Stratigraphic, Paleoclimatic, and Paleobiogeographic Significance of Tertiary Sporomorphs from Massachusetts

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1308

Stratigraphic, Paleoclimatic, and Paleobiogeographic Significance of Tertiary Sporomorphs from Massachusetts

By NORMAN O. FREDERIKSEN

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1308

Subtropical Miocene, temperate Pliocene, and reworked tropical Eocene sporomorph assemblages from eastern Massachusetts are described

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON: 1984

DEPARTMENT OF THE INTERIOR

WILLIAM P. CLARK, *Secretary*

U.S. GEOLOGICAL SURVEY

Dallas L. Peck, *Director*

Library of Congress Cataloging in Publication Data

Frederiksen, Norman O.
Stratigraphic, paeloclimatic, and paleogeographic significance of Tertiary sporomorphs from Massachusetts

(Geological Survey professional paper ; 1308)
Supt. of Docs. no.: I 19.16:1308
1. Palynology—Massachusetts. 2. Paleobotany—Tertiary. I. Title. II. Series.
QE993.F733 1984 561;.13'09744 83–18519

**For sale by the Distribution Branch, U.S. Geological Survey,
604 South Pickett Street, Alexandria, VA 22304**

CONTENTS

ILLUSTRATIONS

[Plates follow references]

TABLES

STRATIGRAPHIC, PALEOCLIMATIC, AND PALEOBIOGEOGRAPHIC SIGNIFICANCE OF TERTIARY SPOROMORPHS FROM MASSACHUSETTS

By NORMAN O. FREDERIKSEN

ABSTRACT

Little has been published on the Tertiary sporomorph (spore and pollen) floras of New England. For this paper, I have examined 24 sporomorph samples from six localities in Plymouth County and Martha's Vineyard, Mass. Two independently dated samples, from the middle Miocene and Pliocene, respectively, of Gay Head, Martha's Vineyard, show that the Miocene flora of eastern Massachusetts represents rich subtropical forest, whereas the Pliocene flora reflects a relatively depauperate cool temperate forest. This middle Miocene sporomorph assemblage is compared with Tertiary assemblages from five other localities in eastern Massachusetts, and these six assemblages are compared with Miocene assemblages, most of them previously described, from Maryland and New Jersey. All six Massachusetts assemblages are similar to those from the Miocene of the Middle Atlantic States, but because the obvious qualitative (presence-absence) changes were few in the sporomorph floras of the Middle Atlantic States during the Miocene, it cannot be determined from the taxon lists whether all the Massachusetts samples are middle Miocene like the independently dated sample from Gay Head. Climatic differences among Miocene samples in New Jersey have been determined on the basis of relative frequencies of the main sporomorph taxa. However, taxon percentages could not be found for the Plymouth County samples because they contain abundant reworked sporomorphs.

The reworked sporomorphs show that Miocene strata of Plymouth County were derived at least in part from sediments of Late Cretaceous, Paleocene, and early Eocene to earliest middle Eocene ages. Most of the reworked sporomorphs are probably early Eocene to earliest middle Eocene in age, and all these taxa are also found in the Gulf Coast, showing that the Atlantic and Gulf Coastal Plains seem to have formed one floristic and climatic province in the early Eocene to early middle Eocene. At that time, the climate of coastal Massachusetts was probably winter-dry tropical.

Miocene samples of Martha's Vineyard probably lack reworked palynomorphs. Counts of sporomorph taxa from these samples, and the taxon lists for all the samples, suggest that, in the Miocene, Massachusetts was covered with dense Mixed Mesophytic conifer-hardwood forest that included several exotic elements such as *Sciadopitys, Podocarpus, Engelhardia* group, and perhaps *Gleichenia-Dicranopteris.*

INTRODUCTION

Tertiary deposits in eastern Massachusetts have been known at least since 1824 (Hitchcock, 1824; see White, 1890), but the ages of the scattered Tertiary outcrops in the region have been a matter of debate. The main purpose of this paper is to correlate the best known outcrops with well-dated sections farther south on the Atlantic Coastal Plain and, where possible, to determine correlations among the individual Tertiary outcrops of eastern Massachusetts. The sporomorph assemblages also have significant paleofloristic, paleobiogeographic, and paleoclimatic implications because little has been published on Tertiary floras of Northeastern United States except on the Oligocene(?) Brandon lignite flora of Vermont (fig. 1; Traverse, 1955; many papers by B. H. Tiffney). Finally, the reworked sporomorphs in many of the Massachusetts samples offer information about cycles of reworking, about the provenance of the Neogene sediments, and about Paleogene biogeography and climates.

The 24 Massachusetts samples that I studied are listed in table 1. They were prepared by means of standard acid maceration as well as by swirling (Funkhouser and Evitt, 1959) and (or) $ZnBr_2$ separation. Residues were mounted in glycerine jelly or vinylite AYAF (vinyl acetate resin). Coordinates listed in table 6 at the end of the paper locate the illustrated specimens on Leitz microscope 871956 at the U.S. Geological Survey, Reston, Va., where slides used in this study are stored; for methods of relocating specimens on other microscopes, see Frederiksen and Christopher (1978) and Frederiksen (1978b).

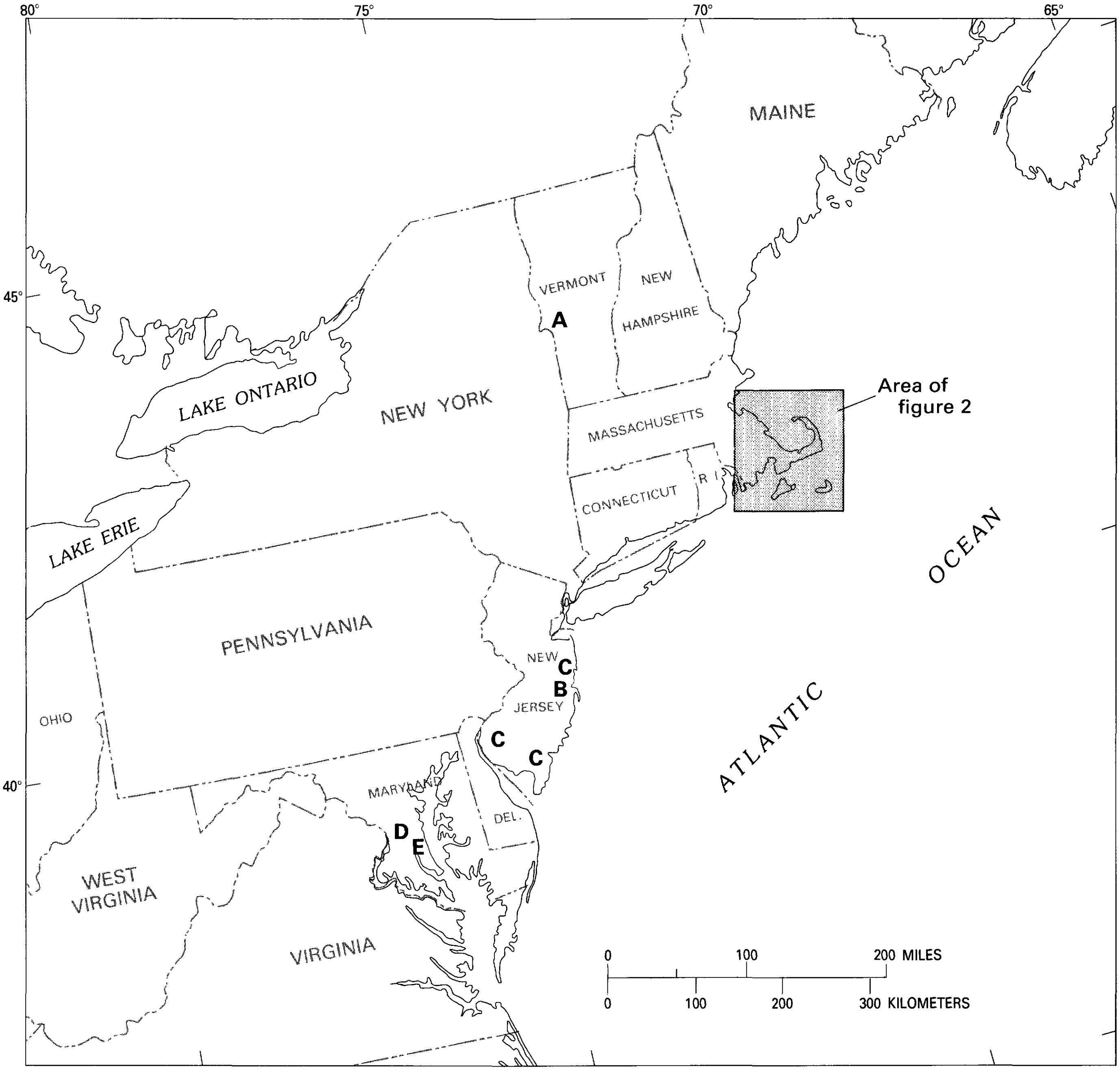


FIGURE 1.—Middle Atlantic and Northeastern States, showing localities (other than those in Massachusetts) mentioned in text. Shaded area indicates eastern Massachusetts study area of figure 2. A, Brandon lignite (Traverse, 1955; Tiffney, 1977–1979). B, Legler lignite (Rachele, 1976). C, Wells and surface samples studied by Goldstein (1974). D, Prince Georges County, Md. (table 4 of this paper). E, Calvert County, Md. (Garner, 1976, and probably Leopold, 1969).

ACKNOWLEDGMENTS

I am particularly grateful to C. A. Kaye, U.S. Geological Survey, who initiated my interest in this project, provided most of the samples, offered guidance in the field and provided background data on the stratigraphy and structure of eastern Massachusetts. I also thank B. H. Tiffney, Yale University, for some botanical and paleobotanical interpretations, R. L. Pierce, Mobil Oil Corporation, for suggesting references to the distribution of fossil *Sciadopitys*, F. C. Whitmore, Jr., U.S. Geological Survey, for providing information about sampling localities in Massachusetts, and L. D. Rachele for supplying slides of sporomorphs from the Legler lignite. B. H. Tiffney, Yale University, and T. A. Ager and F. C. Whitmore, Jr., U.S. Geological

Survey, reviewed the first draft of this paper and offered helpful suggestions for its improvement.

PREVIOUS PALYNOLOGICAL STUDIES

Paleocene and Eocene sporomorphs from the middle and southern parts of the Atlantic Coastal Plain are rather well known (Leopold, 1959; Groot and Groot, 1962; Brenner and Patricelli, 1977; Brenner and others, 1979; Frederiksen and Christopher, 1978; Frederiksen, 1978a, 1979, 1980b), but Oligocene assemblages from this region have been little studied (Hazel and others, 1977; Frederiksen and Christopher, 1978; Frederiksen, 1980b). Only two papers (Leopold, 1969; Rachele, 1976) and one abstract (Sirkin and Owens, 1976) have been published on Neogene sporomorph assemblages from the Atlantic Coastal Plain south of New England, but an unpublished thesis (Garner, 1976) and an unpublished dissertation (Goldstein, 1974) also provide useful information.

Little has been published on the Cretaceous and Tertiary palynology of Massachusetts. Sayles and Knox (1943, p. 1607) mentioned recovering "a well-preserved pollen flora" from Cretaceous and Tertiary strata of the Marshfield area and from Martha's Vineyard (fig. 2), but they gave no further details. W. S. Hoffmeister (in Zeigler and others, 1960) and Groot and Groot (1964) recovered Cretaceous, Paleocene, and Eocene sporomorphs from three wells on Cape Cod (fig. 2), and E. B. Leopold found Eocene sporomorphs at Scituate Third Cliff (unpublished work cited by Chute, 1965, and Kaye, 1967a, p. 1037; fig. 3, and locality 5 of table 1 of this paper). Cretaceous and Tertiary palynomorphs were reported by R. A. Christopher, F. E. May, and N. O. Frederiksen in two test wells on Nantucket and Martha's Vineyard (Folger and others, 1978; Hall and others, 1980; fig. 2). A summary of some results of the present palynological study was given in 1979 (Frederiksen and others, 1979). Nothing has been published on pre-Quaternary palynology of New England outside of Massachusetts, except for Traverse's (1955) extensive study of pollen from the Brandon lignite (probably Oligocene) of Vermont (fig. 1).

BIOSTRATIGRAPHY

Miocene and Pliocene strata in Massachusetts have been known since the 19th century when fossils from these units were first studied in detail (Lyell, 1843; Verrill, 1878; Dall, 1894). The presence of Eocene rocks in Massachusetts has been suspected since Crosby (1881) and Brown (1905a, b) found Eocene mollusk-bearing boulders and pebbles in glacial drift on Cape Cod and Chappaquiddick Island. Fossiliferous Eocene rocks have also been dredged from the Continental Slope south of Cape Cod (Gibson, 1965, and references therein). Eocene fossils of various kinds have been found in deposits on Nantucket, Martha's Vineyard, and on the Massachusetts mainland (Zeigler and others, 1960; Kaye, 1967a; Folger and others, 1978; Frederiksen and others, 1979; Hall and others, 1980), but the question in each place is the age of the enclosing matrix—is it Eocene, Neogene, or Pleistocene?

Correlation of Tertiary strata in Massachusetts is difficult for several reasons: outcrops are few and widely scattered, calcareous and vertebrate fossils are absent or rare in some outcrops, and reworking of fossils into younger strata is common. However, perhaps the most difficult problems are caused by glacial disturbance of pre-existing sediments. Thrusting, overturning, transporting, and mixing of strata by glacial action are so pervasive that the original Tertiary stratigraphy of the region is obscure, and it is possible that all Tertiary strata remaining in Massachusetts have been dislocated (Woodworth and Wigglesworth, 1934; Kaye, 1964a, b, 1979). A good example of a confusing sequence of strata is found in U.S. Geological Survey well ENW–50, in the central part of Martha's Vineyard (fig. 2), the lithostratigraphy and biostratigraphy of which were described by Hall and others (1980). At depths between 43 and 48 m, sparse sporomorphs suggest that the strata are Neogene. C. A. Kaye (in Hall and others, 1980) tentatively correlated this interval with a Pliocene bed at Gay Head on the basis of mineralogy and the presence of barnacle shells. Below 48 m is an unfossiliferous interval that extends to 61 m. Between 61 and 70 m, four core samples contain a diverse assemblage of Neogene as well as Cretaceous, Paleocene, and Eocene sporomorphs. Cores from 64 to 77 m also contain early Tertiary calcareous nannofossils and foraminifers. In 1977, when I studied the sporomorph assemblages, I interpreted them to mean that the interval at least from 61 to 70 m is Miocene, containing reworked Cretaceous and early Tertiary sporomorphs. Opposed to this interpretation is the fact, presented in the present paper, that reworked sporomorphs have not been recognized in definite Miocene samples from Martha's Vineyard. Hall and others (1980) interpreted the data to indicate that the interval from 61 to 77 m is in place (not glacially dislocated) and is early Tertiary in age; that is, they believed that the early Tertiary fossils are autochthonous and that the Neogene sporomorphs are contaminants, in spite of the absence of diverse Neogene sporomorph assemblages in any of the samples above the supposed lower Tertiary interval in the well. A third interpretation is that of C. A. Kaye (cited by Hall and others, 1980, p. 6, 8; oral commun., 1981) who, on the basis of sediment mineralogy, considered that the interval in the well at least from 53 to 77 m is likely to be Pleistocene. Kaye is not surprised that strata apparently of Neogene age overlie probable Pleistocene drift in this well: "The inversion of normal stratigraphic position indicated here is a common occurrence in the large Gay Head moraine, where the essential structure is an imbricated pile of thrust plates" (quoted by Hall and others, 1980, p. 6).

BLOCKHOUSE SLIDE SECTION

The only outcropping section in New England that includes more than one Tertiary lithologic unit is in the northern part of Gay Head cliffs, Martha's Vineyard. Three Neogene units are present there and were sampled in the Blockhouse Slide (table 1, loc. 1a; fig. 4). I began with this section because it includes almost the only units sampled for this study that have been independently dated by means of other fossils. In descending order, the units, and samples representing them, are:

R1280 Shelly sand
R1270A Ferruginous clay
R1267 Greensand

Further details on the sample localities and the units studied for this paper are given in table 1.

Fossils from the greensand at Gay Head have been the object of study since the 18th century (see White, 1890). The most thorough investigations have been those of Dall (1894) and Kaye and others (1979). Dall (1894, p. 299), on the basis of vertebrates, crustaceans, and mollusks from the greensand, decided that this bed is "certainly not lower than the St. Mary's fauna and probably between that and the Yorktown beds." The St. Marys Formation is now known to be upper middle Miocene and (or) upper Miocene; the Yorktown Formation is Pliocene (Blackwelder, 1981). On the other hand, Kaye and others (1979), on the basis of vertebrates, concluded that the greensand at Gay Head is early middle Miocene in age.

The distinction of the ferruginous clay as a separate unit from weathered greensand seems not to have been mentioned in published papers except by Kaye (1964a, p. C136), who referred to this bed as a "massive ferruginous clay." The age of the clay has not previously been determined because it lacks calcareous fossils.

The first mention of the shelly sand as a distinct unit above the ferruginous clay at Gay Head was by Dall and Harris (1892, p. 36). On the basis of mollusks, the shelly sand has been considered by successive workers as "perhaps" Pliocene (Dall, 1894, p. 300), as early Pliocene (Woodworth and Wigglesworth, 1934, p. 30), as Pleistocene (Raup and Lawrence, 1963), and as correlative with the Yorktown Formation to the south—that is, as Pliocene in age (Druid Wilson, cited by Hall and others, 1980, p. 6). Ostracodes from the shelly sand are also very similar to those from the Yorktown Formation and indicate that the shelly sand is Pliocene or possibly latest Miocene in age (T. M. Cronin, oral commun., 1981).

