

Stratigraphic distribution of some pollen
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of the Middle Atlantic States

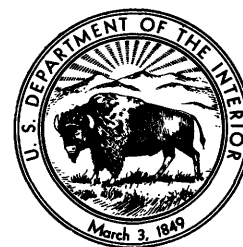
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By JACK A. WOLFE

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STRATIGRAPHIC DISTRIBUTION OF SOME POLLEN TYPES FROM THE CAMPANIAN AND LOWER MAESTRICHTIAN ROCKS (UPPER CRETACEOUS) OF THE MIDDLE ATLANTIC STATES

By JACK A. WOLFE

ABSTRACT

Analysis of 74 pollen samples from the Cliffwood beds of the upper part of the Magothy Formation and from the younger marine Cretaceous rocks indicates that 10 informal biostratigraphic subdivisions can be made of this Campanian and lower Maestrichtian section. Comparison of these subdivisions in the northern Raritan embayment with those in the southern Salisbury embayment indicate that the Woodbury Clay in the north is a facies of the upper part of the Merchantville Formation to the south. The pollen data can be interpreted to support the concept that the lower part of the Mount Laurel Sand in the south is the biostratigraphic equivalent to the Wenonah Formation in the north. The "Matawan" previously recognized on the west shore of Chesapeake Bay is shown to be "Monmouth" and equivalent in age to part of the Navesink Formation of the Monmouth Group. The biostratigraphic subdivisions proposed form the basis for correlations of the Late Cretaceous rocks of the Mississippi embayment with those of the Atlantic Coastal Plain. Fluctuations in the relative abundance of bisaccate coniferous pollen are interpreted as climatic fluctuations. A total of 104 dicotyledonous pollen types are briefly discussed and illustrated.

INTRODUCTION

The difficulties of correlating the Campanian and Maestrichtian (Upper Cretaceous) rock units on the Atlantic Coastal Plain have been amply discussed by Sohl and Mello (in Owens and others, 1970). The marine faunas contain few ammonites, and many of the faunas contain long-ranging taxa or are of low diversity. Further, because of preservational factors, determinable mollusks are uncommon in many of the units. It was thought, therefore, that pollen studies might provide a supplementary and more consistent means of correlating these rocks. Some pollen assemblages had, in fact, been described from these rocks (Gray and Groot, 1966), but the described taxa were few, and some of the samples were obviously stratigraphically misplaced (Owens and others, 1970), particularly those from the Chesapeake and Delaware Canal.

In 1969 an extensive series of samples was collected for analysis. These samples, which were collected with the assistance of J. P. Minard, J. P. Owens, and N. F. Sohl, were supplemented with a few samples collected earlier by Owens and Sohl. The productivity of the sam-

ples was remarkable; of the 58 samples collected from these marine horizons, 57 contained determinable material. With the exception of the Tinton Sand, all the Campanian and Maestrichtian units have produced pollen assemblages. In addition, the assemblages of the upper part of the Magothy Formation have been preliminarily studied based on 17 samples; these samples are also of Campanian age.

For their advice and assistance on various aspects of this study, I wish to thank E. B. Leopold, J. P. Minard, J. P. Owens, N. F. Sohl, and R. T. Tschudy.

GEOLOGIC OCCURRENCE

In the Middle Atlantic States, the Campanian and Maestrichtian rocks occur in a belt extending from northeastern New Jersey south to the vicinity of Washington, D.C. (fig. 1). Studies of these rocks (Owens and others, 1970) indicate that the depositional history in the northern area—the Raritan embayment (central and northern New Jersey)—was somewhat different than in the southern area—the Salisbury embayment (Maryland, Delaware, and southern New Jersey). Several of the units can be traced from one embayment to the other, but other rock units are present in only one embayment (fig. 2). Whether the absence of some lithostratigraphic units is due to facies changes and time transgressive phenomena cannot be certainly determined without resort to paleontologic work.

Older studies (for example, Clark, 1916) divided the Campanian and Maestrichtian rocks into two basic units: the Matawan Formation (or Group) and the Monmouth Formation (or Group), the Matawan of supposed Campanian age and the Monmouth of supposed Maestrichtian age. Further, the underlying Magothy Formation was considered to be of Turonian age and unrelated to these other units. From the east shore of Chesapeake Bay and north, Owens, Minard, Sohl, and Mello (1970) have shown that the subdivision into Matawan and Monmouth along the age-stage boundary

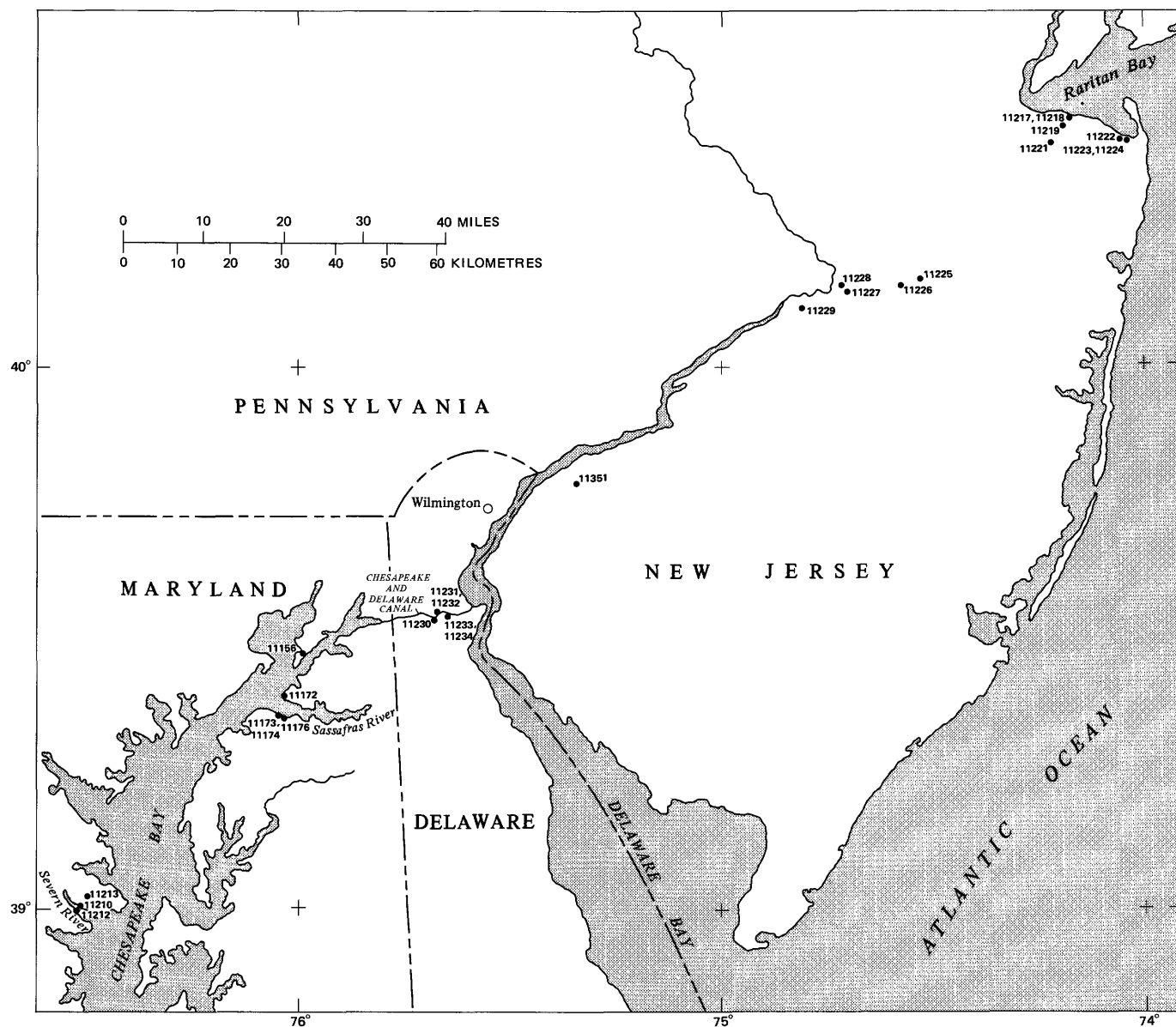


FIGURE 1.—General location of sampling sites in the Coastal Plain of the Middle Atlantic States. Numbers refer to USGS paleobotany localities, details for which are given in the section on "Fossil localities."

is simplistic and that much of the "Monmouth" is, in fact, of Campanian age. Further, the upper part of the Magothy Formation (the Cliffwood beds and equivalent horizons) has been shown to be of probable earliest Campanian age (Wolfe and Pakiser, 1971). On the west shore of Chesapeake Bay, where mapping has not yet progressed to the stage where the units mapped by Owens, Minard, Sohl, and Mello (1970) can be recognized in most areas, the older terminology of Matawan and Monmouth is still applied.

About half the samples were collected from central and northern New Jersey and represent all the Campanian and Maestrichtian units except for the Mount

Laurel Sand (the one sample collected from this unit was barren) and the Tinton Sand. In eastern Maryland, Delaware, and southern New Jersey, all the units recognized by Owens, Minard, Sohl, and Mello (1970) produced pollen assemblages. On the west shore of Chesapeake Bay, the supposed Matawan was sampled, but, as discussed in the section on "Biostratigraphy," this Matawan is equivalent in age to part of the Navesink Formation and is thus assignable to the Monmouth.

The Campanian-Maestrichtian boundary recognized in this report (within the Navesink Formation) is based on the work of Sohl and Mello (in Owens and others,

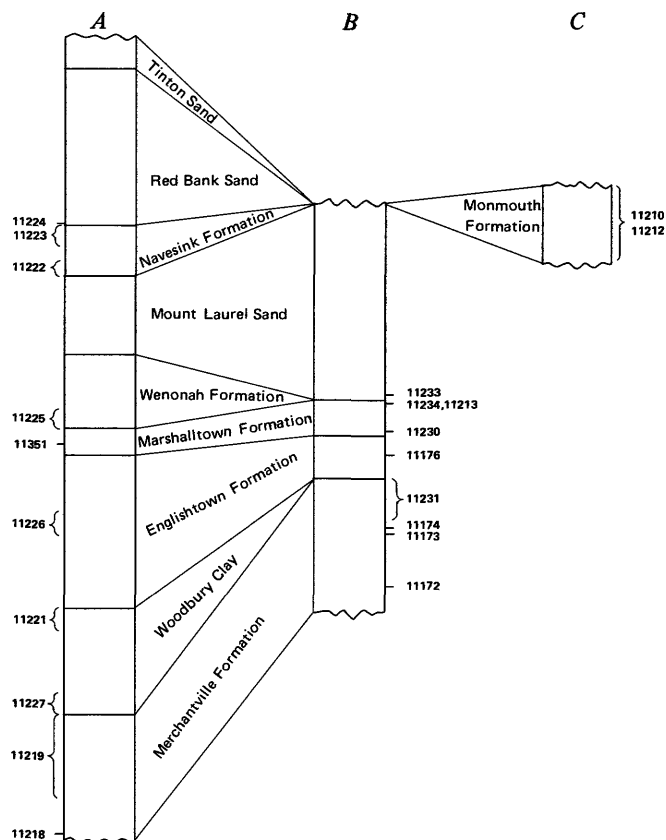


FIGURE 2.—Generalized sections of the post-Magothy Cretaceous rocks of the Middle Atlantic States. A, New Jersey; B, Delaware and eastern Maryland; C, Western shore of Chesapeake Bay. Numbers indicate approximate stratigraphic position of localities. A and B modified from Owens and Minard (in Owens and others, 1970).

1970). Other workers, specialists in planktonic Foraminifera in particular, would place the boundary lower, probably at or near the base of the Mount Laurel Sand.

BIOSTRATIGRAPHY

Six major divisions are proposed for Campanian to lower Maestrichtian rocks of the Raritan and Salisbury embayments; the divisions are based on the stratigraphic ranges of dicotyledonous pollen (table 1). Four of these major divisions have recognizable subzones; thus a total of 10 informal biostratigraphic units are recognized. A sequence of informal palynologic zones for the Potomac Group and Raritan Formation, which has been proposed (for example, Brenner, 1963), are numbered sequentially in roman numerals. Although it might be desirable to continue the numbering sequence for the zones discussed in this report, the number of zones between the Raritan and Magothy Formations cannot now be determined and the Magothy pollen floras need further study to determine the zonation.

Considering the unknown number of zones that may

eventually be recognized between the Raritan Formation and the rock units of Campanian age, I have started a new numbering sequence prefixed by "CA," which stands for Campanian, and "MA," which stands for Maestrichtian. Subzones within the major zones are denoted by suffixes, for example, "A" for the lowest subzone. Zone 6, which is of both Campanian and Maestrichtian age, has the prefix CA-6/MA-1.

