A Revised Marine Diatom Zonation for Miocene Strata of the Southeastern United States

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By GEORGE W. ANDREWS

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A REVISED MARINE DIATOM ZONATION FOR MIOCENE STRATA OF THE SOUTHEASTERN UNITED STATES

By GEORGE W. ANDREWS

ABSTRACT

The sequence of East Coast Diatom Zones proposed by Andrews (1978) for the Miocene strata of the Chesapeake Bay region of Maryland has been successfully applied in correlation of shallow marine Miocene deposits throughout much of the Southeastern United States. This report incorporates data from Coastal Plain Miocene sedimentary rocks in the onshore areas from New Jersey to southern Georgia and as far updip as near the Fall Line. The list of diatom taxa has been evaluated in more than 10 years of study, and it is herein revised to include only those diatoms that have proved to be valuable as markers. The stratigraphic ranges of the marker diatoms have also been revised in light of further study and new data.

This report presents a correlation between these revised diatom zones and planktonic foraminifera N zones, calcareous nannofossil NN zones, silicoflagellate zones, and radiolaria zones, as well as with the current radiometric absolute time scale. The Coastal Plain strata herein dated by diatoms range in age from early Miocene (Burdigalian) to middle Miocene (middle Serravallian), or from approximately 19.1 Ma to 12.6 Ma. The relatively abundant diatom content of the Miocene marine strata in this interval may be the result of a global alteration in climate that allowed upwelling waters to supply nutrients for abundant diatom production.

INTRODUCTION

The report of Andrews (1978) entitled "Marine Diatom Sequence in Miocene Strata of the Chesapeake Bay Region, Maryland," with its proposal for seven East Coast Diatom Zones, was prepared well over 10 years ago. Later study and evaluation suggest that, although this zonation appears to be basically sound, the further knowledge obtained from recent lithostratigraphic and diatom biostratigraphic studies could increase the accuracy and usefulness of this diatom zonation scheme. The principles of the East Coast Diatom Zonation have been applied along the Atlantic Coastal Plain from New Jersey (Andrews, 1987) to Georgia (Abbott and Andrews, 1979) and have even been extended to a Miocene deposit marginal to the Gulf of Mexico (Andrews and Abbott, 1985) as well as from near the modern coastline to near the inner margin of the Atlantic Coastal Plain in Virginia (Andrews, 1986). This report synthesizes information on marine diatom biostratigraphy, some as yet unpublished, from the Miocene strata of the Atlantic Coastal Plain, with the purpose of expanding the usefulness of diatom zonation from the relatively restricted Chesapeake Bay region to the entire Coastal Plain province.

The most extensively exposed stratigraphic section showing the greatest age variation of marine Miocene rocks in the Eastern United States is along the western shore of Chesapeake Bay in Maryland. This remains the primary reference section for the biostratigraphic zonation of this report. Of secondary utility are sections exposed along the Patuxent River in Maryland, on both sides of the Potomac River between Maryland and Virginia, and along the Rappahannock River in Virginia. In most other areas the outcrops are small and of extremely limited stratigraphic range. Throughout much of the Coastal Plain region we are limited in study to samples obtained by various subsurface techniques. The development of a comprehensive regional diatom biostratigraphy has depended on information from all of these sources and its resultant synthesis into a workable system.

ACKNOWLEDGMENTS

The author expresses his appreciation to W.H. Abbott, Mobil, Dallas, Tex., and to J.A. Barron, U.S. Geological Survey, Menlo Park, Calif., for their constructive reviews of the manuscript and their many helpful suggestions. J.A. Barron also provided data for the correlation of radiolarian and silicoflagellate zonations to the absolute time scale, and this has contributed to a more accurate dating of the East Coast Miocene deposits than has been previously possible.

PREVIOUS WORK

Previous work on the Miocene diatoms of the Southeastern United States has been summarized by Andrews

(1976, p. 4-6; 1978, p. 371). The earlier of these publications discussed extensively the "Bermuda" diatom locality originally studied by Bailey (1845) and other 19th century diatomists and concluded that perhaps these diatoms came from the Bermuda Hundred in Virginia because they certainly did not come from the Bermuda Islands. However, it is now known that these so-called "Bermuda" assemblages contain diatoms indicative of East Coast Diatom Zone 1, including the marker diatom *Actinoptychus heliopelta*. These diatoms suggest correlation with Bed 3A of the Calvert Formation. This bed and its distinctive diatom assemblage have not been recognized anywhere in Virginia and indeed are known only from a relatively restricted area in Anne Arundel, Calvert, and Charles Counties, Md. The "Bermuda" diatom assemblage appears to be identical with the "Nottingham" assemblage of the 19th century diatomists, now known to crop out near Dunkirk, Md., and elsewhere along the Patuxent River. If the "Bermuda" name is not simply an error, the origin of this early collection is still in doubt.

Several works on the Miocene diatom biostratigraphy of the Southeastern United States have been published since the summaries of Andrews (1976, 1978). Abbott (1978) examined diatoms and silicoflagellates in the Atlantic margin region bordering the Southeastern United States and proposed a sequence of Atlantic Miocene Siliceous Microfossil Zones (see fig. 1). A study was made of middle Miocene marine diatoms from the Hawthorn Formation within the Ridgeland Trough in South Carolina and Georgia by Abbott and Andrews (1979). Diatoms from the Eastover Formation at Petersburg, Va., were reported on by Andrews (1980), and that report is relevant to younger Neogene deposits in the region. A study of Miocene diatoms from the Oak Grove core, Westmoreland County, Va., was made by Andrews (*in* Gibson and others, 1980, p. 27, 28). Miocene diatoms from the Pamunkey River area in Virginia and from the Popes Creek area in Maryland were studied by Andrews (1984b and 1984a, respectively). A study of both marine and nonmarine Miocene diatoms from the Hawthorn Formation in the Gulf Trough, Thomas County, Ga., was published by Andrews and Abbott (1985). Miocene diatom assemblages from the Choptank and Eastover Formations exposed at Richmond, Va., were examined by Andrews (1986). A report on Miocene marker diatoms of the Kirkwood Formation of New Jersey was published by Andrews (1987). All of the above publications have contributed data that have influenced this revision of East Coast diatom zonation. In addition, a large number of unpublished referred collections, from both boreholes and outcrops, have been examined in the Washington, D.C./Reston, Va., diatom laboratory of the U.S. Geological Survey, and these have all contributed to this revised zonation.

MIOCENE STRATIGRAPHY

The Miocene stratigraphy of the type area for this diatom zonation must be discussed to provide a foundation for this East Coast diatom biostratigraphy. The excellence of the Maryland Miocene stratigraphic section has been recognized for many years, and Shattuck (1904, p. 41-64) prepared a comprehensive bibliography on the Miocene of Maryland for the years 1669-1903. More recent histories of the stratigraphic nomenclature of these deposits have been prepared by Andrews (1976, p. 2; 1978, p. 371, 372). The modern Miocene stratigraphic nomenclature of the region began with Shattuck (1902), who divided the Miocene of the Maryland Coastal Plain into the Calvert, Choptank, and St. Marys Formations. The Calvert Formation was later subdivided by Shattuck (1904) into a lower Fairhaven Diatomaceous Earth Member and an upper Plum Point Marl Member. Shattuck (1904, p. 72-86) further subdivided the Calvert, Choptank, and St. Marys Formations into 24 sequentially numbered "zones." These are not biostratigraphic zones in any modern sense, and his term "zone" is inappropriate for use today. They are local lithologic units of subformational rank and are referred to simply as "beds" in this report. These beds have, upon detailed study, proved to be so inconsistent in character that regarding them as units of uniform stratigraphic value and formalizing their status has, in many instances, proved to be impossible. However, with modifications, these bed numbers are used as a convenient means of discussion. The formal nomenclature of the Miocene section adopted in this paper is the classification of Ward (1984), which is shown in figure 1. To summarize, Beds 1 and 2 may still be retained in the Fairhaven Member of the Calvert Formation of Shattuck (1904). They are, however, thin beds at the base of the Calvert Formation and nondiatomaceous, so they are not considered further in this report. Bed 3 is now recognized to consist of two beds of similar lithology but separated by a substantial hiatus; these beds are considered separately as Beds 3A and 3B, both formally classified in the Fairhaven Member of the Calvert Formation. Beds 4 through 9 were established on the subtle distinction of their fossil mollusk content, a distinction that is valid only locally between Chesapeake Beach and Randle Cliff, Md. They are herein treated as a single unit, Bed 4-9, and classified in the Plum Point Member of the Calvert Formation. Beds 10, 11, 12, and 13 are distinctive along Chesapeake Bay and are also included in the Plum Point Member. Beds 14 and 15 are distinctive and, as proposed by Ward (1984), are herein referred to the Calvert Beach Member of the Calvert Formation, a member name originally given by Gernant (1970) to the strata he recognized as Bed 16 of the Choptank Formation. As pointed out by Ward (1984), Bed 16 was misconceived by Shattuck (1904); therefore, Shattuck's "Zone 16," as exposed south of Scientists Cliffs on Chesapeake Bay, is combined with Bed 15. Shattuck (1904) made the unfortunate choice of the Calvert-Choptank formational boundary between his "Zone 15" and his defectively conceived "Zone 16." This boundary is now placed at the base of Bed 17. Beds 17, 18, and 19 are distinctive and are respectively termed the Drumcliff, St. Leonard, and Boston Cliffs Members of the Choptank Formation as proposed by Gernant (1970). Bed 20 has been transferred from the Choptank to the St. Marys Formation. Shattuck's "Zones" 21 through 24 in the St. Marys Formation are not known to be diatomaceous and thus are of no concern to this report.

The temporal control of the Miocene stratigraphy and diatom biostratigraphy for this study is given by the time scale of Berggren, Kent, Flynn, and Van Couvering (1985). No radiometric dates are available from the Calvert and Choptank Formations of this area. Only a few beds have been tied into the planktonic foraminiferal and silicoflagellate biostratigraphies that are closely controlled by the above time scale. Hence, many of the absolute ages suggested for beds and diatom zones should be considered only careful estimates. When studies of other well-dated fossil groups are made for the Miocene strata of this area, these ages will certainly be improved in accuracy.

The oldest diatom assemblage in the Calvert Formation is found in Bed 3A, which crops out principally along the Patuxent River in Maryland. The deposit is probably middle early Miocene (middle Burdigalian) in age, and it is estimated to range from about 19.1 to 18.8 Ma. Bed 3A seems to be separated from Bed 3B by a substantial hiatus, perhaps by as much as 2 million years. Bed 3B (upper part of the Fairhaven Member of the Calvert Formation) and Beds 4 through 13 (Plum Point Member of the Calvert Formation) probably range in age from late early Miocene (Burdigalian) to middle Miocene (basal Serravallian) and are estimated to range from about 16.9 to 15.0 Ma. Evidence from a physical unconformity and a distinctive gap in the diatom biostratigraphy suggests a hiatus estimated at about 0.6 million years between Beds 13 and 14. Beds 14 and 15 of the Calvert Formation and Beds 17 through 19 of the Choptank Formation are probably middle middle Miocene (early to middle Serravallian) in age, with an estimated time range from 14.4 to 12.6 Ma. There is still no firm date for the top of the Choptank Formation, and the estimated date of 12.6 Ma must be viewed with caution.

REFERENCE LOCALITIES

Because the marine Miocene stratigraphic section in Maryland is more complete and relatively well exposed, it serves well as a basis for a biostratigraphic diatom zonation. Two separate compound reference sections are necessary to include all ages of Miocene strata in the region. The oldest Miocene strata, Bed 3A, are exposed along the east bank of the Patuxent River in Calvert County, Md., between Lyons Creek Wharf and Jones Point. The best and most complete exposure is in the abandoned Kaylorite pit west of Dunkirk, Md. (Site A of Andrews, 1978, p. 372, 373). Although Shattuck (1904) reported outcrops of this deposit in the uplands between the Patuxent River and Chesapeake Bay, these localities have not been found in recent years. There is no locality known where the next younger Miocene strata, Bed 3B, crops out in contact with Bed 3A. This contact has been observed in borings at Fairhaven (Anne Arundel County), Maidstone Farm (Calvert County), and Waldorf (Charles County), all in Maryland (G.W. Andrews, unpub. data).

The second compound reference section is along the west shore of Chesapeake Bay from the north at Fairhaven (Anne Arundel County) to the south in the vicinity of the Calvert Cliffs Nuclear Power Plant of the Baltimore Gas and Electric Company in Calvert County, Md. This reference section includes Sites B through E and Site G of Andrews (1978, p. 373, 374) and also other outcrops in this area of the west shore of Chesapeake Bay. Beds 3B through 19 are exposed in gently southward dipping strata along this coast. Outcrops of all beds are readily accessible at points along this shoreline, although individual beds may be difficult to access in any given locality because of the steepness of the cliffs.

The outcrops exposed in the above-outlined reference sections provide the most nearly complete Miocene section in any region of the Eastern United States. Thus their use as a basis for biostratigraphic zonation seems to be appropriate. These outcrops have been extensively discussed with regard to lithology, stratigraphic significance, and geologic age by Ward (1984).

MARKER DIATOMS

This report presents a revised evaluation of selected Miocene marine marker diatoms in Atlantic Coastal Plain deposits of the Eastern United States. To have value as a marker, a diatom taxon should (1) be

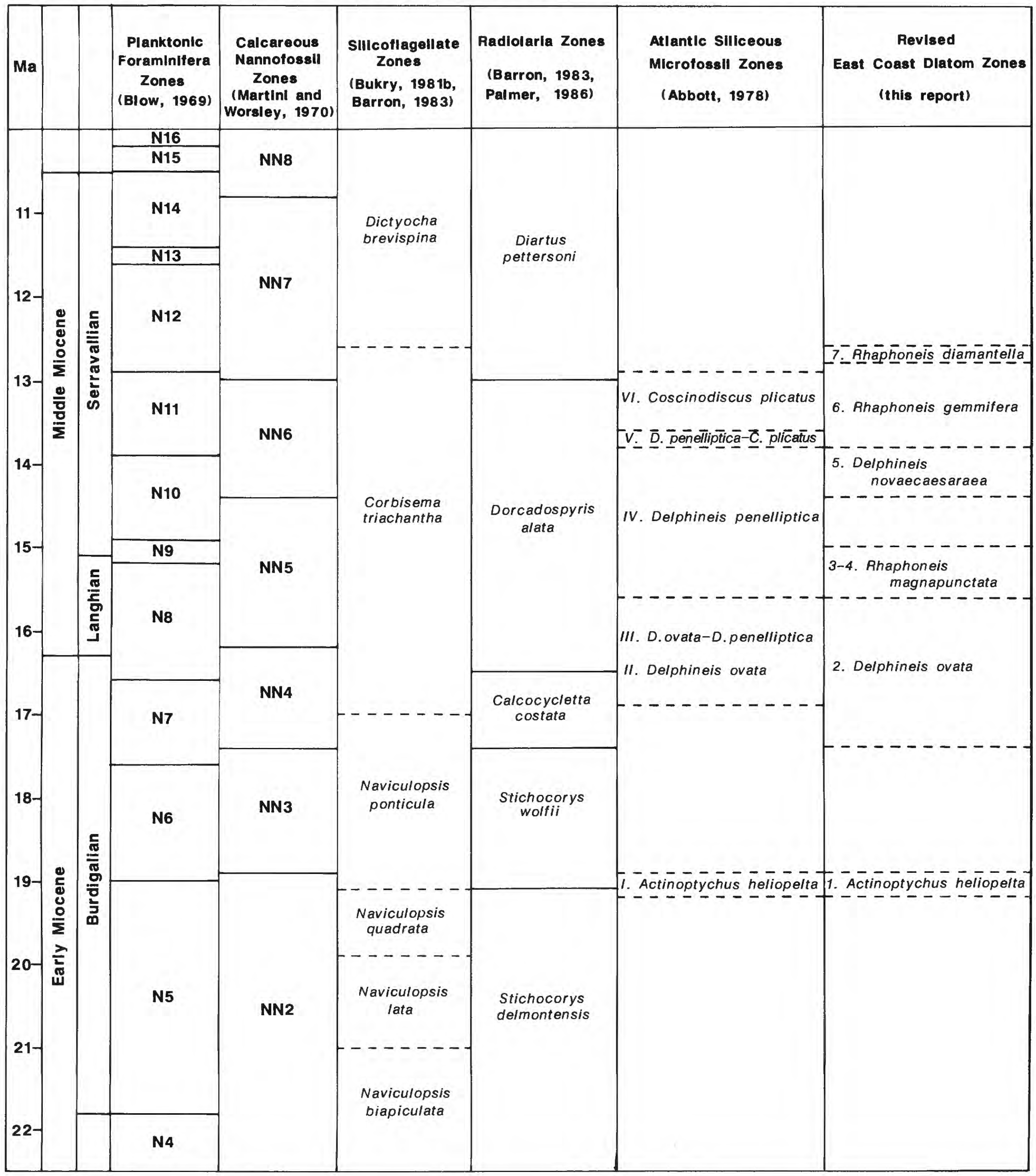
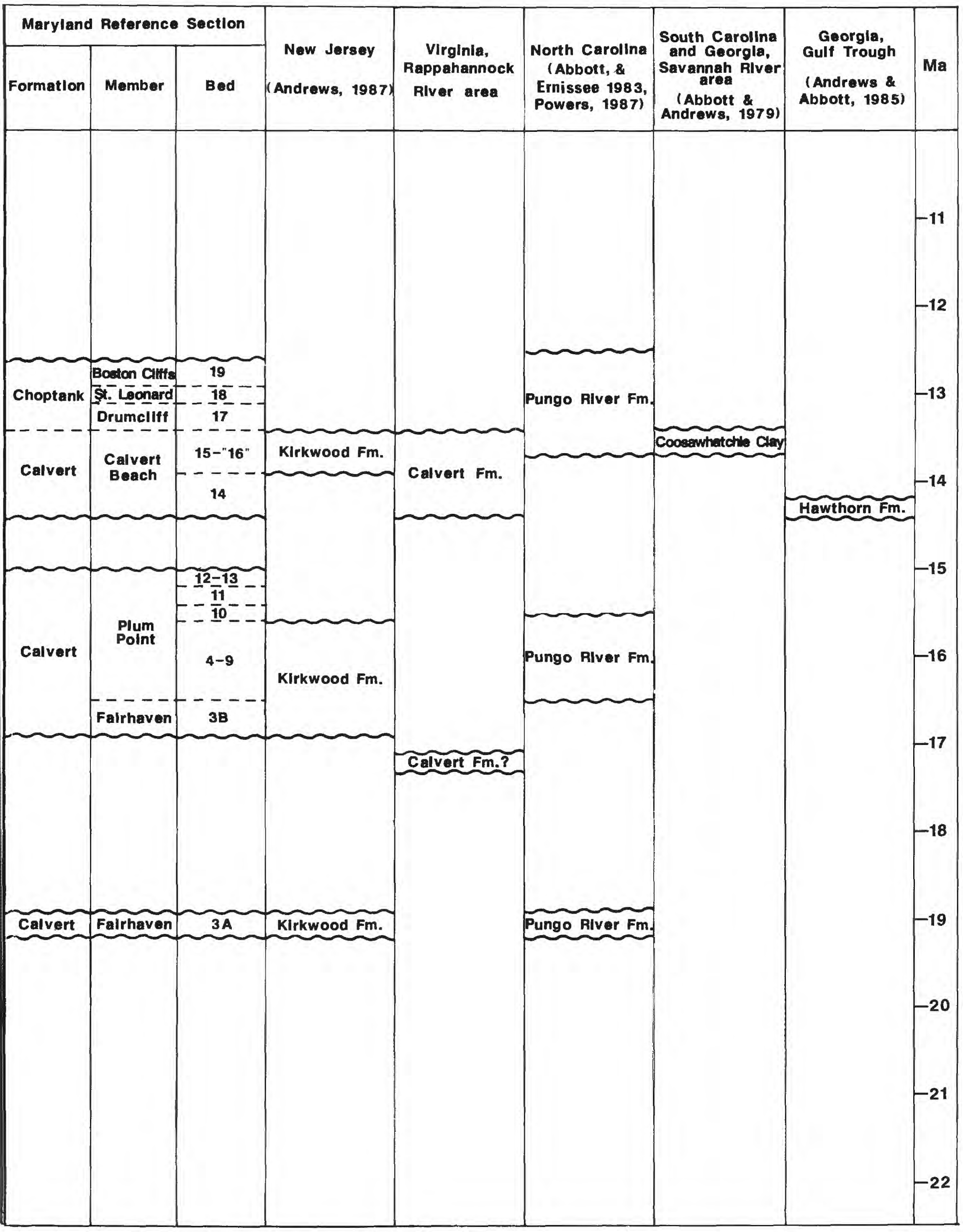


FIGURE 1.—Correlation of revised East Coast Diatom Zones with other fossil



zonations and with stratigraphic sections in the Eastern United States.

morphologically distinct enough to be readily identifiable, (2) have a limited and determinable stratigraphic occurrence, (3) have a widespread distribution, at least in the paleogeographic and paleoecologic province under consideration, and (4) occur in sufficient abundance to be found readily in most samples within its stratigraphic range. After nearly 10 years of testing, the marker taxa selected for this report fulfill all of these requirements in varying degrees. A few of the taxa listed in the previous report by Andrews (1978) have not proved to be useful to any great extent, and they have been omitted from this report. A few others showing promise as useful marker diatoms have been added. Stratigraphic ranges have, in some instances, been modified because the broader base of this study has indicated ranges different from those shown in the 1978 report. Errors resulting from incorrect identification and taxonomic misunderstanding have been corrected when recognized.

The zonation presented here remains heavily dependent on taxa of the benthic diatom genera *Rhaphoneis*, *Delphineis*, and *Sceptroneis*. This has a basis in earlier reports on *Rhaphoneis* (Andrews, 1975) and in the delineation and description of *Delphineis* (Andrews, 1977, 1981) and the description of stratigraphically significant taxa of these genera (Andrews, 1978). Generally, these taxa have proved useful in stratigraphic correlation of Miocene rocks deposited in the shallow marine paleoenvironments of the Atlantic Coastal Plain.

Some species of the genus *Actinoptychus* Ehrenberg seem to be useful as markers, particularly *A. heliopelta*, *A. marylandicus*, and *A. virginicus*. Other species related to the modern *A. splendens* have been proved of dubious value (see Andrews, 1987), and they have been omitted from this report. The six-sectored forms commonly assigned to *A. senarius* range from pre-Miocene to Holocene deposits. Whether or not all such forms are truly conspecific remains to be determined.

A few species recognized as important in deep-sea correlation have been retained in this report. The ranges of *Raphidodiscus marylandicus* Christian and *Coscinodiscus lewisianus* Greville have been extended on the basis of recently observed occurrences in this region. Neither of these species occurs with sufficient consistency or abundance to be truly useful as a regional marker diatom. The same restriction applies to the taxa identified as *Thalassiosira grunowii* Akiba and Yanagisawa and *Denticulopsis hustedtii* (Simonsen and Kanaya) Simonsen. Both the plicate species of *Thalassiosira* and the genus *Denticulopsis* should be stratigraphically useful, if in the future they are found in sufficient abundance so that stratigraphic ranges can be more readily delineated.