Table 2 shows that the greensand (sample R1267; lower middle Miocene) has a much more diverse sporomorph flora than the two overlying units and includes pollen grains from a wide variety of dicot trees. The sporomorph assemblages from the ferruginous clay (sample R1270A) and from the shelly sand (sample R1280; Pliocene) are much less diverse; they include little pollen from dicot trees and consist mainly of pollen of *Pinus*, shrubs and herbs, and spores of *Sphagnum* and pteridophytes. Whereas R1267 represents the rich forest of a humid subtropical climate (in the climatic classification of Trewartha, 1968), R1270A and R1280 represent low-diversity cool temperate forests. The rare sporomorphs of *Gleicheniidites* (pl. 1, fig. 1), Paleogene type of *Carya* (pl. 2, fig. 30), and Palmae in R1280 are undoubtedly reworked, whereas *Podocarpus* (pl. 1, fig. 7), *Pterocarya* type (pl. 1, fig. 25), and *Sciadopitys* (pl. 1, figs. 2–6) are represented by many specimens in R1267, and these genera, in addition to possible *Gleicheniidites*, are probably indigenous in that sample. The only published work on Pliocene sporomophs of the Atlantic Coastal Plain is an abstract by Sirkin and Owens (1976) on supposed upper Pliocene deposits of the Delmarva Peninsula. These authors found a *Pinus-Quercus-Carya*-NAP (nonarboreal pollen) assemblage that includes *Pterocarya* type. This assemblage is much richer than that from the Pliocene of Massachusetts.

In summary, table 2 shows that the Gay Head floras of the early middle Miocene (R1267) were distinctly different from those of the Pliocene (R1280). Sporomorphs of R1270A are much more similar to those of R1280 than to those of R1267; thus, the ferruginous clay is probably Pliocene in age.

OTHER NEOGENE LOCALITIES

Having finished the examination of the Blockhouse Slide assemblages (locality 1a of table 1), I turned to samples from five other localities in eastern Massachusetts, as follows (figs. 2–4):

Locality
1b. Former White Spur, Gay Head, Martha's Vineyard
2. Zacks Cliffs, Martha's Vineyard
3a, b. Near Marshfield Center, Plymouth County
4. Marshfield Cranberry Bog no. 1 corehole, Plymouth County
5. Scituate Third Cliff, Plymouth County

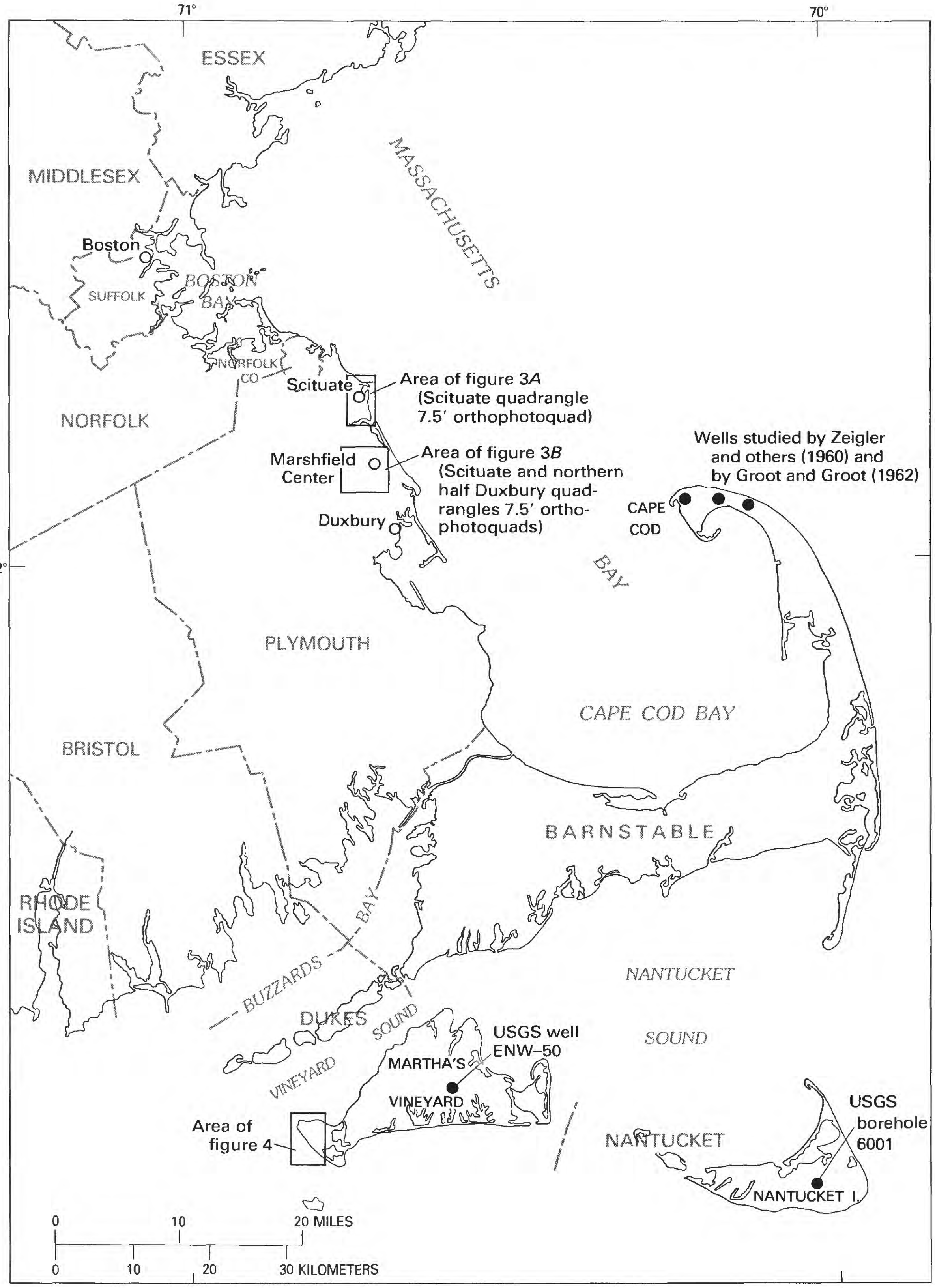


FIGURE 2.—Eastern Massachusetts showing study area. County boundaries are shown by dashed line.

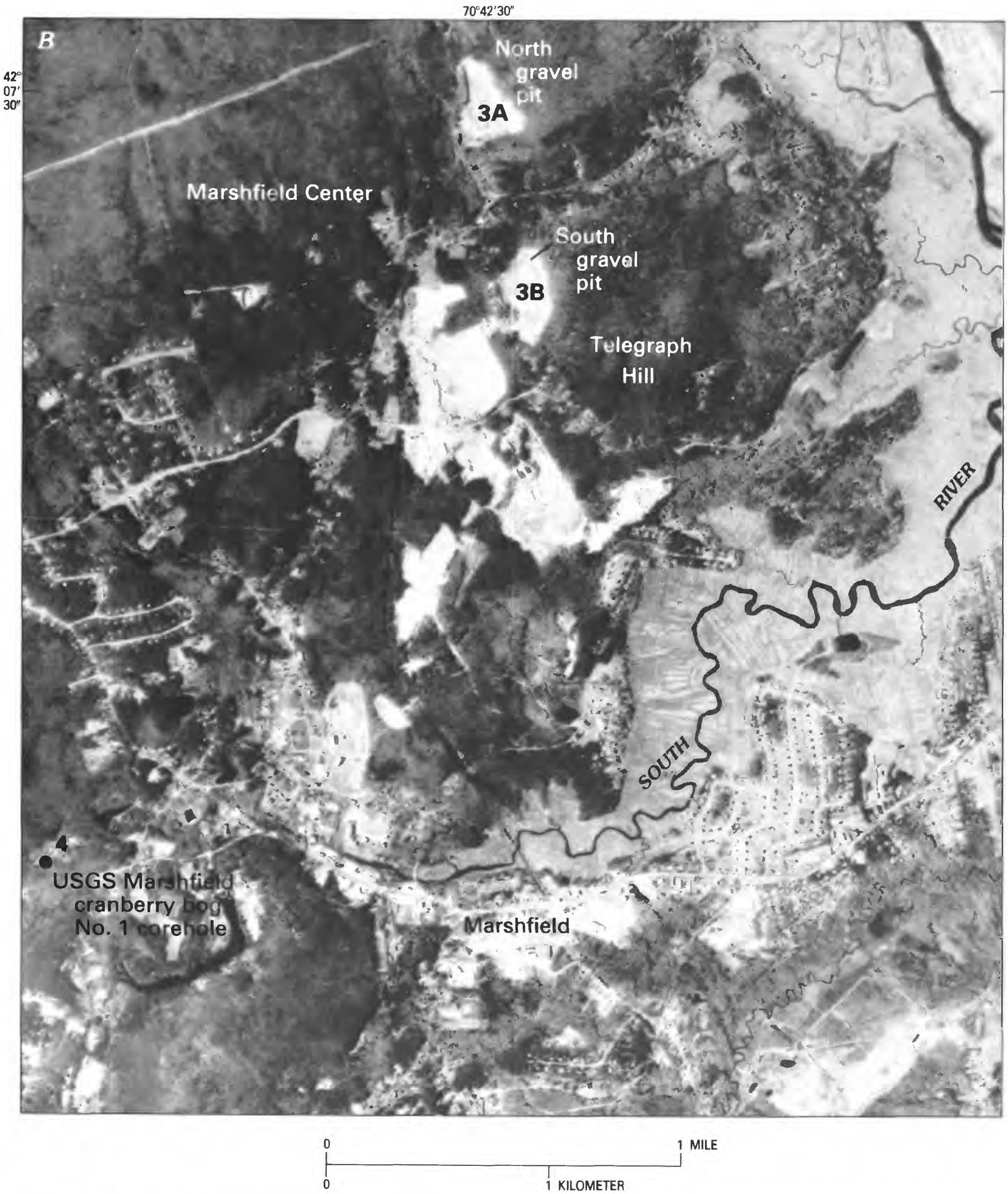
The greensand beds at former White Spur and in Zacks Cliffs could represent the same bed as the middle Miocene greensand (sample R1267) in Blockhouse Slide, but this is difficult to prove because the three units are structurally disconnected. The greensand at former White Spur, although in the same moraine (probably of Illinoian age) as Blockhouse Slide, is in a different thrust plate than the slide, and the greensand in Zacks Cliffs is in a different moraine (probably of Wisconsinan age; Kaye, 1964b, c, 1980a). Tertiary strata near Marshfield and Marshfield Center and in Scituate Third Cliff are probably in the same Illinoian moraine as the greensand beds at Gay Head; like the deposits of Gay Head, the mainland units occur in imbricated thrust plates (Kaye, 1964a, b, 1979, 1980b).

Glauconitic silt in the Marshfield area has been known since Hitchcock (1833, 1838, 1841) reported that a bed having this lithology was present in the shallow subsurface resting on or not far above granite bedrock. Hitchcock (1841, v. 2, p. 427) noted that this bed "may be the same stratum of green sand as has been described at Gay Head." On the basis of scarce mollusks, Shaler (1890, p. 447) believed the Gay Head greensand to be younger than the Marshfield area glauconitic silt and wrote that the silt bed was evidently Cretaceous in age. Bowman (1906) and Emerson (1917) stated that W. H. Dall (apparently in an unpublished report) had determined mollusks from the Marshfield area glauconitic silt to be Miocene in age. Woodworth and Wigglesworth (1934, p. 21) listed the few taxa of fossils found in the greensand near Marshfield, and, on the basis of both fossils and lithology, they considered this bed probably to be the same unit as the greensand at Gay Head.

Little previous work has been done on the age and correlation of the Tertiary glauconitic clay at Scituate Third Cliff. Bowman (1905, 1906) reported that useful fossils were virtually absent at this locality; he tentatively correlated the Scituate Third Cliff deposit with the glauconitic silt near Marshfield, which he considered to be Miocene. However, in 1906, Bowman (p. 325) thought the Scituate bed might instead be Eocene or Oligocene in age. Preliminary study of sporomorphs from this locality by E. B. Leopold (cited by Chute, 1965, and Kaye, 1967a, p. 1037) also suggested that the deposit may be Eocene.

OCCURRENCES OF MIOCENE TAXA

Table 3 summarizes the occurrences of Miocene taxa at the six localities studied for this paper. Reasons for considering the sporomorphs to be Miocene will be explained in this and the following section of the paper. The list of taxa in table 3 is not exhaustive, for several



◀▲ FIGURE 3.—Scituate (*A*) and northern half of Duxbury (*B*) 7.5′ quadrangles, Massachusetts. Numbers refer to localities listed in table 1. Orthophotomap base by U.S. Geological Survey, 1:25,000.

reasons. Except for the unpublished thesis of Garner (1976), no data, especially in the form of photomicrographs, are available from the Atlantic Coastal Plain concerning Neogene sporomorphs other than those assigned to extant taxa. In the Plymouth County samples I found quite a few sporomorph taxa that I could not assign to living genera but that I also did not recognize as being Paleogene in age; thus, I did not know whether these sporomorphs were Miocene or Paleogene. Most of these taxa have been omitted from table 3. However, I have illustrated several of the exotic or extinct forms found in the Miocene samples from Martha's Vineyard because these samples seem to lack reworked sporomorphs; for this reason, I believe that the apparently extinct sporomorph forms from the Martha's Vineyard samples are probably Miocene in age (pl. 1, figs. 23, 24, 26; pl. 2, figs. 1–2, 5). Several of the taxa listed in table 3 are probably Miocene but may possibly be reworked from the Eocene. *Boehlensipollis hohlii* Krutzsch 1962 (pl. 2, fig. 4) belongs to Elaeagnaceae, and *Ephedripites hungaricus* Nagy 1963 (pl. 1, fig. 12) was undoubtedly produced by *Ephedra*. The oldest

TABLE 1.—*Sample localities and numerical list of samples*

[Blockhouse Slide and White Spur are unpublished names used by C. A. Kaye (written commun., 1981)]

Sample localities

Locality number	Description
1.	Gay Head Cliffs, Martha's Vineyard. Tertiary beds here are in imbricated thrust sheets containing Cretaceous, Tertiary, and Pleistocene strata; the entire mass is part of the Gay Head moraine probably of Illinoian age (Woodworth and Wigglesworth, 1934; Kaye, 1964b, 1972, 1979). The entire cliff is undergoing rapid erosion.
1a.	Blockhouse Slide, northern end of Gay Head Cliffs, Martha's Vineyard, northwestern part of Squibnocket 7.5′ quadrangle, Dukes County, Mass. Lat 41° 21.10′ N., long 70° 50.15′ W. Samples R1267, R1270A, and R1280. The Neogene units were exposed high in the cliff in 1978–1979. The exposure consisted of a recumbent isoclinal syncline overlain by a thrust plate having Upper Cretaceous sediments at its base (Kaye, 1980b; C. A. Kaye, written commun., 1979).
1b.	Near beach level at former White Spur, Gay Head Cliffs, Martha's Vineyard, lat 41° 21.16′ N., long 70° 50.12′ W. The Tertiary greensand (sample R1555) was exposed after Hurricane "Donna" in 1960 (C. A. Kaye, written commun., 1979).
2.	Zacks Cliffs, Martha's Vineyard, lat 41° 19′ N., long 70° 49′ W. Sample R1513. The bed containing sporomorphs is 0.3–0.6 m thick and has been glacially dislocated (Kaye, 1964b, fig. 1; 1964c, p. 8; 1980a; C. A. Kaye, oral commun., 1981).
3.	Near Marshfield Center, Plymouth County. In this area, the glauconitic silts are found in two Pleistocene thrust sheets, one above the other (Kaye, 1979; C. A. Kaye, oral commun., 1978).
3a.	North gravel pit, northeast of Marshfield Center, on the east side of Church Street, southernmost part of Scituate 7.5′ quadrangle and northernmost part of Duxbury 7.5′ quadrangle. Lat 42° 7.50′ N., long 70° 42.42′ W. Samples D5260 2–3.
3b.	South gravel pit, between Marshfield Center and Telegraph Hill, northwestern part of Duxbury 7.5′ quadrangle. Lat 42° 6.93′ N., long 70° 42.42′ W. Samples D5259 1–12.
4.	U.S. Geological Survey Marshfield Cranberry Bog no. 1 corehole, lat 42° 5.67′ N., long 70° 43.75′ W., Duxbury 7.5′ quadrangle, Plymouth County. Sample R1524.
5.	Scituate Third Cliff, Scituate 7.5′ quadrangle, Plymouth County. Lat 42° 10.88′ N., long 70° 43.05′ W. Samples D1885A and R1394A–C. The Tertiary siltstone and claystone are in Pleistocene thrust sheets (Bowman, 1906; Kaye, 1979).

TABLE 1.—*Sample localities and numerical list of samples*—Continued

Numerical list of samples

Sample number	Locality
D1885A	Dark-greenish-gray glauconitic clay from base of Scituate Third Cliff, locality 5.
D5259 1–12	South pit near Marshfield Center, locality 3b. Samples D5259 1–4 (numbered in ascending order) are from the lower thrust sheet at the base of the pit; samples D5259 5–12 (numbered in ascending order) are from the upper thrust sheet. Light-gray (dark-gray when wet) laminated micaceous glauconitic clayey silt.
D5260 2–3	North pit near Marshfield Center, locality 3a. Samples D5260 2–3 (numbered in ascending order) are from the silt above the Pleistocene sand and gravel in this pit. Same lithology as D5259 1–12.
R1267	Greensand from Blockhouse Slide, Gay Head, locality 1a. Green, weathering brown, very glauconitic, phosphatic, shelly, pebbly sand.
R1270A	Highly ferruginous, slightly glauconitic massive clay, overlying R1267 and underlying R1280, at Blockhouse Slide, Gay Head, locality 1a.
R1280	Shelly sand overlying R1270A at Blockhouse Slide, Gay Head, locality 1a. Interbedded sand, silt, and clay, light-greenish-gray, glauconitic, shelly; sand is fine- to coarse-grained.
R1394A–C	Scituate Third Cliff, locality 5. Sample R1394A is light-olive-gray, very micaceous silt from toe of slide; R1394B, medium-dark-olive-gray, silty, slightly micaceous clay from toe of slide; R1394C, medium-dark-olive-gray, slightly micaceous clay.
R1513	Greensand from Zacks Cliffs, locality 2.
R1524	U.S. Geological Survey Marshfield Cranberry Bog no. 1 corehole, locality 4. Sample is greensand from 14.5–15 ft (4.4–4.6 m) below surface.
R1555	Greensand near beach level, former White Spur, Gay Head, locality 1b.

