T. callosus* from Zone NP 9 (pl. 25, fig. 9) appear to be identical to those found in Zone NP 12 (pl. 25, fig. 1a).

Occurrence.—This species first occurs in New Jersey in mid Zone NP 9 and was observed at least as high as Zone NP 12 in New Jersey and Maryland. Perch-Nielsen (1985, fig. 58) reported that *T. callosus* occurs from Zones NP 12 to NP 15.

Toweius eminens (Bramlette & Sullivan, 1961) Gartner, 1971 var. *eminens* autonym

Plate 26, figures 1, 3, 4, 6, 8, 10, 11; plate 27, figure 1;
plate 37, figures 23, 24

Coccolithus eminens Bramlette & Sullivan, 1961, p. 139, pl. 1, fig. 3a–d.
Toweius eminens (Bramlette & Sullivan, 1961) Gartner, 1971, p. 114.

Remarks.—Romein (1979, p. 125) placed *Toweius tovae* in synonymy with *Toweius eminens*. The present authors agree that *T. tovae* and *T. eminens* cannot be distinguished except by number of perforations, and they more properly belong in the same species. *Toweius eminens* was defined as having four pores, while *T. tovae* was defined as having six pores (Perch-Nielsen, 1971a, p. 360). However, specimens from New Jersey, Maryland, and Virginia from Zones NP 5 through lower NP 9 contain three, four, five, six, seven, eight, or nine pores, and no one number of holes appears to be dominant. *Toweius eminens* var. *eminens* autonym is herein established to distinguish forms that have three or four perforations on the distal surface (originally called *T. eminens*) from those that have five to nine perforations (has been called *T. tovae*, but herein is renamed to *T. eminens* var. *tovae* stat. nov.). The establishment of two varieties was necessary in order to distinguish specimens of *T. eminens* that evolve into *Toweius occultatus* (*T. eminens* var. *eminens* autonym; see fig. 23) from specimens that probably evolve into *Toweius serotinus* n. sp. (*T. eminens* var. *tovae* stat. nov.). See the Evolution of Calcareous Nannofossils section for additional discussion of these species and varieties.

On the proximal surface of both varieties of *T. eminens*, there is a fine grid, which is nearly identical in all specimens. The bars that separate the pores on the distal surface of both varieties of *T. eminens* frequently extend down to the proximal surface as a more solid region of the proximal grid (pl. 26, figs. 9–11). On most specimens, the proximal surface grid, which is dissolution resistant, is easily visible through the large pores on the distal surface. The central portion of this grid thickens and domes upwards and actually extends up to the distal surface (pl. 26, fig. 1) where it is seen as a cluster of small pores in the center of the specimen.

Occurrence.—*Toweius eminens* var. *eminens* autonym occurs in Zone NP 5 to upper Zone NP 9 in New Jersey, Alabama, Maryland, and Virginia. Perch-Nielsen (1985) reported this species from Zones NP 7 to NP 10. The specimen illustrated on plate 26, figure 1, confirms a Zone NP 5 occurrence for this species. In the upper part of Zone NP 9, *T. eminens* var. *eminens* autonym evolves into *T. occultatus* (fig. 23). This occurs at the Vincentown Formation-Manasquan Formation transitional boundary (fig. 18).

Toweius eminens (Bramlette & Sullivan, 1961) Gartner, 1971 var. *tovae* Perch-Nielsen, 1971 stat. nov.

Plate 26, figures 2, 5a,b, 7, 9; plate 27, figures 2, 3, 5, 8; plate 37, figure 22

Toweius tovae Perch-Nielsen, 1971, p. 359–360, pl. 13, figs. 1–3; pl. 14, figs. 8, 9.

Remarks.—See *T. eminens* var. *eminens* autonym for a general discussion of the species *T. eminens*. *Toweius eminens* var. *tovae* stat. nov. is herein established to distinguish forms that have five to nine perforations (which have been called *T. tovae*, but herein are renamed to *T. eminens* var. *tovae* stat. nov.) from those that have three or four perforations on the distal surface (originally called *T. eminens* but here changed to *T. eminens* var. *eminens* autonym). The authors believe it is necessary to establish two varieties in order to distinguish specimens that probably evolve into *Toweius serotinus* n. sp. (*T. eminens* var. *tovae* stat. nov.) from specimens that evolve into *Toweius occultatus* (*T. eminens* var. *eminens* autonym). See the section on Events Surrounding the Paleocene-Eocene Boundary for additional discussion of these species and varieties.

Occurrence.—*Toweius eminens* var. *tovae* stat. nov. occurs from Zone NP 5 to upper Zone NP 9. *Toweius eminens* var. *tovae* stat. nov. and *T. eminens* var. *eminens* autonym have nearly identical ranges; the LAD of *T. eminens* var. *tovae* stat. nov. occurs no more than 2 ft above the LAD of *T. eminens* var. *eminens* autonym in the Clayton core (fig. 17). The specimen illustrated in plate 26, figure 2, confirms a Zone NP 5 placement for *T. eminens* var. *tovae* stat. nov. In upper Zone NP 9, *T. eminens* var. *tovae* stat. nov. probably evolves into *Toweius serotinus* n. sp.

Toweius occultatus (Locker, 1967) Perch-Nielsen, 1971

Plate 27, figures 4, 6, 9–12; plate 28, figures 1–5, 7–9, 11, 12; plate 37, figures 31–34

Remarks.—Typical forms of *Toweius occultatus* have two lateral projections into the central area, which in most specimens do not join. A thin grid covers the central area on the proximal side, and this grid, which is visible through the distal pores, is easily dissolved away. The pattern of the proximal surface grid is similar to that in *T. eminens* var. *eminens* autonym, from which it evolved; however, *T. occultatus* no longer has the central thickening of the grid toward the distal surface that is present in *T. eminens* var. *eminens* autonym. The projections into the central area are solid and continuous from the distal to the proximal surface and are not concealed by the grid on the proximal surface (pl. 28, figs. 5, 11). Early specimens of *T. occultatus* also may have two longitudinal projections into the central area (pl. 27, figs. 4, 6), and these certainly could in the past have been included within the species *T. eminens* var. *eminens* autonym. However, once the population has evolved sufficiently so that the majority of specimens have 1) only two perforations, 2) projections that do not meet, and 3) projections parallel to the long axis that are much smaller than those parallel to the short axis, the species is considered to officially shift to *T. occultatus* (319.4 ft in the Clayton core, fig 17; see fig. 23).

Toweius occultatus is somewhat larger when it first appears in upper Zone NP 9 (approximately 6.5 µm) than it is in Zones NP 12 and NP 13 (approximately 5.3 µm). Occasionally, instead of two lateral projections, there are three or four lateral projections into the central area (pl. 28, fig. 1). This contrasts with earlier forms where additional smaller projections are longitudinal projections. This new type of variation first appears at 307.2 ft in the Clayton Core (fig. 17; this is 14 ft above the top of the Vincentown Formation-Manasquan Formation boundary) and occurs sporadically until the extinction of this species in Zone NP 13. Variation in the number of projections into the central area appears to be typical of this genus. See the Evolution of Calcareous Nannofossils section (item number 6) for additional discussion of the evolution of this species.

Occurrence.—*Toweius occultatus* occurs from upper Zone NP 9 to Zone NP 13 in New Jersey. This species also occurs in similarly aged sediments in Alabama, Maryland, and Virginia. Perch-Nielsen (1985, fig. 58) reported that *T. occultatus* occurs from upper Zone NP 9 to lower Zone NP 12.

Toweius pertusus (Sullivan, 1965) Romein, 1979

Plate 29, figures 1–10; plate 37, figures 21, 26–28

Remarks.—The central area on the distal surface of this species is covered by a thick coarse grid of irregularly shaped pores that extends from the proximal to the distal surface. From Zones NP 5 to NP 10, the number of pores in the central area varies from six to twenty-seven. *Toweius pertusus* can be distinguished from *T. eminens* var. *tovae* stat. nov. by its smaller size and the presence of a coarse, not fine, grid on the proximal surface (pl. 29, figs. 8–10). *Prinsius bisulcus* (Stradner, 1963) Hay & Mohler, 1967, which appears to be very similar to *T. pertusus*, probably has been used for specimens of *T. pertusus* with a small number of perforations. Additional SEM study is necessary to determine whether *P. bisulcus* warrants placement in synonymy with *T. pertusus*. Throughout Zones NP 9, NP 10, and NP 11, the number of central perforations increases (see figs. 24 and 25), and the central area becomes increasingly more recessed below the distal surface (pl. 29, figs. 1–3). Plate 29, figure 7, illustrates a typical form from Zone NP 8 in which the outer edge that surrounds the pores is not recessed.

Occurrence.—*Toweius pertusus* commonly occurs from Zone NP 4 to at least the lower part of Zone NP 10 in New Jersey. This species also occurs commonly in Alabama, Maryland, and Virginia. The upper range is imprecisely known in New Jersey; Perch-Nielsen (1985, fig. 58) reported that *T. pertusus* occurs from Zones NP 6 to NP 12.

Toweius serotinus Bybell & Self-Trail n. sp.

Plate 27, figure 7; plate 28, figures 6, 10; plate 37, figures 29, 30, 35

Diagnosis.—Member of the genus *Toweius* with 13–19 pores in the center of the distal surface and a fine grid covering the proximal surface.

Description.—The central distal surface pores can be slightly smaller than the pores located along the circumference of the pore area. The pore region is continuous with and at the same level as the distal collar or wall (pl. 28, fig. 6). The proximal surface grid resembles the proximal grid of *Toweius eminens* var. *tovae* stat. nov. However, the proximal grid no longer extends up to the distal surface; this is visible on plate 28, figure 10, in which much of the distal surface is dissolved away. Specimens are generally 6–8 μm in size.

Remarks.—The present authors believe that *T. serotinus* n. sp. evolved from *T. eminens* var. *tovae* stat. nov. in late Zone NP 9. Both species are the same size, but *T. serotinus* n. sp. has larger pores in the central area and lacks the central upward bulge of the proximal grid found in *T. eminens* var. *tovae* stat. nov. When *T. serotinus* n. sp. first appears in upper Zone NP 9, *Toweius pertusus* is smaller and has the central pores recessed below the level of the distal collar. *Toweius serotinus* n. sp. can be distinguished from *T. eminens* var. *tovae* stat. nov. and *T. pertusus* with both the SEM and the light microscope. See the Evolution of Calcareous Nannofossils section for additional information on *T. serotinus* n. sp.

Holotype.—Plate 28, figure 6, SEM photomicrograph number 464–24.

Paratype.—Plate 27, figure 7, SEM photomicrograph number 493–1.

Type Locality.—Holotype, New Jersey, Clayton core, 298.5 ft, Zone NP 10, Manasquan Formation. Paratype, New Jersey, Clayton core, 317 ft, Zone NP 9, Manasquan Formation.

Occurrence.—This species occurs in upper Zone NP 9 and lower Zone NP 10 in New Jersey and in Virginia. *Toweius serotinus* n. sp. is never very common and probably represents a fairly unsuccessful evolutionary experiment.

Depository.—The original scanning electron photomicrographs and negatives are stored at the U.S. Geological Survey in Reston, Va.

Transversopontis pulcher (Deflandre *in* Deflandre & Fert, 1954) Perch-Nielsen, 1967

Plate 30, figures 1–10; plate 38, figures 1–3

Remarks.—Early forms of this elliptical species in upper Zone NP 9 have two large, rounded perforations and a narrow rim. The basal plate (distal view) has a very rough appearance due to the presence of small chunks of calcite that are oriented parallel to the rim (pl. 30, fig. 1). Specimens in Zone NP 10 (pl. 30, figs. 4, 5) have a wider, taller rim and a somewhat smoother basal plate than those in upper Zone NP 9 (fig. 26a,b). The differences do not appear to be the result of preservational variation. The authors believe that evolution continues in Zone NP 11 (pl. 30, fig. 6) by additional thickening of the rim, smoothing of the basal plate, and the appearance and deepening of basal perforations around the outer portion of the basal plate (fig. 26*C*). By Zone NP 12, typical *T. pulcher* forms are present (pl. 30, fig. 7; fig. 26*D*).

In SEM photomicrographs, specimens of early *T. pulcher* are very difficult to distinguish from *Zygodiscus herlyni*; the most distinguishing feature in *T. pulcher* is the crack parallel to the long axis that bifurcates the central bar (pl. 30, figs. 1–3). This crack, which also is present in typical younger specimens of *T. pulcher* from Zone NP 12 (pl. 30, fig. 7), is absent in specimens of *Z. herlyni* (pl. 31, figs. 3–6). Early forms of *T. pulcher* usually have more rounded central perforations than the more semicircular shape of the perforations in *Z. herlyni*. With the light microscope, early *T. pulcher* is very easy to distinguish from *Z. herlyni*; the central bar is optically distinct in *Z. herlyni* (pl. 38, fig. 4) but is optically continuous in all forms of *T. pulcher* (pl. 38, fig. 1). *Discolithus* sp. aff. *D. pulcher* of Bramlette and Sullivan (1961, pl. 3, fig. 9) is probably an early form of *T. pulcher*. *Pontosphaera*, *Zygodiscus*, and *Transversopontis* are very similar in their basic construction, and the present authors are undecided whether these genera should be placed in synonymy.

Occurrence.—Transversopontis pulcher first occurs in the upper part of Zone NP 9 and extends well up into the Eocene. In the absence of the genus *Rhomboaster*, the FAD of this species can be used to approximate the Paleocene-Eocene boundary.

Zygodiscus herlyni **Sullivan, 1964**

Plate 31, figures 3–6; plate 38, figures 4, 5, 9

Remarks.—As mentioned in the discussion above, in SEM photomicrographs early specimens of *T. pulcher* closely resemble those of *Z. herlyni*. The major difference lies in the structure of the central bar; in *Z. herlyni* the bar is optically discontinuous in the light microscope (pl. 38, fig. 4) and consists of a series of laths parallel to the short axis (pl. 31, figs. 3a, 4, 5b), and in *T. pulcher* the bar is an optically continuous (pl. 38, fig. 1) and much simpler structure with a longitudinal crack (pl. 30, fig. 5).

Occurrence.—Zygodiscus herlyni ranges from Zones NP 7 to NP 11 in New Jersey, Alabama, Maryland, and Virginia.

Zygrhablithus bijugatus **(Deflandre *in* Deflandre & Fert, 1954) Deflandre, 1959**

Plate 31, figure 7; plate 38, figures 6–8

Semiholiolithus kerabyi Perch-Nielsen, 1971a, p. 357, pl. 9, figs. 5–7; pl. 10, figs. 1–6; pl. 14, figs. 19–21.

Remarks.—Semiholiolithus kerabyi is herein placed in synonymy with *Zygrhablithus bijugatus* because these two species cannot be differentiated consistently with either the light microscope or with the SEM. *Zygrhablithus bijugatus* has a significant amount of structural and probably biostratigraphic variation; this variation can easily accommodate the differences found between typical specimens and specimens that previously were placed within *S. kerabyi*.

Occurrence.—Zygrhablithus bijugatus occurs sporadically in Zones NP 8 to NP 10 and more consistently in younger sediments in New Jersey, Alabama, Maryland, and Virginia.

REFERENCES CITED

Aubry, M.-P. 1989, Handbook of Cenozoic calcareous nannoplankton Book 3: Ortholithae (Pentaliths, and others) Heliolithae (Fasciculiths, Sphenoliths and others): New York, Micropaleontology Press, The American Museum of Natural History, 279 p.

Aubry, M.P., Berggren, W.A., Kent, D.V., Flynn, J.J., Klitgord, K.D., Obradovich, J.D., and Prothero, D.R., 1988, Paleogene geochronology: An integrated approach: Paleoceanography, v. 3, p. 707–742.

Berggren, W.A., 1969, Paleogene biostratigraphy and planktonic foraminifera of northern Europe: Proceedings 1st International Conference on Planktonic Microfossils, 1967, v. 1, p. 121–160.

Berggren, W.A., Kent, D.V., and Flynn, J.J., 1985, Jurassic to Paleogene: Part 2—Paleogene geochronology and chronostratigraphy, *in* Snelling, N.J., ed., The chronology of the geological record, The Geological Society of London, Memoirs, no. 10, p. 141–195.

Bolli, H.M., 1957, The genera *Globigerina* and *Globorotalia* in the Paleocene-lower Eocene Lizard Springs Formation of Trinidad BWI: U.S. National Museum Bulletin, v. 215, p. 51–81.

———1966, Zonation of Cretaceous to Pliocene marine sediments based on planktonic Foraminifera: Boletin Informacion Asociacion Venezolana de Geologia, Mineria, y Petroleo, v. 9, no. 1, p. 3–32.

Bramlette, M.N., and Riedel, W.R., 1954, Stratigraphic value of discoasters and some other microfossils related to Recent coccolithophores: Journal of Paleontology, v. 28, p. 385–403.

Bramlette, M.N., and Sullivan, F.R., 1961, Coccolithophorids and related nannoplankton of the early Tertiary in California: Micropaleontology, v. 7, no. 2, p. 129–174.

Brönnimann, Paul and Stradner, Herbert, 1960, Die Foraminiferen und Discoasteridenzonen von Kuba und ihre interkontinentale Korrelation: Erdoel-Zeitschrift, v. 76, p. 364–369.

Bukry, David, 1969, Upper Cretaceous coccoliths from Texas and Europe: University of Kansas Paleontological Contributions, Article 51, 79 p.

———1972, Further comments on coccolith stratigraphy, Leg 12, Deep Sea Drilling Project, *in* Laughton, A.S., Berggren, W.A., and others, Initial Reports of the Deep Sea Drilling Project, v. 12: Washington, D.C., U.S. Government Printing Office, p. 1071–1083.

———1973, Low-latitude coccolith biostratigraphic zonation, *in* Edgar, N.T., and others, Initial Reports of the Deep Sea Drilling Project, v. 15: Washington, D.C., U.S. Government Printing Office, p. 685–703.

———1978, Biostratigraphy of Cenozoic marine sediments by calcareous nannofossils: Micropaleontology, v. 24, p. 44–60.

Bukry, David, and Percival, S.F., 1971, New Tertiary calcareous nannofossils: Tulane Studies in Geology and Paleontology, v. 8, no. 3, p. 123–146.

Deflandre, Georges, 1959, Sur les nannofossiles calcaires et leur systématique: Revue de Micropaléontologie, v. 2, no. 3, p. 127–152.

Faris, Mahmoud, 1992, Morphometry of *Discoaster multiradiatus* Bramlette & Riedel (1954) and its biochronological significance in the early Paleogene of Egypt: Delta Journal of Science, v. 16, no. 1, p. 152–170.

Gartner, Stefan, 1971, Calcareous nannofossils from the JOIDES Blake Plateau cores and revision of Paleogene nannofossil zonation: Tulane Studies in Geology and Paleontology, v. 8, p. 101–121.

Gibson, T.G., and Bybell, L.M., in press, Sedimentary patterns across the Paleocene-Eocene boundary in the Atlantic and Gulf Coastal Plains of the United States: Geologie.

Gibson, T.G., Bybell, L.M., and Owens, J.P., 1993, Latest Paleocene lithologic and biotic events in neritic deposits of southwestern New Jersey: Paleoceanography, v. 8, no. 4, p. 495–514.

Haq, B.U., and Aubry, M.-P., 1981, Early Cenozoic calcareous nannoplankton biostratigraphy & paleobiogeography of North Africa and the Middle East and Trans-Tethyan correlations: *In* Salem, M.J., and Busrewil, M.T., Geology of Libya, v. 1, Academic Press (London), p. 271–304.

Hay, W.W., and Mohler, H.P., 1967, Calcareous nannoplankton from early Tertiary rocks at Pont Labau, France, and Paleocene-early Eocene correlations: Journal of Paleontology, v. 41, no. 6, p. 1505–1541.

Heck, S.E. van, and Prins, Ben, 1987, A refined nannoplankton zonation for the Danian of the Central North Sea: Abhandlungen der Geologischen Bundesanstalt Wien, v. 39, p. 285–303.

Martini, Erlend, 1961, Nannoplankton aus dem Tertiär und der obersten Kreide von SW-Frankreich: Senckenbergiana Lethaea, v. 42, p. 1–32.

———1971, Standard Tertiary and Quaternary calcareous nannoplankton zonation: Planktonic Conference, 2d, Rome 1969, Proceedings, p. 739–785.

Müller, Carla, 1979, Calcareous nannofossils from the North Atlantic (Leg 48), *in* Montadert, Lucien, Roberts, D.G., and others, Initial Reports of the Deep Sea Drilling Project, v. 48: Washington, D.C., U.S. Government Printing Office, p. 589–639.

Okada, Hisatake, and Bukry, David, 1980, Supplementary modification and introduction of code numbers to the low-latitude coccolith biostratigraphic zonation (Bukry, 1973; 1975): Marine Micropaleontology, v. 5, no. 3, p. 321–325.

Owens, J.P., Bybell, L.M., Paulachok, Gary, Ager, T.A., Sugarman, P.J., and Gonzales, V.M., 1988, Stratigraphy of the Tertiary sediments in a 945-foot (288 m) corehole near Mays Landing in the southeastern New Jersey Coastal Plain: U.S. Geological Survey Professional Paper 1484, p. 1–39.

Perch-Nielsen, Katharina, 1971a, Einige neue Coccolithen aus dem Paleozän der Bucht von Biskaya: Bulletin of the Geological Society of Denmark, v. 20, p. 347–361.

———1971b, Elektronenmikroskopische Untersuchungen an Coccolithen und verwandten Formen aus dem Eozän von Dänmark: Kongelige Danske Videnskabernes Selskab Biologishe, v. 18, no. 3, p. 1–76.

———1979, Calcareous nannofossil zonation at the Cretaceous/Tertiary boundary in Denmark: Proceedings Cretaceous-Tertiary Boundary Event Symposium, Copenhagen, v. 1, p. 115–135.

———1985, Cenozoic calcareous nannofossils, *in* Bolli, H.M., Saunders, J.B., and Perch-Nielsen, Katharina, eds., Plankton stratigraphy: Cambridge, Cambridge University Press, p. 427–554.

Perch-Nielsen, Katharina, and Petters, S.W., 1981, Cretaceous and Eocene microfossil ages from the southern Benue Trouch, Nigeria: Archives des Sciences, v. 34, no. 2, p. 211–218.

Poore, R.Z., and Bybell, L.M., 1988, Eocene to Miocene biostratigraphy of New Jersey core ACGS #4: Implications for regional stratigraphy: U.S. Geological Survey Bulletin 1829, p. 1–22.

Pospichal, J.J., and Wise, S.W., 1990, Paleocene to middle Eocene calcareous nannofossils of ODP Sites 689 and 690, Maud Rise, Weddell Sea, *in* Barker, P.F., Kennett, J.P., and others, Proceedings of the Ocean Drilling Program, Scientific Results, v. 113, p. 613–638.

Premoli-Silva, Isabella, and Bolli, H.M., 1973, Late Cretaceous to Eocene planktonic foraminifera and stratigraphy of Leg 15 Sites in the Caribbean Sea, *in* Edgar, N.T., Saunders, J.B., and others, Initial Reports of the Deep Sea Drilling Project, v. 15, Washington, D.C., U.S. Government Printing Office, p. 499–547.

Proto Decima, Franca, Roth, P.H., and Todesco, Livio, 1975, Nannoplancton calcareo del Paleocene e dell'Eocene della sezione di Possagno: Schweizerische Paläontologische Abhandlungen, v. 97, p. 35–55.

Reinhardt, Peter, 1966, Zur Taxionomie und Biostratigraphie des fossilen Nannoplanktons aus dem Malm, der Kreide und dem Alttertiär Mitteleuropas: Freiberger Forschungshefte, C196, p. 5–109.

Romein, A.J.T., 1979, Lineages in early Paleogene calcareous nannoplankton: Utrecht Micropaleontological Bulletins, no. 22, p. 1–231.

Shafik, Samir, and Stradner, Herbert, 1971, Nannofossils from the Eastern Desert, Egypt with reference to Maastrichtian nannofossils from the USSR: Jahrbuch der Geologische Bundesanstalt, v. 17, p. 69–104.

Shamrai, I.A., 1963, Nekotorye formy verkhnemelovykh i paleogenovykh kokkolitov i diskoasterov na yuge russkoi platformy: Izvestiya Vysshikh Uchebnyk Zavedenii Geologiya i Razvedka, v. 6, no. 4, p. 27–40.

Stainforth, R.M., Lamb, J.L., Luterbacher, Hans, Beard, J.H., and Jeffords, R.M., 1975, Cenozoic planktonic foraminiferal zonation and characteristic index forms: University of Kansas Paleontological Contributions, Article 62, p. 1–425.

Steinmetz, J.C., and Stradner, Herbert, 1984, Cenozoic calcareous nannofossils from Deep Sea Drilling Project Leg 75, southeast Atlantic Ocean, *in* Hay, W.W., Sibuet, J.C., and others, Initial Reports of the Deep Sea Drilling Project, v. 75: Washington, D.C., U.S. Government Printing Office, p. 671–753.

Stradner, Herbert, 1958, Die fossilen Discoasteriden Österreichs, Teil 1: Die in den Bohrkernen der Tiefbohrung Korneuburg 1 enthaltenen Discoasteriden, Erdoel-Zeitschrift, v. 74, p. 178–188.

———1961, Vorkommen von Nannofossilien im Mesozoikum und Alttertiär: Erdoel-Zeitschrift, v. 77, no. 3, p. 77–88.

Wei, Wuchang, 1992, Biometric study of *Discoaster multiradiatus* and its biochronological utility: Memorie di Scienze Geologiche, v. 43, p. 219–235.

Wise, S.W., and Wind, F.H., 1976, Mesozoic and Cenozoic calcareous nannofossils recovered by DSDP Leg 36 drilling on the Falkland Plateau, southwest Atlantic sector of the Southern Ocean, *in* Parker, P.F., Dalziel, I.W.D., and others, Initial Reports of the Deep Sea Drilling Project, v. 36, U.S. Government Printing Office, p. 269–491.

PLATES 1–38

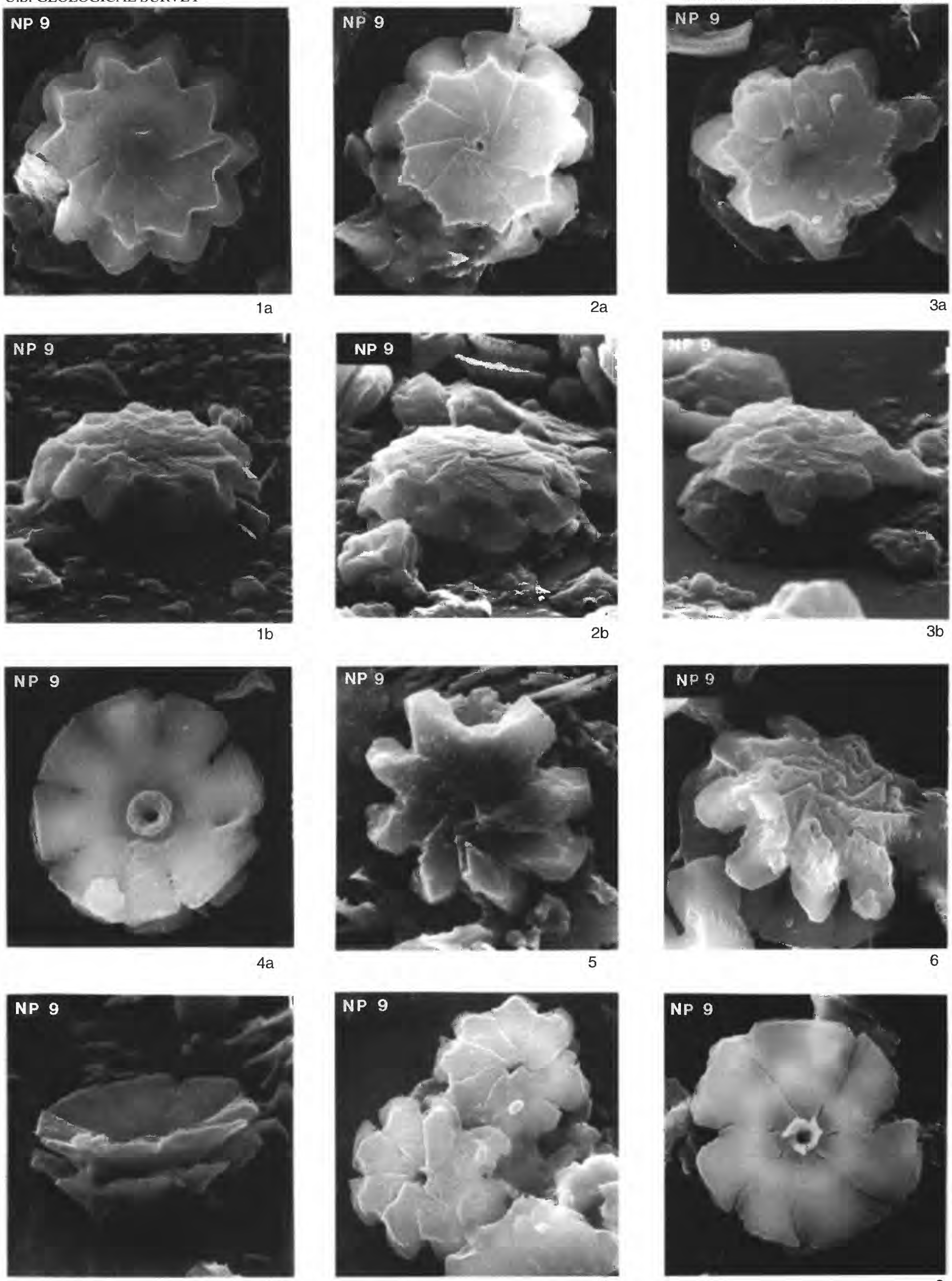
PLATE 1

[Designation of calcareous nannofossil zone of Martini (1971) shown in upper left corner of each photomicrograph]

Figures 1–7. *Biantholithus astralis*

- 1a. Distal view (diameter, 11.5 μm), Zone NP 9, Clayton core (307.2 ft), New Jersey.
- 1b. Same specimen—tilted view showing presence of distal and proximal shields.
- 2a. Distal view (diameter, 10.6 μm), Zone NP 9, GL 915 core (130 ft), New Jersey.
- 2b. Same specimen—tilted view.
- 3a. Distal view (diameter, 8.8 μm), Zone NP 9, GL 913 core (125 ft), New Jersey.
- 3b. Same specimen—tilted view.
- 4a. Proximal view (diameter, 9.7 μm), Zone NP 9, Clayton core (348.5 ft), New Jersey.
- 4b. Same specimen—tilted view.
- 5. Distal view (diameter, 11.2 μm), Zone NP 9, Aquia Creek locality, Virginia.
- 6. Distal view (diameter, 9 μm), Zone NP 9, Clayton core (322 ft), New Jersey.
- 7. Distal view (diameter, 8.3 μm), Zone NP 9, GL 915 core (130 ft), New Jersey.

8. *Biantholithus sparsus*?—proximal view (diameter, 8.5 μm), Zone NP 9, Clayton core (322 ft), New Jersey.



