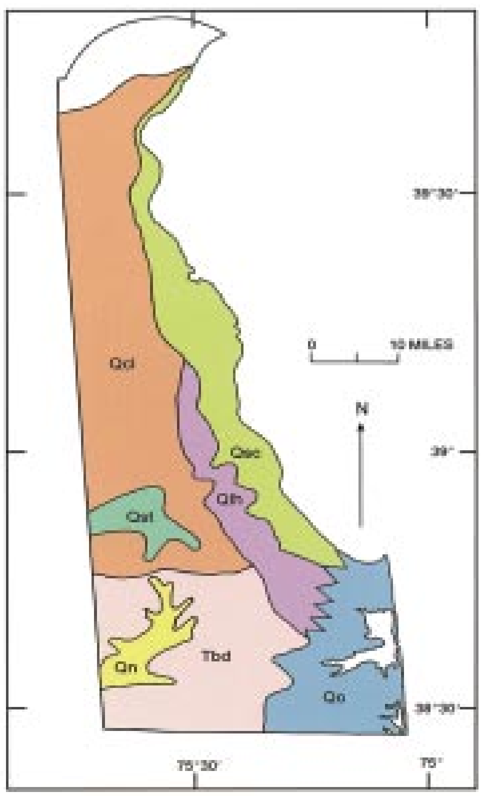
State of Delaware
DELAWARE GEOLOGICAL SURVEY
Robert R. Jordan, State Geologist

REPORT OF INVESTIGATIONS NO. 58

THE PLIOCENE AND QUATERNARY DEPOSITS OF DELAWARE: PALYNOLOGY, AGES, AND PALEOENVIRONMENTS

by

Johan J. Groot and Robert R. Jordan



University of Delaware
Newark, Delaware

1999

State of Delaware
DELAWARE GEOLOGICAL SURVEY
Robert R. Jordan, State Geologist

REPORT OF INVESTIGATIONS NO. 58

THE PLIOCENE AND QUATERNARY DEPOSITS OF DELAWARE: PALYNOLOGY, AGES, AND PALEOENVIRONMENTS

by

Johan J. Groot and Robert R. Jordan

University of Delaware
Newark, Delaware

1999

CONTENTS

ILLUSTRATIONS

TABLES

APPENDIXES

THE PLIOCENE AND QUATERNARY DEPOSITS OF DELAWARE: PALYNOLOGY, AGES, AND PALEOENVIRONMENTS

Johan J. Groot and Robert R. Jordan

ABSTRACT

The surficial Pliocene and Quaternary sedimentary deposits of the Atlantic Coastal Plain of Delaware comprise several formal and informal stratigraphic units. Their ages and the paleoenvironments they represent are interpreted on the basis of palynological and lithologic data and, to a lesser degree, on geomorphology.

The pollen assemblages of the Pliocene Beaverdam Formation are characterized by an abundance of *Quercus* and *Carya* and rare exotics including *Sciadopitys* and *Pterocarya*. The Columbia Formation, a fluvial deposit of early middle to middle middle Pleistocene age, contains pollen assemblages dominated by *Pinus* with variable percentages of *Picea* and *Quercus*, indicating a cool-temperate to cold climate. The Omar Formation, as originally defined, ranges in age from late Pliocene to late Pleistocene and contains a variety of pollen assemblages representing fluvial, estuarine, marsh, and bog paleoenvironments. The sediments of the Lynch Heights and Scotts Corners formations (Delaware Bay Group) are mostly of estuarine origin and of middle middle and late Pleistocene age, respectively. The Nanticoke deposits of middle and late Pleistocene age are found adjacent to or within the present valley of the Nanticoke River and its tributaries; pollen assemblages indicate mostly estuarine and fluvial paleoenvironments. Only two pollen samples from the Staytonville unit were analyzed: one indicates a fresh-water swamp during a period of cold to cool-temperate Wisconsinan(?) climate; the other is dominated by *Quercus* and some fresh-water elements, and its age is either Holocene or interglacial oxygen-isotope stage 5. Other unnamed Quaternary (Wisconsinan or Holocene) deposits, or at least their peaty components, are discontinuous and were probably deposited in shallow depressions on the surfaces of Pliocene and older Quaternary deposits; their pollen assemblages indicate either a cold climate (isotope stage 2?) or cool-temperate or temperate climates (isotope stage 5? [Sangamonian] or Holocene).

The palynological data indicate at least three temperate to warm-temperate intervals alternating with three cold periods. Estimated mean annual temperatures during oxygen-isotope substage 5e reached 14°C, slightly warmer than present. The coldest interval was probably isotope stage 12, although other cold periods were stages 2 and 6 and substage 5d(?). During the cold intervals estimated mean annual temperatures were probably 2° to 3°C.

Estimates of past sea levels are +42 ft (msl) during the Pliocene, +40 ft during oxygen-isotope stage 9 or 11 (Ramsey, 1997), and +20 ft during substage 5e. The relatively high sea level of +40 ft during stage 9 or 11 indicates possible tectonic uplift during the mid-Pleistocene.

INTRODUCTION

Purpose and Scope

The named post-Miocene deposits of Delaware (Fig. 1) comprise the Beaverdam, Omar, and Columbia formations (Jordan, 1962), the Staytonville unit (Jordan, 1964, 1974), the Scotts Corners and Lynch Heights formations (Ramsey, 1993, 1997), and the Nanticoke deposits (Ramsey and Schenck, 1990; Andres and Ramsey, 1996). Other Quaternary sediments studied for this report are not yet assigned to a stratigraphic unit(s).

Determining the ages of these deposits has, until recently, been difficult owing to a paucity of fossils. This dearth of fossils, except in some of the Pleistocene estuarine sediments, meant a lack of age control that is essential to the understanding of the stratigraphy and geologic history of the sediments. The deposits were generally considered to be of Pleistocene age because their lithologic characteristics indicated that major climatic and sea-level changes had occurred that were associated with continental glaciations. Even so, Jordan (1974, p. 35) recognized that it was "...impossible to prove that any material belongs definitely to the Pleistocene." Since 1974, progress has been made in dating many of the surficial deposits by a combination of palynological, aminostratigraphic, and radiometric methods, resulting in assigning a Pliocene age to the Beaverdam Formation (Owens and Denny, 1979; Groot et al., 1990), and determining the ages of various Quaternary deposits in terms of marine oxygen-isotope stages (Groot et al.,1990, 1995).

Mainly on the basis of palynological criteria, the purposes of this report are (1) to report the ages of the post-Miocene sediments of Delaware, particularly of the Quaternary deposits, and (2) to interpret their paleoenvironments. The scope of the investigation is limited to those sediments that contain palynomorphs (mostly pollen and spores, but also some dinocysts and algal material), and by the number of available samples. Palynological analyses listed in this report are considered representative of a much larger set of analyses in the files of the Delaware Geological Survey (DGS). Mapping the areal extent of the Pliocene and Quaternary units investigated was not an objective of this report. Geologic mapping is actively being pursued by other staff members of the DGS who use the palynostratigraphic data that are summarized in this report.

Sample numbers, well numbers, and outcrop identifiers used in this paper are according to systems of the DGS. Figure 2 shows the locations of the wells and outcrops (DGSIDs) that were sampled for this study; their latitudes and longitudes are given in Appendix 1. Precise locations, detailed descriptions, and master samples can be obtained from the records and archives of the DGS.

Previous Investigations

Jordan (1962, p. 42-43) first reported the presence of plant microfossils in the Omar Formation and states that the pollen and spores indicate that the formation "...was deposited under climatic conditions which include both moderate

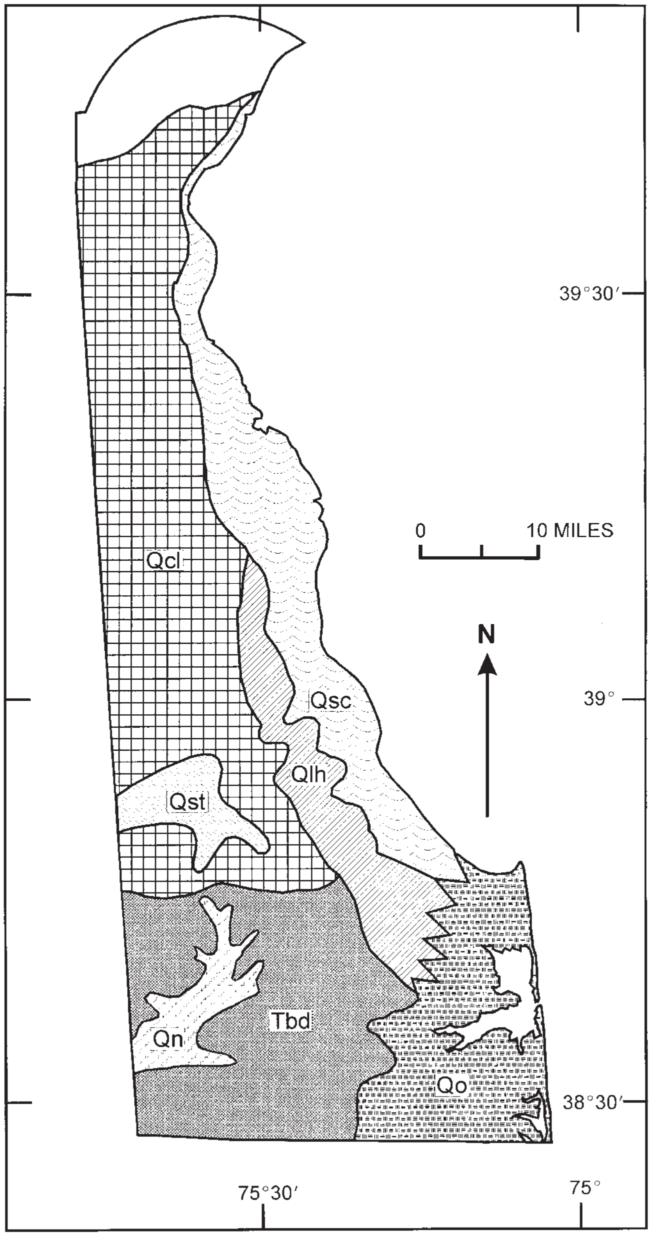


Figure 1. Map showing the generalized distribution of the named post-Miocene stratigraphic units of this report (after Ramsey and Schenck, 1990; Andres and Ramsey, 1995, 1997; Ramsey, 1993, 1997; and work in progress by K.W. Ramsey). Other Quaternary deposits and Holocene paralic deposits are not shown. Tbd–Beaverdam Formation; Qcl–Columbia Formation; Qo–Omar Formation; Qlh–Lynch Heights Formation; Qsc–Scotts Corners Formation; Qn–Nanticoke deposits; Qst–Staytonville unit.