TABLE 2.—*Sporomorph taxa in three Neogene samples from Blockhouse Slide, Gay Head, Martha's Vineyard, Mass.*

[In descending order, samples are: R1280, Pliocene; R1270A, age uncertain; R1267, middle Miocene]

Taxa	R1280	R1270A	R1267
Trees:			
Abies			?
Alnus	X		X
Betula	X		X
Carya			X
Castanea			X
Cornaceae			?
Fagus			X
Ilex			X
Larix			?
Liquidambar			X
Nyssa			X
Picea	?	X	X
Pinus	X	X	X
Quercus			X
Taxodiaceae-Cupressaceae-Taxaceae			X
Tsuga			X
Ulmus-Zelkova			X
Low shrubs, herbs, vines:			
Caryophyllaceae	?		
Chenopodiaceae-Amaranthaceae			?
Compositae, short spine	X		X
Compositae, long spine			X
Cyperaceae			?
Ericaceae	X		X
Gramineae	X	X	X
Myrica	?		X
Aquatics and semiaquatics:			
Myriophyllum			X
Sparganium-Typha			X
Pteridophytes and bryophytes:			
Lycopodium	X	X	X
Osmunda			X
Sphagnum	X	X	X
Selaginella		X	
Botrychium	?		
Exotics:			
Carya (Paleogene type)	X		
Momipites spackmanianus complex			?
Gleicheniidites	X		?
Palmae	X		
Podocarpus			X
Pterocarya type			X
Sciadopitys			X

known occurrences of these two species in the Atlantic and Gulf Coastal Plains are in the late middle Eocene (Frederiksen, 1980a). No palynological evidence exists that the Miocene sediments of Massachusetts were derived from reworking of sediments as young as late middle Eocene; therefore, *Boehlensipollis hohlii* and *Ephedripites hungaricus* in the Miocene are probably autochthonous. *Pseudolaesopollis* may include pollen grains of both Cyrillaceae (*Costaea* type; Frederiksen, 1980b) and Clethraceae. On the Gulf Coast, *Pseudolaesopollis* ranges down into the upper Paleocene (Frederiksen, 1980b), but *Clethra* still lives in New England. The *Momipites spackmanianus* complex has its first appearance in the Eocene but undoubtedly ranges up into the Neogene; this taxon is discussed later in this section of the paper. *Neogenisporis* Krutzsch 1962 appears to be morphologically indistinguishable from *Gleicheniidites* Ross 1949; however, in Europe, *Neogenisporis* has a range base in the middle Oligocene whereas *Gleicheniidites* has a range top in the Eocene (Krutzsch, 1962). Gleichenioid spores have not previously been reported from the Neogene of eastern United States. In short, the very rare gleichenioid spores in the Miocene of Massachusetts could be reworked *Gleicheniidites* or indigenous *Neogenisporis*.

Previous palynological work on the Neogene of the Atlantic Coastal Plain has been done on the Calvert, Choptank, and St. Marys Formations of Maryland (Leopold, 1969; Garner, 1976), on the Kirkwood Formation (Goldstein, 1974) and the overlying Cohansey Sand (Rachele, 1976) of New Jersey, and on the Walston Silt and Beaverdam Sand of the Delmarva Peninsula (Sirkin and Owens, 1976). The Calvert Formation is lower Miocene and lower middle Miocene, the Choptank Formation is middle middle to upper middle Miocene, and the St. Marys Formation is upper middle Miocene and (or) upper Miocene (Abbott and Andrews, 1979, text-fig. 3; Blackwelder, 1981; Gibson, in press). The Kirkwood Formation is lower Miocene to perhaps middle upper Miocene (Goldstein, 1974). Rachele (1976) concluded, on the basis of sporomorph assemblages, that the Legler lignite in the Cohansey Sand of New Jersey is late Miocene or early Pliocene in age; however, from the data presented by Leopold (1969), Goldstein (1974), and Garner (1976), and by comparison with table 2 of this paper, the Legler lignite is Miocene rather than Pliocene. The Cohansey Sand overlies the Kirkwood Formation; the Cohansey is, therefore, presumably late Miocene in age. Sirkin and Owens (1976) considered the Walston Silt and the Beaverdam Sand to be late Pliocene in age.

Garner's (1976) samples from the Calvert Formation of Calvert County, Md., included some from the Fairhaven Member, which is probably lower Miocene (Blackwelder, 1981). I also examined three samples of approximately the same age from the Patuxent River valley, Prince Georges County, Md. (Lower Marlboro 7.5′ quadrangle, lat 38° 40.08′ N., long 76° 42.00′ W.; see table 4 and fig. 1). The samples were supplied by L. W. Ward, who noted (written commun., 1979) that sample R2171B "contains molluscan molds much like those on Pamunkey River [of east-central Virginia] that were found to be late Oligocene. Sample R2171D is basal Calvert Formation (probably early Miocene)." Sample R2171C is from an intermediate position in the section. All three of these samples have similar

FIGURE 4.—Western part of Martha's Vineyard, Massachusetts, Squibnocket 7.5′ quadrangle. Orthophotomap base by U.S. Geological Survey, 1:25,000.

assemblages, and they are not likely to be very different in age. I suspect that all three samples are Miocene because they all contain *Sciadopitys*, which I have never seen in an Oligocene assemblage from the Atlantic and Gulf Coastal Plains.

Most individual taxa from the Massachusetts Miocene (table 3) have no known biostratigraphic significance within the middle and upper Tertiary of the Atlantic Coastal Plain. *Cyrilla-Cliftonia*, *Gordonia*, Sapotaceae, and *Symplocos* still live in Eastern United States but not as far north as Maryland (however, *Symplocos* still lives as far north as Virginia and therefore is not included in fig. 5). The modern range of *Podocarpus* does not extend north of Mexico, and *Pterocarya* is now extinct in the Americas. *Cyrilla-Cliftonia*, *Gordonia*, *Podocarpus*, and *Pterocarya* type range stratigraphically as high as the Cohansey Sand (probably upper Miocene) in New Jersey (Rachele, 1976), and Wolfe (1975) and Sirkin and Owens (1976) found *Pterocarya* type in the Pliocene of Eastern United States (fig. 5). *Gordonia* is not known certainly from older rocks than the Brandon lignite (probably Oligocene) of Vermont (Traverse, 1955). *Ephedra*, Sapotaceae, and *Symplocos* have not been reported in Maryland from strata higher than the Calvert Formation (lower Miocene to lower middle Miocene; Leopold, 1969; Garner, 1976). *Symplocos* was not found in the Kirkwood Formation of New Jersey, but *Ephedra* and Sapotaceae range there as high as beds that are approximately Calvert in age (Goldstein, 1974). Among pollen forms that now occur in the Middle Atlantic States and New England, Compositae pollen is found as low in the section as the Calvert Formation in Maryland (Leopold, 1969; Garner,

TABLE 3.—*Sporomorph taxa in Miocene strata of eastern Massachusetts*

[All taxa listed here are probably represented by nonreworked grains; however, particularly in samples from Plymouth County, some taxa may be represented in part by reworked specimens]

	Plymouth County			Martha's Vineyard		
	D5259 1-12 D5260 2, 3	R1524	D1885A R1394 A-C	R1267	R1513	R1555
Trees:						
Abies				?		
Alnus	X	X	X	X	X	X
Betula	X	X	X	X	X	X
Carya	X	X	X	X	X	X
Castanea	X		X	X		X
Comptonia		?			?	
Cornaceae				?		
Corylus	X					
Cyrilla-Cliftonia	X	X	X			
Fagus	X			X	X	
Gordonia	X					
Ilex	X	X	X	X	X	X
Juglans type	X					
Larix				?		
Liquidambar	X	X	X	X	X	
Momipites spackmanianus complex[1]	X	X	X	?	?	
Morus	?					
Nyssa	X		X	X	X	X
Picea	X	X	X	X	X	X
Pinus	X	X	X	X	X	X
Platanus	X					
Podocarpus	X	X	X	X		X
Pterocarya type	X	X	X	X	X	X
Quercus	X	X	X	X	X	X
Salix	X		X			
Sapotaceae	X					
Sciadopitys	X		X	X	?	X
Symplocos	X					
Taxodiaceae-Cupressaceae-Taxaceae	X	X	X	X	X	X
Tilia	X	X	X		X	X
Tsuga	X	X	X	X	X	X
Ulmus-Zelkova			X	X		X
Low shrubs, herbs, vines:						
Boehlensipollis hohlii Krutzsch 1962[1]	X					
Chenopodiaceae-Amaranthaceae	X	X	X	?	X	
Compositae, short spine	X	X	X	X	X	X
Compositae, long spine	X		X	X		
Cyperaceae				?		
Ephedripites hungaricus Nagy 1963[1]	X					
Ericaceae	X	X		X		
Gramineae	X	X		X	X	
Ludwigia	X	X				
Malvaceae	X					
Myrica	X	X	X	X		
Pseudolaesopollis spp.[1]			X			X
Umbelliferae		X				
Aquatics and semiaquatics:						
Myriophyllum				X	?	
Sparganium-Typha	X			X		
Pteridophytes and bryophytes:						
Gleicheniidites or *Neogenisporis*[1]	X			X		
Lycopodium	X		X	X		X
Osmunda	X	X	X	X	X	
Sphagnum	X	X	X	X	X	X
Selaginella	X					

[1]Probably Miocene but possibly reworked from the Eocene.

1976). Compositae pollen first appears in the Kirkwood Formation of New Jersey in strata of approximately late middle Miocene age (Goldstein, 1974), but I doubt that the apparent lack of pollen of this family in strata of Calvert age in New Jersey is very significant; in my experience, Compositae pollen is erratic in its occurrence throughout the Neogene. Umbelliferae pollen has its lowest known occurrence, in the Middle Atlantic States, in the Choptank Formation (middle middle to upper middle Miocene) of Maryland (Leopold, 1969), but this pollen form is considerably sparser even than Compositae pollen in the Neogene; thus, the lower limit of the range of Umbelliferae pollen must be considered to be poorly known.

Sciadopitys (umbrella pine) now lives only in Japan. The few previous records of the genus in eastern North America are:

1. Elsik and Dilcher (1974, p. 74, pl. 28, fig. 59) illustrated a pollen grain from the middle Eocene of Tennessee that they tentatively attributed to *Sciadopitys*.
2. Leopold (1969, p. 409) stated that *Sciadopitys* pollen occurred in the Paleogene of the Middle Atlantic States but was lacking from the Miocene of the same region. However, I saw no specimens of the genus during an extensive palynological study of the Paleogene of Virginia (Frederiksen, 1979).
3. A clay sample from western Kentucky contained pollen of *Sciadopitys* and *Pterocarya* type, along with presently native sporomorph taxa, and was thought to be Pliocene but possibly Miocene or latest Oligocene in age (R. H. Tschudy, quoted by Finch and Minard, 1966).

I have seen many specimens of *Sciadopitys* in samples from various localities of the Atlantic Coastal Plain:

1. The genus is found in many of the samples of table 3, including those from Martha's Vineyard that seem to lack reworked Paleogene palynomorphs.
2. *Sciadopitys* also occurs together with other Neogene sporomorphs in core samples at depths between 61 and 70 m in probable Pleistocene deposits in well ENW-50 on Martha's Vineyard (this well is discussed at the beginning of the "Biostratigraphy" section of this paper). A list of most of the Neogene sporomorph taxa in the cores was given by Hall and others (1980, p. 6); however, the following taxa found in the well samples do not appear on the published list: *Sciadopitys, Liquidambar, Podocarpus,* and possibly *Momipites annulatus* Frederiksen & Christopher 1978.
3. I also found pollen of *Sciadopitys* in samples from Maryland of probable early Miocene age (table 4).

All specimens of *Sciadopitys* that I have found in the Neogene of the Atlantic Coastal Plain belong to *S. serrata* (Potonié & Venitz 1934) Martin & Rouse 1966. Additional records of *Sciadopitys* from North America and other continents are mentioned in the section on Miocene climate.

Momipites is a form genus for pollen of the *Engelhardia-Alfaroa-Oreomunnea* complex (family Juglandaceae). Specimens of *Momipites* are sparse in the Miocene samples from Plymouth County and very rare in the samples from Martha's Vineyard. Pollen of *Momipites* is common in the lower Tertiary of the Atlantic and Gulf Coastal Plains, and the possibility existed that all the grains of this genus in the Miocene samples might be reworked. Rachele (1976, fig. 6(9)) illustrated a specimen that she referred to as *Engelhardia* from the upper Miocene Legler lignite of New Jersey. She kindly sent me several slides of her material, and I found that triatriate pollen grains are sparse in the samples but that several forms of *Momipites* are present. These are illustrated in plate 1, figures 18, 20–22. Because these specimens are from lignite, they are unlikely to be reworked. Figures 17–18 and 19–20 of

TABLE 4.—*Sporomorph taxa in three samples from the upper Oligocene(?) (sample R2171B) to the lower Miocene or lower middle Miocene (sample R2171D) of Maryland*

[Sample R2171C is from an intermediate position in section]

Taxa	Samples		
	R2171D	R2171C	R2171B
Alnus	------	X	X
Carya	X	X	X
Castanea	------	------	X
Ephedra	------	?	X
Ericaceae	X	X	X
Fagus	X		
Gramineae	------	------	X
Ilex	X	X	X
Juglans	X		
Liquidambar	X	X	X
Momipites spackmanianus complex	X	X	X
Myricaceae	?	X	
Nyssa	X	X	X
aff. Palmae	------	X	X
Picea	X		X
Pinus	X	X	X
Platanus	X		
Podocarpus	X	X	
Quercus	X	X	X
Rhoipites angustus Frederiksen 1980a	------	X	
Sapotaceae	X	X	X
Sciadopitys	X	X	X
Symplocos	------	------	X
Taxodiaceae-Cupressaceae-Taxaceae	------	X	X
Tilia	X	X	X
Ulmus-Zelkova	X	X	X

plate 1 are similar to the type specimens of *Momipites spackmanianus* (Traverse 1955) Nichols 1973, and *M. annulatus* Frederiksen & Christopher 1978, respectively. The type specimens of these two species are morphologically different from each other, but in Oligocene and Miocene samples that I have seen, a complete range of morphotypes exists between these two end members (see also the specimens from the Miocene Calvert Formation of Maryland illustrated by Garner, 1976, pl. 8, figs. 18–21); thus, *Momipites spackmanianus* and *M. annulatus* may be conspecific. For simplicity, I refer to these two species in this paper as belonging to the *Momipites spackmanianus* complex. The *M. spackmanianus* complex ranges down into the uppermost Eocene of the Gulf Coast (Frederiksen, 1981) and is 5–36 percent of total sporomorphs in the upper Oligocene of South Carolina (Frederiksen and Christopher, 1978), but it seems to decrease rapidly in relative frequency in the Miocene.

The specimen from the Legler lignite labelled *Momipites* aff. *M. coryloides* Wodehouse 1933 (pl. 1, figs. 21–22) is similar to early Tertiary specimens assigned to this species (the type specimen of *M. coryloides* is from the middle Eocene), but, because of the paucity of *Momipites* specimens in the Legler lignite samples, I could not determine whether the lignite contains a distinct group of specimens similar to *M. coryloides* or whether the specimen of plate 1, figures 21–22 is simply an end member of the population forming the *M. spackmanianus* complex.

Specimens attributed in this paper to *Pterocarya* type probably belong mainly or entirely to *Pterocarya* itself. Although *Juglans* may also produce *Pterocarya*-like grains (Nichols, 1973), in my experience *Pterocarya* type specimens are far more common throughout the Tertiary of the Atlantic and Gulf Coastal Plains than *Juglans* type grains. For example, in the Miocene of Massachusetts (table 3), *Pterocarya* type was found at all six sampled localities, whereas *Juglans* type was found at only one. *Cyclocarya* (one extant species in China, included by some authors in *Pterocarya*) has pollen grains somewhat similar to, but probably distinguishable from, those of *Pterocarya s.s.* (Kuprianova, 1965).

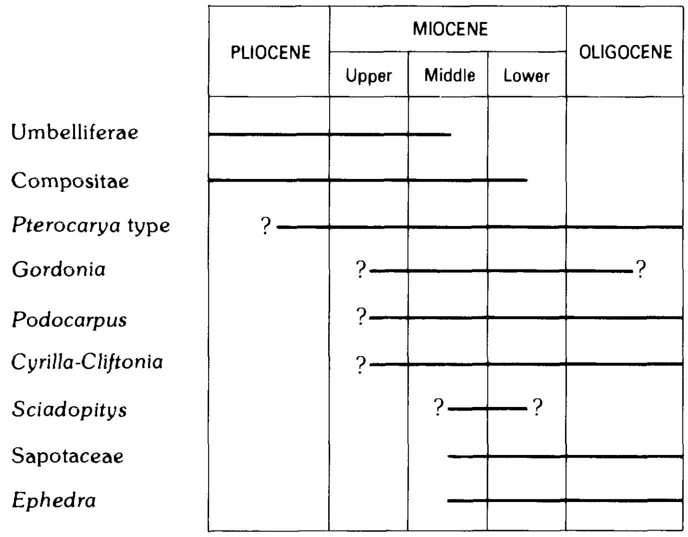


FIGURE 5.—Known geologic ranges, in the Middle Atlantic States and New England, of stratigraphically important Miocene sporomorph taxa in Massachusetts. See text for sources of data.

COMPARISON OF ASSEMBLAGES

Sporomorph assemblages of the Calvert, Choptank, St. Marys, Kirkwood, and Cohansey Formations of the Middle Atlantic States (Leopold, 1969; Goldstein, 1974; Garner, 1976; Rachele, 1976; table 4 of this paper) are very similar to each other and to the assemblages from the six Massachusetts localities of table 3, at least as far as presence-absence data are concerned. Clearly, all six Tertiary deposits of table 3 are Miocene in age. They have much more diverse floras than the Pliocene samples of table 2; they are unlikely to be Oligocene, the probable age of the Brandon lignite of Vermont, because they contain pollen of Compositae, Umbelliferae, and *Sciadopitys* (fig. 5); and the Paleogene sporomorphs in some of the table 3 samples must be reworked. I cannot determine from the available data whether all six deposits of table 3 are the same age; that is, whether they are all middle Miocene like sample R1267. However, the samples from near Marshfield Center contain *Ephedra*, *Symplocos*, and Sapotaceae. If the specimens of these taxa are indigenous and not reworked, these samples should be no younger than Calvert age; that is, no younger than middle Miocene (fig. 5).