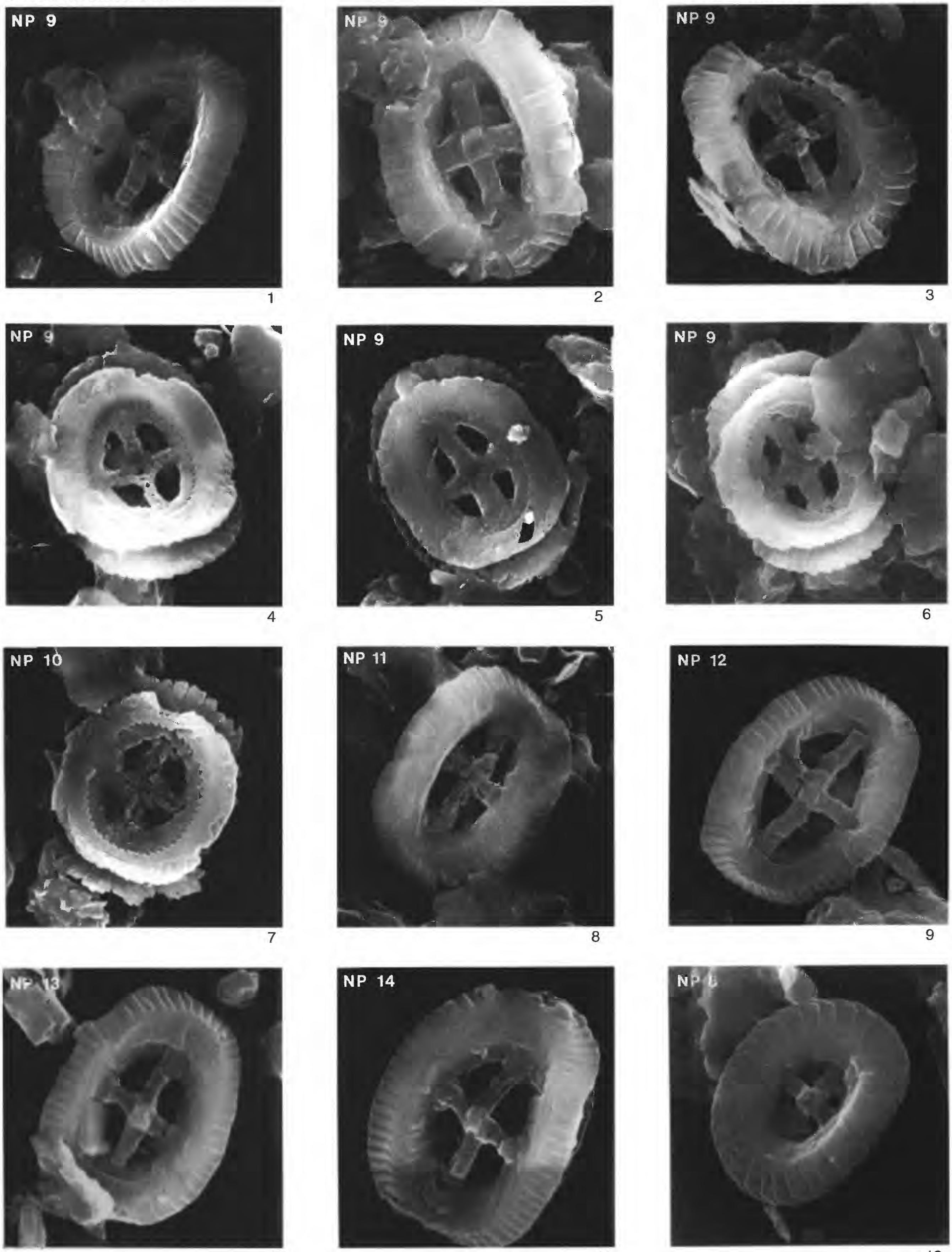
BIANTHOLITHUS

PLATE 2

[Designation of calcareous nannofossil zone of Martini (1971) shown in upper left corner of each photomicrograph]

Figures 1–11. *Campylosphaera dela*

1. Distal view (length, 6.9 µm), Zone NP 9, Clayton core (307.9 ft), New Jersey.
2. Distal view (length, 6.6 µm), Zone NP 9, Clayton core (307.9 ft), New Jersey.
3. Distal view (length, 6.5 µm), Zone NP 9, Clayton core (307.2 ft), New Jersey.
4. Proximal view (length, 6.3 µm), Zone NP 9, GL 917 core (220 ft), New Jersey.
5. Proximal view (length, 7.2 µm), Zone NP 9, Clayton core (309.6 ft), New Jersey.
6. Proximal view (length, 6.5 µm), Zone NP 9, Clayton core (307.2 ft), New Jersey.
7. Proximal view (length, 6.2 µm), Zone NP 10, New Brooklyn core (360 ft), New Jersey.
8. Distal view (length, 7.3 µm), Zone NP 11, Butler Place core (570 ft), New Jersey.
9. Distal view (length, 8.2 µm), Zone NP 12, Solomons Island core (386.7 ft), Maryland.
10. Distal view (length, 8.3 µm), Zone NP 13, ACGS-4 core (908 ft), New Jersey.
11. Distal view (length, 8.7 µm), Zone NP 14, ACGS-4 core (900 ft), New Jersey.
12. ?*Campylosphaera* sp.—possible ancestor for *Campylosphaera dela*—distal view (length, 5.5 µm), Zone NP 8, K 15 core (120 ft), New Jersey.



CAMPYLOSPHAERA

PLATE 3

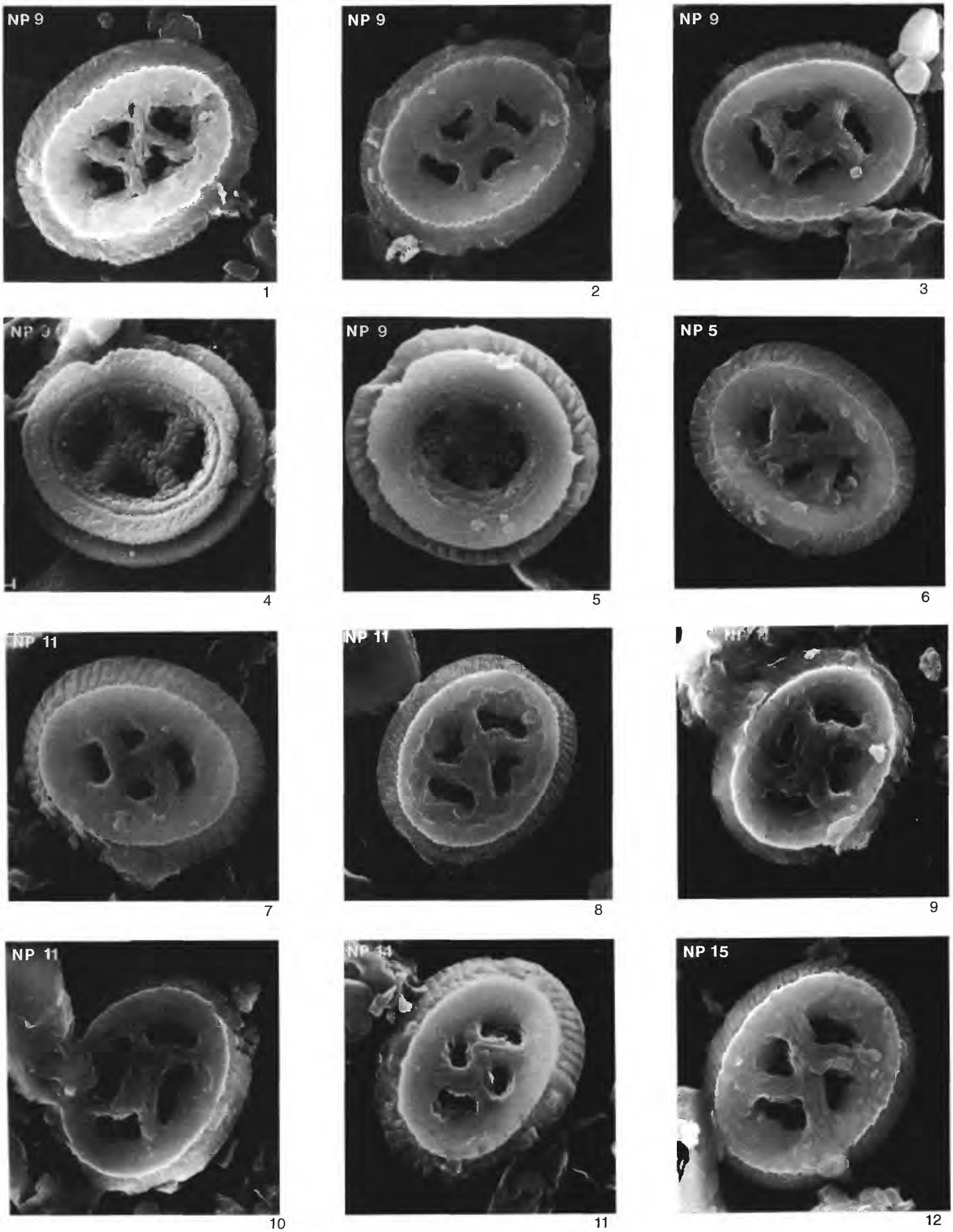
[Designation of calcareous nannofossil zone of Martini (1971) shown in upper left corner of each photomicrograph]

Figures 1–8, 11, 12. *Chiasmolithus bidens*

1. Distal view (length, 8.6 µm), Zone NP 9, Clayton core (324.4 ft), New Jersey.
2. Distal view (length, 9.5 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.
3. Distal view (length, 11.1 µm), Zone NP 9, GL 916 core (95 ft), New Jersey.
4. Proximal view (length, 10.3 µm), Zone NP 9, Aquia Creek locality, Virginia.
5. Proximal view (length, 8.1 µm), Zone NP 9, Piscataway Creek locality, Maryland.
6. Distal view (length, 9.1 µm), Zone NP 5, GL 915 core (150 ft), New Jersey.
7. Distal view (length, 9.5 µm), Zone NP 11, Butler Place core (550 ft), New Jersey.
8. Distal view (length, 12.5 µm), Zone NP 11, Solomons Island core (394 ft), Maryland.
11. Distal view (length, 9.2 µm), Zone NP 14, ACGS-4 core (900 ft), New Jersey.
12. Distal view (length, 11.3 µm), Zone NP 15, Clayton core (232 ft), New Jersey.

9, 10. *Chiasmolithus eograndis*

9. Distal view (length, 15.8 µm), Zone NP 11, Butler Place core (570 ft), New Jersey.
10. Distal view (length, 16.7 µm), Zone NP 11, Butler Place core (550 ft), New Jersey.



CHIASMOLITHUS

PLATE 4

[Designation of calcareous nannofossil zone of Martini (1971) shown in upper left corner of each photomicrograph]

Figures 1–4. *Chiasmolithus consuetus* s. ampl.

1a. Distal view (length, 14.2 µm), Zone NP 9, Clayton core (317.4 ft), New Jersey.

1b. Same specimen—tilted view.

2. Distal view (length, 10.5 µm), Zone NP 9, Clayton core (322 ft), New Jersey.

3. Distal view (length, 6.9 µm), Zone NP 9, Clayton core (309.6 ft), New Jersey.

4. Proximal view (length, 5.4 µm), Zone NP 9, Clayton core (307.2 ft), New Jersey.

5. *Cruciplacolithus* sp.— distal view (length, 10.7 µm), Zone NP 9, Clayton core (317.4 ft), New Jersey.

6–8. *Coccolithus pelagicus*

6a. Distal view (length, 7.3 µm), Zone NP 9, Clayton core (348.5 ft), New Jersey.

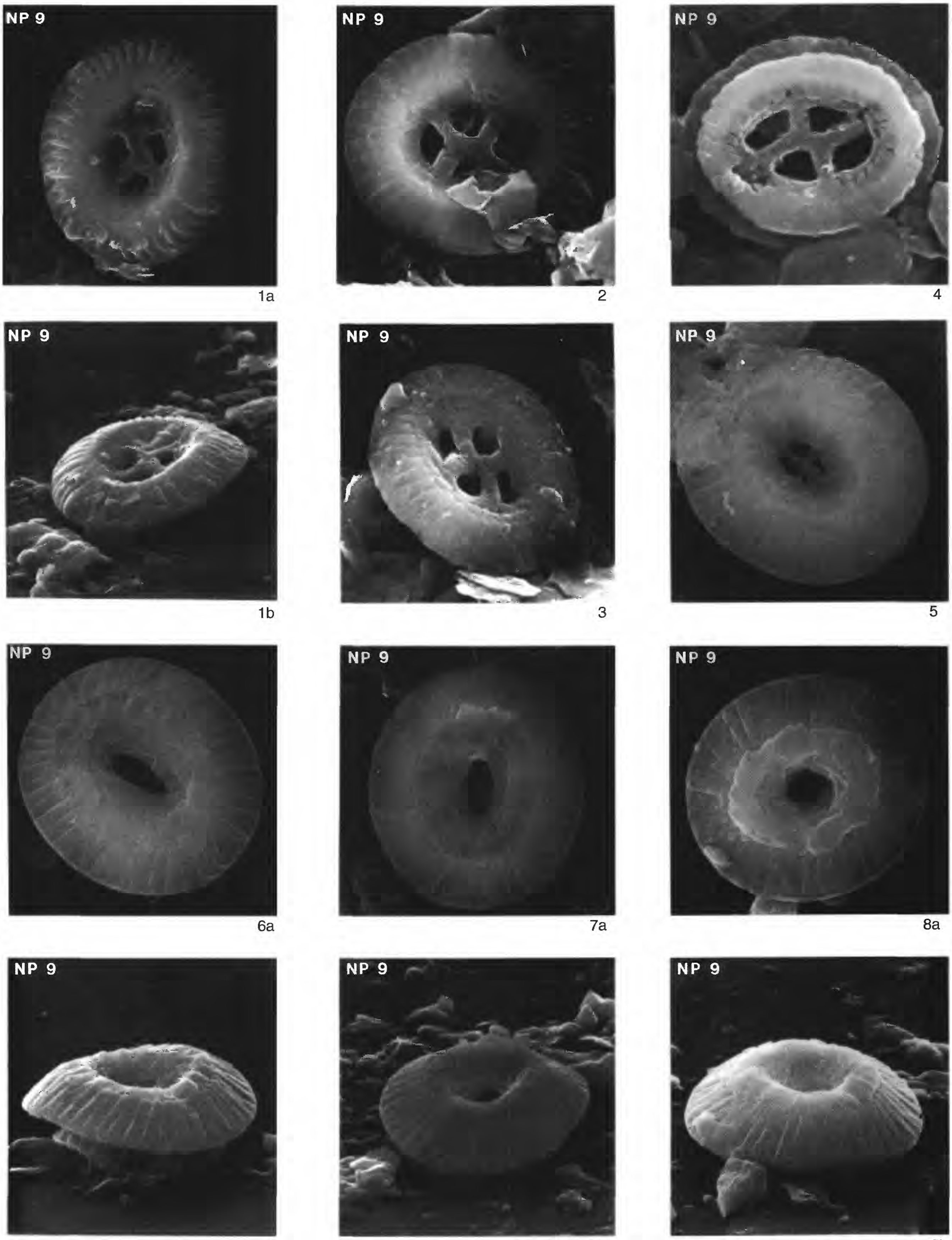
6b. Same specimen—tilted view.

7a. Distal view (length, 7.0 µm), Zone NP 9, Clayton core (307.9 ft), New Jersey.

7b. Same specimen—tilted view.

8a. Distal view (length, 7.1 µm), Zone NP 9, Clayton core (307.2 ft), New Jersey (overgrowth on collar).

8b. Same specimen—tilted view.



CHIASMOLITHUS, CRUCIPLACOLITHUS, AND *COCCOLITHUS*

PLATE 5

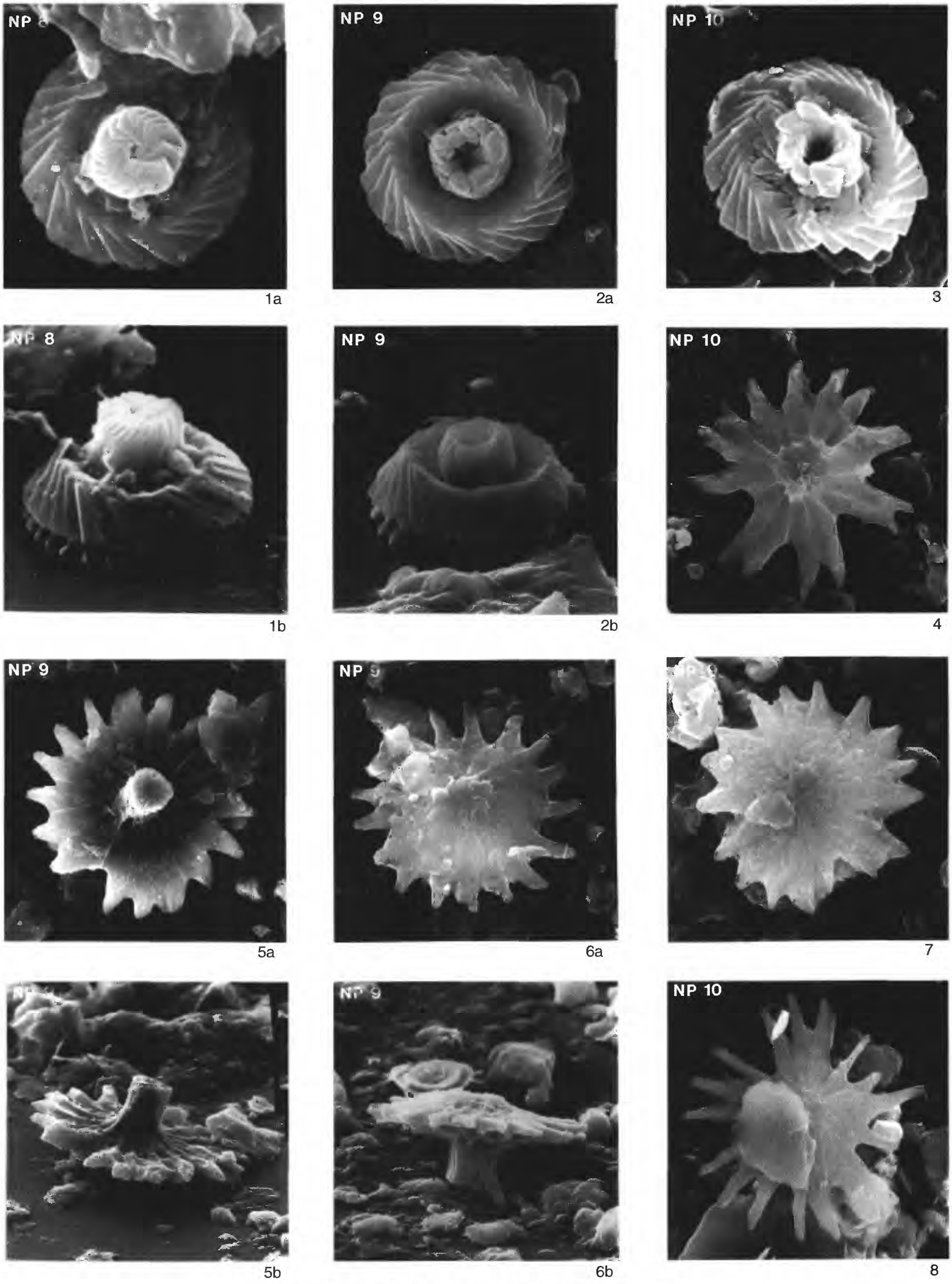
[Designation of calcareous nannofossil zone of Martini (1971) shown in upper left corner of each photomicrograph]

Figures 1–3. *Cyclagelosphaera prima* n. comb.

- 1a. Distal view (diameter, 4.8 µm), Zone NP 8, Solomons Island core (565.7 ft), Maryland.
- 1b. Same specimen—tilted view.
- 2a. Distal view (diameter, 4.1 µm), Zone NP 9, GL 915 core (130 ft), New Jersey.
- 2b. Same specimen—tilted view.
- 3. Distal view (diameter, 4.7µm), Zone NP 10, Solomons Island core (405.7 ft), Maryland.

4–8. *Discoaster anartios* n. sp.

- 4. Paratype, side 1 (diameter, 16.1 µm), Zone NP 10, Clayton core (298.5 ft), New Jersey.
- 5a. Holotype, side 1 (diameter, 15.8 µm), Zone NP 9, Clayton core (307.2 ft), New Jersey.
- 5b. Same specimen—tilted view.
- 6a. Side 2 (diameter, 14.3 µm), Zone NP 9, Clayton core (307.2 ft), New Jersey.
- 6b. Same specimen—tilted view.
- 7. Side 2 (diameter, 13.0 µm), Zone NP 9, Clayton core (309.6 ft), New Jersey.
- 8. Paratype, side 2 (diameter, 18.7 µm), Zone NP 10, Clayton core (298.5 ft), New Jersey.



CYCLAGELOSPHAERA AND *DISCOASTER*

PLATE 6

[Designation of calcareous nannofossil zone of Martini (1971) shown in upper left corner of each photomicrograph]

Figures 1–5. *Discoaster diastypus*

1. Side 1 (diameter, 18.1 µm), Zone NP 10, C226 core (254.4 ft), Alabama.
2. Side 2 (diameter, 16.6 µm), Zone NP 10, C226 core (254.4 ft), Alabama.
3. Side 2 (diameter, 19.4 µm), Zone NP 10, C226 core (254.4 ft), Alabama.
4. Side 2 (diameter, 18.7 µm), Zone NP 10, C226 core (254.4 ft), Alabama.
5. Side 2 (diameter, 20.3 µm), Zone NP 10, C226 core (254.4 ft), Alabama.

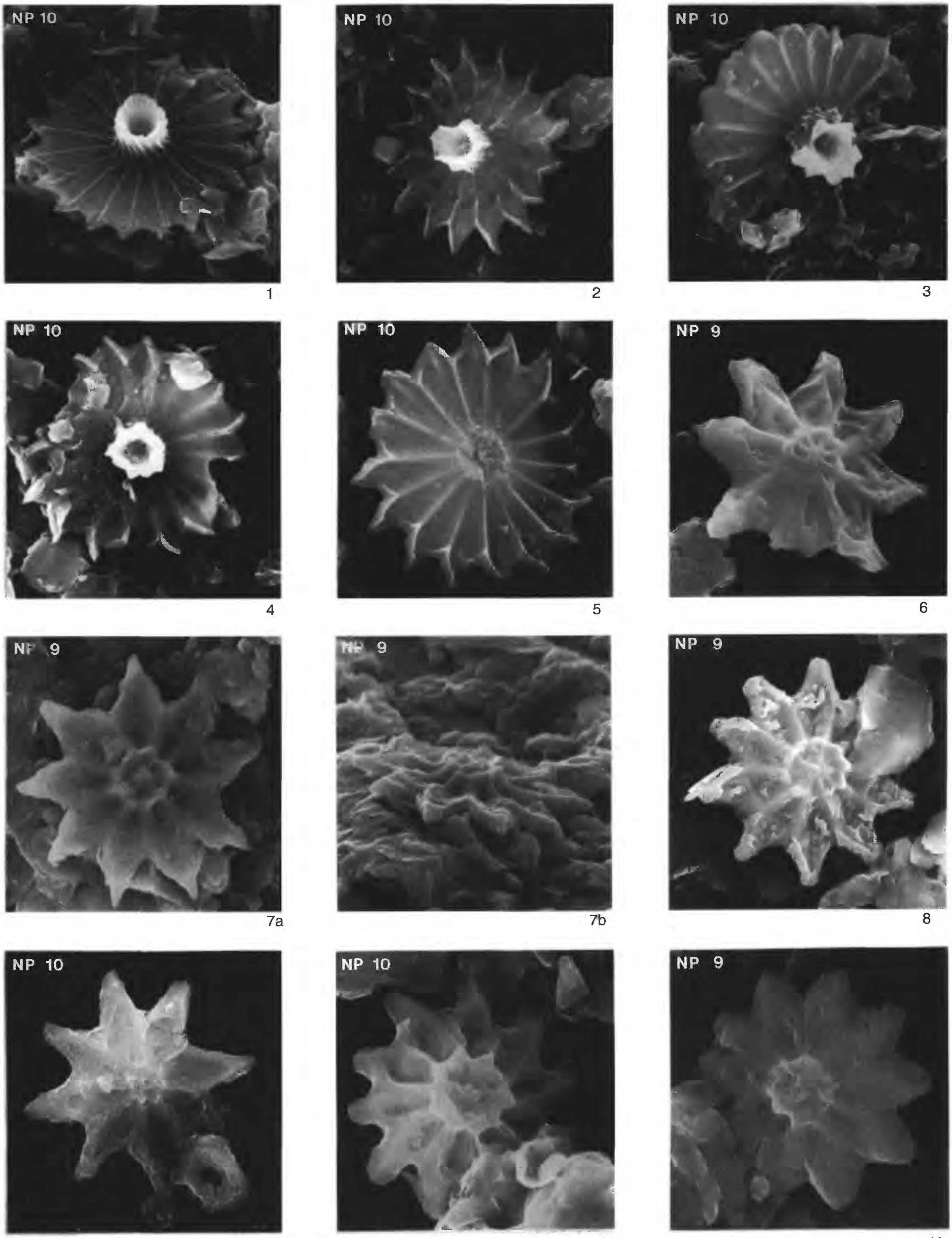
6–11. *Discoaster falcatus*

6. Side 1 (diameter, 14.1 µm), Zone NP 9, Clayton core (322 ft), New Jersey.

7a. Side 1 (diameter, 17.5 µm), Zone NP 9, Clayton core (307.9 ft), New Jersey.

7b. Same specimen—tilted view.

8. Side 1 (diameter, 12.7 µm), Zone NP 9, GL 917 core (225 ft), New Jersey.
9. Side 1 (diameter, 15.0 µm), Zone NP 10, New Brooklyn core (360 ft), New Jersey.
10. Side 1 (diameter, 9.1 µm), Zone NP 10, GL 915 core (100 ft), New Jersey.
11. Side 1 (diameter, 8.6 µm), Zone NP 9, Clayton core (317.4 ft), New Jersey.


NP 10
1
NP 10
2
NP 10
3
NP 10
4
NP 10
5
NP 9
6
NP 9
7a
NP 9
7b
NP 9
8
NP 10
9
NP 10
10
NP 9
11

DISCOASTER

PLATE 7

[Designation of calcareous nannofossil zone of Martini (1971) shown in upper left corner of each photomicrograph]

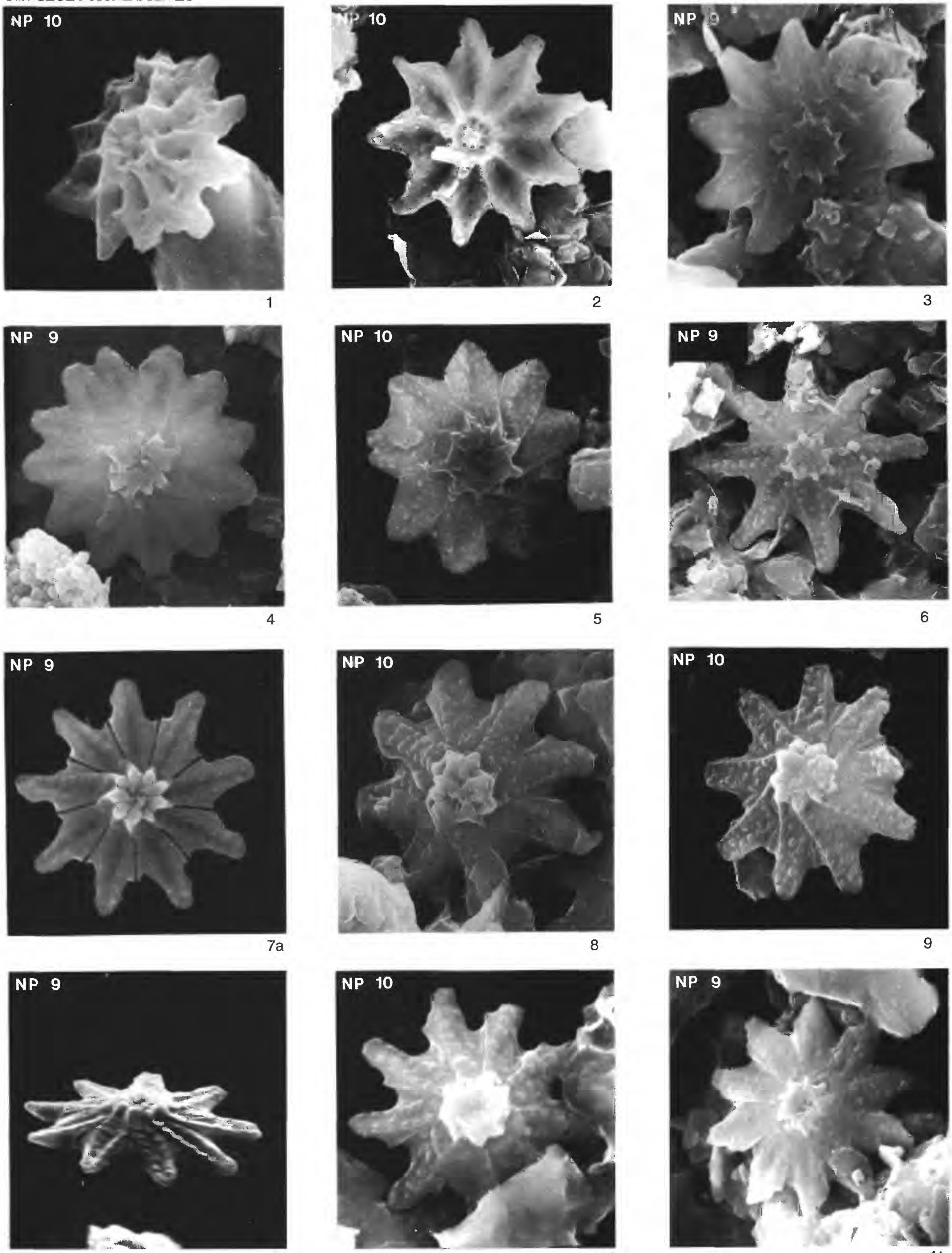
Figures 1–11. *Discoaster falcatus*

1. Side 1 (diameter, 10.7 µm), Zone NP 10, GL 915 core (100 ft), New Jersey.
2. Side 1 (diameter, 15.6 µm), Zone NP 10, Clayton core (298.5 ft), New Jersey.
3. Side 2 (diameter, 17.2 µm), Zone NP 9, GL 915 core (110 ft), New Jersey.
4. Questionable early form—side 2 (diameter, 10.9 µm), Zone NP 9, Clayton core (348.5 ft), New Jersey.
5. Side 2 (diameter, 12.3 µm), Zone NP 10, GL 917 core (200 ft), New Jersey.
6. Side 2 (diameter, 15.0 µm), Zone NP 9, Clayton core (322 ft), New Jersey.

7a. Side 2 (diameter, 13.6 µm), Zone NP 9, Bells Landing locality, Alabama.