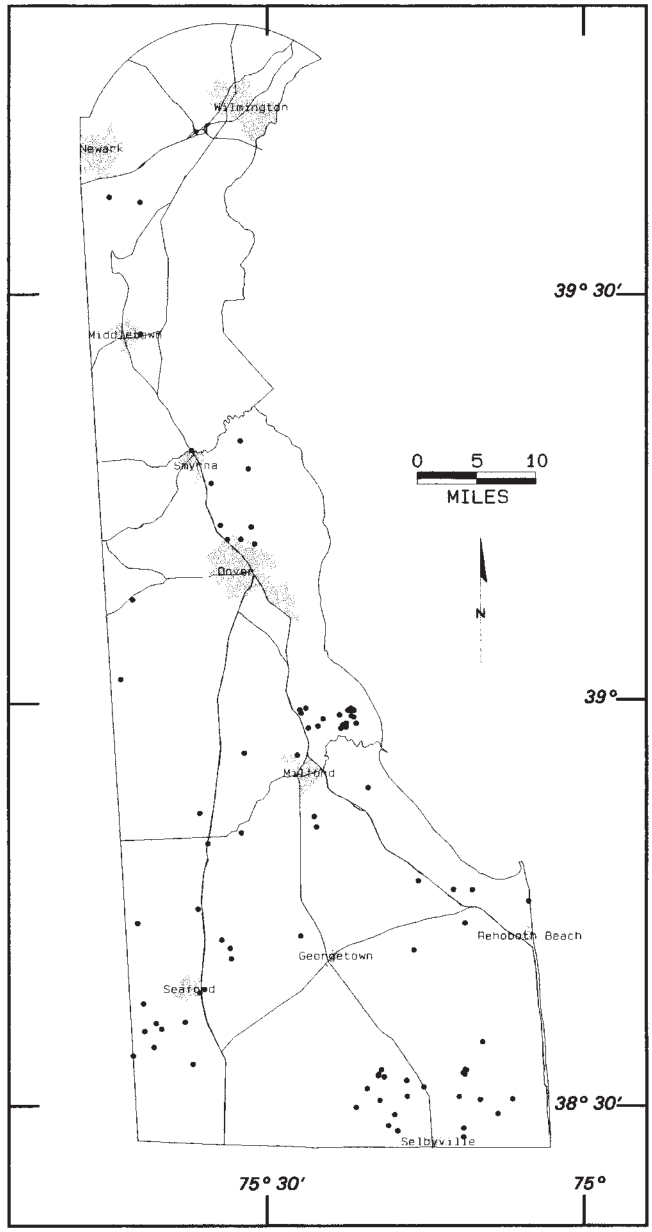


Figure 2. Map showing the locations of the wells and outcrops (DGSIDs) that were sampled for this study (see Appendix 1).

and cold temperatures." Owens and Denny (1979) briefly described pollen assemblages of the "Pensauken" (Columbia) and Beaverdam formations, and several other Quaternary deposits, and interpreted those assemblages in terms of age and paleoclimate. They were the first to state that the Beaverdam Formation is of Pliocene age on the basis of its palynoflora; they considered the Omar Formation to be of early Sangamonian age, with palynofloras dominated by oak-pine-hickory assemblages indicating a warm-temperate climate, but with some samples suggesting a cool-temperate climate.

Of special interest is Owens and Denny's (1979) interpretation of the age of the "Pensauken" (Columbia), because this formation is one of the largest in areal extent and volume of all the surficial sediments of Delaware, and it provides large quantities of ground water and sand and gravel and is therefore of considerable economic importance. Owens and Denny report a personal communication by L.A. Sirkin (1973) who found pollen assemblages that indicate a cool-temperate climate and other assemblages suggesting a warm-temperate climate. *Pterocarya*[1] pollen was also found in some samples. On the basis of those findings the age of the

[1] For the scientific and common names of plant taxa see Appendix 2.

"Pensauken" was considered to be Tertiary, probably Miocene, but other investigators assigned different ages to the Pensauken (in New Jersey), e.g., early Pleistocene (Berry and Hawkins, 1935) and Pliocene (Brenner, 1991, reported by Stanford, 1997).

Sirkin et al. (1977) and Denny et al. (1979) described a palynoflora from the Parsonsburg Sand in the central Delmarva Peninsula. The pollen assemblages of *Pinus*, *Picea*, *Betula*, *Alnus*, and other genera were interpreted as indicating a climate cooler and drier than at present, and radiocarbon analyses indicated a late Wisconsinan age. Groot et al. (1990) discussed the ages of some surficial sediments of southern Delaware and agreed with Owens and Denny (1979) that the Beaverdam Formation is of Pliocene age. Groot considered the Omar Formation to be mostly of Quaternary age, but in part latest Pliocene. Nickmann and Demarest (1982) made a detailed study of some Pleistocene interglacial sediments from southern Delaware, dated at 500,000–1,000,000 years BP (before present). They distinguished three pollen zones in a 450-cm core, generally indicating temperate-moist climates and environments of deposition ranging from estuarine to fresh-water marsh.

Groot (in Groot et al., 1995) studied the pollen assemblages of the 305 m of Quaternary sediments cored in AMCOR 6021C located on the upper continental slope off New Jersey. Paleoclimates were characterized in terms of a climate index, defined as the logarithm of the ratio of the total percentage of pollen of temperate and warm-temperate taxa to that of cold-climate taxa. Temperate and warm-temperate taxa include *Quercus*, *Carya*, *Carpinus*, *Castanea*, *Juglans*, *Liquidambar*, *Nyssa*, and *Taxodium*. Cold-climate taxa are *Picea* and *Abies* (Groot et al., 1995, p. 21). Marine oxygen-isotope stages were assigned to the various temperate and cold-climate intervals revealed by these assemblages. Figure 3 shows the interpretation of these intervals in comparison with the Specmap oxygen-isotope curve of Imbrie et al. (1984). In addition, the stratigraphic distribution of *Quercus* pollen species was determined, thus providing an opportunity to correlate the continental slope deposits with those of Delaware.

Several investigators have reported radiometric dates of Pleistocene deposits. Jordan and Talley (1976) mentioned two radiocarbon dates on shell material from the Omar Formation at Pepper Creek (Qh41-a, Appendix 1), one of 34,000 ± 2,000 years BP, and the other 37,000 or 38,000-plus

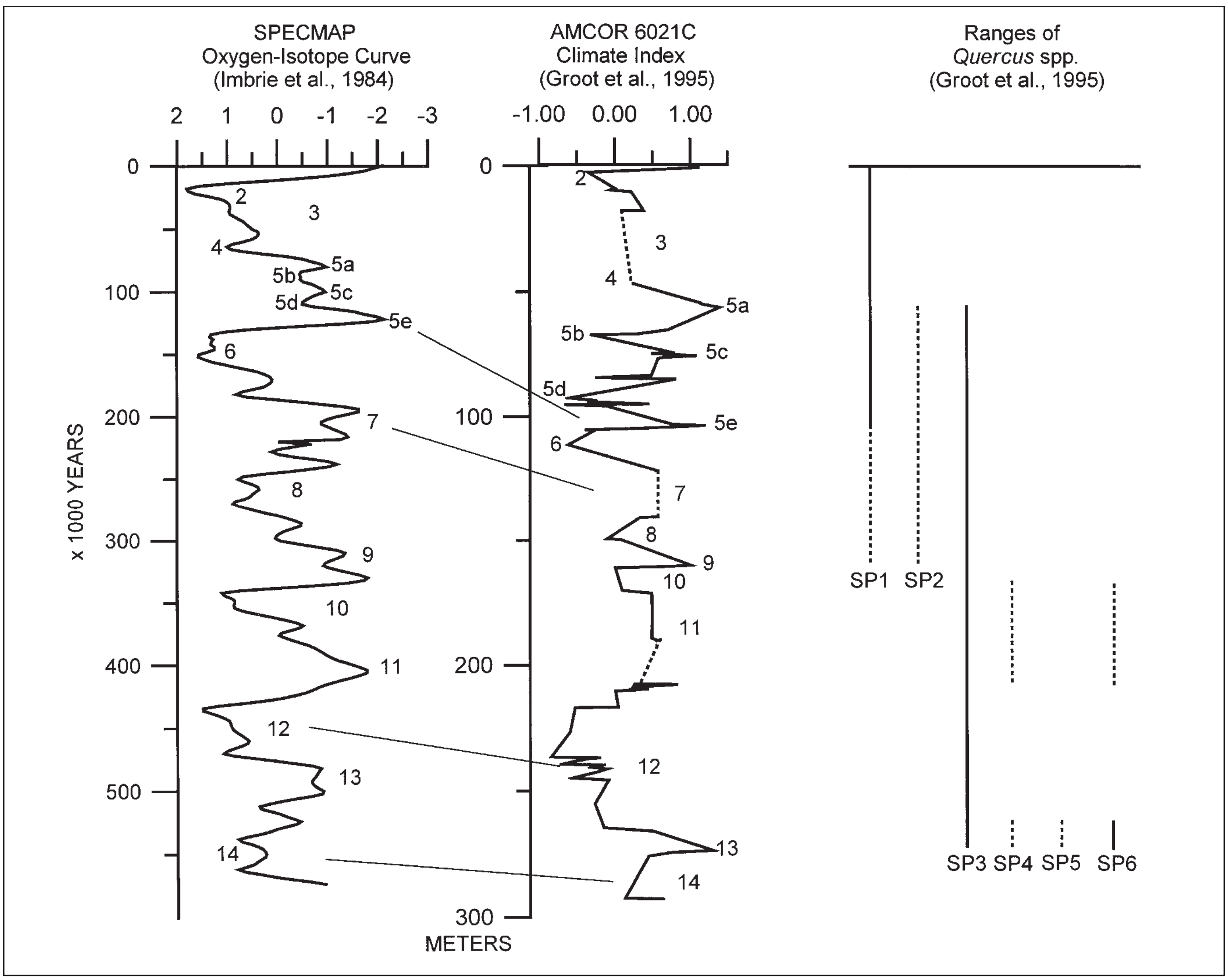


Figure 3. The Specmap oxygen-isotope curve adapted from Imbrie et al. (1984) and the climate index curve and stratigraphic distribution of *Quercus* spp. of AMCOR 6021C interpreted in terms of oxygen-isotope stages (after Groot et al., 1995).

years; however, these dates are probably invalid owing to contamination by younger carbon (Ramsey and Baxter, 1996). Sirkin and Owens (1976) reported two distinct ages for palynologically different deposits of the Omar Formation: 60,000 to 80,000 years BP (early to middle Wisconsinan age) and 126,000 years BP (Sangamonian age). Wehmiller (in Groot et al., 1990, p. 14) reports that a U-Th date of about 120,000 years obtained by Mixon et al. (1982) on oyster shells from the Pepper Creek locality is not unreasonable, but he recognizes that its accuracy is doubtful because of the inherent problems of that method of dating mollusk shells.

Aminostratigraphic data for Pleistocene sediments of Delaware have been summarized by Wehmiller and Belknap (1982), and the estimated ages of several deposits have been related to marine oxygen-isotope stages (Wehmiller, in Groot et al., 1990). The shell material needed for these amino acid analyses, however, has only been found at a small number of sites in Delaware and is not available from the fluvial deposits that form the major portion of the total volume of Quaternary sediments.

Jordan (1962, 1964, 1974) considered the Beaverdam and Omar formations as interfingering facies of the Columbia formation, therefore of Pleistocene age. Groot et al. (1990), however, established the Pliocene age of the Beaverdam and, on the basis of the occurrence of Tertiary exotic pollen grains, a Pliocene age for the lower part of the Omar Formation at its type locality and nearby. Relying on this information, Ramsey and Schenck (1990) show the lower Omar as a separate upper Pliocene unit unconformably overlying the Beaverdam and overlain unconformably by the upper Omar of Pleistocene age.