If climatic fluctuations took place during Miocene time as suggested by Goldstein (1974), then sporomorph relative frequency data would be useful for zoning the Miocene and perhaps for determining whether all the samples of table 3 are the same age. Unfortunately, the presence of large numbers of reworked sporomorphs in samples from Plymouth County makes accurate counts of Miocene specimens from these samples difficult or impossible.

REWORKED SPOROMORPHS

Figure 6 lists the 42 Paleogene sporomorph taxa that have been found as reworked specimens in Miocene samples from Plymouth County. These strata are composed at least in part of reworked sediments; the ages of

Taxa	Miocene samples from Massachusetts: Marshfield Center pits D5259 1–12 D5260 2,3	Marshfield bog core R1524	Scituate Third Cliff D1885A R1394A–C	Ranges on the Gulf and Atlantic Coastal Plains: EOCENE, Middle, Middle and upper parts	EOCENE, Middle, Lower part	EOCENE, Lower	PALEOCENE, Upper	PALEOCENE, Lower
Nuxpollenites psilatus Frederiksen 1979	X			—	—	—		
Milfordia hungarica (Kedves 1965) Krutzsch 1970	X			— ? —	— ? —	—		
Pompeckjoidaepollenites subhercynicus (Krutzsch 1954) Krutzsch *in* Góczán *et al.* 1967	X		?		—	—		
"*Platycaryapollis semicyclus*" Krutzsch & Vanhoorne 1977			X		—	—		
Platycaryapollenites triplicatus (Elsik 1974) Frederiksen & Christopher 1978	X		X		—	—		
Platycaryapollenites swasticoidus (Elsik 1974) Frederiksen & Christopher 1978	X				—	—		
Momipites-Plicatopollis-Platycaryapollenites complex of Frederiksen 1979	X				—	—		
Interpollis microsupplingensis Krutzsch 1961	X				—	—		
Dicolpopollis cf. *D. kalewensis* of Tschudy 1973a			X		—	—		
Anacolosidites reklawensis Elsik 1974	X		X		—	—		
Platycarya platycaryoides (Roche 1969) Frederiksen & Christopher 1978	X		X	—	—	—	?	
Intratriporopollenites ollivierae Gruas-Cavagnetto 1976	X			—	—	—	—	
Carya spp. <29 µm	X		X		—	—	—	
Triatriopollenites turgidus (Pflug *in* Thomson & Pflug 1953) Frederiksen 1979	X		X			—	—	
Basopollis obscurocostata Tschudy 1975	X		X			—	—	
Kyandopollenites anneratus Stover *in* Stover *et al.* 1966	X		X				—	
Trudopollis plena Tschudy 1975	X		X	—	—	—	—	—
Porocolpopollenites virginiensis Frederiksen 1979	X		X	—	—	—	—	—
Pistillipollenites macgregorii Rouse 1962	X			—	—	—	—	—
Nudopollis terminalis (Pflug & Thomson *in* Thomson & Pflug 1953) Pflug 1953	X	X	X	—	—	—	—	—
Momipites coryloides Wodehouse 1933	X			—	—	—	—	—
Milfordia minima Krutzsch 1970	X		X	—	—	—	—	—
Milfordia incerta (Pflug & Thomson *in* Thomson & Pflug 1953) Krutzsch 1961	X		X	—	—	—	—	—
Tricolpites asper Frederiksen 1978a	X		X		—	—	—	—

FIGURE 6.—Reworked Paleogene sporomorphs in Miocene strata of Plymouth County, Mass., and known ranges of the taxa on the Gulf and Atlantic Coastal Plains.

Taxa	Miocene samples from Massachusetts: Marshfield Center pits D5259 1-12 D5260 2,3	Marshfield bog core R1524	Scituate Third Cliff D1885A R1394A-C
Plicatopollis spp. of the *P. lunata* type	X		X
Pseudoplicapollis limitata Frederiksen 1978a	X		
Labrapollis globosa (Pflug *in* Thomson & Pflug 1953) Krutzsch 1968	X		
Favitricolporites baculoferus Pflug *in* Thomson & Pflug 1953) Srivastava 1972	X		
Tricolpites redactus Frederiksen 1978a	X		
Subtriporopollenites anulatus Pflug & Thomson *in* Thomson & Pflug 1953	X		
Momipites strictus Frederiksen & Christopher 1978		X	
Momipites actinus Nichols & Ott 1978	X		
Momipites inaequalis group of Frederiksen & Christopher 1978	X	X	X
Cicatricosisporites dorogensis Potonié & Gelletich 1933	X		X
Casuarinidites spp.	X	X	X
Thomsonipollis magnifica (Pflug *in* Thomson & Pflug 1953) Krutzsch 1960	X		X
Momipites tenuipolus group of Nichols 1973	?		X
Betula infrequens Stanley 1965	X	X	X
Holkopollenites spp. of *H. chemardensis* type	X		
Choanopollenites alabamicus (Srivastava 1972) Frederiksen 1979	X		
Pseudoplicapollis serena Tschudy 1975	X		?
Pseudoplicapollis cf. *P. endocuspis* Tschudy 1975		X	

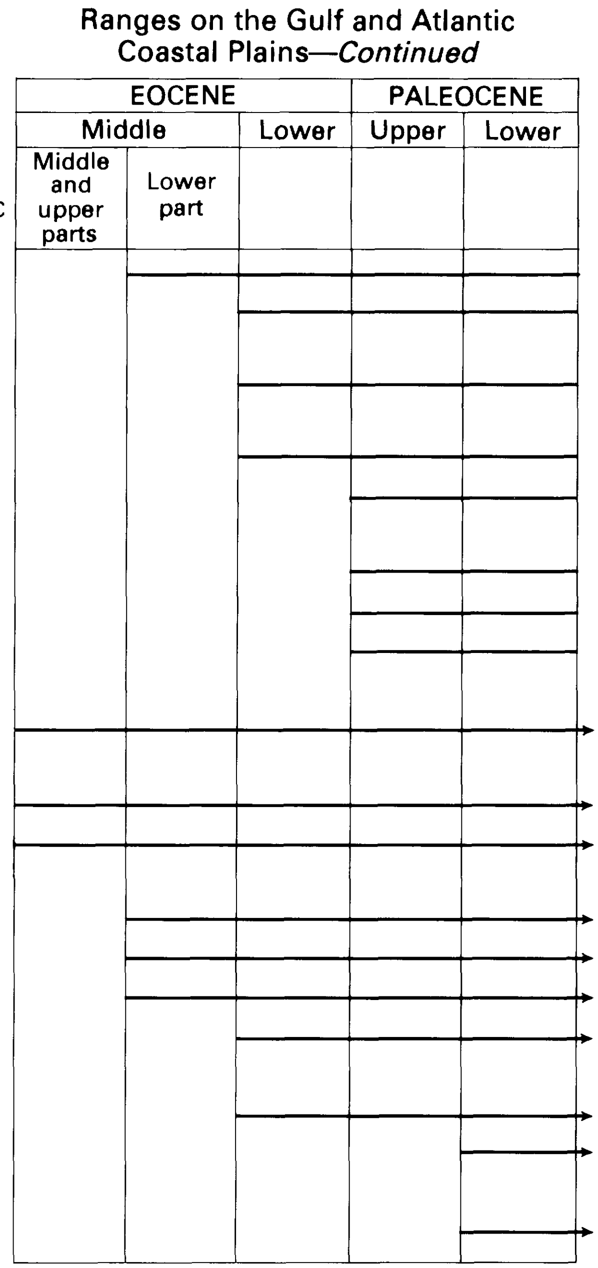


FIGURE 6.—Continued

at least some of the reworked sediments may be inferred from the known ranges of the reworked sporomorphs. Nine sporomorph forms (not listed in fig. 6) are Late Cretaceous types not known to range into the Tertiary: *Appendicisporites* sp., *Aquilapollenites* sp. (pl. 4, fig. 20), *Basopollis*? sp. (pl. 4, fig. 16), *Complexiopollis funiculus* Tschudy 1973b (pl. 4, fig. 15), *Endoinfundibulapollis*? sp. (pl. 4, figs. 17–18), *Holkopollenites* sp. (CP3D-3 of Wolfe, 1976), *Nyssapollenites* sp., *Plicapollis* sp. (pl. 4, fig. 14), and *Trudopollis* sp. (pl. 4, fig. 19). Two species, *Pseudoplicapollis serena* Tschudy 1975 (pl. 4, fig. 6) and *Pseudoplicapollis* cf. *P. endocuspis* Tschudy 1975 (pl. 4, figs. 10–11), are known only from the Upper Cretaceous and lower Paleocene. Five species, *Momipites actinus* Nichols & Ott 1978 (pl. 2, fig. 14), *Momipites strictus* Frederiksen & Christopher 1978 (pl. 2, fig. 13), *Subtriporopollenites anulatus* Pflug & Thomson in Thomson & Pflug 1953 (pl. 3, figs. 4–5), *Tricolpites redactus* Frederiksen 1978a, and *Kyandopollenites anneratus* Stover *in* Stover *et al.* 1966 (pl. 4, fig. 12) are restricted to the Paleocene; *K. anneratus* is known only from the upper Paleocene. Eight or nine species and species groups of figure 6 are apparently restricted to the lower Eocene and lowermost part of the middle Eocene. None of the reworked sporomorphs have ranges limited to rocks younger than early middle Eocene.

In short, the reworked sporomorphs suggest that rocks of at least three ages contributed sporomorphs (and sediments) to the Massachusetts Miocene: Upper Cretaceous, Paleocene, and lower Eocene to lowermost middle Eocene. Of these three age groups of rocks, those of the lower Eocene and lowermost middle Eocene undoubtedly contributed the most sediment to the Miocene. Evidence is, first, that reworked sporomorphs of the Cretaceous and Paleocene are rare in the Miocene, even though Cretaceous rocks of the region are rich in sporomorphs as shown by the abundance of reworked Cretaceous sporomorphs in Pleistocene sediments of the area (R. A. Christopher, written commun., 1977). Second, one of the more common reworked species in the Miocene is *Platycarya platycaryoides* (Roche 1969) Frederiksen & Christopher 1978 (pl. 2, fig. 19). In Southeastern United States, this species ranges from the lower Eocene to the upper part of the middle Eocene or even slightly higher, but it is abundant only in the lower Eocene and, to a lesser degree, in the lowermost middle Eocene (Tschudy, 1973a; Elsik, 1974; Frederiksen and Christopher, 1978; Frederiksen, 1979).

Figure 6 includes data from 19 samples, all of which are from Plymouth County, Mass. All Miocene samples examined from this county contain reworked Paleogene sporomorphs. It was difficult to estimate the frequency of reworked specimens relative to total sporomorphs in these sediments because many of the specimens found belong to taxa having such long ranges that the grains could be either Eocene or Miocene. Furthermore, autochthonous grains could not be distinguished from allochthonous specimens on the basis of the preservation or staining properties of the grains, as preservation is generally excellent and most grains of all ages accept stain in a similar way. However, I estimate that reworked specimens make up about 1–10 percent of total sporomorphs in the different Miocene samples from Plymouth County. In contrast, none of the three Miocene samples examined from Martha's Vineyard (R1267, R1513, R1555) contain sporomorphs that I recognized as reworked, with the possible exception of *Gleicheniidites* in sample R1267 (this genus is discussed in the section "Occurrences of Miocene Taxa"). Apparently, the Miocene sediments of Martha's Vineyard are at least in part of different provenance than those of Plymouth County.

POSSIBLE PALEOGENE STRATA IN MASSACHUSETTS

As mentioned previously in this paper, several authors have concluded on the basis of fossils that lower Tertiary strata still exist in Massachusetts. Folger and others (1978) identified Paleocene and Eocene rocks in two boreholes on Nantucket Island. Hall and others (1980) believed that Paleocene and Eocene strata are included in the section cut by well ENW-50 on Martha's Vineyard, but C. A. Kaye (cited by Hall and others, 1980; oral commun., 1981) considered that these strata are Pleistocene and contain reworked early Tertiary fossils. E. B. Leopold (cited by Chute, 1965, and Kaye, 1967a) thought that the glauconitic clay at Scituate Third Cliff in Plymouth County (fig. 3) might be Eocene on the basis of Eocene sporomorphs recovered from that bed, but I have shown in this paper that the bed is Miocene and contains reworked sporomorphs of Cretaceous to Eocene ages.

The only remaining records of possible lower Tertiary rocks on the Massachusetts mainland are in papers by Zeigler and others (1960) and Groot and Groot (1964). W. S. Hoffmeister recovered sporomorphs from three wells on Cape Cod (fig. 2). He reported (Zeigler and others, 1960, p. 1397) that these specimens "have a definite Eocene aspect. Although Upper Cretaceous elements are also present, the evidence points to an Eocene age (probably Lower Eocene).... Encountering the foraminiferal genus *Elphidium* at 230 feet in the No. 1 well helps to confirm the Eocene age for these sediments...." Hoffmeister did not name or illustrate any of the sporomorph taxa he found, and I have been unable to obtain his slides to check whether the Eocene material might be reworked. However, Groot and Groot (1964) looked at material from a well near Holden's Pond, Cape Cod, probably one of the same wells examined by Hoffmeister (the easternmost of the three Cape Cod wells in fig. 2 of this paper). Groot and Groot (1964) also considered their well samples to be Eocene in age. They presented a list of sporomorph form-taxa found in the samples, but these genera have such long ranges that the list is not very helpful in deciding whether the early Tertiary sporomorphs are reworked or not. However, Groot and Groot (1964, pl. 1) also illustrated 13 specimens from their samples, and these are very interesting. Among the grains illustrated by Groot and Groot are the following:

"*Extratriporopollenites*" (pl. 1, fig. 6) = probably *Choanopollenites* sp., Upper Cretaceous

"*Latipollis conspicuus*" (pl. 1, fig. 11) and perhaps "Triporate pollen sp. 2" (pl. 1, fig. 12) = *Choanopollenites conspicuus* (Groot & Groot 1962) Tschudy 1975, Upper Cretaceous to lower Paleocene

"Triporate pollen sp. 3" (pl. 1, fig. 10) = *Kyandopollenites anneratus* Stover *in* Stover *et al.* 1966, upper Paleocene

"*Triatriopollenites*" (pl. 1, fig. 3) = *Betula infrequens* Stanley 1965, Upper Cretaceous to lower part of the middle Eocene

"*Triporopollenites*" (pl. 1, fig. 2) = *Casuarinidites* sp., lower Paleocene to middle Eocene

"*Caryapollenites*" (pl. 1, fig. 4) = *Carya* spp. <29 μm of Tschudy (1973a) and Frederiksen and Christopher (1978), upper Paleocene to lower part of the middle Eocene

The remainder of the taxa shown in the plate of Groot and Groot (1964) have long ranges, generally at least from Upper Cretaceous to Eocene.

In summary, the well samples contain sporomorphs of Late Cretaceous, Paleocene, and perhaps early Eocene to early middle Eocene ages according to the plate of Groot and Groot (1964); the same strata contain Eocene sporomorphs and post-Paleocene foraminifers according to Zeigler and others (1960). Thus the sporomorph assemblages from the Cape Cod wells are very similar to the reworked sporomorphs in Miocene material from Plymouth County (this paper) and in Quaternary samples from various Massachusetts localities (Groot and Groot, 1964, and references therein). If the samples from the Cape Cod wells are Eocene, as assumed by Zeigler and others (1960) and Groot and Groot (1964), then it is necessary to postulate that Cretaceous and Paleocene sporomorphs were reworked into Eocene sediments, which in turn were reworked into Miocene and then again into Quaternary sediments. It seems much more likely to me that only two cycles of massive sporomorph reworking have taken place in eastern Massachusetts; that is, during Miocene and Quaternary times. In summary, I do not believe that any reliable evidence exists that lower Tertiary strata are still present on the Massachusetts mainland.

EOCENE PHYTOGEOGRAPHY AND CLIMATE

Besides providing provenance information about the Miocene sediments, figure 6 is also significant because few other data are available, or are likely to become available, on the nature of Paleogene floras of Northeastern United States. No Paleogene rocks are known to crop out in this region except the Brandon lignite of Vermont, which is probably Oligocene (Traverse, 1955; Tiffney, 1977, 1979). Sporomorphs are present in subsurface Paleogene rocks of offshore eastern Canada, but very little has been published about them in that region (Williams, 1975; Williams and Brideaux, 1975; Williams and Bujak, 1977; Barss and others, 1979). It is interesting that all Paleogene species and species groups found in Miocene strata of Massachusetts (fig. 6) are also known from the Paleogene of the Gulf Coast; apparently, at least the early Eocene to earliest middle Eocene flora of the Coastal Plain extended with little change from the Gulf Coast at least as far north as Massachusetts. A similar phenomenon was observed in Virginia, where the late Paleocene and early Eocene sporomorph floras are very similar to coeval floras of the Gulf Coast (Frederiksen, 1979).

Several reasons may be suggested to explain the strong resemblance of the Eocene flora of Massachusetts to the coeval flora of the Gulf Coast:

1. Massachusetts was at a lower latitude in the Eocene than now (fig. 7). I obtained the following figures from the paleocontinental maps of Smith and Briden (1977), extrapolating to values at 49 m.y. ago, the age of the early Eocene-middle Eocene boundary (Hardenbol and Berggren, 1978) and the approximate age of the reworked Eocene sporomorphs in the Massachusetts Miocene deposits:

	Present	*Eocene (49 m.y. ago)*
Latitude of Boston, Mass.	42.4°	38°
Latitude of Georgia-Florida boundary	30.7°	29°
Difference in latitude	11.7°	9°

These figures and the maps of Smith and Briden (1977) show that Massachusetts was about 4° closer to the equator at 49 m.y. ago than now, mainly because of the counterclockwise rotation of North America since the Eocene. An additional effect of the rotation of North America was a smaller difference in latitude between the Gulf Coast and Massachusetts in the Eocene than now.

2. As Wolfe (1979, p. 26) pointed out, "Until development of extensive ice sheets and an ice-covered Arctic Ocean in the late Cenozoic, cold waves from the Arctic probably would not have been as intense as at present." Therefore, greater equability would have prevailed at middle and high latitudes than exists now (Potter, 1976, p. 85–86; Lamb, 1977, p. 281).