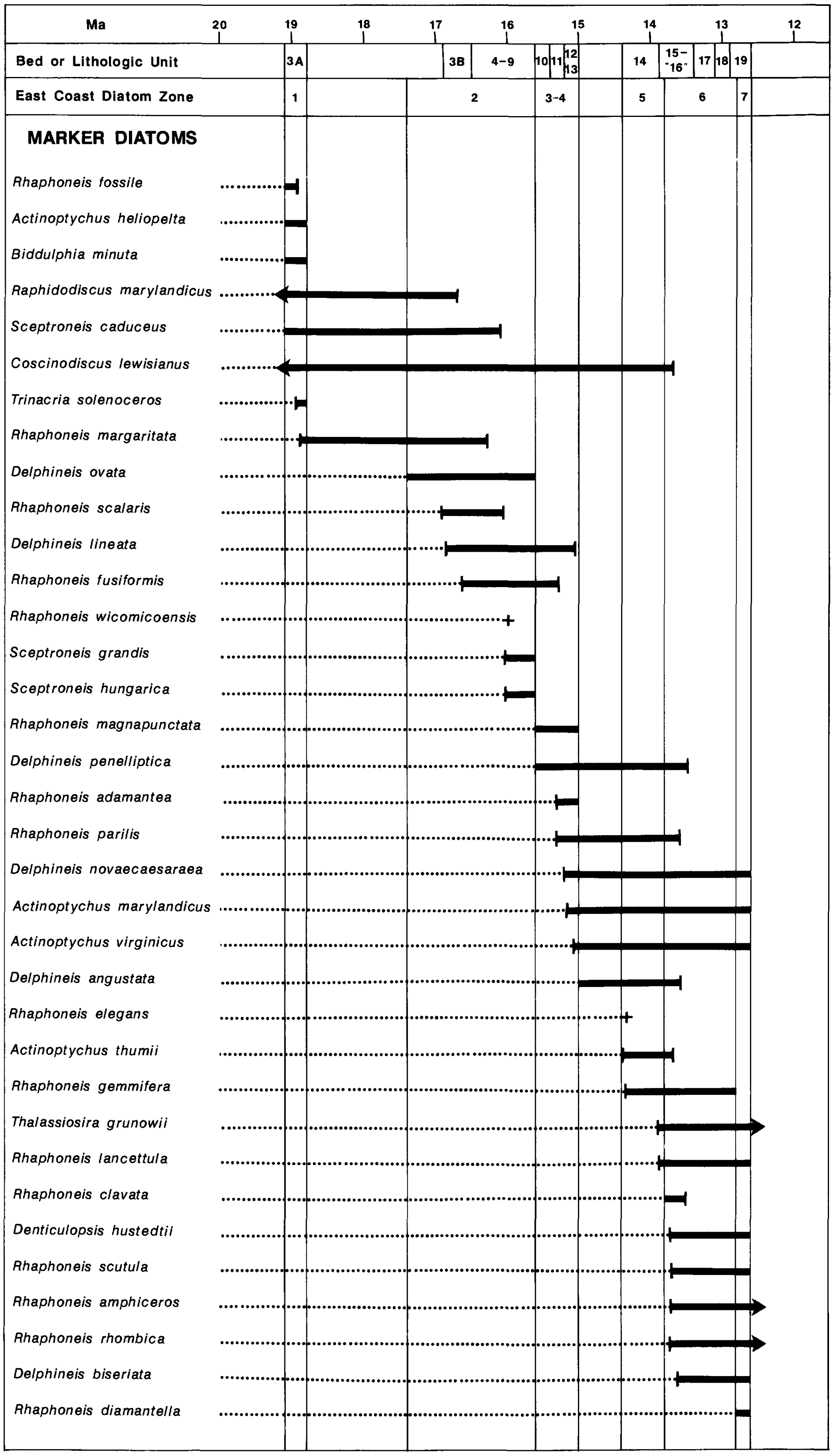
PALEOECOLOGY

The Miocene strata of the Coastal Plain of the Southeastern United States contain diatom assemblages generally indicative of deposition in a shallow open-shelf marine environment. Nearly all of these assemblages that have been studied are dominated by the small centric diatom taxa, *Paralia sulcata* and *Melosira westii*, which are considered to be planktonic species restricted, for the most part, to shallow shelf environments. These assemblages also show a rich variety of pennate diatoms as well as numerous large, heavily silicified centric diatoms, many of which are probably benthic in life habit and hence indicative of a shallow environment of growth. The Miocene marine diatom assemblages of this region do vary laterally, and some of these variations may be attributed to changes in paleoecology. On the other hand, differential preservation between localities and samples presents a serious complication for meaningful paleoecologic comparisons.

This report is primarily about diatom biostratigraphy, and, hence, it is more concerned with variations in diatom assemblages in the vertical dimension. Variations in this direction are equally difficult to evaluate. Whether the first or last observation of a diatom taxon in a stratigraphic section is a true first appearance or a true extinction is always problematical. In many instances such appearances and disappearances may well represent a shift in paleoecological conditions. No claim is here made that the first or last occurrence of any marker taxon presented in this report (see figs. 2, 3) is absolute in terms of geologic time. However, these diatom ranges have been tested in an extensive area of the Atlantic Coastal Plain, and they appear to hold true for this paleoecologic province during Miocene time.

The following discussion summarizes some of the paleoecologic observations made in connection with this study, primarily with regard to the reference sections in Maryland. The early Miocene deposit of East Coast Diatom Zone 1 and Bed 3A of the Calvert Formation is the most highly diatomaceous deposit in the region. This bed is fine grained and rich in diatoms (but by no means free of impurities), and it shows a highly localized distribution. Changes in diatom and silicoflagellate assemblages in a relatively thin stratigraphic section suggest slow deposition in quiet waters having a small influx of clastic materials. This deposit appears to have

FIGURE 2.—Stratigraphic ranges of marine marker diatom species, Eastern United States. Vertical ticks indicate the beginning or end of range within a zone; crosses indicate a short known range; arrows indicate a known range beyond the scope of this chart.


Ma
20
19
18
17
16
15
14
13
12
Bed or Lithologic Unit
3A
3B
4-9
10
11
12
13
14
15-
"16"
17
18
19
East Coast Diatom Zone
1
2
3-4
5
6
7
MARKER DIATOMS
Rhaphoneis fossile
Actinoptychus heliopelta
Biddulphia minuta
Raphidodiscus marylandicus
Sceptroneis caduceus
Coscinodiscus lewisianus
Trinacria solenoceros
Rhaphoneis margaritata
Delphineis ovata
Rhaphoneis scalaris
Delphineis lineata
Rhaphoneis fusiformis
Rhaphoneis wicomicoensis
Sceptroneis grandis
Sceptroneis hungarica
Rhaphoneis magnapunctata
Delphineis penelliptica
Rhaphoneis adamantea
Rhaphoneis parilis
Delphineis novaecaesaraea
Actinoptychus marylandicus
Actinoptychus virginicus
Delphineis angustata
Rhaphoneis elegans
Actinoptychus thumii
Rhaphoneis gemmifera
Thalassiosira grunowii
Rhaphoneis lancettula
Rhaphoneis clavata
Denticulopsis hustedtii
Rhaphoneis scutula
Rhaphoneis amphiceros
Rhaphoneis rhombica
Delphineis biseriata
Rhaphoneis diamantella

accumulated in a restricted shallow arm of the Burdigalian Sea. A much thicker and more clastic section occurs in rocks of equivalent age in the Kirkwood Formation of New Jersey. A near source of clastic sediments must have produced a thicker and coarser grained deposit in the lower part of the Kirkwood Formation in New Jersey than is found in equivalent beds in Maryland.

Following a substantial hiatus, the major marine transgression of East Diatom Zone 2 and Bed 3B of the Calvert Formation spread widely into the Maryland area. Bed 3B was deposited as a relatively fine grained sediment, and indeed it is difficult to distinguish from Bed 3A on lithology alone in subsurface samples. However, in broader perspective, although it is diatomaceous, the diatom content is reduced from that of Bed 3A and is replaced by abundant clay, silt, and fine sand. Molds of fossil mollusks, as well as evidence of considerable bioturbation, are common in Bed 3B.

One of the most distinctive stratigraphic contacts of the Maryland Miocene section within the Calvert Formation is that between Bed 3B of the Fairhaven Member and Bed 4 of the Plum Point Member. The fine-grained Fairhaven is immediately overlain by a thin, sandy bed containing abundant pyncnodont mollusks (Bed 4) and a sandy sequence of deposits through Bed 9. The diatom assemblages continue with little change across this contact, suggesting that an increased influx of clastics, rather than a hiatus in time or a marked change in paleoecology, produced this abrupt lithic discontinuity within East Coast Diatom Zone 2.

East Coast Diatom Zone 3-4 begins with the oldest prominently shelly stratum of the Calvert Formation, Bed 10. Although it contains an abundant molluskan fauna, Bed 10 is very sparingly diatomaceous to nondiatomaceous. Beds 11-13, also in Zone 3-4, contain argillaceous sandy silts with moderately good diatom assemblages and extensive evidence of bioturbation by marine organisms.

East Coast Diatom Zone 5 is apparently separated from Zone 3-4 by a substantial hiatus, discussed elsewhere in this report. It represents the inception of a major marine transgression of middle Miocene age (Serravallian), beginning with Bed 14 of the Calvert Formation in Maryland. Bed 14 is basically a shelly argillaceous sand in Maryland, but its widespread equivalents in Virginia are represented by a finer grained, gray, argillaceous silt and fine sand. Although East Coast Diatom Zone 5 was separated by Andrews (1978) from overlying Zone 6 at about the middle of Bed 15 of the Calvert Formation on the basis of a perceived change in the diatom assemblages, this change has now been blurred by more detailed studies, as indicated in figure 3 of this report. In the section south of Scientists Cliffs, Md., the change is not abrupt; rather, the new species of Zone 6 are phased in over a few feet of section. This zonal boundary does not apparently indicate more than a gradual introduction of new species or a shift in paleoecology.

Although the changes in diatom assemblages in East Coast Diatom Zones 5-7 (Beds 14-"16" of the Calvert Formation and Beds 17-19 of the Choptank Formation) are not as striking as in older parts of the Maryland Miocene section, there remains sufficient change for meaningful diatom zonation. The lithologic variations in these strata are probably of greater paleoecologic significance, for they are somewhat cyclical in nature. Bed 14 is a shelly sand, Bed 15 (including "16") a silty clay, Bed 17 a shelly sand, Bed 18 a silty clay, and Bed 19 again a shelly sand. The paleoecologic significance of these changes is at present poorly understood.

The paleoecology of the molluskan faunas of the Choptank Formation in Maryland and Virginia has been studied by Gernant (1970), and the paleoecology of the diatom assemblages of the Pungo River Formation in North Carolina has been studied by Powers (1987). Beyond this, little definitive work has been done on the paleoecology of the Miocene strata of the Atlantic Coastal Plain. A comprehensive interdisciplinary study containing detailed reports on lithostratigraphy, biostratigraphy, and regional distribution of several megafossil and microfossil groups and their paleoecological interpretation would be a major contribution to science. Unfortunately, such studies do not exist. The diatom assemblages that the author has examined for this work seem to reflect broadly a shallow shelf marine environment, and they indicate little that would suggest minor changes in paleoecology. Perhaps other techniques of study and analysis of diatoms as well as other organisms would yield further meaningful interpretations.

Only one nonmarine Miocene diatom assemblage from the Coastal Plain has been recorded, that from the Hawthorn Formation of Georgia described by Andrews and Abbott (1985). The Miocene age of this nonmarine bed cannot be doubted because it was found intercalated in Miocene marine beds. Other such nonmarine deposits must have been formed, but doubtless most have been destroyed by postdepositional erosion.

The comparative richness of these Coastal Plain marine diatom assemblages may furnish clues as to their origin in Miocene time. One may postulate that the Miocene Atlantic Ocean was similar in water circulation to the modern Atlantic Ocean. There was probably a flow of cool water from the north along the coast, analogous to the present-day Labrador Current, and a warmer water mass in the south-central Atlantic Ocean. However, the temperature contrast between these two water bodies may have been considerably less than the

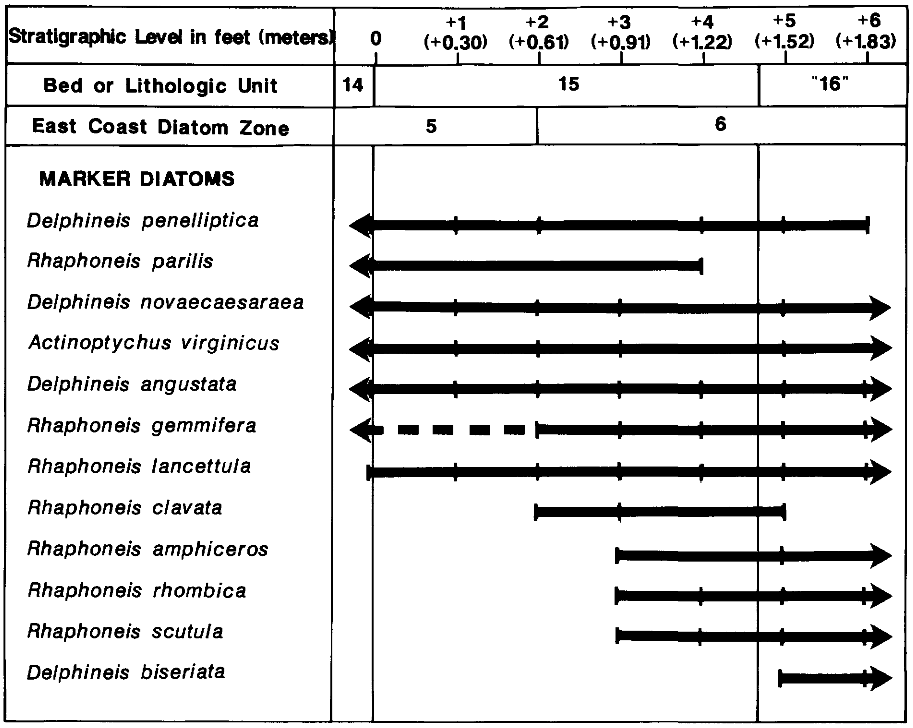


FIGURE 3.—Stratigraphic ranges of selected marine marker diatom species, Beds 14 through "16," Scientists Cliffs area, Calvert County, Md. Vertical ticks indicate the observed occurrence of the species at a given depth; arrows indicate a known range beyond the scope of this chart.

contrast now, resulting in a weaker and more diffuse Miocene Gulf Stream than that existing at present. Such a weakened Gulf Stream would probably have enhanced the formation of isolated warm water cells, or gyres, within the cooler coastal water body. These rotating water gyres would draw nutrient-laden bottom waters to the surface, and these waters could well have been swept onto the shallow shelf and promoted growth of richly varied and abundant diatom assemblages during late early and middle Miocene time. The rich diatom assemblages presuppose an abundance of nutrient-laden waters, however derived.

The genus *Delphineis* has been noted as an indicator of upwelling marine waters (Schuette and Schrader, 1979). *Delphineis* is common in the marine deposits studied for this report, and this suggests that the Miocene assemblages were produced, at least in part, by upwelling waters. Perhaps the genus *Rhaphoneis,* which is morphologically similar, may characterize upwelling waters in shallower environments, but this seems not to have yet been documented.

OCCURRENCE AND PRESERVATION

The lack of diatom assemblages in parts of the Tertiary section along the East Coast of the United States remains a problem. The apparent absence of diatoms in onshore deposits of Paleogene age seems to be a problem of preservation. Abbott (1975) has demonstrated the occurrence of marine diatoms in clays of late Eocene age from South Carolina and Georgia. However, no diatom assemblage well enough preserved for meaningful study has yet been discovered.

Diatom assemblages from Tertiary strata of post-Serravallian age are scarce in the Coastal Plain. Marine diatoms from the Eastover Formation (late Miocene) have been reported at Petersburg, Va., by Andrews (1980), along the Pamunkey River, Va., by Andrews (1984b) and at Richmond, Va., by Andrews (1986). Many other deposits of Eastover age have been found to be barren of diatoms. The Miocene St. Marys Formation in Maryland and Virginia has not produced diatoms except for the basal bed (Bed 20). The Yorktown

Formation of Pliocene age has not yet produced a diatom assemblage. Part of the problem with these strata may well be lack of preservation of diatoms. Pyritized casts replacing diatoms have been observed occasionally in these strata. On the other hand, global cooling during these time intervals may well have produced an oceanographic scenario with a more intensely structured Gulf Stream held farther out in the Atlantic Ocean. This may have reduced the flow of nutrient-laden upwelling water into the shallow coastal areas and thus depleted the diatom populations.

Baldauf and Palmer (1986) considered the variation in silica deposition in the North Atlantic Ocean Basin in Miocene time and concluded that the greatest productivity of silica occurred during high sea level stands. They state that "biogenic silica deposition declined on the shelf during the middle Miocene and vanished in the late Miocene, probably in response to falling sea level and increased terriginous influx...." Falling sea level may be related to climatic cooling and, hence, to decreased upwelling, as suggested above. Snyder, Riggs, Hine, and Snyder (1984) suggest that a complicated interrelation between sea level, bottom topography, and flow dynamics of the Gulf Stream contributed to the deposition of phosphate in the Miocene deposits of North Carolina. All of these factors may well have contributed to the deposition of biogenic silica in the Coastal Plain deposits of the Eastern United States.

REVISED DIATOM ZONATION

The revised diatom zonation adopted for this report is presented in the column so labeled in figure 1. This zonation essentially follows that of Andrews (1978), but it shows important modifications. The earlier study was based on data derived from outcrop samples and core samples from the Baltimore Gas and Electric Company borehole, all in the reference section of the Chesapeake Bay area of Maryland. The present zonation uses the earlier study as a basis, but it adds new information not only from the Chesapeake Bay area but also from other localities in the Southeastern United States. The correlation of these revised East Coast Diatom Zones with the current radiometric time scale and with the standard zonation schemes for planktonic foraminifera and calcareous nannoplankton is based on the correlation chart of Berggren, Kent, Flynn, and Van Couvering (1985). It is believed that this revised diatom zonation can be judiciously applied to Miocene marine diatomaceous deposits of the Coastal Plain in the Southeastern United States from central New Jersey to southern Georgia and from the Fall Line to approximately the modern coastline. The following sequence of East Coast Diatom Zones is proposed, numbered from the base upward and defined on the basis of diatom occurrence.

1. *Actinoptychus heliopelta* Assemblage Zone. The base and top of this zone are defined by the first and last occurrence of *Actinoptychus heliopelta* Grunow; however, because neither the base nor the top of this zone is precisely known (as shown in fig. 1), it must be considered an assemblage zone. Other important marker species for this zone are *Rhaphoneis fossile* (Grunow) Andrews, *Biddulphia minuta* (Greville) Andrews, *Sceptroneis caduceus* Ehrenberg, *Raphidodiscus marylandicus* Christian, *Coscinodiscus lewisianus* Greville, and *Trinacria solenoceros* (Ehrenberg) VanLandingham.

This zone occurs as Bed 3A of the Calvert Formation along the Patuxent River near Dunkirk, Md., in the subsurface at Maidstone Farm, Fairhaven, and Waldorf, Md., and at several localities reported by Shattuck (1904) in the same area. The zone was reported in a well near Salisbury, Md., by Lohman (1948) and in a Dover, Del., well and the AMCOR 6011 well (offshore New Jersey) by Abbott (1978). The zone is known in the subsurface at Wildwood, N.J., and near Atlantic City, N.J. (Andrews, 1987). It is found in the Pungo River Formation of North Carolina (Powers, 1987). Despite its relatively widespread distribution, the occurrence of East Coast Diatom Zone 1 is extremely restricted geographically compared with Zone 2.

Although the diatom assemblage of Zone 1 is substantially different from that of Zone 2, which suggests a substantially older age, correlation is dependent on other organisms. The section of diatomaceous sediments exposed near Dunkirk, Md., contains the silicoflagellate marker *Naviculopsis quadrata* at the base, a mixed assemblage of *N. quadrata* and *Naviculopsis ponticula* near the middle, and *N. ponticula* at the top (Karen L. Wetmore, oral commun., 1986). This indicates that the *N. quadrata-N. ponticula* silicoflagellate zone boundary falls within East Coast Diatom Zone 1. The subsurface lithostratigraphy of the Kirkwood Formation of New Jersey has suggested that part of East Coast Diatom Zone 1 may be as old as planktonic foraminifera zone N5 (see Andrews, 1987).

Zone 1 can be correlated with reasonable certainty with the middle part of the Burdigalian Stage of early Miocene age. The absolute age of Zone 1 is estimated to be from about 19.1 Ma to 18.9 Ma.

2. *Delphineis ovata* Range Zone. The base is at the first occurrence of *Delphineis ovata* Andrews and the top is at the last occurrence of *Delphineis ovata;* however, the base of this zone is not precisely known because of the regional hiatus between Zones 1 and 2 (see fig. 1). Other important marker species for this zone are

Sceptroneis caduceus, Raphidodiscus marylandicus, Coscinodiscus lewisianus, Rhaphoneis margaritata Andrews, *Rhaphoneis scalaris* Ehrenberg, *Delphineis lineata* Andrews, *Rhaphoneis fusiformis* Andrews, *Rhaphoneis wicomicoensis* Lohman, *Sceptroneis grandis* Abbott, and *Sceptroneis hungarica* (Pantocsek) Andrews.

This zone includes Bed 3B and the interval of Beds 4-9 of the Calvert Formation as exposed in the Chesapeake Bay area of Maryland. The base of this zone has tentatively been extended downward from that reported by Andrews (1978) on the basis of data obtained from a thin bed near the base of the Miocene section cropping out opposite Horsehead Point along the Rappahannock River in King George County, Va. This bed contains a sparse assemblage of siliceous microfossils, including *Delphineis ovata* and the silicoflagellate *Naviculopsis navicula*, but it does not contain *Actinoptychus heliopelta*. This suggests correlation with East Coast Diatom Zone 2, but the occurrence of *N. navicula*, a constituent of the *Naviculopsis ponticula* silicoflagellate zone, indicates an age older than Bed 3B of the Calvert Formation. The author has, therefore, conservatively extended East Coast Diatom Zone 2 downward to near the top of the *Naviculopsis ponticula* silicoflagellate zone, dated at about 17.0 Ma.

Zone 2 begins in the upper part of the Burdigalian Stage of late early Miocene age and extends upward into the lower part of the Langhian Stage of early middle Miocene age.

The absolute age of Zone 2 is estimated to be from about 17.4 Ma to 15.6 Ma. The time span between Zones 1 and 2 (18.9 Ma to 17.4 Ma) cannot be assigned to either zone with certainty.

3-4. *Rhaphoneis magnapunctata* Range Zone. The base is at the first occurrence of *Rhaphoneis magnapunctata* Andrews and the top is at the last occurrence of the same species. This zone combines Zones 3 and 4 of Andrews (1978) because further study has suggested that the subdivision into Zones 3 and 4 can no longer be justified. Other important marker species include *Delphineis lineata, Rhaphoneis fusiformis, Delphineis penelliptica* Andrews, *Rhaphoneis adamantea* Andrews, *Rhaphoneis parilis* Hanna, and *Delphineis novaecaesaraea* (Kain & Schultze) Andrews. Three species—*Actinoptychus marylandicus* Andrews, *A. virginicus* (Grunow) Andrews, and *Delphineis angustata* (Pantocsek) Andrews—were observed and reported by Andrews (1978) from the top of Zone 3-4. All of these species are more common in Zone 5 and younger deposits, and they may be intrusive into the top of Zone 3-4 by bioturbation.