The fact that most zonal and subzonal boundaries proposed here are approximately coincidental with lithostratigraphic boundaries (table 1) may be a reflection of incomplete sampling across lithostratigraphic boundaries. For example, one of the most distinct assemblages, that of Zone CA-4, is based on samples from the middle part of the Englishtown Formation. Had the lower and upper parts of the Englishtown been sampled, Zone CA-4 might not appear as palynologically distinctive as described in this report. However, in the instance of the boundary between Zones CA-1 and CA-2, the assemblage from 11217-H at the top of the Magothy Formation is clearly distinct from that from 11218 at the base of the Merchantville; the latter assemblage, nevertheless, does have features intermediate between the uppermost Magothy assemblage and the assemblages from the middle part of the Merchantville (11219-A-F). The differences between the assemblages such as those from 11217-H and 11218 may reflect a definite hiatus; indeed, a sharp disconformity separates the Magothy and Merchantville (Owens and others, 1970).

Zone CA-1 and older Magothy strata—Pollen assemblages from the Magothy Formation have been discussed and partly illustrated elsewhere (Wolfe and Pakiser, 1971). Additional samples not reported on before have been studied to a limited extent, but the work has not progressed to the stage of presentation other than to indicate that the Magothy sequences in the Raritan embayment appear different than those in the Salisbury embayment. I emphasize that these suggestions may be premature. The Magothy sequence in the Raritan embayment (in descending order) appears to be:

Cliffwood beds (Zone CA-1): Normapolles-dominated assemblage that has some strong similarities to the Merchantville, particularly the basal Merchantville.

Morgan beds (Santonian): Similar to the Cliffwood, as well as to the Amboy stoneware clay.

Amboy Stoneware Clay Member (Santonian): Normapolles dominated, but greater diversity than in Morgan beds.

Old Bridge Sand Member (Coniacian?): Conifer dominated (bisaccates), low diversity of Normapolles (*Pseudoplicapollis*, *Trudopollis*,

chantville Formation. A sample (11218) from the basal Merchantville immediately above the contact with the Cliffwood beds at Cliffwood Beach contains at least 10 pollen species not yet found in samples from the Cliffwood beds (11217-A through G). This basal Merchantville sample, however, also contains three species that occur in the Cliffwood but not in other Merchantville samples. Particularly significant is the fact that, as in the Cliffwood samples, "*Proteacidites*" is lacking in 11218 but the probable pre-"*Proteacidites*" (NQ-1) is present. On this basis, the basal Merchantville beds at Cliffwood Beach, from which 11218 was collected, are recognized as Subzone CA-2A, as distinguished from the Merchantville samples from the Oschwald pit (11219A through G), in which "*Proteacidites*" is present in most samples and NQ-1 is absent in all. Further, at least 12 species are found in the Oschwald Merchantville but not in 11218 or the Cliffwood beds. Analyses of samples from the interval between 11218 and 11219-A (approximately middle part of Merchantville), might show the compositions between 11218 and other Merchantville samples to intergrade.

The Merchantville Formation exposed in Maryland and Delaware was sampled at four localities (11172, 11173, 11174, and 11231). The pollen assemblages from three of these localities (11172, 11173, 11174), correspond well with Subzone CA-2B. At 11231, (samples A-F) in the upper part of the Merchantville along the Chesapeake and Delaware Canal, the pollen assemblages do not correlate with the Oschwald Merchantville; as discussed below, these Merchantville samples that represent Zone CA-3, are from an age equivalent of the Woodbury Clay. Indeed, Owens, Minard, Sohl, and Mello (1970) indicate that along the Sassafras River, the Merchantville grades upward into the Englishtown Formation and the Woodbury Clay is absent. Such data clearly indicate that the age equivalent of the Woodbury Clay is here within either the Merchantville or the Englishtown, and the pollen data indicate that the Woodbury equivalent is within the Merchantville. More recently, Minard (1974, p. 20) has revised earlier concepts on the supposed pinching out of the Woodbury in southern New Jersey, proposing that the Woodbury is present (but coarser than to the north) and was erroneously included in the upper part of the Merchantville. The molluscan evidence within the Merchantville exposed in the canal section indicates that possibly the Woodbury Clay equivalent is absent (Sohl and Mello in Owens and others, 1970), but Sohl (oral commun., 1975) considers the molluscan data based on new collections to be equivocal in determining the presence or absence of a Woodbury equivalent.

A sample (11156) from the east shore of Maryland on Elk Neck is also from Subzone CA-2B. Although the

beds from which this sample was collected had previously been assigned to the Magothy Formation (Owens and others, 1970), the palynologic data strongly indicate an age equivalent of the Oschwald Merchantville. Owens (oral commun., 1975), moreover, states that the assignment of these Elk Neck beds to the Magothy was uncertain and that these beds could, on geologic grounds, represent either Merchantville or Englishtown, as well as Magothy.

Zone CA-3.—This zone includes the Woodbury Clay of central and northern New Jersey and the upper part of the Merchantville Formation in the Salisbury embayment. At least 10 species occur in samples 11227 (A through D; lower part of Woodbury) and not in the Oschwald Merchantville (11219). An additional four species occur in samples 11221 (A and B; upper part of Woodbury) and not lower in the section. In addition, four species range from the Oschwald Merchantville up into the lower part of the Woodbury but not into the upper part. On this basis, the lower part of the Woodbury Clay is assigned to a subzone (CA-3A) distinct from that (CA-3B) of the upper part. In the upper part of the Merchantville exposed in the Chesapeake and Delaware Canal (locality 11231), samples A-D in particular bear a strong resemblance to assemblages characterizing Subzone CA-3A, whereas sample D and particularly sample E more closely resemble the assemblages from Subzone CA-3B.

Zone CA-4.—Three samples (11226-A through C) from the middle part of the Englishtown Formation in the Raritan embayment and one sample (11176) from the Englishtown of the Salisbury embayment all closely resemble one another and concomitantly are highly dissimilar from samples from higher or lower units. Ten species are restricted to the Englishtown, eight have their lowest occurrence in this unit, and nine have their highest occurrence. According to Sohl and Mello (in Owens and others, 1970), the Englishtown Formation is probably of latest early Campanian age.

Zone CA-5.—This zone includes the Marshalltown Formation, Wenonah Formation, and at least the lower part of the Mount Laurel Sand. More than 20 species have their lowest occurrence in this zone, whereas 11 species that occur lower in the section have their last occurrence. Six species have their highest occurrence in the Marshalltown Formation, six have their lowest occurrence, and two are restricted to this unit; on this basis, the Marshalltown assemblages form the basis for Subzone CA-5A. An additional 10 species have their highest occurrence in the Wenonah or Mount Laurel, whereas six species have their lowest occurrences in these units, which are assigned to Subzone CA-5B. On the basis of present data, it would be difficult, if not impossible, to distinguish between the pollen as-

semblages from the Wenonah Formation and the one assemblage from the lower part of the Mount Laurel. Indeed, Sohl and Mello (in Owens and others, 1970) suggest that the lower part of the Mount Laurel in the canal section (from which the one Mount Laurel pollen sample was obtained) may in fact represent the time equivalent of the Wenonah to the north in New Jersey. The pollen data are consistent with such an interpretation.

Zone CA-6/MA-1.—This zone includes the Navesink Formation and at least the basal part of the Red Bank Sand in the Raritan embayment. In the Salisbury embayment, the Monmouth Formation exposed at Round Bay on the Severn River falls within this zone. At least 18 species are known in this zone but not in lower zones; the upward extent of the ranges of many of these species is not known.

Subdivisions of this zone are not entirely satisfactory. A considerable number of species are known only in the Red Bank, but as only one Red Bank sample has been examined, the stratigraphic significance of these species (most of which are not discussed or illustrated in this report) is uncertain. The samples from the uppermost part of the Navesink closely resemble those from the lowermost part: of the 22 uppermost Navesink species, for example, 18 occur in the lowermost Navesink. Although reliance on a single lineage may be tenuous, NK-2 is consistently found through 11223-B in the uppermost Navesink, whereas NK-3 occurs in 11223-C and in the Red Bank. Lending some support for a biostratigraphic division between 11223-B and 11223-C is the fact that 11 species are known through 11223-B but are not known in either 11223-C or the Red Bank. Although admittedly tentative, the uppermost Navesink sample and the Red Bank sample form the basis for Subzone CA-6/MA-1B (this subzone is, of course, entirely of Maestrichtian age), whereas the samples lower in the Navesink form the basis for Subzone CA-6/MA-1A.

The Monmouth Formation along Severn River contains several species that have not yet been found in the New Jersey section. Of the species common to both sections, the Severn River Monmouth clearly correlates with Subzone CA-6/MA-1A. Four of the Severn River species are not known in the upper Navesink or Red Bank; three are not known in the lower Navesink or older samples. In general, the Monmouth Formation along Severn River would appear to be approximately equivalent to the middle part of the Navesink Formation, although age equivalents of both the upper (but not uppermost) and lower Navesink could be represented. The ammonite found in the upper part of the Severn River Monmouth is a species that, in New Jersey, is restricted to the upper Navesink and Red Bank.

SIGNIFICANCE TO LITHOSTRATIGRAPHIC UNITS

Owens and Minard (in Owens and others, 1970) consider that the Woodbury Clay of New Jersey thins southwestward and is absent in the Chesapeake and Delaware Canal section. Minard (1974) has revised this interpretation; he suggests that the Woodbury may lose its identity by a facies change to the south. The palynologic data indicate that beds of Woodbury age (Zone CA-3) are present in the canal section in the upper part of the Merchantville Formation, that is, the upper boundary of the Merchantville is time-transgressive (or the Woodbury Clay is a facies of the upper part of the Merchantville).

Along the Sassafras River, the upper part of the Merchantville (but not the uppermost part) contains assemblages assignable to Zone CA-2B. Possibly beds of Woodbury age are present here; this could be determined with certainty if the uppermost Merchantville were sampled.

Owens, Minard, Sohl, and Mello (1970) state that the Mount Laurel Sand in the Chesapeake and Delaware Canal grades downward into the Marshalltown Formation, the intervening Wenonah Formation having thinned out in southern New Jersey. The palynologic data could be interpreted to substantiate this conclusion; the assemblage from the lower part of the Mount Laurel in the canal assemblage does not differ significantly from the Wenonah assemblages. In order to substantiate this interpretation with certainty, it would first be necessary to determine if the Mount Laurel pollen assemblage in central and northern New Jersey were recognizably younger than the one assemblage from the Mount Laurel in the canal. Unfortunately, the one barren sample collected was from the Mount Laurel in northern New Jersey.

Owens and Minard (in Owens and others, 1970) indicate that the Navesink Formation thins southward from northern New Jersey and is absent in the section along the east shore of Chesapeake Bay. On the west shore, however, rocks equivalent in age to the Navesink are well represented along the Severn River. Further, although the upper part of the Merchantville along the Chesapeake and Delaware Canal is equivalent in age to the Woodbury Clay (Zone CA-2), to the west along the Sassafras River the upper part of the Merchantville is equivalent in age to the Merchantville of northern New Jersey (Zone CA-2); to this time, no rocks of Zone CA-3 have been determined along Chesapeake Bay. As discussed earlier in this report, the Magothy Formation exposed along the Severn River appears to be older than the Magothy Formation exposed along the Chesapeake and Delaware Canal and in southern New Jersey. Finally, rocks in southern New Jersey and Maryland tra-

ditionally assigned to the Raritan Formation have been shown to represent the uppermost part of the Potomac Group, and beds of an age equivalent to the Raritan Formation of northern New Jersey are apparently absent in outcrop in southern New Jersey, Delaware, and Maryland (Doyle, 1969; Wolfe and Pakiser, 1971). The depositional history of the Raritan embayment thus appears to be significantly different from the depositional history in the Salisbury embayment (particularly in the areas now adjacent to Chesapeake Bay).

CORRELATIONS WITH POLLEN ASSEMBLAGES FROM THE MISSISSIPPI EMBAYMENT

A large number of species of the Normapolles complex has been described by Tschudy (1975) based on material from the Mississippi embayment. Additionally, Tschudy has allowed me to compare the Atlantic Coastal Plain assemblages with illustrations of unpublished assemblage plates from various samples from the Campanian and Maestrichtian rocks of the embayment.

Two points of disagreement exist between the ages suggested here for the Mississippi embayment assemblages and the ages assigned to the assemblages by Tschudy (1975). First, the sampled Coffee Sand of Tennessee clearly correlates with the Englishtown Formation (Zone CA-4), whereas Tschudy (1975) assigned the Coffee Sand to the upper Campanian and considered his sample to be younger than samples from the Cusseta Sand Member of the Ripley Formation (Zone CA-5). Tschudy's sample (D3412) is stated to be from the middle part of the type section of the Coffee Sand; the suggested correlation of these rocks with the lower Campanian Englishtown Formation is in accordance with correlations proposed by Sohl (1964a, 1964b) and Sohl and Mello (in Owens and others, 1970). Sohl considers only the upper part of the Coffee Sand to be equivalent to the lower part of the Cusseta Sand Member, the remainder of the Coffee Sand being of early Campanian age. Second, Tschudy (1975) assigns the Coon Creek Tongue of the Ripley Formation to the Maestrichtian. The data in this report support the opinion of Sohl (in Owens and others, 1970) that the Coon Creek Tongue is of late Campanian age.