3. The warm trade wind belt was much broader during times of ice-free poles than now, and the entire Atlantic and Gulf Coastal province probably lay within this belt in the Eocene (Flohn, 1964, p. 513).

Previous work on Eocene climates in Eastern United States has been based on material from the Gulf Coast and the Mississippi embayment. Middle Eocene plant megafossils from Kentucky and Tennessee, at the northern end of the Mississippi embayment, suggest a climate near the boundary between winter-dry tropical and humid subtropical in the climatic classification of Trewartha (1968) (Dilcher, 1973; D. L. Dilcher, *in* Frederiksen, 1980c, p. 730). Along the eastern Gulf Coast, the late middle Eocene to late Eocene climate was probably winter-dry tropical on the basis of sporomorphs (Frederiksen, 1980c). Maximum warmth in the North American Tertiary seems to have prevailed in the middle Eocene (Wolfe, 1978). Considering the great similarity between the Eocene sporomorph floras of the Gulf Coast, Virginia, and Massachusetts, I think we are justified in extending the tropical zone into coastal New England in the middle Eocene (fig. 7). Additional evidence about Paleogene climates in Massachusetts comes from the discovery by Kaye (1967a) of bauxite

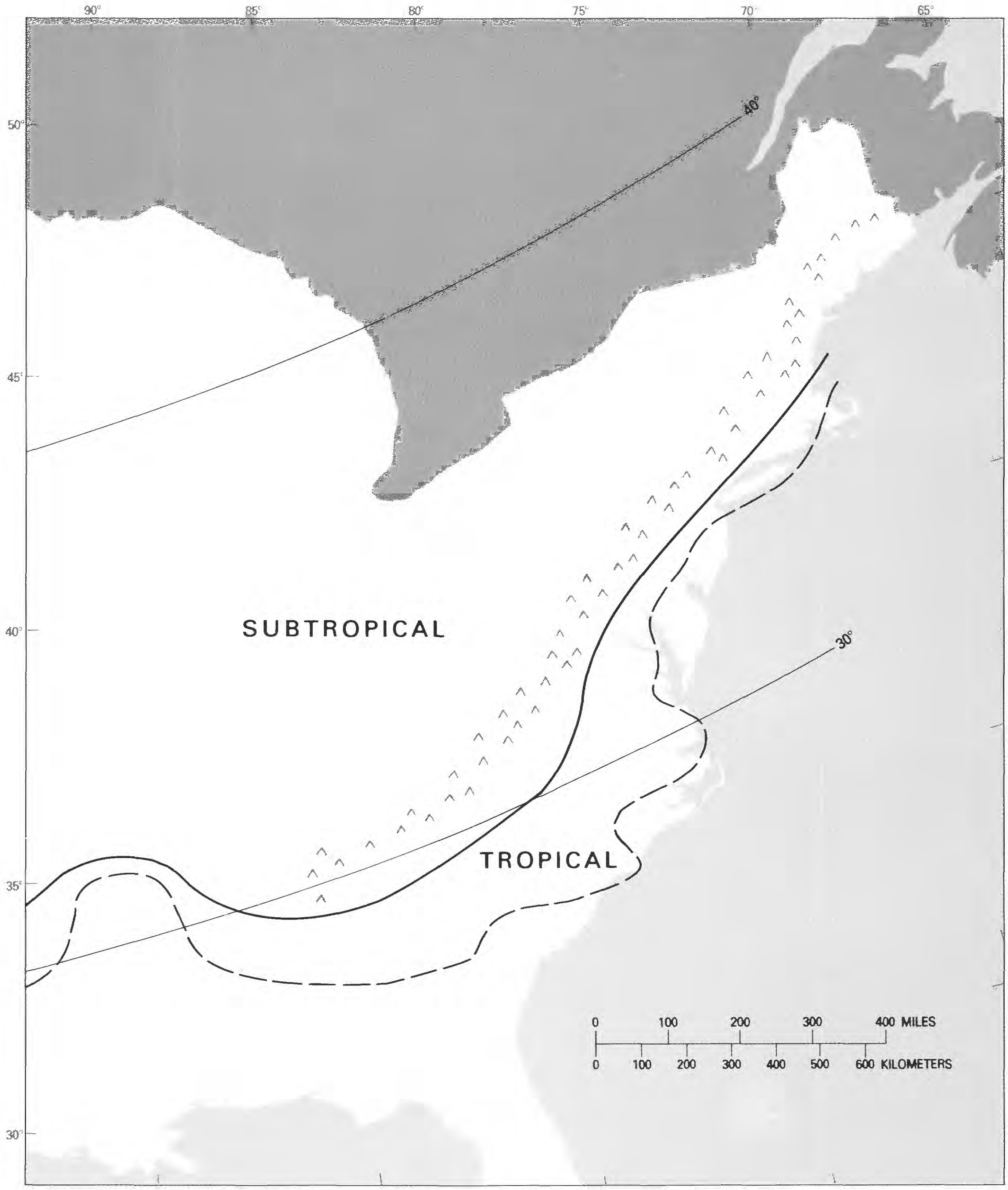


Figure 7.—Middle Eocene topography, shoreline (dashed line), and tropical-subtropical boundary (thick line) in the eastern part of the United States. Paleolatitudes are from Smith and Briden (1977).

pebbles in Pleistocene drift on Martha's Vineyard. Kaye (1967a, p. 1037) wrote that "The age of the New England . . . bauxitization . . . is conjectural, but in all likelihood it is the same as that of the deposits in Arkansas and in southeastern United States." Tertiary bauxites and mineable kaolin deposits in the latter regions formed in late Paleocene to middle Eocene time (Gordon and others, 1958; Overstreet, 1964; Tschudy and Patterson, 1975). Bauxite apparently forms only in tropical and near-tropical climates where humus is destroyed before humic acids can be produced (Schwarzbach, 1963, p. 23). Kaolin deposits are found in eastern Massachusetts, western Massachusetts, and western Vermont (Burt, 1929, and references therein; Kaye, 1967b) and may be the same age as the formation of bauxite in the same region. At Brandon, Vt., the kaolin underlies the lignite (Hitchcock and others, 1861, v. 1, p. 227–228; Woodworth, 1904) that is Oligocene or possibly early Miocene in age. The kaolins indicate that deep weathering took place in New England, apparently in the early Tertiary, in a warm, moist climate.

MIOCENE VEGETATION AND CLIMATE

VEGETATION

Table 5 shows the percentage composition of sporomorph taxa in two of the three Miocene samples from Martha's Vineyard, which appear to lack reworked sporomorphs. Sporomorphs were too sparse to count in the third sample, R1513. Relative frequencies of the taxa in samples R1267 and R1555 are rather similar; the main difference between the two samples is in the percentage of TCT pollen (Taxodiaceae-Cupressaceae-Taxaceae), which is about three times greater in R1555 than in R1267. The TCT grains in these samples are all or nearly all nonligulate; thus, they do not belong to such taxodiaceous genera as *Cryptomeria*, *Glyptostrobus*, *Metasequoia*, and *Sequoia* or perhaps even *Taxodium*. In both samples, conifer pollen makes up more than half the assemblage; the main angiosperm forms are *Quercus* and *Carya*. "Other angiosperms" in table 5 are mainly triporates and tricolporates that could not be identified with modern taxa. All the angiosperms of table 5 are wind-pollinated except *Ilex* and some Compositae. *Pinus*, *Betula*, and *Alnus* are heavy producers of pollen and are always over-represented in Quaternary pollen spectra (Faegri and Iversen, 1975, and references therein). Therefore, the scarcity of *Betula* and *Alnus* pollen in the two samples means trees of these two genera must also have been scarce in the vegetation. In Europe and Japan, *Quercus* is slightly over-represented to slightly under-represented in modern pollen spectra, but in Eastern United States, *Quercus* is greatly over-represented by pollen (Davis, 1963; Watts, 1969). Among other common pollen types in temperate to subtropical forests of the Northern Hemisphere, *Picea*, *Tsuga*, and *Fagus* are generally represented by pollen roughly in proportion to the abundance of trees of these taxa in the vegetation, but *Thuja* (Cupressaceae), *Tilia*, and *Acer* are considerably under-represented by pollen (Faegri and Iversen, 1975). *Sciadopitys* produces abundant pollen; in Miocene brown coals of Germany, this genus is 50 percent or more of the sporomorph assemblage in some samples (Thiergart, 1949; Thomson and Pflug, 1953; Krutzsch, 1971). However, these data do not necessarily indicate that *Sciadopitys* is over-represented by pollen because wood and abundant needles of this genus are also found in the coals (Teichmüller, 1958).

TABLE 5.—*Relative frequencies (percentages) of sporomorph taxa in Miocene samples from Martha's Vineyard, Mass.*

[Count was at least 300 grains per sample. T=trace (less than 1 percent)]

Taxa	Sample R1267	Sample R1555
Spores	-------	T
Conifers:		
Pinus haploxylon type	20	20
Pinus sylvestris type	24	16
Picea	8	7
Sciadopitys	7	5
Tsuga	T	2
Taxodiaceae-Cupressaceae-Taxaceae (TCT)	5	14
Podocarpus	2	
Dicot trees and shrubs:		
Quercus	22	15
Carya	5	4
Alnus	-------	2
Castanea	-------	1
Ilex	-------	T
Pterocarya type	-------	T
Ulmus-Zelkova	-------	T
Myrica	-------	T
Betula	-------	T
Fagus	-------	T
Monocots, mostly herbs and shrubs:		
Gramineae	2	T
Compositae	T	1
Chenopodiaceae-Amaranthaceae	-------	T
Monocolpate (probably Palmae)	-------	T
Other angiosperms	5	8

Correction factors intended to translate pollen percentages into relative frequencies of trees in the forest are difficult to apply in Quaternary studies and much more difficult to apply to Miocene sporomorph samples. Interpretation of table 5 is the more uncertain because these samples are from marine deposits whose sporomorph contents reflect the broad regional vegetation and not particular local plant communities. Even though *Pinus* and *Quercus* were probably not as dominant in the vegetation as the sporomorph percentages in table 5 suggest, surely *Pinus*, *Picea*, *Sciadopitys*, TCT, *Quercus*, *Carya*, and other temperate to subtropical hardwoods were abundant; the prevailing vegetation may be described as high-diversity low-dominance conifer-hardwood forest.

The low percentages of sporomorphs from herbs and shrubs (table 5) could be misleading to some extent because sporomorphs from nonarboreal plants are not widely distributed, at least by wind; however, because most sporomorphs are delivered to the sea by streams rather than by wind (Muller, 1959), the low percentages of nonarboreal pollen in table 5 probably indicate that Massachusetts was heavily forested in the Miocene. The inner edge of the Massachusetts Coastal Plain during the Tertiary probably extended from about the position of Boston southwestward across the State (Woodworth and Wigglesworth, 1934, p. 85; Kaye, 1967a, fig. 1). Therefore, during the Miocene transgression, the Coastal Plain was probably very narrow or may not have existed at all, and the forest contributing sporomorphs to the sea lived mainly or entirely in hilly country better drained than habitats on the present Coastal Plain.

Wolfe (1977, p. 48) considered that the Miocene vegetation of Eastern United States was probably Mixed Mesophytic forest. Table 3 confirms Wolfe's impression that the Miocene flora of this region had many genera in common with the modern Mixed Mesophytic forest of the central Appalachian Mountains, and the relative frequencies of the various Miocene taxa (table 5) are fairly similar to those in the modern forest. Holocene pollen spectra from Mixed Mesophytic forest in Tennessee are dominated by *Quercus* or co-dominated by *Quercus* and *Pinus* and also have significant percentages of one or more of the following: *Fraxinus*, *Carya*, *Liquidambar*, and *Tsuga* (Martin and Gray, 1962; Delcourt, 1979).

CLIMATE

Figure 8 lists the modern taxa that are represented by Miocene sporomorphs from the Massachusetts samples but do not now live in New England. As I explained in the section "Other Neogene Localities," table 3 emphasizes the modern taxa in the sporomorph flora; floristic, geographic, and climatic affinities remain to be determined for the sporomorphs that could not be identified with modern taxa. *Cyrilla* and *Cliftonia* are difficult if not impossible to distinguish from each other on the basis of pollen grains; living members of the *Engelhardia* group are the genera *Engelhardia*, *Alfaroa*, and *Oreomunnea*, all of which have similar pollen grains; and *Gleichenia* and *Dicranopteris* have the same kinds of spores. Nearly all the taxa of figure 8 are now confined to climates that are warmer than the present cool temperate climate of New England. An exception is *Ephedra*; this genus now lives primarily in boreal (largely montane-boreal), summer-dry subtropical, and semiarid to arid regions. However, *Ephedra distachya* L. extends along "sandy shores and stream-banks" into temperate northwestern France and the central Ukraine (Tutin and others, 1964, p. 40). *Ephedra* undoubtedly had a broader climatic range in the Tertiary than now. Most of the taxa of figure 8 still live in North America. In fact, of the taxa in figure 8, only *Pterocarya* and *Sciadopitys* are now lacking from the region that extends from southeastern United States to Central America. Figure 8 shows that nearly all the warm temperate to subtropical elements in the Miocene flora of Massachusetts are also found in Asia, but few of these taxa now live in Europe and Africa.

Sciadopitys (pl. 1, figs. 2–6) is now confined to broad-leaved deciduous and broad-leaved evergreen forests in mountains of central and southern Japan (Numata, 1974). *Sciadopitys* has existed at least since the Cretaceous, and during the Paleogene it ranged from Japan to Siberia, Kazakhstan, Europe, Ellesmere Island, and British Columbia (Tokunaga, 1955; Florin, 1963; Piel, 1971; Rouse and others, 1971; Krutzsch, 1971; Rouse, 1977). It has also been reported from the Neogene of Alaska and western Canada (Martin and Rouse, 1966; Leopold, 1969), but the genus has not been found in the Tertiary of the Rocky Mountains. The widespread distribution of *Sciadopitys* in the Tertiary indicates that it has had a much broader climatic range than at present; Krutzsch (1971, p. 33) remarked that fossil pollen similar to modern *Sciadopitys* "shows a considerably greater (broader) climatic amplitude than for example the tsugoid forms." The association of *Pinus*, *Picea*, *Tsuga*, *Sciadopitys*, TCT, and *Podocarpus* in the Miocene of Massachussetts is interesting because it is very similar to conifer-taxad associations in modern broad-leaved evergreen forests of southwestern Japan (Numata, 1974). These forests are dominated by *Quercus* and *Castanopsis* but include stands of Pinaceae (*Pinus*, *Picea*, *Tsuga*, *Abies*), Taxodiaceae (*Sciadopitys*, *Cryptomeria*), Cupressaceae (*Chamaecyparis*), Taxaceae (*Torreya*), and Podocarpaceae (*Podocarpus*).

In summary, the data of figure 8 indicate that in the Miocene Massachusetts was warmer than now. Probably the climate at that time was humid subtropical in the sense of Trewartha (1968), but because the number of taxa in figure 8 is a rather small proportion of the total identified taxa in the flora (table 3), Massachusetts was probably in the northern part of the subtropical belt.

In a previous section of the paper I showed that the

Taxon	Modern climatic range				Modern geographic range					
	D	Cf	Aw	Ar	North America including Mexico	Central and South America	Europe	Africa	Asia	Australia and New Zealand
Sciadopitys	—	—							X	
Ephedra	—	—	—		X	X	X		X	
Pterocarya		—					X		X	
Cyrilla and *Cliftonia*		—	—	—	X	X				
Engelhardia group		—	—	—	X	X			X	
Gleichenia and *Dicranopteris*		—	—	—	X	X		X	X	X
Gordonia		—	—	—	X				X	
Palmae		—	—	—	X	X		X	X	X
Podocarpus		—	—	—	X	X		X	X	X
Sapotaceae		—	—	—	X	X		X	X	X
Symplocos		—	—	—	X	X			X	X

FIGURE 8.—Modern climatic and geographic ranges of exotic genera and families represented by Miocene sporomorphs from Massachusetts. [Climate symbols are those of Trewartha (1968): D = temperate; Cf = humid subtropical; Aw = winter-dry tropical; Ar = wet tropical. Some taxa listed here also occur in summer-dry subtropical, semiarid, or even arid climates.]

Eocene climate of coastal Massachusetts was probably winter-dry tropical. On the basis of modern climatic affinities of plant megafossils from the Brandon lignite, which is probably Oligocene, Tiffney (1978, p. 79) considered that the climate of Vermont in Brandon time was similar to that "found in southeastern China, southeastern North America, and the mountains of Vera Cruz, Mexico." These data of Tiffney (1978) indicate that in the Oligocene, inland New England was humid subtropical in the sense of Trewartha (1968) and was perhaps in the warm part of that climatic belt. Along the coast the climate should have been slightly more equable—that is, the annual high and low temperatures should have deviated less from the annual mean—than inland. In the present paper I have shown that in the Miocene, coastal New England was probably also humid subtropical but probably lay in the cooler part of that belt and that during at least part of Pliocene time this region was temperate, apparently cool temperate. These four Tertiary data points (Eocene of Massachusetts, Oligocene of Vermont, and Miocene and Pliocene of Massachusetts) indicate much better than was previously possible for New England the nature of the Eocene climate there and the trend toward cooler climates after the Eocene.