The other named Pleistocene units of this report are the Nanticoke deposits which unconformably overlie the Beaverdam Formation along the Nanticoke River and its tributaries (Ramsey and Schenck, 1990; Andres and Ramsey, 1995, 1996); the Lynch Heights and Scotts Corners formations comprising the Delaware Bay Group which unconformably overlies the Columbia Formation along the western shore of Delaware Bay (Ramsey, 1993, 1997); and the Staytonville unit, characterized by the relatively large amount of fine-grained matrix in the sands and by mottling, which Jordan (1974) considered a facies of the Columbia Formation in the Staytonville area. In addition, palynomorphs from other unnamed surficial Quaternary deposits of Delaware were studied for this report.

Acknowledgments

Several members of the Delaware Geological Survey contributed to the preparation of this report. Charles T. Smith was responsible for all laboratory work and prepared Plates 1–3. Dorothy C. Windish typed the tables, appendixes, and several drafts of the manuscript which were checked for accuracy by John H. Talley. Richard N. Benson constructed Figures 1, 3, and 5, and Kelvin W. Ramsey drafted Figure 4. Nicole M. Minni of the Water Resources Agency at the University of Delaware prepared the well and outcrop location map, Figure 2.

A. Scott Andres, Richard N. Benson, and Kelvin W. Ramsey of the DGS, Thomas A. Ager of the U.S. Geological Survey, and Alfred Traverse of Pennsylvania State University critically reviewed the manuscript and offered several suggestions for its improvement.

SOME GENERAL OBSERVATIONS ABOUT THE PALYNOLOGY OF THE POST-MIOCENE SEDIMENTS OF DELAWARE

Plates 1–3 illustrate selected palynomorph taxa useful for determining ages and paleoenvironments of the post-Miocene deposits of Delaware.

In this report, the separation between Pliocene and Quaternary deposits is primarily based on the presence or absence of pollen of exotic plants, that is, pollen of plants that are extinct in eastern North America. These exotics include *Pterocarya*, *Sciadopitys*, *Cupuliferoidaepollenites fallax*, and *Momipites* (*Engelhardia* type); all of them are rare and do not occur in all Pliocene samples (Groot et al., 1990). The criteria for recognizing the Pliocene deposits in Delaware are described in the section dealing with the Beaverdam Formation.

The stratigraphy of the Quaternary sediments is largely based on (1) the occurrence of six different *Quercus* pollen species (Plates 1 and 2) in various oxygen-isotope stages interpreted for AMCOR 6021C (Fig. 3), a cored borehole off the New Jersey coast, (2) the presence of these species in Pleistocene deposits in Delaware, and (3) the correlation of aminozones to oxygen-isotope stages (Wehmiller, in Groot et al., 1995). Results are shown in Table 1 (see Table 4 of Groot et al., 1995).

Many samples contain other species of *Quercus* than the six recognized in the study of AMCOR 6021C. This is

Table 1. Occurrences of some *Quercus* spp. vs. amino zones and oxygen isotope stages, Omar Formation.

DGS ID	Sample No.	Location	Amino Zone	Interpreted correlation with O-isotope stages	*Quercus* sp.
Qh41-a	40962	Pepper Creek	IIa	5e	3 and 1
Nh44-a	41142	Lewes area	IIc	9	3
Ri13-a	40969	Dirickson Creek	IId	11-13-15	6 and 3
Qi54-02	25197	Miller Creek	IId	11-13-15	6 and 3
Qi51-04	25047-25050	Roxana	IId	11-13-15	3 and 6

not surprising considering the great number of *Quercus* species that are present in North America today and unknown numbers of extinct *Quercus* species in the late Tertiary.

There is some reworking of the estuarine sediments of the Delaware Bay coastal zone, as indicated by the occurrence of some Cretaceous and Tertiary palynomorphs in some samples. Some *Quercus* pollen is reworked also. In these samples the determination of the isotope stage is based on the presence of the youngest *Quercus* species.

In addition to interpretations of paleoclimates by means of the climate index as described previously, palynomorph assemblages can also be interpreted in terms of paleoenvironments. Pollen of *Liquidambar* and *Nyssa* indicates humid or swampy conditions and a temperate or warm-temperate climate. *Picea* and *Abies* indicate a cold climate; pollen of the Chenopodiaceae is common in brackish water estuarine and lagoonal environments, and *Typha*, *Sparganium* and *Myriophyllum* indicate fresh-water deposits. Gramineae plus Cyperaceae pollen suggests a marsh environment, and abundant spores of *Sphagnum* indicate a bog.

BEAVERDAM FORMATION

The Beaverdam Formation consists primarily of white to buff to greenish-gray medium quartz sand with some beds of coarse gravelly sand and light gray to greenish-gray silty clay (Ramsey, in Groot et al., 1990). Clay beds are common in the lower part of the formation, and they occur sporadically in the upper part. On the basis of its lithologic characteristics, the lower part of the Beaverdam has been interpreted as being of fluvial origin, and the upper part is considered estuarine (Ramsey, in Groot et al., 1990).

Age and Paleoenvironment

Analyses of palynomorph assemblages are shown in Table 2 and in detail in Appendix 3 The main characteristics of the assemblages are (1) the generally low percentages of *Pinus*, (2) the high frequencies or even dominance of *Quercus*, (3) the common occurrence of *Carya*, and (4) the consistent presence of TCT[2] (including *Taxodium*), *Tilia*, and of rare pollen of exotics in nearly all samples. The exotics include *Sciadopitys*, *Pterocarya*, *Momipites (Engelhardia* type), *Tricolporopollenites edmundii*, *Cyrilla*, *Cupuliferoidaepollenites fallax*, and *Ulmus serotina* type (Groot et al., 1990).

Table 2. Analyses of pollen assemblages in samples from the Beaverdam Formation.

DGS ID	Sample No.	Elevation (ft)		Climate Index	Climate	Age (Stage)	Environment of Deposition	Remarks
		Land Surface	Sample					
Pc43-01	22826	25.2	-10	>1.4	wt	early Plio	fluvial?	*T. edmundii* P., *Pterocarya* 1%
Pc43-01	22827	25.2	-15	>1.4	wt	early Plio	fluvial?	*Sciadopitys* P., *Pterocarya* P.
Qb15-01	84440	5	-19	>1.4	wt	early Plio	fluvial?	*Momipites* P., *Sciadopitys* 1%
Ob24-a	42203	45	+42	>1.4	t	Plio	near-shore marine	*Picea* P., *Momipites*, *Pterocarya* 1%
Pd21-07	83166	30	-40	>1.4	twt	Plio	?	*Sciadopitys* 2%
Og45-01	85203	38	+20	1.4	t	late Plio	estuarine	*Pterocarya* 1%, *Picea* 2%, *Sciadopitys* P.
Qi11-a	41109	7	-1	>1.4	t	late Plio	fresh-water deposit?	*Pterocarya* P., *Picea* P.
Qi11-a	41110	7	-3	>1.4	t	late Plio	estuarine	*Pterocarya* P., *Picea* P.
Qi11-a	41111	7	-5	>1.4	t	late Plio	estuarine	*Pterocarya* P., *Picea* P.
Oh25-10	83438	21	-6	1.11	t	late Plio	estuarine ?	*Sciadopitys*, *Picea* P.

wt = warm-temperate; t = temperate; twt = temperate-warm-temperate; P = present, <1% of the pollen sum

[2] TCT: Taxodiaceae, Cupressaceae, Taxaceae

In Western Europe, *Sciadopitys*, *T. edmundii*, and *C. fallax* became extinct either in the mid-Miocene or at the end of the Pliocene; *Pterocarya* appears to have continued its presence until the mid-Pleistocene (Traverse, 1988, Table 15.1). Several other genera, mostly those that flourish in a moist, temperate to warm-temperate climate, became extinct in the late Pliocene or the early Pleistocene in Europe, but they continue to be present in the mid- and south Atlantic regions of North America, e.g., *Liquidambar*, *Nyssa*, *Symplocos*, and *Taxodium*. Thus, extinctions did not necessarily occur everywhere at exactly the same time. Nevertheless, the presence of *Pterocarya*, *Sciadopitys*, *C. fallax,* and other exotic taxa in the Beaverdam Formation indicates a Pliocene age.

Samples from the lower part of the Beaverdam Formation have very low percentages of non-arboreal pollen. Those present include some fern spores of the Polypodiaceae, and in some samples, a few pollen of the Compositae, Umbelliferae, and Onagraceae. In addition, some fresh-water algal material and *Sparganium* have been identified. These palynomorphs and the absence of Chenopodiaceae (except 1 percent in sample 84440) indicate a non-estuarine, fluvial environment. This interpretation is in accord with that based on lithologic criteria.

The climate that prevailed during the deposition of the lower Beaverdam in early Pliocene time was warm-temperate, as indicated by the presence of *Momipites* and *Taxodium*.

The upper part of the Beaverdam differs from the lower part in having higher percentages of non-arboreal pollen (up to 40 percent), fewer exotics, and the consistent presence of some *Picea* pollen. *Pterocarya* is generally the only exotic, except in sample 42203 which appears to be transitional between the lower and upper parts of the formation. High frequencies of Compositae, the presence of Chenopodiaceae, and some Gramineae suggest an estuarine or brackish marsh environment. These assemblages also indicate a climate that is cooler than that of the early Pliocene. Groot et al. (1990) expressed the opinion that this relatively cool interval occurred about 2.5 to 2.0 million years ago and may be the equivalent of the Praetiglian of Western Europe, and therefore of late Pliocene age.

The presence of dinocysts (2 percent of the pollen sum) in sample 42203 indicates that relative sea level reached at least +42 ft (msl[3]) during the Pliocene.

COLUMBIA FORMATION

The Columbia Formation is fundamentally a medium and coarse quartz sand with variable but significant admixtures of gravel, although the gravel content has been overstated frequently in the literature. Cobbles and boulders are moderately common. Some of these are of the angular type attributed to ice rafting. The sand is generally tan, brown, or reddish brown, suggesting oxidation. Thin light gray silt layers of small areal extent occur in some places.

The coarseness of the sediments varies considerably from bed to bed, and, to a lesser degree, from outcrop to outcrop, but it does show a somewhat systematic decrease southward in the down-current direction. Sorting is also variable, but it improves in the down-current direction, mainly due to attrition in the larger grade sizes. Details of texture and composition may be found in Jordan (1964).

The Columbia Formation is distinctly bedded. Cut-and-fill structures occur locally, and a few slump features are present. Cross-bedding is generally well developed and tends to be of the tabular type. Some individual cross-beds persist through distances of hundreds of feet. The magnitudes of the vector means of dip azimuths are large at individual outcrops, an indication of strong unidirectional currents. Jordan (1964) showed that paleocurrent directions, based on cross-bedding, trend south-southwest in northern Delaware tangent to the present curve of the Delaware River in that area before assuming a more southerly direction.