The placement of Tschudy's sample D3412 from the Coffee Sand in Zone CA-4 is based on the number of species in common. The following forms illustrated in this report also occur in D3412:

- NA-1 (CA-3B—CA-4)
- NB-1 (CA-2A—CA-4)
- NC-1 (CA-2B—CA-4)
- ND-3 (CA-3A—CA-5B)
- NE-1 (CA-1—CA-5A)
- NE-2 (CA-4—CA-5A)
- NJ-2 (CA-4—CA6/MA-1A)

- NM-1 (CA-4—CA-5B)
- NO-1 (CA-3B—CA-5B)
- CP3B-5 (CA-4)
- CP3E-1 (CA-2B—CA-5B)

The overlap of ranges of several species concomitant with the occurrence of CP3B-5 indicate that D3412 is assignable to Zone CA-4.

The following species occur in D3260 from the upper part of the Cusseta Sand Member of the Ripley Formation in Alabama:

- NA-8 (CA-5B—CA-6/MA-1B)
- NE-3 (CA-5A—CA-6/MA-1A)
- NF-4 (CA-4—CA-5B)
- NR-1 (CA-5A)
- PR-7 (CA-4—CA-6/MA-1B)
- MPH-1 (CA-5A—CA-5B)

This assemblage is clearly indicative of Zone CA-5; Sohl and Mello (in Owens and others, 1970) correlate the Cusseta Sand member with the Marshalltown and Wenonah Formations and the lower part of the Mount Laurel Sand, a correlation in agreement with that suggested here. Which subzone of Zone CA-5 D3260 should be placed in is not certain; NR-1 would indicate Subzone CA-5A, but the occurrences of this species are so uncommon that I would prefer to rely on the range of NA-8 and suggest that D3260 is from beds correlative with the Wenonah Formation or the lower part of the Mount Laurel Sand. In fact, NR-1 is known in probable CA-5B or CA-6/MA-1A samples in the Mississippi embayment.

Sample D3413 from the Cook Creek Tongue of the Ripley Formation in Tennessee contains the following species:

- NA-3 (CA-5B)
- NA-8 (CA-5B—CA-6/MA-1B)
- NC-2 (CA-2A—CA-5B)
- NE-3 (CA-5B—CA-6/MA-1B)
- NN-1 (CA-4—CA-5B)
- NO-2 (CA-5A—CA-5B)
- NT-1 (CA-5B—CA-6/MA-1A)
- CP3F-2 (CA-5B—CA-6/MA-1B)

The co-occurrence of these species is indicative of Subzone CA-5B; that is, this part of the Cook Creek Tongue is correlative with either the Wenonah Formation or the Mount Laurel Sand. Sohl (1964a) and Sohl and Mello (in Owens and others, 1970) correlate the Coon Creek in Tennessee with the Mount Laurel Sand and the uppermost part of the Wenonah Formation.

The McNairy Sand Member of the Ripley Formation has yielded specimens of NN-2 (CA-6/MA-1A and B) at locality D3358 and NA-8 (CA-5B—CA-6/MA-1B), NG-1 (CA-6/MA-1A), NK-2 (CA-6/MA-1A), and MPH-2 (CA-6/MA-1A) at locality D1967. The correlation indicated is of the bulk of the Navesink Formation

with the McNairy Sand Member; that is, the McNairy can be assigned to Subzone CA-6/MA-1A. Sohl (1964a) also correlated the McNairy with the bulk of the Navesink.

The type locality of the Owl Creek Formation (D3410) contains the following species:

NH-1 (CA-6/MA-1A)

NK-3 (CA-6/MA-1B)

NO-3 (CA-6/MA-1A and B)

PR-7 (CA-4—CA-6/MA-1B)

The assignment to Zone CA-6/MA-1 is clear, and probably locality D3410 is in Subzone B of this zone. The occurrence of NK-3, which is thought to be descended from NK-2 in Subzone A, is considered to be more significant than the occurrence of NH-1.

The basic similarity of the Atlantic Coastal Plain and Mississippi embayment pollen sequences from Zone CA-4 through Zone CA-6/MA-1B is strong evidence of the overall validity of the proposed zonation. It would, however, be desirable to sample the Mississippi embayment section in more detail, particularly in the Coffee Sand; presumably, the lower part of this unit would produce assemblages assignable to Zones CA-1 through CA-3. The correlations suggested here are in consistent agreement with those suggested by Sohl and Mello (in Owens and others, 1970, fig. 23).

CORRELATIONS WITH POLLEN ASSEMBLAGES FROM THE CAPE FEAR ARCH

Sampling of the Cretaceous units of North Carolina has been extremely limited; thus far, only two productive samples—both from the Black Creek Formation—have been analyzed. The oldest sample, D5019 from Walker's Bluff on the Cape Fear River, contains the following species:

NB-1 (CA-2A—CA-4)

ND-3 (CA-3A—CA-5B)

C3A-1 (CA-2A—CA-4)

CP3B-3 (CA-3A and B)

The placement of this sample is in Zone CA-3, although it cannot be determined which subzone is represented. The second sample, D5018 from Jessup's Landing on the Cape Fear River, contains the following species:

ND-3 (CA-3A—CA-5B)

NE-3 (CA-5A—CA-6/MA-1B)

NN-1 (CA-4—CA-5B)

PR-7 (CA-4—CA-6/MA-1B)

C3B-3 (CA-5A—CA-6/MA-1B)

This sample is assignable to Zone CA-5, but, as with the other Black Creek sample, the assemblage is too small to determine which subzone is represented. Nevertheless, the palynologic data are consistent with the invertebrate evidence (Sohl and Mello in Owens and others, 1970), which indicates that the Black Creek Formation

contains correlatives of the Woodbury Clay (Zone CA-3) and Marshalltown and Wenonah Formations (Zone CA-5).

PALEOECOLOGY

Most of the angiospermous pollen types found cannot be related with certainty to extant families or even orders, and this makes paleoecological interpretations based on distributions of extant related taxa of little value. One aspect of the various samples is notable: the percentages of bisaccate pollen in both the Raritan embayment and Salisbury embayment sections seem to fluctuate sharply (fig. 3). The bisaccate pollen represents various coniferous genera, particularly those included in Podocarpaceae and Pinaceae.

Two periods of deposition of abundant bisaccate pollen are apparent: one during Woodbury time (Zone CA-3) and another during Marshalltown through part of Navesink time (Zone CA-5 through part of CA-6/MA-1A). In contrast during Cliffwood and Merchantville time (Zones CA-1 and CA-2) and Englishstown time (Zone CA-4), representation of bisaccate pollen is low to moderate whereas pollen of the Normapolles complex is well represented. Apparently another period of low bisaccate representation began in the upper part of the section during Navesink time.

The fluctuations in relative abundance of bisaccate pollen and Normapolles pollen have no obvious relation to the sedimentary cycles proposed by Owens and Minard (in Owens and others, 1970). For example, the Merchantville and Marshalltown Formations both represent the initial transgressive phase of their respective cycles, but the former has only a moderate representation of bisaccate pollen and the latter has a high representation of this type of pollen. A second example is that the Mount Laurel (high bisaccate) and Englishstown (low bisaccate) both represent the closing phase of their respective cycles. These examples indicate that factors such as water depth or distance from shore have little, if any, bearing on the pollen fluctuations.

If the sedimentary cycles have no relation to the pollen fluctuations, then possibly the fluctuations represent climatic changes, with the high bisaccate periods representing cool intervals relative to the low bisaccate periods. Such fluctuations in climate could represent the same series of cycles suggested for the Tertiary (Wolfe, 1971). In order to test this hypothesis, I calculated backward from the well-documented cooling that occurred about 32 m.y. ago, assuming that each complete cycle had a duration of 9.5 m.y. (Wolfe, 1971) and that a warm period of a given cycle had the same duration as a cool period of that cycle. The predicted ages of the warm and cool periods are given in table 2, as are the radiometric ages on the various rock units (Owens and

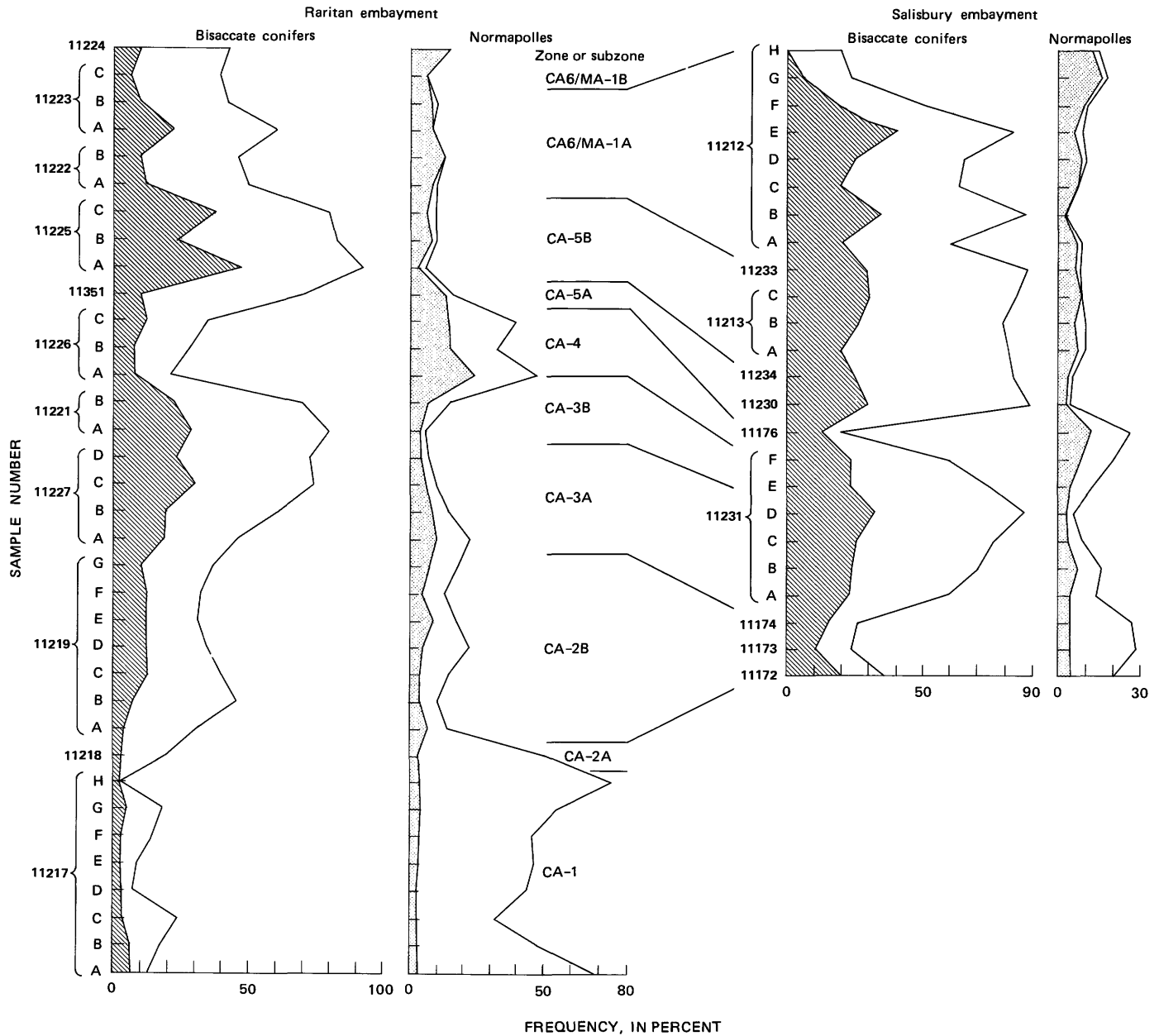


FIGURE 3.—Relative abundance of certain major pollen types in the Campanian and Maestrichtian rocks of the Middle Atlantic States. Based on counts of 200 pollen grains per sample. Lined areas, the podocarpaceous *Rugubivesiculites*; shaded areas, structurally simpler Normapolles types.

Sohl, 1973). The agreement between the predicted and radiometric ages is extremely close and is certainly within the experimental error of the radiometric ages. It should be noted that the Magothy assemblages typically have a low bisaccate representation, except for the Old Bridge Sand Member assemblages from the base of the Magothy. The Old Bridge, then, would apparently be about 84 m.y. old—the age predicted for the end of the next oldest cool period.