7b. Same specimen—tilted view.

8. Side 2 (diameter, 11.5 µm), Zone NP 10, GL 915 core (100 ft), New Jersey.
9. Side 2 (diameter, 10.7 µm), Zone NP 10, C226 core (254.4 ft), Alabama.
10. Side 2 (diameter, 10.0 µm), Zone NP 10, GL 915 core (100 ft), New Jersey.
11. Side 2 (diameter, 15.3 µm), Zone NP 9, GL 917 core (220 ft), New Jersey.


NP 10
1
10
2
NP
3
NP 9
4
NP 10
5
NP 9
6
NP 9
7a
NP 10
8
NP 10
9
NP 9
7b
NP 10
10
NP 9
11

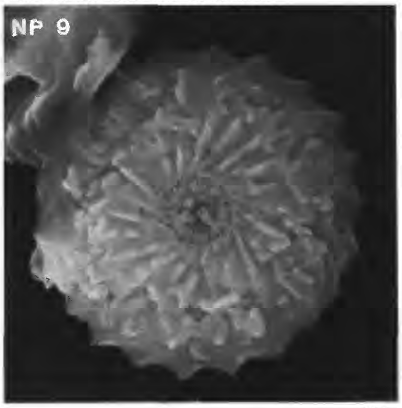
DISCOASTER

PLATE 8

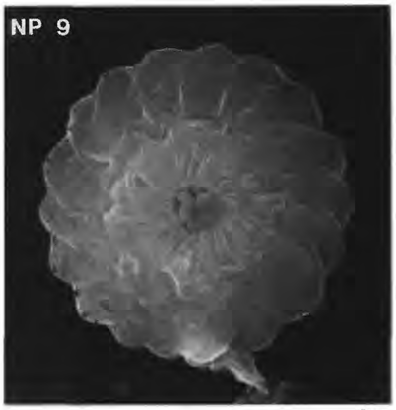
[Designation of calcareous nannofossil zone of Martini (1971) shown in upper left corner of each photomicrograph]

Figures 1–9. *Discoaster lenticularis*

1a. Flat side (diameter, 6.3 µm), Zone NP 9, K 15 core (115 ft), New Jersey.
1b. Same specimen—tilted view.
2a. Flat side (diameter, 6.4 µm), Zone NP 9, Clayton core (324.4 ft), New Jersey.
2b. Same specimen—tilted view.
3a. Flat side (diameter, 8.1 µm), Zone NP 9, Clayton core (324.4 ft), New Jersey.
3b. Same specimen—tilted view.
4. Flat side (diameter, 8.6 µm), Zone NP 9, Clayton core (307.9 ft), New Jersey.
5. Convex side (diameter, 7.3 µm), Zone NP 9, Clayton core (306.9 ft), New Jersey.
6. Convex side (diameter, 5.1 µm), Zone NP 9, Clayton core (307.2 ft), New Jersey.
7. Flat side (diameter, 8.0 µm), Zone NP 10, GL 915 core (100 ft), New Jersey.
8. Convex side (diameter, 5.7 µm), Zone NP 9, GL 913 core (125 ft), New Jersey.
9. Convex side (diameter, 7.4 µm), Zone NP 10, Clayton core (302.5 ft), New Jersey.

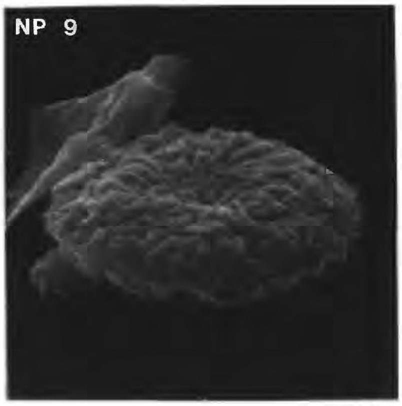


1a

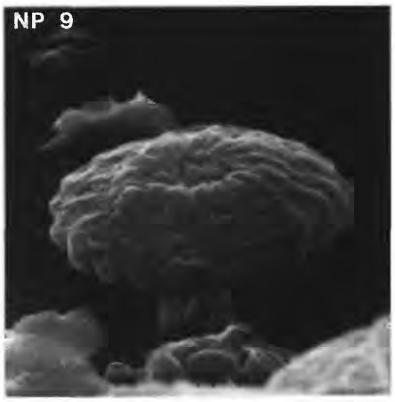


2a

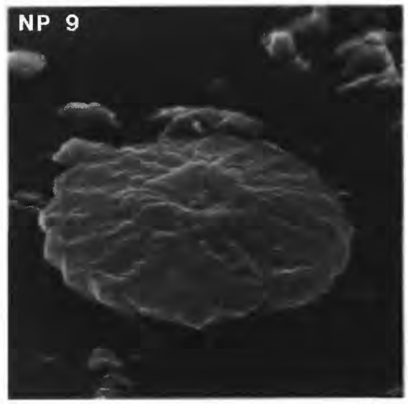
3a



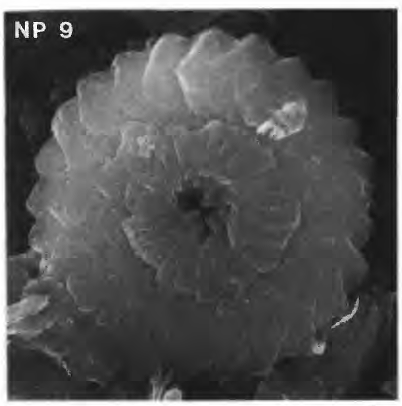
1b



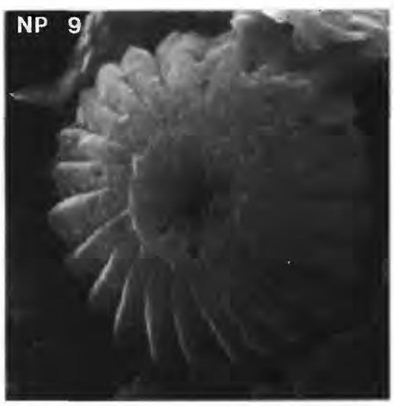
2b



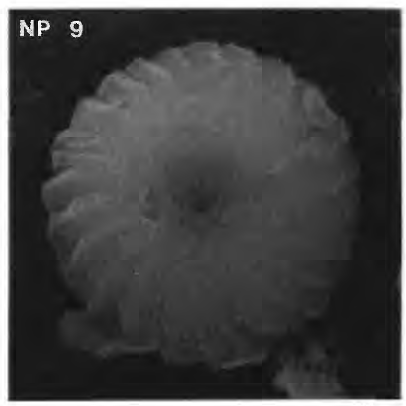
3b



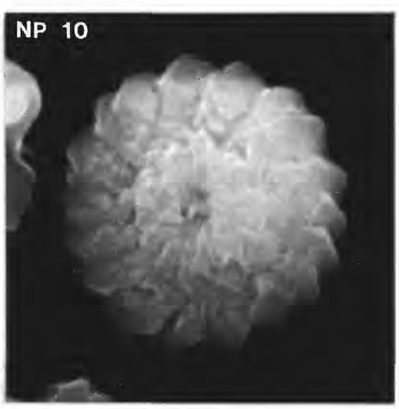
4



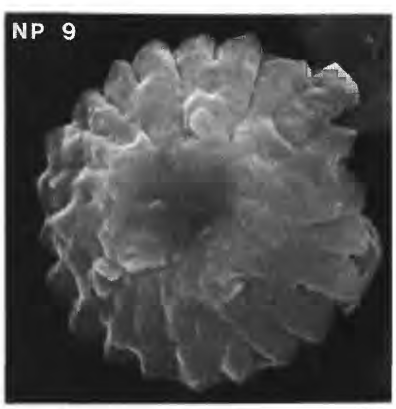
5



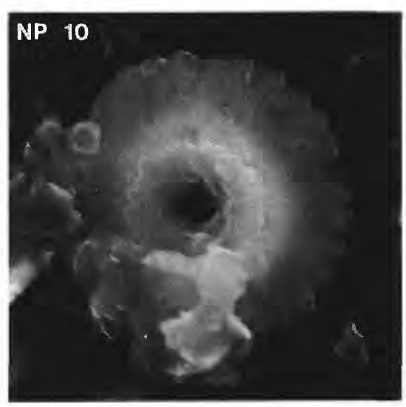
6



7



8



9

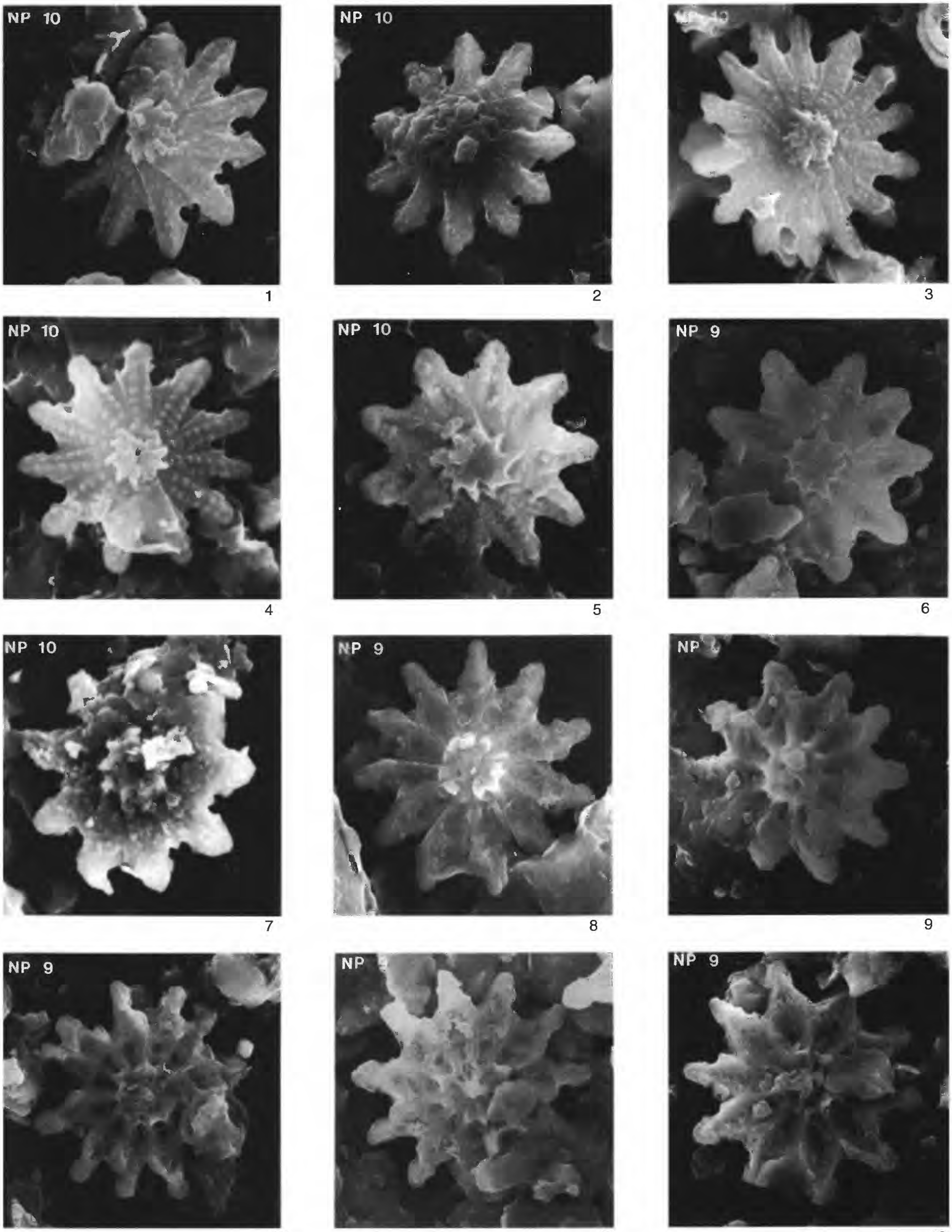
DISCOASTER

PLATE 9

[Designation of calcareous nannofossil zone of Martini (1971) shown in upper left corner of each photomicrograph]

Figures 1–12. *Discoaster limbatus*

1. Side 2 (diameter, 13.2 µm), Zone NP 10, C226 core (254.4 ft), Alabama.
2. Side 2 (diameter, 13.7 µm), Zone NP 10, Solomons Island core (400.5 ft), Maryland.
3. Side 2 (diameter, 18.7 µm), Zone NP 10, GL 915 core (100 ft), New Jersey.
4. Side 2 (diameter, 12.5 µm), Zone NP 10, GL 915 core (100 ft), New Jersey.
5. Side 2 (diameter, 17.2 µm), Zone NP 10, GL 917 core (200 ft), New Jersey.
6. Side 2 (diameter, 16.7 µm), Zone NP 9, Clayton core (307.2 ft), New Jersey.
7. Side 2 (diameter, 13.6 µm), Zone NP 10, Hatchetigbee locality, Alabama.
8. Side 1 (diameter, 10.5 µm), Zone NP 9, GL 915 core (130 ft), New Jersey.
9. Side 1 (diameter, 13.7 µm), Zone NP 9, Clayton core (307.2 ft), New Jersey.
10. Side 1 (diameter, 17.2 µm), Zone NP 9, Clayton core (309.6 ft), New Jersey.
11. Side 1 (diameter, 15.0 µm), Zone NP 9, Clayton core (314 ft), New Jersey.
12. Side 1 (diameter, 19.1 µm), Zone NP 9, Clayton core (309.6 ft), New Jersey.


NP 10
1
NP 10
2
3
NP 10
4
NP 10
5
NP 9
6
NP 10
7
NP 9
8
NP
9
NP 9
10
NP
11
NP 9
12

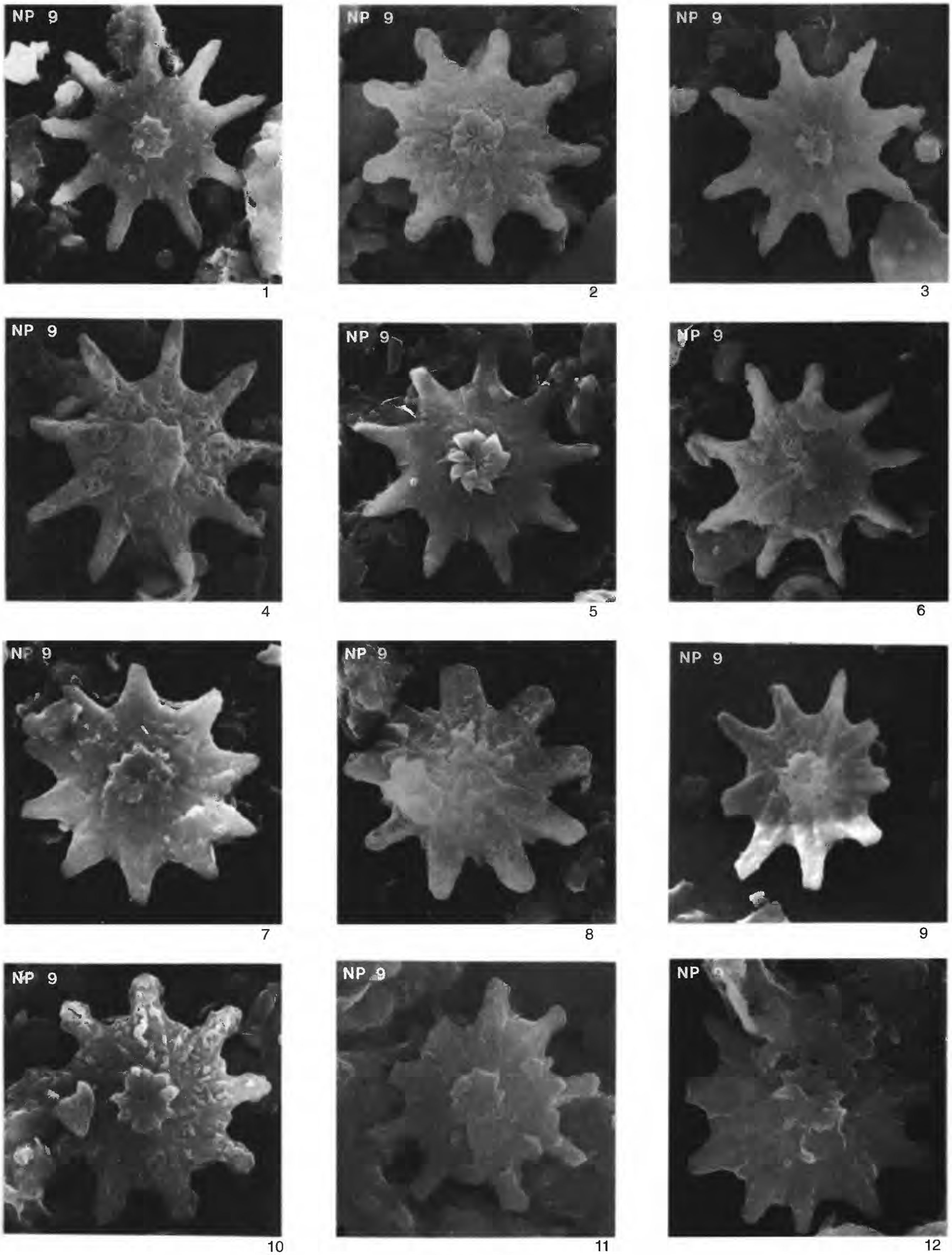
DISCOASTER

PLATE 10

[Designation of calcareous nannofossil zone of Martini (1971) shown in upper left corner of each photomicrograph]

Figures 1–12. *Discoaster mediosus* s. ampl.

1. Side 1 (diameter, 18.7 µm), Zone NP 9, Clayton core (317 ft), New Jersey.
2. Side 1 (diameter, 16.9 µm), Zone NP 9, Clayton core (314 ft), New Jersey.
3. Side 1 (diameter, 18.4 µm), Zone NP 9, Clayton core (317.4 ft), New Jersey.
4. Side 1 (diameter, 12.6 µm), Zone NP 9, Clayton core (314 ft), New Jersey.
5. Side 1 (diameter, 13.9 µm), Zone NP 9, GL 917 core (220 ft), New Jersey.
6. Side 1 (diameter, 18.7 µm), Zone NP 9, Clayton core (314 ft), New Jersey.
7. Side 2 (diameter, 17.2 µm), Zone NP 9, GL 915 core (110 ft), New Jersey.
8. Side 1 (diameter, 12.9 µm), Zone NP 9, Clayton core (317.4 ft), New Jersey.
9. Side 2 (diameter, 13.2 µm), Zone NP 9, GL 917 core (220 ft), New Jersey.
10. Side 2 (diameter, 14.3 µm), Zone NP 9, GL 917 core (225 ft), New Jersey.
11. Side 2 (diameter, 13.6 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.
12. Side 2 (diameter, 12.2 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.


NP 9
1
NP 9
2
NP 9
3
NP 9
4
NP 9
5
NP 9
6
NP 9
7
NP 9
8
NP 9
9
NP 9
10
NP 9
11
NP
12

DISCOASTER

PLATE 11

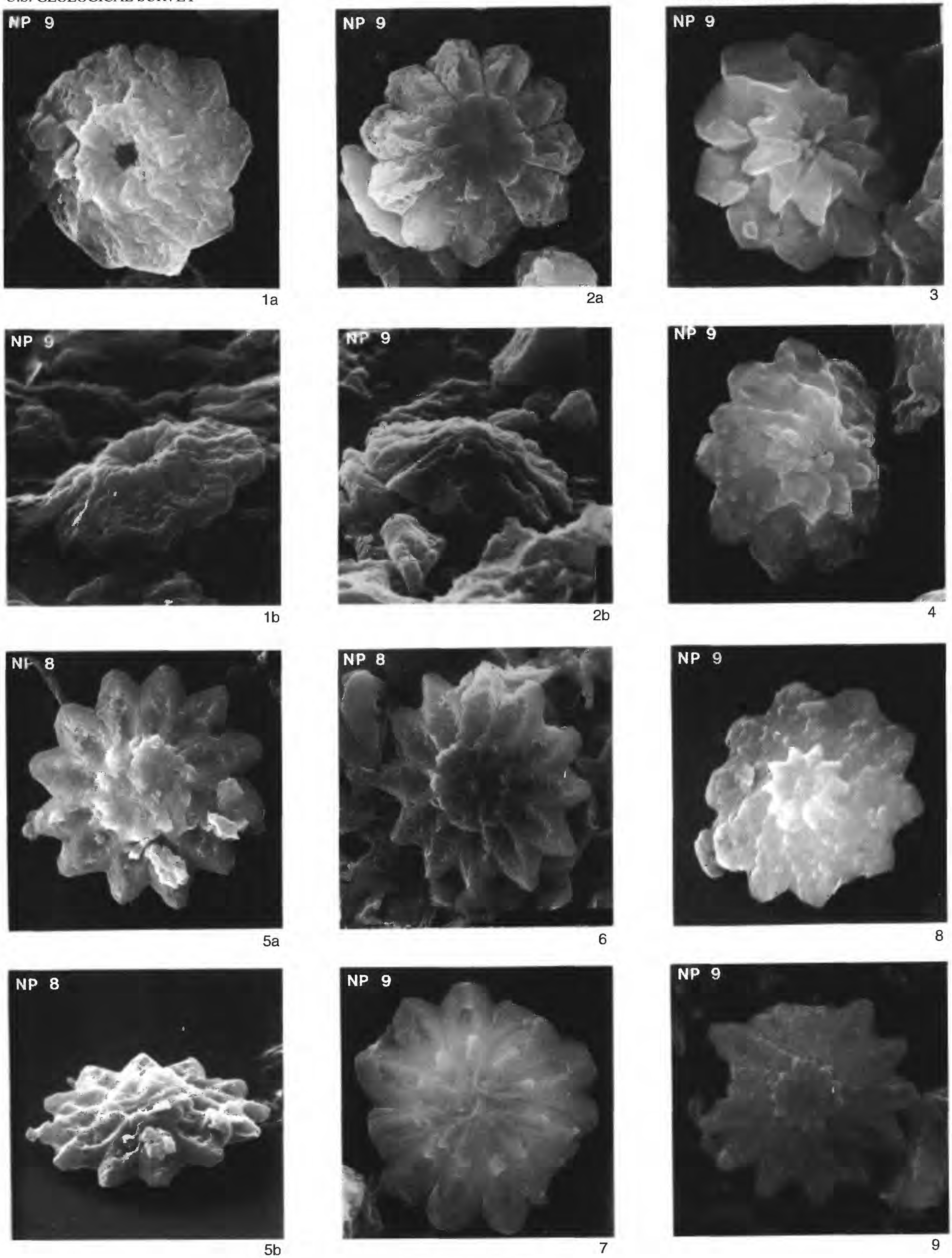
[Designation of calcareous nannofossil zone of Martini (1971) shown in upper left corner of each photomicrograph]

Figures 1–4, 8. *Discoaster* sp. aff. *D. mohleri*

1a. Diameter, 7.4 µm; Zone NP 9; Clayton core (309.6 ft), New Jersey.
1b. Same specimen—tilted view.
2a. Diameter, 13.0 µm; Zone NP 9; Clayton core (321.4 ft), New Jersey.
2b. Same specimen—tilted view.
3. Diameter, 6.4 µm; Zone NP 9; Clayton core (306.9 ft), New Jersey.
4. Diameter, 7.6 µm; Zone NP 9; Clayton core (322 ft), New Jersey.
8. Diameter, 7.6 µm; Zone NP 9; GL 913 core (125 ft), New Jersey.

5–7, 9. *Discoaster splendidus*

5a. Side 1 (diameter, 10.3 µm), Zone NP 8, GL 916 core (100 ft), New Jersey.
5b. Same specimen—tilted view.
6. Side 1 (diameter, 16.7 µm), Zone NP 8, GL 915 core (135 ft), New Jersey.
7. Side 1 (diameter, 10.7 µm), Zone NP 9, Clayton core (348.5 ft), New Jersey.
9. Side 2 (diameter, 10.7 µm), Zone NP 9, GL 915 core (130 ft), New Jersey.


NP 9
1a
NP 9
2a
NP 9
3
NP 9
1b
NP 9
2b
NP 9
4
NP 8
5a
NP 8
6
NP 9
8
NP 8
5b
NP 9
7
NP 9
9

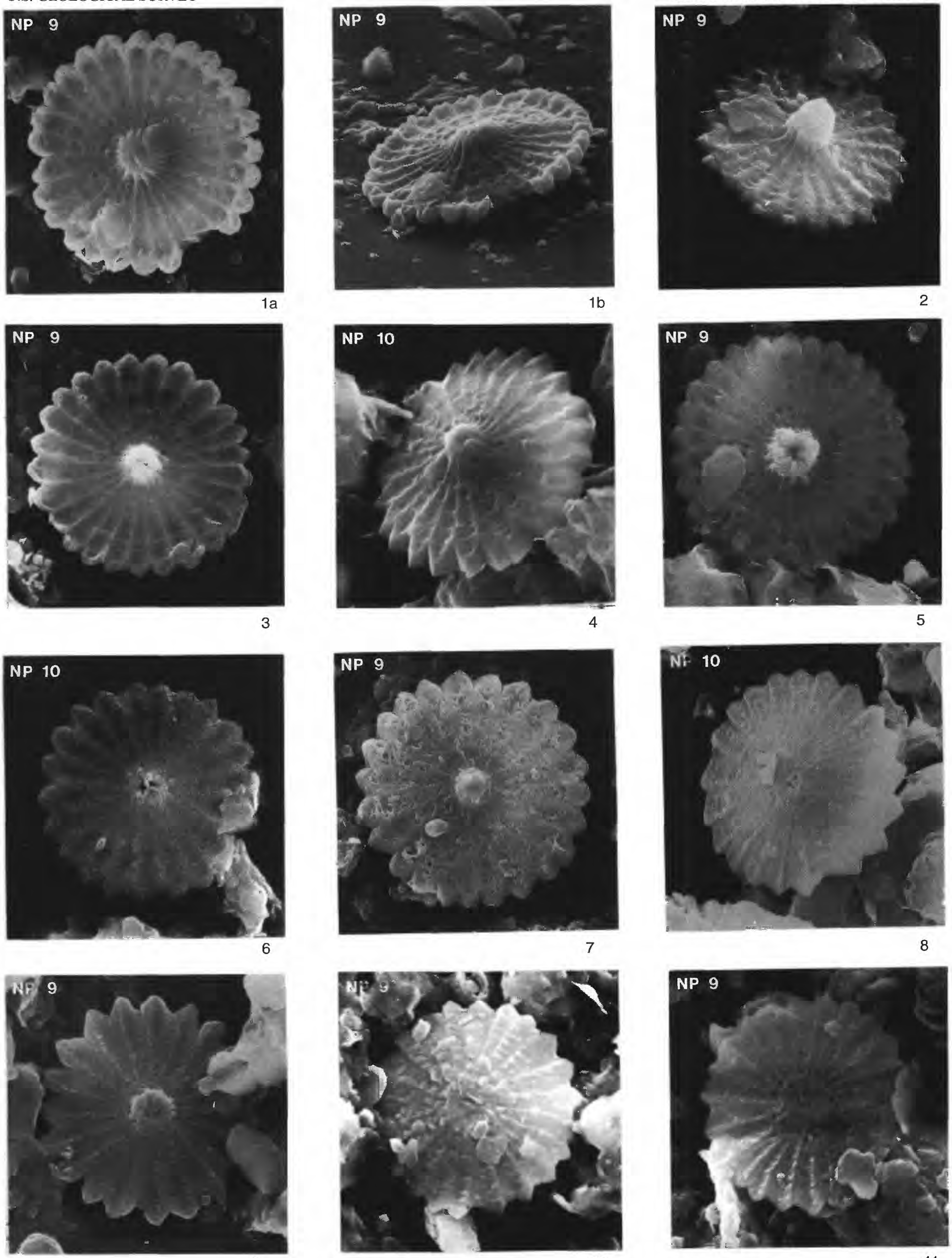
DISCOASTER

PLATE 12

[Designation of calcareous nannofossil zone of Martini (1971) shown in upper left corner of each photomicrograph]

Figures 1–11. *Discoaster multiradiatus*

1a. Side 1 (diameter, 16.9 μm), Zone NP 9, Clayton core (321.4 ft), New Jersey.
1b. Same specimen—tilted view.
2. Side 1 (diameter, 13.2 μm), Zone NP 9, GL 917 core (220 ft), New Jersey.
3. Side 1 (diameter, 14.0 μm), Zone NP 9, Clayton core (322 ft), New Jersey.
4. Side 1 (diameter, 17.2 μm), Zone NP 10, GL 915 core (100 ft), New Jersey.
5. Side 1 (diameter, 15.2 μm), Zone NP 9, Clayton core (321.4 ft), New Jersey.
6. Side 1 (diameter, 14.0 μm), Zone NP 10, Clayton core (298.5 ft), New Jersey.
7. Side 1 (diameter, 14.7 μm), Zone NP 9, Clayton core (314 ft), New Jersey.
8. Side 2 (diameter, 14.0 μm), Zone NP 10, GL 915 core (100 ft), New Jersey.
9. Side 2 (diameter, 15.8 μm), Zone NP 9, Clayton core (324.4 ft), New Jersey.
10. Side 2 (diameter, 15.6 μm), Zone NP 9, GL 915 core (110 ft), New Jersey.
11. Side 2 (diameter, 17.2 μm), Zone NP 9, GL 917 core (220 ft), New Jersey.