This zone includes Beds 10 through 13 of the Calvert Formation in the Chesapeake Bay region of Maryland. Beds of equivalent Miocene age are relatively widespread in Virginia, but Zone 3-4 does not seem to represent a major marine transgression on the Atlantic Coastal Plain.

Zone 3-4 is correlated with the upper part of the Langhian Stage of early middle Miocene age and the lowermost part of the Serravallian Stage of middle Miocene age.

The absolute age of Zone 3-4 is estimated to be from about 15.6 Ma to 15.0 Ma.

5. *Delphineis novaecaesaraea* Partial Range Zone. The base is immediately above the last occurrence of *Rhaphoneis magnapunctata* and the top is at the first occurrence of *Rhaphoneis clavata* Andrews. Important marker diatoms include *Delphineis penelliptica, Rhaphoneis parilis, Actinoptychus marylandicus, Actinoptychus virginicus, Delphineis angustata, Actinoptychus thumii* (Schmidt) Hanna, *Rhaphoneis elegans* (Pantocsek and Grunow) Hanna, *Rhaphoneis gemmifera* Ehrenberg, and *Thalassiosira grunowii* Akiba and Yanagisawa.

This zone includes all of Bed 14 and the lower part of Bed 15 in the Chesapeake Bay region of Maryland. Although the beds encompassed by this zone do not show outstanding development along Chesapeake Bay, they thicken markedly on the south shore of the Potomac River in Westmoreland County, Va., along the Rappahannock River, and elsewhere in Virginia. The beds correlated with Zone 5 probably represent the initial phase of a substantial marine transgression along the Coastal Plain.

This zone is correlated with the lower part of the Serravallian Stage of early middle Miocene age.

The absolute age of Zone 5 is estimated to be from about 14.4 Ma to 13.8 Ma. Although it is not obvious in the section of the Calvert Formation along Chesapeake Bay, there appears to be a substantial hiatus between beds deposited during Zone 3-4 and Zone 5 episodes. Evidence of such a hiatus is much more compelling in Virginia. There is a visible erosional unconformity at this level along the south bank of the Potomac River between Westmoreland State Park and Wakefield. The Bed 14 equivalent in Virginia is much more thickly developed than in Maryland. In a large number of boreholes studied in Virginia, relatively fresh Bed 14 equivalent (Zone 5) diatom assemblages overlie relatively degraded and apparently weathered assemblages of Beds 12-13 (Zone 3-4) age. The length of this post-Zone 3-4-pre-Zone 5 hiatus cannot be stated with certainty, but it perhaps lasted from 15.0 Ma to 14.4 Ma.

6. *Rhaphoneis gemmifera* Partial Range Zone. The base is at the first occurrence of *Rhaphoneis clavata* and the top is at the last occurrence of *Rhaphoneis gemmifera*.

Important marker diatoms include *Delphineis penelliptica, Rhaphoneis parilis, Delphineis novaecaesaraea, Actinoptychus marylandicus, Actinoptychus virginicus, Delphineis angustata, Rhaphoneis gemmifera, Thalassiosira grunowii, Rhaphoneis lancettula* Grunow, *Rhaphoneis clavata, Denticulopsis hustedtii* (Simonsen and Kanaya) Simonsen, *Rhaphoneis scutula* Andrews, *Rhaphoneis amphiceros* (Ehrenberg) Ehrenberg, *Rhaphoneis rhombica* (Grunow) Andrews, and *Delphineis biseriata* (Grunow) Andrews.

This zone includes about the upper three-fourths of Bed 15 (here construed as including Bed "16" of earlier workers) of the Calvert Formation and Beds 17 and 18 and the lower part of Bed 19 of the Choptank Formation in the Chesapeake Bay region of Maryland. Bed 15 of Zone 6 seems to represent a major transgression of marine deposits on the Atlantic Coastal Plain.

This zone is correlated with the middle part of the Serravallian Stage and is about middle middle Miocene in age.

The absolute age of Zone 6 is estimated to be from about 13.8 Ma to 12.8 Ma.

7. *Rhaphoneis diamantella* Partial Range Zone. The base is at the last occurrence of *Rhaphoneis gemmifera* and the top is at the last occurrence of *Rhaphoneis diamantella* Andrews. It is not known whether *R. diamantella* ranges above Bed 19 of the Choptank Formation or Bed 20 (now considered to be basal St. Marys Formation), as reported by Andrews (1978). For practical purposes, this zone is identified by the occurrence of *R. diamantella.*

Important marker diatoms include *Delphineis novaecaesaraea, Actinoptychus marylandicus, Actinoptychus virginicus, Thalassiosira grunowii, Rhaphoneis lancettula, Denticulopsis hustedtii, Rhaphoneis scutula, Rhaphoneis amphiceros, Rhaphoneis rhombica, Delphineis biseriata,* and *Rhaphoneis diamantella.*

This zone includes the upper part of Bed 19 of the Choptank Formation in the Chesapeake Bay region of Maryland. It may extend into Bed 20, the lowermost lithologic unit of the St. Marys Formation. Zone 7, as represented by equivalents of Bed 19, may represent a major marine transgression on the coastal plain. However, many of the rocks of this age have probably been removed by post-Choptank erosion. As reported by Andrews (1986), East Coast Diatom Zone 7 is represented by a substantial section far updip at Richmond, Va., and near the Fall Line. It was probably preserved there by local crustal downwarping.

This zone is correlated with the middle part of the Serravallian Stage and is about middle middle Miocene in age.

The absolute age of Zone 7 is estimated to be from about 12.8 Ma to 12.6 Ma.

CORRELATION OF EAST COAST DIATOM ZONES

GENERAL STATEMENT

A correlation between the revised East Coast Diatom Zones and the diatomaceous Miocene beds of the Coastal Plain with the radiometric time scale and other fossil zonation schemes is proposed in figure 1. New information that has become available in the last 10 years now permits a more accurate and more meaningful correlation than when the East Coast Diatom Zones were first proposed by Andrews (1978). The absolute age dating in this report is based on the time scale of Berggren, Kent, Flynn, and Van Couvering (1985), and this, of course, will be subject to future change as new information and interpretations are developed. There is an ambiguity in the boundary between the Langhian and Serravallian Stages of middle Miocene age in the time scale of Berggren, Kent, Flynn, and Van Couvering (1985). It is beyond the scope of this paper to evaluate the criteria for this boundary, so the author has arbitrarily chosen the earlier date, about 15.1 Ma, for this boundary. This date assigns a relatively short period of time to the Langhian Stage, and this conforms more closely to the time scales in use for the last several years.

RADIOMETRIC DATING

There are no radiometric dates, to the author's knowledge, of the Miocene deposits directly concerned in this report. The only possibly pertinent radiometric date is a K/Ar date of 12.5 Ma on glauconite from the restricted St. Marys Formation (Unit B) reported by Blackwelder and Ward (1976). This stratigraphic level is younger than any of those herein described. The age of 12.5 Ma for the St. Marys Formation is only slightly younger than the age of the top of the Choptank Formation postulated in figure 1 of this report. However, the age of the top of this section is not firmly controlled.

PLANKTONIC FORAMINIFERA CORRELATION

The correlation of this East Coast diatom zonation is probably better established with planktonic foraminifera than with any other fossil group. In this report the correlation of the planktonic foraminifera zonation— "N" zones of Blow (1969)— with the absolute time scale follows that given by Berggren, Kent, Flynn, and Van Couvering (1985). Gibson (1971) stated that Bed 10 of the Calvert Formation in Maryland contains planktonic foraminifera indicative of Zone N8 or N9 of Blow (1969). Forester (1980) reported that Bed 12 of the Calvert Formation contains planktonic foraminifera indicative of Zone N9. Paul Huddlestun (oral commun. to Lauck Ward, 1986) stated that Bed 10 of the Calvert

Formation contains foraminifera indicative of Zone N8, whereas Bed 12 contains foraminifera indicative of the top of Zone N8 or the bottom of Zone N9.

The most extensive scheme of correlation of the East Coast Miocene deposits and diatom zones with planktonic foraminiferal zones has been made by Abbott (1978). Although his Atlantic Siliceous Microfossil Zones were established on parameters different from those of the East Coast Diatom Zones of Andrews (1978) and this study, his conclusions can be readily adapted to this study. Lacking a comprehensive set of definitive dates based on foraminifera, the diatom zones of this report are generally correlated with the planktonic foraminiferal "N" zones based on the personal communication of Felix Gradstein to W.H. Abbott, as reported by Abbott (1978, p. 28). Although the correlations given in this report may differ in a few details, there are no significant anomalies.

CALCAREOUS NANNOFOSSIL CORRELATION

The only published calcareous nannofossil zonation of the Miocene Coastal Plain deposits seems to be that of N.Y. Park *in* Palmer (1986, p. 27). The Calvert and Choptank Formations of Maryland are correlated by Park with calcareous nannofossil Zones NN4-NN6. This is in general agreement with the correlation of the East Coast Diatom Zones as presented in this report with the planktonic foraminifera zones and the radiometric time scale.

SILICOFLAGELLATE CORRELATION

The silicoflagellate zones shown in figure 1 are those of Bukry (1981). These zones are here correlated with the calcareous nannofossil NN zones, the planktonic foraminifera N zones, and the absolute time scale by Berggren, Kent, Flynn, and Van Couvering (1985) following Barron (1983) and Barron (written commun., 1987). The silicoflagellate zonation has been invaluable for correlating East Coast Diatom Zone 1 in the Burdigalian Stage of early Miocene age. Silicoflagellates are less useful in making fine stratigraphic distinctions in beds of middle Miocene age in this region. Middle Miocene silicoflagellates seem to be long ranging, and a lack of distinctive, short-ranging species renders detailed correlation and zonation difficult (see Bukry, 1981b, p. 434).

RADIOLARIAN CORRELATION

A study of the radiolaria of the Calvert and Choptank Formations has been made recently by Palmer (1986). She has observed five distinctive zones, and their correlation with other zonation schemes is shown in figure 1 following suggestions by J.A. Barron (written commun., 1987). Palmer's study is important in that it proves that another siliceous microfossil group can be found in sufficient abundance in East Coast Miocene deposits to be useful in correlation. Distinctive radiolarian assemblages can be delineated in these deposits.

OTHER DIATOM CORRELATIONS

The Atlantic Siliceous Microfossil Zones proposed by Abbott (1978) have been discussed previously in this report. A leading value of Abbott's zonation is that it links shallow-water diatom assemblages with better known deep-marine-water assemblages. The diatoms used for delineation of the East Coast Diatom Zones of this report are restricted mainly to shallow marine environments, and some are unknown in deeper marine deposits. Occasional deep marine diatom taxa are found in shallow marine deposits, but their occurrence is usually too rare and too inconsistent to be of much value. In many instances, there is not enough similarity between shallow, predominantly benthic marine assemblages and deep, predominantly planktonic marine assemblages to construct a meaningful correlation. Suggestions for correlation of these shallow-water deposits with deep marine deposits were made by Andrews (1978) and more extensively by Abbott (1978). Even the more detailed deep-sea diatom zonations recently published by Barron (1985) and Barron and others (1985) for the equatorial Pacific Ocean area are difficult to correlate directly by diatoms with this study because of the disparity of diatom taxa used for these respective studies.

SYSTEMATIC PALEONTOLOGY

The systematic treatment of taxonomy in this report is conservative and follows that of earlier reports on fossil marine diatom assemblages of the Southeastern United States. The first citation in each synonymy is the basionym of the taxon. The second citation is the name adopted for use in this report if that name is a revision of the basionym. Subsequent citations include synonyms, misidentifications, misspellings, incorrect attributions of authorship, and other errata. The synonymies are not exhaustive but emphasize reported fossil occurrences in the Southeastern United States. Revised descriptions of the marker taxa are included in this report in order to present current ideas and to render this a definitive work in its own right. The discussions of the taxa develop the results of more than 10 years of study and consideration. The geologic ranges have been revised to include previous studies and other, as yet unpublished observations.

Genus ACTINOPTYCHUS Ehrenberg, 1841

Actinoptychus heliopelta Grunow

Plate 1, figures 1, 2; plate 5, figures 1, 2

Actinoptychus heliopelta Grunow *in* Van Heurck, 1883, pl. 123, fig. 3; Pantocsek, 1886, pt. 1, p. 61; Schmidt, *in* Schmidt and others, 1890, pl. 153, fig. 22; Wolle, 1894, pl. 103, fig. 2; De-Toni, 1894, p. 1377; Boyer, 1904, p. 499, pl. 134, fig. 3; Lohman, 1948, p. 169, pl. 9, fig. 3; Cavallero, 1974, p. 22, pl. 1, fig. 5; Andrews, 1978, p. 382, pl. 1, figs. 7, 8; pl. 6, fig. 2; Andrews, 1979, p. 79-98, pls. 1-5; Andrews, 1987, p. 8, 9, pl. 1, figs. 1, 2.

Heliopelta spp. Ehrenberg, 1845, p. 268.

Description.—Valve round, discoid, with relatively wide, slanting marginal rim surrounding a main area of alternating raised and depressed sectors. Diameter of observed specimens 33- 244 μm. Slanting marginal rim ornamented with radial rows of fine pores, about 15 pores in 10 μm, arranged in hexagonal pattern. Exterior of rim also ornamented with fine radial ridges, subregular in spacing and showing spinules of silica on their surfaces. Near inner margin of rim is single row of large pores, the sides of which may be elongated into distinct hollow tubes up to 8 μm in length; tubes oriented normal to rim of valve. Each of these external pores, or tubes, connects to a single labiate process on inside of valve. Exit pores of labiate processes show, in some specimens, single stubby spine directed from inside toward opening. Number, spacing, and symmetry of labiate processes vary greatly within species and are more extensively discussed by Andrews (1979). Internal labiate processes vary from short and simple to relatively long and curved.

The main part of the valve is sharply divided into raised and depressed sectors, 6 to 12 sectors in the specimens observed; 14-, 16-, 18-, and 20-sectored forms have been described in the literature, but they must be extremely rare. (The terms "raised" and "depressed" for valve sectors refer to the external expression of the sectors.) The raised sectors show a coarse areolate net on the outside surface, with about two and one-half large rounded areolae in 10 μm, arranged in a hexagonal pattern. The depressed sectors show a finer external areolate net, with about five areolae in 10 μm, arranged in a "benzene ring" type of pattern.

The interior of the valve shows a much finer pore structure than the exterior. The pores on the raised sectors form a hexagonal net with about 11 or 12 pores in 10 μm, whereas the pores on the depressed sectors form a quincuncial net with about 10 or 11 pores in 10 μm along the diagonal rows. In some small six-sectored specimens the internal pores are irregularly scattered in the depressed sectors.

The central area is hyaline, warped at the margin to attach to alternate undulating sectors. In some larger specimens the hyaline area may extend as pointed rays into the depressed sectors. Many specimens show small, subtriangular hyaline areas between the raised and depressed sectors at their juncture with the marginal rim.

Discussion.—A more complete synonymy and discussion of the nomenclatural history of this taxon is given by Andrews (1979). *Actinoptychus heliopelta* was probably derived from *A. senarius* sensu lato, a six-sectored form reported from rocks as old as Cretaceous to modern marine environments. Indeed, the simpler, six-sectored forms of *A. heliopelta* may be diffcult to distinguish from *A. senarius* in some instances. However, *A. heliopelta* shows a distinctive slanting marginal rim which results in a thicker and more convex frustule than in *A. senarius*. Furthermore, *A. senarius* has been restricted, at least by definition, to specimens showing six sectors, whereas *A. heliopelta* may show many more, as indicated above. *A. heliopelta* shows increasing complexity in placement of the marginal labiate processes depending on size and number of sectors (Andrews, 1979). *A. senarius*, on the other hand, usually shows only one labiate process centered on the rim of each raised sector. The only exception to this rule known to the author was reported by Andrews and Abbott (1985, pl. 12, figs. 1, 2).

In some specimens of *Actinoptychus heliopelta* the hyaline centers are preserved, even though the rest of the valve may have been destroyed by dissolution. Such distinctive four-, five-, and six-pointed, star-shaped fragments may be useful as markers, even though the rest of the specimen is not preserved.

Known geologic range.—Found throughout East Coast Diatom Zone 1 in Maryland and New Jersey; restricted to Bed 3A of the Calvert Formation in Maryland, both above and below the *Naviculopsis quadrata*-*Naviculopsis ponticula* silicoflagellate zone boundary. It has not been observed in a deposit on the Rappahannock River, Va., which may be near the top of the *Naviculopsis ponticula* silicoflagellate zone. The earliest occurrence of this species is unknown. It is probably restricted to the Burdigalian Stage of early Miocene age.

Actinoptychus marylandicus Andrews

Plate 1, figure 4; plate 5, figure 3

Actinoptychus marylandicus Andrews, 1976, p. 14, pl. 4, figs. 3-6; Andrews, 1978, p. 383, pl. 2, figs. 1, 2; Abbott and Andrews, 1979, p. 232, pl. 1, fig. 10; Andrews and Abbott, 1985, p. 70, pl. 6, figs. 8, 9; Andrews, 1986, p. 508, fig. 4.5.

Description.—Valve round, discoid, fragile, with margin in many specimens missing or poorly preserved. Main part of valve divided into alternately raised and depressed sectors, from 10 to 18 sectors in specimens observed. Externally raised sectors more finely areolate, and each raised sector has single labiate process situated centrally near margin of valve. Main part of sector covered with fine areolae, about 16 areolae in 10 µm, arranged in hexagonal pattern. Many raised sectors show short, narrow hyaline blade extending outward from hyaline central area.

The externally depressed sectors are more coarsely areolate. They show a single row of areolae at the margin, succeeded inwardly by a narrow but distinct hyaline band. The main part of the sector is covered with parallel rows of areolae, about 10 areolae in 10 µm, normal to the margin of the valve and arranged in a quincuncial pattern. A bladelike hyaline area in the center of the depressed sector extends from the hyaline central area about one-third to one-half the distance to the margin of the sector. This bladelike hyaline area results from the occlusion of one to three rows of areolae in the center of each depressed sector. The central area is hyaline, with vague concentric markings, and is warped near the margin to join alternate sectors on different planes.

Discussion.—This species shows obvious morphologic affinities to *Actinoptychus virginicus*, but it is readily distinguishable by its prominent bladelike hyaline areas in the center of the depressed sectors as well as the narrower and shorter bladelike hyaline areas in the center of the raised sectors. *A. virginicus* shows an irregular hyaline area in the depressed sectors and seldom any indication of a hyaline blade in the raised sectors. *A. marylandicus* seems to be more infrequent in occurrence than *A. virginicus*.

Known geologic range.—From near the top of East Coast Diatom Zone 3-4 to the top of Zone 7. In Maryland it ranges from Bed 12 of the Calvert Formation through Bed 19 of the Choptank Formation. The species seems to be restricted to the uppermost part of the Langhian and the Serravallian Stages of middle Miocene age. Although morphologically distinct, *A. marylandicus* is by no means common or consistent in occurrence. It is hence a less useful marker diatom than the related *A. virginicus*.

Actinoptychus thumii (Schmidt) Hanna

Plate 1, figure 3

Actinoptychus stella var. *thumii* Schmidt, *in* Schmidt and others, 1886, pl. 90, figs. 3-5; Pantocsek, 1886, pt. 1, p. 65, 66, pl. 8, fig. 65.
Actinoptychus thumii (Schmidt) Hanna, 1932, p. 171, pl. 4, figs. 3, 4; Andrews, 1978, p. 383, 384, pl. 2, fig. 6; Andrews and Abbott, 1985, p. 70, 71.

Description.—Valve round, discoid, divided into six alternately raised and depressed sectors by relatively sharp and deep crimping. Entire valve shows stellate pattern of ornamentation, often not readily observed because of disparity of focus in alternate sectors. Outer margin of valve has narrow band of very fine areolate structure. Externally raised sectors covered with very fine areolae. Single prominent labiate process situated in center of areolate rims, and narrow hyaline ray extends from area of labiate process to hyaline central area.

The externally depressed sectors are more coarsely marked than the alternately raised sectors; they show a triangular area covered with areolae arranged in a hexagonal pattern, about 22 areolae in 10 µm, completely surrounded by a hyaline band about 2 µm wide. The central hyaline area is about one-sixth the width of the valve.

Discussion.—Although this species has been found only rarely in East Coast Miocene deposits, its distinctive morphology makes it useful as a marker diatom.

Known geologic range.—Previously reported by Andrews (1978) from near the base of Bed 14 of the Calvert Formation in Maryland and by Andrews and Abbott (1985) from the Hawthorn Formation of approximately equivalent age in Georgia. Recently the author has found this species in a core taken from near Haynesville, Va., in beds approximately equivalent to the lower middle part of Bed 15 of the Calvert Formation. This suggests occurrence from about the middle of East Coast Diatom Zone 5 to the lower part of Zone 6 in the lower part of the Serravallian Stage of early middle Miocene age. Although this diatom is highly distinctive in morphology, its occurrence is so rare and sporadic that a stratigraphic range cannot be stated with certainty. The Haynesville core represents a relatively downdip section compared with most other cores used in this study. *A. thumii* may have been ecologically restricted to colder or deeper marine waters than were common during the deposition of many East Coast Miocene deposits. The statement by Schrader and Fenner (1976, p. 931) that *A. thumii* became extinct at the end of the Oligocene in Norwegian Sea cores contradicts the results of this study.

Actinoptychus virginicus (Grunow) Andrews

Plate 1, figure 5; plate 5, figure 4

Actinoptychus vulgaris var. *virginica* Grunow *in* Van Heurck, 1883, pl. 121, fig. 7.
Actinoptychus virginicus (Grunow) Andrews, 1976, p. 15, pl. 4, figs. 9-12; Andrews, 1978, p. 384, pl. 2, figs. 2-5; Abbott and Andrews, 1979, p. 232, 233, pl. 1, fig. 12; Andrews and Abbott, 1985, p. 71; Andrews, 1986, p. 510, fig. 4.6.

Description.—Valve round, discoid, fragile, with margin in many specimens missing or poorly preserved. Main part of valve divided into alternately raised and depressed sectors, from 10 to 18 sectors in specimens observed. Externally raised sectors are more finely areolate, and each raised sector has single labiate process situated centrally near margin of valve. Main part of sector covered with fine areolae, about 16 areolae in 10 μm, arranged in hexagonal pattern.

The externally depressed sectors are more coarsely areolate. They show a single row of areolae at the margin, succeeded inwardly by a narrow but distinct hyaline band. The main part of the sector is covered with parallel rows of areolae, about 10 areolae in 10 μm, normal to the margin of the valve and arranged in a quincuncial pattern. An irregular hyaline area is present in the center of each depressed sector, seemingly an extension of the hyaline central area of the valve and probably the result of the occlusion of an irregular patch of areolae. The central area is hyaline, with vague concentric markings, and is warped near the margin to join alternate sectors on different planes.

Discussion.—Actinoptychus virginicus is morphologically similar to *A. marylandicus* and differs principally in the ornamentation of its depressed sectors. These two taxa, however, seem to be sufficiently and consistently morphologically distinctive to justify their recognition as separate species.