TABLE 6.—*Locations of illustrated specimens*

[Sample localities are described in table 1. All illustrated specimens are from the Miocene of Massachuseetts except those from sample R1292A, which is from the Legler lignite, Ocean County, N. J. (see Rachele, 1976)]

Plate	Figure	Slide	Coordinates
1	1	D5259-1(2)	23.9 × 96.0
	2	R1555(1)	28.0 × 101.5
	3	R1267(2)	60.1 × 107.9
	4-5	R1555(1)	25.9 × 112.1
	6	R1267(2)	52.0 × 106.1
	7	R1267(2)	35.4 × 107.9
	8	R1555(1)	27.3 × 104.0
	9	R1394C(2)	45.0 × 101.3
	10	R1555(1)	27.3 × 104.0
	11	R1555(1)	29.9 × 100.5
	12	D5259-1(4)	32.5 × 102.2
	13	R1267(2)	48.2 × 106.6
	14	D5259-1(1)	31.4 × 94.3
	15	R1513(1)	40.0 × 99.6

TABLE 6.—*Locations of illustrated specimens*—Continued

Plate	Figure	Slide	Coordinates
	16	R1267(2)	36.0 × 109.2
	17	D5259-2(6)	34.5 × 106.0
	18	R1292A(3)	48.4 × 106.7
	19	D5259-1(4)	33.5 × 110.2
	20	R1292A(3)	49.3 × 101.4
	21-22	R1292A(1)	25.1 × 112.2
	23	R1267(2)	43.5 × 108.7
	24	R1267(2)	42.0 × 98.6
	25	D5259-1(1)	18.5 × 95.6
	26	R1267(2)	35.4 × 96.6
	27-28	D5259-5(3)	30.5 × 95.0
2	1-2	R1267(2)	35.5 × 98.3
	3	D5259-1(2)	11.6 × 98.2
	4	D5259-11(3)	10.0 × 108.3
	5	R1555(1)	26.7 × 103.5
	6	D5259-3(4)	31.5 × 107.4
	7	D5259-1(2)	28.7 × 99.3
	8	D5259-3(4)	30.0 × 92.8
	9	D5259-1(4)	30.0 × 93.4
	10	D5259-9(4)	33.1 × 103.0
	11	D5259-1(2)	17.3 × 96.2
	12	D5259-11(3)	10.1 × 100.0
	13	D5259-1(2)	27.7 × 112.0
	14	D5260-3(3)	32.0 × 94.2
	15	D5259-11(3)	10.5 × 96.6
	16	D5259-3(4)	31.0 × 109.6
	17	R1394C(2)	43.9 × 103.4
	18	D5260-3(3)	14.0 × 106.1
	19	D5259-1(2)	12.6 × 111.8
	20	D5260-3(3)	28.0 × 102.0
	21	D5259-2(6)	30.0 × 98.0
	22	D5259-8(3)	33.9 × 113.0
	23	D5260-3(3)	27.0 × 107.3
	24	D5260-3(3)	14.9 × 110.1
	25	D5259-4(4)	30.0 × 100.8
	26	D5259-2(6)	34.5 × 96.3
	27	D5259-8(3)	36.6 × 112.5
	28	D5259-11(3)	12.0 × 97.3
	29	D5259-6(4)	35.7 × 100.7
	30	D5260-3(3)	28.0 × 104.8
3	1	D5259-4(4)	34.4 × 106.8
	2	D5260-3(3)	30.6 × 111.0
	3	D5260-3(3)	14.0 × 106.0
	4-5	D5259-6(4)	34.5 × 104.6
	6	D5259-1(1)	26.6 × 108.6
	7	D5259-1(1)	24.3 × 100.6
	8	D1885A(1)	33.0 × 108.3
	9	D5260-3(3)	15.2 × 98 .7
	10	D5259-1(4)	30.9 × 96.9
	11	D5259-11(3)	14.0 × 107.0
	12	D5259-5(3)	33.2 × 107.3
	13	D5260-2(3)	34.0 × 94.8
	14	R1394C(2)	44.0 × 112.6
	15	D5259-4(4)	34.5 × 110.9
	16	D5260-3(3)	27.0 × 107.5
	17	D5259-2(6)	33.2 × 107.0
	18	D5259-7(3)	13.7 × 104.6
	19	R1394C(2)	48.0 × 107.2
	20	D5260-2(3)	32.0 × 110.0
	21	D5259-9(4)	34.6 × 103.6
	22	D5260-3(3)	14.0 × 106.1
	23	D5259-8(3)	36.9 × 102.5
	24	D5259-9(4)	31.0 × 93.0
	25	D5259-1(2)	16.3 × 99.9
	26	D5259-11(3)	11.9 × 106.3
	27	D5259-1(1)	22.2 × 107.3
4	1	D5259-1(1)	25.7 × 97.8
	2	R1394C(2)	45.5 × 106.5
	3	R1394A(1)	48.6 × 100.0
	4	D5259-4(4)	32.0 × 97.6
	5	D5260-3(3)	13.0 × 97.2
	6	D5260-3(3)	27.1 × 101.0
	7	D5259-1(4)	29.9 × 94.8
	8	D5259-1(4)	33.1 × 107.8
	9	D5260-3(3)	14.9 × 103.1
	10-11	R1524(1)	48.8 × 101.5
	12	D5259-1(2)	16.8 × 97.0
	13	D5259-11(3)	13.0 × 99.6
	14	D5259-6(4)	36.9 × 112.0
	15	D5259-6(4)	34.5 × 113.1
	16	D5260-3(3)	29.1 × 109.0
	17-18	D5260-3(3)	31.0 × 99.5
	19	D5259-1(2)	32.0 × 100.3
	20	D5259-5(3)	33.6 × 109.0

REFERENCES CITED

Abbott, W. H., and Andrews, G. W., 1979, Middle Miocene marine diatoms from the Hawthorn Formation within the Ridgeland Trough, South Carolina and Georgia: Micropaleontology, v. 25, p. 225-271.

Barss, M. S., Bujak, J. P., and Williams, G. L., 1979, Palynological zonation and correlation of sixty-seven wells, eastern Canada: Geological Survey of Canada Paper 78-24, 118 p.

Blackwelder, B. W., 1981, Late Cenozoic marine deposition in the United States Atlantic Coastal Plain related to tectonism and global climate: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 34, p. 87-114.

Bowman, Isaiah, 1905, Pre-Pleistocene deposits at Third Cliff, Massachusetts: Science, v. 21, p. 993-994.

_____1906, Northward extension of the Atlantic Preglacial deposits: American Journal of Science, 4th ser., v. 22, p. 313-325.

Brenner, G. J., and Patricelli, Judith, 1977, Palynology of the Marlboro Clay (Eocene) from Prince Georges County, Maryland [abs.]: Palynology, v. 1, p. 171-172.

Brenner, G. J., Patricelli, Judith, and Rachele, Linda, 1979, Palynology of the Paleocene-Eocene sediments from PGDf—36 well, Prince Georges County, Maryland (U.S.A.) [abs.]: Palynology, v. 3, p. 280.

Brown, T. C., 1905a, A new lower Tertiary fauna from Chappaquiddick Island, Martha's Vineyard: Science, v. 21, p. 990-991.

_____1905b, A new lower Tertiary fauna from Chappaquiddick Island, Martha's Vineyard: American Journal of Science, 4th ser., v. 20, p. 229-239.

Burt, F. A., 1929, The origin of the Bennington kaolins: Report of the State Geologist on the mineral industries and geology of Vermont, 1927-1928, v. 16, p. 65-84.

Chute, N. E., 1965, Geologic map of the Scituate quadrangle, Plymouth County, Massachusetts: U.S. Geological Survey Geologic Quadrangle Map GQ-467, scale 1:24,000.

Crosby, W. O., 1881, On the occurrence of fossiliferous boulders in the drift of Truro, on Cape Cod, Mass.: Boston Society of Natural History Proceedings, v. 20, p. 136-140.

Dall, W. H., 1894, Notes on the Miocene and Pliocene of Gay Head, Martha's Vineyard, Mass., and on the "Land phosphate" of the Ashley River district, South Carolina: American Journal of Science, 3d ser., v. 48, p. 296-301.

Dall, W. H., and Harris, G. D., 1892, Correlation papers, Neocene: U.S. Geological Survey Bulletin 84, 349 p.

Davis, M. B., 1963, On the theory of pollen analysis: American Journal of Science, v. 261, p. 897-912.

Delcourt, H. R., 1979, Late Quaternary vegetation history of the eastern Highland Rim and adjacent Cumberland Plateau of Tennessee: Ecological Monographs, v. 49, p. 255-280.

Dilcher, D. L., 1973, A paleoclimatic interpretation of the Eocene floras of southeastern North America, *in* Graham, Alan, ed., Vegetation and vegetational history of northern Latin America: Amsterdam, Elsevier, p. 39-59.

Elsik, W. C., 1974, Characteristic Eocene palynomorphs in the Gulf Coast, U.S.A: Palaeontographica, v. 149, Abt. B, p. 90-111.

Elsik, W. C., and Dilcher, D. L., 1974, Palynology and age of clays exposed in Lawrence clay pit, Henry County, Tennessee: Palaeontographica, v. 146, Abt. B, p. 65-87.

Emerson, B. K., 1917, Geology of Massachusetts and Rhode Island: U.S. Geological Survey Bulletin 597, 289 p.

Faegri, Knut, and Iversen, Johs., 1975, Textbook of pollen analysis (3d ed., rev. by K. Faegri): New York, Hafner, 295 p.

Finch, W. I., and Minard, J. P., 1966, Geologic map of the Farmington quadrangle, Graves County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-530, scale 1:24,000.

Flohn, H., 1964, Grundfragen der Paläoklimatologie im Lichte einer theoretischen Klimatologie: Geologisches Rundschau, v. 54, p. 504-515.

Florin, Rudolf, 1963, The distribution of conifer and taxad genera in time and space: Acta Horti Bergiani, v. 20, p. 121-312.

Folger, D. W., Hathaway, J. C., Christopher, R. A., Valentine, P. C., and Poag, C. W., 1978, Stratigraphic test well, Nantucket Island, Massachusetts: U.S. Geological Survey Circular 773, 28 p.

Frederiksen, N. O., 1969, Stratigraphy and palynology of the Jackson Stage (upper Eocene) and adjacent strata of Mississippi and western Alabama: Madison, University of Wisconsin, unpublished Ph.D. dissertation, 356 p.

_____1973, New mid-Tertiary spores and pollen grains from Mississippi and Alabama: Tulane Studies in Geology and Paleontology, v. 10, p. 65-86.

_____1978a, New Paleogene pollen species from the Gulf and Atlantic Coastal Plains: U.S. Geological Survey Journal of Research, v. 6, p. 691-696.

_____1978b, Note on the conversion of microscope stage coordinates: Micropaleontology, v. 24, p. 222-223.

_____1979, Paleogene sporomorph biostratigraphy, northeastern Virginia: Palynology, v. 3, p. 129-167.

_____1980a, Sporomorphs from the Jackson Group (upper Eocene) and adjacent strata of Mississippi and western Alabama: U.S. Geological Survey Professional Paper 1084, 75 p.

_____1980b, Paleogene sporomorphs from South Carolina and quantitative correlations with the Gulf Coast: Palynology, v. 4, p. 125-179.

_____1980c, Mid-Tertiary climate of southeastern United States: the sporomorph evidence: Journal of Paleontology, v. 54, p. 728-739.

_____1981, Middle Eocene to early Oligocene plant communities of the Gulf Coast, *in* Gray, Jane, Boucot, A. J., and Berry, W. B. N., eds., Communities of the past: Stroudsburg, Pa., Hutchinson Ross, p. 493-549.

Frederiksen, N. O., and Christopher, R. A., 1978, Taxonomy and biostratigraphy of Late Cretaceous and Paleogene triatriate pollen from South Carolina: Palynology, v. 2, p. 113-145.

Frederiksen, N. O., Kaye, C. A., and Whitmore, F. C., Jr., 1979, Miocene sporomorphs from Massachusetts, *in* Geological Survey Research 1979: U.S. Geological Survey Professional Paper 1150, p. 215-216.

Funkhouser, J. W., and Evitt, W. R., 1959, Preparation techniques for acid-insoluble microfossils: Micropaleontology, v. 5, p. 369-375.

Garner, J. C., Jr., 1976, Palynomorphs of the Calvert Formation (Miocene) of Maryland: University of Rhode Island, unpublished M. S. thesis, 187 p.

Gibson, T. G., 1965, Eocene and Miocene rocks off the northeastern coast of the United States: Deep-Sea Research, v. 12, p. 975-981.

_____in press, Miocene and Pliocene Pectinidae (Bivalvia) from the Lee Creek Mine, North Carolina, and adjacent areas: Smithsonian Contributions to Paleobiology.

Góczan, Ferenc, Groot, J. J., Krutzsch, Wilfried, and Pacltová, Blanka, 1967, Die Gattungen des "Stemma Normapolles Pflug 1953b" (Angiospermae)—Neubeschreibungen und Revision europäischer Formen (Oberkreide bis Eozän): Paläontologische Abhandlungen, v. 2, Abt. B, no. 3, p. 429-539.

Goldstein, F. R., 1974, Paleoenvironmental analyses of the Kirkwood Formation: Rutgers University, unpublished Ph.D. dissertation, 70 p.

Gordon, Mackenzie, Jr., Tracey, J. I., Jr., and Ellis, M. W., 1958, Geology of the Arkansas bauxite region: U.S. Geological Survey Professional Paper 299, 268 p.

Groot, C. R., and Groot, J. J., 1964, The pollen flora of Quaternary sediments beneath Nantucket Shoals: American Journal of Science, v. 262, p. 488-493.

Groot, J. J., and Groot, C. R., 1962, Some plant microfossils from the Brightseat Formation (Paleocene) of Maryland: Palaeontographica, v. 111, Abt. B, p. 161-171.

Gruas-Cavagnetto, Carla, 1976, Étude palynologique du sondage de la Defénse (Paris): Revue de Micropaléontologie, v. 19, p. 27-46.

Hall, R. E., Poppe, L. J., and Ferrebee, W. M., 1980, A stratigraphic test well, Martha's Vineyard, Massachusetts: U.S. Geological Survey Bulletin 1488, 19 p.

Hardenbol, J., and Berggren, W. A., 1978, A new Paleogene numerical time scale, *in* Cohee, G. V., Glaessner, M. F., and Hedberg, H. D., eds., Contributions to the geologic time scale: American Association of Petroleum Geologists Studies in Geology, no. 6, p. 213-234.

Hazel, J. E., Bybell, L. M., Christopher, R. A., Frederiksen, N. O., May, F. E., McLean, D. M., Poore, R. Z., Smith, C. C., Sohl, N. F., Valentine, P. C., and Witmer, R. J., 1977, Biostratigraphy of the deep corehole (Clubhouse Crossroads corehole 1) near Charleston, South Carolina: U.S. Geological Survey Professional Paper 1028-F, p. 71-89.

Hitchcock, Edward, 1824, Notices of the geology of Martha's Vineyard, and the Elizabeth Islands: American Journal of Science, v. 7, p. 240-248.

_____1833, Report on the geology, mineralogy, botany and zoology of Massachusetts: Amherst, J.S. and C. Adams, 700 p.

_____1838, Report on a re-examination of the economical geology of Massachusetts: Boston, Dutton and Wentworth, 139 p.

_____1841, Final report on the geology of Massachusetts: Amherst, J. S. and C. Adams, 2 v.

Hitchcock, Edward, Hitchcock, Edward, Jr., Hager, A. D., and Hitchcock, C. H., 1861, Report on the geology of Vermont: Claremont, N.H., 2 v.

Kaye, C. A., 1964a, Outline of Pleistocene geology of Martha's Vineyard, Massachusetts: U.S. Geological Survey Professional Paper 501-C, p. C134-C139.

______1964b, Illinoian and early Wisconsin moraines of Martha's Vineyard, Massachusetts, *in* Geological Survey Research 1964: U.S. Geological Survey Professional Paper 501-C, p. C140-C143.

______1964c, The Pleistocene geology of Martha's Vineyard, Mass.: Unpublished itinerary for the Friends of the Pleistocene, 27th Annual Reunion, May 23 and 24, 1964, Katama, Martha's Vineyard, Massachusetts, 9 p.

______1967a, Fossiliferous bauxite in glacial drift, Martha's Vineyard, Massachusetts: Science, v. 157, p. 1035-1037.

______1967b, Kaolinization of bedrock of the Boston, Massachusetts, area, *in* Geological Survey Research 1967: U.S. Geological Survey Professional Paper 575-C, p. C165-C172.

______1972, Outline of the geology of Martha's Vineyard, Nantucket, and the Elizabeth Islands, Massachusetts: Unpublished report for the National Park Service, 21 p.

______1979, Gay Head, Marshfield Hills, Stellwagen Bank, and Jeffreys Ledge(?) — segments of a major pre-Wisconsin moraine of southeastern New England [abs.]: Geological Society of America, Northeastern Section, 14th Annual Meeting, March 1-3, 1979, Hershey, Pennsylvania, Abstracts with Programs, p. 18-19.

______1980a, Late Wisconsinan glaciation of Martha's Vineyard and a peripheral ice cap for coastal New England [abs.]: Geological Society of America, Northeastern Section, 15th Annual Meeting, March 13-15, 1980, Philadelphia, Pennsylvania, Abstracts with Programs, p. 44.

______1980b, Geologic profile of Gay Head Cliff, Martha's Vineyard, Massachusetts: U.S. Geological Survey Open-file Report 80-148.

Kaye, C. A., Whitmore, F. C., Jr., Ray, C. E., and Purdy, R. W., 1979, Vertebrate faunas of Gay Head, Martha's Vineyard, Massachusetts, *in* Geological Survey Research 1979: U.S. Geological Survey Professional Paper 1150, p. 216.

Kedves, M., 1965, A new Restionaceae pollen type from the Hungarian Lower Tertiary layers: Advancing Frontiers of Plant Sciences, v. 13, p. 49-54.

Krutzsch, Wilfried, 1954, Bemerkungen zur Benennung und Klassifikation fossiler (insbesondere tertiärer) Pollen und Sporen: Geologie, v. 3, p. 258-311.

______1960, Ueber *Thomsonipollis magnificus* (Th. & Pf. 1953) n. fgen. n. comb. und Bemerkungen zur regionalen Verbreitung einiger Pollengruppen im älteren Paläogen: Freiberger Forschungshefte, no. C 86, p. 54-65.

______1961, Beitrag zur Sporenpaläontologie der präoberoligozänen kontinentalen und marinen Tertiarablagerungen Brandenburgs: Geologische Gesellschaft DDR Berichte, v. 5, p. 290-343.

______1962, Stratigraphisch bzw. botanisch wichtige neue Sporen- und Pollenformen aus dem deutschen Tertiär: Geologie, v. 11, no. 3, p. 265-306.

______1967, Der Florenwechsel im Alttertiär Mitteleuropas auf Grund von sporenpaläontologischen Untersuchungen: Zentrales Geologisches Institut, Abhandlungen, v. 10, p. 17-37.