NP 9
1a
NP 9
1b
NP 9
2
NP 9
3
NP 10
4
NP 9
5
NP 10
6
NP 9
7
NP 10
8
NP 9
9
10
NP 9
11

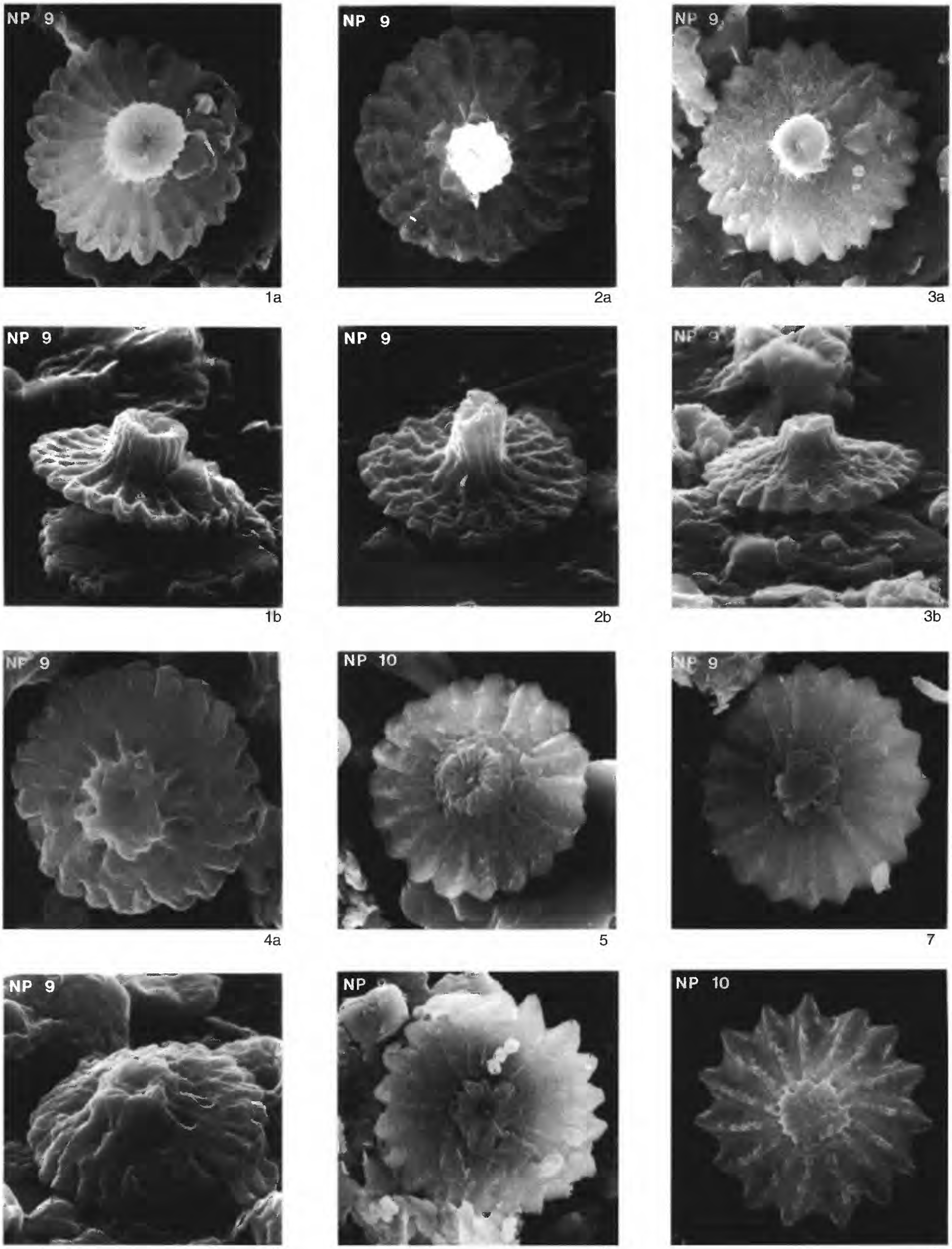
DISCOASTER

PLATE 13

[Designation of calcareous nannofossil zone of Martini (1971) shown in upper left corner of each photomicrograph]

Figures 1–8. *Discoaster salisburgensis*

1a. Side 1 (diameter, 10.4 µm), Zone NP 9, Clayton core (322 ft), New Jersey.
1b. Same specimen—tilted view.
2a. Side 1 (diameter, 9.7 µm), Zone NP 9, K 15 core (115 ft), New Jersey.
2b. Same specimen—tilted view.
3a. Side 1 (diameter, 12.7 µm), Zone NP 9, GL 915 core (130 ft), New Jersey.
3b. Same specimen—tilted view.
4a. Side 1 (diameter, 7.9 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.
4b. Same specimen—tilted view.
5. Side 2 (diameter, 13.0 µm), Zone NP 10, GL 915 core (100 ft), New Jersey.
6. Side 2 (diameter, 13.6 µm), Zone NP 9, Clayton core (307.2 ft), New Jersey.
7. Side 2 (diameter, 9.1 µm), Zone NP 9, K 15 core (105 ft), New Jersey.
8. Side 2 (diameter, 13.6 µm), Zone NP 10, C226 core (254.4 ft), Alabama.



DISCOASTER

PLATE 14

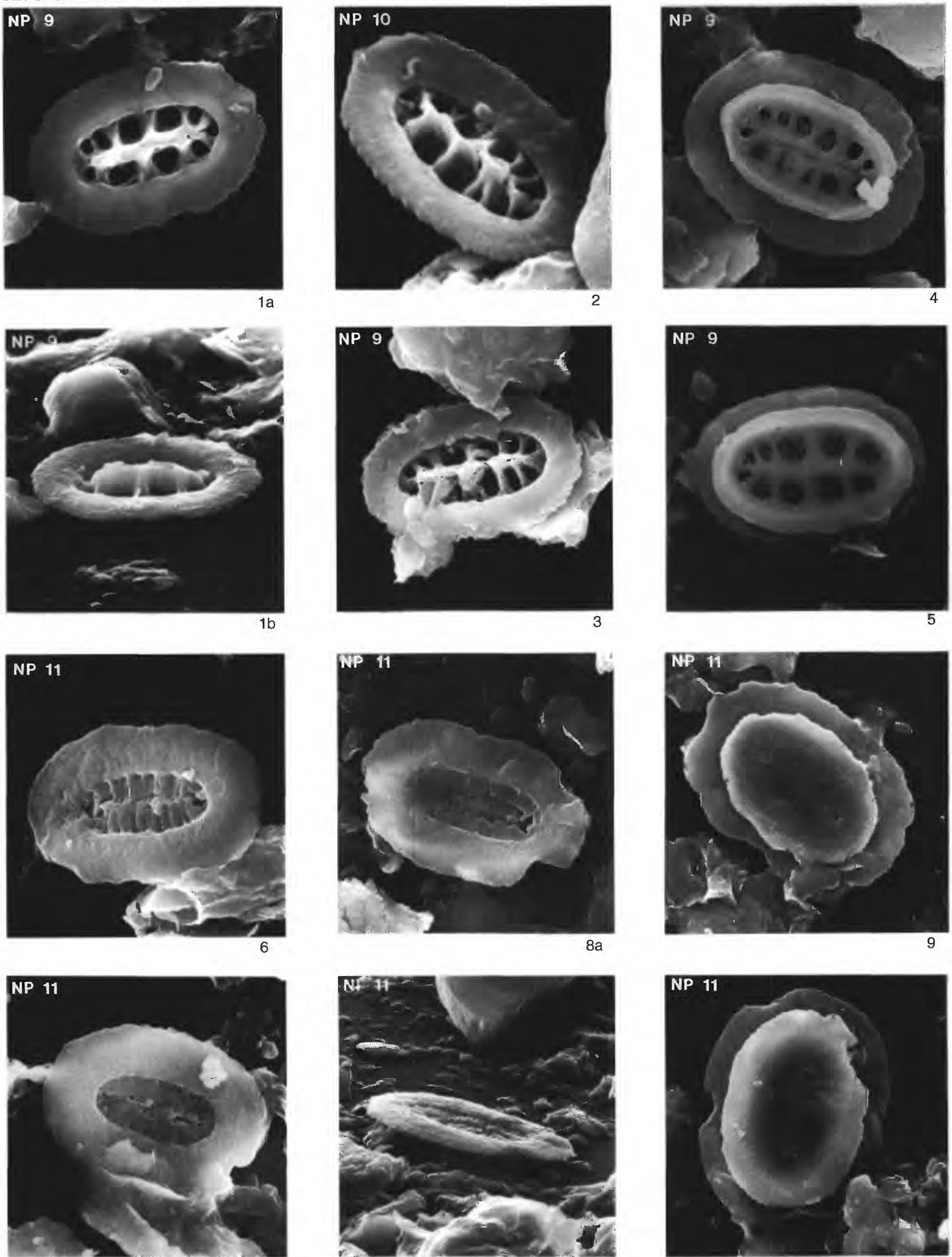
[Designation of calcareous nannofossil zone of Martini (1971) shown in upper left corner of each photomicrograph]

Figures 1–5. *Ellipsolithus distichus*

- 1a. Distal view (length, 11.1 µm), Zone NP 9, Clayton core (322 ft), New Jersey.
- 1b. Same specimen—tilted view.
- 2. Distal view (length, 10.6 µm), Zone NP 10, GL 915 core (100 ft), New Jersey.
- 3. Distal view (length, 10.4 µm), Zone NP 9, GL 913 core (140 ft), New Jersey.
- 4. Proximal view (length, 6.2 µm), Zone NP 9, Clayton core (317.4 ft), New Jersey.
- 5. Proximal view (length, 7.6 µm), Zone NP 9, GL 915 core (130 ft), New Jersey.

6–10. *Ellipsolithus macellus*

- 6. Distal view (length, 10.9 µm), Zone NP 11, Butler Place core (570 ft), New Jersey.
- 7. Distal view (length, 14.0 µm), Zone NP 11, Butler Place core (570 ft), New Jersey.
- 8a. Distal view (length, 10.9 µm), Zone NP 11, Butler Place core (570 ft), New Jersey.
- 8b. Same specimen—tilted view.
- 9. Proximal view (length, 11.1 µm), Zone NP 11, Butler Place core (570 ft), New Jersey.
- 10. Proximal view (length, 12.3 µm), Zone NP 11, Butler Place core (550 ft), New Jersey.



ELLIPSOLITHUS

PLATE 15

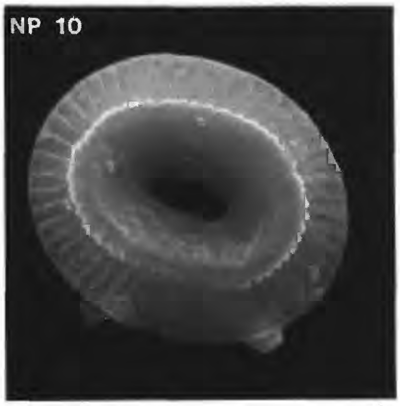
[Designation of calcareous nannofossil zone of Martini (1971) shown in upper left corner of each photomicrograph]

Figures 1, 2. *Ericsonia subpertusa*

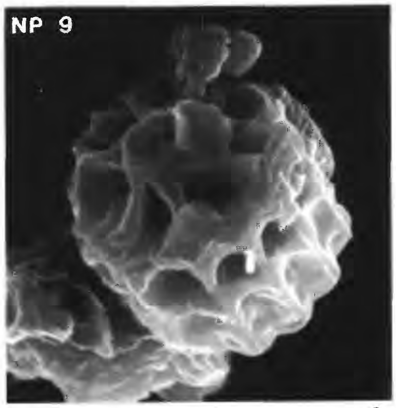
1. Distal view (length, 8.8 µm), Zone NP 10, Solomons Island core (400.5 ft), Maryland.
2. Distal view (length, 11.5 µm), Zone NP 11, Butler Place core (570 ft), New Jersey.

3–7. *Fasciculithus involutus*

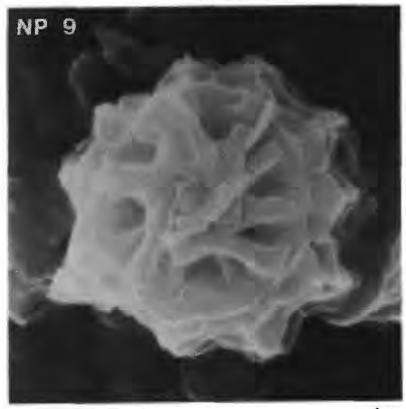
3a. Top oblique view (height, 7.4 µm), Zone NP 9, GL 913 core (140 ft), New Jersey.
3b. Same specimen—side view.
4a. Top view (height, 3.6 µm), Zone NP 9, Clayton core (322 ft), New Jersey.
4b. Same specimen—side view.
5a. Top view (height, 3.9 µm), Zone NP 9, GL 917 core (225 ft), New Jersey.
5b. Same specimen—side view.
6a. Top view (height, 4.8 µm), Zone NP 9, GL 915 core (130 ft), New Jersey.
6b. Same specimen—side view.
7a. Side and bottom view (height, 3.1 µm), Zone NP 9, K 15 core (115 ft), New Jersey.
7b. Same specimen—bottom view.



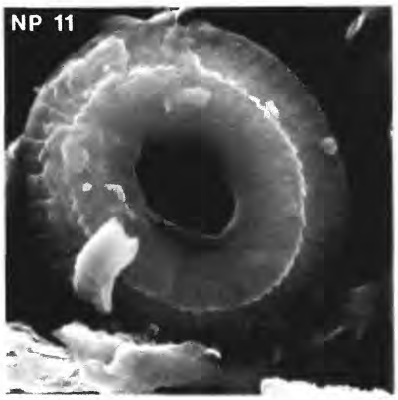
1



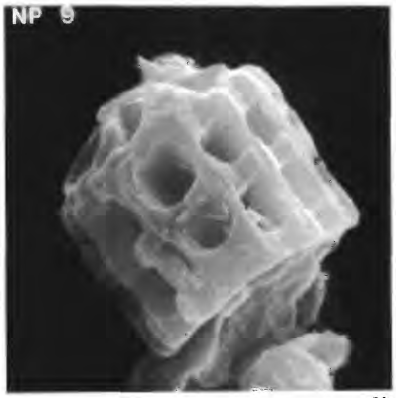
3a



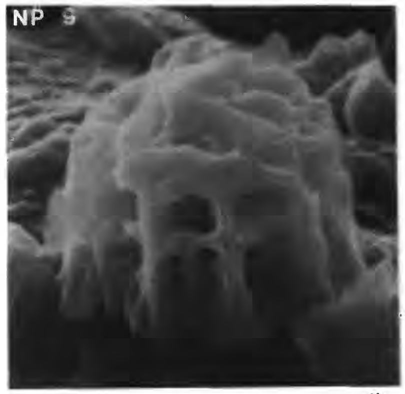
4a



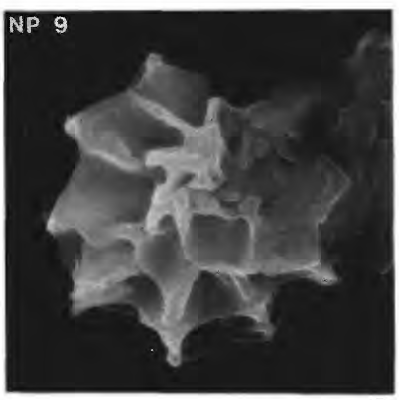
2



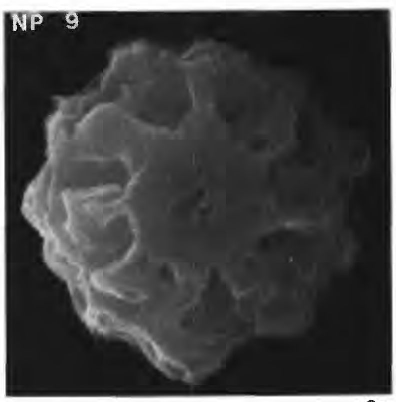
3b



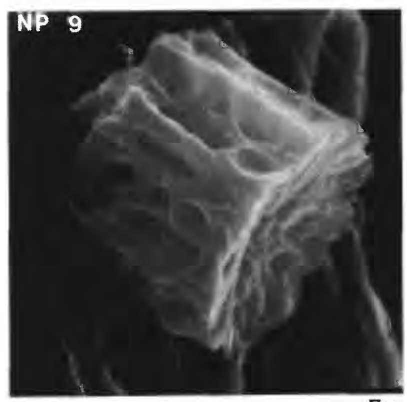
4b



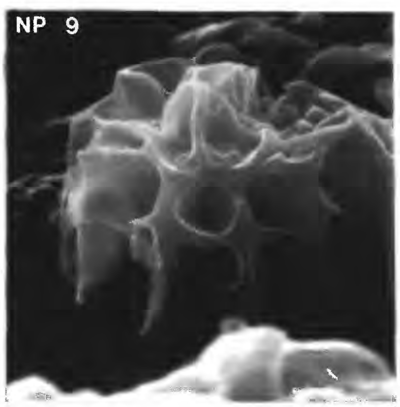
5a



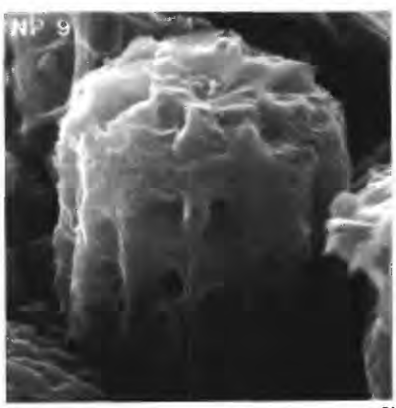
6a



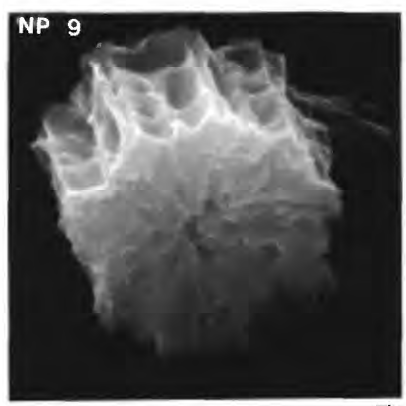
7a



5b



6b



7b

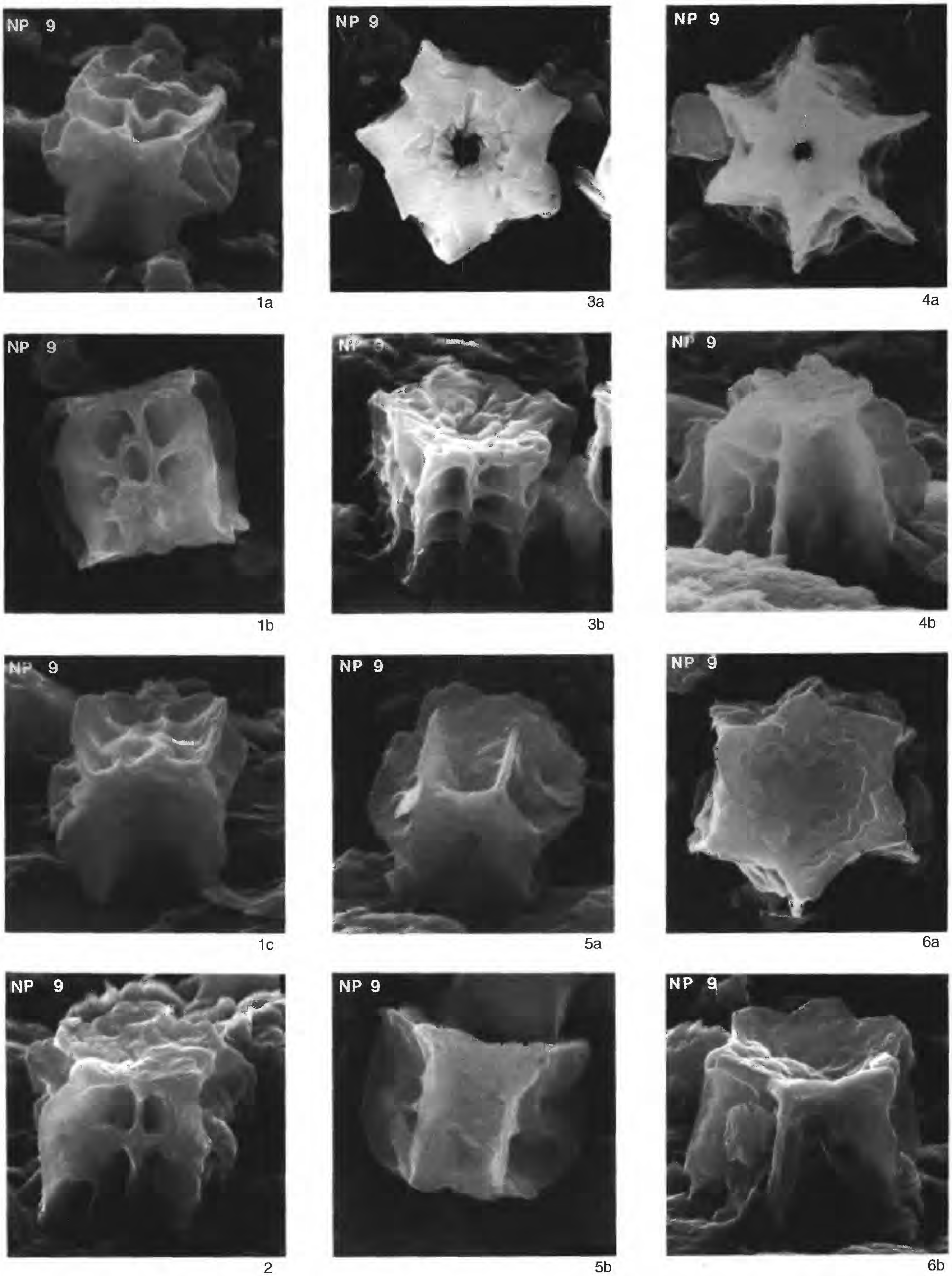
ERICSONIA AND *FASCICULITHUS*

PLATE 16

[Designation of calcareous nannofossil zone of Martini (1971) shown in upper left corner of each photomicrograph]

Figures 1–6. *Fasciculithus sidereus* n. sp.

1a. Holotype, top oblique view (height, 4.1 µm), Zone NP 9, Clayton core (306.9 ft), New Jersey.
1b. Same specimen—side view.
1c. Same specimen—bottom oblique view.
2. Side and top view (height, 4.7 µm), Zone NP 9, Clayton core (307.2 ft), New Jersey.
3a. Paratype, bottom view (height, 3.2 µm), Zone NP 9, GL 917 core (225 ft), New Jersey.
3b. Same specimen—side view.
4a. Top view (height, 4.2 µm), Zone NP 9, Clayton core (317.4 ft), New Jersey.
4b. Same specimen—side view.
5a. Paratype, top oblique view (height, 3.3 µm), Zone NP 9, Clayton core (306.9 ft), New Jersey.
5b. Same specimen—side view.
6a. Bottom view (height, 4.9 µm), Zone NP 9, Clayton core (307.9 ft), New Jersey.
6b. Same specimen—side view.



FASCICULITHUS

PLATE 17

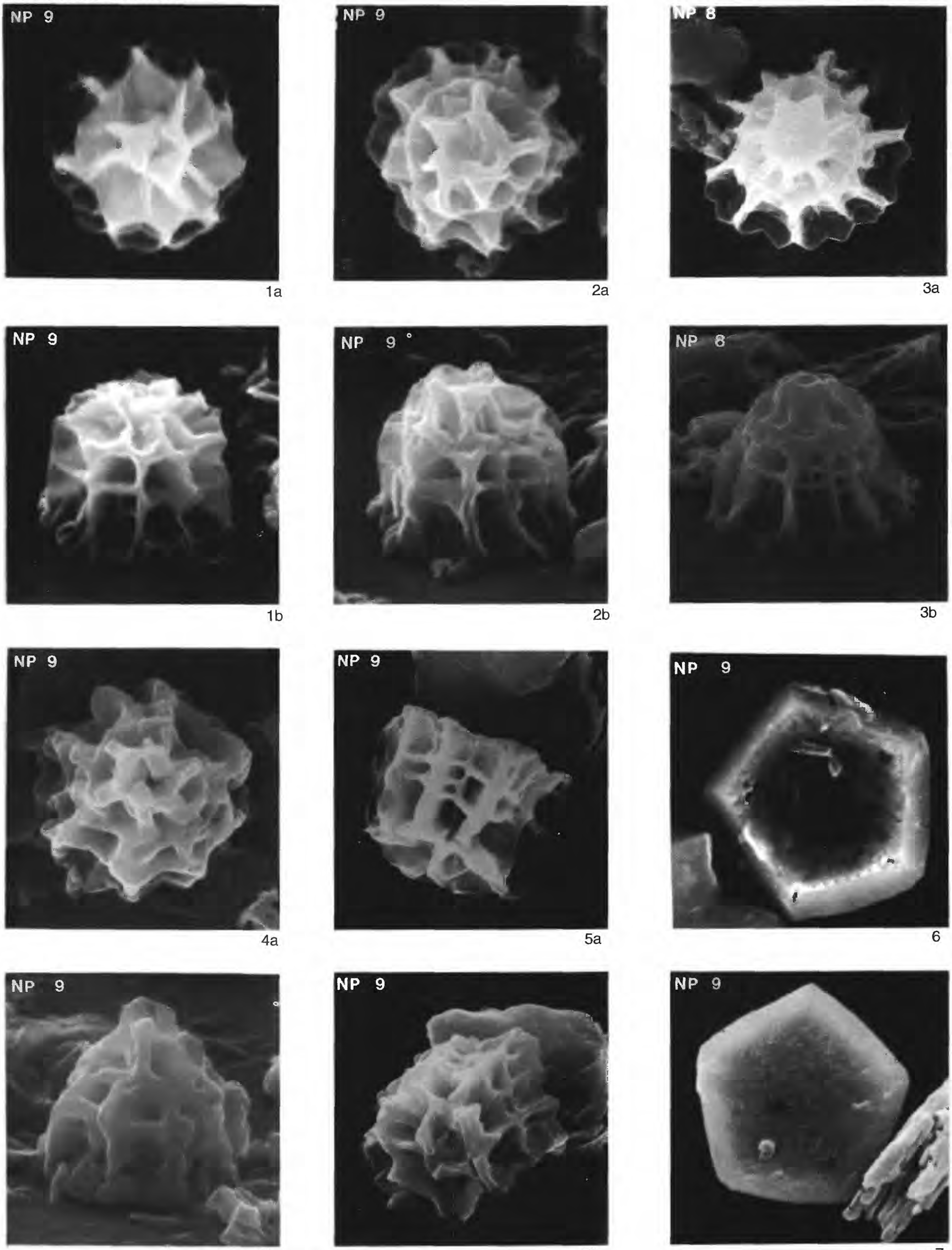
[Designation of calcareous nannofossil zone of Martini (1971) shown in upper left corner of each photomicrograph]

Figures 1–5. *Fasciculithus thomasii*

1a. Top view (height, 4.3 µm), Zone NP 9, Aquia Creek locality, Virginia.
1b. Same specimen—side view.
2a. Top view (height, 4.1 µm), Zone NP 9, GL 913 core (140 ft), New Jersey.
2b. Same specimen—side view.
3a. Top view (height, 4.3 µm), Zone NP 8, K 15 core (120 ft), New Jersey.
3b. Same specimen—side view.
4a. Top view (height, 3.7 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.
4b. Same specimen—side view.
5a. Side view (height, 4.1 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.
5b. Same specimen—top oblique view.

6, 7. *Goniolithus fluckigeri*

6. Side 1 (diameter, 5.7 µm), Zone NP 9, GL 917 core (225 ft), New Jersey.
7. Side 2 (diameter, 5.3 µm), Zone NP 9, GL 913 core (140 ft), New Jersey.



FASCICULITHUS AND *GONIOLITHUS*

PLATE 18

[Designation of calcareous nannofossil zone of Martini (1971) shown in upper left corner of each photomicrograph]

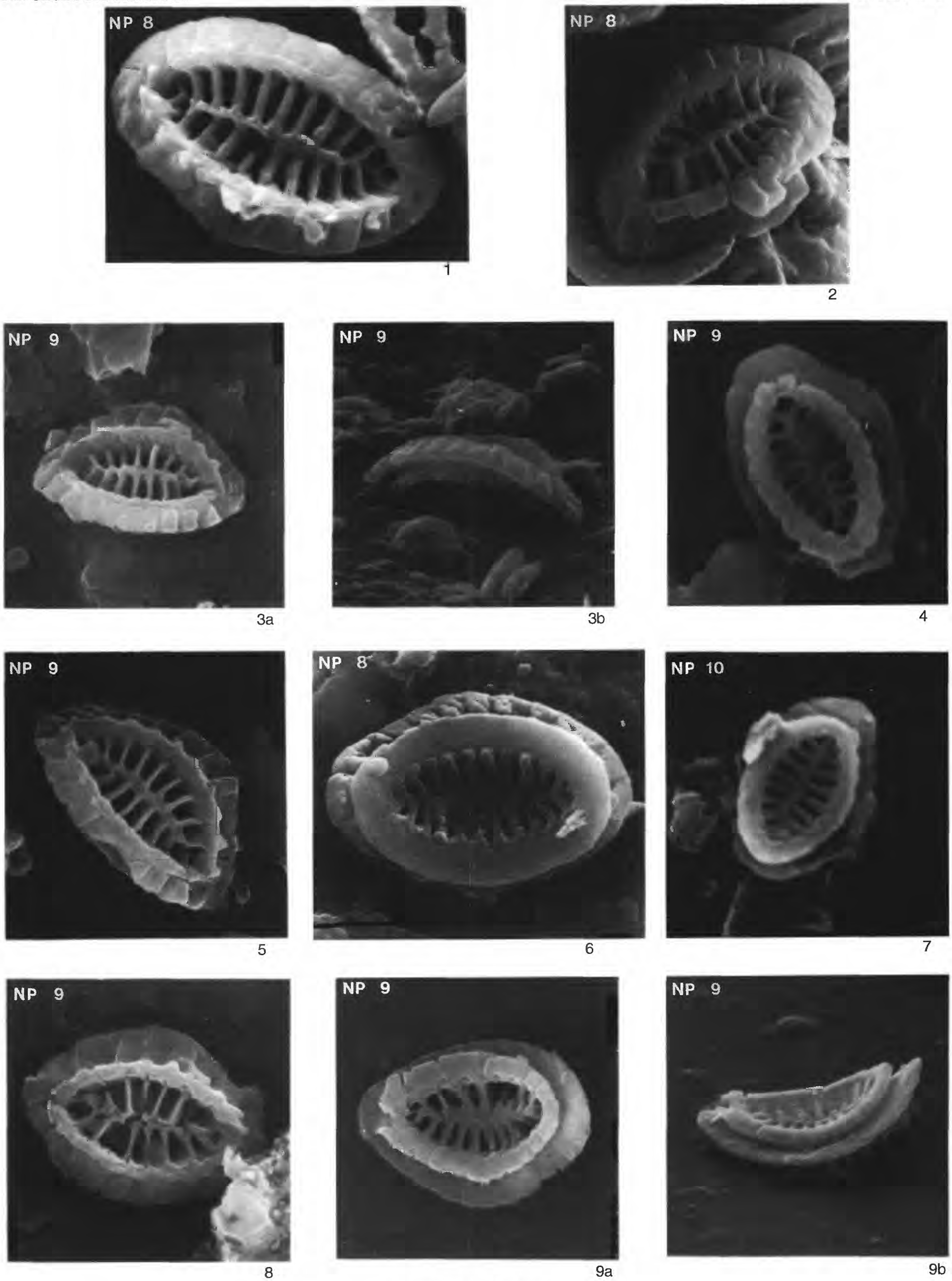
Figures 1–9. *Hornibrookina arca* n. sp.

1. Holotype, distal view (length, 6.5 µm), Zone NP 8, Aquia Creek locality, Virginia.
2. Paratype, distal view (length, 5.4 µm), Zone NP 8, Piscataway Creek locality, Maryland.

3a. Distal view (length, 5.3 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.
3b. Same specimen—tilted view.

4. Proximal view (length, 4.7 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.
5. Distal view (length, 5.3 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.
6. Paratype, proximal view (length, 6.2 µm), Zone NP 8, Piscataway Creek locality, Maryland.
7. Proximal view (length, 5.0 µm), Zone NP 10, Waldorf core (218.2 ft), Maryland.
8. Distal view (length, 5.5 µm), Zone NP 9, Clayton core (348.5 ft), New Jersey.

9a. Proximal view (length, 5.2 µm), Zone NP 9, Clayton core (348.5 ft), New Jersey.
9b. Same specimen—tilted view.