Except for the Piedmont province in northernmost Delaware, the Columbia Formation covers the northern two-thirds of the state. It is absent in a few localities where older underlying units crop out. The bottom contact of the Columbia Formation is marked by an erosional angular unconformity that truncates underlying Cretaceous and Tertiary strata. The thickness of the formation ranges up to approximately 100 ft (Jordan, 1964). Available well records indicate that the thickness of the Columbia is highly variable and that its irregular bottom contact represents intensive channeling into the older deposits. Indeed, sand- and gravel-filled channels cutting older units occur in the banks of the Chesapeake and Delaware Canal at several localities (Groot et al., 1954). Rasmussen et al. (1957) mapped and described a system of these channels in New Castle County.

Ward and Groot (1957) opined that meltwater streams and low sea-level were major factors in the deposition of the Columbia Formation. Jordan (1964, 1974) also attributed a fluvial origin to the formation. Stanford (1997) describes the Pensauken Formation of New Jersey, the presumed equivalent of the Columbia of Delaware (Owens and Minard, 1979), as a yellow arkosic sand with a basal cobble gravel in places. Like the Columbia, the Pensauken is considered a deposit of a braided channel network with a consistent and strong southwest paleoflow direction. The Pensauken is probably not of glacial origin, given the temperate flora and pollen it contains, and the presence of pre-Pleistocene exotics suggests a Pliocene age (Stanford, 1997).

Age and Paleoenvironment

Analyses of pollen assemblages of seven samples of the Columbia Formation are shown in Table 3 and in detail in Appendix 4. The assemblages are characterized by high percentages of *Pinus*, common *Picea*, some *Alnus*, *Quercus*, and other temperate taxa. The non-arboreal component generally includes Compositae and Gramineae, and some pollen of aquatic plants. These assemblages, with climate indices ranging between -0.57 to +0.5, indicate a cold to cool-temperate climate. The presence of pollen of aquatics and the absence of pollen characteristic of estuarine sediments suggest deposition in fresh water. The implications of the palynological analyses, therefore, are consistent with the inter-

[3] msl=mean sea level

Table 3. Analyses of pollen assemblages in samples from the Columbia Formation.

DGS ID	Sample No.	Elevation (ft.)		Climate Index	Climate	Age (Stage)	Environment of Deposition	Remarks
		Land Surface	Sample					
Db31-60	25411	45	+5	+0.5	ct	Q12-11	fluvial	
Fb34-09	32541	65	+47	-0.05	ct	Q12-11	confer, hard-wood forest	
Fb34-09	22695	65	+41	+0.25	ct	Q12-11	conifer, hard-wood forest	
Fb34-09	22696	65	+40	-0.57	c	Q12-11	boreal forest	
Hc24-05	83219	20	+34	-0.13	ct	Q12-11	conifer, hard-wood forest	
Mc45-03	83160	60	+29	-0.3	ct	Q12-11	boreal forest	
Id45-a	41686	21	+13	+0.48	ct	Q12-11	?	

ct = cool-temperate; c = cold

pretation of the lithology: fluvial deposition of a large volume of mostly coarse sediments during the transition from a cold to a temperate period or from a glacial to an interglacial interval. This interpretation is corroborated by Hyyppa (in Flint, 1940) who found fresh-water diatoms in the Columbia sediments near Middletown and considered them to be deposited by melt-water streams.

The age of the Columbia Formation and of its New Jersey presumed equivalent, the Pensauken, is controversial. Berry and Hawkins (1935) described plant fossils found in the Pensauken and interpreted them to indicate a warm-temperate climate and an early Pleistocene age. Owens and Minard (1979), however, assigned a late Miocene age to the Pensauken-Columbia based on correlation to subsurface units in the Delmarva Peninsula. Brenner (in Stanford, 1997, p. 1–13) identified pollen in several samples of a black clay bed within the upper part of the Pensauken near Princeton, New Jersey. He found that pine, oak, and hickory dominated, with hemlock, spruce, fir, and birch common in several samples, and the pre-Pleistocene exotics *Engelhardia*, *Pterocarya*, and *Sciadopitys* present in some samples. He considered the combination of cool-temperate climate indicators and exotic pollen an indication of a Pliocene age. If Brenner's interpretation is correct, the age of the Pensauken in New Jersey is the same as the age of the Beaverdam Formation of southern Delaware.

To date, no temperate or warm-temperate pollen assemblages have been found in the Columbia Formation of Delaware, and neither have exotic pollen, except very rarely. For instance, sample 25411 has one degraded grain that may be *Sciadopitys*, and sample 32541 has one grain of *Todisporites* and one of *Gleicheniidites*. This sporadic occurrence of exotics ranging in age from Cretaceous or early Tertiary to Pliocene is due to reworking and is not considered an indication of age and paleoclimate.

The interpretation of the age of the Columbia Formation in Delaware is largely based on the occurrence of *Quercus* species 4, 5, and 6 encountered in this formation and in those cores of AMCOR 6021C that were assigned by Groot et al. (1995) to oxygen-isotope stages 11(?) to 14(?). Palynological analyses show that stage 12(?) was an extremely cold interval, colder than stage 2. Other very severe intervals identified in AMCOR 6021C are stages 6 and 5d, whereas stages 4, 8, and 14(?) were much milder. This interpretation is quite similar to that offered by Shackleton (1987) who stated (p. 187) that "...stages 12 and 16 were more extreme than stage 2, stage 6 perhaps marginally more extreme. Stage 10 was perhaps marginally less extreme than stage 2, while stages 4, 8, 14, and 18 were significantly less important." Thus, the climate curve of AMCOR 6021C (Groot et al., 1995, Figure 2) parallels the findings quoted above for the cold periods prior to stage 14(?) (inclusive).

The cold interval interpreted as stage 12(?) in AMCOR 6021C is in agreement with the findings of Mountain et al. (1994) on the basis of calcareous nannofossil studies of cores of ODP site 903, downslope from AMCOR 6021C. It is therefore reasonable to assume that the assignment of oxygen-isotope stages of the Quaternary sediments encountered in the AMCOR cores is correct. And in view of the fact that (1) *Quercus* spp. 4, 5, and 6 occur both in stages 11–13 of the AMCOR hole and in the Columbia Formation and (2) the climate during the deposition of this formation was cold to cool-temperate, the Columbia was probably deposited during the transition of stage 12 to stage 11.

It is unfortunate that AMCOR 6021C did not penetrate the complete Quaternary section, which would have required drilling and coring an additional 110m. Consequently, there is no record of *Quercus* species that occurred in the early Pleistocene at the AMCOR site, but if species 4, 5, and 6 were also present at that time, the Columbia Formation could be older than stage 12-11 (middle middle Pleistocene), presumably at the transition of stage 16 to stage 15 (early middle Pleistocene), considering that stage 16 was a very severe cold interval, like stage 12. Whereas there is evidence of stage 12 glaciation in eastern New York, northeastern Pennsylvania, and New Jersey (pre-Illinoian drift), there is no such evidence of stage 16 glaciation. In the New England and Long Island areas, glaciation within the stage 12 through 18 interval is inferred from seismic reflection data (Richmond and Fullerton 1986).

Colman et al. (1990) mapped three generations of the ancestral Susquehanna River system beneath Chesapeake Bay and the southern Delmarva Peninsula. These channel systems were formed during glacial-stage low sea-level stands. The youngest paleochannel was considered to be of late Wisconsinan age, the intermediate one to be late Illinoian (about 150 Ka[4]) and the oldest one 200 Ka to 400 Ka. In terms of oxygen-isotope stages, these channels can be assigned to stages 2, 6, and 8 to 10, and perhaps 12, but no older. Thus it appears that Colman et al. (1990) recorded in the southern part of the Delmarva Peninsula only three major glacial events, not demonstrably older than stage 12.

The palynological evidence, the data concerning glaciations in eastern Pennsylvania and New Jersey (Richmond and Fullerton, 1986), and the presence of paleochannels reported by Colman et al. (1990) indicate that the age of the Columbia Formation is most likely to be the transition from stage 12 to stage 11. However, in view of the fact that dating glacial deposits and paleochannels is not always a straightforward matter, the possibility should be kept in mind that the Columbia Formation is older, at least in part, than stage 12-11, and was deposited in stage 16-15. Even so, the age of the Columbia would be middle Pleistocene, not early Pleistocene or Pliocene.

Available data indicate (1) the age equivalency of the Pensauken of New Jersey and the Beaverdam of Delaware (assuming that the exotics found by Brenner in the Pensauken are not reworked) and (2) that the age of the Columbia of Delaware, where determined palynologically, differs from the age of the Pensauken of New Jersey. It is possible that the Columbia and Pensauken formations have different source areas as well as different ages.

OMAR FORMATION

The salient feature of this formation is lithologic heterogeneity. Medium and coarse sands are interbedded with clayey sands, silts, and clays. In some places, for instance at Pepper Creek and Dirickson Creek agricultural ditches northeast of Shelbyville (Qh41-a and Ri13-a, respectively), shell beds occur, usually bioherms of *Crassostrea virginica* and *Mercenaria* (Groot et al., 1990). The Omar was deposited unconformably on the Beaverdam Formation, and the lowermost part of Pliocene age is interpreted to have accumulated in valleys cut in the Beaverdam (Ramsey and Schenck, 1990).

Jordan (1962, p. 42) described the lithology of the formation as follows:

> The Omar Formation consists of interbedded, gray to dark gray, quartz sands and silts. Individual beds range in thickness from a few inches to more than 10 ft. Thinner layers of clay or silt, some only a few millimeters thick have been found in sand beds. The sands are variable in texture but tend to be fine and may be well sorted or only moderately well sorted....The sands of the Beaverdam Formation are more homogeneous than the Omar Formation. The Beaverdam in general is coarser, better sorted, lighter in color and lacking in organic matter... although thin individual beds of the Omar may approach the appearance of the Beaverdam. The silts of the Omar contrast strongly with the almost entirely arenaceous Beaverdam.

The Omar Formation occurs in southeastern Delaware and extends south into coastal Maryland. It generally overlies the Beaverdam Formation with a rather sharp contact. The mineralogy of the sands is similar to that of the other surficial units, subarkosic with a full heavy mineral suite. The average thickness of the unit is about 45 ft, with individual sand and silt units on the order of 5 ft thick.

Shell beds, dominated by the oyster *Crassostrea*, are known from several localities, particularly Pepper Creek and Dirickson Creek agricultural ditches. Pelecypods, gastropods, and foraminifers indicate shallow and brackish water deposition. Some beds contain woody fragments, and some dark silts are somewhat organic (Jordan, 1974).

Ages and Paleoenvironments

Data on pollen assemblages obtained from cores of borehole Qh44-01, the type section of the Omar Formation, and from boreholes Rg22-01, Rg23-01 (both designated Omar reference sections by Jordan, 1962), and Qi51-04, plus some outcrop samples are shown in Table 4 and Appendix 5.

Although the Beaverdam Formation consists mainly of sand, it does encompass some beds of silt that are lithologically indistinguishable from silts in the Omar. The lower 10 ft of the 50-ft-thick Omar in the type section borehole (+22 ft to -28 ft msl in Qh44-01, Jordan,1962, Plate 4) is a gray-blue silt. If this silt were assigned to the Beaverdam, a possibility on the basis of its Pliocene age (see below), the thickness of the type Omar would be only 40 ft; however, in view of the lithologic heterogeneity indicated by the electric logs and considering the characteristics of the Omar, the thickness of this formation is taken to be 50 ft in the type section (Jordan, 1962, p. 42), from +22 ft to -28 ft msl.