______1968, *Brosipollis* und *Labrapollis*, zwei neue Pollengenera aus dem Tertiär Mitteleuropas: Review of Palaeobotany and Palynology, v. 6, p. 61-70.

______1970, Monoporate, monocolpate, longicolpate, dicolpate und ephedroide (polyplicate) Pollenformen, Lf. VII *of* Atlas der mittel- und jungtertiären dispersen Sporen- und Pollen- sowie der Mikroplanktonformen des nördlichen Mitteleuropas: Jena, VEB Gustav Fischer Verlag, 175 p.

______1971, Coniferenpollen (Saccites und "Inaperturates"), Lf. VI *of* Atlas der mittel- und jungtertiären dispersen Sporen- und Pollen- sowie der Mikroplanktonformen des nördlichen Mitteleuropas: Jena, VEB Gustav Fischer Verlag, 234 p.

Krutzsch, Wilfried, and Vanhoorne, Rogier, 1977, Die Pollenflora von Epinois und Loksbergen in Belgien: Palaeontographica, v. 163, Abt. B, p. 1-110.

Kuprianova, L. A., 1965, Palinologiya serezhkotsvetnykh (Amentiferae) (Palynology of the Amentiferae): Moscow, Nauka, 215 p.

Lamb, H. H., 1977, Climate: present, past and future; v. 2, Climatic history and the future: London, Methuen, 835 p.

Leopold, E. B., 1959, Pollen, spores, and marine microfossils, *in* Malde, H. E., Geology of the Charleston phosphate area, South Carolina: U.S. Geological Survey Bulletin 1079, p. 22-25.

______1969, Late Cenozoic palynology, *in* Tschudy, R. H., and Scott, R. A., eds., Aspects of palynology: New York, Wiley-Interscience, p. 377-438.

Leopold, E. B., and MacGinitie, H. D., 1972, Development and affinities of Tertiary floras in the Rocky Mountains, *in* Graham, Alan, ed., Floristics and paleofloristics of Asia and eastern North America: Amsterdam, Elsevier, p. 147-200.

Lyell, Charles, 1843, On the Tertiary strata of the island of Martha's Vineyard in Massachusetts: American Journal of Science, v. 45, p. 318-320.

Martin, H. A., and Rouse, G. E., 1966, Palynology of Late Tertiary sediments from Queen Charlotte Islands, British Columbia: Canadian Journal of Botany, v. 44, p. 171-208.

Martin, P. S., and Gray, Jane, 1962, Pollen analysis and the Cenozoic: Science, v. 137, p. 103-111.

Muller, Jan, 1959, Palynology of Recent Orinoco delta and shelf sediments: Micropaleontology, v. 5, p. 1-32.

Nagy, Eszter, 1963, Occurrence of the genus *Ephedripites* in the Neogene of Hungary: Grana Palynologica, v. 4, p. 277-280c.

Nichols, D. J., 1973, North American and European species of *Momipites* ("*Engelhardtia*") and related genera: Geoscience and Man, v. 7, p. 103-117.

Nichols, D. J., and Ott, H. L., 1978, Biostratigraphy and evolution of the *Momipites-Caryapollenites* lineage in the Early Tertiary of the Wind River Basin, Wyoming: Palynology, v. 2, p. 93-112.

Numata, Makoto, 1974, ed., The flora and vegetation of Japan: Tokyo, Kodansha, 294 p.

Overstreet, E. F., 1964, Geology of the southeastern bauxite deposits: U.S. Geological Survey Bulletin 1199-A, p. A1-A19.

Pflug, H. D., 1953, Zur Entstehung und Entwicklung des angiospermiden Pollens in der Erdgeschichte: Palaeontographica, v. 95, Abt. B, p. 60-171.

Piel, K. M., 1971, Palynology of Oligocene sediments from central British Columbia: Canadian Journal of Botany, v. 49, p. 1885-1920.

Potonié, Robert, and Gelletich, Johann, 1933, Ueber Pteridophyten-Sporen einer eocänen Braunkohle aus Dorog in Ungarn: Sitzungsberichte der Gesellschaft Naturforschender Freunde zu Berlin, Jahrgang 1932, p. 517-528.

Potonié, Robert, and Venitz, Herbert, 1934, Zur Mikrobotanik des miocänen Humodils der niederrheinischen Bucht: Preussische Geologische Landesanstalt, Arbeiten aus dem Institut für Paläobotanik und Petrographie der Brennsteine, v. 5, p. 5-54.

Potter, F. W., Jr., 1976, Investigations of angiosperms from the Eocene of southeastern North America: pollen assemblages from Miller pit, Henry County, Tennessee: Palaeontographica, v. 57, Abt. B, p. 44-96.

Rachele, L. D., 1976, Palynology of the Legler lignite: a deposit in the Tertiary Cohansey Formation of New Jersey, U.S.A.: Review of Palaeobotany and Palynology, v. 22, p. 225-252.

Raup, D. M., and Lawrence, D. R., 1963, Paleoecology of Pleistocene mollusks from Marthas Vineyard, Massachusetts: Journal of Paleontology, v. 37, p. 472-485.

Roche, E., 1969, Étude palynologique de sédiments du Montien continental et du Landénien supérieur en Hainaut: Societé Belge de Géologie, de Paléontologie et d'Hydrologie, Bulletin 78, p. 131-146.

Ross, N. E., 1949, On a Cretaceous pollen and spore bearing clay of Scania: Geological Institutions of the University of Uppsala Bulletin, v. 34, p. 25-43.

Rouse, G. E., 1962, Plant microfossils from the Burrard Formation of western British Columbia: Micropaleontology, v. 8, p. 187-218.

______1977, Paleogene palynomorph ranges in western and northern Canada, *in* Elsik, W. C., ed., Contributions of stratigraphic palynology, v. 1, Cenozoic palynology: American Association of Stratigraphic Palynologists, Inc., Contribution Series, no. 5A, p. 48-65.

Rouse, G. E., Hopkins, W. S., Jr., and Piel, K. M., 1971, Palynology of some Late Cretaceous and Early Tertiary deposits in British Columbia and adjacent Alberta: Geological Society of American Special Paper 127, p. 213-246.

Sayles, R. W., and Knox, A. S., 1943, Fossiliferous tills and intertill beds of Cape Cod, Massachusetts: Geological Society of America Bulletin, v. 54, p. 1569-1612.

Schwarzbach, Martin, 1963, Climates of the past: London, D. Van Nostrand, 328 p.

Scott, R. A., Barghoorn, E. S., and Leopold, E. B., 1960, How old are the angiosperms?: American Journal of Science, v. 258-A, p. 284-299.

Shaler, N. S., 1890, Tertiary and Cretaceous deposits of eastern Massachusetts: Geological Society of America Bulletin, v. 1, p. 443-452.

Simpson, J. B., 1961, The Tertiary pollen-flora of Mull and Ardnamurchan: Royal Society of Edinburgh, Transactions, v. 64, no. 16, p. 421-468.

Sirkin, L. A., and Owens, J. P., 1976, Applied pollen stratigraphic studies in the Delmarva Peninsula [abs.]: Geological Society of America, Northeastern and Southeastern Sections Joint Annual Meeting, March 25-27, 1976, Arlington, Va., Abstracts with Programs, p. 268.

Smith, A. G., and Briden, J. C., 1977, Mesozoic and Cenozoic paleocontinental maps: Cambridge, University Press, 63 p.

Srivastava, S. K., 1972, Some spores and pollen from the Paleocene Oak Hill Member of the Naheola Formation, Alabama (U.S.A.): Review of Palaeobotany and Palynology, v. 14, p. 217-285.

Stanley, E. A., 1965, Upper Cretaceous and Paleocene plant microfossils and Paleocene dinoflagellates and hystrichosphaerids from northwestern South Dakota: Bulletins of American Paleontology, v. 49, no. 222, p. 177-384.

Stover, L. E., Elsik, W. C., and Fairchild, W. W., 1966, New genera and species of early Tertiary palynomorphs from Gulf Coast: Kansas University Paleontological Contributions—Paper 5, 11 p.

Teichmüller, Marlies, 1958, Rekonstruktionen verschiedener Moortypen des Hauptflözes der niederrheinischen Braunkohle: Fortschritte in der Geologie von Rheinland und Westfalen, v. 2, p. 599-612.

Thiergart, Friedrich, 1949, Die *Sciadopitys*-Zone und der *Sciadopitys*-Vorstoss in der Niederrheinischen Braunkohle: Braunkohle, Wärme und Energie, v. 1, no. 9-10, p. 153-156.

Thomson, P. W., and Pflug, Hans, 1953, Pollen und Sporen des mitteleuropäischen Tertiärs: Palaeontographica, v. 94, Abt. B, p. 1-138.

Tiffney, B. H., 1977, Contributions to a monograph of the fruit and seed flora of the Brandon lignite: Harvard University, unpublished Ph. D. dissertation, 303 p.

______1978, Climatic implications of the flora of the mid-Oligocene Brandon Lignite of west-central Vermont [abs.]: Botanical Society of America, Miscellaneous Series Publication 156, p. 79.

______1979, Fruits and seeds of the Brandon lignite III. *Turpinia* (Staphyleaceae): Brittonia, v. 31, p. 39-51.

Tokunaga, Shigemoto, 1955, Pollenanalyses of the known coal seams in the Bibai area, Sorachi District, Ishikari coal field, Hokkaido: Japan Geological Survey Bulletin, v. 6, no. 9, p. 11-32.

Traverse, Alfred, 1955, Pollen analysis of the Brandon lignite of Vermont: U.S. Bureau of Mines Report of Investigations 5151, 107 p.

Trewartha, G. T., 1968, An introduction to climate (4th ed.): New York, McGraw-Hill, 408 p.

Tschudy, R. H., 1973a, Stratigraphic distribution of significant Eocene palynomorphs of the Mississippi embayment: U.S. Geological Survey Professional Paper 743-B, 24 p.

______1973b, *Complexiopollis* pollen lineage in Mississippi embayment rocks: U.S. Geological Survey Professional Paper 743-C, 15 p.

______1975, Normapolles pollen from the Mississippi embayment: U.S. Geological Survey Professional Paper 865, 40 p.

Tschudy, R. H., and Patterson, S. H., 1975, Palynological evidence for Late Cretaceous, Paleocene, and early and middle Eocene ages for strata in the kaolin belt, central Georgia: U.S. Geological Survey Journal of Research, v. 3, p. 437-445.

Tutin, T. G., Heywood, V. H., Burges, N. A., Valentine, D. H., Walters, S. M., and Webb, D. A., eds., 1964, Flora europaea, v. 1: Cambridge, University Press, 464 p.

Verrill, A. E., 1878, Occurrence of fossiliferous Tertiary rocks on the Grand Bank and George's Bank: American Journal of Science, 3d ser., v. 16, p. 323-324.

Watts, W. A., 1969, A pollen diagram from Mud Lake, Marion County, north-central Florida: Geological Society of America Bulletin, v. 80, p. 631-642.

White, David, 1890, On Cretaceous plants from Martha's Vineyard: American Journal of Science, 3d ser., v. 39, p. 93-101.

Williams, G. L., 1975, Dinoflagellate and spore stratigraphy of the Mesozoic-Cenozoic, offshore eastern Canada: Geological Survey of Canada Paper 74-30, v. 2, p. 107-146.

Williams, G. L., and Brideaux, W. W., 1975, Palynologic analyses of Upper Mesozoic and Cenozoic rocks of the Grand Banks, Atlantic continental margin: Geological Survey of Canada Bulletin 236, 163 p.

Williams, G. L., and Bujak, J. P., 1977, Cenozoic palynostratigraphy of offshore eastern Canada, *in* Elsik, W.C., ed., Contributions of stratigraphic palynology, v. 1, Cenozoic palynology: American Association of Stratigraphic Palynologists, Inc., Contribution Series, no. 5A, p. 14-47.

Wodehouse, R. P., 1933, Tertiary pollen. II, The oil shales of the Eocene Green River formation: Torrey Botanical Club Bulletin, v. 60, p. 479-524.

Wolfe, J. A., 1975, Some aspects of plant geography of the Northern Hemisphere during the Late Cretaceous and Tertiary: Missouri Botanical Garden Annals, v. 62, p. 264-279.

______1976, Stratigraphic distribution of some pollen types from the Campanian and lower Maestrichtian rocks (Upper Cretaceous) of the Middle Atlantic States: U.S. Geological Survey Professional Paper 977, 18 p.

______1977, Paleogene floras from the Gulf of Alaska region: U.S. Geological Survey Professional Paper 997, 108 p.

______1978, A paleobotanical interpretation of Tertiary climates in the Northern Hemisphere: American Scientist, v. 66, p. 694-703.

______1979, Temperature parameters of humid to mesic forests of eastern Asia and relation to forests of other regions of the Northern Hemisphere and Australasia: U.S. Geological Survey Professional Paper 1106, 37 p.

Woodworth, J. B., 1904, The Brandon clays: Report of the State Geologist on the mineral industries and geology of certain areas of Vermont, 1903-1904, v. 4, p. 166-173.

Woodworth, J. B., and Wigglesworth, Edward, 1934, Geography and geology of the region including Cape Cod, the Elizabeth Islands, Nantucket, Martha's Vineyard, No Mans Land and Block Island: Harvard University Museum of Comparative Zoology Memoir 52, 322 p.

Zeigler, J. M., Hoffmeister, W. S., Giese, Graham, and Tasha, Herman, 1960, Discovery of Eocene sediments in subsurface of Cape Cod: Science, v. 132, p. 1397-1398.

PLATES 1–4

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

PLATE 1

[Magnification × 1,000]

FIGURE 1. *Gleicheniidites* sp.; near Marshfield Center.

2–6. *Sciadopitys serrata* (Potonie & Venitz 1934) Martin & Rouse 1966; Gay Head.

7. *Podocarpus* sp.; Gay Head.

8–11. *Tsuga* spp., for comparison with *Sciadopitys*. In *Tsuga* the protrusions are more obviously hollow, more evenly spaced, and within any one specimen more uniform than in *Sciadopitys*. In different forms of *Tsuga* the protrusions may be small (fig. 9) to large (fig. 11). Figures 8, 10, 11, Gay Head; figure 9, Scituate Third Cliff.

12. *Ephedripites hungaricus* Nagy 1963; near Marshfield Center.

13–14. *Myrica* spp. Figure 13, Gay Head, probably Miocene; figure 14, near Marshfield Center, probably Miocene but possibly Paleogene.

15. *Comptonia*? sp.; Zacks Cliffs.

16. *Betula* sp.; Gay Head.

17–18. *Momipites spackmanianus* (Traverse 1955) Nichols 1973. Figure 17, near Marshfield Center; figure 18, Legler lignite, New Jersey.

19–20. *Momipites annulatus* Frederiksen & Christopher 1978. This species has a triradiate structure, but the annulus, shape, and size are probably the same as in *M. spackmanianus*. Figure 19, near Marshfield Center; figure 20, Legler lignite, New Jersey.

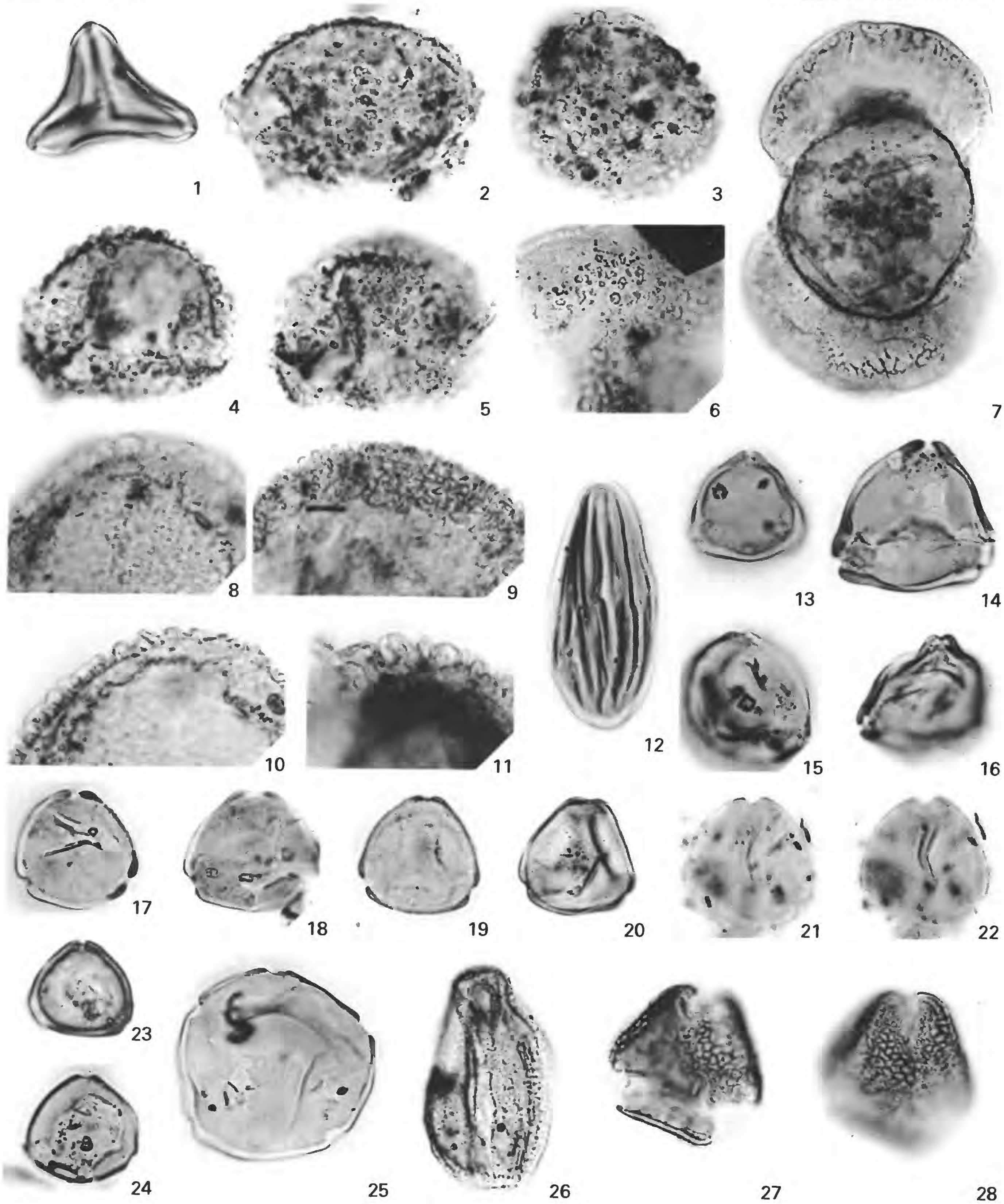
21–22. *Momipites* aff. *M. coryloides* Wodehouse 1933; Legler lignite, New Jersey.