The percentages of bisaccate and Normapolles pollen

could be used in a general manner to indicate age in local correlations. High Normapolles representation, for example, occurs only in CA-4 and in CA-2 and older beds. Another trend in these samples is the increasing proportion of structurally simpler types of Normapolles relative to the more complex types (for example, *Pseudoplicapollis*, *Trudopollis*, *Plicapollis*, *Endoinfundibulapollis*). This increase is particularly apparent between Zones CA-4 and CA-5 and continues during the supposed cool period of Zone CA-5. One possible explana-

TABLE 2.—Comparison of ages predicted on the basis of climatic cycles with radiometric ages in Campanian and Maestrichtian rocks of the Middle Atlantic States
[Radiometric ages from Owens and Sohl (1973)].

Climate	Rock unit (or subdivision)	Predicted age (m.y.)	Radiometric ages (m.y.)
Warm	Red Bank Sand Navesink Formation, upper part Navesink Formation, middle part	65.3	62.8±2.2, 63.2±1.9
Cool	Navesink Formation, lower part Mount Laurel Sand Wenonah Formation Marshalltown Formation	70.0	68.2±2.4, 71.4±2.5
Warm	Englishtown Formation	74.8	
Cool	Woodbury Clay	79.5	74.0±2.5
Warm	Merchantville Formation Cliffwood beds of Magothy Formation Morgan beds of Magothy Formation Amboy Stoneware Fire Clay Member of Magothy Formation	84.3	80.7±4.0, 81.2±2.6
Cool	Old Bridge Sand Member of Magothy Formation		

tion is that, contrary to earlier speculation (Wolfe, 1973), the cooler climate of Zone CA-5 was an impetus to the rise of the wind-pollinated amentiferous groups from the Normapolles stock; at least some of the simpler Normapolles types can be related to some extant amentiferous groups (see discussion of types NK and NN on page 13).

SIGNIFICANT POLLEN TYPES

Rather than enter into the controversial area of nomenclature of fossilized pollen, I have chosen to adopt an expedient course of coding most of the pollen types. Where previously described genera and species can be recognized, the probably formal designation has been pointed out. As Hughes (for example, Hughes and Moody-Stuart, 1967) has exhaustively pointed out, there has been a definite tendency for palynologists to apply previously published names to new material that, to a greater or lesser extent, differs from the type specimen or suite on which the names are based. This, in turn, has led to apparently broad stratigraphic ranges, not of great use in biostratigraphy. I readily admit that some of the "code species" distinguished in this report may not be of specific rank to some palynologists, but the recognition of minor differences that appear to be correlative with stratigraphic differences will, I hope, make this report of more value to palynologists interested in stratigraphy.

In this section of the report, the pollen types of apparent stratigraphic, biogeographic, or evolutionary significance are discussed. The pollen types have been

broken down into several major categories: the Normapolles complex (N), tricolpates (C3), tricolporates (CP3), "Proteacidites" (PR), and miscellaneous pollen types (MP). A letter immediately following the above designations indicates that two or more genera are taken to have been included in the overall designation and the letters represent different genera. The number following the dash indicates the different pollen species.

Not all the pollen types found in the current study are discussed here or illustrated. Fern spores have been ignored, and most gymnospermous and monocotyledonous pollen; and though 104 dicotyledonous pollen types are discussed and figured, at least an equal number that were photographed in the surveys were found to be typically rare and therefore ignored.

Type NA (Basopollis and Choanopollenites).—These two genera are characterized by the presence of a distinct mesopore and a broad endopore; the wall complex forming the mesopore protrudes toward the exopore. In erecting *Choanopollenites*, Stover (in Stover and others, 1966) noted that *Basopollis* had a vestibulum, and, by inference, *Choanopollenites* does not. From Stover's figure 1a on plate 5, a distinct (albeit weak) endopore is apparent, and thus *Choanopollenites* does, in fact, possess a vestibulum. The only feature distinguishing the two genera is that the wall complex forming the mesopore is thickened at the mesopore in *Choanopollenites*, whereas the probably homologous wall complex in *Basopollis* is of uniform thickness. Were I considering formal nomenclatorial problems in this report, I would

consider *Choanopollenites* a junior synonym of *Basopollis*.

Type NA-1 (pl. 1, fig. 1) is closely similar to *Choanopollenites discipulus* R. Tschudy from the late Maestrichtian and Paleocene of the Mississippi embayment (Tschudy, 1975). The Atlantic Coastal Plain species, however, has a larger atrium, and the walls forming the exopore are less thickened and less protruding than in *C. discipulus*. Type NA-1 occurs in the Woodbury and Englishtown. Tschudy (1973) suggested that *C. discipulus* was derived from *C. transitus* R. Tschudy, which in turn was derived from some species of *Complexiopollis*. The Atlantic Coastal Plain sequence, however, indicates that the *C. discipulus* type is in fact older than the *C. transitus* type. Whether *Choanopollenites* is directly derived from any type of *Complexiopollis* is, I think, open to question. *Choanopollenites* has an apertural structure fundamentally similar to that of *Basopollis*, which, as Góczán, Groot, Krutzsch, and Pacltová (1967, p. 487) have shown, is most similar to that of *Plicapollis*. Further, *Complexiopollis abditus* R. Tschudy, one of the possible ancestors for *Choanopollenites* suggested by Tschudy (1973), is fundamentally different from both *Complexiopollis* and *Choanopollenites*. This species has equatorial thickenings of the outer wall layer that extend toward the poles (so-called arci), and these thickenings form the exopore (this is evident from Tschudy's photographs), not the mesopore (as misinterpreted in Tschudy's text-fig. 5); this species is common in the Merchantville and Woodbury (see discussion of type NB on page 00).

Type NA-2 (pl. 1, fig. 2) is similar to NA-3 (pl. 1, fig. 3; *Choanopollenites transitus* R. Tschudy) except that the outer wall is of consistent thickness, that is, there is no tendency for the wall to be enlarged around the exopore. Type NA-2, which is confined to the Englishtown and Marshalltown, is apparently ancestral to NA-3. Type NA-3 ranges from the Marshalltown-Wenonah transition through the middle part of the Navesink. Type NA-4 (pl. 1, fig. 4) is known only from the uppermost part of the Severn River Monmouth; this type has the mesopore extending almost to the inner part of the exopore (and hence the atrium is extremely small), bulbous, protruding amb, and is larger than NA-2 and NA-3. Tschudy (1973, figs. 9-13) illustrated grains from the Paleocene Clayton Formation that conform to NA-4.

Type NA-5 (pl. 1, fig. 5) has been found in only one sample from the upper part of the Severn River Monmouth. Except for its smaller size, NA-5 is similar to *Choanopollenites* sp. A of Tschudy (1973), which is known from the Paleocene Clayton Formation. Type NA-5 is perhaps ancestral to this Tertiary species.

Type NA-6 (pl. 1, fig. 6) from the Merchantville is the

oldest known *Choanopollenites*. The more rounded amb, larger atria, and more conspicuous radial baculae distinguish NA-6 from NA-2. NA-7 (pl. 1, fig. 7) from the Englishtown has thickened walls forming the exopore, and radial baculae are very indistinct. Similar to NA-7 but with conspicuous radial baculae is NA-8 (pl. 1, fig. 8; Wenonah through Red Bank.) Type NA-8 also resembles *C. conspicuus* (Groot and Groot) R. Tschudy, but *C. conspicuus* is larger and has a narrower mesopore.

Type NB.—As discussed above, this type is probably not closely related to *Complexiopollis*. Type NB-1 (pl. 1, fig. 9; basal Merchantville through Englishtown) compares well with "*Complexiopollis*" *abditus* R. Tschudy. Although Tschudy (1973) cited the range of "*C.*" *abditus* as Coniacian through upper Campanian, Wolfe and Pakiser (1971) indicated that the Eutaw Formation, from which Tschudy's "Coniacian" sample came, is of Santonian through earliest Campanian age, and Sohl (in Owens and others, 1970) indicated that the Coffee Sand, from which Tschudy's "late Campanian" sample came, is of early Campanian age.

Type NB-2 (pl. 1, fig. 10) has, in the present study, been found only in the basal Merchantville. Wolfe and Pakiser (1971, fig. 5-m), however, reported the same form from the Cliffwood beds of the Magothy Formation. Type NB-3 (pl. 1, figs. 11, 12) differs from NB-2 by having the thickenings of the wall extend farther toward the poles; NB-3 closely resembles "*Complexiopollis*" *microverrucosus* R. Tschudy, except that the latter has the walls thickened around the exopore. Possibly NB-3 is descended from NB-2; NB-3 is known from the upper part of the Merchantville through the upper part of the Severn River Monmouth.

Type NC (*Pseudoplicapollis*).—At least three basic types of NC can be distinguished. Type NC-1 (pl. 1, fig. 13), which occurs from the Merchantville through the Englishtown, is characterized by a thickened wall surrounding the exopore; type NC-2 (pl. 1, fig. 14; Merchantville through Wenonah), which was described by Tschudy (1975) as *P. endocuspis*, has little or no enlargement of the wall around the pore, and also has less conspicuous plicae than NC-1. Type NC-3 (pl. 1, fig. 15) has no enlargement of the wall around the pore, very weak plicae, and a broad vestibulum; this type ranges from the Merchantville through the Severn River Monmouth.

Type ND.—This Normapolles type falls outside of the bounds of previously described genera as circumscribed by Góczán, Groot, Krutzsch, and Pacltová (1967). Type ND is particularly close to *Plicapollis* but differs in that the endopore is V-shaped or U-shaped inwardly. Type ND-1 (pl. 1, fig. 16) is larger than ND-2 (pl. 1, fig. 17) and has distinct sculpturing in contrast to the almost

psilate condition in ND-2. ND-1 is rare in the Merchantville through Englishtown; ND-2 is rare but is restricted to the Marshalltown and Wenonah.

Type ND-3 (pl. 1, fig. 18) typically has weakly developed Y-shaped thickenings and a broadly U- or V-shaped endopore. This species is common from the Woodbury through the Wenonah.

Type (NE) *Plicapollis*.—Several distinct types of *Plicapollis* have been recognized, but only four appear to be of common occurrence. Type NE-1 (pl. 1, fig. 19; *P. rusticus* R. Tschudy) is common from the Magothy through the Woodbury and occurs up into the Marshalltown. Type NE-2 (pl. 1, fig. 20; *P. retusus* R. Tschudy) has been found only in the Englishtown and Marshalltown, and type NE-3 (pl. 1, fig. 21; *P. usitatus* R. Tschudy) ranges from the uppermost Marshalltown through the Navesink and the Severn River Monmouth. From this stratigraphic distribution, it is tempting to suggest that NE-1 is the type ancestral to at least NE-3, which differs primarily by its smaller size and thinner walls.

Type NE-4 (pl. 1, fig. 22) differs from NE-1 by its smaller size, thin walls, and round body. Type NE-2 has conspicuous radial baculae on the interior of the exopore. Type NE-4 is most similar to NE-3, but NE-3 has a considerably larger atrium. Although NE-4 technically conforms to *Plicapollis* in pore structure, in other characters it closely resembles *Pseudoplicapollis* (type NC) and may be a species of this genus that has converged with *Plicapollis*. To this time NE-4 is known only from the lower part of the Merchantville.

Types NF (*Trudopollis*) and NM (*Endoinfundibulapollis*).—NF (*Trudopollis*) and NM (*Endoinfundibulapollis*) are treated together because they are linked by intermediate forms. Type NF-1 (pl. 1, figs. 23, 24) has an endopore of varying width, and in some specimens (particularly from the higher part of the Merchantville; pl. 1, fig. 24) the vestibulum is large, apparently as a result of the collapse of the inner wall(s) inward into the grain. In NF-2 (pl. 1, fig. 25; restricted to the Woodbury), the wall around the exopore is considerably thinner (as is the wall elsewhere) than in NF-1, and the inner wall(s) is pulled even more inward. In NM-1, (pl. 1, fig. 26), which represents Tschudy's (1975) type species of *Endoinfundibulapollis*, found from the Englishtown through the Wenonah, the vestibulum is consistently larger than in NF-2.

Type NF-3 (pl. 1, fig. 27) appears to represent a distinct *Trudopollis*, but one that has no obvious ancestral type lower in the section. NF-3 has been found only in the Mount Laurel.

Type NF-4 (pl. 1, fig. 28) is rare in the Englishtown and Wenonah. In shape, size, and sculpturing, this species appears to fall within *Trudopollis variabilis* R. Tschudy.

Type NG *Pseudatlantopollis*.—Type NG (pl. 1, figs. 29, 30) appears to fall near *Pseudatlantopollis simulatus* R. Tschudy. Tschudy, however, stated that the size range of this species is 20–26 μm (based on 35 specimens), whereas the two Navesink specimens are 29 and 32 μm . The size difference, coupled with the somewhat rounder shape of the Navesink grains, may indicate that the Navesink species is new.

Type NH (*Interpollis*).—This species was included by Tschudy (1975) as *Interpollis cf. I. supplingensis*. None of the specimens from the Severn River Monmouth display an equatorial constriction and all possess a thickened endopore; this morphologic consistency in the Maryland material indicates that Tschudy's (1975) specimens figured on plate 4, figures 14, 15, probably represent a species different from the other specimens he referred to *I. cf. I. supplingensis*.