Known geologic range.—From the lower part of Bed 13 of the Calvert Formation to the top of Bed 19 of the Choptank Formation, and therefore from the top of East Coast Diatom Zone 3-4 through Zone 7 (uppermost Langhian and lower Serravallian Stages of early middle Miocene age). The first occurrence is slightly younger than that for *A. marylandicus*, but *A. virginicus* is much more consistent and abundant throughout its stratigraphic range. The distinctive morphology of the species makes it useful as a marker diatom, even though it is somewhat long ranging.

Genus BIDDULPHIA Gray, 1821

Biddulphia minuta (Greville) Andrews, n. comb.

Plate 5, figures 5, 6

Amphitetras minuta Greville, 1861, p. 77, pl. 9, fig. 11.
Biddulphia decipiens Grunow *in* Van Heurck, 1882, pl. 100, figs. 3, 4; Wolle, 1894, pl. 98, figs. 5, 6; De-Toni, 1894, p. 878; Boyer, 1901, p. 716, 717; Boyer, 1904, p. 493, pl. 134, fig. 8.
Amphitetras (Biddulphia) altemans (sic) H.L. Smith *in* Christian, 1887, p. 67.
Triceratium antediluvianum var. *minutum* (Greville) Mills, 1935, p. 1619; VanLandingham, 1967, p. 182.

Description.—Valve cruciform, with central part of sides produced laterally so that width and length of valve are subequal. Length of observed specimen 48 μm, width 41 μm. Surface of valve covered with network of closely packed areolae, five or six areolae in 10 μm at center, finer toward apices. Areolae arranged in parallel to slightly convergent rows toward apices, and in slightly divergent rows toward ends of lateral protuberances. Areolae radiate from center of valve and show secondary orientation in concentric rings near center of valve. In some specimens small areolae or pores interspersed throughout areolate net. Ends of valve show rim of relatively large round ocellus, which is not preserved in most specimens. Lateral protuberances ornamented near end by single spine, slightly canted from normal to valve surface. Internal fine structures not known.

Discussion.—Biddulphia minuta is a distinctive marker fossil, with frequent occurrence within its stratigraphic range in East Coast Miocene rocks. Greville (1861) originally described this species from the deposit at Nottingham, Md., and his brief description and single figure are unequivocally distinctive for this species. The author has, therefore, placed the better known name, *B. decipiens* Grunow, into synonymy. Whether this species should be assigned to *Biddulphia* or *Triceratium* is a philosophical question that cannot be dealt with here.

Known geologic range.—From East Coast Diatom Zone 1, and Shattuck (1904) reports the species only from deposits now identified with this zone. It occurs frequently in Bed 3A of the Calvert Formation. Burdigalian Stage and early Miocene in age.

Genus COSCINODISCUS Ehrenberg, 1838

Coscinodiscus lewisianus Greville

Plate 1, figures 8, 9

Coscinodiscus lewisianus Greville, 1866, p. 78, 79, pl. 8, figs. 8-10; Pantocsek, 1886, p. 70, pl. 25, fig. 232; Rattray, 1889, p. 598; Wolle, 1894, pl. 94, fig. 18; Boyer, 1904, p. 505, pl. 134, fig. 16; Reinhold, 1937, p. 96, 97, pl. 8, fig. 11; Lohman, 1948, p. 161, pl. 6, fig. 7; Lohman, 1974, p. 355, pl. 2, fig. 1; Andrews, 1978, p. 381, pl. 1, figs. 1, 2.

Description.—Valve flat, elliptical in outline. Length of observed specimens varies from about 30 to 106 μm, width about two-fifths of length in larger specimens, smaller specimens more rounded. Marginal zone about 4 μm wide, covered with an orderly quincuncial pattern of fine areolae. Main part of valve ornamented by slightly curved longitudinal rows of large areolae, about four rows in 10 μm and about five areolae in 10 μm along the row. These coarse areolae irregularly distributed at center of valve.

Discussion.—This morphologically distinctive species is usually rare and sporadic in occurrence in East Coast Miocene deposits. Considering recent research to provide a more rational basis for the genus *Coscinodiscus*, the inclusion of this species in that genus seems questionable.

Known geologic range.—Although previously reported by Andrews (1978) to range through East Coast Diatom Zones 1 and 2, this range must be extended upward to the lower part of Zone 6, based on more recent observations. It has been observed in equivalents of Beds 3A-15 of the Calvert Formation, but it is never common, and occurrence above the Bed 9 equivalent is very rare and inconsistent. This is a relatively long-ranging marker species; Barron (1983) has reported it from beds of earliest Miocene age (*Rocella gelida* Zone), and Fenner (1984) has reported it from beds of Oligocene age (*Bogorovia veniamini* Zone). This study suggests that it ranges upward to beds of the Serravallian Stage of middle Miocene age.

Genus DELPHINEIS Andrews, 1977

Delphineis angustata (Pantocsek) Andrews

Plate 2, figures 1, 2; plate 6, figures 2, 3

Rhaphoneis angustata Pantocsek, 1886, pt. 1, p. 33, pl. 11, fig. 97; pl. 30, fig. 313; Lohman, 1948, p. 180, 181, pl. 11, fig. 11; Lohman, 1974, p. 352, pl. 5, fig. 14; Andrews, 1975, p. 203, 204, pl. 1, figs. 5, 6; Andrews, 1976, p. 20, pl. 7, figs. 1, 2.

Delphineis angustata (Pantocsek) Andrews, 1977, p. 250, 251, pl. 1, figs. 1-4; pl. 2, figs. 21, 23; pl. 3, figs. 29, 30; Andrews, 1978, p. 389, 390, pl. 5, figs. 1, 2; Abbott and Andrews, 1979, p. 242, pl. 4, fig. 1; Andrews and Abbott, 1985, p. 77, pl. 8, figs. 9, 10.

Description.—Valve linear and elongate, tapering slightly from near center to bluntly rounded apices. Length of observed specimens 31 to 50 μm, width about 7 to 8 μm. Transverse rows of areolae short, five rows in 10 μm, consisting of two areolae in shallow external grooves. Areolae are secondarily arranged in longitudinal rows. Transverse rows of areolae parallel for almost the length of the valve, becoming slightly radiate near apices. Apical striae, composed of fine areolae or pores, curve completely around ends of valve. Transverse rows of areolae are well aligned across relatively narrow hyaline axial area. Apical ornamentation typical for genus—two fine pores penetrating each end of valve and a single internal labiate process on each end of valve; these processes oriented diagonally to longitudinal axis of valve.

Discussion.—*Delphineis angustata* is distinguished from the more elongate specimens of *D. penelliptica* by two, instead of three, areolae in the transverse rows. The areolae of *D. angustata* are also relatively larger, and the valves usually appear to be more robustly silicified than those of *D. penelliptica*.

Known geologic range.—From the upper part of Bed 13 of the Calvert Formation (where it may be intrusive), and certainly from the base of Bed 14 to the upper part of Bed 15, and therefore East Coast Diatom Zone 5 and lower part of Zone 6 (Serravallian Stage of middle Miocene age). Andrews (1976, p. 20, pl. 7, figs. 1, 2) and Andrews (1978) reported a range upward into East Coast Diatom Zone 7 of the Choptank Formation. This upward limit has not been verified by later studies. The specimens figured by Andrews (1976) are much more finely marked than is typical for *D. angustata*. They appear to pertain to a distinct, but as yet unstudied, species of *Delphineis*.

Delphineis biseriata (Grunow) Andrews

Plate 2, figures 3-5; plate 6, figure 4

Rhaphoneis biseriata Grunow *in* Pantocsek, 1886, pt. 1, p. 35, pl. 27, fig. 263; Andrews, 1975, p. 204, pl. 1, fig. 7.

Delphineis biseriata (Grunow) Andrews, 1978, p. 390-392, pl. 5, figs. 3-5; pl. 8, figs. 3, 4; Andrews, 1986, p. 518, fig. 6.7.

Description.—Valve linear, tapering slightly to bluntly rounded apices. Length of observed specimens about 40 to 50 μm, width 6 to 9 μm. Transverse rows of areolae reduced to single row of large areolae, five to five and one-half areolae in 10 μm along lateral margins of face of valve, with an analogous single row of large areolae on mantle of valve. Hyaline axial area relatively broad, about one-half the width of the valve, and marginal areolae are well aligned across it. Single row of fine marginal areolae or pores ornament ends of valve. Between pairs of marginal areolae narrow but distinct siliceous ribs or pseudosepta cross axial area of valve. Apical ornamentation consists of two fine pores penetrating valve and a single labiate process.

Discussion.—*Delphineis biseriata* is readily distinguished by the single rows of relatively large areolae on the valve face and by the noticeable transverse siliceous ribs. The single rows of areolae on the valve face and the analogous rows on the valve mantle suggest possible derivation from *D. angustata*, as does its succeeding stratigraphic occurrence. *D. biseriata* has been confused with *Denticulopsis* because of its prominent transverse pseudosepta. However, the rows of distinct areolae along both margins of the valve sufficiently distinguish this species from that genus.

Known geologic range.—From the upper part of Bed 15 through Bed 19 of the Calvert Formation, and therefore in East Coast Diatom Zones 6 and 7 (Serravallian Stage of middle Miocene age). In the section south of Scientists Cliffs, Md., *D. biseriata* seems to replace the analogous form, *D. angustata*, abruptly in Bed 15, at about the point where it is succeeded by the ill-conceived "Bed 16," which is considered in this report to be the upper part of Bed 15. Whether this is a true first occurrence of *D. biseriata* or a regional first occurrence controlled by ecology may be debatable. I have seen rare specimens of this species in localities (New Jersey, Haynesville, Va.) in rocks of earlier Miocene age, which perhaps were deposited in deeper sedimentary environments. However, *D. biseriata* appears to be a relatively consistent marker diatom for shallow marine strata in the Southeastern United States.

Delphineis lineata Andrews

Plate 2, figures 6-8

Delphineis lineata Andrews, 1977, p. 251, pl. 1, figs. 5-7; Andrews, 1978, p. 392, pl. 5, figs. 6-8.

Description.—Valve broadly linear, with smoothly rounded apices; lateral margins slightly concave in some specimens. Length of observed specimens 32 to 50 μm, width about 7 to 8 μm. Transverse rows of areolae parallel, 8 to 10 rows in 10 μm in center, becoming radiate near ends where they grade imperceptibly into finer apical striae around ends of valve. Three to four relatively fine areolae in external grooves on each transverse row, pairs of rows aligned across hyaline axial area. Axial area variable in width in different specimens, sometimes showing traces of occluded areolae aligned with transverse rows. Apical structures probably those common to the genus, but not yet observed in this species.

Discussion.—*Delphineis lineata* shows apparent affinites to *D. novaecaesaraea* but lacks the distinctively expanded and pointed ends of that species. Although morphologically distinctive, the species is rare and inconsistent in occurrence in East Coast Miocene deposits.

Known geologic range.—Found from the lower part of Bed 3B to the lower part of Bed 13 of the Calvert Formation of Maryland, and therefore in East Coast Diatom Zones 2 and 3-4 (upper part of Burdigalian Stage of early Miocene age through Langhian Stage of early middle Miocene age). Although *D. lineata* is distinctive in morphology, its scarcity and sporadic occurrence make it a less than optimum marker diatom.

Delphineis novaecaesaraea (Kain and Schultze) Andrews

Plate 2, figures 9-12; plate 6, figures 5, 6

Dimeregramma novaecaesaraea Kain and Schultze, 1889, p. 74, pl. 89, figs. 1, 1b; Wolle, 1894, pl. 5, figs. 16, 22; Lohman, 1948, p. 184, 185, pl. 11, figs. 4, 5.

Delphineis novaecaesaraea (Kain and Schultze) Andrews, 1977, p. 250, 251, pl. 2, figs. 23, 24; pl. 3, figs. 31, 32; Andrews, 1978, p. 392, pl. 5, figs. 9-11; pl. 8, fig. 7; Abbott and Andrews, 1979, p. 242, 243, pl. 4, fig. 3; pl. 7, figs. 5, 6; Andrews and Abbott, 1985, p. 77, pl. 8, fig. 14; Andrews, 1986, p. 518, figs. 6.6, 11.5.

Description.—Valve linear, usually having a slight expansion at center and slightly to distinctly inflated acute apices. Length of observed specimens 36 to 98 μm, width about 7 to 8 μm. Transverse rows of areolae, seven or eight rows in 10 μm, short, formed by external grooves with two areolae at the base. Transverse rows of areolae parallel, becoming radiate toward apices, where they grade imperceptibly into finer rows of areolae or pores around ends of valve. Hyaline axial area about 2.5 to 3 μm in width, relatively broad for *Delphineis*, and pairs of transverse rows of areolae well aligned across it. Two very fine pores on each end of valve as well as single internal labiate process; these processes oriented diagonally to longitudinal axis.

Discussion.—*Delphineis novaecaesaraea* is a distinctive marker diatom readily identifiable because of its cuneate inflated apices. Its occurrence in East Coast Miocene deposits may be somewhat facies controlled.

Known geologic range.—From Bed 12 through Bed 19 of the Calvert Formation in Maryland, and therefore in East Coast Diatom Zones 3-4 through 7 (upper Langhian and Serravallian Stages of early middle Miocene age). The upper limit of this species is here extended beyond that published by Andrews (1978). Although *D. novaecaesaraea* is common in most sections and is widely distributed, its occurrence seems to be controlled by unknown ecological factors. Its absence in some beds and localities is unaccountable under our present knowledge.

Delphineis ovata Andrews

Plate 2, figures 13-16; plate 6, figures 7, 8

Delphineis ovata Andrews, 1977, p. 252, 253, pl. 1, figs. 12-15; pl. 2, figs. 25, 26; pl. 4, figs. 33, 34; Andrews, 1978, p. 392, 394, pl. 5, figs. 12-14; pl. 8, figs. 5, 6; Andrews, 1987, p. 10, pl. 1, figs. 8-14; pl. 3, fig. 11.

Description.—Valve elliptical to linear-elliptical, with curved elliptical lateral margins terminating in bluntly rounded apices. Length of observed specimens 28 to 89 μm, width about 9 to 10 μm. About seven transverse rows of areolae in 10 μm, consisting of external grooves containing three or four areolae near center but reducing to two areolae near apices. Transverse rows of areolae parallel at center, becoming distinctly radiate near apices; finer rows curve completely around ends of valve. Hyaline axial area narrow, about 1 μm wide, and pairs of transverse rows of areolae well aligned across it. Ends of valve show two fine pores and a single labiate process; these processes oriented diagonally to longitudinal axis.

Discussion.—*Delphineis ovata* resembles most nearly *D. penelliptica*, and some individuals may be difficult to distinguish. However, *D. ovata* shows a generally elliptical outline and smoothly curved lateral margins, whereas *D. penelliptica* shows a distinct taper of the lateral margins toward the apices. Abbott (1978) reported a zone of mixed *D. ovata* and *D. penelliptica* in his Atlantic margin studies. In the more nearshore deposits studied for this report, the transition between the two species seems to be more abrupt, with mixing observed only at the upper limit of *D. ovata* and at the lower limit of *D. penelliptica*.

Known geologic range.—From at least the upper part of the *Naviculopsis ponticula* silicoflagellate zone (about 17.0 Ma) to the top of Bed 9 of the Calvert Formation of Maryland, and therefore in East Coast Diatom Zone 2 (upper Burdigalian to lower Langhian Stage of late early to early middle Miocene age). The first occurrence is extended downward in this report on the basis of an occurrence near Horsehead Point on the Rappahannock River in Virginia. The species has not been observed in Bed 3A of the Calvert Formation in Maryland.

Delphineis penelliptica Andrews

Plate 2, figures 17-20; plate 6, figures 9, 10

Delphineis penelliptica Andrews, 1977, p. 253, 254, pl. 1, figs. 16-20; pl. 2, figs. 27, 28; pl. 4, figs. 35, 36; Andrews, 1978, p. 395, 396, pl. 5, figs. 15-17; pl. 8, fig. 8; Andrews and Abbott, 1985, p. 77, pl. 8, figs. 11-13; pl. 13, fig. 1.

Description.—Valve elliptical-lanceolate to lanceolate, with lateral margins tapering with but slight curvature toward narrowly rounded apices. Length of observed specimens 28 to 82 μm, width about 10 to 12 μm. Transverse rows of areolae consist of external grooves containing three or four areolae near center, but reduced to one or two areolae near apices. About five and one-half to seven transverse rows of areolae in 10 μm, parallel at center but becoming slightly radiate and finer near apices. Fine rows of smaller areolae or pores curve around ends of valves. Hyaline axial area narrow, about 1 μm wide, and pairs of transverse rows of areolae well aligned across it. Ends of valve show two fine pores and a single labiate process; these processes oriented diagonally to longitudinal axis.

Discussion.—*Delphineis penelliptica* differs from *D. ovata* by its less rounded and more tapering lateral margins. These tapering margins are also seen in *D. angustata*, and occasional elongate specimens of *D. penelliptica* may be confused with that species. However, the areolae are discernibly finer in *D. penelliptica* and three or four are found in each transverse row, whereas *D. angustata* shows only two relatively larger areolae in each transverse row. A possible evolutionary trend from *D. ovata* to *D. penelliptica* to *D. angustata* may deserve consideration.

Known geologic range.—From the upper part of Bed 9 to the upper part of Bed 15 of the Calvert Formation in Maryland, and therefore in East Coast Diatom Zone 3-4 through lower part of Zone 6 (Langhian and Serravallian Stages of early middle Miocene age). *D. penelliptica* is a distinctive, widely distributed marker diatom with relatively consistent occurrence.

Genus DENTICULOPSIS Simonsen, 1979

Denticulopsis hustedtii (Simonsen and Kanaya) Simonsen

Plate 2, figures 21-24

Denticula hustedtii Simonsen and Kanaya, 1961, p. 501, pl. 1, figs. 19-25; Schrader, 1973b, p. 418, pl. 1, figs. 12, 13; Andrews, 1978, p. 400, 402, pl. 5, figs. 25-27; Abbott and Andrews, 1979, p. 243, pl. 4, fig. 4; pl. 7, fig. 4.

Denticulopsis hustedtii (Simonsen and Kanaya) Simonsen, 1979, p. 64; Andrews, 1986, p. 518, 519, fig. 6.9.

Description.—Valve elliptical to linear-elliptical, with bluntly rounded ends. Length of observed specimens 19-36 μm, width 5-8 μm. About three transverse pseudosepta in 10 μm, between them one to three secondary pseudosepta that do not penetrate very deeply. Valve ornamented with fine transverse rows of fine areolae. Raphe marginal.

Discussion.—*Denticulopsis hustedtii* is distinctive because of its transverse pseudosepta. However, the species is not common or consistent in occurrence in East Coast Miocene deposits.

Known geologic range.—From the lower middle of Bed 15 through Bed 19 of the Calvert Formation of Maryland, and therefore in East Coast Diatom Zones 6 and 7 (Serravallian Stage of middle Miocene age). Barron (1985) suggested its first appearance at about 14.2 Ma. Schrader (1973b) indicated a range as young as Pliocene.

Genus RAPHIDODISCUS H.L. Smith, *in* Christian, 1887

Raphidodiscus marylandicus Christian

Plate 2, figures 25, 26

Melonavicula marylandica Christian, 1886, p. 218 (nomen nudum).
Raphidodiscus marylandicus Christian, 1887, p. 66-68; Vorce, 1889, p. 132-137, pl. 6, 1 fig.; De-Toni, 1891, p. 313; Wolle, 1894, pl. 84, fig. 1; Van Heurck, 1896, pl. 35, fig. 913a; Hanna, 1932, p. 208-210, pl. 14, figs. 3, 4; Lohman, 1948, p. 186, pl. 11, fig. 13; Andrews, 1974, p. 231-243, pls. 1-5; Andrews, 1978, p. 400, pl. 5, figs. 23, 24.

Description.—Valve subround to very nearly round. Length of observed specimens 16-42 μm, width occasionally equal to length but usually 1-3 μm less. Outer rim of valve ornamented with fine areolae in radial rows, about 18 rows in 10 μm, on margin of valve and continuing around on mantle of valve, where they can be observed in girdle view. Inside rim area is intermediate zone of alternating ridges and grooves with rows of areolae in base of grooves. About eight or nine of these coarser rows of areolae in 10 μm, and about 12-14 areolae in 10 μm. Central part of valve naviculate in outline, depressed with rib and finer areolate groove structure continuing inward toward median line of valve. Fine areolae or pores in base of exterior grooves in this part of valve are occluded on inside of valve to form smoothly hyaline surface. Axial area linear, hyaline, containing two sharply raised elongate-ovate areas with raphe segments centered in each. Girdle is relatively wide hyaline band. No internal processes have been observed.

Discussion.—A more complete description of *Raphidodiscus marylandicus* can be found in Andrews (1974). Although this diatom is very distinctive in morphology, its occurrence is rare and inconsistent in East Coast

Miocene deposits. The complicated taxonomic history of this species is more completely discussed by Andrews (1974). Several species were assigned to the genus by early authors, but most of these seem to have little merit and have not stood the test of time. A possible exception is *Raphidodiscus mikrotatos* (Pantocsek) Tempère and Peragallo. If *Raphidodiscus* is indeed a monotypic genus, then this name of Pantocsek (1886) has precedence over *R. marylandicus* of Christian (1887). However, Hajós (1982) distinguishes and figures both *R. marylandicus* and *R. mikrotatos* from beds of the lower Miocene Eggenburgian Stage in the Central Paratethys area of Hungary. It may be that these two species are distinctive, so the author has retained the long-standing usage of *R. marylandicus* for the species occurring in the Miocene marine deposits of the Eastern United States.

Known geologic range.—The previous greatly restricted range published by Andrews (1974, 1978) must be extended on the basis of further study. *R. marylandicus* is now known to occur sparingly throughout Bed 3A and at least through the lower two-thirds of Bed 3B of the Calvert Formation in Maryland, and therefore in East Coast Diatom Zones 1 and 2 (middle to upper Burdigalian Stage of late early Miocene age). However, the occurrence is so sparse in the East Coast sections that this species may range higher. The first occurrence, presumably in the early Miocene, cannot be determined from this study. Schrader and Fenner (1976, p. 995) stated that *R. marylandicus* ranges through most of the early Miocene in deep-sea sediments. Barron (1983, p. 497) shows a range in the eastern tropical Pacific from 21 to about 16.5 Ma.

Genus RHAPHONEIS Ehrenberg, 1844

Rhaphoneis adamantea Andrews

Plate 2, figures 27-29; plate 6, figure 14

Rhaphoneis adamantea Andrews, 1978, p. 384, 385, pl. 2, figs. 9-11; Andrews and Abbott, 1985, p. 82, 83, pl. 9, figs. 7, 8; pl. 13, figs. 2, 3.

Description.—Valve lozenge-shaped, with obtusely rounded lateral margins and narrowly rounded, sometimes slightly produced apices. Length of observed specimens 36-80 μm, width 20-30 μm. About three or four transverse rows of large, round areolae in 10 μm, parallel in the center to slightly radiate near the apices. Areolae show a secondary arrangement in slightly curved longitudinal rows. Transverse rows of areolae not aligned across very narrow hyaline axial area. Single labiate process is subcentered in each end of valve. Pseudocellus consists of small field of fine pores at tip of valve. Vela supported by two struts and show roughly concentric pattern of fine openings.

Discussion.—Except for its lozenge-shaped outline, *Rhaphoneis adamantea* is similar in detailed morphology to the more variable and elongate species *R. magnapunctata*.