Sample 20775, at an elevation of -23 ft, contains *Sciadopitys*, indicating a pre- Quaternary age; *Sciadopitys* occurs in the Bacons Castle Formation and the Yorktown Formation of Virginia, both of Pliocene age, and in the Pliocene Beaverdam Formation. At present, *Cyrilla* occurs in the Atlantic and Gulf coastal plains from Virginia southward, and with *Nyssa*, *Liquidambar*, and *Taxodium* indicates a warm-temperate and moist environment. Sample 20774, at -18 ft msl, contains *Tricolporopollenites edmundii*,

[4] Ka = thousand years

Table 4. Analyses of pollen assemblages in samples from the Omar Formation.

DGS ID	Sample No.	Elevation (ft.)		Climate Index	Climate	Age (Stage)	Environment of Deposition	Remarks
		Land Surface	Sample					
Qh44-01	20763	22	+20	>1.4	wt	Q1?	Bog	*Sphagnum* 43%. Tasmanitids common
Qh44-01	20765	22	+17	0.97	t	Q	fluvial/estuarine ?	
Qh44-01	20766	22	+13	1.47	t	Q	estuarine?	
Qh44-01	20767	22	+8	>1.4	wt	Q	fresh water marsh	
Qh44-01	20768	22	+6	>1.4	wt	Q	fresh water environment	*Nyssa* and *Liquidambar* common
Qh44-01	20769	22	+1	-0.75	c	Q	bog	Fern spores (Polypodiaceae) 23%
Qh44-01	20770	22	-2	>1.4	wt	Q	fresh water deposit	*Ulmus serotina** P. *Taxodium* P.
Qh44-01	20771	22	-7	>1.4	wt	?	fresh water deposit	*Rhus** P. *Momipites*(?) P; *Pterocarya* P. Exotics may be reworked.
Qh44-01	20772	22	-12	>1.4	wt	?	?	Poor preservation. *Symplocos* * P.
Qh44-01	20773	22	-15	1.3	t	?	fresh water deposit	Green algal material. *Cyrilla* P.
Qh44-01	20774	22	-18	1.7	wt	Plio	lagoonal	*T. edmundii, Cyrilla, Alangium*(?)
Qh44-01	20775	22	-23	>1.4	wt	Plio	lagoonal	*Sciadopitys**, Podocarpus, Taxodium, Cyrilla*
Nh44-a	41142	22	+6.5	1.4	t	Q9	*estuarine	*Quercus* sp. 3 common
Qh41-a	40962	22	+6	?1.4	?	Q5	estuarine	*Quercus* sp. 1
Ri13-a	40969	22	+10	>1.4	wt	Q11,13	estuarine	
Qh34-09	85678	16	+10	1.36	t	Q5	estuarine?	
Qh34-09	85679	16	+6	>1.4	t	Q5	estuarine	
Qh35-04	85652	16	-8	>1.4	t	Q5	estuarine	
Qh35-08	85709	17	+3	>1.4	twt	Q5	lagoonal	
Qh35-09	85711	17	+3	>1.4	t	Q5?	est/lagoonal	
Qi51-04	25046	21	+2.5	>1.4	wt	Q	estuarine	
Qi51-04	25047	21	-9	>1.4	wt	Q	estuarine	

Table 4 (continued). Analyses of pollen assemblages in samples from the Omar Formation.

DGS ID	Sample No.	Elevation (ft.)		Climate Index	Climate	Age (Stage)	Environment of Deposition	Remarks
		Land Surface	Sample					
Qi51-04	25049	21	-34.5	1.3	t	Q11,13	estuarine	*Quercus* sp. 3,6, amino zone IId
Qi51-04	25050	21	-64	>1.4	wt	Q11,13	estuarine	*Quercus* sp. 3,5,6
Qi54-02	25197	5	-10	>1.4	wt	Q11,13	estuarine/mari ne	*Quercus* sp. 6,3
Rg23-01	20735	39	+32	-0.56	c	Q1?	swamp	*Pinus, Picea*, Cyperaceae assemblage
Rg23-01	20737	39	+28	0.78	ct	Q	swamp	
Rg23-01	20738	39	+18	1.6	wt	Q11-13?	estuarine or lagoonal	*P. edmundii* P., *Quercus* sp. 6 Suggests middle Q
Rg23-01	20739	39	+8	>1.4	wt	Plio?	Fluvial or estuarine	*Quercus* sp. suggests Pliocene. *Sequoia* type P.
Rg23-01	20740	39	-2	0.95	t	?	Swamp/bog	Poor preservation
Rg23-01	20741	39	-12	>1.4	wt	?	Bog	Poor preservation. *Cyrilla* P.
Rg22-01	20749	40	+38	>1.4	wt	Q1?	Swamp	Poor preservation
Rg22-01	20750	40	+30	-0.58	c	Q2?	Swamp	*Pinus* dominated; *Selaginella* 1%; Cyperaceae 9%
Rg22-01	20751	40	+28	-0.3	c	Q2?	Marsh	*Pinus, Picea , Alnus, Betula* assemblage
Rg22-01	20752	40	+24	-0.14	ct	Q2?	*Sphagnum* bog	*Pinus, Alnus, Picea* assemblage; *Sphagnum* 35%
Rg22-01	20753	40	+21	1.3	t	Q	bog or swamp	*Betula, Alnus, Pinus* assemblage
Rg22-01	20754	40	+18	0.92	t	Q	?	*Pinus* dominant
Rg22-01	20755	40	+12	>1.4	wt	Plio	?	*Quercus* sp. * suggest Pliocene age
Rg22-01	20756	40	-2	>1.4	wt	Plio	fluvial or estuarine	*Momipites**, *T. fallax, Ulmus serotina*(?), *Pterocarya*

c = cold; ct = cool-temperate; t = temperate; twt = temperate-warm-temperate; wt = warm-temperate

*see Plate 1

Alangium(?) sp., *Cyrilla*, and a *Sequoia* type pollen, and is also considered to be of Pliocene age. *Liquidambar* and *Nyssa* are present, as in sample 20775, but in lower percentages compared with sample 20775. Chenopodiaceae pollen is rare, and fresh-water algal remains are common, suggesting an upper estuarine environment of deposition. Sample 20773, at an elevation -15 ft msl, has a pollen assemblage similar to that of 20774, but with lower frequencies of *Liquidambar* and *Nyssa* and a lack of exotics, except *Cyrilla*. Fresh-water algal material is common, as in sample 20774. Sample 20771, at -7 ft msl, contains *Pterocarya*(?), *Symplocos*, and *Momipites*(?). The uncertainty of identification of the exotics makes it difficult to determine the age of this sample.

Sample 20770, at -2 ft msl, lacks Chenopodiaceae and exotics but contains pollen of *Nuphar* and *Myriophyllum*, suggesting a fresh-water deposit. *Taxodium* and *Ulmus serotina*(?) indicate moist warm-temperate conditions. The age of this sample may be early or middle Pleistocene.

A cold climate and a bog environment are indicated by the pollen assemblage of sample 20769 with 22 percent of spruce pollen and a near absence of temperate-climate taxa. A Quaternary age is indicated, but which oxygen isotope stage is represented is not known, except that it is probably not stage 2, 3, or 4, as it is overlain by 20 ft of sediment with temperate climate pollen assemblages.

Samples 20768 to 20765 all have pollen assemblages indicating a temperate climate, but they vary in their paleoenvironments from fresh-water marsh to estuarine. There is no evidence of the presence of *Quercus* species 1, 5, and 6, but species 3 occurs in sample 20768, suggesting that these samples were deposited in isotope stage 7 or 9. The poorly preserved palynomorph assemblage of sample 20763 at +20 ft in Qh44-01 is dominated by *Sphagnum* spores; tasmanitids are common; *Nyssa* is the most frequent of the arboreal pollen. A temperate-moist climate is suggested. The few poorly preserved *Quercus* pollen grains do not give any indication as to the oxygen-isotope stage represented by this sample; however, it is possible that this bog deposit developed in a low spot on the surface of the Quaternary (stage 9?) deposits at this (the type) location of the Omar, and is of Holocene age.

Pollen assemblages obtained from samples of borehole Rg22-01 (Omar reference section) indicate a Pliocene age at -2 ft, and possibly at +12 ft. Overlying these sediments are bog and swamp deposits, with climate indices indicating mostly cold or cool-temperate conditions; they are perhaps of Wisconsinan age.

In borehole Rg23-01 (Omar reference section), Pliocene sediments may occur at +8 ft, but the evidence is not strong. At +18 ft estuarine or lagoonal deposits with *Quercus* sp. 6 suggest a middle Pleistocene age. Above 18 ft, swamp deposits of probable Wisconsinan age occur, as in Rg22-01.

Amino acid racemization analyses of shells obtained from the Omar Formation have been interpreted in terms of aminozones and correlated with oxygen-isotope stages by Wehmiller et al. (1988) and Groot et al. (1990, 1995). The results are shown in Table 1.

It is clear from the data presented in Table 4 and the occurrence of exotics in the type section at altitudes of -18 and -23 ft msl that the Omar Formation, as originally defined by Jordan (1962), ranges in age from late Pliocene to late Pleistocene. There are at least three Quaternary oxygen-isotope stages (substage 5e [Table 1], stages 9, and 11 or 13), each recording a temperate (interglacial) climate, represented in the Omar in southern Delaware. In addition, at least two cold stages are represented in the type section.

Paleoenvironments range from estuarine and lagoonal to fresh-water marsh, boreal forest and bog, with estuarine sediments deposited during temperate-climate intervals and high sea levels most common. Hiatuses in deposition and periods of erosion must have occurred during cold climate periods, resulting in several unconformities within the Omar Formation.

DELAWARE BAY GROUP

The Delaware Bay Group encompasses estuarine, tidal marsh, and some fresh-water marsh sediments that were laid down after deposition of the Columbia Formation. The Group comprises two formations, the older Lynch Heights and the younger Scotts Corners (Ramsey, 1993, 1997). The surficial expression of these formations is that of terraces, separated by a scarp (Ramsey, 1997), that descend from elevations of 20 to 30 ft on the Lynch Heights to elevations of 15 ft or less on the Scotts Corners. The toe of the scarp is at about 18 ft (Ramsey, 1997).

The lithology of the sediments is quite varied: "...reddish brown to gray, medium to coarse quartzose sands with common beds of fine to medium sand and very fine to fine sandy silt" (Ramsey, 1997, p. 8). Also present are some organic-rich clayey silts. The deposits are heterogeneous both vertically and horizontally.

The Lynch Heights Formation consists of a lower medium to coarse quartzose sand, a middle clayey silt, and a fine to medium sand fining upward (Ramsey, 1997). The Scotts Corners Formation, which lies unconformably on the Lynch Heights, is composed of light gray to brown, fine to coarse sands and pebble gravel with discontinuous beds of organic-rich clayey silt. Ramsey (1997) interpreted that each of the formations was deposited during more than one cycle of sea-level rise and fall.