HORNIBROOKINA

PLATE 19

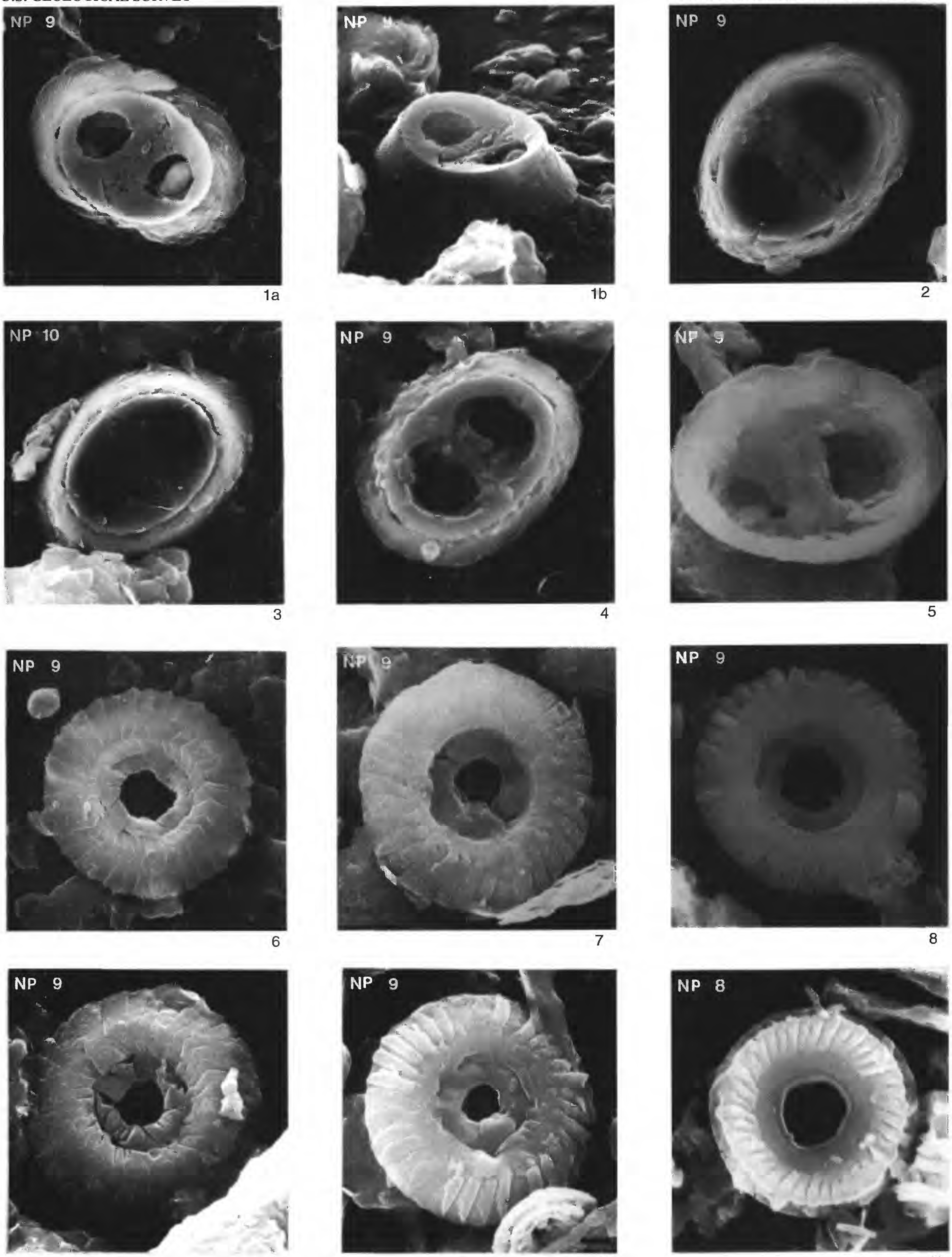
[Designation of calcareous nannofossil zone of Martini (1971) shown in upper left corner of each photomicrograph]

Figures 1–5. *Lophodolithus nascens*

- 1a. Proximal view (length, 11.9 µm), Zone NP 9, GL 917 core (225 ft), New Jersey.
- 1b. Same specimen—tilted view.
- 2. Proximal view (length, 11.7 µm), Zone NP 9, Clayton core (309.6 ft), New Jersey.
- 3. Proximal view (length, 11.3 µm), Zone NP 10, GL 917 core (195 ft), New Jersey.
- 4. Proximal view (length, 10.2 µm), Zone NP 9, GL 915 core (130 ft), New Jersey.
- 5. Distal view (length, 12.6 µm), Zone NP 9, Clayton core (314 ft), New Jersey.

6–11. *Markalius apertus*

- 6. Distal view (diameter, 7.2 µm), Zone NP 9, GL 917 core (220 ft), New Jersey.
- 7. Distal view (diameter, 7.7 µm), Zone NP 9, Clayton core (314 ft), New Jersey.
- 8. Distal view (diameter, 7.4 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.
- 9. Distal view (diameter, 8.3 µm), Zone NP 9, GL 916 core (95 ft), New Jersey.
- 10. Distal view (diameter, 8.2 µm), Zone NP 9, GL 917 core (225 ft), New Jersey.
- 11. Proximal view (diameter, 7.2 µm), Zone NP 8, K 15 core (125 ft), New Jersey.



LOPHODOLITHUS AND *MARKALIUS*

PLATE 20

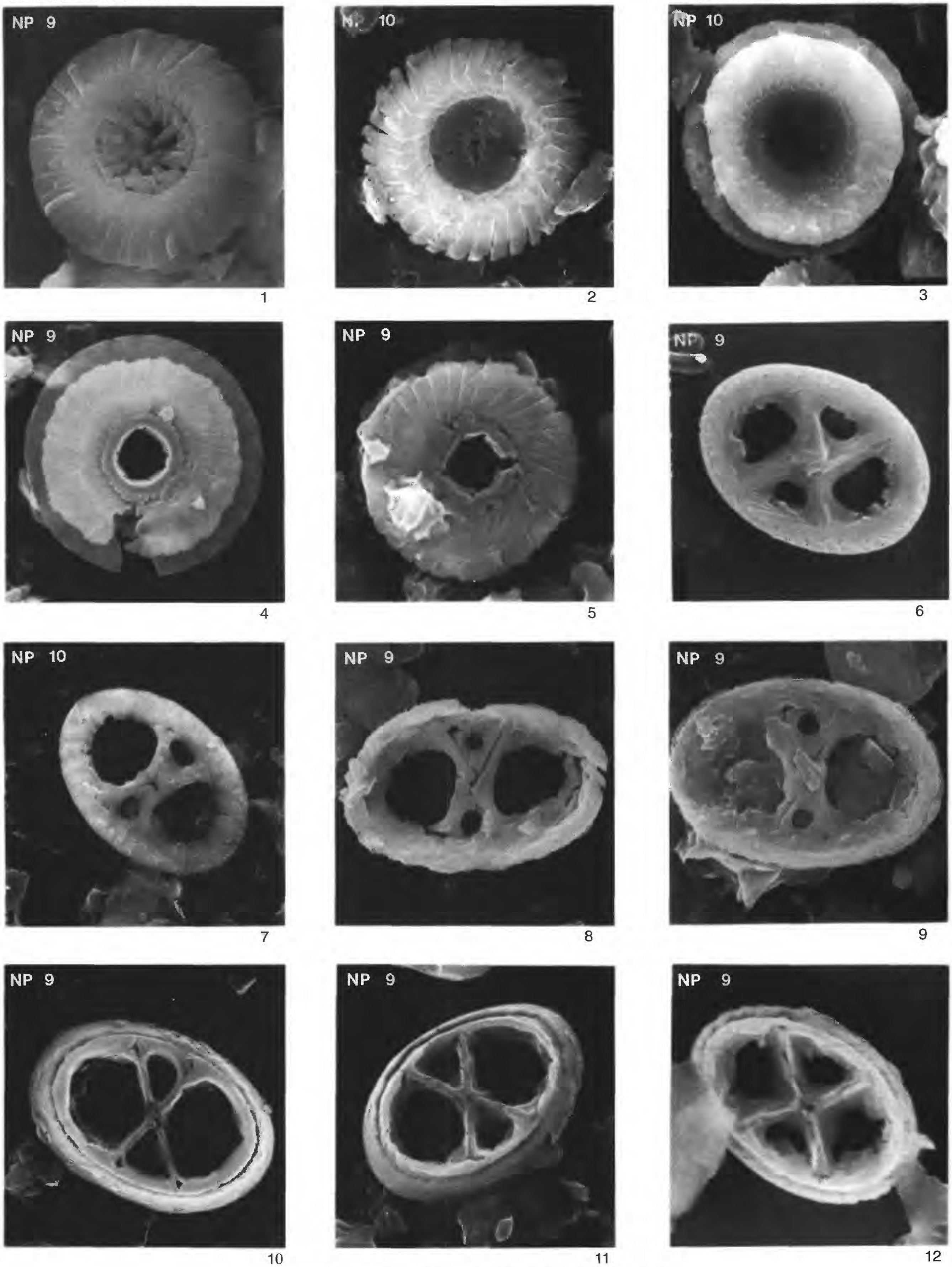
[Designation of calcareous nannofossil zone of Martini (1971) shown in upper left corner of each photomicrograph]

Figures 1–5. *Markalius inversus*

1. Distal view (diameter, 8.1 µm), Zone NP 9, Clayton core (324.4 ft), New Jersey.
2. Distal view (diameter, 7.6 µm), Zone NP 10, GL 917 core (195 ft), New Jersey.
3. Proximal view (diameter, 8.3 µm), Zone NP 10, GL 917 core (195 ft), New Jersey.
4. Proximal view—central area missing (diameter, 7.0 µm), Zone NP 9, GL 916 core (95 ft), New Jersey.
5. Proximal view—central area missing (diameter, 6.4 µm), Zone NP 9, GL 916 core (95 ft), New Jersey.

6–12. *Neochiastozygus concinnus* s. ampl.

6. Distal view—broad crossbar (length, 6.0 µm), Zone NP 9, GL 915 core (130 ft), New Jersey.
7. Distal view—narrow crossbar (length, 8.2 µm), Zone NP 10, Clayton core (302.5 ft), New Jersey.
8. Distal view—narrow crossbar (length, 8.7 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.
9. Distal view—narrow crossbar (length, 8.7 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.
10. Proximal view—narrow crossbar (length, 8.9 µm), Zone NP 9, GL 917 core (220 ft), New Jersey.
11. Proximal view—narrow crossbar (length, 7.1 µm), Zone NP 9, GL 917 core (220 ft), New Jersey.
12. Proximal view—broad crossbar (length, 6.3 µm), Zone NP 9, K 15 core (105 ft), New Jersey.



MARKALIUS AND *NEOCHIASTOZYGUS*

PLATE 21

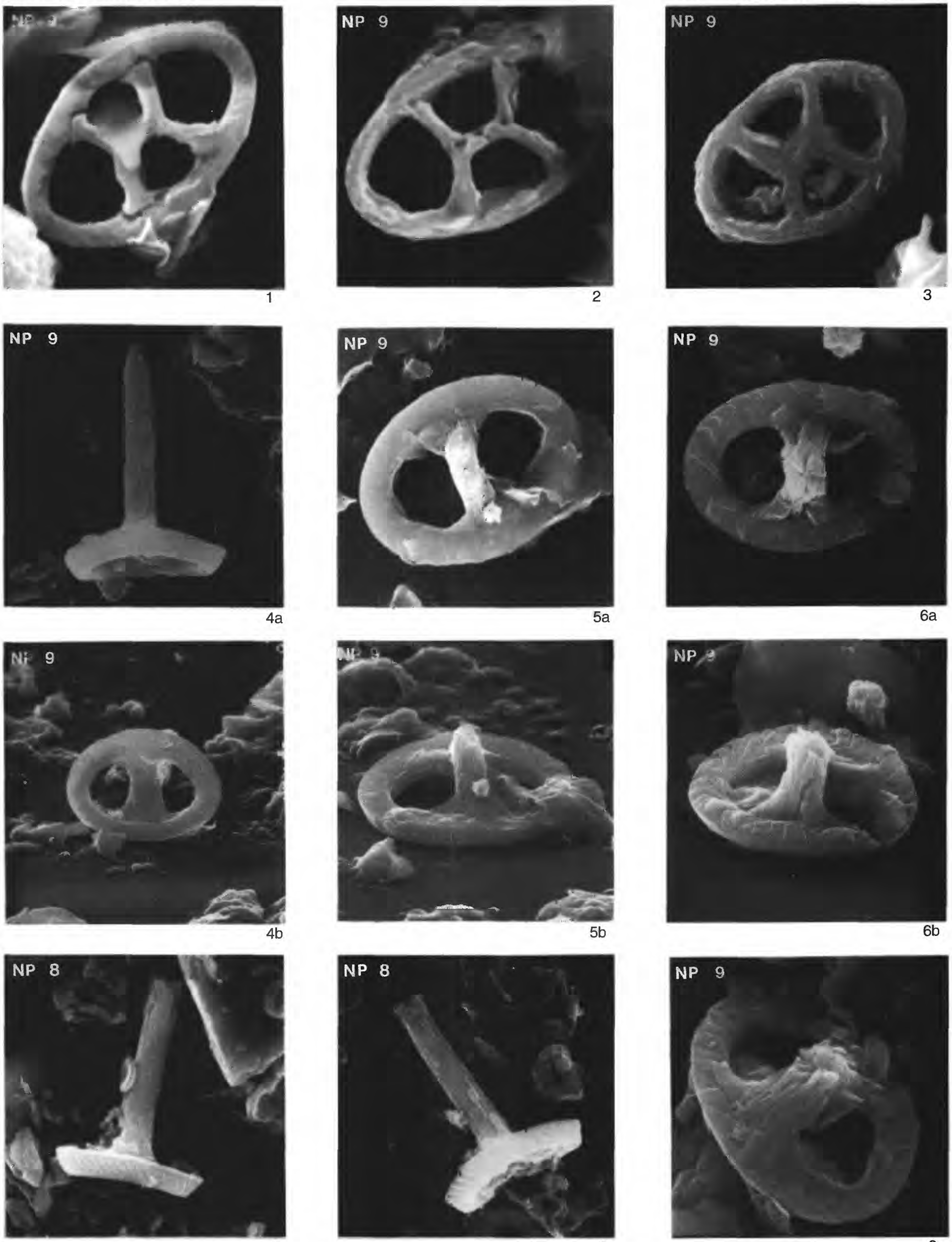
[Designation of calcareous nannofossil zone of Martini (1971) shown in upper left corner of each photomicrograph]

Figures 1–3. *Neococcolithes dubius*

1. Distal view (length, 7.0 µm), Zone NP 9, Aquia Creek locality, Virginia.
2. Distal view (length, 7.4 µm), Zone NP 9, Aquia Creek locality, Virginia.
3. Proximal view (length, 5.5 µm), Zone NP 9, GL 913 core (140 ft), New Jersey.

4–9. *Placozygus sigmoides*

- 4a. Side view (length of base, 8.1 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.
- 4b. Same specimen—bottom view.
- 5a. Top view (length of base, 8.1 µm), Zone NP 9, GL 915 core (130 ft), New Jersey.
- 5b. Same specimen—side view.
- 6a. Top view (length of base, 8.1 µm), Zone NP 9, Clayton core (322 ft), New Jersey.
- 6b. Same specimen—side view.
- 7. Side view (length of base, 9.5 µm), Zone NP 8, GL 915 core (140 ft), New Jersey.
- 8. Side view (length of base, 8.3 µm), Zone NP 8, GL 915 core (140 ft), New Jersey.
- 9. Top view (length of base, 8.3 µm), Zone NP 9, Clayton core (306.9 ft), New Jersey.



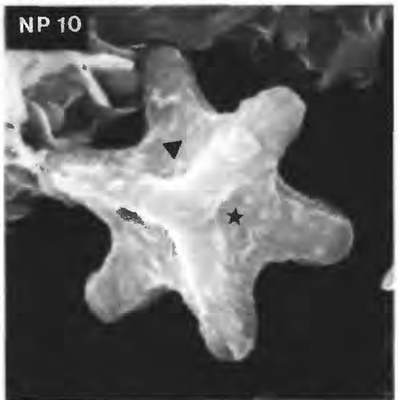
NEOCOCCOLITHES AND *PLACOZYGUS*

PLATE 22

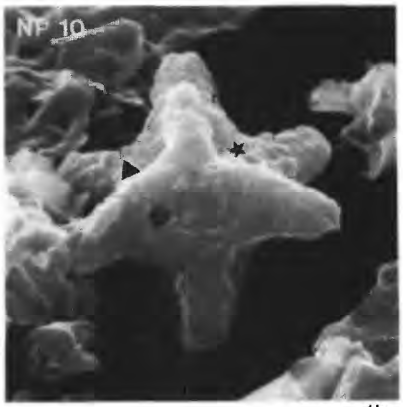
[Designation of calcareous nannofossil zone of Martini (1971) shown in upper left corner of each photomicrograph. Star, triangle, and circle symbols were added to some photomicrographs to help locate the same rhombohedron surface as specimens were rotated and tilted]

Figures 1–4. *Rhomboaster bramlettei* n. comb.

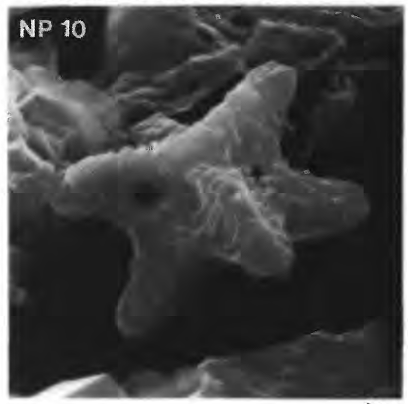
1a. Diameter, 9.5 μm; Zone NP 10; Pea River locality, Alabama.
1b. Same specimen—tilted and rotated view.
1c. Same specimen—tilted and rotated view.
1d. Same specimen—tilted and rotated view.
1e. Same specimen—tilted and rotated view.
1f. Same specimen—tilted and rotated view.
1g. Same specimen—tilted and rotated view.
2. Diameter, 11.9 μm; Zone NP 10; New Brooklyn core (360 ft), New Jersey.
3. Diameter, 12.2 μm; Zone NP 10; GL 915 core (95 ft), New Jersey.
4a. Diameter, 10.2 μm; Zone NP 10; Pea River locality, Alabama.
4b. Same specimen—tilted and rotated view.
4c. Same specimen—tilted and rotated view.



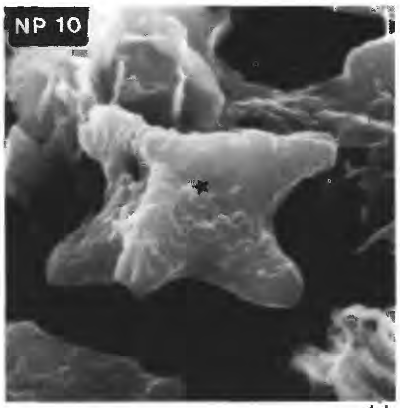
1a



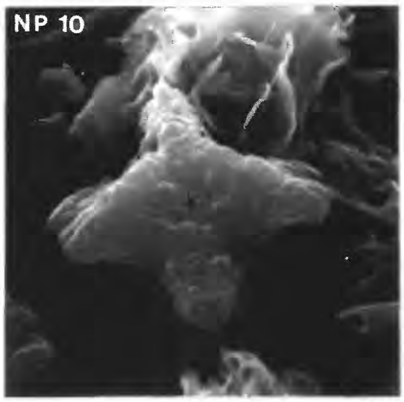
1b



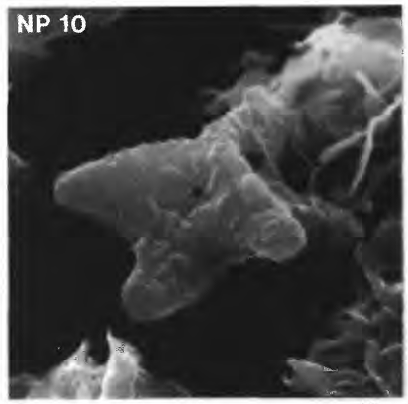
1c



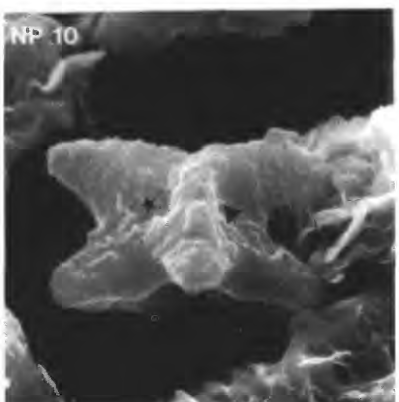
1d



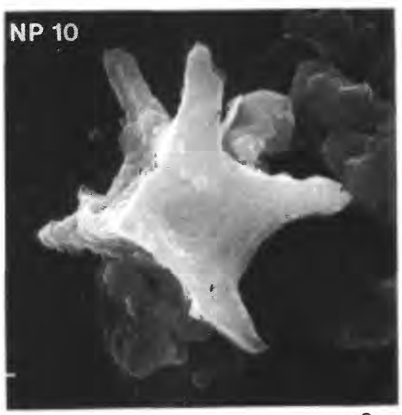
1e



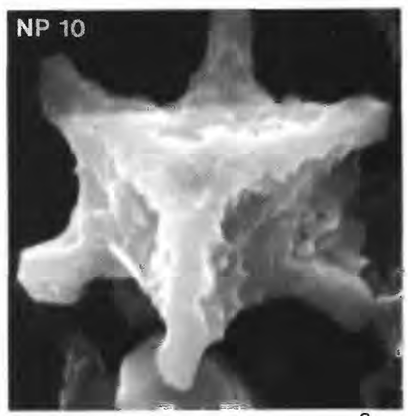
1f



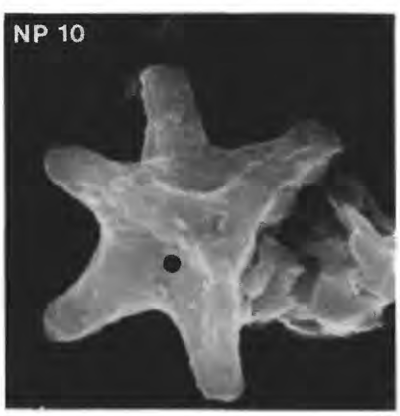
1g



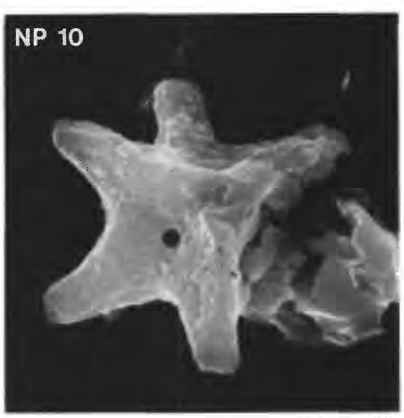
2



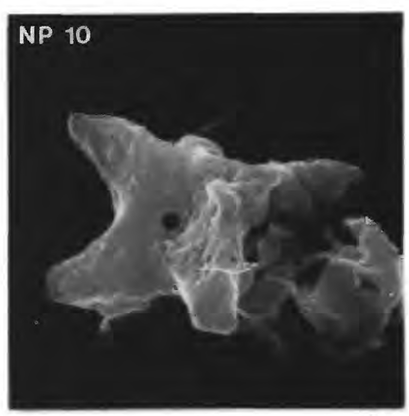
3



4a



4b



4c

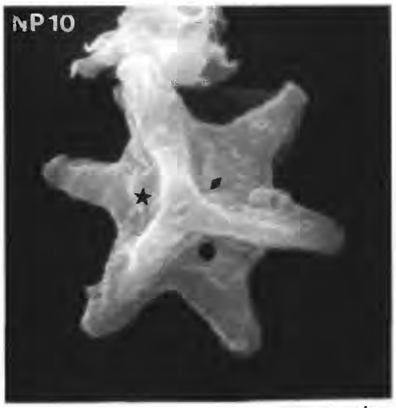
RHOMBOASTER

PLATE 23

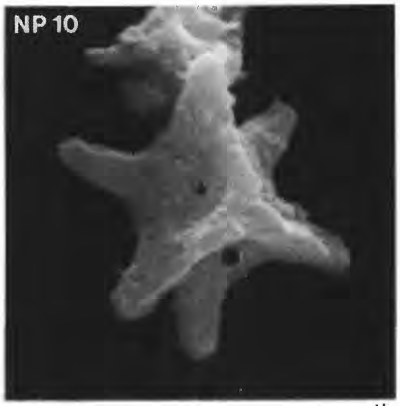
[Designation of calcareous nannofossil zone of Martini (1971) shown in upper left corner of each photomicrograph. Star, triangle, circle, diamond, and arrow symbols were added to some photomicrographs to help locate the same rhombohedron surface as specimens were rotated and tilted]

Figures 1–4. *Rhomboaster bramlettei* n. comb.

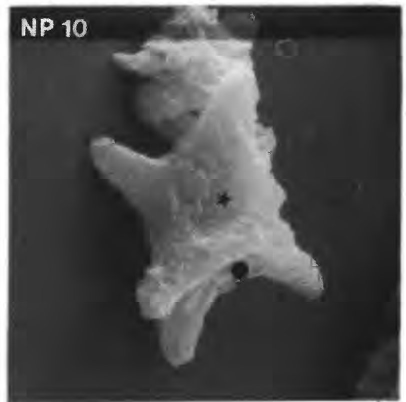
1a. Diameter, 10.2 µm; Zone NP 10; Pea River locality, Alabama.
1b. Same specimen—tilted view.
1c. Same specimen—tilted and rotated view.
1d. Same specimen—tilted and rotated view.
1e. Same specimen—tilted and rotated view.
1f. Same specimen—tilt removed.
2a. Partially dissolved specimen (diameter, 7.9 µm), Zone NP 10, Solomons Island core (405.7 ft), Maryland.
2b. Same specimen—tilted view.
2c. Same specimen—tilted and rotated view.
2d. Same specimen—tilted and rotated view.
3. Diameter, 13.0 µm; Zone NP 10; GL 917 core (195 ft), New Jersey.
4. Short-rayed specimen (diameter, 8.0 µm), Zone NP 10, Highway 69 locality, Alabama.



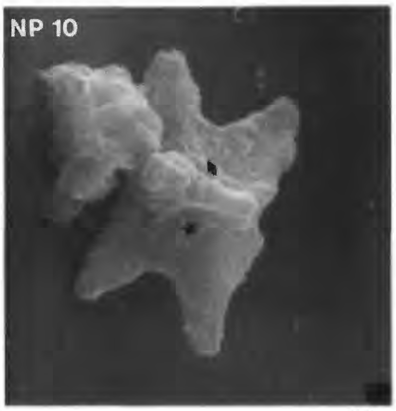
1a



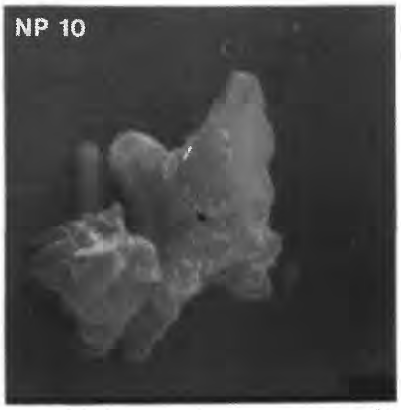
1b



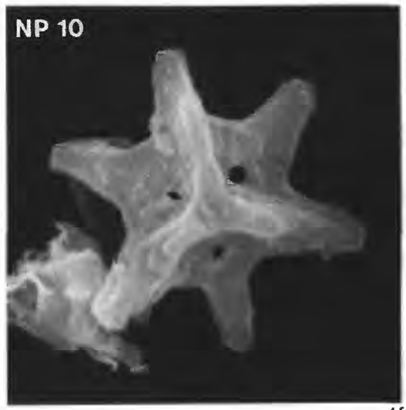
1c



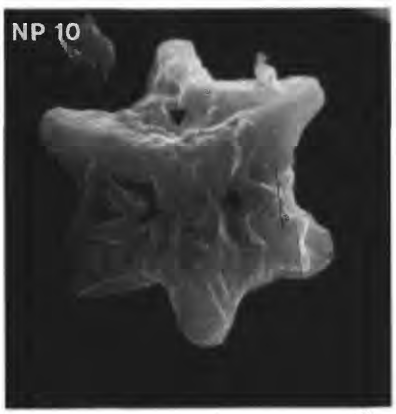
1d



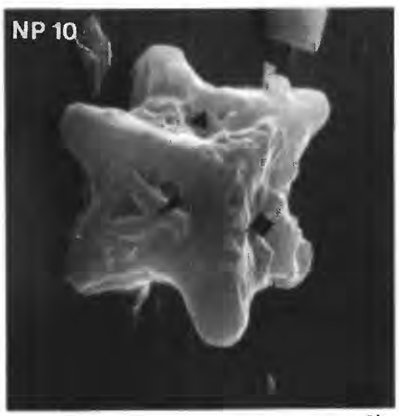
1e



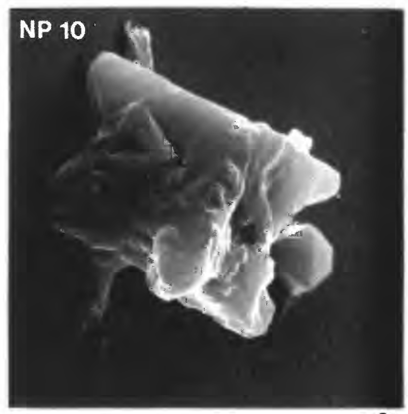
1f



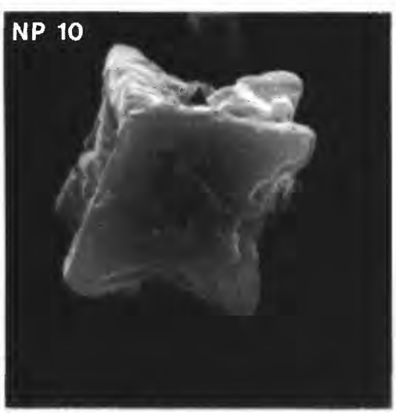
2a



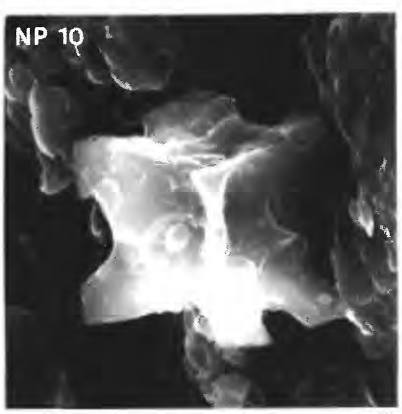
2b



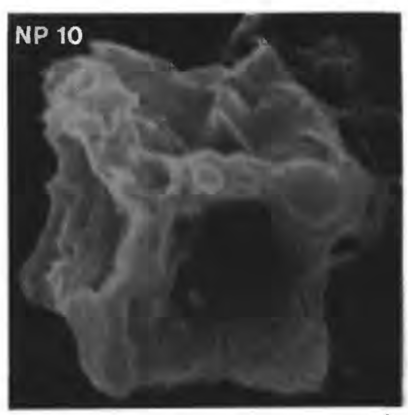
2c



2d



3



4

RHOMBOASTER

PLATE 24

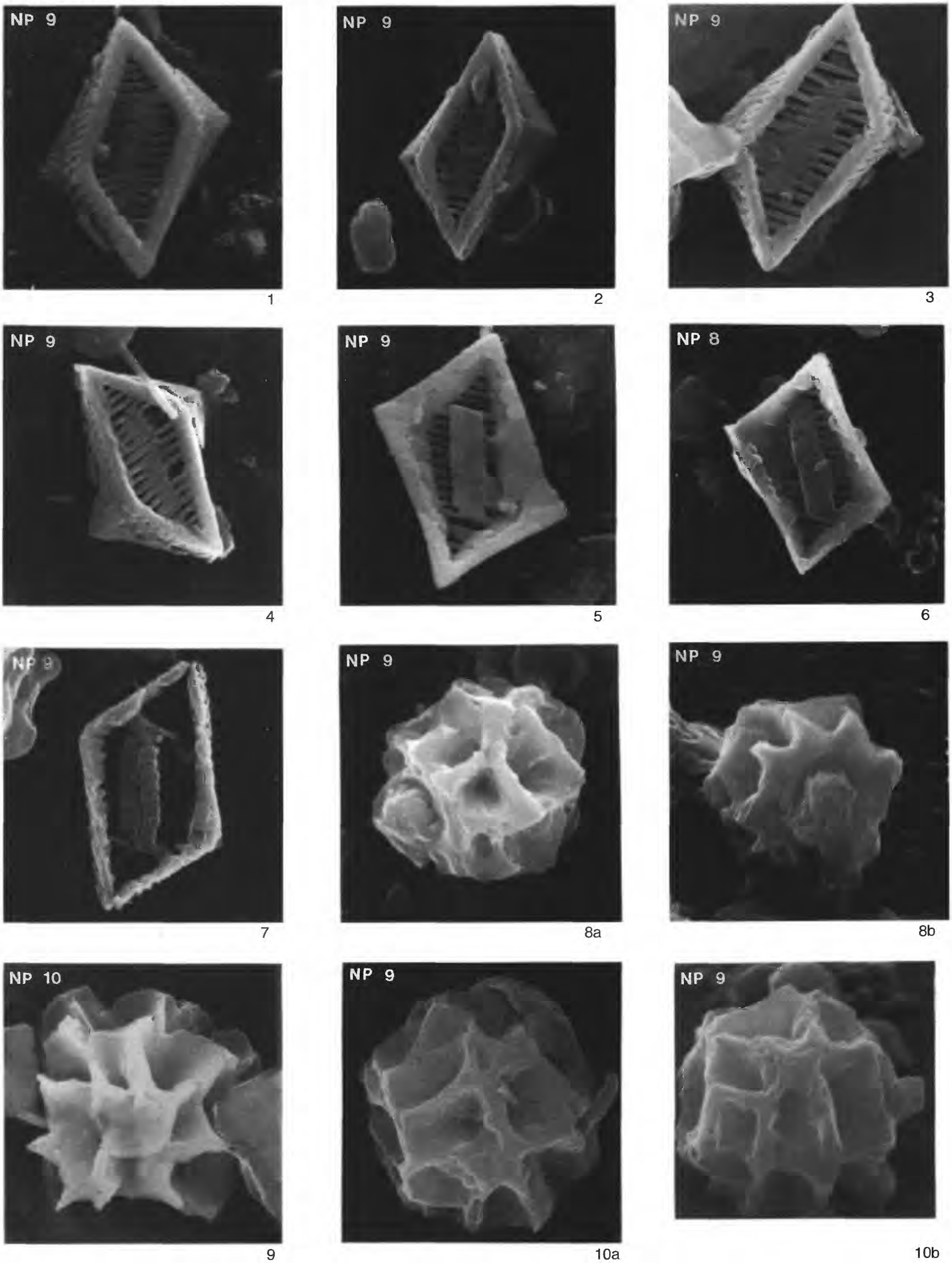
[Designation of calcareous nannofossil zone of Martini (1971) shown in upper left corner of each photomicrograph]