Known geologic range.—From about the middle of Bed 11 through Bed 13 of the Calvert Formation of Maryland, and therefore in East Coast Diatom Zone 3-4 (upper part of Langhian Stage to base of Serravallian Stage of early middle Miocene age).

Rhaphoneis amphiceros (Ehrenberg) Ehrenberg

Plate 2, figures 34, 35; plate 6, figures 12, 13

Cocconeis amphiceros Ehrenberg, 1840, p. 206.

Rhaphoneis amphiceros (Ehrenberg) Ehrenberg, 1844, p. 87; Ehrenberg, 1854, pl. 18, fig. 82; pl. 33, pt. 14, fig. 22; Van Heurck, 1881, pl. 36, figs. 22, 23; Hustedt, 1931, p. 174, fig. 680; Hendey, 1964, p. 154, pl. 26, figs. 1-4; Lohman, 1974, p. 352, pl. 5, fig. 15; Andrews, 1975, p. 204, 205, pl. 1, figs. 9-12; Andrews, 1976, p. 20, pl. 6, figs. 13, 14; Andrews, 1978, p. 385, pl. 2, figs. 7, 8; pl. 6, fig. 8; Andrews, 1980, p. 33, pl. 3, fig. 8; pl. 5, fig. 2; Andrews, 1986, p. 529, figs. 8.3, 11.4.

Description.—Valve rhombic-lanceolate, with broadly rounded lateral margins and produced, sharply rounded apices. Length of observed specimens 29-71 μm, width about 18-25 μm. Shorter specimens more rhombic in outline, whereas longer specimens more lanceolate. Surface of valve covered with transverse rows of fine areolae, and rows show distinctive radial orientation and curvature. About eight transverse rows of areolae in 10 μm, and about eight areolae in 10 μm along row. Areolae also show secondary orientation in nearly straight longitudinal rows. Hyaline axial area narrowly lanceolate and very narrow near apices. Transverse rows of areolae inconsistent in alignment across axial area. Apical pseudocelli composed of small field of fine pores. Inside of each end of valve shows single labiate process, centrally situated and immediately inward on valve from pseudocellus.

Discussion.— *Rhaphoneis amphiceros* has been in the past a "catch all" term for various forms of *Rhaphoneis* of the same general morphology and outline. The strict interpretation given here follows that of Andrews (1978). Obviously related species such as the rotund *R. rhombica* and the angular *R. scutula* are differentiated from *R. amphiceros* sensu stricto in this report.

Known geologic range.—From the lower middle part of Bed 15 of the Calvert Formation through Bed 19 of the Choptank Formation of Maryland, and therefore in East Coast Diatom Zones 6 and 7 (Serravallian Stage of middle Miocene age). However, Miocene specimens are morphologically indistinguishable from those in modern marine environments, so the range must extend from middle Miocene to the present.

Rhaphoneis clavata Andrews

Plate 2, figures 30-33; plate 6, figure 11

Rhaphoneis clavata Andrews, 1978, p. 385, pl. 3, figs. 4-7; pl. 6, fig. 7.

Description.—Valve narrow, clavate-lanceolate, with lateral margins tapering gently toward apices. Small, rounded apices may be slightly capitate in some specimens. Length of observed specimens 48-110 μm, width about 9 or 10 μm. About six areolae in 10 μm on valve surface, arranged in both transverse and longitudinal rows to form a quadrate pattern of ornamentation. Hyaline axial area very narrowly distinguishable in some specimens and obscure in others. Transverse rows of areolae well aligned across axial area. Fine pores of apical pseudocelli fill tips of valve, and each end shows single internal labiate process.

Discussion.—*Rhaphoneis clavata* is apparently the only form of *Rhaphoneis* with a distinctly clavate outline. This species shows many affinities to *R. lancettula*, and in a mixed assemblage some individuals may be so slightly clavate that they are difficult to distinguish from that species. Although some specimens may resemble *Sceptroneis* in their clavate outline, the detailed morphology indicates a close relationship to the group of *Rhaphoneis* species including *R. lancettula.*

Known geologic range.—This taxon has a very short range within Bed 15 of the Calvert Formation in Maryland, and therefore in East Coast Diatom Zone 6 (Serravallian Stage of middle Miocene age). Its distinctive morphology, limited stratigraphic range, and widespread distribution make *R. clavata* an important marker diatom.

Rhaphoneis diamantella Andrews

Plate 2, figures 36-38; plate 7, figure 1

Rhaphoneis diamantella Andrews, 1975, p. 207, 208, pl. 2, figs. 21-24; pl. 4, figs. 61-63; Andrews, 1976, p. 20, 21, pl. 6, figs. 15-18; Andrews, 1978, p. 385, 386, pl. 3, figs. 8, 9; Andrews, 1986, p. 529, figs. 8.4, 11.3.

Description.—Valve lozenge-shaped, obtuse to rounded at center of lateral margins, tapering by straight or slightly concave sides to bluntly pointed apices. Length of observed specimens 33-70 μm, width about 15-22 μm. Transverse rows of relatively large areolae parallel at center to slightly radiate near apices. About five transverse rows of areolae in 10 μm, and about five areolae in 10 μm along the row. Hyaline axial area narrow near apices and only slightly expanded at center of valve. Transverse rows of areolae not aligned across axial area. Apical structures include small, finely porous pseudocelli, which are rarely preserved.

Discussion.—Its lozenge shape and relatively coarse areolate structure make this species morphologically distinctive. Although never common or abundant, *Rhaphoneis diamantella* is usually consistent in occurrence in East Coast Miocene rocks.

Known geologic range.—*R. diamantella* is the definitive marker diatom for Bed 19 of the Choptank Formation, and therefore for East Coast Diatom Zone 7 (Serravallian Stage of middle Miocene age). Because the overlying St. Marys Formation is not known to be diatomaceous, the upper range of this species is unknown. It has not been observed in studied deposits of the still younger Miocene Eastover Formation.

Rhaphoneis elegans (Pantocsek and Grunow) Hanna

Plate 4, figures 1-3

Rhaphoneis gemmifera var. *elegans* Pantocsek and Grunow *in* Pantocsek, 1886, pt. 1, p. 34, pl. 2, fig. 21; pl. 20, fig. 179; pl. 27, fig. 264; pl. 30, fig. 317.

Rhaphoneis elegans (Pantocsek and Grunow) Hanna, 1932, p. 213, pl. 15, figs. 6-8; Lohman, 1948, p. 182, pl. 11, fig. 2; Lohman, 1974, p. 353, pl. 6, fig. 1; Andrews, 1975, p. 208, pl. 2, figs. 25-27; Andrews, 1978, p. 386, pl. 3, figs. 10, 11.

Description.—Valve subrhomboid, with obtusely rounded lateral margins at center and elongate, protracted apices. Length of observed specimens about 40 μm, width about 15-17 μm. Areolae large, arranged in slightly radiating transverse rows, five rows in 10 μm. Areolae show secondary orientation in somewhat poorly organized longitudinal rows. Hyaline axial area 1.5-2 μm wide at center, narrowing toward apices. Transverse rows of areolae not aligned across axial area. Apical structures not observed.

Discussion.—*Rhaphoneis elegans* may resemble *R. gemmifera*, but it can usually be differentiated because of its more protracted apices and relatively larger areolae.

Known geologic range.—In the lowermost part of Bed 14 of the Calvert Formation of Maryland, and therefore near the base of East Coast Diatom Zone 5 (lower Serravallian Stage of early middle Miocene age). This distinctive diatom is rarely observed, probably because of its restricted stratigraphic range in East Coast Miocene deposits.

Rhaphoneis fossile (Grunow) Andrews

Plate 4, figures 4-6; plate 7, figures 2, 3

Dimeregramma fossile Grunow *in* Pantocsek, 1886, pt. 1, p. 33, pl. 8, fig. 67; pl. 27, fig. 265; Wolle, 1894, pl. 63, fig. 27; Schrader and Fenner, 1976, p. 979, pl. 5, figs. 12, 13, 22.

Rhaphoneis fossile (Grunow) Andrews, 1978, p. 386, pl. 3, figs. 12, 13; pl. 6, fig. 6.

Description.—Valve narrowly lozenge-shaped, with lateral margins obtusely rounded at center and tapering evenly toward bluntly pointed apices. Length of observed specimens 32-40 μm, width about 12-15 μm. Lateral parts of valve ornamented by single row of large, transversely elliptical areolae, about three and one-half areolae in 10 μm at center, smaller and less elliptical toward apices. External openings of areolae covered with delicate cribrum showing pattern of irregular fine pores and connected to edge of areola by several struts. Hyaline axial area narrowly lanceolate, 1.5-2 μm wide at center, tapering toward ends. Lateral areolae not aligned across axial area. Single round areola pierces mantle in alignment with each large areola on face of valve. Pseudocellus reduced to one or two small apical pores. Single internal labiate process at each end of valve.

Discussion.—This taxon is here retained in the genus *Rhaphoneis* although its affinities are somewhat uncertain. It is a distinctive marker diatom for East Coast Miocene rocks.

Known geologic range.—Restricted to the lower part of Bed 3A of the Calvert Formation as exposed near Dunkirk, Md., and therefore to the older part of East Coast Diatom Zone 1 (middle Burdigalian Stage of early Miocene age). This is a distinctive marker diatom, and it is frequent to common within its stratigraphic range.

Rhaphoneis fusiformis Andrews

Plate 4, figures 7-10

Rhaphoneis fusiformis Andrews, 1978, p. 386, pl. 3, figs. 14-16; Andrews, 1987, p. 10, pl. 2, figs. 1- 4.

Description.—Valve lanceolate, with smoothly rounded lateral margins. Apices protracted, narrowly rounded to bluntly pointed, somewhat asymmetrical and many slightly bent in relation to longitudinal axis. Length of observed specimens 32-65 μm, width about 11-15 μm. Transverse rows composed of a few relatively large areolae, about five or six rows in 10 μm. Hyaline axial area varies from narrow to about one-third the width of valve, and transverse rows of areolae not aligned across it. Apical fine structures not observed.

Discussion.— *Rhaphoneis fusiformis* shows a superficial resemblance to *R. gemmifera,* but it is distinctly more narrowly lanceolate and asymmetric than that species. The specimens designated *R. fusiformis* by Andrews and Abbott (1985, p. 83, pl. 9, figs. 11-13; pl. 13, fig. 5) appear to be consistently clavate and are probably an as yet unnamed species of *Sceptroneis.*

Known geologic range.—From the upper part of Bed 3B to about the middle of Bed 11 of the Calvert Formation in Maryland, and therefore in East Coast Diatom Zones 2 and 3-4 (upper part of Burdigalian Stage of late early Miocene age to Langhian Stage of early middle Miocene age). Its distinctive morphology and common occurrence make this species a useful marker diatom.

Rhaphoneis gemmifera Ehrenberg

Plate 4, figures 11-14; plate 7, figures 4, 5

Rhaphoneis gemmifera Ehrenberg, 1844, p. 87; Grunow *in* Van Heurck, 1881, pl. 36, fig. 31; Pantocsek, 1886, pt. 1, p. 34, pl. 12, fig. 104; Boyer, 1904, p. 488, 489, pl. 135, fig. 11; Lohman, 1948, p. 181, pl. 11, fig. 1; Andrews, 1975, p. 208-210, pl. 2, figs. 28, 29; Andrews, 1978, p. 387, pl. 3, figs. 17-19; pl. 6, figs. 3-5; pl. 7, fig. 8; Abbott and Andrews, 1979, p. 250, pl. 5, fig. 14.

Description.—Valve rhombic-lanceolate, with broadly rounded lateral margins and produced, sharply rounded apices. Length of observed specimens 28-95 μm, width about 15-20 μm. Transverse rows of relatively large areolae, about five rows in 10 μm. Rows of areolae slightly radiate, and areolae show secondary orientation in slightly curved longitudinal rows. Hyaline axial area narrowly lanceolate, about 2 μm at center and decreasing in width toward apices. Transverse rows of areolae not aligned across axial area. Each end of valve contains a single centrally located labiate process, and fine pores of pseudocellus radiate from it toward apical margin of valve.

Discussion.—*Rhaphoneis gemmifera* is here strictly interpreted following Andrews (1978). Although *R. gemmifera* has long been confused with *R. amphiceros* and made a variety of the latter species by some authors, it appears to be a distinct species and not closely related to *R. amphiceros*. In the past, *R. gemmifera* may also have been confused with *R. margaritata* and *R. magnapunctata* on the basis of general outline, but both of these species are usually larger and more coarsely areolate. *R. gemmifera* appears to be most closely related to *R. elegans*, but it can be readily differentiated because of the much longer protracted apices of that species.

Known geologic range.—From near the base of Bed 14 of the Calvert Formation to about the middle of Bed 19 of the Choptank Formation in Maryland, and therefore from near the base of East Coast Diatom Zone 5 to near the top of Zone 6 (Serravallian Stage of middle Miocene age). *R. gemmifera* is a distinctive species that is common throughout its stratigraphic range. Further study suggests that the species ranges below the mid-Bed 15 level as reported by Andrews (1978).

Rhaphoneis lancettula Grunow

Plate 4, figures 15-17; plate 7, figures 6, 7

Rhaphoneis lancettula Grunow *in* Pantocsek, 1886, pt. 1, p. 35, pl. 27, fig. 271; Andrews, 1975, p. 214, pl. 3, figs. 39, 40; Andrews, 1976, p. 21, pl. 7, figs. 4, 5; Andrews, 1978, p. 387, pl. 3, figs. 20, 21; pl. 7, fig. 4; Andrews, 1986, p. 529, fig. 8.7.

Description.—Valve narrow, lanceolate, with lateral margins tapering gently toward apices, then becoming nearly parallel to attenuate valve in apical direction. Apices rounded, slightly capitate in some specimens.

Length of observed specimens 41-114 μm, width 7-10 μm. Five or six areolae in 10 μm, arranged in parallel transverse and longitudinal rows to form quadrate pattern of ornamentation. Axial area obscure, identified only as central hyaline space between longitudinal rows of areolae and not noticeably wider than spaces between other longitudinal rows of areolae. Apical structures rarely preserved, but presumably similar to other species of *Rhaphoneis*.

Discussion.—*Rhaphoneis lancettula* shows obvious affinities to *R. parilis* and *R. clavata*, and some individuals may be difficult to distinguish from those species. *R. parilis*, however, is usually more distinctly lanceolate and less elongate than *R. lancettula*. *R. parilis* also shows a distinct, though narrow, hyaline axial area. *R. clavata* is perhaps even more similar in morphology to *R. lancettula*, but it can be distinguished because of its clavate outline.

Known geologic range.—From the top of Bed 14 of the Calvert Formation through Bed 19 of the Choptank Formation in Maryland, and therefore from the top of East Coast Diatom Zone 5 through Zone 7 (Serravallian Stage of middle Miocene age). *R. lancettula* is a distinctive marker diatom, but its occurrence is perhaps facies related, for it is not dependably consistent.

Rhaphoneis magnapunctata Andrews

Plate 3, figures 1-4; plate 7, figures 8, 9

Rhaphoneis magnapunctata Andrews, 1978, p. 387, 388, pl. 4, figs. 1-4; pl. 7, fig. 2; Andrews and Abbott, 1985, p. 83, pl. 9, figs. 14-16; pl. 13, fig. 7.

Description.—Valve large, variable in outline from subrhomboidal to narrowly lanceolate with protracted attenuate apices. Ends of valve very narrowly rounded. Length of observed specimens about 50-150 μm, but fragments of much larger specimens have been observed; width about 12-34 μm and possibly greater. Three or four transverse rows of areolae in 10 μm, parallel, composed of very large areolae with secondary arrangement in slightly wavy longitudinal rows. Although areola spacing usually remains constant throughout valve, in some larger specimens areolae increase in size near attenuate apices. Some valves slightly longitudinally asymmetrical and a bit bent near apices. Hyaline axial area very narrow and practically obliterated by coarse areolae near apices. Transverse rows of areolae not aligned across axial area. Single internal labiate process and pseudocellus consisting of small fine pore field at each tip of valve.

Discussion.—*Rhaphoneis magnapunctata* shows the coarsest areolation of any *Rhaphoneis* observed in East Coast Miocene rocks. Although areola spacing is similar to that of *R. margaritata*, the areolae of *R. magnapunctata* are discernibly larger, and they increase in size toward the apices of the valve. The large areolae apparently weaken the valve structure so that the largest specimens are preserved only as fragments. *R. magnapunctata* shows affinities to *R. adamantea*, though the latter species is smaller and distinctly more rhomboid in outline. The narrower specimens of *R. magnapunctata* may be difficult to differentiate from some of the more robust forms of *Sceptroneis*, but whole specimens of *Sceptroneis* show a distinctly clavate outline.

Known geologic range.—From Bed 10 through Bed 13 of the Calvert Formation in Maryland, and therefore throughout East Coast Diatom Zone 3-4 (upper part of Langhian Stage to basal part of Serravallian Stage of early middle Miocene age). *R. magnapunctata* is an excellent marker diatom because of its large size and large pores. The valves are commonly found broken, which is suggestive of structural weakness.

Rhaphoneis margaritata Andrews

Plate 3, figures 5-9; plate 7, figure 10

Rhaphoneis margaritata Andrews, 1978, p. 388, pl. 4, figs. 5-9; pl. 7, fig. 1; Andrews, 1987, p. 10, 11, pl. 2, figs. 5-12; pl. 3, fig. 10.

Description.—Valve variable in size and shape, smaller specimens subrhomboidal with somewhat produced apices, larger specimens lanceolate with protracted attenuate apices. Ends narrowly rounded. Length of observed specimens 40-156 μm, width about 25-30 μm. Three and one-half to four and one-half transverse rows of areolae in 10 μm, parallel in larger specimens to slightly radiate in smaller specimens. Rows of areolae show secondary arrangement in straight longitudinal lines. Hyaline axial area very narrow to almost indiscernible near apices. Transverse rows of areolae not aligned across axial area. Single internal labiate process near apices. Apical pseudocellus well developed, with fine pores radiating toward end of valve.

Discussion.—*Rhaphoneis margaritata* is a large and coarsely areolate form showing general affinities in outline and morphology to *R. magnapunctata*. It can be differentiated from the latter species because it is generally more symmetrical and better ordered. Although the spacing of the areolae of these two species is similar, the actual areolae of *R. magnapunctata* are noticeably larger than those of *R. margaritata*, and they commonly increase in size toward the apices. Care must be exercized in differentiating this species from the larger and more robust species of *Sceptroneis*, which are more or less distinctly clavate in outline.

Known geologic range.—From the upper part of Bed 3A of the Calvert Formation into the Bed 4-9 interval in Maryland, and therefore from near the top of East Coast Diatom Zone 1 through most of Zone 2 (upper Burdigalian to middle Langhian Stage of late early to early middle Miocene age). Although this species is seldom abundant, it is relatively consistent in morphology and occurrence.

Rhaphoneis parilis Hanna

Plate 4, figures 18, 19

Rhaphoneis parilis Hanna, 1932, p. 214, pl. 16, figs. 2-4; Lohman, 1948, p. 182, pl. 11, fig. 10; Andrews, 1975, p. 214, 215, pl. 3, figs. 41-44; Andrews, 1978, p. 388, pl. 3, figs. 22, 23; pl. 7, fig. 3; Andrews and Abbott, 1985, p. 83, pl. 9, figs. 17-19; pl. 13, fig. 6.

Description.—Valve narrowly lanceolate, long and slender, tapering to protracted apices and with very obtusely rounded lateral margins. Ends of valve very narrowly rounded. Length of observed specimens 39-60 μm, width about 8-11 μm. Transverse rows of areolae parallel, six or seven rows in 10 μm, straight, composed of rows of evenly spaced, small but distinct areolae. Areolae arranged secondarily in straight longitudinal rows with both transverse and longitudinal spacing about equal, so that valve shows distinctly near-quadrate areolate pattern. Hyaline axial area very narrow, but distinct. Transverse rows of areolae aligned across axial area. Apical areas show pseudocelli composed of fine pores and single internal labiate process near each end.

Discussion.—*Rhaphoneis parilis* is relatively broader at the center, more distinctly lanceolate, lacks capitate apices and shows a narrow but discernible hyaline axial area, all features that distinguish it from *R. lancettula*. These features plus lack of a clavate outline distinguish *R. parilis* from *R. clavata*. The near-quadrate spacing of the areolae on the valve face distinguishes *R. parilis* from the younger species, *R. fusus* and *R. fatula*, in which the transverse rows of areolae are distinctly more widely spaced than are the longitudinal rows.

Known geologic range.—From Bed 11 to about the middle of Bed 15 of the Calvert Formation in Maryland, and therefore from East Coast Diatom Zone 3-4 to the lower part of Zone 6 (upper part of Langhian Stage into lower part of Serravallian Stage of early middle Miocene age). This is apparently a facies-related diatom, for it is not at all consistent in occurrence. Also, the somewhat delicate valves may not always be well preserved.

Rhaphoneis rhombica (Grunow) Andrews

Plate 4, figures 25-27; plate 8, figure 1

Rhaphoneis amphiceros var. *rhombica*, Grunow *in* Van Heurck, 1881, pl. 36, figs. 20, 21.

Rhaphoneis rhombica (Grunow) Andrews, 1975, p. 210, 211, pl. 2, figs. 33, 34; Andrews, 1978, p. 388, 389, pl. 3, figs. 30, 31; Abbott and Andrews, 1979, p. 251, pl. 5, fig. 22; Andrews, 1980, p. 34, pl. 3, fig. 9; Andrews, 1986, p. 530, figs. 8.5, 11.7.

Rhaphoneis rhombus Ehrenberg, 1844, p. 87 (part); Ehrenberg, 1854, pl. 18, figs. 84, 85.

Rhaphoneis obesula Hanna, 1932, p. 214, pl. 16, fig. 1.

Description.—Valve suborbicular, with broadly rounded lateral margins and stubby, obtusely rounded apices. Length of observed specimens 21-37 μm, width about 16-18 μm. Transverse rows of areolae, about eight rows in 10 μm, formed of rows of fine areolae with pronounced radial curvature toward lateral margins. Hyaline axial area narrow, tapering toward apices. Transverse rows of areolae not aligned across axial area. Apical structures similar to *R. amphiceros.*

Discussion.—*Rhaphoneis rhombica* has been considered in the past to be a variety of *R. amphiceros* in modern diatom assemblages (Andrews, 1975). It was separated in an effort to identify morphologic forms previously lumped as "*R. amphiceros*" and in the hope that this form might have differential stratigraphic value. The author retains it as a separate species in this report pending further investigation. Although similar to *R. amphiceros* in most respects, it can be identified by its rotund outline.

Known geologic range.—Coincident with *R. amphiceros*, from the lower middle part of Bed 15 of the Calvert Formation in Maryland, and throughout the overlying Choptank Formation and continuing to modern marine environments, and therefore through East Coast Diatom Zones 6 and 7 (Serravallian Stage of middle Miocene to Holocene age).

Rhaphoneis scalaris Ehrenberg

Plate 4, figures 20, 21; plate 8, figure 2

Rhaphoneis scalaris Ehrenberg, 1845, p. 271; Grunow *in* Van Heurck, 1881, pl. 36, fig. 32; Wolle, 1894, pl. 37, fig. 16; Lohman, 1948, p. 183, pl. 11, fig. 3; Andrews, 1975, p. 216, pl. 3, figs. 49, 50; pl. 5, figs. 64, 65; Andrews, 1978, p. 389, pl. 4, figs. 10, 11; pl. 7, fig. 6; Andrews, 1987, p. 11, pl. 2, figs. 20-23; pl. 3, fig. 9.