Ages and Paleoenvironments

Lynch Heights Formation

Table 5 is a summary of the palynology of the Lynch Heights Formation. Detailed results of palynological analyses are given in Appendix 6. The pollen assemblages of this formation are generally dominated by *Pinus*, relatively modest frequencies of *Quercus*, and a paucity of *Tsuga*. The nonarboreal component of the assemblages is primarily composed of Compositae, Gramineae, Chenopodiaceae, *Sphagnum*, and Polypodiaceae. Among the *Quercus* pollen, species 3 is the most frequent, indicating a middle middle Pleistocene age, probably oxygen-isotope stage 9 or 11(?).

Analyses in Table 5 indicate a transgression during a temperate or warm-temperate period, followed by a regression during a very cold interval, and a renewed transgres-

Table 5. Analyses of pollen assemblages in samples from the Lynch Heights Formation.

DGS ID	Sample No.	Elevation (ft.)		Climate Index	Climate	Age (Stage)	Environment of Deposition	Remarks
		Land Surface	Sample					
Le44-09	85436	41	+28	0.48	ct	Q9, 11?	estuarine/salt marsh	
Le44-09	85439	41	+18.5	0.48	ct	Q9, 11?	marsh	Cool temperate, sea level above 30 ft, perhaps 40 ft
Le25-12	25639	30	+18.5	0.78	ct	Q9, 11?	estuarine	
Lf21-19	25627	30	+14.5	0.75	ct	Q9, 11?	estuarine	
Le15-g	41420	22	+12.5	-1.77	vc	Q9, 11?	boreal forest	Very cold; sea level below +12 ft
Mg21-06	25658-1	10	+8	>1.4	wt	Q9, 11?	estuarine?	
Le14-18	25706-1	28	+8	>1.4	wt	Q9, 11?	marsh?	
Mg21-06	25658-2	10	+7	1.4	wt	Q9, 11?	estuarine?	Temperate to warm temperate climate
Le14-18	25706-2	28	+7	1.15	t	Q9, 11?	marsh?	
Lf24-02	25659-1	7	+6	>1.4	wt	Q9, 11?	?	
Le14-18	25707-1	28	+6	>1.4	wt	Q9, 11?	marsh?	Rising sea level
Lf24-02	25659-2	7	+5	>1.4	wt	Q9, 11?	?	
Le14-18	25707-2	28	+5	>1.4	wt	Q9, 11?	marsh?	

ct = cool-temperate; vc = very cold; wt = warm-temperate; t = temperate

sion to an elevation of at least 30 ft, or perhaps 40 ft (the maximum height of the terrace), during a cool-temperate period.

Scotts Corners Formation

The pollen assemblages of this formation (Table 6, Appendix 7) differ from those of the Lynch Heights by having generally higher percentages of *Quercus* and lower frequencies of *Pinus*. In addition, 16 of the 28 samples analyzed contain *Tsuga* pollen, from <1 to 11 percent of the pollen sum. *Liquidambar*, not found in the Lynch Heights Formation, is present in 13 samples, with a maximum frequency of 13 percent. Common nonarboreal taxa include Compositae, Gramineae, Chenopodiaceae, and Polypodiaceae. Nearly all samples, except 41422, have pollen assemblages suggesting a warm-temperate, moist climate, warmer and more humid than the one that prevailed, at least in part, during the deposition of the Lynch Heights Formation; five samples indicate a cool-temperate climate.. The predominance of *Quercus* sp. 1 indicates that the age of the Scotts Corners is late Pleistocene. Table 6 records a transgression during a warm-temperate humid period (oxygen-isotope substage 5e?), a regression during a cold interval (possibly stage 5d), and a renewed rise of sea level (perhaps during substage 5c or 5a). The palynological as well as the lithologic data described by Ramsey (1997) indicate that both the Scotts Corners and Lynch Heights formations each represent at least two transgressions and one regression.

Deposits in the Smyrna Area

The analyses of pollen assemblages of two samples (86317, 86319) from near Smyrna, tentatively assigned to the Scotts Corners Formation, are shown in Table 6 and in detail in Appendix 7. *Quercus* sp. 1 is present, suggesting isotope stage 5 and a Sangamonian age. Whereas the pollen assemblages of the Scotts Corners in the Milford area indicate temperate to warm-temperate conditions, the Smyrna area samples suggest a cool-temperate to temperate climate.

Table 6. Analyses of pollen assemblages in samples from the Scotts Corners Formation.

DGS ID	Sample No.	Elevation (ft.)		Climate Index	Climate	Age (Stage)	Environment of Deposition	Remarks
		Land Surface	Sample					
Lf21-b	41367	18	+8.5	>1.4	wt	Q5	estuarine	
Lf23-x	41469	9	+6.75	>1.4	wt	Q5	?	*Tsuga* 6%, *Liquidambar* P
Lf23-u	41464	10.5	+3.5	>1.4	wt	Q5	estuarine	
Lf14-b	41323	8	+2.25	>1.4	wt	Q5	estuarine	*Tsuga* P
Le14-a	41373	20	+2	~1.4	t	Q5	fresh water marsh	*Tsuga* 3%: *Liquidambar* 2%
Lf13-a	40975	7.5	+2	>1.4	wt	Q5	marsh	
Lf23-t	41422	11	+2	-1	c	Q5	boreal forest	*Pinus*, *Picea*, *Sphagnum*
Lf23-x	41465	9	+1	>1.4	wt	Q5	estuarine	*Tsuga* 6%; *Liquidambar* 3%
Lf23-ac	41482	9.5	+0.5	>1.4	wt	Q5	estuarine	*Tsuga* 6%; *Liquidambar* 1%
Lf14-a	40976	11	0	>1.4	wt	Q5	estuarine	*Liquidambar* P
Lf14-p	41425	8	0	>1.4	wt	Q5	?	*Tsuga* P
Lf23-x	41472	9	-0.25	>1.4	wt	Q5	estuarine	*Tsuga* 2%; *Liquidambar* 12%
Lf14-j	41336	5	-1.5	>1.4	wt	Q5	marsh	
Lf14-e	41334	4	-1.5	>1.4	wt	Q5	marsh	*Tsuga* P
Lf14-c	41330	6	-1.5	>1.4	wt	Q5	fresh water marsh	*Tsuga* 1%; *Liquidambar* P
Lf23-ad	41489	9	-2	0.9	t	Q5	estuarine	*Tsuga* P
Lf23-ac	41485	9.5	-2	>1.4	wt	Q5	estuarine?	*Tsuga* 6%; *Liquidambar* 13%
Lf14-p	41431	8	-2.5	0.98	t	Q5	?	*Tsuga* 11%; *Liquidambar* 3%
Lf14-n	41356	4	-4	>1.4	wt	Q5	marsh?	*Tsuga* 2%; *Liquidambar* 2%
Lf14-m	41353	3	-4	>1.4	wt	Q5	marsh?	
Lf14-p	41435	8	-5.25	>1.4	wt	Q5	?	*Tsuga* 3%; *Liquidambar* 6%
Lf23-f	41344	5	-6.5	>1.4	wt	Q5	?	*Tsuga* P; *Liquidambar* 5%
Ng45-01	87465	16	+3.5	0.5	ct	Q	brackish marsh	
Ng45-01	87466	16	+1	0.7	ct	Q	marsh	
Ng45-01	87467	16	-2.5	0.25	ct	Q	brackish marsh	
Nh45-02	25044	9	-6	>1.4	t-moist	Q5?	estuarine	
Hd13-02	86317	16	+4	0.25	ct	Q5	estuarine	
Hd13-02	86319	16	-1	0.13	ct	Q5	estuarine	

wt = warm-temperate; t = temperate; c = cold; ct = cool-temperate; P = Present

There is no palynological and lithologic evidence of the presence of the Lynch Heights Formation in the Smyrna area.

Two samples of deposits in the Smyrna area (86330, 86348, Table 9) are from sediments overlying the Scotts Corners. They are of a *Sphagnum* bog and a boreal forest, with climate indices ranging from 0 to about -1.3.

NANTICOKE DEPOSITS

For the purposes of this report, the Nanticoke deposits are mostly estuarine and fluvial deposits of Quaternary age that are found adjacent to or within the present valley of the Nanticoke River and its tributaries. The sediments consist of light to medium brown to light gray, fine to medium quartz sand with scattered coarse sand, granules and pebbles, and gray to brown, clayey sandy silt, and silty clayey sand (Jordan, 1974; Andres and Ramsey, 1996). Some shells and shell fragments have been reported from the deposits to the south of Seaford. In the vicinity of Seaford, descriptions of the facies attributed to shorelines may be found in Jordan and Talley (1976).

Age and Paleoenvironment

Detailed palynological analyses of the Nanticoke deposits are included in a report on the Seaford area (Andres and Ramsey, 1996). The essential characteristics of the pollen assemblages identified as indicating estuarine and fluvial environments are shown in Table 7 and Appendix 8. The data presented in Table 7 indicate that (1) the climate suggested by the pollen assemblages was either temperate or warm-temperate, except for one cold-temperate sample, and (2) sediment samples interpreted as representing stages 7(?) or 9, and 11 or 13 occur at higher elevations than those of stage 5. The implication is that middle Pleistocene relative sea levels were higher than those of the late Pleistocene. Further discussion of sea levels follows later in this report.

STAYTONVILLE UNIT

This informal unit is composed of tan, brown, yellow, and gray, fine and medium sands and some silts, characterized by their poor sorting and irregular and indistinct bed-

Table 7. Analyses of pollen assemblages in samples from estuarine and fluvial Nanticoke deposits.

DGS ID	Sample No.	Elevation (ft.)		Climate Index	Climate	Age (Stage)	Environment of Deposition	Remarks
		Land Surface	Sample					
Pc51-01	22711	6	-3.7	>1.4	wt	Q5	estuarine	*Quercus* dominant
Pc51-01	22712	6	-9	>1.4	wt	Q5	fluvial	*Quercus* dominant
Pc51-01	22713	6	-14	>1.4	wt	Q5	estuarine	*Quercus* dominant
Qc24-06	22774	29	+12	>1.4	wt	Q7,9	fluvial?	*Quercus* dominant
Pc41-01	22782	22.6	+11.5	>1.4	wt	Q11,13	fluvial?	*Pinus* dominant
Pc25-04	22792	25.7	+17.2	1.3	t	Q11,13	estuarine	*Pinus*, *Quercus*
Pc25-04	22793	25.7	+14.8	>1.4	wt	Q11,13	estuarine	*Pinus*, *Quercus*
Od43-a3	41495	30	+22	0.9	t	Q>5	estuarine	
Pb34-04	84098	36	+25	-	t	Q	estuarine	*Pinus* dominant, very few *Quercus* pollen
Qb23-01	84431	6	+2	>1.4	wt	Q5	estuarine	
Qb23-01	84434	6	-6	1.4	t	Q5	fluvial-estuarine	
Pb55-03	84659	32	+8	>1.4	wt	Q11,13	estuarine	
Od32-c	42199	32	+26	>1.4	wt	Q7,9	?	
Pb55-03	84658	32	+16	0.87	t	Q	?	
Pb55-03	84655	32	+25	0.14	ct	Q	marsh?	

ct = cool-temperate; t = temperate; wt = warm-temperate

Table 8. Analyses of pollen assemblages in samples from the Staytonville unit.