23–24. *Triporopollenites* spp. Neither specimen has modifications of the exine at the pores, but the specimens differ in exine thickness. Both specimens are from Gay Head.

25. *Pterocarya* type; near Marshfield Center.

26. *Fraxinoipollenites* sp.; Gay Head.

27–28. *Gordonia* sp.; near Marshfield Center.

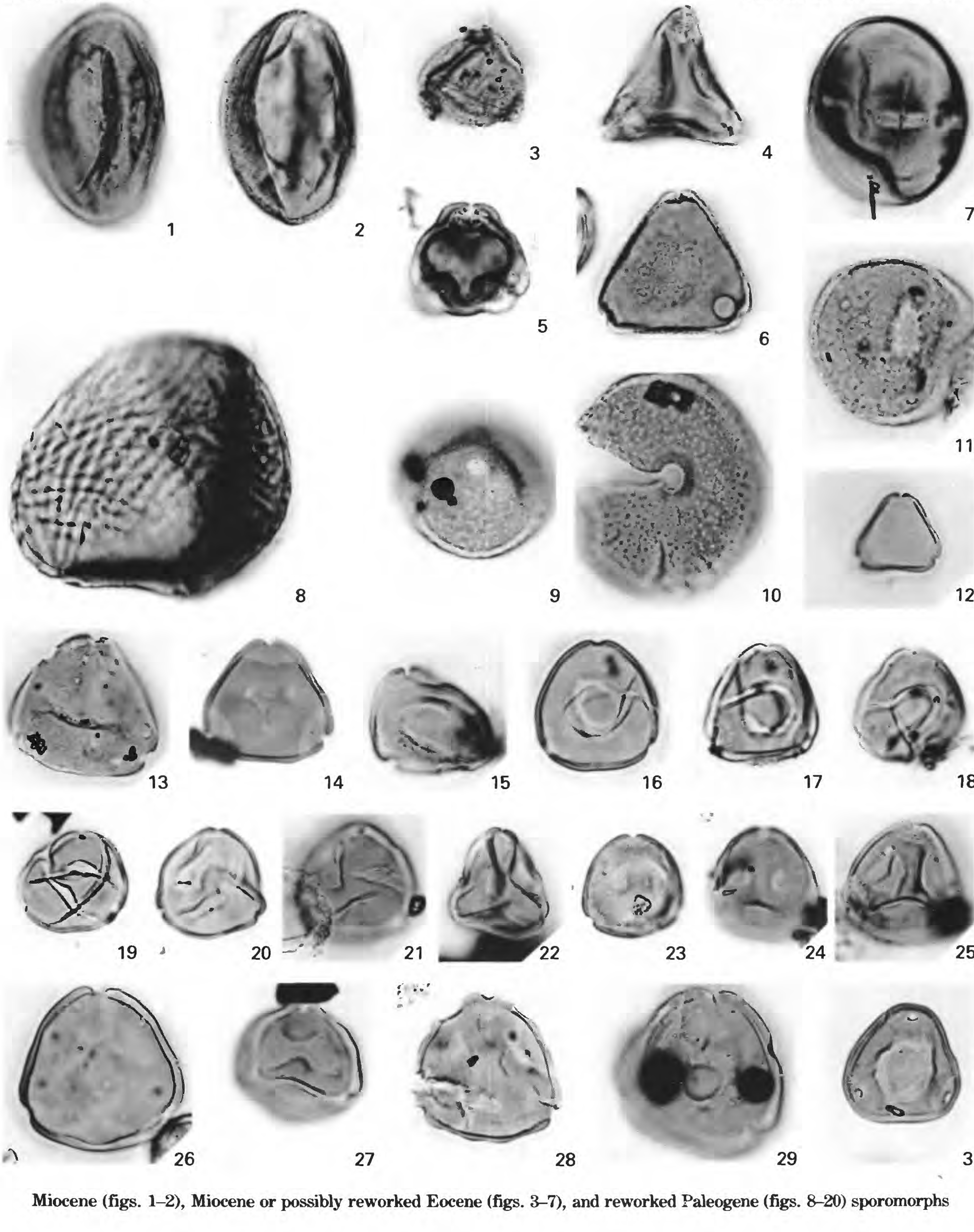


MIOCENE SPOROMORPHS

PLATE 2

[Magnification × 1,000. Specimens are from near Marshfield Center unless otherwise indicated]

FIGURES 1–2. Cornaceae?; Gay Head.
3. *Symplocos* sp.
4. *Boehlensipollis hohlii* Krutzsch 1962.
5. *Pseudolaesopollis* sp.; Gay Head.
6. *Symplocos* sp.
7. *Tetracolporopollenites* sp. (Sapotaceae); note shortness of colpi.
8. *Cicatricosisporites dorogensis* Potonié & Gelletich 1933.
9. *Milfordia minima* Krutzsch 1970.
10. *Milfordia hungarica* (Kedves 1965) Krutzsch 1970.
11. *Milfordia incerta* (Pflug & Thomson *in* Thomson & Pflug 1953) Krutzsch 1961.
12. *Momipites microfoveolatus* (Stanley 1965) Nichols 1973.
13. *Momipites strictus* Frederiksen & Christopher 1978.
14. *Momipites actinus* Nichols & Ott 1978.
15. *Momipites tenuipolus* group of Nichols 1973, emend. Frederiksen & Christopher 1978.
16–18. "*Platycaryapollis semicyclus*" Krutzsch & Vanhoorne 1977. Figure 17 is a specimen from Scituate Third Cliff.
19. *Platycarya platycaryoides* (Roche 1969) Frederiksen & Christopher 1978.
20. *Platycarya* sp.
21. *Platycaryapollenites swasticoidus* (Elsik 1974) Frederiksen & Christopher 1978.
22. *Platycaryapollenites triplicatus* (Elsik 1974) Frederiksen & Christopher 1978.
23. *Plicatopollis* sp. of the *P. triorbicularis* type.
24–25. *Plicatopollis* spp. of the *P. lunata* type.
26–29. *Momipites-Plicatopollis-Platycaryapollenites* (*MPP*) complex of Frederiksen 1979. Note the thick exine and uneven outline in all these specimens, typical of the *MPP* complex which, so far as known, is limited to the lower Eocene and lowest part of the middle Eocene on the Gulf Coast.
  26. A specimen similar to *Momipites coryloides* Wodehouse 1933.
  27. Note the broad, uneven pseudocolpus.
  28. A specimen that seems to be corroded but probably has affinities to *Platycaryapollenites*.
  29. A specimen having morphological affinities to the *Momipites tenuipolus* group; compare with plate 2, figure 15.
30. *Carya* sp. $< 29\ \mu m$.



Miocene (figs. 1–2), Miocene or possibly reworked Eocene (figs. 3–7), and reworked Paleogene (figs. 8–20) sporomorphs

PLATE 3

[Magnification × 1,000. Specimens are from near Marshfield Center unless otherwise indicated]

FIGURES 1–2. *Triatriopollenites turgidus* (Pflug *in* Thomson & Pflug 1953) Frederiksen 1979.

3. *Labrapollis globosa* (Pflug *in* Thomson & Pflug 1953) Krutzsch 1968.

4–5. *Subtriporopollenites anulatus* Pflug & Thomson *in* Thomson & Pflug 1953.

6. *Casuarinidites convexus* (Groot & Groot 1962) Frederiksen & Christopher 1978.

7. *Casuarinidites* sp.

8. *Casuarinidites pulcher* (Simpson 1961) Srivastava 1972; specimen is from Scituate Third Cliff.

9. *Casuarinidites* aff. *C. sparsus* Frederiksen & Christopher 1978.

10. *Betula infrequens* Stanley 1965.

11. *Pistillipollenites mcgregorii* Rouse 1962.

12. *Interpollis microsupplingensis* Krutzsch 1961.

13. *Anacolosidites reklawensis* Elsik 1974.

14. *Dicolpopollis* cf. *D. kalewensis* of Tschudy 1973a; specimen is from Scituate Third Cliff.

15–16. *Tricolpites asper* Frederiksen 1978a.

17–19. *Intratriporopollenites ollivierae* Gruas-Cavagnetto 1976. Specimen of figure 19 is from Scituate Third Cliff.

20–21. *Nuxpollenites psilatus* Frederiksen 1979. The outline is slightly uneven; this is also true of the protologue specimens from Virginia.

22. *Nuxpollenites* sp. An unusually small specimen for this genus; perhaps this is an immature grain.

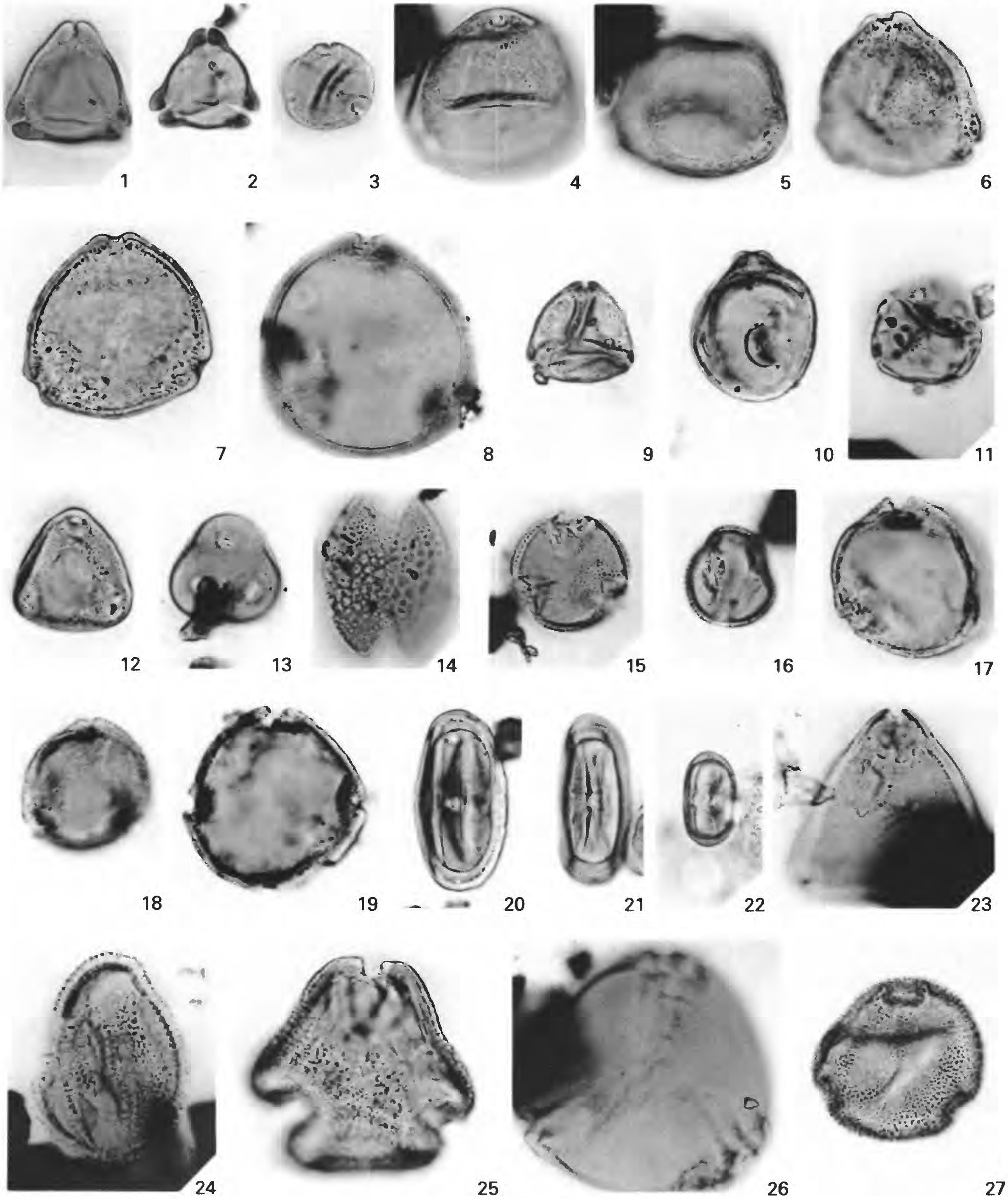
23. *Porocolpopollenites virginiensis* Frederiksen 1979.

24. *Favitricolporites baculoferus* (Pflug *in* Thomson & Pflug 1953) Srivastava 1972.

25. *Holkopollenites chemardensis* Fairchild *in* Stover *et al.* 1966.

26. *Holkopollenites*? sp.

27. *Thomsonipollis magnifica* (Pflug *in* Thomson & Pflug 1953) Krutzsch 1960.



Reworked Paleogene pollen grains

PLATE 4

[Magnification × 1,000. Specimens are from the Marshfield Center area unless otherwise indicated]

FIGURE 1. *Nudopollis terminalis* (Pflug & Thomson *in* Thomson & Pflug 1953) Pflug 1953.

2. *Trudopollis plena* Tschudy 1975; Scituate Third Cliff.

3–4. *Pompeckjoidaepollenites subhercynicus* (Krutzsch 1954) Krutzsch *in* Góczán *et al.* 1967. Specimen of figure 3 is from Scituate Third Cliff.

5. *Basopollis obscurocostata* Tschudy 1975.

6. *Pseudoplicapollis serena* Tschudy 1975.

7–8. *Pseudoplicapollis limitata* Frederiksen 1978a.

9. *Pseudoplicapollis*? or *Nudopollis*?

10–11. *Pseudoplicapollis* cf. *P. endocuspis* of Frederiksen 1979.

12. *Kyandopollenites anneratus* Stover *in* Stover *et al.* 1966.

13. *Choanopollenites* sp.

14. *Plicapollis* sp.

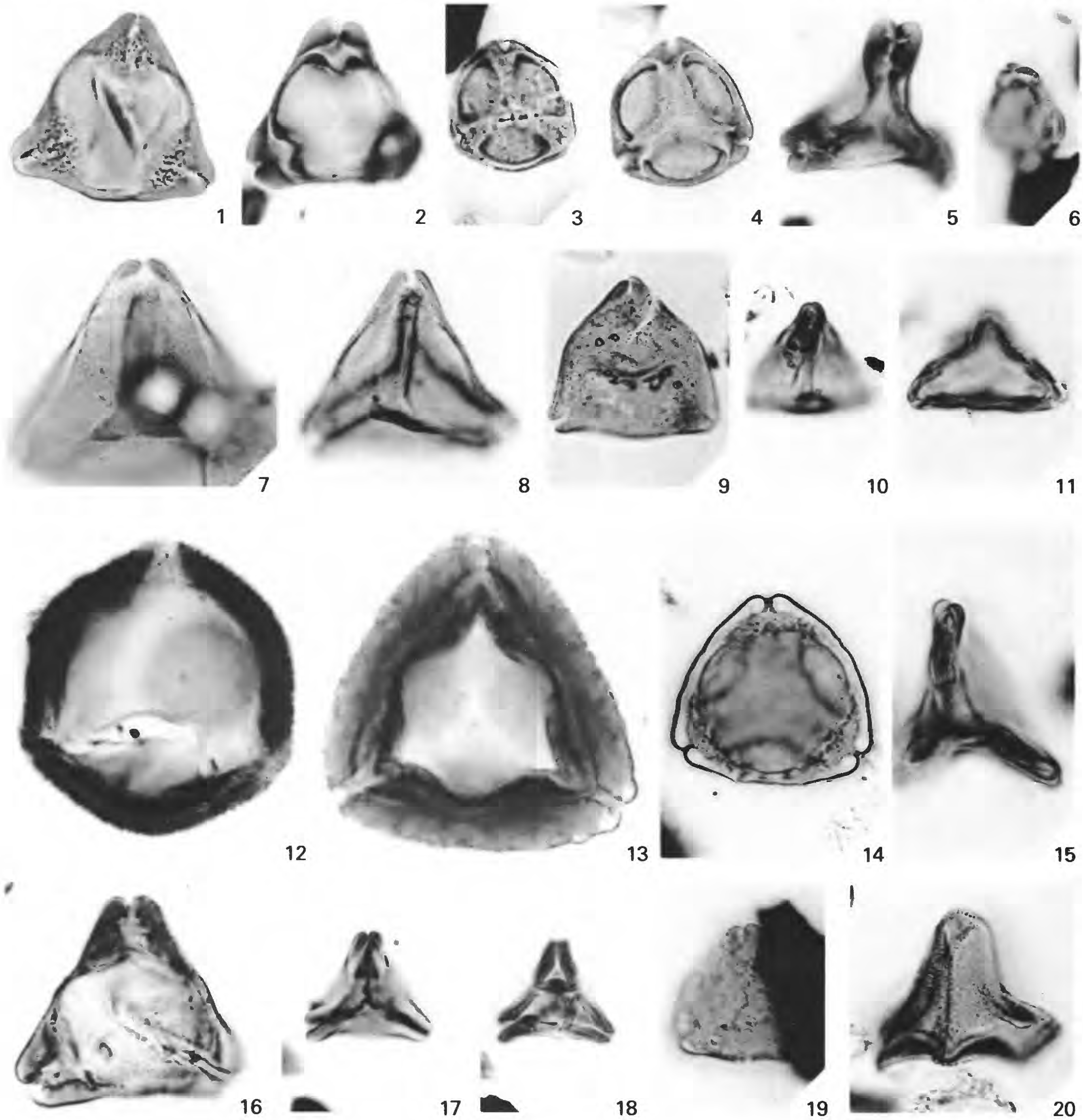
15. *Complexiopollis funiculus* Tschudy 1973b.

16. *Basopollis*? sp.

17–18. *Endoinfundibulapollis*? sp.

19. *Trudopollis* sp.

20. *Aquilapollenites* sp.



Reworked Paleogene and Cretaceous pollen grains

☆ U.S. GOVERNMENT PRINTING OFFICE: 1984-421-419:402