Description.—Valve narrowly lanceolate, with protracted apices. Length of observed specimens 50-119 μm, width about 9-14 μm. Four to four and one-half transverse rows of areolae in 10 μm, composed of areolae irregularly sized in transverse dimension. Transverse rows of areolae separated by strong siliceous transverse ribs, but areolae themselves separated by thinner longitudinal septa located near outer surface of valve. Hyaline axial area narrow, but distinct, tapering slightly toward apices. Transverse rows of areolae not aligned across axial area. Small apical pseudocellus of fine pores on each end of valve, but is poorly preserved in most specimens. Apical processes not known.

Discussion.— *Rhaphoneis scalaris* is a distinctive species characterized by its delicate lanceolate shape and its peculiar elongate and irregular areolae. Its relationship to other species of *Rhaphoneis* is undetermined.

Known geologic range.—From the base of Bed 3B to the upper part of the Bed 4-9 interval of the Calvert

Formation in Maryland, and therefore restricted to East Coast Diatom Zone 2 (upper Burdigalian Stage of late early Miocene age to Langhian Stage of early middle Miocene age). *R. scalaris* is usually scarce, but it is consistent in occurrence throughout its range.

Rhaphoneis scutula Andrews

Plate 4, figures 22-24; plate 8, figure 3

Rhaphoneis scutula Andrews, 1978, p. 389, pl. 3, figs. 27-29; pl. 7, fig. 7; Andrews, 1986, p. 530, figs. 8.6, 11.6.

Description.—Valve rhombic or lozenge-shaped, with rounded obtuse lateral margins and produced, sharply rounded apices. Length of observed specimens 40-65 µm, width about 18-22 µm. Surface of valve covered with radiate transverse rows of areolae, distinctively curved in relatively wide specimens. About seven or eight transverse rows of areolae in 10 µm, with areolae showing secondary orientation in nearly straight longitudinal rows, giving a warped quadrate ornamentation to valve as a whole. Hyaline axial area narrow, and transverse rows of areolae not aligned across it. Single interior labiate process in each end of valve and apical pseudocellus of fine pores.

Discussion.—*Rhaphoneis scutula* shows close affinities to *R. amphiceros* but can be readily separated by its more angular lateral margins and its more lozenge shaped outline. This distinctive outline does not seem to be present in modern populations of *R. amphiceros* sensu lato, and hence this species appears to be useful as a guide fossil for East Coast Miocene rocks.

Known geologic range.—From the lower middle part of Bed 15 of the Calvert Formation through Bed 19 of the Choptank Formation of Maryland, and therefore in East Coast Diatom Zones 6 and 7 (Serravallian Stage of middle Miocene age). Although this species is seldom abundant, occurrence is generally consistent throughout its stratigraphic range.

Rhaphoneis wicomicoensis Lohman

Plate 4, figure 28

Rhaphoneis wicomicoensis Lohman, 1948, p. 183, pl. 11, fig. 9; Andrews, 1975, p. 216, 217, pl. 3, fig. 51; Andrews, 1978, p. 389, pl. 4, fig. 12.

Description.—Valve lanceolate, with protracted apices. Length of observed specimens about 40 µm, width about 8 µm. Single row of marginal areolae on edge of valve face. These marginal areolae are small and round near ends of valve, larger, transversely elongated, and about four and one-half areolae in 10 µm at center of valve. Hyaline axial area about one-third the width of valve, narrowing toward apices. Alignment of pairs of marginal areolae across axial area uncertain. Apical fine structures not known.

Discussion.—Although *Rhaphoneis wicomicoensis* is a morphologically distinctive species, it may have affinities to *R. scalaris.*

Known geologic range.—In the Bed 4-9 interval of the Calvert Formation of Maryland, and therefore in East Coast Diatom Zone 2 (Langhian Stage of early middle Miocene age). It is rare in East Coast Miocene deposits, and its total range is not known with certainty.

Genus SCEPTRONEIS Ehrenberg, 1844

Sceptroneis caduceus Ehrenberg

Plate 4, figures 29-32; plate 8, figures 4, 5

Sceptroneis caduceus Ehrenberg, 1845, p. 271; Ehrenberg, 1854, pl. 33, pt. 17, fig. 15; Van Heurck, 1881, pl. 37, fig. 5; Wolle, 1894, pl. 37, fig. 13; Boyer, 1904, p. 489, pl. 135, fig. 12; Hustedt, 1931, p. 130, fig. 651; Lohman, 1948, p. 183, 184, pl. 11, fig. 7; Andrews, 1978, p. 396, 398, pl. 5, figs. 18-20; pl. 8, figs. 9, 10; Andrews, 1987, p. 11, 12, pl. 3, figs. 1-5.

Description.—Valve slender, elongate, clavate, with a larger broadly rounded capitate head-pole and a smaller sharply rounded foot-pole. Most specimens show slight lateral swelling near center of valve. Many specimens slightly curved and others somewhat twisted around longitudinal axis. Species highly variable in size and shape and cannot be considered well ordered. Length of observed specimens 57-269 µm, width about 8-10 µm. Fragments of large specimens suggest that maximum length is undoubtedly greater. About five transverse rows of fine areolae in 10 µm, orientation parallel. Rows of areolae not evenly spaced, and areolae not evenly spaced along row. Hyaline axial area slightly irregular and narrow, but discernible. Transverse rows of areolae not aligned across axial area. Each end shows single centrally situated internal labiate process, forming focal point of fine pores of pseudocellus radiating to tip of valve. Apical fine structures large enough to be visible under light microscope in head-poles of some specimens.

Discussion.—*Sceptroneis caduceus* is again restricted to the more delicate forms following Andrews (1978). More heavily silicified forms are assigned to *S. grandis* and *S. hungarica.* The taxon figured by Schrader and Fenner (1976, pl. 4, figs. 11-16) as "*Sceptroneis* aff. *caducea* Ehrenberg" appears to be less clavate and more coarsely areolate than the species observed in East Coast deposits.

Known geologic range.—Throughout Beds 3A and 3B to the upper part of the Bed 4-9 interval of the Calvert Formation in Maryland, and therefore in East Coast Diatom Zone 1 and nearly all of Zone 2 (middle Burdigalian Stage of late early Miocene age to Langhian Stage of early middle Miocene age). The first occurrence of *S. caduceus* may well be lower in the Burdigalian

Stage than can be determined from this study. The species is distinctive in morphology, often abundant, and usually consistent in occurrence. It is an important marker diatom.

Sceptroneis grandis Abbott

Plate 4, figures 33, 34

Sceptroneis grandis Abbott *in* Abbott and Ernissee, 1983, p. 302, 303, pl. 11, fig. 7; pl. 12, fig. 1; Andrews, 1987, p. 12, pl. 3, figs. 6, 7.
Sceptroneis caduceus Hanna, 1932 (not Ehrenberg, 1845), p. 216, 217, pl. 16, figs. 5-7.

Description.—Valve heavily silicified, clavate, lanceolate, with a bluntly rounded head-pole and a more narrowly rounded foot-pole. Reported length 114-200 μm, width about 15-17 μm. About three and one-half short and parallel rows of areolae in 10 μm, areolae relatively large and well defined. Transverse rows of areolae not aligned across axial area. Hyaline axial area very narrow to distinguishable only by misalignment of areolae on either side. Both ends show a pseudocellus of fine pores in rows radiating toward tip of valve. Focal point of fine pores of pseudocellus probably a single labiate process, but structure not readily discernible under light microscope.

Discussion.—*Sceptroneis grandis* is readily distinguishable from *S. caduceus* because of its distinctly heavier silicification and coarser areolation. Because of possible differential stratigraphic value, the author prefers to identify shorter, heavily silicified forms of *Sceptroneis* as *S. hungarica*.

Known geologic range.—From the upper part of the Bed 4-9 interval of the Calvert Formation in Maryland, and therefore from the upper part of East Coast Diatom Zone 2 (Langhian Stage of early middle Miocene age). The range of this species seems to succeed that of *S. caduceus*, and in no instance has the author seen both *S. caduceus* and *S. grandis* in the same assemblage. The morphology of *S. grandis* is distinctive and its occurrence is relatively consistent, but its abundance is highly variable. It is a useful marker diatom, but distribution may be somewhat ecologically controlled.

Sceptroneis hungarica (Pantocsek) Andrews

Plate 4, figures 35, 36

Rhaphoneis hungarica Pantocsek, 1886, pt. 1, p. 34, pl. 3, fig. 30; pl. 25, fig. 224.
Sceptroneis hungarica (Pantocsek) Andrews, 1978, p. 398, 400, pl. 5, figs. 21, 22.

Description.—Valve lanceolate, with slight longitudinal asymmetry and ends slightly produced. Head-pole bluntly rounded and foot-pole somewhat more narrowly rounded. Length of observed specimens 48-85 μm, width about 15-18 μm. Three to three and one-half transverse rows of areolae in 10 μm; areolae large, round, and closely packed. Transverse rows of areolae parallel in center to slightly radiate near apices, and areolae show secondary arrangement in longitudinal rows. Axial area very narrow, discernible only as line dividing nonaligned striae on either side of valve. Pseudocellus evident on head-pole of some specimens, but other apical structures have not been observed.

Discussion.—The relatively short, heavily silicified forms of *Sceptroneis* are here assigned to *S. hungarica*. The relationship of the morphologic species *S. hungarica* and *S. grandis* is deserving of further investigation.

Known geologic range.—Same as for *S. grandis*, that is, the upper part of East Coast Diatom Zone 2. The morphologic forms here assigned to *S. hungarica* are distinctive, but they are relatively rare and inconsistent in occurrence in their stratigraphic range.

Genus THALASSIOSIRA Cleve, 1873

Thalassiosira grunowii Akiba and Yanagisawa

Plate 1, figures 6, 7; plate 6, figure 1

Coscinodiscus plicatus Grunow *in* Schmidt and others, 1878, pl. 59, fig. 1; Grunow, 1884, p. 73, pl. 3, fig. 10; Schrader, 1973a, p. 703, pl. 6, fig. 23; Schrader, 1974, p. 913, pl. 15, figs. 21, 22; pl. 16, figs. 9-15; pl. 21, figs. 1, 2, 5-7; Andrews, 1978, p. 381, 382, pl. 1, figs. 3, 4; pl. 6, fig. 1; Abbott and Andrews, 1979, p. 239, pl. 3, fig. 7; Andrews, 1986, p. 515, figs. 5.9, 10.3, 10.4.
Thalassiosira grunowii Akiba and Yanagisawa, 1985, p. 493, pl. 27, fig. 5; pl. 29, figs. 1-86; pl. 30, figs. 1-10.

Description.—Valve round, with single straight median plication resulting in one half of valve concave and other half convex. Diameter of observed specimens 40 to 70 μm. Valve completely covered with network of areolae, uniformly spaced at about seven or eight areolae in 10 μm and containing a few intercalated fine pores. Areolae arranged in irregular radial rows and secondarily in curved decussating rows. Margin narrow, finely striate, with short but distinct spines, about three spines in 10 μm. A central area cannot be distinguished.

Discussion.—Although Schrader (1974) indicated his intent to subdivide *Thalassiosira grunowii* (*Coscinodiscus plicatus*) into six groups, this work has not yet been forthcoming. The use of *T. grunowii* for these plicate forms is here adopted following the suggestion of Akiba and Yanagisawa (1985).

Known geologic range.—From near the top of Bed 14 of the Calvert Formation of Maryland through Bed 19 of the Choptank Formation, and therefore from the uppermost part of East Coast Diatom Zone 5 through Zone 7 (Serravallian Stage of middle Miocene age). *T.*

grunowii is, however, never abundant or consistent in occurrence in shallow-water deposits of this region, and its main importance as a marker here is its more abundant occurrence in deeper marine deposits. Schrader (1973b, p. 723) reported the occurrence of *T. grunowii* from his North Pacific Diatom Zones 17 through 19. Barron (1975) reported that *T. grunowii* ranges into North Pacific Diatom Zone XI (late Miocene). Barron (1980) indicated that the last occurrence of *T. grunowii* defines his subzone a/b boundary of the late Miocene *Denticulopsis hustedtii* Zone, with a total range from about 14 Ma to 8 Ma.

Genus TRINACRIA Heiberg, 1863

Trinacria solenoceros (Ehrenberg) VanLandingham

Plate 8, figures 6-8

Triceratium solenoceros Ehrenberg, 1845, p. 273; Schmidt, *in* Schmidt and others, 1882, pl. 77, fig. 21; Schmidt, 1886, pl. 96, fig. 11.
Trinacria solenoceros (Ehrenberg) VanLandingham, 1971, pt. 4, p. 2046.
Hemiaulus solenoceros (Ehrenberg) Boyer, 1901, p. 739.

Description.—Valve triangular, with deeply concave sides and angles greatly produced into slender arms, so that valve outline is reminiscent of a three-bladed airplane propeller. Altitude of observed specimens about 88 to 123 μm. Ends of angles show a short, truncated process directed outward from face of valve, slightly deflected from normal to face of valve. Margins of valve strengthened by raised rim around perimeter. Surface of valve slightly raised in center as a circular nodule. Surface of valve covered with large areolae, about five areolae in 10 μm, with a single, somewhat irregular row paralleling raised margin of valve and parallel rows on valve arms. Similar areolae, irregular in shape and distribution, cover center of valve. Truncated and deflected processes on ends of valve show irregularly distributed pores and a crenulated margin. Single labiate process near center of interior of valve.

Discussion.—Because of its slender arms and delicate construction, *Trinacria solenoceros* is seldom found as whole specimens in East Coast Miocene rocks. However, its highly distinctive morphology makes it useful as a marker diatom, even if only fragments are observed.

Known geologic range.—From the lower part of Bed 3A of the Calvert Formation as exposed near Dunkirk, Md., and therefore from East Coast Diatom Zone 1 (middle Burdigalian Stage of early Miocene age). The species is usually rare, but it is a useful marker diatom. The first occurrence of this diatom may well be lower in the Burdigalian Stage than can be determined by this study.

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PLATES 1-8

[Contact photographs of the plates in this report are available, at cost, from U.S. Geological Survey Library, Federal Center, Denver, Colorado 80225]

PLATE 1

FIGURES 1, 2. *Actinoptychus heliopelta* Grunow (p.14).

1. USGS diatom cat. no. 4020-14A, X500, diameter 110 μm. From USGS diatom locality 6529, Bed 3A, Calvert Formation, Calvert Co., Md.
2. USGS diatom cat. no. 4020-18. X500, diameter 120 μm. From USGS diatom locality 6529, Bed 3A, Calvert Formation, Calvert Co., Md.

3. *Actinoptychus thumii* (Schmidt) Hanna (p. 15). USGS diatom cat. no. 3860-15, X1,000, diameter 42 μm. From USGS diatom locality 6110, Bed 14, Calvert Formation, St. Marys Co., Md.

4. *Actinoptychus marylandicus* Andrews (p. 14). USGS diatom cat. no. 3797-6, X1,000, diameter about 74 μm. From USGS diatom locality 6159, Bed 19, Choptank Formation, Calvert Co., Md.

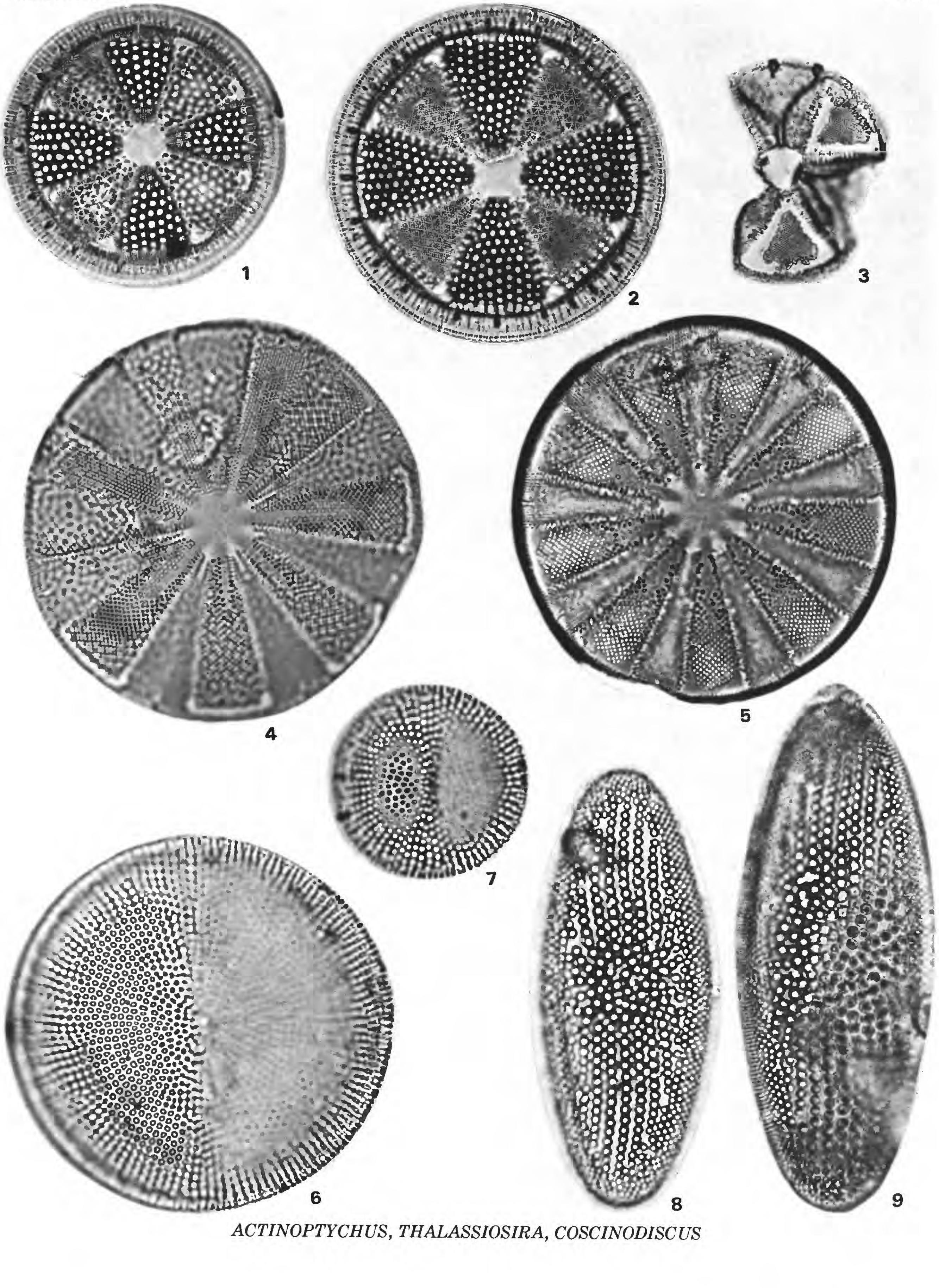
5. *Actinoptychus virginicus* (Grunow) Andrews (p. 15). USGS diatom cat. no. 3988-12, X1,000, diameter 72 μm. From USGS diatom locality 6499, Coosawhatchie Clay Member of the Hawthorn Formation, Berrys Landing, Effingham Co., Ga.

6, 7. *Thalassiosira grunowii* Akiba and Yanagisawa (p. 26).

6. USGS diatom cat. no. 3791-13, X1,000, diameter 70 μm. From USGS diatom locality 6153, Bed 17, Choptank Formation, Calvert Co., Md.
7. USGS diatom cat. no. 3865-24, X1,000, diameter 35 μm. From USGS diatom locality 6123, Bed 14, Calvert Formation, Calvert Co., Md.

8, 9. *Coscinodiscus lewisianus* Greville (p. 16).

8. USGS diatom cat. no. 4027-13, X1,000, length 82 μm. From USGS diatom locality 6536, Bed 4, Calvert Formation, Calvert Co., Md.
9. USGS diatom cat. no. 4027-14, X1,000, length 95 μm. From USGS diatom locality 6536, Bed 4, Calvert Formation, Calvert Co., Md.



ACTINOPTYCHUS, THALASSIOSIRA, COSCINODISCUS

PLATE 2

[All photographs ×1,000]

FIGURES 1, 2. *Delphineis angustata* (Pantocsek) Andrews (p. 17).
- 1. USGS diatom cat. no. 3865-1, length 81 μm. From USGS diatom locality 6123, Bed 14, Calvert Formation, Calvert Co., Md.
- 2. USGS diatom cat. no. 3866-28, length 70 μm. From USGS diatom locality 6124, Bed 15, Calvert Formation, Calvert Co., Md.

3-5. *Delphineis biseriata* (Grunow) Andrews (p. 17).
- 3. USGS diatom cat. no. 3850-15, length 40 μm. From USGS diatom locality 6220, Bed 18, Choptank Formation, Calvert Co., Md.
- 4. USGS diatom cat. no. 3792-16, length 44 μm. From USGS diatom locality 6154, Bed 18, Choptank Formation, Calvert Co., Md.
- 5. USGS diatom cat. no. 3792-24, length 49 μm. From USGS diatom locality 6154, Bed 18, Choptank Formation, Calvert Co., Md.

6-8. *Delphineis lineata* Andrews (p. 18).
- 6. USGS diatom cat. no. 4027-17, length 40 μm. From USGS diatom locality 6535, Bed 4, Calvert Formation, Calvert Co., Md.
- 7. USGS diatom cat. no. 3816-12, length 43 μm. From USGS diatom locality 6184, Bed 3B, Calvert Formation, Calvert Co., Md.
- 8. USGS diatom cat. no. 4029-11, length 50 μm. From USGS diatom locality 6538, Bed 5, Calvert Formation, Calvert Co., Md.

9-12. *Delphineis novaecaesaraea* (Kain and Schultze) Andrews (p. 18).
- 9. USGS diatom cat. no. 3866-31, length 42 μm. From USGS diatom locality 6124, Bed 15, Calvert Formation, Calvert Co., Md.
- 10. USGS diatom cat. no. 3865-22, length 61 μm. From USGS diatom locality 6123, Bed 14, Calvert Formation, Calvert Co., Md.
- 11. USGS diatom cat. no. 3865-10, length 68 μm. From USGS diatom locality 6123, Bed 14, Calvert Formation, Calvert Co., Md.
- 12. USGS diatom cat. no. 3845-16, length 87 μm. From USGS diatom locality 6214, Bed 15, Calvert Formation, Calvert Co., Md.

13-16. *Delphineis ovata* Andrews (p. 18).
- 13. USGS diatom cat. no. 4034-1, length 33 μm. From USGS diatom locality 6543, Bed 7, Calvert Formation, Calvert Co., Md.
- 14. USGS diatom cat. no. 4031-5, length 39 μm. From USGS diatom locality 6540, Bed 6, Calvert Formation, Calvert Co., Md.
- 15. USGS diatom cat. no. 4025-5, length 42 μm. From USGS diatom locality 6534, Bed 3B, Calvert Formation, Calvert Co., Md.
- 16. USGS diatom cat. no. 4031-9, length 80 μm. From USGS diatom locality 6540, Bed 6, Calvert Formation, Calvert Co., Md.