Figures 1–7. *Scapholithus apertus*

1. Side 2 (length, 6.2 µm), Zone NP 9, Aquia Creek locality, Virginia.
2. Side 2 (length, 4.7 µm), Zone NP 9, GL 913 core (140 ft), New Jersey.
3. Side 2 (length, 4.7 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.
4. Side 2 (length, 4.5 µm), Zone NP 9, GL 915 core (130 ft), New Jersey.
5. Side 1 (length, 5.9 µm), Zone NP 9, Aquia Creek locality, Virginia.
6. Side 1 (length, 4.2 µm), Zone NP 8, GL 917 core (240 ft), New Jersey.
7. Side 1—dissolved specimen (length, 4.3 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.

8–10. *Sphenolithus primus*

8a. Side view (height, 5.9 µm), Zone NP 9, GL 915 core (130 ft), New Jersey.
8b. Same specimen—bottom view.
9. Side view (height, 6.4 µm), Zone NP 10, GL 915 core (100 ft), New Jersey.
10a. Top view (height, 6.4 µm), Zone NP 9, Clayton core (348.5 ft), New Jersey.
10b. Same specimen—side view.



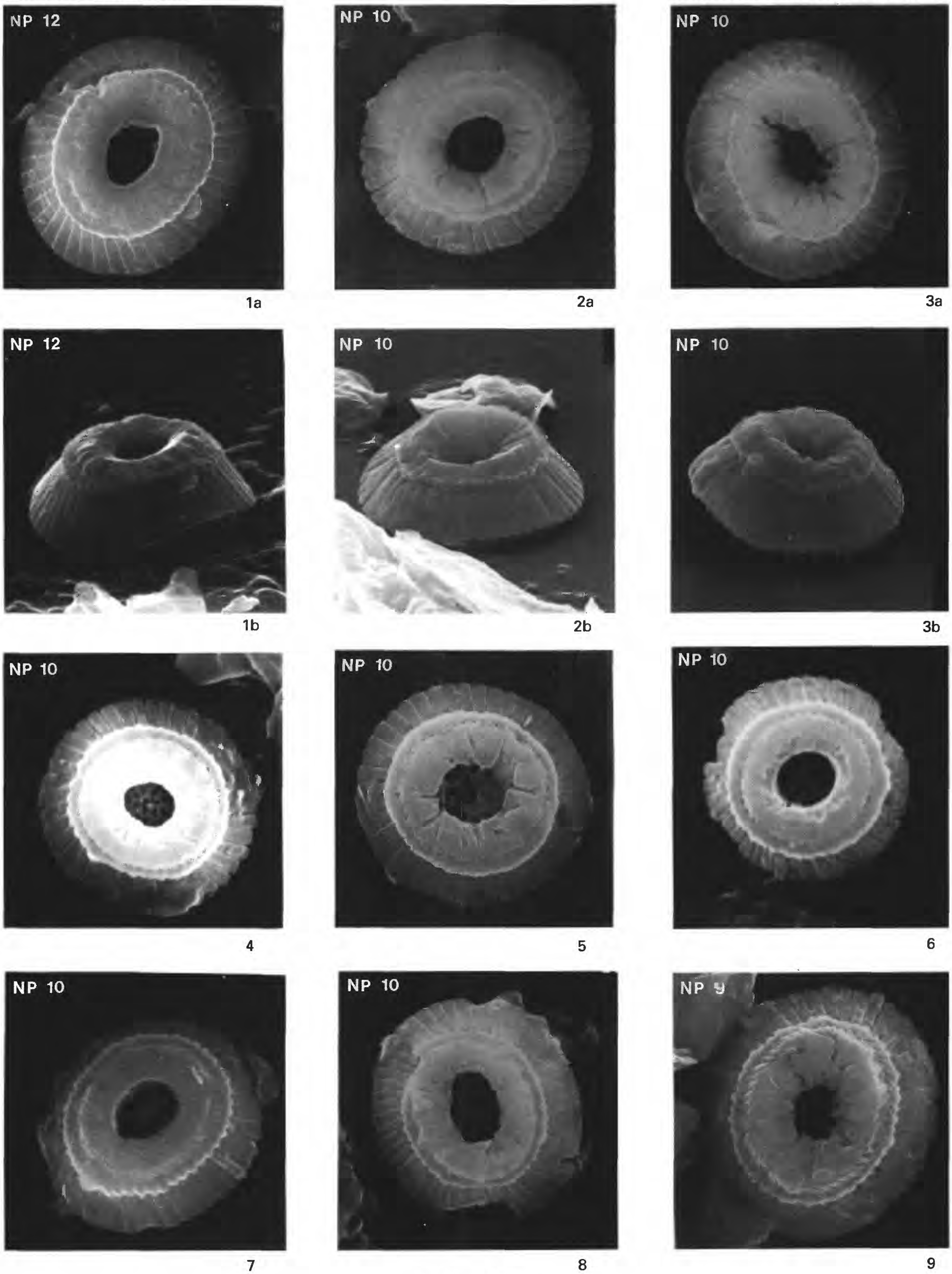
SCAPHOLITHUS AND *SPHENOLITHUS*

PLATE 25

[Designation of calcareous nannofossil zone of Martini (1971) shown in upper left corner of each photomicrograph]

Figures 1–9. *Toweius callosus*

1a. Distal view (length, 6.4 µm), Zone NP 12, Silverton Road core (403.9 ft), New Jersey.
1b. Same specimen—tilted view.
2a. Distal view (length, 7.6 µm), Zone NP 10, GL 915 core (100 ft), New Jersey.
2b. Same specimen—tilted view.
3a. Distal view (length, 6.0 µm), Zone NP 10, GL 915 core (100 ft), New Jersey.
3b. Same specimen—tilted view.
4. Distal view (length, 6.4 µm), Zone NP 10, C226 core (254.4 ft), Alabama.
5. Distal view (length, 5.9 µm), Zone NP 10, GL 915 core (100 ft), New Jersey.
6. Distal view (length, 5.2 µm), Zone NP 10, C226 core (254.4 ft), Alabama.
7. Distal view (length, 5.7 µm), Zone NP 10, Solomons Island core (399.2 ft), Maryland.
8. Distal view (length, 7.1 µm), Zone NP 10, GL 915 core (100 ft), New Jersey.
9. Distal view (length, 6.2 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.


NP 12
1a
NP 10
2a
NP 10
3a
NP 12
1b
NP 10
2b
NP 10
3b
NP 10
4
NP 10
5
NP 10
6
NP 10
7
NP 10
8
NP 9
9

TOWEIUS

PLATE 26

[Designation of calcareous nannofossil zone of Martini (1971) shown in upper left corner of each photomicrograph]

Figure 1. *Toweius eminens* var. *eminens* autonym—distal view (length, 6.7 μm), Zone NP 5, Solomons Island core (581.3 ft), Maryland.

2. *Toweius eminens* var. *tovae* stat. nov.—distal view (length, 7.6 μm), Zone NP 5, Solomons Island core (581.3 ft), Maryland.

3, 4. *Toweius eminens* var. *eminens* autonym

3. Distal view (length, 8.2 μm), Zone NP 9, Clayton core (348.5 ft), New Jersey.
4. Distal view (length, 5.4 μm), Zone NP 9, Clayton core (348.5 ft), New Jersey.

5. *Toweius eminens* var. *tovae* stat. nov.

5a. Distal view (length, 7.1 μm), Zone NP 9, Clayton core (348.5 ft), New Jersey.
5b. Same specimen—tilted view.

6. *Toweius eminens* var. *eminens* autonym—distal view (length, 7.7 μm), Zone NP 9, Clayton core (322 ft), New Jersey.

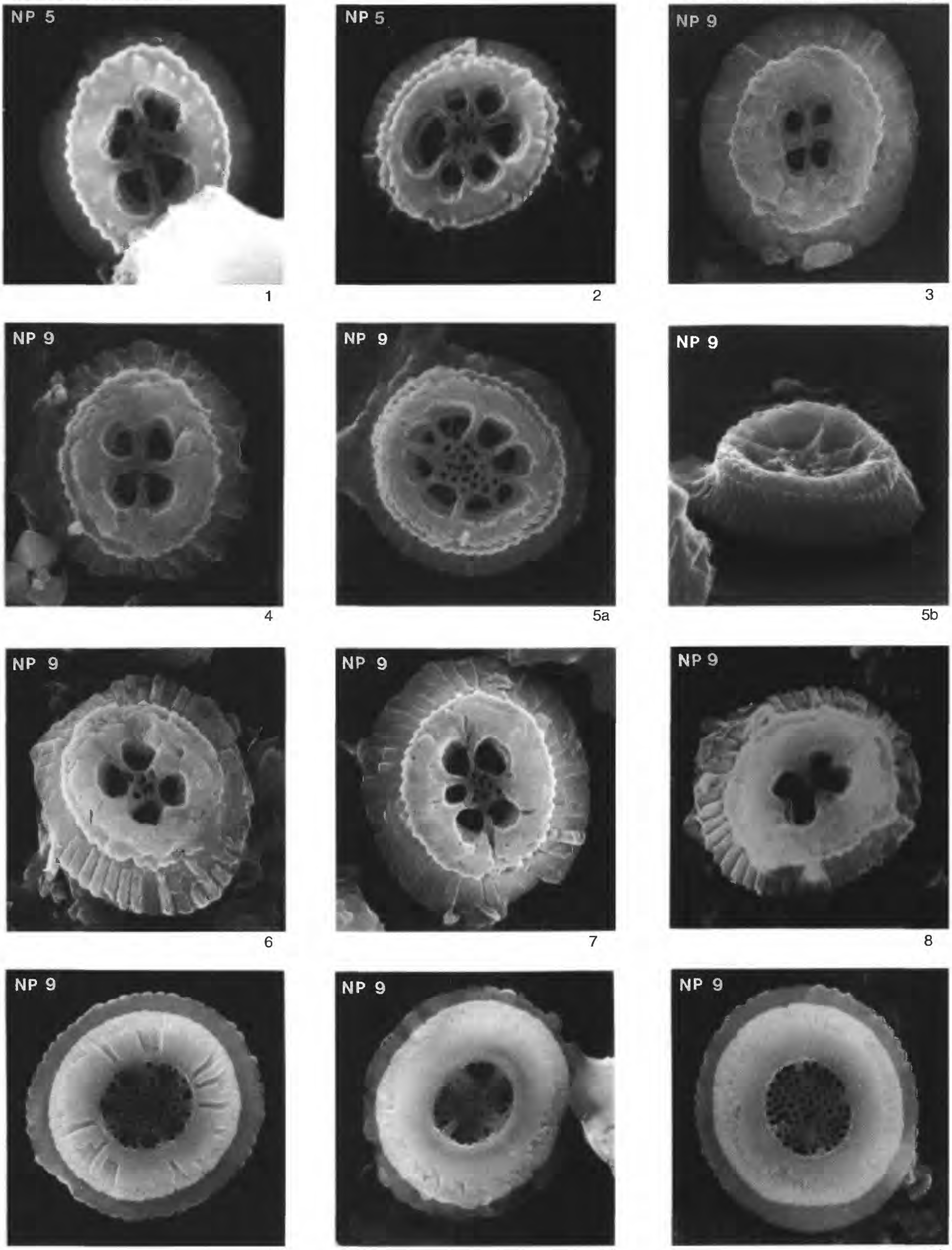
7. *Toweius eminens* var. *tovae* stat. nov.—distal view (length, 6.9 μm), Zone NP 9, Clayton core (322 ft), New Jersey.

8. *Toweius eminens* var. *eminens* autonym—distal view (length, 7.9 μm), Zone NP 9, Clayton core (322 ft), New Jersey.

9. *Toweius eminens* var. *tovae* stat. nov.—proximal view (length, 7.7 μm), Zone NP 9, Clayton core (322 ft), New Jersey.

10, 11. *Toweius eminens* var. *eminens* autonym

10. Proximal view (length, 7.7 μm), Zone NP 9, Clayton core (322 ft), New Jersey.
11. Proximal view (length, 7.8 μm), Zone NP 9, Clayton core (321.4 ft), New Jersey.


NP 5
1
NP 5
2
NP 9
3
NP 9
4
NP 9
5a
NP 9
5b
NP 9
6
NP 9
7
NP 9
8
NP 9
9
NP 9
10
NP 9
11

TOWEIUS

PLATE 27

[Designation of calcareous nannofossil zone of Martini (1971) shown in upper left corner of each photomicrograph]

Figure 1. *Toweius eminens* var. *eminens* autonym—distal view (length, 8.7 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.

2, 3. *Toweius eminens* var. *tovae* stat. nov.

- 2. Distal view (length, 8.1 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.
- 3. Distal view (length, 7.6 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.

4. *Toweius occultatus*—distal view (length, 6.3 µm), Zone NP 9, Clayton core (317.4 ft), New Jersey.

5. *Toweius eminens* var. *tovae* stat. nov.—possibly reworked—distal view (length, 6.7 µm), Zone NP 9, Clayton core (317.4 ft), New Jersey.

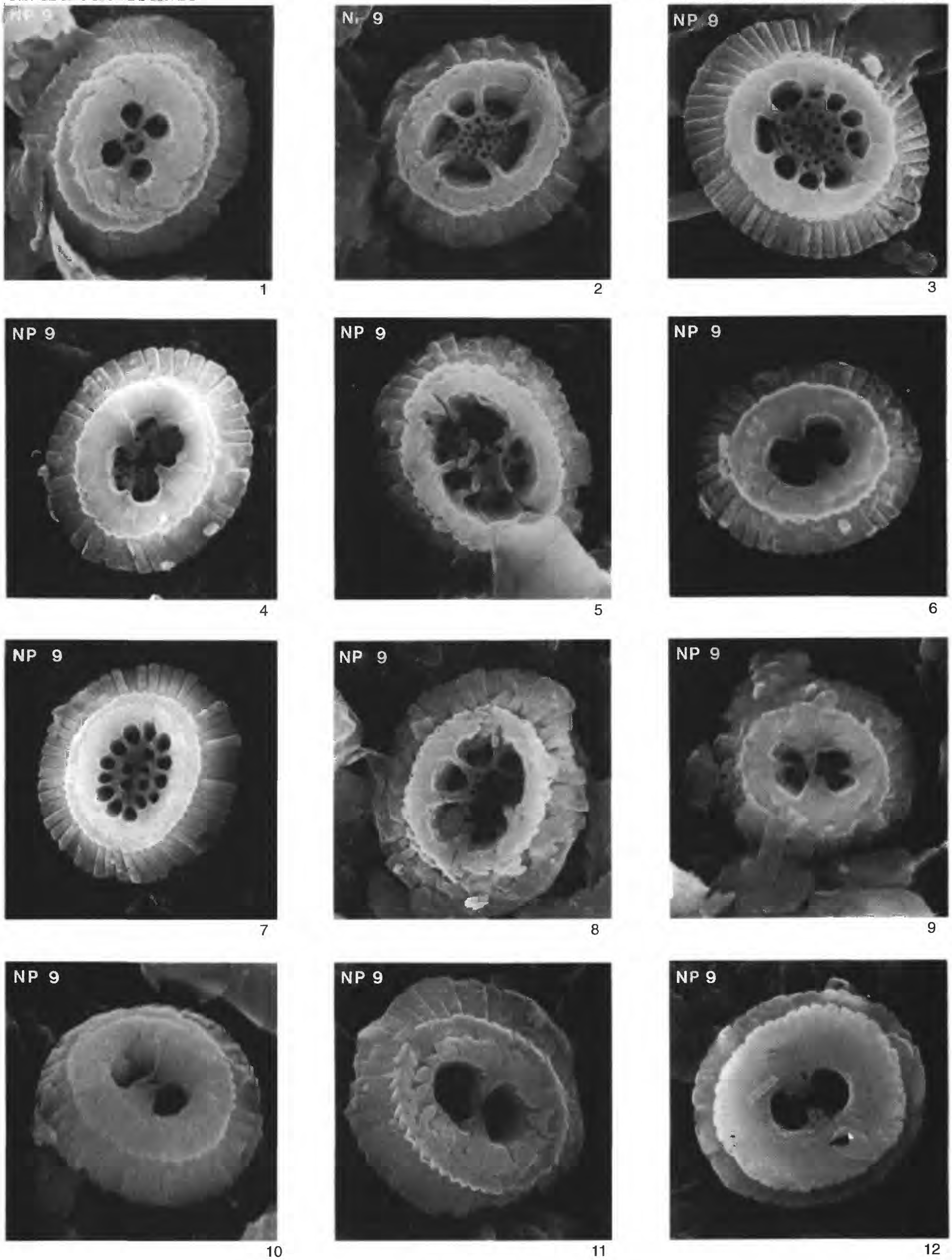
6. *Toweius occultatus*—distal view (length, 6.6 µm), Zone NP 9, Clayton core (317.4 ft), New Jersey.

7. *Toweius serotinus* n. sp.—paratype, distal view (length, 7.2 µm), Zone NP 9, Clayton core (317 ft), New Jersey.

8. *Toweius eminens* var. *tovae* stat. nov.—possibly reworked—distal view (length, 6.9 µm), Zone NP 9, Clayton core (314 ft), New Jersey.

9–12. *Toweius occultatus*

- 9. Distal view (length, 6.5 µm), Zone NP 9, Clayton core (314 ft), New Jersey.
- 10. Distal view (length, 7.3 µm), Zone NP 9, Clayton core (314 ft), New Jersey.
- 11. Distal view (length, 6.3 µm), Zone NP 9, Clayton core (309.6 ft), New Jersey.
- 12. Proximal view (length, 6.3 µm), Zone NP 9, Clayton core (309.6 ft), New Jersey.



TOWEIUS

PLATE 28

[Designation of calcareous nannofossil zone of Martini (1971) shown in upper left corner of each photomicrograph]

Figures 1–5. *Toweius occultatus*

1. Distal view (length, 7.8 µm), Zone NP 9, Clayton core (307.2 ft), New Jersey.
2. Distal view (length, 6.2 µm), Zone NP 9, Clayton core (307.2 ft), New Jersey.
3. Distal view (length, 6.8 µm), Zone NP 9, Clayton core (307.2 ft), New Jersey.
4. Distal view (length, 6.3 µm), Zone NP 9, Clayton core (307.2 ft), New Jersey.
5. Proximal view (length, 6.5 µm), Zone NP 9, Clayton core (307.2 ft), New Jersey.

6. *Toweius serotinus* n. sp.—holotype, distal view (length, 7.5 µm), Zone NP 10, Clayton core (298.5 ft), New Jersey.

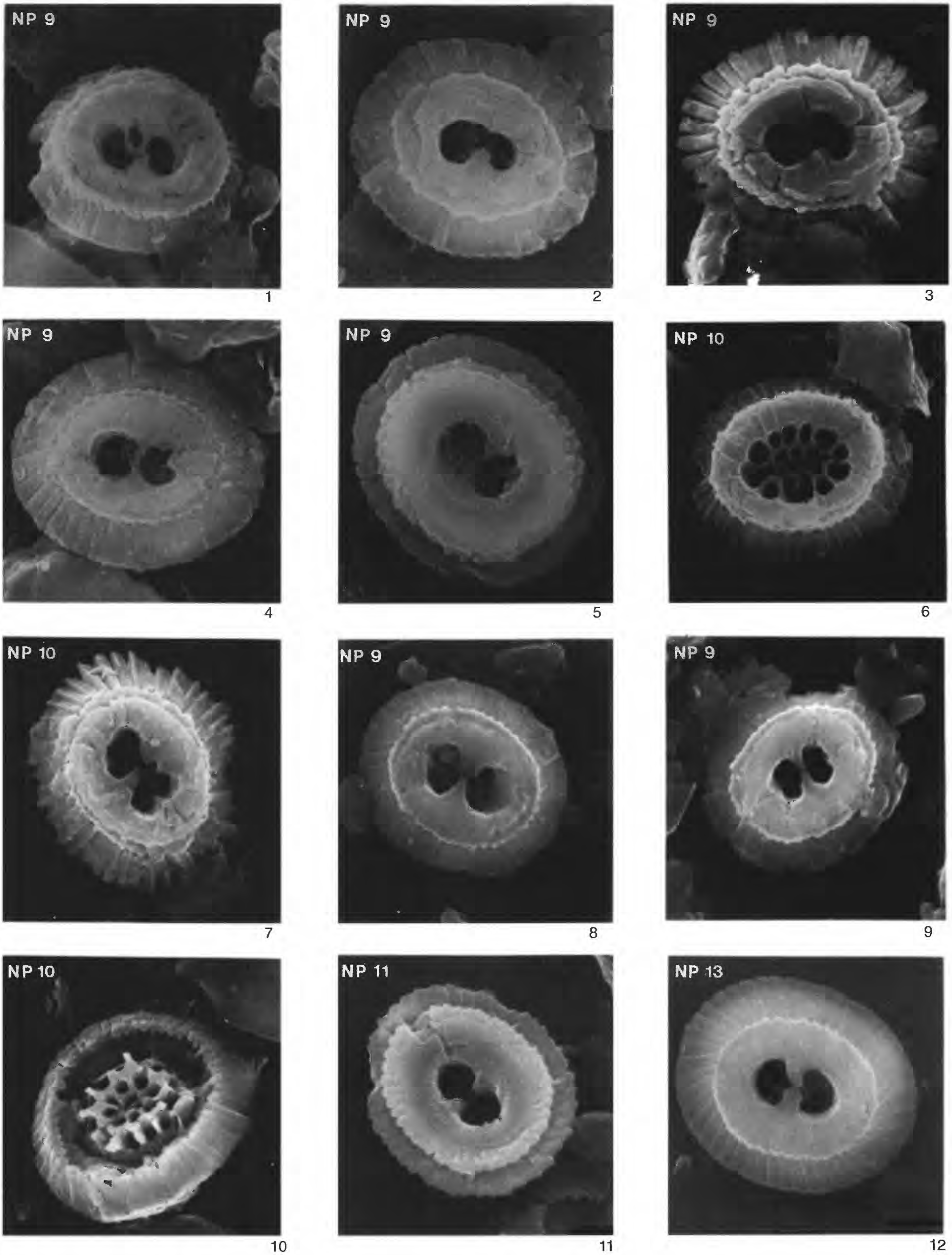
7–9. *Toweius occultatus*

7. Distal view (length, 7.0 µm), Zone NP 10, Clayton core (298.5 ft), New Jersey.
8. Distal view (length, 6.2 µm), Zone NP 9, GL 913 core (115 ft), New Jersey.
9. Distal view (length, 5.4 µm), Zone NP 9, GL 913 core (115 ft), New Jersey.

10. *Toweius serotinus* n. sp.—Distal view (length, 7.6 µm), Zone NP 10, New Brooklyn core (360 ft), New Jersey.

11, 12. *Toweius occultatus*

11. Proximal view (length, 5.1 µm), Zone NP 11, Solomons Island core (394 ft), Maryland.
12. Distal view (length, 5.2 µm), Zone NP 13, Allaire State Park–2 core (240 ft), New Jersey.


NP 9
1
NP 9
2
NP 9
3
NP 9
4
NP 9
5
NP 10
6
NP 10
7
NP 9
8
NP 9
9
NP 10
10
NP 11
11
NP 13
12

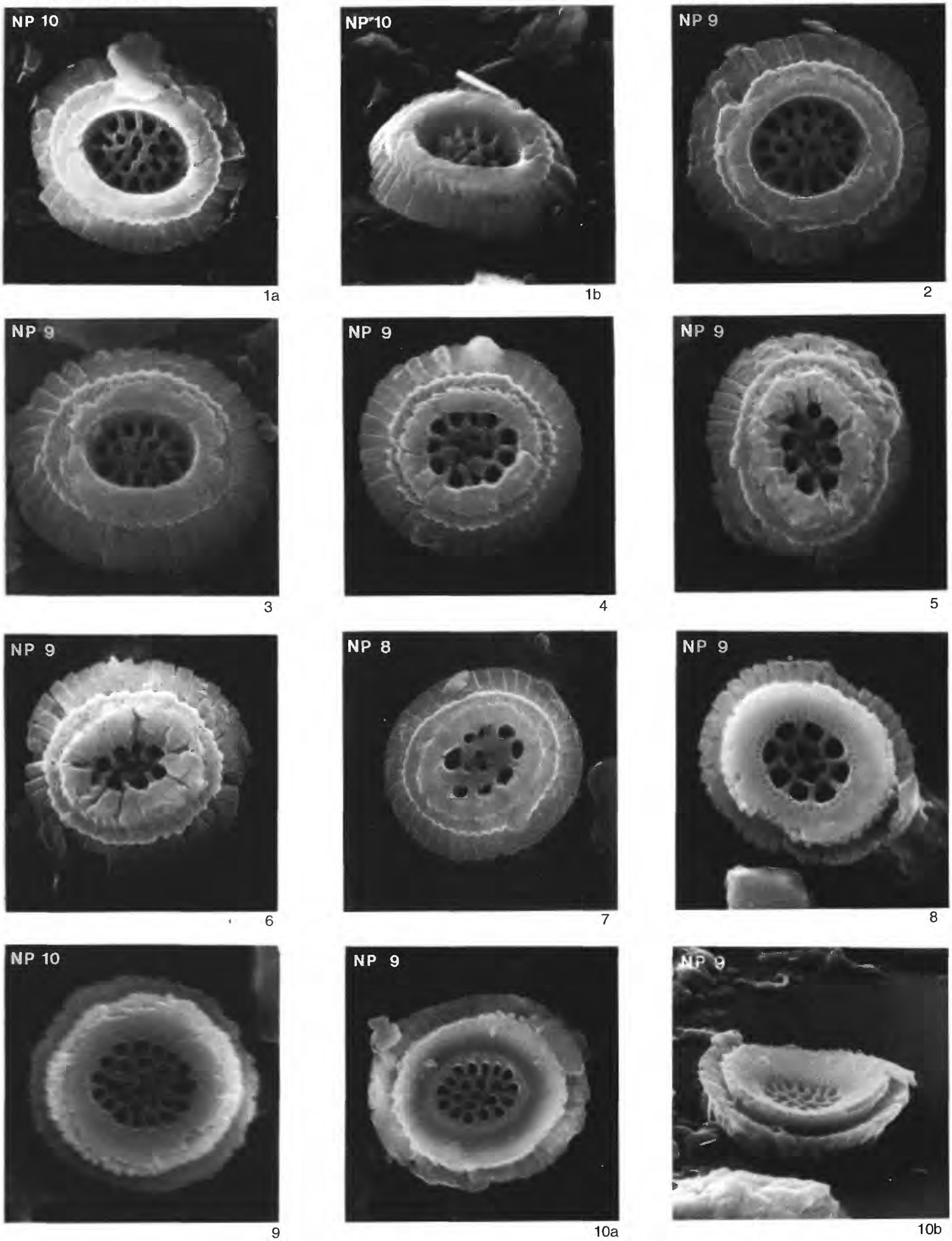
TOWEIUS

PLATE 29

[Designation of calcareous nannofossil zone of Martini (1971) shown in upper left corner of each photomicrograph]

Figures 1–10. *Toweius pertusus*

1a. Distal view (length, 5.1 µm), Zone NP 10, Clayton core (302.5 ft), New Jersey.
1b. Same specimen—tilted view.
2. Distal view (length, 5.5 µm), Zone NP 9, Clayton core (307.9 ft), New Jersey.
3. Distal view (length, 5.5 µm), Zone NP 9, Clayton core (317.4 ft), New Jersey.
4. Distal view (length, 4.7 µm), Zone NP 9, Aquia Creek locality, Virginia.
5. Distal view (length, 5.5 µm), Zone NP 9, GL 916 core (95 ft), New Jersey.
6. Distal view (length, 5.4 µm), Zone NP 9, GL 916 core (95 ft), New Jersey.
7. Distal view (length, 4.3 µm), Zone NP 8, K 15 core (120 ft), New Jersey.
8. Proximal view (length, 5.2 µm), Zone NP 9, GL 916 core (95 ft), New Jersey.
9. Proximal view (length, 5.3 µm), Zone NP 10, Clayton core (298.5 ft), New Jersey.
10a. Proximal view (length, 5.1 µm), Zone NP 9, Clayton core (314 ft), New Jersey.
10b. Same specimen—tilted view.