Whether NH-1 (pl. 1, fig. 35) could be validly referred to *Interpollis* is highly questionable. The facts that arci are absent and that it lacks an equatorial constriction indicate that NH- probably represents a distinct genus. Although both NH-1 and *Interpollis* have subequatorial pores, other Normapolles genera and derivatives have this tendency. It seems clear that *Carya* has developed subequatorial pores independently, and that this character, in itself, is not an indication of close relationship.

Type NI.—This Normapolles type has a pronounced Y-shaped polar thickening that enlarges into oculi around the pores. Of previously described genera, NI is apparently closest to *Bohemiapollis* but lacks the long, narrow canal of the exopore. NI-1 (pl. 1, figs. 31, 32) occurs in the basal Merchantville and in the Woodbury, whereas NI-2 (pl. 1, figs. 33, 34) occurs in the Englishtown. NI-2 differs by having a smaller atrium and exopore.

Type NJ (*Extremipollis*).—One Woodbury sample contains a small type of *Extremipollis* (NJ-1; pl. 2, fig. 1), the oldest known in North America or Europe. The larger *E. vivus* R. Tschudy (NJ-2; pl. 2, fig. 2) occurs from the Englishtown through the upper part of the Navesink.

Type NK.—Góczán, Groot, Krutzsch, and Pacltová (1967) have suggested that certain structures in the grains of the extant *Rhoiptelea* are homologous with similar structures in the Normapolles genus *Complexiopollis*; by inference, therefore, Rhoipteleaceae and the allied Juglandaceae could be considered as relicts of the Normapolles complex. Wolfe (1973) suggested that certain pollen grains from the Severn River Maestrichtian were assignable to Rhoipteleaceae and Juglandaceae and had features indicative of a derivation from the Normapolles complex. Further study has now indicated the strong probability that both ex-

tant families of Juglandales are, in fact, derivatives from certain Normapolles types.

A pollen type (NK-1 pl. 2, fig. 3) restricted to the Marshalltown, Wenonah, and Mount Laurel, is of definite Normapolles affinities, as indicated by the radial baculae on the interior of the exopore. These grains appear to be structurally less complex than *Trudopollis*, which also has a somewhat thicker wall (particularly at the exopore), larger vestibulum, and a narrower endopore. Type NK-1 has a polar thinning on one hemisphere; this thin area is more conspicuous on grains with somewhat thicker walls.

Grains (NK-2; pl. 2, fig. 4) from the Severn River section of the Monmouth Group are slightly less aspidate than in NK-1, lack radial baculae on the interior of the exopore, and have a somewhat thinner wall although the same type of conspicuous polar thinning is consistently present. Type NK-2 is similar to type NK-3 in the uppermost Navesink and Red Bank. NK-3 differs by being smaller than NK-2 and having thinner walls. Pollen grains from the Paleocene of the Mississippi embayment that are perhaps the same entity as NK-3 (pl. 2, fig. 5) have been assigned to the extant *Engelhardtia* (for example, Elsik, 1968). I consider that the types NK-1, NK-2, and NK-3 represent a series transitional from the Normapolles complex (from *Trudopollis* or a close relative) to Juglandales.

Type NL (Praebasopollis).—Type NL-1 (pl. 2, fig. 6) is confined to the lower Merchantville but is especially common in 11218. The bulbous pores are particularly characteristic of this species. Type NL-2 (pl. 2, fig. 7) from the Woodbury has less bulbous pores.

Type NM.—See type NF.

Type NN.—Pollen type NN, which occurs from the Englishtown through the Mount Laurel, is characterized by the Y-shaped polar thickening, thick walls, and an exopore that has radial baculae on the interior. Except for the difference in structure of the wall in the polar area, NN-1 (pl. 2, fig. 8) is highly similar to NK-1 (pl. 2, fig. 3). Type NN-2 (pl. 2, fig. 9), which occurs in the Navesink, Red Bank, and Severn River Monmouth, lacks radial baculae, has a smaller and rounder exopore, and has thinner walls than NN-1. As pointed out previously (Wolfe, 1973), the type represented by NN-2 is probably assignable to Rhoipteleaceae.

If, as suggested here, types ancestral to Juglandaceae and Rhoipteleaceae have Normapolles characteristics, then clearly some true Normapolles must be members of Juglandales. That is, both NK-1 and NN-1 would have had a common ancestor and that ancestor must be within Juglandales if this order is a clade rather than a grade.

Type NO (*Osculapollis*).—Type NO-1 (pl. 2, fig. 10) conforms well to *Osculapollis aequalis* R. Tschudy. This

is a common species from the Englishtown through the Mount Laurel. A more rotund form of *Osculapollis* (NO-2 pl. 2, fig. 11) that has pronouncedly aspidate pores occurs in the Marshalltown through Mount Laurel. A form (NO-3; pl. 2, fig. 12) similar to NO-2 occurs in the Navesink through Red Bank and in the Severn River Monmouth; this form differs from NO-2 by being smaller. NO-4 (pl. 2, fig. 13) is the oldest record of the genus; this basal Merchantville species is similar to *O. perspectus* R. Tschudy but has a smaller atrium and tends to have more aspidate exopores.

Type NO-5 (pl. 2, fig. 14; Wenonah) is a polyporate (5-7 pores) that has the basic pore structure of *Osculapollis*. Conceivably NO-5 is a variant of NO-1, but NO-1 occurs abundantly in several other samples in which NO-5 is lacking.

Type NP.—This genus has pollen that is decidedly triangular in polar view with a broadly rounded amb. The outer and inner wall layers are of approximately equal thickness; the wall forming the endopore is ragged in the region of the pore. Type NP-1 (pl. 2, fig. 15) is thick-walled compared with the other species of the genus; this type is confined to the Marshalltown. NP-2 (pl. 2, fig. 16), in the Wenonah, has markedly thinner walls. Forms assigned to NP-2 in the Navesink and Severn River Monmouth are somewhat smaller than NP-2 in the Wenonah.

Type NQ.—Pronounced sculpturing is unusual for the Normapolles complex but is known in a few genera. That NQ (pl. 2, figs. 17-19) is indeed a Normapolles type is clear from the equatorial thickenings of the outer wall; the structure of this wall and the relation to the exopore are similar to NB. Type NQ, however, has a definite thickening of the exopore on the poleward parts of the slitlike aperture. The sculpturing in NQ tends to be irregular; some grains are uniform, others show a tendency for a gradation in size of the lumina from pole to equator.

The sculpturing in "*Proteacidites*" (or as this name is applied to many grains from the Northern Hemisphere) is typically thought to be gradational, from smaller luminae at the poles to larger luminae at the equator. In fact, some of the "*Proteacidites*" higher in the Coastal Plain section (see below) have uniform sculpturing and some have highly reduced sculpturing. The variability in sculpturing exhibited by these "*Proteacidites*" is similar to that exhibited by NQ. Perhaps the primary distinguishing feature of "*Proteacidites*" is the formation by the inner wall of a collar (or annulus) at the pore. Some specimens of NQ also have a tendency for the formation of a collar, although the collar does not completely envelop the pore. The similarities of NQ to both the Normapolles complex and to "*Proteacidites*" is here interpreted to indicate that, as Tschudy (1971) has

suggested, at least some of the Northern Hemisphere supposed proteaceous grains are derivatives of the Normapolles complex and are not closely related to Proteaceae. Martin (1973) has shown that forms from the Southern Hemisphere that superficially resemble extant Proteaceae have been invalidly considered to be of proteaceous affinities.

Type NR (*Pseudocupollis*).—A single grain (NR-1; pl. 2, fig. 20) compares well with *Pseudocupollis admirabilis* R. Tschudy, which is known from the upper Campanian of the Mississippi embayment. The New Jersey occurrence (Marshalltown) is in the same stratigraphic range; in Europe, the genus is known only from the Santonian and lower Campanian (Góczán and others, 1967).

Type NS (*Longanulipollis*).—NS-1 (pl. 2, fig. 21) from the Englishtown is the sole known representative of *Longanulipollis* in North America. This occurrence is apparently somewhat older than known occurrences of the genus in Europe (late Campanian-Maestrichtian). The North American species is, except for its smaller size, closely similar to the type species of the genus, *L. longianulos* (Gocz.) Gocz.

Type NT (*Pseudovacupollis*).—Tschudy (1975) records *Pseudovacupollis involutus* (NT-1; pl. 2, fig. 22) from several samples from the Mississippi embayment (late early Campanian through Maestrichtian). Thus far, this species has been encountered in two Atlantic Coastal Plain samples which came from Marshalltown-Wenonah transition and the upper part of the Navesink.

Type NU.—This type is one of the simpler Normapolles. The outer and inner walls are of about the same thickness and are thin. The pores are slightly aspidate and slit-shaped. Only a trace of sculpturing is present on the inner wall of the exopore. This species (NU-1; pl. 2, fig. 23) is known from the Englishtown through the Marshalltown-Wenonah transition.

Type NV.—This presumed Normapolles type has the most simplified pore structure of the younger forms of NK and NN. The Y-shaped polar thickening in NN, however, has arms oriented towards the pores, whereas in NV-1 (pl. 2, fig. 24; Wenonah and Severn River Monmouth) the arms are oriented between the pores.

Type PR ("Proteacidites").—As discussed above, the pollen from the Atlantic Coastal Plain Cretaceous that is typically assigned to *Proteacidites* is probably a derivative of the Normapolles complex. Despite extensive search in over 40 samples from the Magothy Formation, no pollen of the type discussed below has been found, and this type is also missing from the sample from the basal Merchantville.

PR-1 (pl. 2, fig. 25) is characterized by a wide pore that has a thin collar; this type, the most wide-ranging,

is found from the Merchantville through the Navesink. PR-2 (pl. 2, figs. 26, 27) from the Merchantville has a narrower, more elongate pore that has a conspicuous collar; also, the wall layers are well differentiated. This differentiation may be a retention of a feature characteristic of the Normapolles complex. PR-3 (pl. 2, fig. 28) from the Englishtown has the coarsest sculpturing of these "*Proteacidites*." PR-4 (pl. 2, fig. 29) from the Wenonah has an elongated collar around the pore; this type is somewhat similar to PR-2 but has thinner walls and more distinct sculpturing. PR-5 (pl. 2, fig. 30) from the Navesink is a small, indistinctly sculptured grain that has thin walls and an elongated collar around the pore. PR-6 (pl. 2, fig. 31) from the Englishtown has a conspicuous collar around the pore but the sculpturing is most reduced of any of these species. PR-7 (pl. 2, fig. 32) from the Englishtown through the Navesink has a pronounced collar around the pore and the sculpturing is fine but distinct.

Type C3A.—Included in this type are grains that are circular in polar view, have broad and deeply incised colpi that are not bordered by thickenings, and have reticulate sculpturing. Type C3A-1 (pl. 3, fig. 1; upper part of Merchantville through Englishtown) is particularly common in the Woodbury. Type C3A-2 (pl. 3, fig. 2; basal Merchantville through Englishtown) is larger and has a finer reticulum than C3A-1. C3A-3 (pl. 3, fig. 3; uppermost Merchantville and lowermost Woodbury) is characterized by the exceptionally coarse reticulum. The Wenonah and Navesink C3A-4 (pl. 3, fig. 4) also has a coarse reticulum, but the ridges are narrow and the size is smaller than in C3A-3. The ridges of the reticulum of C3A-5 (pl. 3, fig. 5; upper Woodbury through Englishtown) are thicker than in C3A-4.

Type C3B.—This type differs from C3A primarily by having thickened colpal borders although typically the colpi are somewhat less broad. C3B-1 (pl. 3, fig. 6) is common in various Woodbury samples. The Englishtown C3B-2 (pl. 3, fig. 7) has a finer reticulum and less deeply incised colpi. C3B-3 (pl. 3, fig. 8) in the Wenonah and Navesink has a coarse reticulum. With an even coarser reticulum and a definitely larger size is C3B-4 (pl. 3, fig. 9) in the Marshalltown.

Type C3C.—This type is approximately triangular in polar view, has colpi that are bordered by thickenings, and has reticulate sculpturing. Because there is some indication of pores, this type might prove to be better classed as a tricolporate (CP3). C3C-1 (pl. 3, fig. 11; Cliffwood and basal Merchantville) has a coarse reticulum that has luminae of irregular shape and size. The Merchantville material of C3C-1 has somewhat less deeply incised colpi; in this character it is more similar to C3C-2 (pl. 3, fig. 12). C3C-2 (Woodbury) has a finer reticulum that has luminae of approximately reg-

ular shape and size, and the Englishtown C3C-3 (pl. 3, fig. 13) has an even finer reticulum. It is possible that these three species are a phyletic series. The distinctiveness of the Woodbury C3C-4 (pl. 3, fig. 10) with its coarse and irregular sculpture, large size, and pronouncedly concave sides indicates little, if any, close relationship to the other species of C3C.