17-20. *Delphineis penelliptica* Andrews (p. 19).
- 17. USGS diatom cat. no. 3860-13, length 28 μm. From USGS diatom locality 6110, Bed 14, Calvert Formation, St. Marys Co., Md.
- 18. USGS diatom cat. no. 3869-11, length 40 μm. From USGS diatom locality 6129, Bed 13, Calvert Formation, Calvert Co., Md.
- 19. USGS diatom cat. no. 3869-4, length 48 μm. From USGS diatom locality 6129, Bed 13, Calvert Formation, Calvert Co., Md.
- 20. USGS diatom cat. no. 3860-14, length 63 μm. From USGS diatom locality 6110, Bed 14, Calvert Formation, St. Marys Co., Md.

21-24. *Denticulopsis hustedtii* (Simonsen and Kanaya) Simonsen (p. 19).
- 21. USGS diatom cat. no., 3866-7, length 32 μm. From USGS diatom locality 6124, Bed 15, Calvert Formation, Calvert Co., Md.
- 22. USGS diatom cat. no. 3791-8, length 36 μm. From USGS diatom locality 6153, Bed 17, Choptank Formation, Calvert Co., Md.
- 23. USGS diatom cat. no. 3851-8, length 37 μm. From USGS diatom locality 6221, Bed 18, Choptank Formation, Calvert Co., Md.
- 24. USGS diatom cat. no. 3850-9, length 38 μm. From USGS diatom locality 6220, Bed 18, Choptank Formation, Calvert Co., Md.

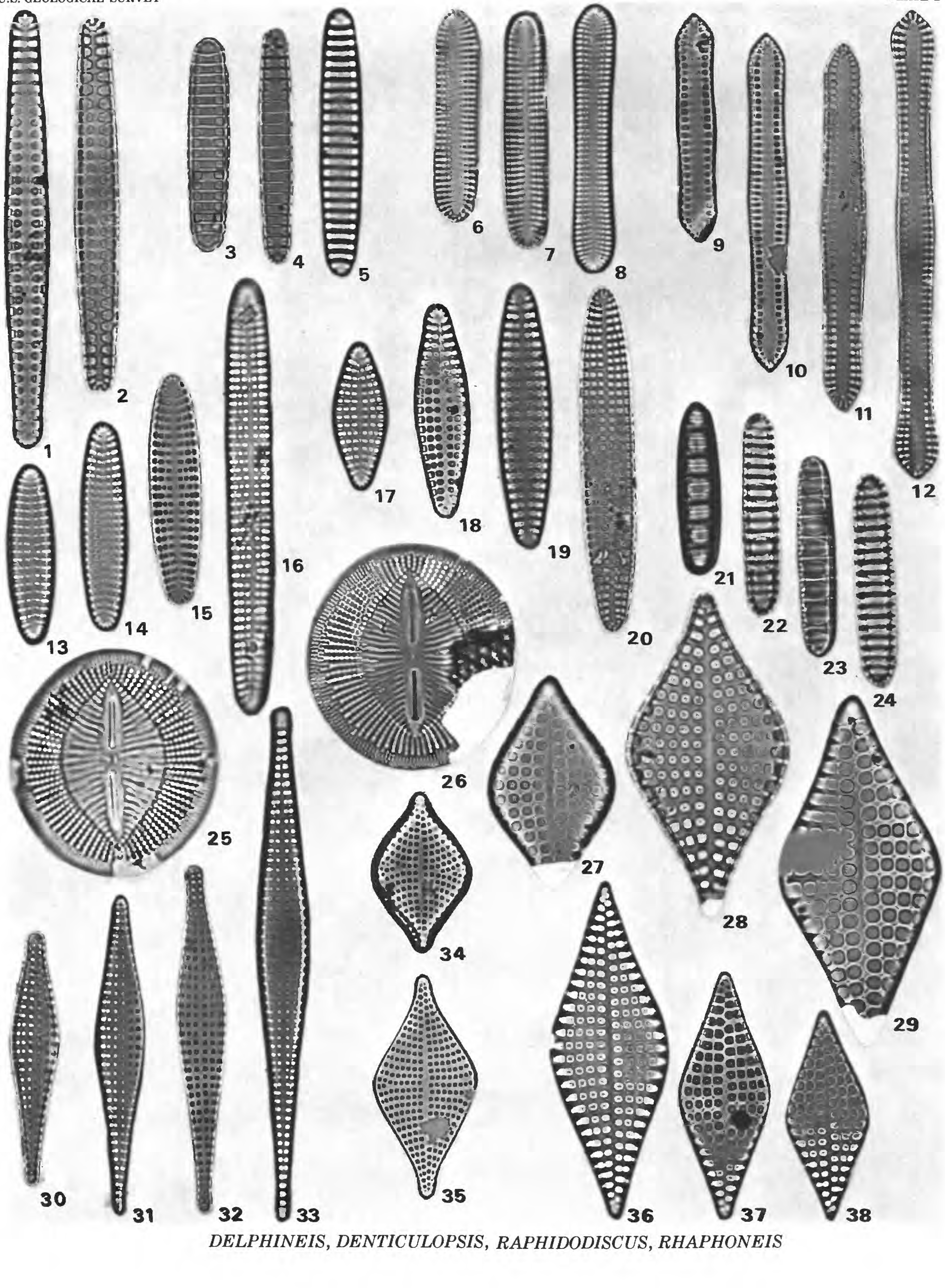
25, 26. *Raphidodiscus marylandicus* Christian (p. 19).
- 25. USGS diatom cat. no. 3827-8, length 41 μm. From USGS diatom locality 6195, Bed 3B, Calvert Formation, Calvert Co., Md.
- 26. USGS diatom cat. no. 3827-5, length 41 μm. From USGS diatom locality 6195, Bed 3B, Calvert Formation, Calvert Co., Md.

27-29. *Rhaphoneis adamantea* Andrews (p. 20).
- 27. USGS diatom cat. no. 3837-1, length about 42 μm. From USGS diatom locality 6206, Bed 11, Calvert Formation, Calvert Co., Md.
- 28. USGS diatom cat. no. 3837-7, length about 62 μm. From USGS diatom locality 6206, Bed 11, Calvert Formation, Calvert Co., Md.
- 29. USGS diatom cat. no. 3868-5, length about 64 μm. From USGS diatom locality 6128, Bed 11, Calvert Formation, Calvert Co., Md.

30-33. *Rhaphoneis clavata* Andrews (p. 21).
- 30. USGS diatom cat. no. 3866-22, length 48 μm. From USGS diatom locality 6124, Bed 15, Calvert Formation, Calvert Co., Md.
- 31. USGS diatom cat. no. 3866-2, length 60 μm. From USGS diatom locality 6124, Bed 15, Calvert Formation, Calvert Co., Md.
- 32. USGS diatom cat. no. 3866-16, length 65 μm. From USGS diatom locality 6124, Bed 15, Calvert Formation, Calvert Co., Md.
- 33. USGS diatom cat. no. 3866-6, length 95 μm. From USGS diatom locality 6124, Bed 15, Calvert Formation, Calvert Co., Md.

34, 35. *Rhaphoneis amphiceros* (Ehrenberg) Ehrenberg (p. 20).
- 34. USGS diatom cat. no. 3792-13, length 30 μm. From USGS diatom locality 6154, Bed 18, Choptank Formation, Calvert Co., Md.
- 35. USGS diatom cat. no. 3792-10, length 43 μm. From USGS diatom locality 6154, Bed 18, Choptank Formation, Calvert Co., Md.

36-38. *Rhaphoneis diamantella* Andrews (p. 21).
- 36. USGS diatom cat. no. 3772-29, length 63 μm. From USGS diatom locality 6098, Bed 19, Choptank Formation, Calvert Co., Md.
- 37. USGS diatom cat. no. 3772-26, length 46 μm. From USGS diatom locality 6098, Bed 19, Choptank Formation, Calvert Co., Md.
- 38. USGS diatom cat. no. 3771-9, length 39 μm. From USGS diatom locality 6098, Bed 19, Choptank Formation, Calvert Co., Md.



DELPHINEIS, DENTICULOPSIS, RAPHIDODISCUS, RHAPHONEIS

PLATE 3

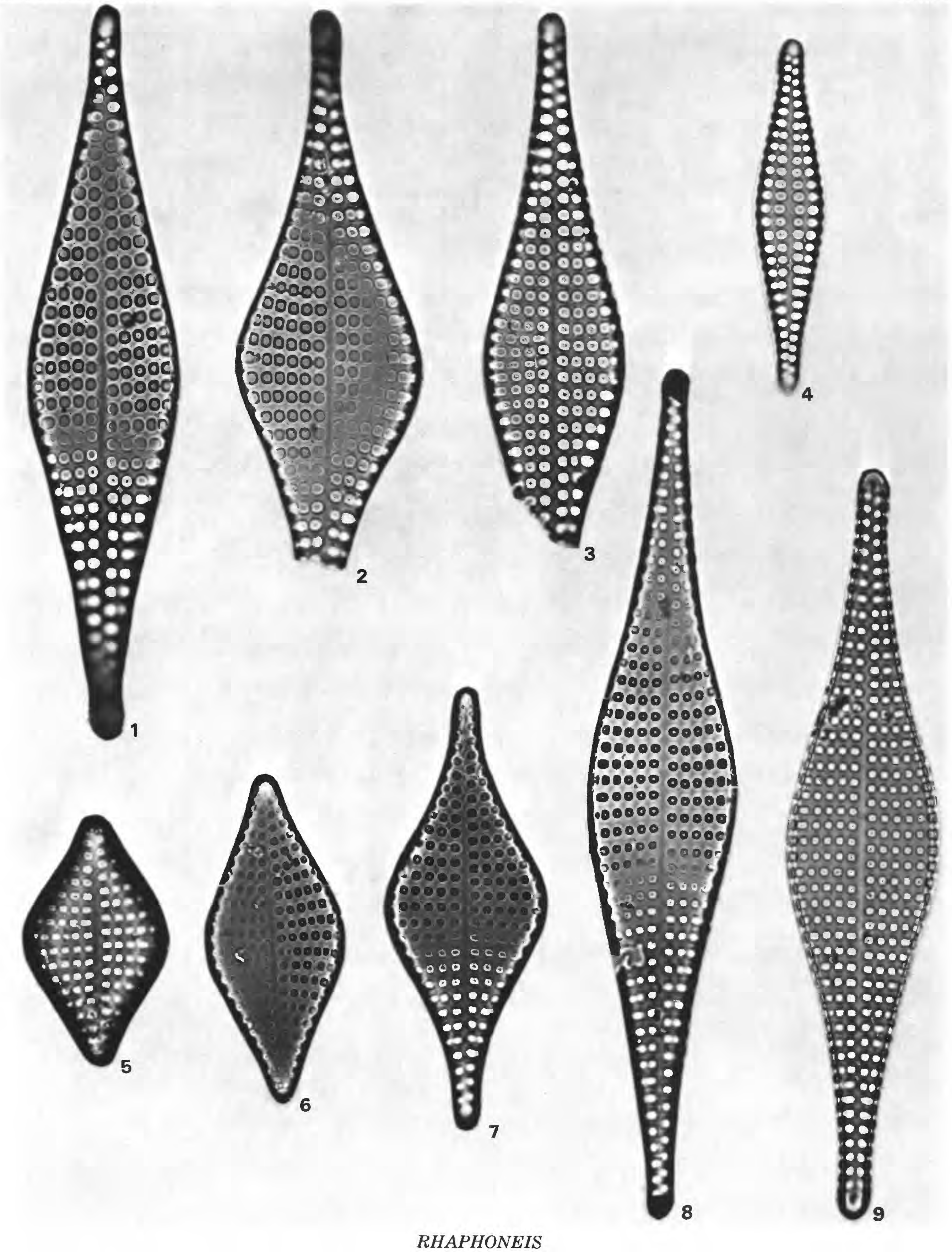
[All photographs X1,000]

FIGURES 1-4. *Rhaphoneis magnapunctata* Andrews (p. 23).

1. USGS diatom cat. no. 3868-1, length 133 μm. From USGS diatom locality 6128, Bed 12, Calvert Formation, Calvert Co., Md.
2. USGS diatom cat. no. 3867-5, length 126 μm. From USGS diatom locality 6127, Bed 11, Calvert Formation, Calvert Co., Md.
3. USGS diatom cat. no. 3869-2, length 150 μm. From USGS diatom locality 6129, Bed 13, Calvert Formation, Calvert Co., Md.
4. USGS diatom cat. no. 3836-6, length 65 μm. From USGS diatom locality 6204, Bed 10, Calvert Formation, Calvert Co., Md.

5-9. *Rhaphoneis margaritata* Andrews (p. 23).

5. USGS diatom cat. no. 4025-13, length 48 μm. From USGS diatom locality 6534, Bed 3B, Calvert Formation, Calvert Co., Md.
6. USGS diatom cat. no. 4029-12, length 61 μm. From USGS diatom locality 6538, Bed 5, Calvert Formation, Calvert Co., Md.
7. USGS diatom cat. no. 4025-12, length 82 μm. From USGS diatom locality 6534, Bed 3B, Calvert Formation, Calvert Co., Md.
8. USGS diatom cat. no. 4025-6, length 156 μm. From USGS diatom locality 6534, Bed 3B, Calvert Formation, Calvert Co., Md.
9. USGS diatom cat. no. 3831-11, length 136 μm. From USGS diatom locality 6199, Bed 3B, Calvert Formation, Calvert Co., Md.



RHAPHONEIS

PLATE 4

[Photographs ×1,000, except as indicated]

FIGURES 1-3. *Rhaphoneis elegans* (Pantocsek and Grunow) Hanna (p. 21).
1. USGS diatom cat. no. 3860-12, length 38 μm. From USGS diatom locality 6110, Bed 14, Calvert Formation, St. Marys Co., Md.
2. USGS diatom cat. no. 3860-8, length about 39 μm. From USGS diatom locality 6110, Bed 14, Calvert Formation, St. Marys Co., Md.
3. USGS diatom cat. no. 3860-11, length about 40 μm. From USGS diatom locality 6110, Bed 14, Calvert Formation, St. Marys Co., Md.

4-6. *Rhaphoneis fossile* (Grunow) Andrews (p. 21).
4. USGS diatom cat. no. 4020-7, length 32 μm. From USGS diatom locality 6429, Bed 3A, Calvert Formation, Calvert Co., Md.
5. USGS diatom cat. no. 4020-5, length 36 μm. From USGS diatom locality 6429, Bed 3A, Calvert Formation, Calvert Co., Md.
6. USGS diatom cat. no. 4020-3, length 40 μm. From USGS diatom locality 6429, Bed 3A, Calvert Formation, Calvert Co., Md.

7-10. *Rhaphoneis fusiformis* Andrews (p. 22).
7. USGS diatom cat. no. 3832-13, length 35 μm. From USGS diatom locality 6200, Bed 3B, Calvert Formation, Calvert Co., Md.
8. USGS diatom cat. no. 3831-10, length 39 μm. From USGS diatom locality 6199, Bed 3B, Calvert Formation, Calvert Co., Md.
9. USGS diatom cat. no. 3832-12, length 40 μm. From USGS diatom locality 6200, Bed 3B, Calvert Formation, Calvert Co., Md.
10. USGS diatom cat. no. 3834-2, length 51 μm. From USGS diatom locality 6202, Bed 4-9, Calvert Formation, Calvert Co., Md.

11-14. *Rhaphoneis gemmifera* Ehrenberg (p. 22).
11. USGS diatom cat. no. 3792-1, length 31 μm. From USGS diatom locality 6154, Bed 18, Choptank Formation, Calvert Co., Md.
12. USGS diatom cat. no. 3792-4, length 40 μm. From USGS diatom locality 6154, Bed 18, Choptank Formation, Calvert Co., Md.
13. USGS diatom cat. no. 3792-7, length 64 μm. From USGS diatom locality 6154, Bed 18, Choptank Formation, Calvert Co., Md.
14. USGS diatom cat. no. 3792-9, length 95 μm. From USGS diatom locality 6154, Bed 18, Choptank Formation, Calvert Co., Md.

15-17. *Rhaphoneis lancettula* Grunow (p. 22).
15. USGS diatom cat. no. 3792-2, length 40 μm. From USGS diatom locality 6154, Bed 18, Choptank Formation, Calvert Co., Md.
16. USGS diatom cat. no. 3792-3, length 58 μm. From USGS diatom locality 6154, Bed 18, Choptank Formation, Calvert Co., Md.
17. USGS diatom cat. no. 3792-11, length 93 μm. From USGS diatom locality 6154, Bed 18, Choptank Formation, Calvert Co., Md.

18, 19. *Rhaphoneis parilis* Hanna (p. 24).
18. USGS diatom cat. no. 3839-4, length 45 μm. From USGS diatom locality 6208, Bed 13, Calvert Formation, Calvert Co., Md.
19. USGS diatom cat. no. 3845-17, length 58 μm. From USGS diatom locality 6214, Bed 15, Calvert Formation, Calvert Co., Md.

20, 21. *Rhaphoneis scalaris* Ehrenberg (p. 24).
20. USGS diatom cat. no. 4027-8, length 87 μm. From USGS diatom locality 6536, Bed 4, Calvert Formation, Calvert Co., Md.
21. USGS diatom cat. no. 4034-11, length 96 μm. From USGS diatom locality 6543, Bed 7, Calvert Formation, Calvert Co., Md.

22-24. *Rhaphoneis scutula* Andrews (p. 25).
22. USGS diatom cat. no. 3792-6, length 59 μm. From USGS diatom locality 6154, Bed 18, Choptank Formation, Calvert Co., Md.
23. USGS diatom cat. no. 3792-17, length 45 μm. From USGS diatom locality 6154, Bed 18, Choptank Formation, Calvert Co., Md.
24. USGS diatom cat. no. 3866-3, length 40 μm. From USGS diatom locality 6124, Bed 15, Calvert Formation, Calvert Co., Md.

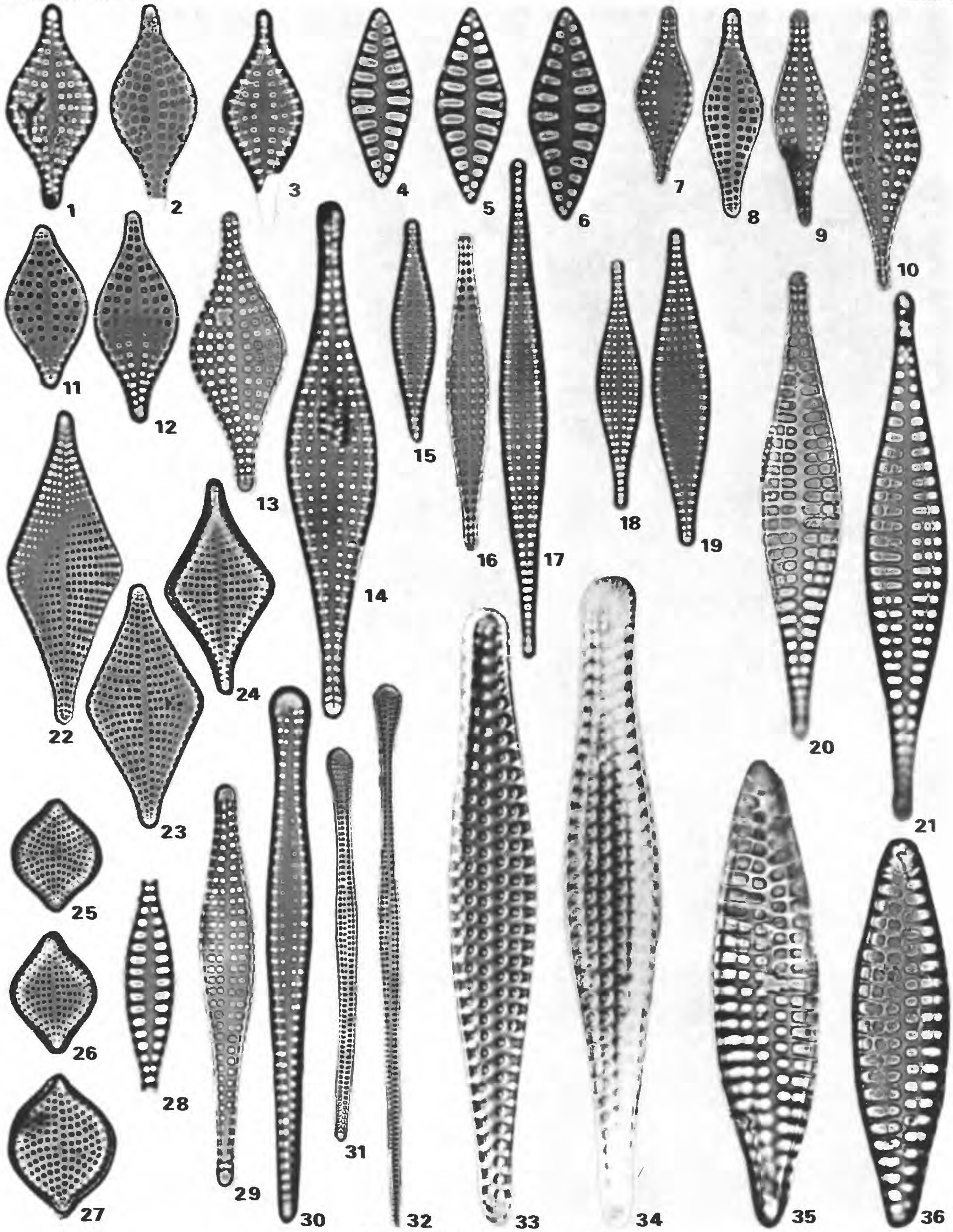
25-27. *Rhaphoneis rhombica* (Grunow) Andrews (p. 24).
25. USGS diatom cat. no. 3866-21, length 21 μm. From USGS diatom locality 6124, Bed 15, Calvert Formation, Calvert Co., Md.
26. USGS diatom cat. no. 3866-12, length 22 μm. From USGS diatom locality 6124, Bed 15, Calvert Formation, Calvert Co., Md.
27. USGS diatom cat. no. 3795-7, length 27 μm. From USGS diatom locality 6157, Bed 19, Choptank Formation, Calvert Co., Md.

28. *Rhaphoneis wicomicoensis* Lohman (p. 25). USGS diatom cat. no. 4034-6, length about 44 μm. From USGS diatom locality 6543, Bed 7, Calvert Formation, Calvert Co., Md.

29-32. *Sceptroneis caduceus* Ehrenberg (p. 25).
29. USGS diatom cat. no. 4020-9, length 75 μm. From USGS diatom locality 6529, Bed 3A, Calvert Formation, Calvert Co., Md.
30. USGS diatom cat. no. 4020-2, length 100 μm. From USGS diatom locality 6529, Bed 3A, Calvert Formation, Calvert Co., Md.
31. USGS diatom cat. no. 4020-1, ×500, length 147 μm. From USGS diatom locality 6529, Bed 3A, Calvert Formation, Calvert Co., Md.
32. USGS diatom cat. no. 4020-12, ×500, length 204 μm. From USGS diatom locality 6529, Bed 3A, Calvert Formation, Calvert Co., Md.

33, 34. *Sceptroneis grandis* Abbott (p. 26).
33. USGS diatom cat. no. 4733-3, length 114 μm. From USGS diatom locality 7291, Kirkwood Formation, Atlantic Co., N.J.
34. USGS diatom cat. no. 4734-13, length 120 μm. From USGS diatom locality 7292, Kirkwood Formation, Atlantic Co., N.J.