NP 10
1a
NP 10
1b
NP 9
2
NP 9
3
NP 9
4
NP 9
5
NP 9
6
NP 8
7
NP 9
8
NP 10
9
NP 9
10a
NP 9
10b

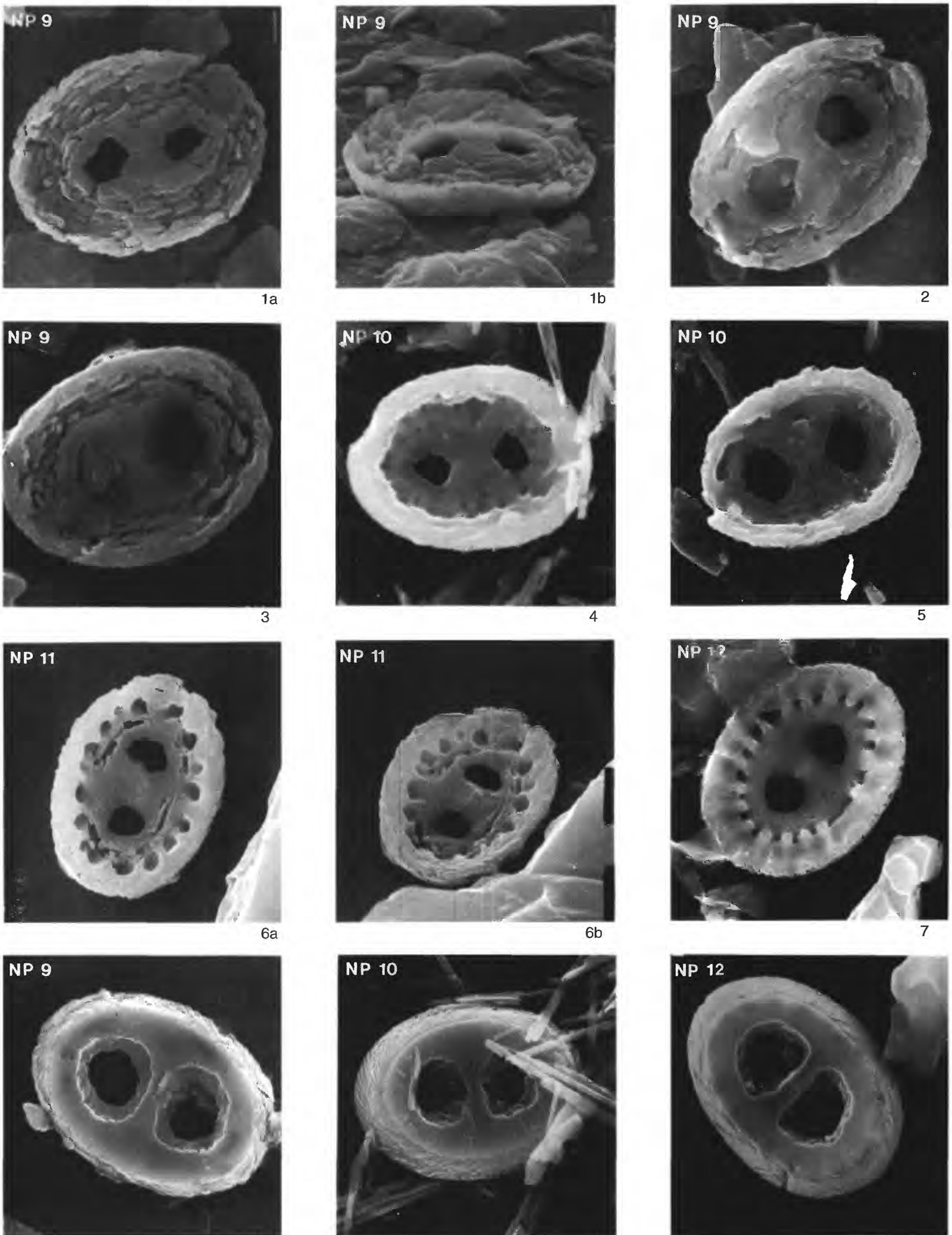
TOWEIUS

PLATE 30

[Designation of calcareous nannofossil zone of Martini (1971) shown in upper left corner of each photomicrograph]

Figures 1–10. *Transversopontis pulcher*

1a. Distal view (length, 7.6 µm), Zone NP 9, Clayton core (317.4 ft), New Jersey.
1b. Same specimen—tilted view.
2. Distal view (length, 8.6 µm), Zone NP 9, Clayton core (307.2 ft), New Jersey.
3. Distal view (length, 7.4 µm), Zone NP 9, Clayton core (306.9 ft), New Jersey.
4. Distal view (length, 7.2 µm), Zone NP 10, Tunnel Springs locality, Alabama.
5. Distal view (length, 6.6 µm), Zone NP 10, Tunnel Springs locality, Alabama.
6a. Distal view (length, 8.6 µm), Zone NP 11, Solomons Island core (394 ft), Maryland.
6b. Same specimen—tilted view.
7. Distal view (length, 10.7 µm), Zone NP 12, Solomons Island core (386.7 ft), Maryland.
8. Proximal view (length, 8.1 µm), Zone NP 9, Clayton core (307.9 ft), New Jersey.
9. Proximal view (length, 7.4 µm), Zone NP 10, Tunnel Springs locality, Alabama.
10. Proximal view (length, 11.5 µm), Zone NP 12, Solomons Island core (386.7 ft), Maryland.



TRANSVERSOPONTIS

PLATE 31

[Designation of calcareous nannofossil zone of Martini (1971) shown in upper left corner of each photomicrograph]

Figures 1, 2. *Rhomboaster spineus*

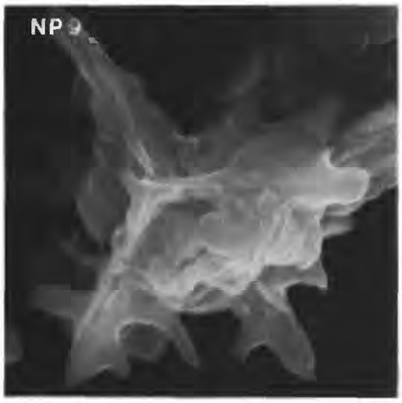
- 1a. Diameter, 13.3 µm; Zone NP 9; Clayton core (307.2 ft), New Jersey.
- 1b. Same specimen—tilted view.
- 2. Diameter, 12.2 µm; Zone NP 10; Clayton core (298.5 ft), New Jersey.

3–6. *Zygodiscus herlyni*

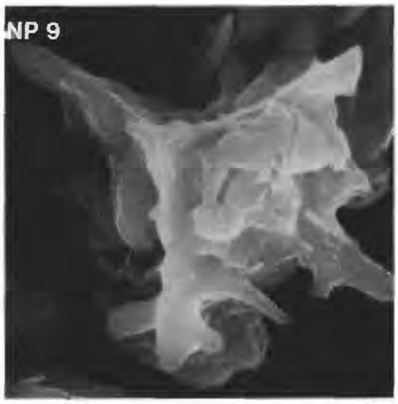
- 3a. Distal view (length, 9.4 µm), Zone NP 9, Clayton core (322 ft), New Jersey.
- 3b. Same specimen—tilted view.
- 4. Distal view (length, 8.1 µm), Zone NP 9, Clayton core (322 ft), New Jersey.
- 5a. Distal view (length, 7.7 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.
- 5b. Same specimen—tilted view.
- 6. Proximal view (length, 8.5 µm), Zone NP 9, Clayton core (322 ft), New Jersey.

7. *Zygrhablithus bijugatus*

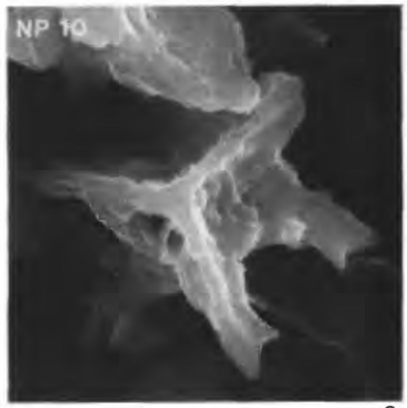
- 7a. Top view (length of base, 5.8 µm), Zone NP 10, Tunnel Springs locality, Alabama.
- 7b. Same specimen—side view.
- 7c. Same specimen—end view.



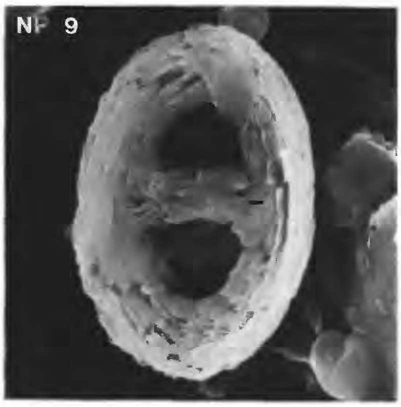
1a



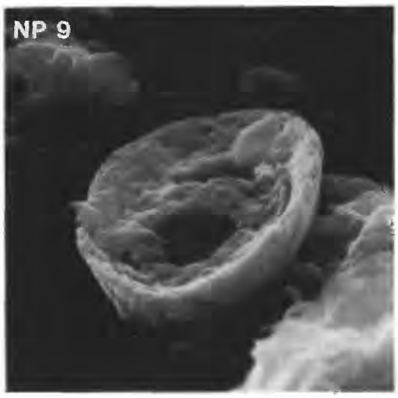
1b



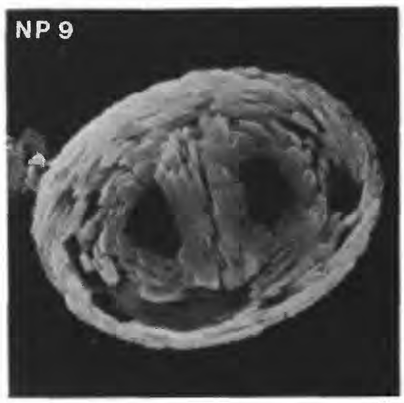
2



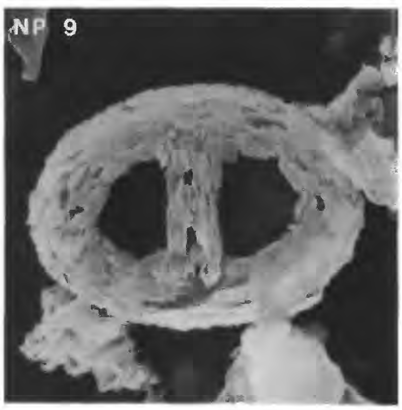
3a



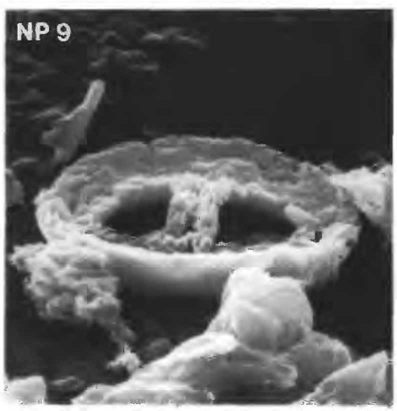
3b



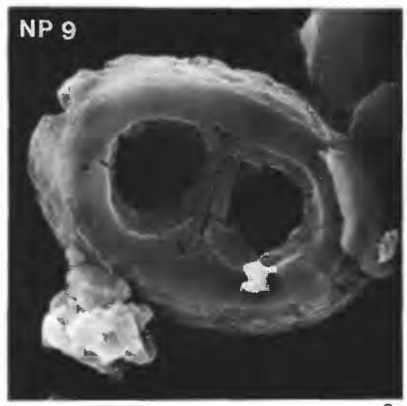
4



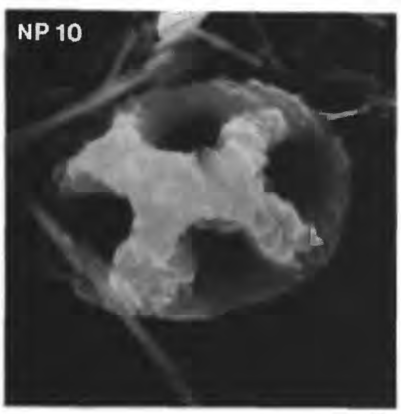
5a



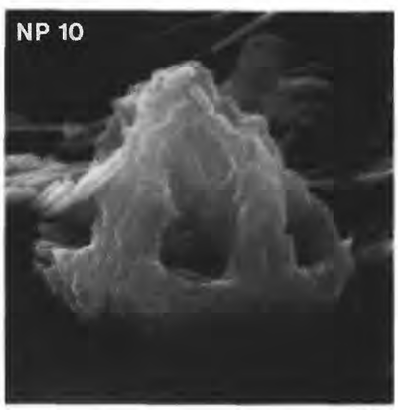
5b



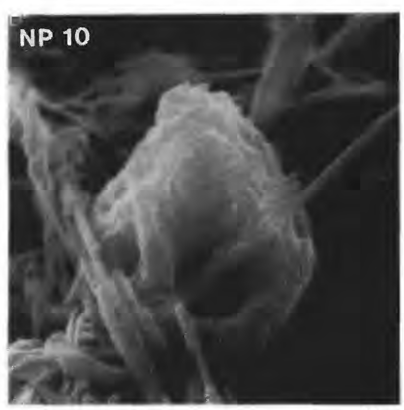
6



7a



7b



7c

RHOMBOASTER, ZYGODISCUS, AND *ZYGRHABLITHUS*

PLATE 32

[XP, cross-polarized light; TL, transmitted light; PC, phase contrast]

Figures 1–3. *Biantholithus astralis*
- 1. XP (diameter, 9.3 μm), Zone NP 9, Clayton core (324.4 ft), New Jersey.
- 2. XP (diameter, 10.9 μm), Zone NP 9, Clayton core (348.5 ft), New Jersey.
- 3. XP (diameter, 9.4 μm), Zone NP 9, Clayton core (324.4 ft), New Jersey.

4. *Biantholithus sparsus*?—XP (diameter, 8.9 μm), Zone NP 10, Clayton core (302.5 ft), New Jersey.

5, 10. *Biscutum* spp.
- 5. XP (length, 5.1 μm), Zone NP 9, GL 913 core (125 ft), New Jersey.
- 10. XP (length, 5.7 μm), Zone NP 9, Clayton core (322 ft), New Jersey.

8, 9. *Campylosphaera dela*
- 8. XP (length, 6.3 μm), Zone NP 9, Clayton core (314 ft), New Jersey.
- 9. XP (length, 7.8 μm), Zone NP 9, Clayton core (321.4 ft), New Jersey.

6, 7, 11, 12. *Chiasmolithus bidens*
- 6. XP (length, 7.8 μm), Zone NP 9, Clayton core (324.4 ft), New Jersey.
- 7. XP (length, 9.1 μm), Zone NP 9, Clayton core (321.4 ft), New Jersey.
- 11. XP (length, 9.0 μm), Zone NP 9, Clayton core (321.4 ft), New Jersey.
- 12. XP (length, 12.5 μm), Zone NP 9, Clayton core (321.4 ft), New Jersey.

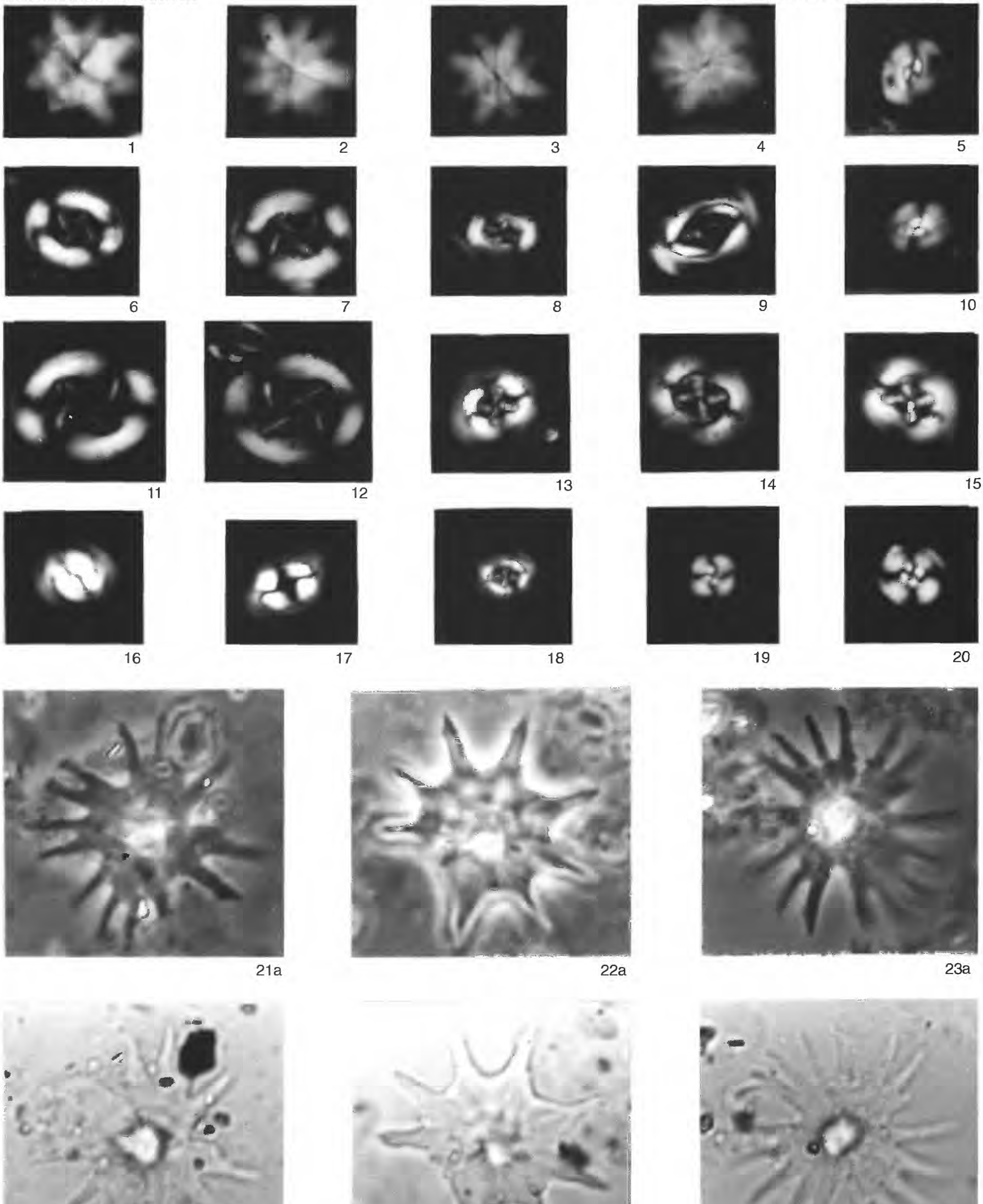
13–15. *Chiasmolithus consuetus* s. ampl.
- 13. XP (length, 9.4 μm), Zone NP 9, Clayton core (348.5 ft), New Jersey.
- 14. XP (length, 11.0 μm), Zone NP 9, Clayton core (324.4 ft), New Jersey.
- 15. XP (length, 10.4 μm), Zone NP 9, Clayton core (348.5 ft), New Jersey.

16, 17. *Coccolithus pelagicus*
- 16. XP (length, 7.8 μm), Zone NP 10, Clayton core (296.5 ft), New Jersey.
- 17. XP (length, 4.7 μm), Zone NP 9, Clayton core (321.4 ft), New Jersey.

18. *Cruciplacolithus* sp., XP (length, 6.3 μm), Zone NP 10, Clayton core (302.5 ft), New Jersey.

19, 20. *Cyclagelosphaera prima* n. comb.
- 19. XP (diameter, 3.9 μm), Zone NP 10, Clayton core (302.5 ft), New Jersey.
- 20. XP (diameter, 4.7 μm), Zone NP 9, Clayton core (321.4 ft), New Jersey.

21–23. *Discoaster anartios* n. sp.
- 21. 21a—PC, 21b—TL (diameter, 18.7 μm), Zone NP 10, Clayton core (302.5 ft), New Jersey.
- 22. 22a—PC, 22b—TL (diameter, 19.2 μm), Zone NP 10, Clayton core (302.5 ft), New Jersey.
- 23. 23a—PC, 23b—TL (diameter, 17.2 μm), Zone NP 10, Clayton core (302.5 ft), New Jersey.



BIANTHOLITHUS, BISCUTUM, CAMPYLOSPHAERA, CHIASMOLITHUS, COCCOLITHUS, CRUCIPLACOLITHUS, CYCLAGELOSPHAERA, AND *DISCOASTER*

PLATE 33

[TL, transmitted light; PC, phase contrast]

Figure 1. *Discoaster anartios* n. sp., 1a—PC, 1b—TL (diameter, 17.2 µm), Zone NP 10, Clayton core (302.5 ft), New Jersey.

2, 3, 8. *Discoaster falcatus*

2. 2a—PC, 2b—TL (diameter, 12.5 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.
3. 3a—PC, 3b—TL (diameter, 15.6 µm), Zone NP 10, Clayton core (302.5 ft), New Jersey.
8. 8a—PC, 8b—TL (diameter, 12.9 µm), Zone NP 9, Clayton core (314 ft), New Jersey.

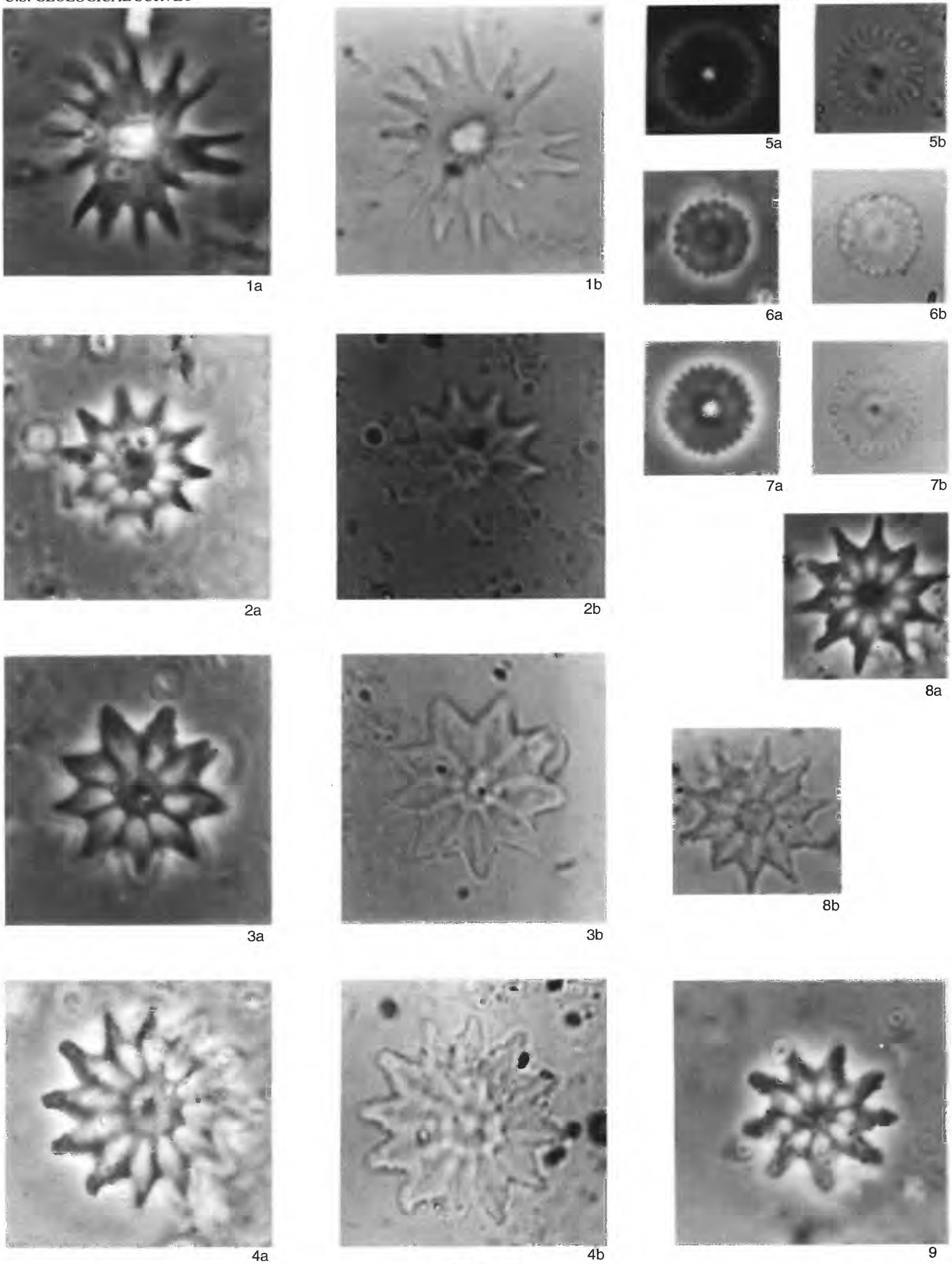
5–7. *Discoaster lenticularis*

5. 5a—PC, 5b—TL (diameter, 7.8 µm), Zone NP 9, Clayton core (314 ft), New Jersey.
6. 6a—PC, 6b—TL (diameter, 9.4 µm), Zone NP 9, Clayton core (324.4 ft), New Jersey.
7. 7a—PC, 7b—TL (diameter, 9.9 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.

4, 9. *Discoaster limbatus*

4 4a—PC, 4b—TL (diameter, 17.6 µm), Zone NP 9, Clayton core (307.2 ft), New Jersey.

9. PC (diameter, 12.5 µm), Zone NP 9, Clayton core (307.2 ft), New Jersey.



DISCOASTER

PLATE 34

[TL, transmitted light; PC, phase contrast]

Figures 1, 2. *Discoaster mediosus* s. ampl.

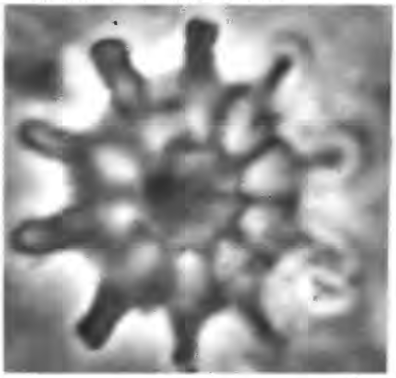
1. 1a—PC, 1b—TL (diameter, 13.7 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.
2. 2a—PC, 2b—TL (diameter, 16.0 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.

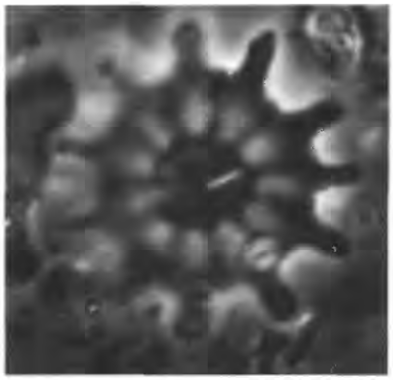
3, 4, 6. *Discoaster* sp. aff. *D. mohleri*

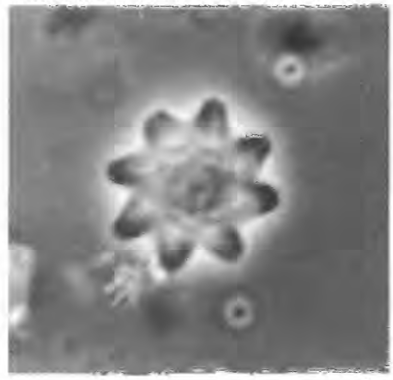
3. 3a—PC, 3b—TL (diameter, 9.4 µm), Zone NP 10, Clayton core (296.5 ft), New Jersey.
4. 4a—PC, 4b—TL (diameter, 10.6 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.
6. 6a—TL, 6b—PC (diameter, 8.6 µm), Zone NP 9, Clayton core (314 ft), New Jersey.

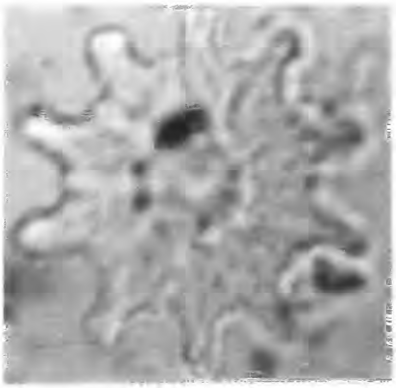
5, 7. *Discoaster multiradiatus*

5. 5a—PC, 5b—TL (diameter, 18.8 µm), Zone NP 9, Clayton core (322 ft), New Jersey.
7. PC (diameter, 11.8 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.