Type CP3A.—This type is characterized by its circular shape in polar view, colpi that have thickened borders, and reticulate sculpturing. CP3A-1 (pl. 3, fig. 16) and CP3A-2 (pl. 3, fig. 14) have overlapping ranges (upper part of Merchantville and Woodbury) but appear to be closely similar. CP3A-2 is smaller and has less deeply incised colpi than CP3A-1. CP3A-3 (pl. 3, fig. 17; Navesink) is similar to CP3A-1 in size and degree of incision of the colpi but has a much finer reticulum.

Type CP3B.—This type is similar to CP3A but is triangular rather than circular in polar view; the outer and inner walls are of equal thickness. CP3B-1 (pl. 3, fig. 15; Cliffwood beds and basal Merchantville) has colpi incised about halfway to the poles and a fine reticulum. CP3B-2 (pl. 3, fig. 18; upper part of Merchantville) has a coarser reticulum and thicker margo than CP3B-1. A common form in several Woodbury samples is CP3B-3 (pl. 3, fig. 19), which has an exceptionally coarse reticulum, pronounced margo, and short colpi. CP3B-4 (pl. 3, fig. 20; upper part of Woodbury) has sculpturing similar to CP3B-2 (except that the reticulum is thicker as in CP3B-5), but the margo is similar in thickness to CP3B-3. CP3B-5 (pl. 3, fig. 21; Englishtown) has sculpturing and margo similar to CP3B-2, but the colpi are short. If these various species represent a phyletic series, it is apparent that the trends toward coarse sculpturing and thickened margo were reversed in late Woodbury times, in contrast to the consistent trends towards shortening of the colpi and increase in thickness of the reticulum.

Whereas the margo in CP3B-1 through 5 tend to thin poleward, in forms CP3B-6, 7, and 8, they tend to be of uniform thickness. CP3B-6 (pl. 4, fig. 1; Woodbury and Merchantville) is similar to CP3B-2 in sculpturing, but the wall of the grain curves around the corners to make a slitlike colpus. CP3B-7 (pl. 4, fig. 2; Englishtown) is smaller than CP3B-6 and has the pore more deeply inset from the corners of the grain. CP3B-8 (pl. 4, fig. 3; Wenonah) is smaller than these two forms and has a finer reticulum.

Type CP3C.—This type is similar to CP3B except that the inner wall is thicker than the outer wall. CP3C-1 (pl. 4, fig. 4; Woodbury) is rare but is so distinctive that it would be readily recognizable and perhaps be an excellent marker. In wall structure and sculpturing, CP3C-1 is similar and may be ancestral to CP3C-2 (pl. 4, fig. 5; Englishtown). CP3C-2 is smaller and the pores are

protruding.

Type CP3D.—Type CP3D is recognized on the basis of the straight channeling of the inner wall and the baculate sculpturing. Tertiary material of this type has been referred to *Holkopollenites* Fairchild (in Stover and others, 1966), which has been recorded by several workers from the Paleocene and Eocene of the Mississippi embayment. The oldest record of this type is small grains from the Cliffwood beds and Merchantville; this species (CP3D-1; pl. 4, figs. 6, 7) varies, as do younger species of the genus, by having concave to convex sides. CP3D-2 (pl. 4, figs. 8, 9; Woodbury and Englishtown) is considerably larger than CP3D-1. CP3D-3 (pl. 4, fig. 10; Marshalltown through Red Bank) has more deeply incised colpi than CP3D-2; there is also a tendency for the sides of the grains to be more convex in CP3D-3 and more concave in CP3D-2. *H. chemardensis* Fairch. has colpi more deeply incised than in CP3D-3.

Type CP3E.—In this type, the inner wall is channeled by anastomosing rather than straight grooves, and the sculpturing is decidedly finer than in *Holkopollenites*. CP3E-1 (pl. 4, fig. 11) occurs in the upper part of the Merchantville, Woodbury, and Englishtown; this type is questionably known in the Mount Laurel. The one grain of this type from the Mount Laurel sample is smaller than any of the Woodbury or Englishtown specimens, but more Mount Laurel specimens will be needed to determine whether this size difference is consistent.

Type CP3F.—This type is pronouncedly brevicolpate, and is triangular in polar view; the apertures are located at the amb. CP3F-1 (pl. 4, fig. 12; Merchantville through Englishtown) is very indistinctly sculptured relative to the more distinct sculpturing of CP3F-2 (pl. 4, fig. 13; Mount Laurel through Red Bank).

Type CP3G.—CP3G-1 (pl. 4, fig. 14; upper part of the Navesink, Red Bank, and Severn River Monmouth) is characterized by exceptionally thick walls. The sculpturing is inconspicuously punctate.

Miscellaneous pollen types.—MPA-1 (pl. 4, fig. 15) is tricolporate, the colpi have thickened borders, and the apertures are located between the corners. This pollen type from the Merchantville is perhaps the forerunner of the bombacaceous type, which is present in the Navesink. Type MPB-1 (pl. 4, fig. 16) is similar in sculpturing and size to pollen of the extant bombacaceous *Cavanelisia*. MPC-1 (pl. 4, fig. 17) from the Severn River Monmouth is probably referable to *Bombacidites* on the basis of having larger meshes at the poles than at the equator (Srivastava, 1972).

MPD-1 (pl. 4, fig. 18) is a characteristic syncolpate known only from the Severn River Monmouth and the Red Bank. Types MPD-2 (pl. 4, fig. 19; Wenonah and Severn River Monmouth) and MPD-3 (pl. 4, fig. 20;

lower part of the Navesink) are less conspicuously sculptured than MPD-1. The sculpturing in MPD-3 is greatly reduced near the colpal borders compared with MPD-2. Fragments of the syncolpate *Trisectoris* occur throughout the section, and this genus is known in the Magothy (Wolfe and Pakiser, 1972). Other syncolpate types are rare; none are known in more than one sample. In general, more different types of syncolpates are known in the upper Campanian and Maestrichtian (at least seven types) than in the lower Campanian (two types).

Polyporates are unknown in the lower Campanian part of the section, whereas at least 10 types are known from samples in the Marshalltown through Red Bank interval. Of these types, only four occur in more than one sample. MPE-1 (pl. 4, figs. 21, 22), which is a polyporate grain that has weak sculpturing, is known from the Severn River Monmouth; this type is perhaps of centrospermous affinity. Polyporate type MPF-1 (pl. 4, figs. 23, 24; Wenonah through Red Bank) has fewer pores than MPE-1, and the membranes covering the pores are flecked; similar pore membranes are found in extant families that are not closely related (for example, Hamamelidaceae and Pistaciaceae) and thus offer no certain clue of affinities. MPG-1 (pl. 4, fig. 25; Navesink and Severn River Monmouth) is a four-pored grain that has verrucate sculpturing; this type is almost certainly of ulmaceous affinity.

Types MPH-1 (pl. 4, fig. 26; Marshalltown and Wenonah) and MPH-2 (pl. 4, fig. 27; lower part of the Navesink and Severn River Monmouth) are polycolporates; MPH-2 differs by having a thinner wall and less conspicuous sculpturing.

MPI-1 (pl. 4, fig. 28) represents *Aquilapollenites*. I have found this in only one sample (from the Wenonah), whereas Evitt (oral commun., 1973) records the genus from the Marshalltown and the Red Bank.

FOSSIL LOCALITIES

11156. Lat 39°28'42" N., long 75°59'36" W. Merchantville Formation. Collector J. P. Owens.
11172. Lat 39°23'55" N., long 76°02'26" W. Merchantville Formation, lower part. Collector J. P. Owens.
11173. Lat 39°22'15" N., long 76°05'30" W. Merchantville Formation, about 10 ft above beach. Collector J. P. Owens.
11174. Same locality as 11173, Merchantville Formation, about 13 ft above beach. Collector J. P. Owens.
11176. Lat 39°21'10" N., long 76°03'58" W. Englishtown Formation, about middle. Collector J. P. Owens.
11210. Lat 39°02'03" N., long 76°33'20" W. Monmouth Formation on southwest side Severn River. A, near base; B, +8 ft; C, +16 ft; D, +20 ft; E, +24 ft. Samples collected about 4 ft apart. Collector J. A. Wolfe.
11212. Lat 39°02'03" N., long 76°33'20" W. Monmouth Formation, on northeast side Severn River. Samples collected about 3 ft apart. Collector J. A. Wolfe.
11213. Lat 39°03'40" N., long 76°33'17" W. uppermost Marshalltown Formation or lowermost Wenonah Formation. Samples collected about 3-4 ft apart. Collector J. A. Wolfe.
11217. Lat 40°26'49" N., long 74°12'39" W. Cliffwood beds of Magothy Formation. A, at mollusk horizon; B, about +15 ft; remainder samples about 2 to 3 ft apart, and H at top. Collector J. A. Wolfe.
11218. Same latitude and longitude as 11217. Merchantville Formation, basal part above reworked bed. Collector J. A. Wolfe.
11219. Lat 40°26'20" N., long 74°14'47" W. Merchantville Formation, middle and upper part. Samples collected about 3 ft apart. Collector J. A. Wolfe.
11221. Lat 40°22'19" N., long 74°18'30" W. Woodbury Clay, upper part. Samples collected about 7 ft apart. Collector J. A. Wolfe.
11222. Lat 40°24'50" N., long 74°01'35" W. Navesink Formation, lower part. A, just above contact with Mount Laurel Sand; B, +3 ft. Collector J. A. Wolfe.
11223. Lat 40°24'49" N., long 74°01'21" W. Navesink Formation, upper part. Samples collected about 3 ft apart. Collector J. A. Wolfe.
11224. Same latitude and longitude as 11223. Red Bank Sand, basal part. Collector J. A. Wolfe.
11225. Lat 40°08'16" N., long 74°33'18" W. Wenonah Formation, basal part. Samples collected about 2 ft apart. Collector J. A. Wolfe.
11226. Lat 40°07'57" N., long 74°36'27" W. Englishtown Formation, middle part. Samples collected about 3 ft apart. Collector J. A. Wolfe.
11227. Lat 40°07'35" N., long 74°42'31" W. Woodbury Clay, lower part. Samples collected about 4-5 ft apart. Collector J. A. Wolfe.
11228. Lat 40°07'40" N., long 74°43'47" W. Magothy Formation, upper part. Samples about 2 ft apart. Collector J. A. Wolfe.
11229. Lat 40°07'19" N., long 74°47'39" W. Magothy Formation, lower part. Collector J. A. Wolfe.
11230. Lat 39°32'37" N., long 75°42'23" W. Marshalltown Formation, lower part. Collector J. A. Wolfe.
11231. Lat 39°32'24" N., long 75°44'35" W. Merchantville Formation, upper part. Samples collected about 2 ft apart. Collector J. A. Wolfe.
11232. Lat 39°32'22" N., long 75°44'35" W. Magothy Formation. A, at base above contact with Potomac Group; B, +10-12 ft; C, +15 ft; D, +25 ft, at top. Collector J. A. Wolfe.
11233. Lat 39°33'12" N., long 75°38'14" W. Mount Laurel Sand, lower part (same as USGS Mesozoic loc. 29585 of Owens and others, 1970, p. 48, "Gryphaea" bed). Collector J. A. Wolfe.
11234. Lat 39°33'12" N., long 75°38'14" W. Marshalltown Formation, near top. Collector J. A. Wolfe.
11351. Excavation along south bank of Mantua Creek, northeast of road and bridge of Rt. 45 at Mantua, Gloucester County, N. J. Same as USGS Mesozoic loc. 30252. Marshalltown Formation, middle part. Collector N. F. Sohl.