35, 36. *Sceptroneis hungarica* (Pantocsek) Andrews (p. 26).
35. USGS diatom cat. no. 3835-18, length 85 μm. From USGS diatom locality 6203, Bed 9-10 interval, Calvert Formation, Calvert Co., Md.
36. USGS diatom cat. no. 3834-1, length 73 μm. From USGS diatom locality 6202, Bed 4-8 interval, Calvert Formation, Calvert Co., Md.



RHAPONEIS, SCEPTRONEIS

PLATE 5

[Scanning electron microscrope photographs]

FIGURES 1, 2. *Actinoptychus heliopelta* Grunow (p. 14).

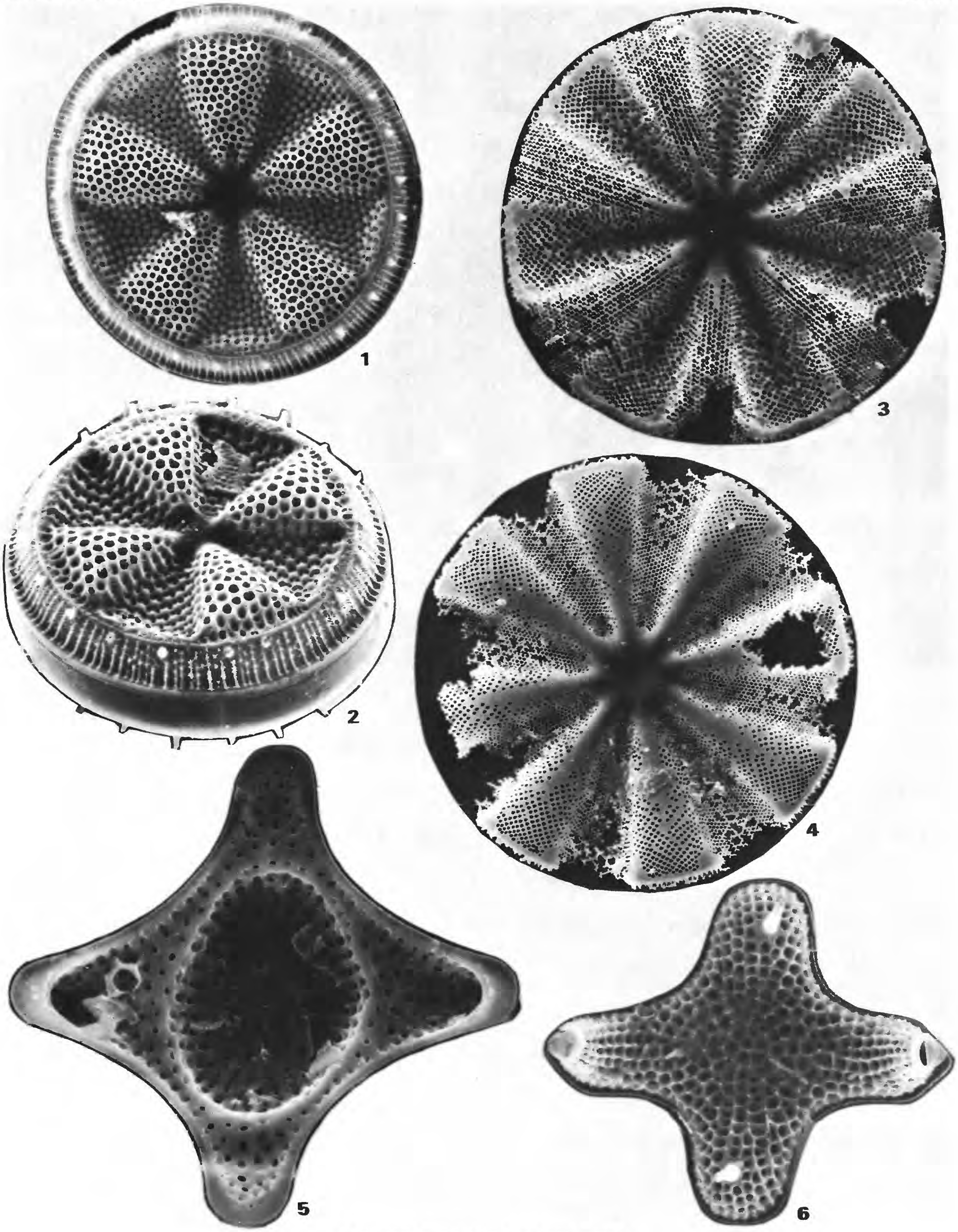
1. Outside of 10-sectored valve, X500, diameter 140 μm. From USGS diatom locality 6529, Bed 3A, Calvert Formation, Calvert Co., Md.
2. Outside of eight-sectored frustule, oblique, X600, diameter 120 μm. From USGS diatom locality 6529, Bed 3A, Calvert Formation, Calvert Co., Md.

3. *Actinoptychus marylandicus* Andrews (p. 14). Outside of 14-sectored valve, X1,225, diameter 67 μm. From USGS diatom locality 6098, Bed 19, Choptank Formation, Calvert Co., Md.

4. *Actinoptychus virginicus* (Grunow) Andrews (p. 15). Inside of 16-sectored valve, X1,560, diameter 53 μm. From USGS diatom locality 6098, Bed 19, Choptank Formation, Calvert Co., Md.

5, 6. *Biddulphia minuta* (Greville) Andrews, n. comb. (p. 16).

5. Inside of valve, X2,500, length 37 μm. From USGS diatom locality 7051, Bed 3A, Calvert Formation, Calvert Co., Md.
6. Outside of valve, X1,600, length 46 μm. From USGS diatom locality 7050, Bed 3A, Calvert Formation, Calvert Co., Md.



ACTINOPTYCHUS, BIDDULPHIA

PLATE 6

[Scanning electron microscrope photographs]

FIGURES 1. *Thalassiosira grunowii* Akiba and Yanagisawa (p. 26). Outside of valve, X2,000, diameter 30 μm. From USGS diatom locality 6154, Bed 18, Choptank Formation, Calvert Co., Md.

2, 3. *Delphineis angustata* (Pantocsek) Andrews (p. 17).

2. Outside of partially separated frustule, X1,650, length 55 μm. From USGS diatom locality 6214, Bed 15, Calvert Formation, Calvert Co., Md.
3. Inside of valve, X1,800, length 57 μm. From USGS diatom locality 6214, Bed 15, Calvert Formation, Calvert Co., Md.

4. *Delphineis biseriata* (Grunow) Andrews (p. 17). Outside of valve, X1,800, length 61 μm. From USGS diatom locality 6154, Bed 18, Choptank Formation, Calvert Co., Md.

5, 6. *Delphineis novaecaesaraea* (Kain and Schultze) Andrews (p. 18).

5. Outside of valve, X1,300, length 82 μm. From USGS diatom locality 6499, Coosawhatchie Clay Member of the Hawthorn Formation, Effingham Co., Ga.
6. Inside of valve, X1,650, length 62 μm. From USGS diatom locality 6499, Coosawhatchie Clay Member of the Hawthorn Formation, Effingham Co., Ga.

7, 8. *Delphineis ovata* Andrews (p. 18).

7. Outside of valve, X2,800, length 33 μm. From USGS diatom locality 6543, Bed 7, Calvert Formation, Calvert Co., Md.
8. Inside of valve, X2,000, length 47 μm. From USGS diatom locality 6543, Bed 7, Calvert Formation, Calvert Co., Md.

9, 10. *Delphineis penelliptica* Andrews (p. 19).

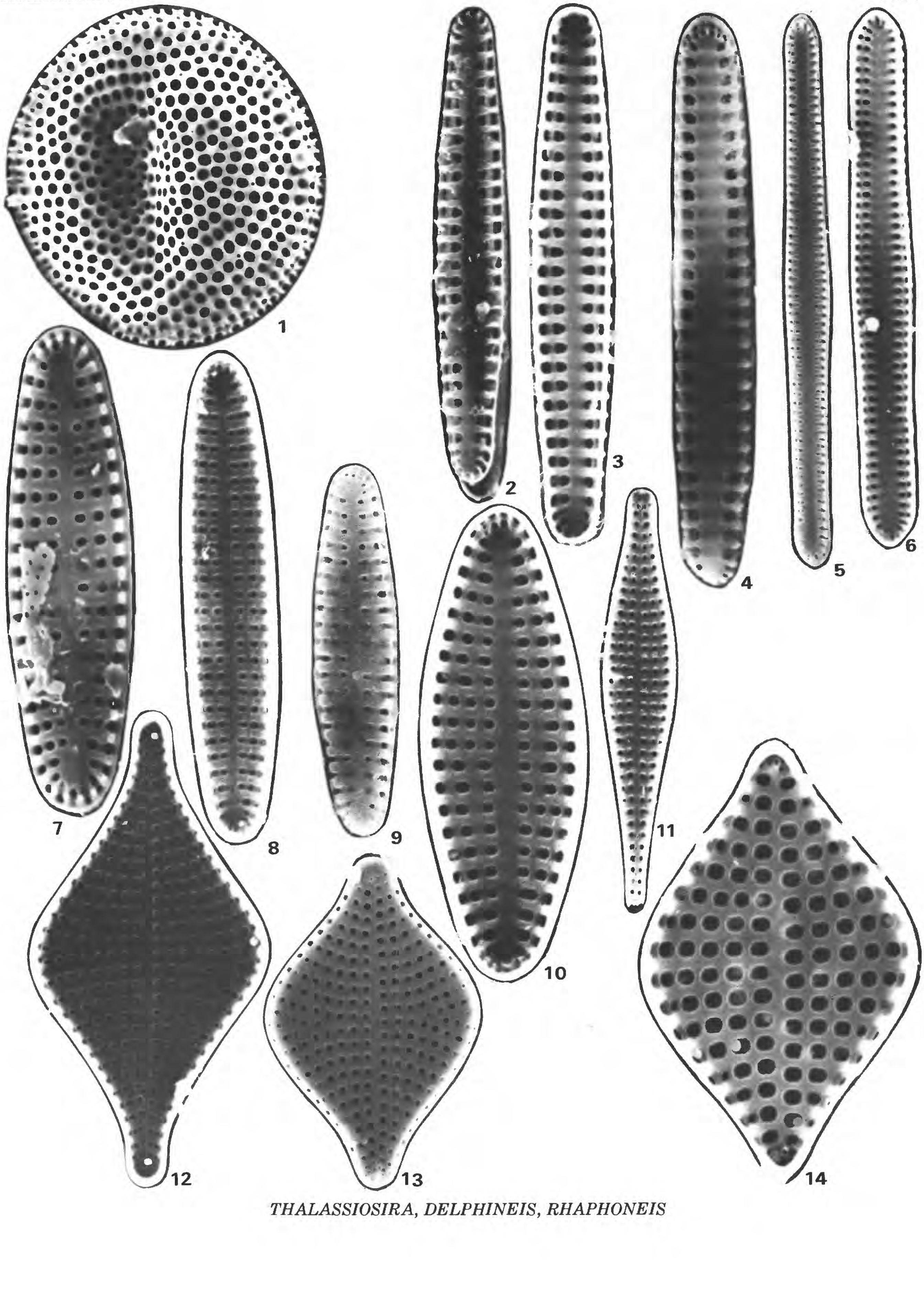
9. Outside of valve, X1,850, length 38 μm. From USGS diatom locality 6468, Hawthorn Formation, Thomas Co., Ga.
10. Inside of valve, X2,400, length 38 μm. From USGS diatom locality 6124, Bed 15, Calvert Formation, Calvert Co., Md.

11. *Rhaphoneis clavata* Andrews (p. 21). Outside of valve, X1,500, length 54 μm. From USGS diatom locality 6124, Bed 15, Calvert Formation, Calvert Co., Md.

12, 13. *Rhaphoneis amphiceros* (Ehrenberg) Ehrenberg (p. 20).

12. Inside of valve, X2,000, length 46 μm. From USGS diatom locality 6124, Bed 15, Calvert Formation, Calvert Co., Md.
13. Outside of valve, X2,000, length 32 μm. From USGS diatom locality 6124, Bed 15, Calvert Formation, Calvert Co., Md.

14. *Rhaphoneis adamantea* Andrews (p. 20). Inside of valve, X2,000, length 43 μm. From USGS diatom locality 5578, Hawthorn Formation, Thomas Co., Ga.



THALASSIOSIRA, DELPHINEIS, RHAPHONEIS

PLATE 7

[Scanning electron microscope photographs]

FIGURES 1. *Rhaphoneis diamantella* Andrews (p. 21). Outside of valve, X2,800, length 28 μm. From USGS diatom locality 6445, Bed 19, Choptank Formation, city of Richmond, Va.

2, 3. *Rhaphoneis fossile* (Grunow) Andrews (p. 21).

- 2. Outside of valve, X2,500, length 34 μm. From USGS diatom locality 7051, Bed 3A, Calvert Formation, Calvert Co., Md.
- 3. Inside of valve, X3,000, length 33 μm. From USGS diatom locality 6529, Bed 3A, Calvert Formation, Calvert Co., Md.

4, 5. *Rhaphoneis gemmifera* Ehrenberg (p. 22).

- 4. Outside of valve, X2,500, length 36 μm. From USGS diatom locality 6124, Bed 15, Calvert Formation, Calvert Co., Md.
- 5. Inside of valve, X2,000, length 29 μm. From USGS diatom locality 6124, Bed 15, Calvert Formation, Calvert Co., Md.

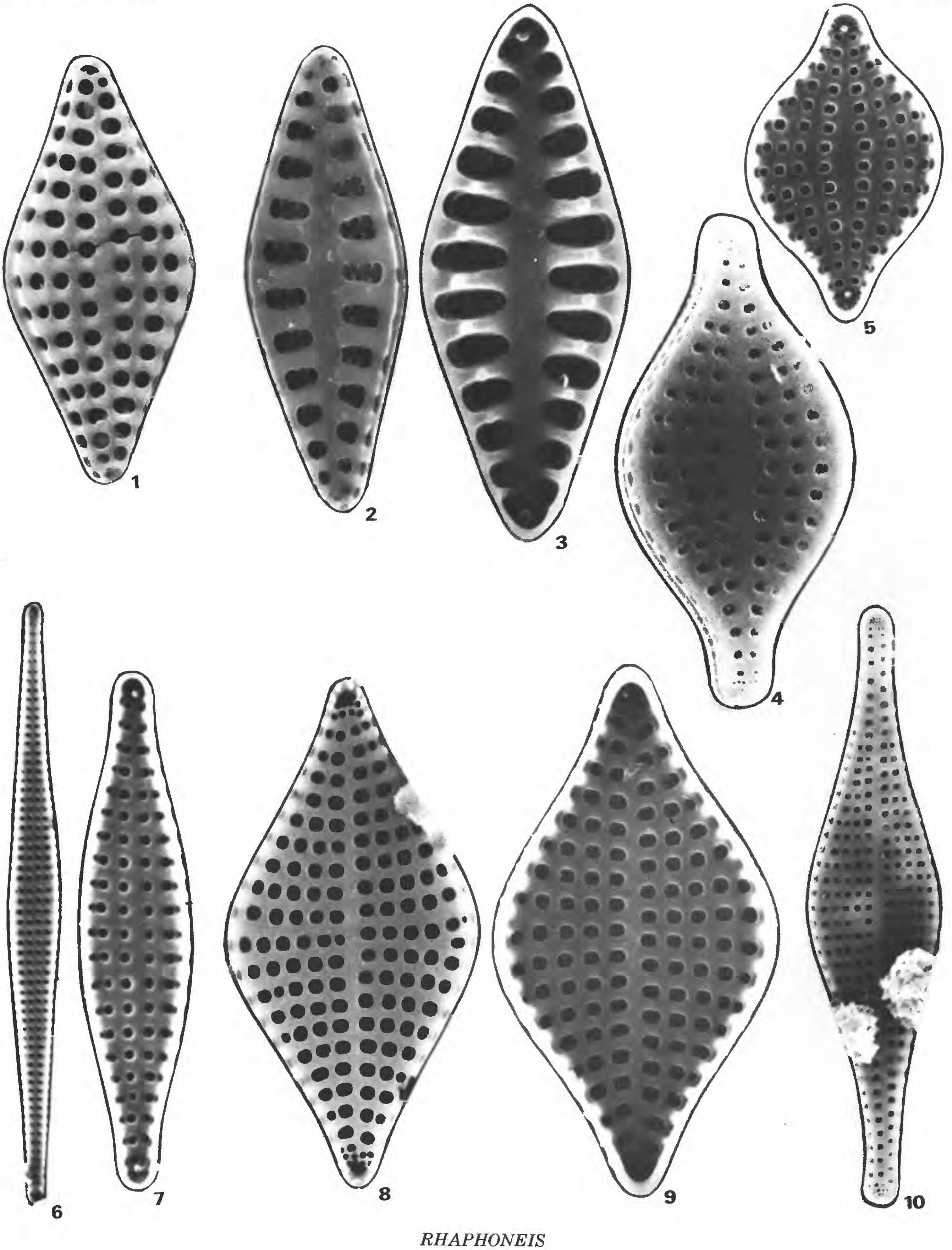
6, 7. *Rhaphoneis lancettula* Grunow (p. 22).

- 6. Outside of valve, X1,000, length 111 μm. From USGS diatom locality 6154, Bed 18, Choptank Formation, Calvert Co., Md.
- 7. Inside of valve, X2,400, length 40 μm. From USGS diatom locality 6154, Bed 18, Choptank Formation, Calvert Co., Md.

8, 9. *Rhaphoneis magnapunctata* Andrews (p. 23).

- 8. Outside of valve, X1,700, length 56 μm. From USGS diatom locality 5578, Hawthorn Formation, Thomas Co., Ga.
- 9. Inside of valve, X2,000, length 49 μm. From USGS diatom locality 5578, Hawthorn Formation, Thomas Co., Ga.

10. *Rhaphoneis margaritata* Andrews (p. 23). Outside of valve, X700, length 158 μm. From USGS diatom locality 6543, Bed 7, Calvert Formation, Calvert Co., Md.



RHAPHONEIS

PLATE 8

[Scanning electron microscope photographs]

FIGURES 1. *Rhaphoneis rhombica* (Grunow) Andrews (p. 24). Inside of valve, X2,590, length 38 μm. From USGS diatom locality 6445, Bed 19, Choptank Formation, city of Richmond, Va.

2. *Rhaphoneis scalaris* Ehrenberg (p. 24). Outside of valve, X1,300, length about 71 μm. From USGS diatom locality 6543, Bed 7, Calvert Formation, Calvert Co., Md.

3. *Rhaphoneis scutula* Andrews (p. 25). Inside of valve, X1,640, length 67 μm. From USGS diatom locality 6445, Bed 19, Choptank Formation, city of Richmond, Va.

4, 5. *Sceptroneis caduceus* Ehrenberg (p. 25).

4. Outside of valve, X644, length 175 μm. From USGS diatom locality 6529, Bed 3A, Calvert Formation, Calvert Co., Md.

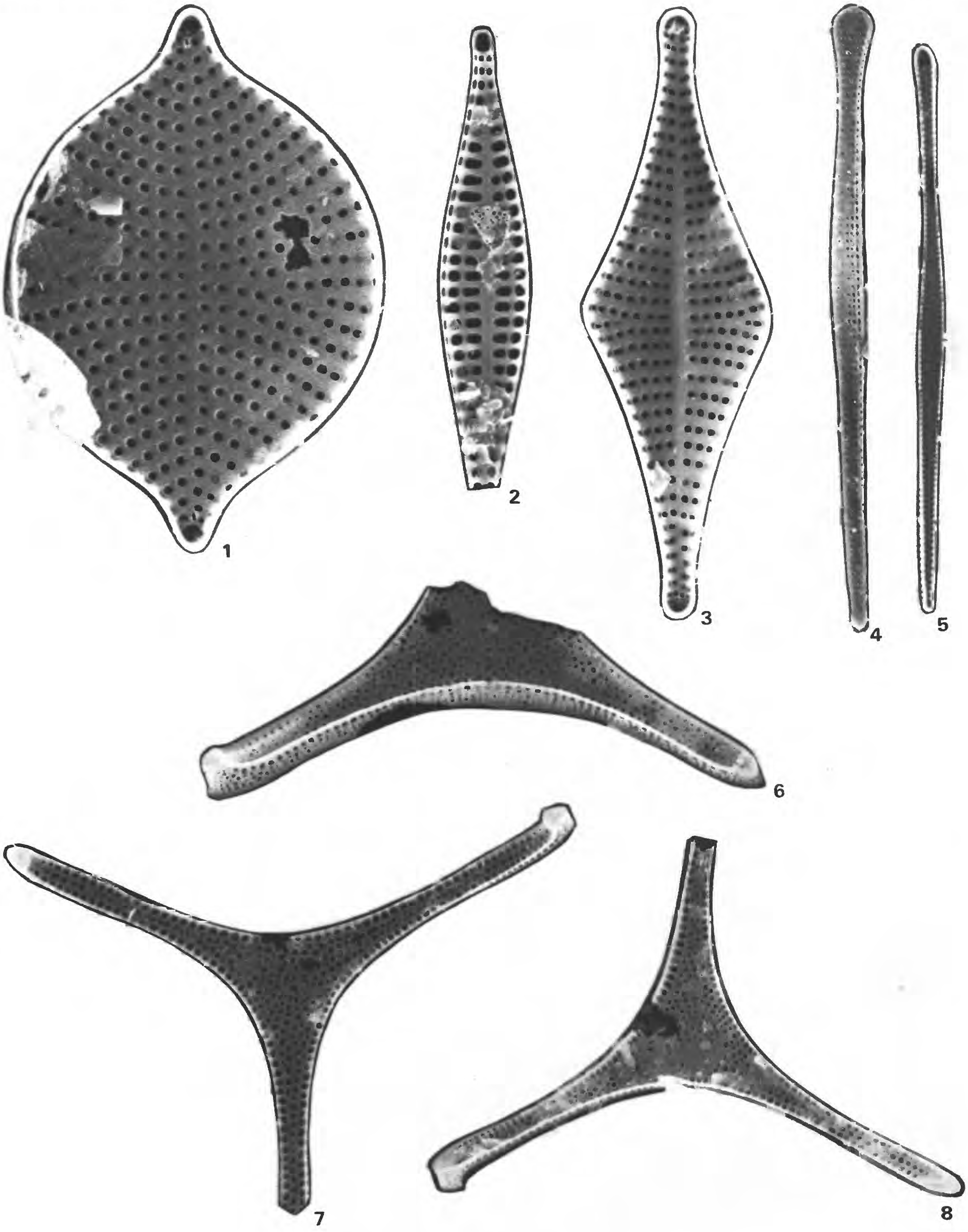
5. Inside of valve, X380, length 271 μm. From USGS diatom locality 6543, Bed 7, Calvert Formation, Calvert Co., Md.

6-8. *Trinacria solenoceros* (Ehrenberg) VanLandingham (p. 27).

6. Inside of valve, X1,000, altitude about 88 μm. From USGS diatom locality 7051, Bed 3A, Calvert Formation, Calvert Co., Md.

7. Outside of valve, X700, altitude about 123 μm. From USGS diatom locality 7051, Bed 3A, Calvert Formation, Calvert Co., Md.

8. Inside of valve, X700, altitude about 121 μm. From USGS diatom locality 7051, Bed 3A, Calvert Formation, Calvert Co., Md.



RHAPHONEIS, SCEPTRONEIS, TRINACRIA

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