DGS ID	Sample No.	Elevation (ft.)		Climate Index	Climate	Age (Stage)	Environment of Deposition	Remarks
		Land Surface	Sample					
Md54-07	26337	53	+48	>1.4	t	Holocene? Q5?		Cysts of blue-green algae. Fresh-water(?) Dinoflagellates
Nc15-a	40464	50	+45	-0.55	c	Wisconsinan ?		*Nuphar* present

c = cold; t = temperate

ding (Jordan, 1964). Mottling is common. Jordan conjectured an estuarine origin for these deposits, primarily because the mottling may be the result of reworking by bottom dwelling organisms; however, a fresh-water swamp was later suggested (Jordan, 1974).

Age and Paleoenvironment

So far, only two samples of this unit have been analyzed palynologically. Analyses of the pollen assemblages are shown in Table 8 and details in Appendix 9. Sample 40464 is characterized by an *Alnus-Pinus-Picea* assemblage and the presence of indicators of fresh water. The paleoenvironment suggested by this assemblage is a fresh-water swamp that existed during a period of cold to cool-temperate climate, probably during the Wisconsinan.

The pollen assemblage of sample 26337 is dominated by *Quercus*, including *Quercus* sp. 1, and by *Botryococcus*, and some fresh-water(?) dinoflagellates. A Holocene or isotope-stage 5 age is suggested. Groot et al. (1995) described the pollen assemblage of one other sample (40463) of the Staytonville; however, it is now known that this sample number is either incorrectly identified or that it does not represent this stratigraphic unit.

The paucity of the available data and their lack of consistency raise a question as to the validity of the Staytonville as a stratigraphic unit. It is possible that the two samples analyzed could well be included within the "other Quaternary deposits" of this report and not assigned to a named stratigraphic unit.

OTHER QUATERNARY DEPOSITS

Rasmussen and Slaughter (1955) described some surficial sediments in southeastern Maryland that consist of poorly-sorted, medium-grained sand with gravel and cobbles, rare boulders, and some silt, clay and peat. They named these deposits the Parsonsburg Sand for "the veneer of sand and associated deposits which compose the rims and, in places, the interior of the 'Maryland Basins.'" (Rasmussen and Slaughter, 1955, p. 118) and considered them to be of Pleistocene age.

Sirkin and Owens (1976) also recognized the Parsonsburg and described it as a widespread sand sheet, largely of dunal origin, that overlies peats dated between 13,000 and 30,000 years BP. These fresh-water peats are characterized by abundant spruce, northern shrubs and herbs, and moderate percentages of non-arboreal pollen, indicating a cold and relatively dry climate and a Wisconsinan age.

Denny et al. (1979, p. B3) state that the Parsonsburg comprises "...parabolic dunes on the east side of the valleys of some of the rivers..., and it blankets large areas on the uplands in the central part of the peninsula." They report peaty sand and clay-silt overlain by bedded fine to coarse sands with some thin lenses of fine gravel in some places.

Rasmussen and Slaughter (1955) included in their description of the Parsonsburg Sand a morphologic criterion, i.e., the association of the deposit with "Maryland Basins." This criterion was not included in the descriptions of the unit by Sirkin et al. (1977) and Denny et al. (1979). In addition, there are differences in the lithologic characteristics mentioned by various authors. These dissimilarities make the validity of the name Parsonsburg Sand questionable, and it is not used in this report, in spite of the fact that somewhat similar deposits are found in several places in Delaware.

R.R. Jordan and J.H. Talley (written communication, 1977) described an outcrop and samples obtained from a hand auger hole at Tappahanna Ditch as a thin layer of gravelly sand overlain by 3.5 ft of peat, which in turn is overlain by a fine to medium sand with organic fragments and a dark gray silt. A similar deposit was described by Demicco (1982). The radiocarbon ages of these two deposits are 28,480 ± 880 and 16,640 ± 260 years BP, respectively (Table 9).

The sediments comprising the category "other Quaternary deposits," or at least their peaty parts, do not form a continuous blanket. They were probably deposited in shallow depressions on the surfaces of the older deposits—Beaverdam Formation and Columbia Formation and other Pleistocene pre-Wisconsinan sediments. The paleoenvironments indicated by the palynological analyses, e.g., forest, bog, marsh, swamp (Table 9), represent upland settings removed from marine influence.

Data on the pollen assemblages of most of the peats sampled from the sediments indicate a cold climate and boreal forest vegetation (Table 9 and Appendix 10). *Pinus* and *Picea* dominate the arboreal assemblages; other com-

Table 9. Analyses of pollen assemblages in samples from other Quaternary deposits.

DGS ID	Sample No.	Elevation (ft.)		Climate Index	Climate	Age (Stage)	Environment of Deposition	Remarks
		Land Surface	Sample					
Db34-a	41020	~38	+35	-1.1	c	Q2?	boreal forest	
Hd34-01	86330	21	+8	-0.15	c	Q2?	bog	
Hd41-03	86348	28	+16	-1.3	c	Q2?	boreal forest	
Id22-a	42368	36	+30	-0.77	c	Q2?	fresh-water marsh	
Id22-a	42369	36	+33	-0.48	c	Q2	fresh-water marsh	C14 15,720[1]
Id25-a	41631	18	+10	>1.4	t	Q5?	open forest	some reworked Tertiary pollen
Id32-a	41517	43	+39	>1.4	t	Q5?	swamp?	undrained depression on the Columbia Fm.
Id34-a	41493	23	+18	-0.23	c	Q2?	bog	
Jb33-a	40822	48	+45	-0.55	c	Q2	boreal forest	C14 28,480± 880 BP[2]
Kb42-01	41391	58	~+55	-1.2	c	Q2	swamp	C14 16,640± 260 BP[3]
Ld44-c	40999	50	+44	>1.4	t	Q	open woods	
Me45-a	40000	50	+42	>1.4	t	Q	open woods	
Mf51-a	40001	35?	+30	>1.4	t	Q	?	
Nj51-02	21468	~5	-49.3	-0.9	c	Q2	swamp?	C14 28,400± 1800 BP[4]
Oc15-08	43371	33	+28	-0.48	c	Q2?	Marsh	
Oe34-02	87684	44	+31.5	-1.5	c	Q2?	boreal forest	
Qf45-04	84885	42	+35	-0.96	c	Q2?	marsh	
Qf45-04	84886	42	+33	<-1.0	c	Q2?	marsh	
Qf54-08	84960	42	+29	-0.42	c	Q2?	marsh-bog	
Qg31-01	85579	45	+28	-1.47	c	Q2?	boreal forest	
Qg31-03	85592	42	+25	-0.58	c	Q2?	fresh-water marsh	
Qg32-06	85654	44	+30	-1.5	c	Q2?	Boreal forest	
Qg33-02	84921	44	+31	-0.74	c	Q2?	marsh-bog	
Qg34-08	84908	37	+31.5	-0.52	c	Q2?	marsh	C14 19,470±110 BP[5]
Qg52-01	84985	38	+26	-0.85	c	Q2?	boreal forest	
Qg54-a	41053	37	+30.25	-1.4	c	Q2?	boreal forest	
Qg54-a	41054	37	+29.25	-1.6	c	Q2?	boreal forest	
Rg13-01	85160	38	+23.5	-0.42	c	Q2?	bog	
Rg13-01	85161	38	+21.5	-0.1	c	Q2?	bog/marsh	
Rh34-a	41005	37	+29.5	-0.43	c	Q2?	boreal forest	
Rh24-a	41055	31	+27	-1.5	c	Q2?	boreal forest	

c=cold; t=temperate

[1] Id22-04, sample elevation 21.3 ft (DGS #204, Ramsey and Baxter, 1996).

[2] Sample elevation 48.5 ft (DGS #116, Ramsey and Baxter, 1996).

[3] Kb45-a, sample elevation 52 ft (DGS #135, Ramsey and Baxter, 1996).

[4] Sample elevation -48.5 ft (DGS #2, Ramsey and Baxter, 1996).

[5] Sample elevation 32 ft ((DGS #219, Ramsey and Baxter, 1996).

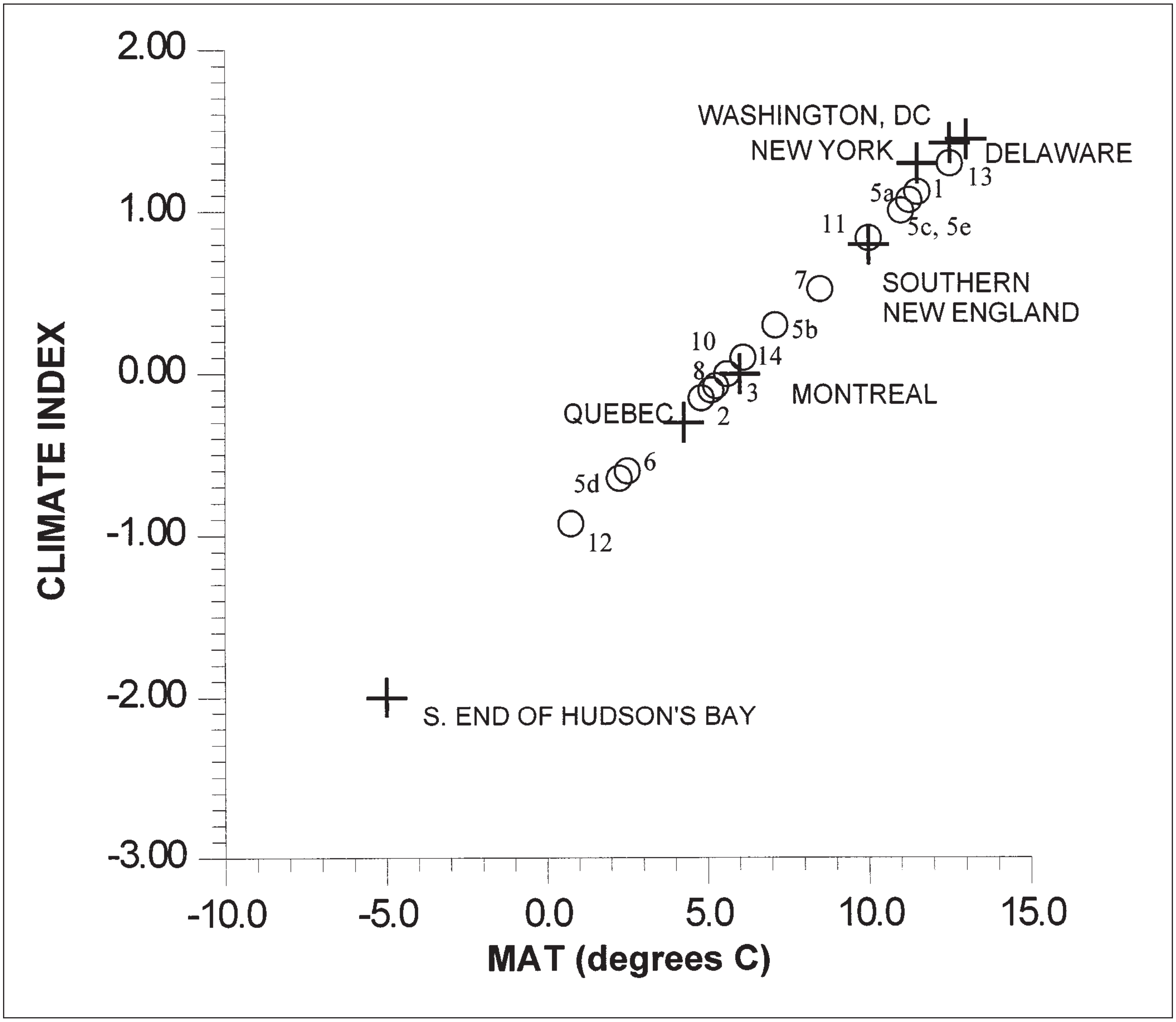


Figure 4. Relationship between climate index and mean annual temperature. Circles are data from AMCOR 6021C (Groot et al., 1995); pluses are calculated from pollen assemblage data of Davis and Webb (1975).

mon taxa are Compositae and Cyperaceae; in many samples Ericaceae are present, and in some *Sphagnum*, *Lycopodium*, and *Selaginella*. Climate indices range from -0.1 to -1.6; the mean is -1.08.