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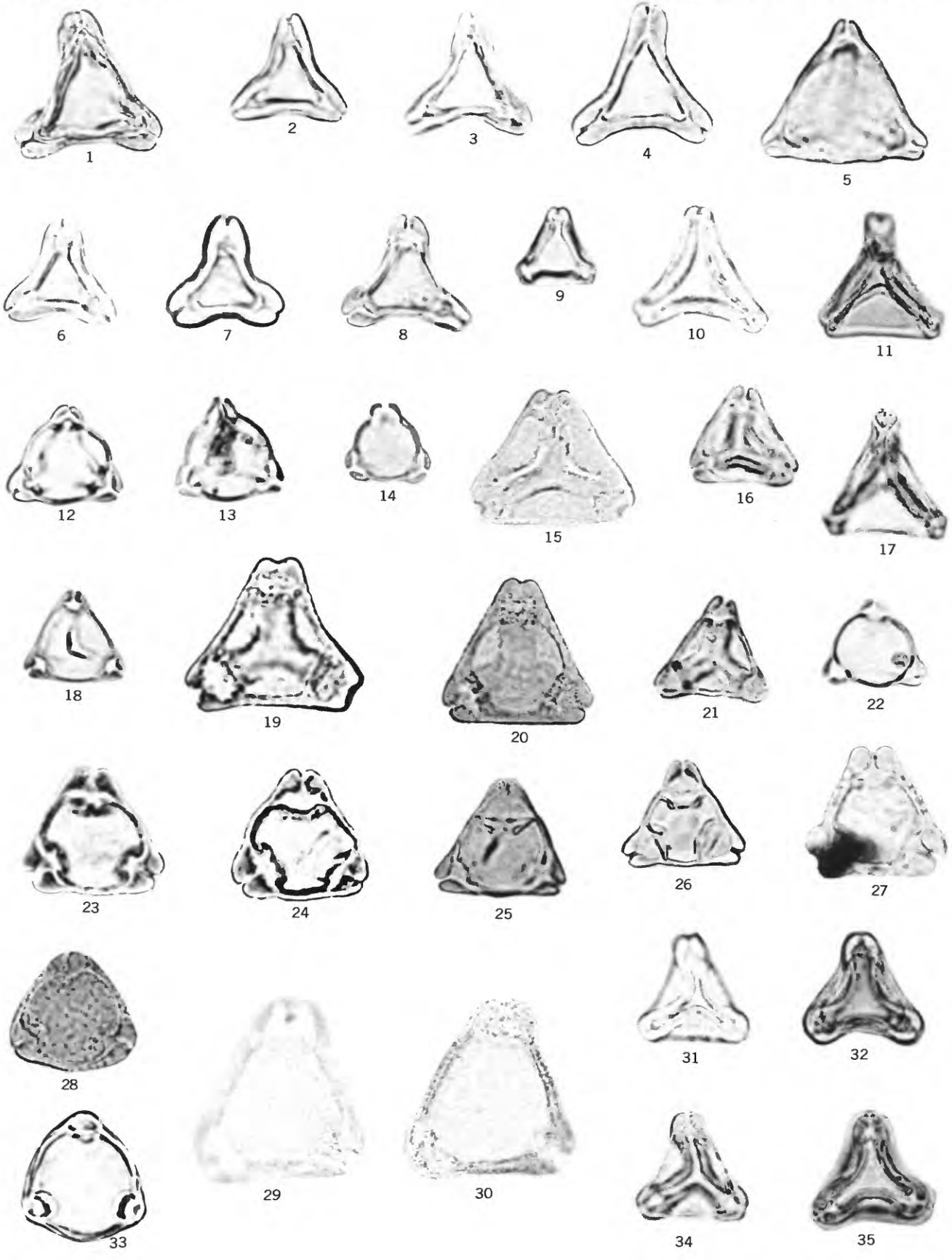
PLATES 1-4

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

PLATE 1

Campanian and Maestrichtian pollen. All figures $\times 1,000$.

- FIGURE 1. NA-1 Englishtown Formation, loc. 11226-A, slide 3, 103.4×14.0
2. NA-2. Englishtown Formation, loc. 11226-C, slide 1, 90.0×3.5 .
3. NA-3. Wenonah Formation, loc. 11213-C, slide 3, 104.6×19.7 .
4. NA-4. Monmouth Formation, loc. 11210-E, slide 2, 102.5×22.4 .
5. NA-5. Monmouth Formation, loc. 11212-H, slide 1, 94.3×4.1 .
6. NA-6. Merchantville Formation, loc. 11218, slide 3, 113.2×3.1 .
7. NA-7. Englishtown Formation, loc. 11226-C, slide 2, 86.1×2.9 .
8. NA-8. Red Bank Sand, loc. 11224, slide 3, 83.3×17.9 .
9. NB-1. Woodbury Clay, loc. 11227-C, slide 2, 88.2×4.7 .
10. NB-2. Merchantville Formation, loc. 11218, slide 3, 90.5×5.0 .
11, 12. NB-3. Wenonah Formation, loc. 11225-C, slide 3, 100.0×7.5 .
13. NC-1. Woodbury Clay, loc. 11221-A, slide 2, 89.0×5.9 .
14. NC-2. Merchantville Formation, loc. 11219-E, slide 2, 100.2×20.6 .
15. NC-3. Marshalltown Formation, loc. 11351, slide 2, 83.1×16.4 .
16. ND-1. Merchantville Formation, loc. 11218, slide 3, 110.0×15.6 .
17. ND-2. Marshalltown Formation, loc. 11230, slide 3, 103.8×15.6 .
18. ND-3. Englishtown Formation, loc. 11176, slide 2, 103.2×13.9 .
19. NE-1. Merchantville Formation, loc. 11219-G, slide 2, 95.3×10.0 .
20. NE-2. Englishtown Formation, loc. 11226-C, slide 3, 80.8×5.2 .
21. NE-3. Wenonah Formation, loc. 11225-C, slide 3, 102.6×6.2 .
22. NE-4. Merchantville Formation, loc. 11219-B, slide 1, 98.4×15.0 .
23, 24. NF-1. 23, Merchantville Formation, loc. 11219-B, slide 1, 90.6×13.9 .
24, Merchantville Formation, loc. 11219-E, slide 2, 83.9×13.3 .
25. NF-2. Woodbury Clay, loc. 11227-B, slide 2, 89.9×18.0 .
26. NM-1. Englishtown Formation, loc. 11176, slide 2, 103.8×12.6 .
27. NF-3. Mount Laurel Sand, loc. 11233, slide 3, 78.9×15.5 .
28. NF-4. Englishtown Formation, loc. 11176, slide 2, 90.3×3.0 .
29, 30. NG-1. Navesink Formation, loc. 11223-A, slide 1, 91.7×5.0 .
31, 32. NI-1. Merchantville Formation, loc. 11218, slide 3, 96.1×5.6 .
33, 34. NI-2. Englishtown Formation, loc. 11226-A, slide 3, 112.7×4.5 .
35. NH-1. Monmouth Formation, loc. 11212-E, slide 2, 96.1×3.3 .

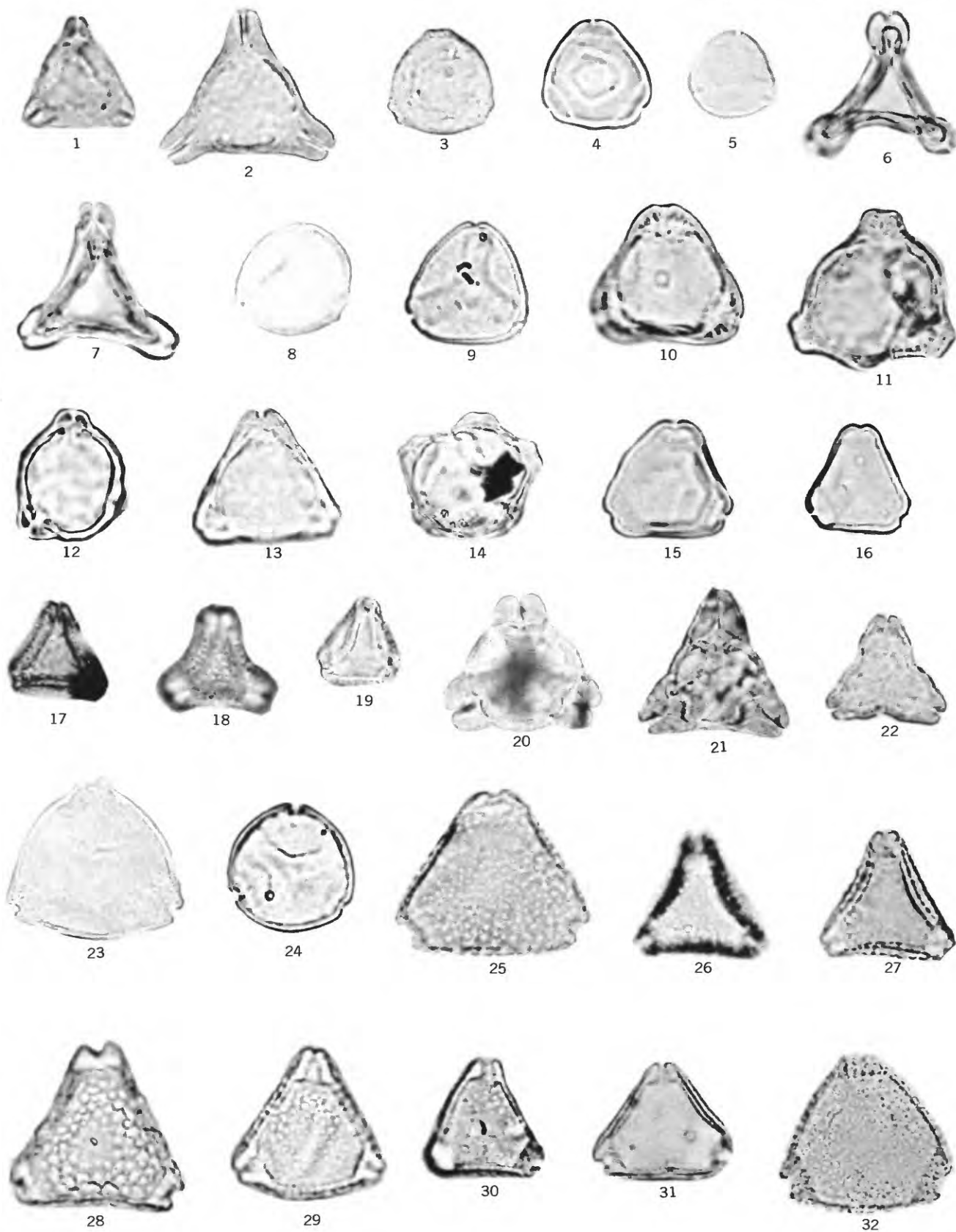


CAMPANIAN AND MAESTRICHTIAN POLLEN, NA-1 TO NH-1

PLATE 2

Campanian and Maestrichtian pollen. All figures $\times 1,000$.

- FIGURE
1. NJ-1. Woodbury Clay, loc. 11227-D, slide 2, 105.3×20.8 .
 2. NJ-2. Mount Laurel Sand, loc. 11233, slide 4, 108.1×19.4 .
 3. NK-1. Wenonah Formation, loc. 11225-B, slide 3, 107.4×2.8 .
 4. NK-2. Monmouth Formation, loc. 11210-E, slide 2, 99.5×4.6 .
 5. NK-3. Red Bank Sand, loc. 11224, slide 3, 94.9×11.4 .
 6. NL-1. Merchantville Formation, loc. 11218, slide 2, 82.4×10.0 .
 7. NL-2. Woodbury Clay, loc. 11227-C, slide 1, 88.5×4.1 .
 8. NN-1. Wenonah Formation, loc. 11213-A, slide 3, 85.1×5.0 .
 9. NN-2. Monmouth Formation, loc. 11210-A, slide 1, 106.9×13.7 .
 10. NO-1. Englishtown Formation, loc. 11226-C, slide 1, 106.2×21.5 .
 11. NO-2. Wenonah Formation, loc. 11225-C, slide 3, 92.8×8.6 .
 12. NO-3. Monmouth Formation, loc. 11212-H, slide 2, 88.8×5.9 .
 13. NO-4. Merchantville Formation, loc. 11218, slide 3, 111.7×4.3 .
 14. NO-5. Wenonah Formation, loc. 11225-B, slide 3, 81.9×17.6 .
 15. NP-1. Marshalltown Formation, loc. 11234, slide 2, 103.7×13.9 .
 16. NP-2. Monmouth Formation, loc. 11212-E, slide 2, 101.6×12.9 .
 - 17-19. NQ-1. 17, Cliffwood beds, loc. 11217-A, slide 2, 102.5×2.9 .
18, Cliffwood beds, loc. 11217-B, slide 2, 81.7×5.2 .
19, Cliffwood beds, loc. 11217-D, slide 2, 99.4×4.8 .
 20. NR-1. Marshalltown Formation, loc. 11234, slide 4, 96.5×10.7 .
 21. NS-1. Englishtown Formation, loc. 11226-C, slide 3, 98.8×13.9 .
 22. NT-1. Navesink Formation, loc. 11223-A, slide 3, 101.8×6.6 .
 23. NU-1. Englishtown Formation, loc. 11226-C, slide 3, 94.9×2.7 .
 24. NV-1. Monmouth Formation, loc. 11212-H, slide 2, 83.5×9.9 .
 25. PR-1. Woodbury Clay, loc. 11221-A, slide 1, 103.8×12.2 .
 - 26, 27. PR-2. Merchantville Formation, loc. 11219-G, slide 2, 90.7×12.9 .
 28. PR-3. Englishtown Formation, loc. 11176, slide 2, 98.0×9.1 .
 29. PR-4. Wenonah Formation, loc. 11225-C, slide 2, 82.0×6.8 .
 30. PR-5. Navesink Formation, loc. 11222-B, slide 2, 106.3×16.5 .
 31. PR-6. Englishtown Formation, loc. 11226-A, slide 1, 101.2×17.2 .
 32. PR-7. Englishtown Formation, loc. 11226-C, slide 3, 86.1×8.4 .