1a

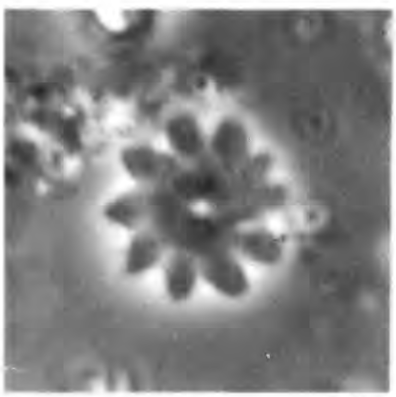

2a

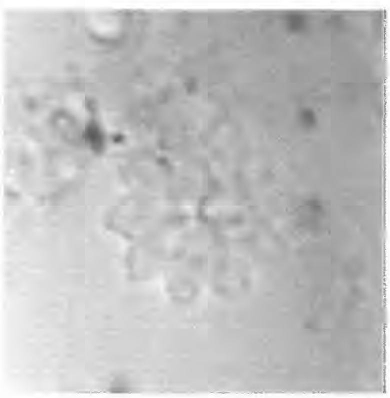

3a

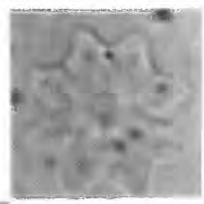

1b

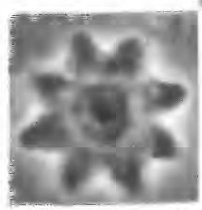

2b

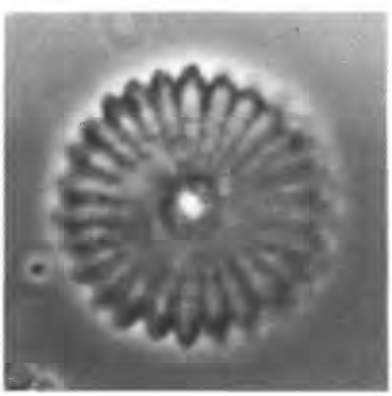

3b

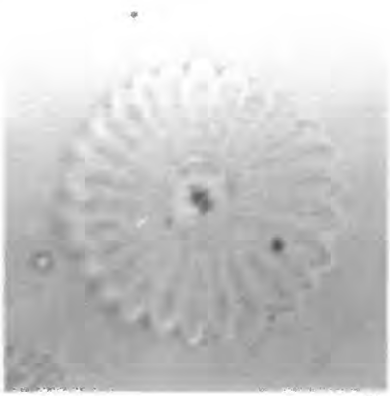

4a

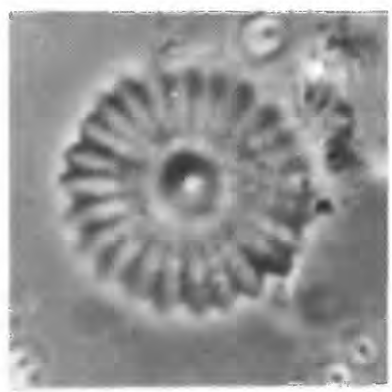

4b


6a


6b


5a


5b


7

DISCOASTER

PLATE 35

[XP, cross-polarized light; TL, transmitted light; PC, phase contrast]

Figures 1, 2. *Discoaster salisburgensis*

1. 1a—PC, 1b—TL (diameter, 16.1 µm), Zone NP 10, GL 915 core (100 ft), New Jersey.
2. 2a—PC, 2b—TL (diameter, 13.6 µm), Zone NP 9, GL 913 core (125 ft), New Jersey.

3, 5. *Discoaster splendidus*

3. 3a—PC, 3b—TL (diameter, 16.7 µm), Zone NP 9, GL 915 core (130 ft), New Jersey.
5. 5a—PC, 5b—TL (diameter, 15.6 µm), Zone NP 9, GL 915 core (130 ft), New Jersey.

4, 6, 7. *Ellipsolithus macellus*

4. XP (length, 16.2 µm), Zone NP 9, GL 913 core (125 ft), New Jersey.
6. XP (length, 12.9 µm), Zone NP 9, Clayton core (348.5 ft), New Jersey.
7. XP (length, 12.5 µm), Zone NP 9, GL 915 core (130 ft), New Jersey.

8, 9. *Ellipsolithus distichus*

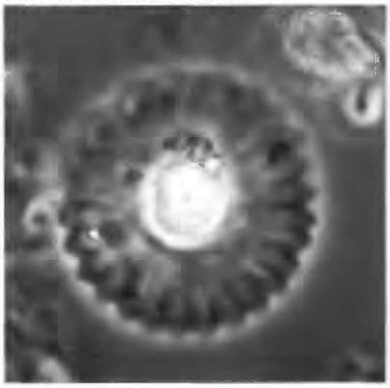
8. XP (length, 9.4 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.
9. XP (length, 6.3 µm), Zone NP 9, Clayton core (317.4 ft), New Jersey.

10, 11. *Ericsonia subpertusa*

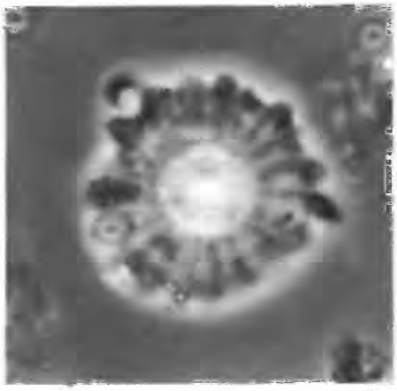
10. XP (length, 9.4 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.
11. XP (length, 5.8 µm), Zone NP 9, Clayton core (314 ft), New Jersey.

12–14. *Fasciculithus aubertae*

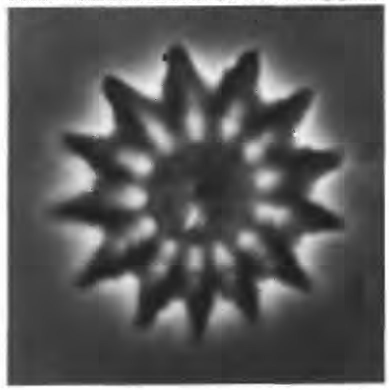
12. XP (height, 3.8 µm), Zone NP 9, Clayton core (348.5 ft), New Jersey.
13. XP (height, 3.5 µm), Zone NP 9, GL 913 core (125 ft), New Jersey.
14. XP (height, 2.3 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.



1a



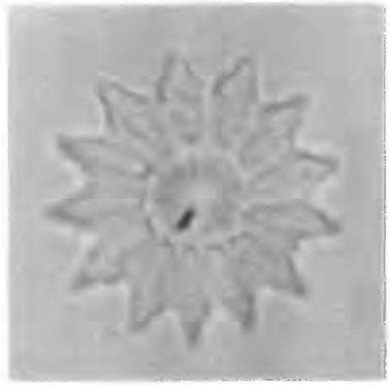
2a



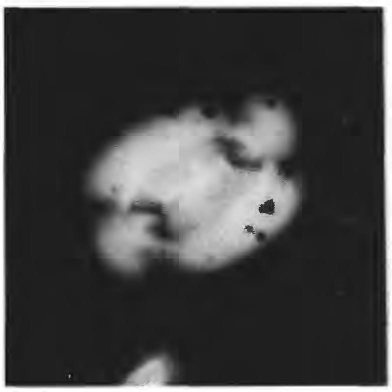
3a

1b

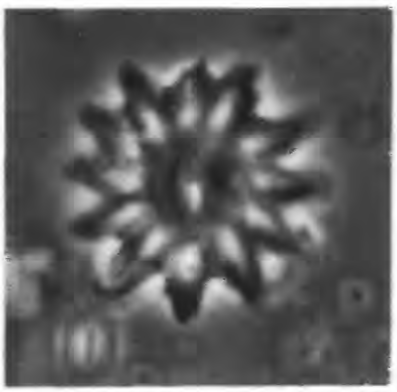
2b



3b



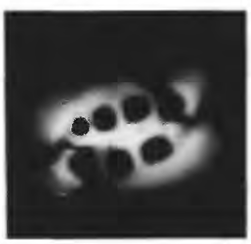
4



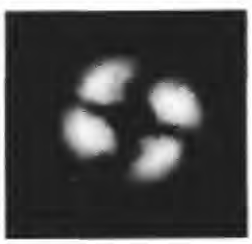
5a

5b

6



8



10

13

12

7

9

11

14

DISCOASTER, ELLIPSOLITHUS, ERICSONIA, AND *FASCICULITHUS*

PLATE 36

[XP, cross-polarized light; PC, phase contrast]

Figures 1–4. *Fasciculithus involutus*

1. XP side view (height, 4.7 μm), Zone NP 10, Clayton core (302.5 ft), New Jersey.
2. XP side view (height, 3.5 μm), Zone NP 9, Clayton core (321.4 ft), New Jersey.
3. XP side view (height, 6.3 μm), Zone NP 9, Clayton core (348.5 ft), New Jersey.
4. XP end view (diameter, 4.7 μm), Zone NP 9, Clayton core (321.4 ft), New Jersey.

5, 10. *Fasciculithus schaubii*

5. XP (height, 8.4 μm), Zone NP 9, Clayton core (324.4 ft), New Jersey.
10. XP (height, 5.7 μm), Zone NP 9, Clayton core (322 ft), New Jersey.

6–9, 11. *Fasciculithus sidereus* n. sp.

6. XP end view (diameter, 4.2 μm), Zone NP 9, Clayton core (317.4 ft), New Jersey.
7. XP end view (diameter, 4.7 μm), Zone NP 9, Clayton core (317.4 ft), New Jersey.
8. XP end view (diameter, 5.6 μm), Zone NP 10, Clayton core (296.5 ft), New Jersey.
9. PC end view (diameter, 4.5 μm), Zone NP 9, Clayton core (317.4 ft), New Jersey.
11. XP end view (diameter, 9.5 μm), Zone NP 10, Clayton core (296.5 ft), New Jersey.

12, 13. *Fasciculithus thomasii*

12. XP (height, 7.8 μm), Zone NP 9, Clayton core (321.4 ft), New Jersey.
13. XP (height, 8.3 μm), Zone NP 9, Clayton core (309.6 ft), New Jersey.

14, 15, 19, 20. *Fasciculithus tympaniformis*

14. XP (height, 5.4 μm), Zone NP 9, GL 915 core (130 ft), New Jersey.
15. XP (height, 4.2 μm), Zone NP 9, GL 915 core (130 ft), New Jersey.
19. XP (height, 4.7 μm), Zone NP 9, Clayton core (309.6 ft), New Jersey.
20. XP (height, 4.7 μm), Zone NP 9, Clayton core (348.5 ft), New Jersey.

16, 21, 22. *Hornibrookina arca* n. sp.

16. XP (length, 6.6 μm), Zone NP 9, Clayton core (321.4 ft), New Jersey.
21. XP (length, 4.7 μm), Zone NP 9, Clayton core (321.4 ft), New Jersey.
22. XP (length, 4.7 μm), Zone NP 9, Clayton core (321.4 ft), New Jersey.

17, 18. *Goniolithus fluckigeri*

17. XP (diameter, 6.7 μm), Zone NP 9, Clayton core (321.4 ft), New Jersey.
18. XP (diameter, 6.3 μm), Zone NP 9, GL 913 core (125 ft), New Jersey.

23–25, 30. *Lophodolithus nascens*

23. XP (length, 10.9 μm), Zone NP 10, Clayton core (302.5 ft), New Jersey.
24. XP (length, 11.3 μm), Zone NP 10, Clayton core (302.5 ft), New Jersey.
25. XP (length, 9.9 μm), Zone NP 10, Clayton core (302.5 ft), New Jersey.
30. XP (length, 12.1 μm), Zone NP 10, Clayton core (302.5 ft), New Jersey.

27–29. *Markalius apertus*

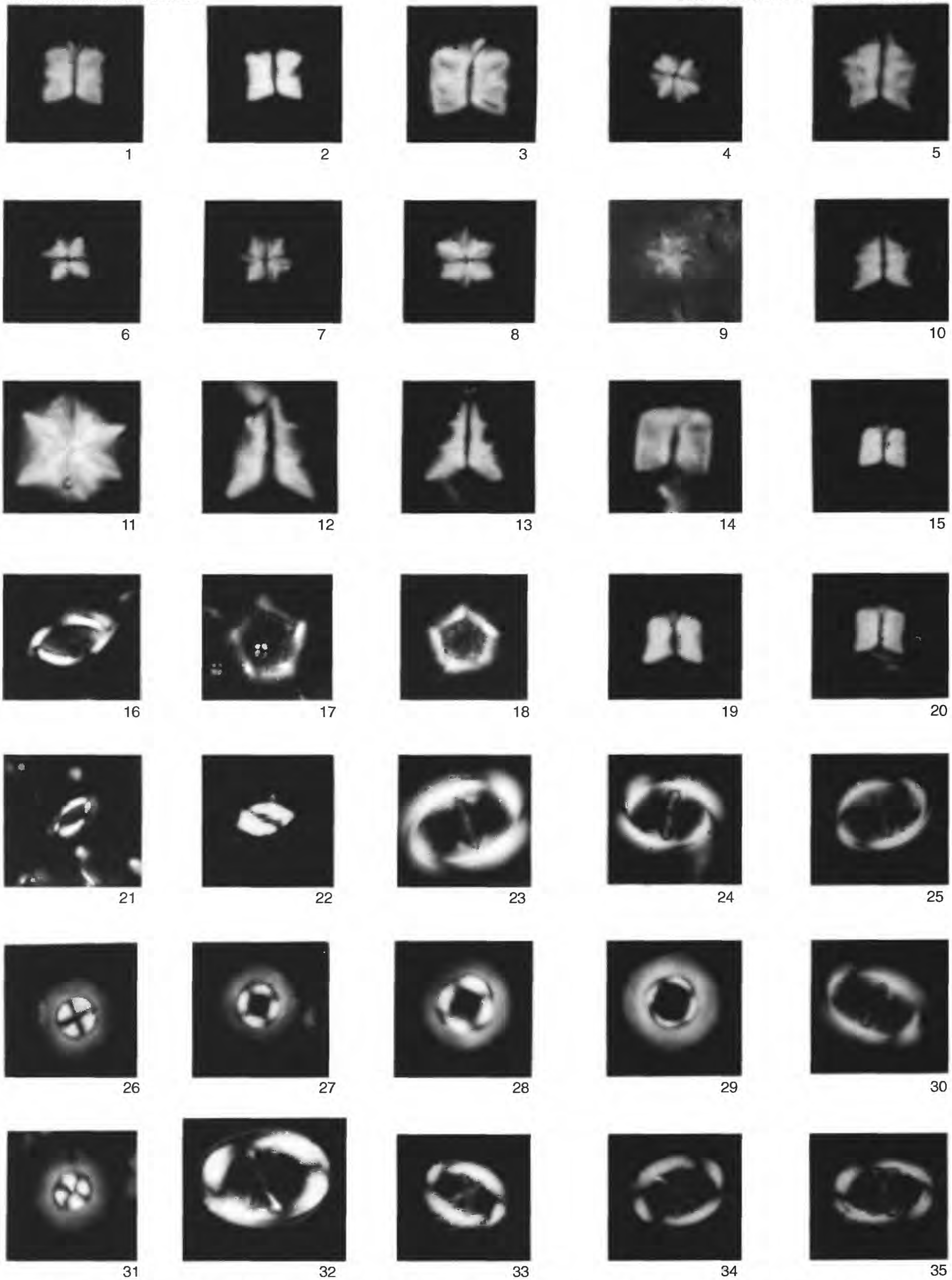
27. XP (diameter, 7.8 μm), Zone NP 9, Clayton core (348.5 ft), New Jersey.
28. XP (diameter, 8.3 μm), Zone NP 9, GL 915 core (130 ft), New Jersey.
29. XP (diameter, 7.8 μm), Zone NP 9, GL 913 core (125 ft), New Jersey.

26, 31. *Markalius inversus*

26. XP (diameter, 6.7 μm), Zone NP 9, Clayton core (324.4 ft), New Jersey.
31. XP (diameter, 6.3 μm), Zone NP 9, Clayton core (324.4 ft), New Jersey.

32–35. *Neochiastozygus concinnus* s. ampl.

32. XP (length, 8.1 μm), Zone NP 9, Clayton core (321.4 ft), New Jersey.
33. XP (length, 6.3 μm), Zone NP 9, Clayton core (321.4 ft), New Jersey.
34. XP, (length, 7.8 μm), Zone NP 9, Clayton core (314 ft), New Jersey.
35. XP (length, 9.4 μm), Zone NP 9, Clayton core (321.4 ft), New Jersey.



FASCICULITHUS, HORNIBROOKINA, GONIOLITHUS, LOPHODOLITHUS, MARKALIUS, AND *NEOCHIASTOZYGUS*

PLATE 37

[XP, cross-polarized light]

Figure 1. *Neochiastozygus imbriei*
1. XP (length, 6.8 µm), Zone NP 9, GL 915 core (130 ft), New Jersey.

2, 3. *Placozygus sigmoides*
2. XP (length, 9.4 µm), Zone NP 9, Clayton core (322 ft), New Jersey.
3. XP (length, 8.3 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.

4, 5, 7–10. *Rhomboaster bramlettei* n. comb.
4. XP (diameter, 7.8 µm), Zone NP 10, Clayton core (296.5 ft), New Jersey.
5. XP (diameter, 8.7 µm), Zone NP 10, Clayton core (296.5 ft), New Jersey.
7. XP (diameter, 10.4 µm), Zone NP 10, Clayton core (296.5 ft), New Jersey.
8. XP (diameter, 6.8 µm), Zone NP 10, Clayton core (296.5 ft), New Jersey.
9. XP (diameter, 10.6 µm), Zone NP 10, GL 915 core (100 ft), New Jersey.
10. XP (diameter, 9.4 µm), Zone NP 10, Clayton core (302.5 ft), New Jersey.

6, 11–13. *Rhomboaster spineus*
6. XP (diameter, 14.5 µm), Zone NP 10, Clayton core (302.5 ft), New Jersey.
11. XP (diameter, 15.6 µm), Zone NP 9, Clayton core (307.2 ft), New Jersey.
12. XP (diameter, 13.0 µm), Zone NP 9, Clayton core (309.6 ft), New Jersey.
13. XP (diameter, 12.7 µm), Zone NP 9, Clayton core (309.6 ft), New Jersey.

14, 15. *Scapholithus apertus*
14. XP (length, 4.2 µm), Zone NP 9, GL 915 core (130 ft), New Jersey.
15. XP (length, 4.7 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.

16. *Sphenolithus anarrhopus*
16. XP (height, 4.7 µm), Zone NP 10, GL 915 core (100 ft), New Jersey.

17, 18. *Sphenolithus primus*
17. XP (height, 6.1 µm), Zone NP 10, Clayton core (296.5 ft), New Jersey.
18. XP (height, 6.3 µm), Zone NP 10, Clayton core (296.5 ft), New Jersey.

19, 20, 25. *Toweius callosus*
19. XP (length, 6.3 µm), Zone NP 10, GL 915 core (100 ft), New Jersey.
20. XP (length, 5.1 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.
25. XP (length, 3.1 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.

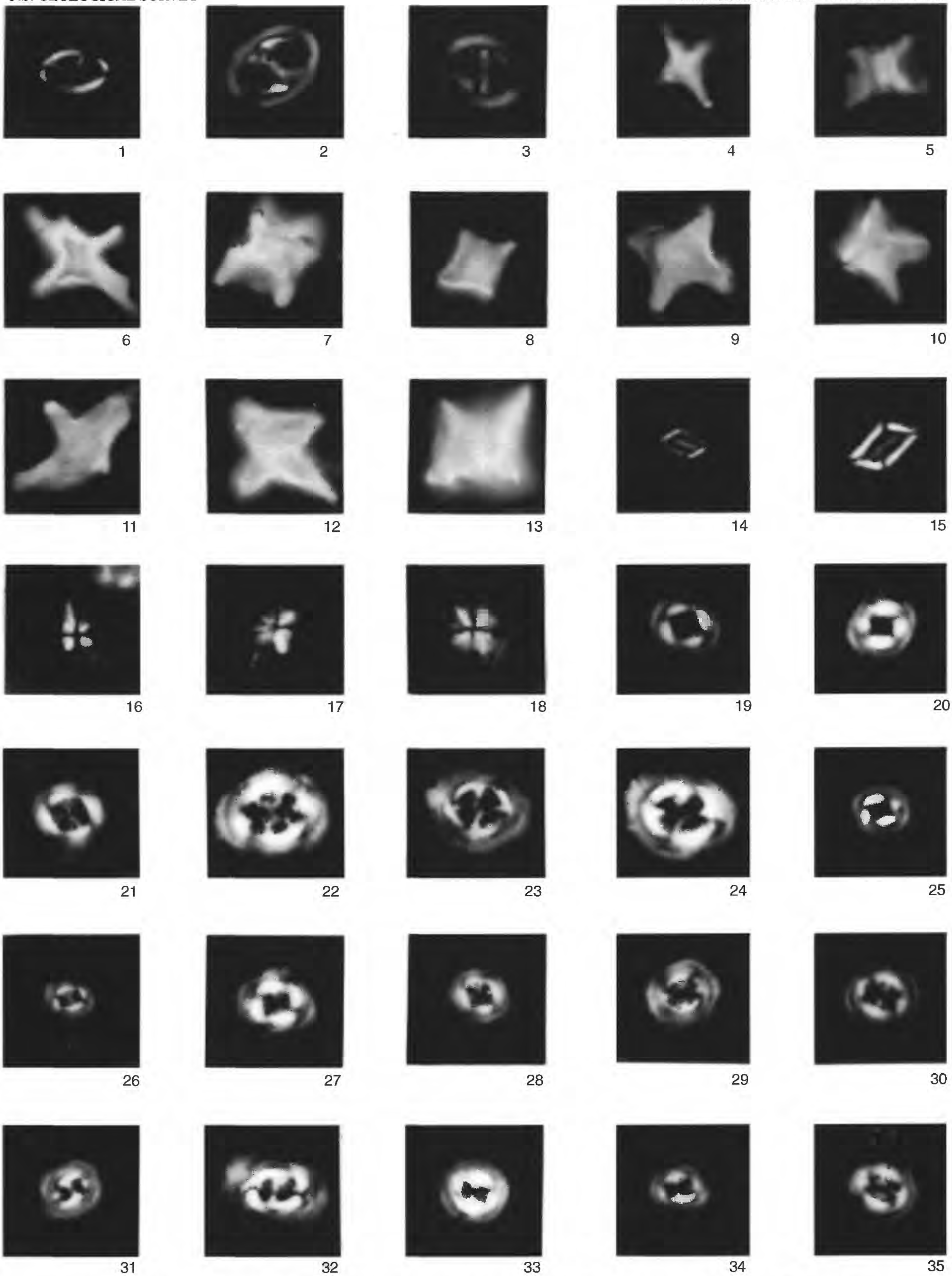
23, 24. *Toweius eminens* var. *eminens* autonym
23. XP (length, 6.3 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.
24. XP (length, 7.8 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.

31–34. *Toweius occultatus*
31. XP (length, 6.3 µm), Zone NP 9, Clayton core (314 ft), New Jersey.
32. XP (length, 6.3 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.
33. XP (length, 6.3 µm), Zone NP 10, Clayton core (296.5 ft), New Jersey.
34. XP (length, 6.3 µm), Zone NP 9, Clayton core (317.4 ft), New Jersey.

21, 26–28. *Toweius pertusus*
21. XP (length, 4.7 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.
26. XP (length, 4.7 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.
27. XP (length, 4.7 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.
28. XP (length, 4.7 µm), Zone NP 9, Clayton core (314 ft), New Jersey.

22. *Toweius eminens* var. *tovae* stat. nov.
22. XP (length, 6.3 µm), Zone NP 9, Clayton core (321.4 ft), New Jersey.

29, 30, 35. *Toweius serotinus* n. sp.
29. XP (length, 6.3 µm), Zone NP 10, Clayton core (302.5 ft), New Jersey.
30. XP (length, 6.3 µm), Zone NP 10, Clayton core (302.5 ft), New Jersey.
35. XP (length, 6.3 µm), Zone NP 10, Clayton core (302.5 ft), New Jersey.



NEOCHIASTOZYGUS, PLACOZYGUS, RHOMBOASTER, SCAPHOLITHUS, SPHENOLITHUS, AND *TOWEIUS*

PLATE 38

[XP, cross-polarized light]

Figures 1–3. *Transversopontis pulcher*

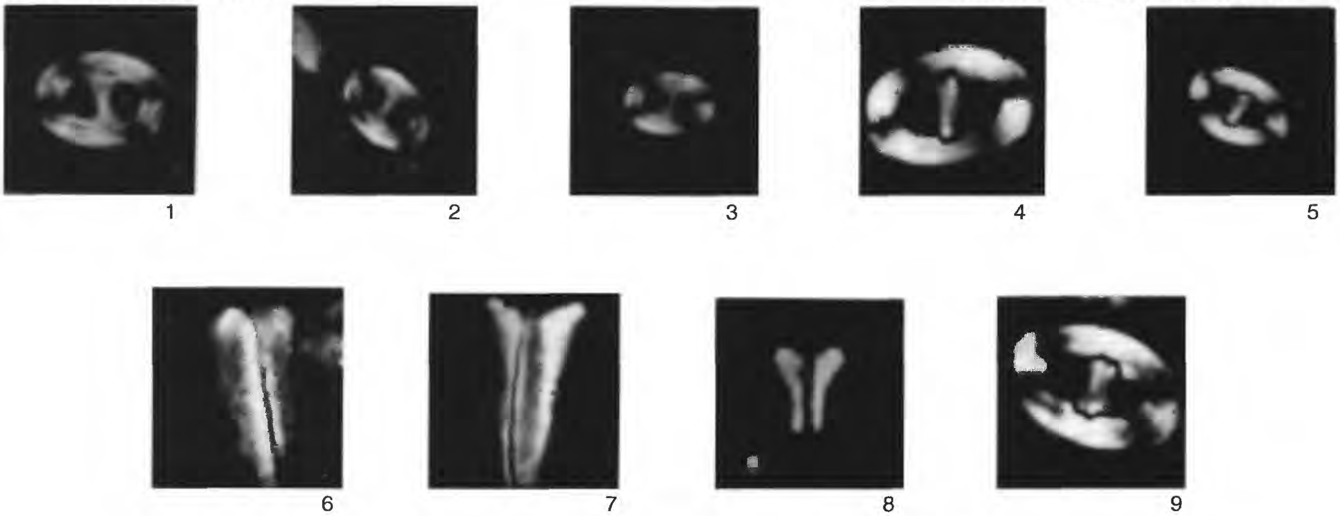
1. XP (length, 7.8 μm), Zone NP 10, Clayton core (302.5 ft), New Jersey.
2. XP (length, 6.3 μm), Zone NP 10, Clayton core (302.5 ft), New Jersey.
3. XP (length, 6.3 μm), Zone NP 10, Clayton core (302.5 ft), New Jersey.

4, 5, 9. *Zygodiscus herlyni*

4. XP (length, 7.8 μm), Zone NP 9, Clayton core (321.4 ft), New Jersey.
5. XP (length, 7.3 μm), Zone NP 9, Clayton core (314 ft), New Jersey.
9. XP (length, 8.2 μm), Zone NP 9, Clayton core (321.4 ft), New Jersey.

6–8. *Zygrhablithus bijugatus*

6. XP (length, 10.5 μm), Zone NP 9, GL 913 core (125 ft), New Jersey.
7. XP (length, 10.9 μm), Zone NP 9, GL 913 core (125 ft), New Jersey.
8. XP (length, 6.3 μm), Zone NP 9, GL 915 core (130 ft), New Jersey.



TRANSVERSOPONTIS, ZYGODISCUS, AND *ZYGRHABLITHUS*

SELECTED SERIES OF U.S. GEOLOGICAL SURVEY PUBLICATIONS

Periodicals

Earthquakes & Volcanoes (issued bimonthly).
Preliminary Determination of Epicenters (issued monthly).

Technical Books and Reports

Professional Papers are mainly comprehensive scientific reports of wide and lasting interest and importance to professional scientists and engineers. Included are reports on the results of resource studies and of topographic, hydrologic, and geologic investigations. They also include collections of related papers addressing different aspects of a single scientific topic.

Bulletins contain significant data and interpretations that are of lasting scientific interest but are generally more limited in scope or geographic coverage than Professional Papers. They include the results of resource studies and of geologic and topographic investigations, as well as collections of short papers related to a specific topic.

Water-Supply Papers are comprehensive reports that present significant interpretive results of hydrologic investigations of wide interest to professional geologists, hydrologists, and engineers. The series covers investigations in all phases of hydrology, including hydrogeology, availability of water, quality of water, and use of water.

Circulars present administrative information or important scientific information of wide popular interest in a format designed for distribution at no cost to the public. Information is usually of short-term interest.

Water-Resources Investigations Reports are papers of an interpretive nature made available to the public outside the formal USGS publications series. Copies are reproduced on request unlike formal USGS publications, and they are also available for public inspection at depositories indicated in USGS catalogs.

Open-File Reports include unpublished manuscript reports, maps, and other material that are made available for public consultation at depositories. They are a nonpermanent form of publication that may be cited in other publications as sources of information.

Maps

Geologic Quadrangle Maps are multicolor geologic maps on topographic bases in 7.5- or 15-minute quadrangle formats (scales mainly 1:24,000 or 1:62,500) showing bedrock, surficial, or engineering geology. Maps generally include brief texts; some maps include structure and columnar sections only.

Geophysical Investigations Maps are on topographic or planimetric bases at various scales; they show results of surveys using geophysical techniques, such as gravity, magnetic, seismic, or radioactivity, which reflect subsurface structures that are of economic or geologic significance. Many maps include correlations with the geology.

Miscellaneous Investigations Series Maps are on planimetric or topographic bases of regular and irregular areas at various scales; they present a wide variety of format and subject matter. The series also includes 7.5-minute quadrangle photogeologic maps on planimetric bases that show geology as interpreted from aerial photographs. Series also includes maps of Mars and the Moon.

Coal Investigations Maps are geologic maps on topographic or planimetric bases at various scales showing bedrock or surficial geology, stratigraphy, and structural relations in certain coal-resource areas.

Oil and Gas Investigations Charts show stratigraphic information for certain oil and gas fields and other areas having petroleum potential.

Miscellaneous Field Studies Maps are multicolor or black-and-white maps on topographic or planimetric bases for quadrangle or irregular areas at various scales. Pre-1971 maps show bedrock geology in relation to specific mining or mineral-deposit problems; post-1971 maps are primarily black-and-white maps on various subjects such as environmental studies or wilderness mineral investigations.

Hydrologic Investigations Atlases are multicolored or black-and-white maps on topographic or planimetric bases presenting a wide range of geohydrologic data of both regular and irregular areas; principal scale is 1:24,000, and regional studies are at 1:250,000 scale or smaller.

Catalogs

Permanent catalogs, as well as some others, giving comprehensive listings of U.S. Geological Survey publications are available under the conditions indicated below from the U.S. Geological Survey, Information Services, Box 25286, Federal Center, Denver, CO 80225. (See latest Price and Availability List.)

"Publications of the Geological Survey, 1879–1961" may be purchased by mail and over the counter in paperback book form and as a set of microfiche.

"Publications of the Geological Survey, 1962–1970" may be purchased by mail and over the counter in paperback book form and as a set of microfiche.

"Publications of the U.S. Geological Survey, 1971–1981" may be purchased by mail and over the counter in paperback book form (two volumes, publications listing and index) and as a set of microfiche.

Supplements for 1982, 1983, 1984, 1985, 1986, and for subsequent years since the last permanent catalog may be purchased by mail and over the counter in paperback book form.

State catalogs, "List of U.S. Geological Survey Geologic and Water-Supply Reports and Maps For (State)," may be purchased by mail and over the counter in paperback booklet form only.

"Price and Availability List of U.S. Geological Survey Publications," issued annually, is available free of charge in paperback booklet form only.

Selected copies of a monthly catalog "New Publications of the U.S. Geological Survey" are available free of charge by mail or may be obtained over the counter in paperback booklet form only. Those wishing a free subscription to the monthly catalog "New Publications of the U.S. Geological Survey" should write to the U.S. Geological Survey, 582 National Center, Reston, VA 22092.

Note—Prices of Government publications listed in older catalogs, announcements, and publications may be incorrect. Therefore, the prices charged may differ from the prices in catalogs, announcements, and publications.