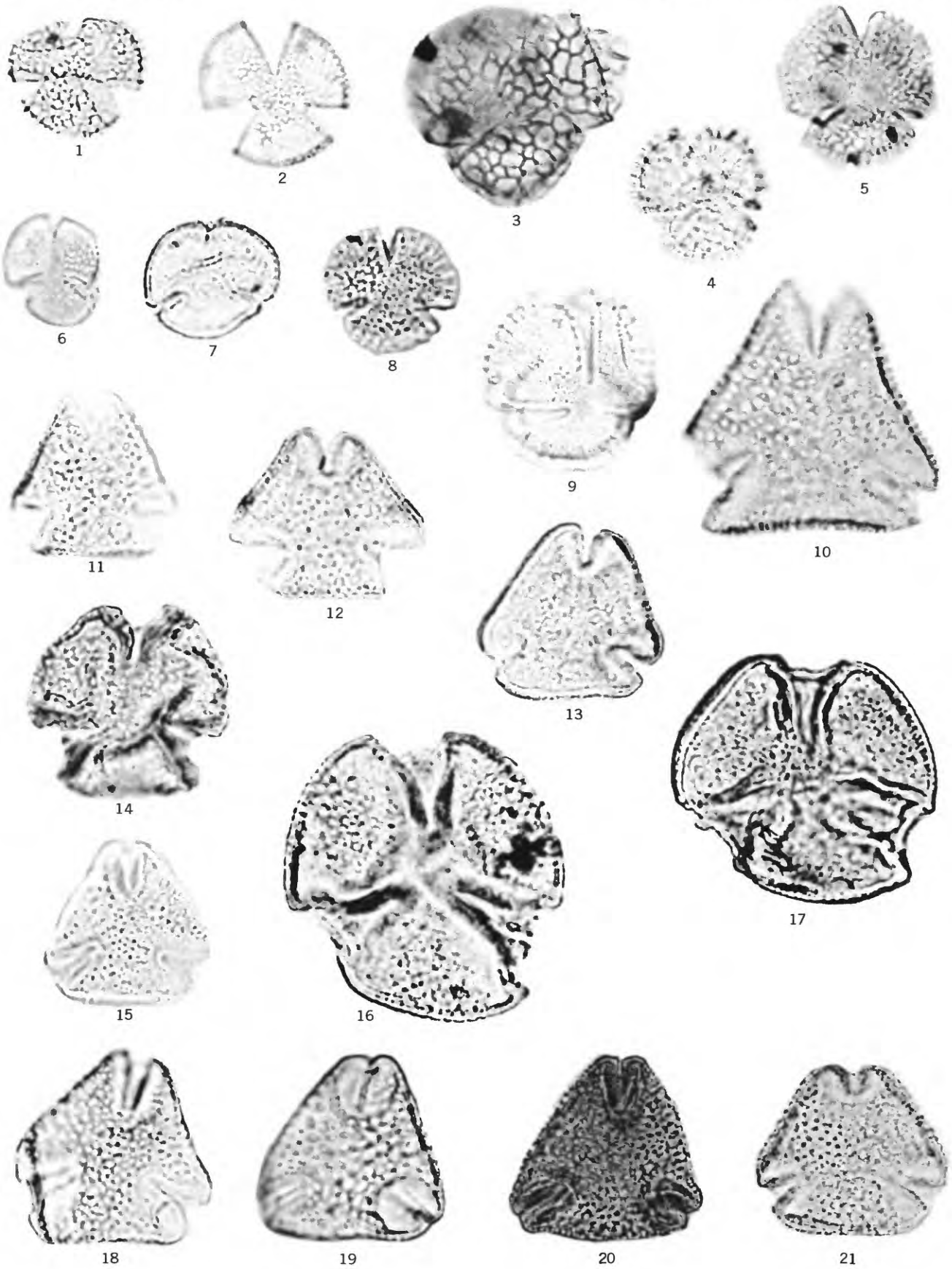


CAMPANIAN AND MAESTRICHTIAN POLLEN, NJ-1 TO PR-7

PLATE 3

Campanian and Maestrichtian pollen. All figures $\times 1,000$.

- FIGURE
1. C3A-1. Merchantville Formation, loc. 11172, slide 1, 104.9×22.4 .
 2. C3A-2. Englishtown Formation, loc. 11226-A, slide 2, 84.4×8.0 .
 3. C3A-3. Woodbury Clay, loc. 11227-C, slide 1, 86.0×14.8 .
 4. C3A-4. Wenonah Formation, loc. 11225-B, slide 3, 87.8×15.2 .
 5. C3A-5. Woodbury Clay, loc. 11221-A, slide 2, 99.3×3.3 .
 6. C3B-1. Woodbury Clay, loc. 11227-C, slide 1, 100.1×3.0 .
 7. C3B-2. Englishtown Formation, loc. 11226-A, slide 1, 83.6×7.3 .
 8. C3B-3. Wenonah Formation, loc. 11213-B, slide 2, 81.4×10.6 .
 9. C3B-4. Marshalltown Formation, loc. 11230, slide 3, 105.7×7.5 .
 10. C3C-4. Woodbury Clay, loc. 11227-C, slide 1, 104.0×6.0 .
 11. C3C-1. Cliffwood beds of Magothy Formation, loc. 11217-C, slide 2, 106.6×3.7 .
 12. C3C-2. Woodbury Clay, loc. 11221-A, slide 1, 101.4×7.9 .
 13. C3C-3. Englishtown Formation, loc. 11226-A, slide 2, 82.6×11.1 .
 14. CP3A-2. Woodbury Clay, loc. 11227-A, slide 1, 108.7×13.3 .
 15. CP3B-1. Cliffwood beds of Magothy Formation, loc. 11217-C, slide 2, 88.7×14.2 .
 16. CP3A-1. Merchantville Formation, loc. 11219-E, slide 2, 107.7×3.7 .
 17. CP3A-3. Navesink Formation, loc. 11222-B, slide 2, 87.3×17.2 .
 18. CP3B-2. Merchantville Formation, loc. 11219-F, slide 2, 101.3×8.1 .
 19. CP3B-3. Woodbury Clay, loc. 11227-D, slide 2, 99.2×8.5 .
 20. CP3B-4. Woodbury Clay, loc. 11221-B, slide 3, 82.3×13.8 .
 21. CP3B-5. Englishtown Formation, loc. 11226-C, slide 3, 99.9×21.2 .

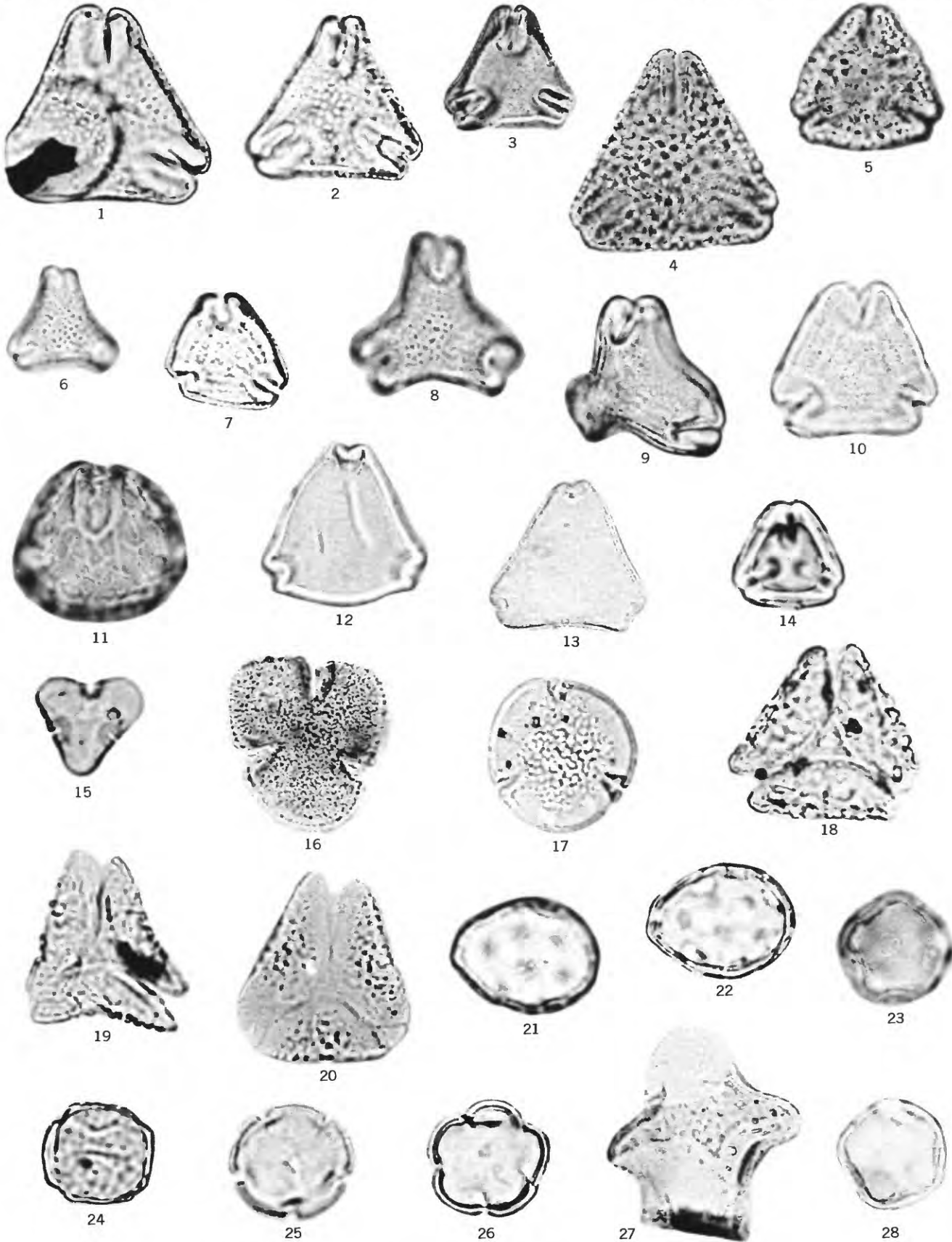


CAMPANIAN AND MAESTRICHTIAN POLLEN, C3A-1 TO CP3B-5

PLATE 4

Campanian and Maestrichtian pollen. All figures $\times 1,000$.

- FIGURE 1. CP3B-6. Merchantville Formation, loc. 11172, slide 1, 90.0×14.0 .
2. CP3B-7. Englishtown Formation, loc. 11226-A, slide 2, 94.8×3.6 .
3. CP3B-8. Wenonah Formation, loc. 11225-C, slide 3, 85.6×5.3 .
4. CP3C-1. Woodbury Clay, loc. 11227-A, slide 2, 93.3×8.5 .
5. CP3C-2. Englishtown Formation, loc. 11226-C, slide 3, 105.7×11.8 .
6, 7. CP3D-1. 6, Cliffwood beds of Magothy Formation, loc. 11217-F, slide 2, 97.1×8.2 .
7, Merchantville Formation, loc. 11173, slide 1, 89.4×5.7 .
8, 9. CP3D-2. 8, Merchantville Formation (Woodbury age), loc. 11231-D, slide 1, 96.5×17.9 .
9, Englishtown Formation, loc. 11176, slide 2, 102.1×8.0 .
10. CP3D-3. Wenonah Formation, loc. 11225-B, slide 3, 106.9×5.3 .
11. CP3E-1. Woodbury Clay, loc. 11231-D, slide 1, 94.9×17.1 .
12. CP3F-1. Englishtown Formation, loc. 11226-A, slide 3, 106.5×5.3 .
13. CP3F-2. Navesink Formation, loc. 11223-B, slide 3, 106.5×17.8 .
14. CP3G-1. Monmouth Formation, loc. 11212-A, slide 2, 102.3×4.5 .
15. MPA-1. Merchantville Formation, loc. 11219-B, slide 1, 101.1×19.6 .
16. MPB-1. Navesink Formation, loc. 11223-B, slide 3, 113.9×22.7 .
17. MPC-1. Monmouth Formation, loc. 11212-G, slide 2, 83.0×2.6 .
18. MPD-1. Monmouth Formation, loc. 11210-B, slide 2, 101.2×6.9 .
19. MPD-2. Wenonah Formation, loc. 11225-C, slide 2, 86.4×16.4 .
20. MPD-3. Navesink Formation, loc. 11223-B, slide 4, 106.3×1.8 .
21, 22. MPE-1. Monmouth Formation, loc. 11212-E, slide 2, 90.0×7.7 .
23, 24. MPF-1. Wenonah Formation, loc. 11213-B, slide 3, 100.4×16.2 .
25. MPG-1. Monmouth Formation, loc. 11212-E, slide 1, 109.3×16.8 .
26. MPH-1. Wenonah Formation, loc. 11213-A, slide 2, 83.4×9.4 .
27. MPH-2. Monmouth Formation, loc. 11210-B, slide 1, 108.4×10.6 .
28. MPI-1. Wenonah Formation, loc. 11213-B, slide 3, 111.6×16.8 .



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