Although most of the surficial deposits overlying the older deposits are presumably of Wisconsinan age and represent a very cold climate, there are five sediment samples having pollen assemblages indicating temperate climates and open forest or swamp environments of deposition (Table 9). They also apparently occupy poorly drained depressions on the surfaces of the older Quaternary deposits. Their ages may range from Holocene to Sangamonian (stage 5).

PLIOCENE AND QUATERNARY TEMPERATURES

Groot et al. (1995) estimated mean annual temperatures for cold and temperate intervals in the source area of the pollen found in AMCOR 6021C, located on the upper continental slope off the New Jersey coast. These estimates are based on the relationship between the present mean annual temperatures and the climate indices for seven locations between northern Delaware and the southern limit of Hudson Bay (Figure 4). These climate indices were calculated from pollen assemblages described by Davis and Webb (1975) for several vegetation regions of eastern North America. As the source of the pollen found in AMCOR 6021C is mainly north of Delaware, the temperatures estimated for various oxygen-isotope stages represented in the AMCOR cores are perhaps 1° or 2°C lower than those that would apply to Delaware. Estimated mean annual temperatures for the state are shown in Table 10.

No early Quaternary deposits have been identified in Delaware, but pollen assemblages from a Cape May, New Jersey, borehole interpreted to be of early Pleistocene age (Groot, 1991) indicate a warm-temperate climate similar to that of the early Pliocene, except that the Quaternary assemblages lack the exotic pollen that characterizes the Pliocene. Apart from Cordilleran glaciations, there is no convincing evidence of glaciation elsewhere in the United States

Table 10. Estimated mean annual temperatures for the Pliocene and the Quaternary, Delaware.

	Estimated Mean Annual Temperature	Approximate age in years BP
early Pliocene	15° C	5 ma BP
late Pliocene	12°C	2.3ma
early Quaternary	15°C	1.5ma to 900ka
Stage 13	14°C	500ka
Stage 12	1.5°C	450ka
Stage 12 to 11	2.5° to 8.5°C	400ka
Stage 11	12°C	360ka
Stage 10	7°C	345ka
Stage 9	13°C	320ka
Stage 8	7°C	275ka
Stage 7	11°C	225ka
Stage 6	3°C	175ka
Stage 5e	14°C	124ka
Stage 5d	3°C	115ka
Stage 5c	13°C	105ka
Stage 5b	8.5°C	95ka
Stage 5a	13°C	80ka
Stage 2	2°C	20ka
Stage 1	13.5°C	<12ka

between 1.65 Ma and 900 Ka (Richmond and Fullerton, 1986), indicating the absence of a cold climate interval if not the prevalence of a warm-temperate climate in the middle Atlantic region in this part of the early Pleistocene.

PLIOCENE AND QUATERNARY SEA LEVELS

Paleontologic, lithologic, and geomorphologic data can be used to estimate relative sea levels of the past. Paleontologic evidence of estuarine or lagoonal deposits that presumably were deposited in shallow brackish or salt water is the presence of shells of *Crassostrea* and *Mercenaria* (mollusks) and of pollen of salt-tolerant plants. Geomorphologic evidence is the identification of estuarine terraces separated by scarps, as described by Ramsey (1997). The altitude of estuarine deposits indicates a minimum sea level as they can be deposited in more than 50 ft of water in an estuary, as they are today in the Delaware Bay.

A relative sea level of at least +42 ft occurred in the Pliocene. During the deposition of the Lynch Heights Formation, oxygen-isotope stage 9 or 11(?), sea level rose to about +40 ft. Minimum sea levels reached during oxygen-isotope stage 5 (Sangamonian) are indicated morphologically by a low terrace adjacent to Delaware Bay (Ramsey, 1997) that reaches an elevation of +20 ft (msl) and by pollen assemblages from the underlying sediments of the Scotts Corners Formation. Also, stage 5 estuarine deposits of the Omar Formation are found up to +20 ft (msl), e.g., in Rg22-01 and Rg23-01.

The temperate- to warm-temperate-climate estuarine deposits referred to are presumably mostly those of substage 5e, although the presence of a very cold interstadial, probably substage 5d, in the Scotts Corners Formation, overlain by temperate-climate deposits, suggests that either substages 5c or 5a are also represented. If so, relative sea level rose above present sea level not only in 5e, but also either in 5c or 5a.

Stage 7 sea level may not have risen above present sea level, as suggested by the Specmap oxygen isotope curve (Fig. 3) and by Cronin (1988). If so, the sediments of the Lynch Heights Formation were deposited in stage 9, or, in part, in stage 11, separated by a very cold period that was either an interstadial or stage 10. The maximum elevation of the estuarine deposits of the Lynch Heights is about 40 ft (Ramsey, 1997). Cool-temperate pollen assemblages indicating an estuarine environment occur at elevations as high as +28 ft (Table 5, sample no. 85436).

Stage 11 (13?) evidence is limited to palynological data. Estuarine sediments of this age occur at +17.2 ft in sample 22792 (Table 7) and at +18 ft in sample 20738 (Table 4). During the Pliocene, sea level reached at least +42 ft as indicated by sample 42203 (Table 2).

The highest recorded sea levels do not necessarily occur at the times of maximum mean annual temperatures, nor do times of temperate or warm-temperate climate precisely coincide with high sea level. An example of a relatively high sea level (only <55 ft below present sea level) at a time of a very cold climate (substage 5d) (Toscano, 1992; Toscano et al., 1989) has been described previously (Groot, 1991). And a striking example is the high sea level (up to +40 ft) during Lynch Heights deposition at a time when the climate was cool-temperate, as indicated by climate indices of 0.75 to 0.48 (Table 5). On the other hand, a sea level more than 73 ft below the present occurred about 8,000 and 9,000 years ago, at a time of a temperate climate, as is suggested by the evidence of a brackish marsh environment at that depth (data in the files of the Delaware Geological Survey). Clearly a time lag of several thousand years is involved between a rapid climate amelioration and a rise of sea level of at least 73 ft.

A substage 5e sea level of about +20 ft (6m) has been assumed in most glacio-eustatic models (Smart and Richards, 1992), and the geomorphologic and palynological data pertaining to Delaware are in agreement with this figure. It may be concluded, therefore, that there is no evidence of any significant tectonic movement in Delaware during the late Pleistocene.

If the deep sea record with regard to sea-level/ice volume represented by Specmap is correct (apart from the substages younger than 5e), stages 9 and 11 had sea levels nearly as high as substage 5e. However, if the interpretation of the age and paleoenvironment of the Lynch Heights Formation is correct, the implied sea level of +40 ft suggests some positive vertical crustal movement. Cronin et al. (1981, p. 239), in their study of sea levels of the U.S. Atlantic Coastal Plain, also concluded that "...there is a primary glacio-eustatic component and probably a secondary neotectonic vertical component to the local Coastal Plain sea level record..." This report confirms that conclusion, at least for pre-5e time.

CONCLUSIONS

The post-Miocene surficial deposits of Delaware are of considerable economic importance because they form the topographic features of most of the state and are prolific sources of ground water, road-building materials, and sand for beach nourishment. Obtaining a more thorough understanding of the lithology, paleoenvironments, ages, and geologic history is therefore a worthwhile endeavor.

Figure 5 summarizes the palynologically determined ages of the post-Miocene stratigraphic units of Delaware as defined to date. The ages of the sediments were determined, whenever possible, by palynological, aminostratigraphic, and radiometric methods. The combination of the study of the stratigraphic distribution of *Quercus* pollen species and of aminostratigraphy proved to be very useful in deposits containing *Quercus* pollen, and radiocarbon dating was essential in determining the ages of Wisconsinan sediments. By means of these methods, deposits of early and late Pliocene age were identified, and at least three temperate to warm-temperate intervals and three cold intervals were determined for the Quaternary sediments. A warm-temperate period occurred in the Pliocene, with a somewhat cooler interval in the late Pliocene. Temperate-climate intervals represented in Quaternary sediments are those of oxygen-isotope stages 11-13-15(?), 7(?), 9, 11(?), and 5. A cool-temperate period is most likely that of stage 12-11 (although possibly of stage 16-15). It was in this period that the Columbia Formation was deposited.

The geologic record preserved in the sedimentary rocks of Pliocene and Pleistocene age is very incomplete owing to long intervals of non-deposition or erosion during periods of low sea level related to glaciations in eastern North America or elsewhere. Lack of evidence of the presence of Pliocene sediments and early Pleistocene deposits in the northern half of Delaware suggests that they were removed by erosion prior to the deposition of the Columbia formation during oxygen-isotope stages 12-11, or perhaps 16-15.

After the middle Pleistocene deposition of the Columbia, several interglacials resulted in the deposition of lagoonal, estuarine, and fluvial sediments along the Delaware Bay coast (the Lynch Heights and Scotts Corners formations), in southeast Sussex County (the Omar Formation), and in the Nanticoke area (the Nanticoke deposits). All these sediments have essentially the same geologic history: deposition during oxygen-isotope stages (and substages) when sea levels were relatively high and erosion/nondeposition when sea levels were relatively low.

REFERENCES CITED

Andres, A.S., and Ramsey, K.W., 1995, Geologic map of the Seaford area, Delaware, scale 1:24,000.

___ 1996, Geology of the Seaford area, Delaware: Delaware Geological Survey Report of Investigations No. 53, 22 p.

Berry, E.W., and Hawkins, A.C., 1935, Flora of the Pensauken Formation in New Jersey: Geological Society of America Bulletin, v. 46, p. 245–252.

Colman, S.M., Halka, J.P., Hobbs, C.H., Mixon, R.B., and Foster, D.S., 1990, Ancient channels of the Susquehanna River beneath Chesapeake Bay and the Delmarva Peninsula: Geological Society of America Bulletin, v. 102, p. 1268–1279.

Cronin, T.M., 1988, Evolution of marine climates of the U.S. Atlantic coast during the past four million years, *in* Shackleton, N.J., West, R.G., and Bowen, D.Q., eds., The last three million years; evolution of climatic variability in the North Atlantic region; a discussion: Philosophical Transactions of the Royal Society of London, B 318 (1191), p. 661–678.

Cronin, T.M., Szabo, B.J., Ager, T.A., Hazel, J.E., and Owens, J.P., 1981, Quaternary climates and sea levels of the U.S. Atlantic Coastal Plain: Science, v. 211, p. 233–240.

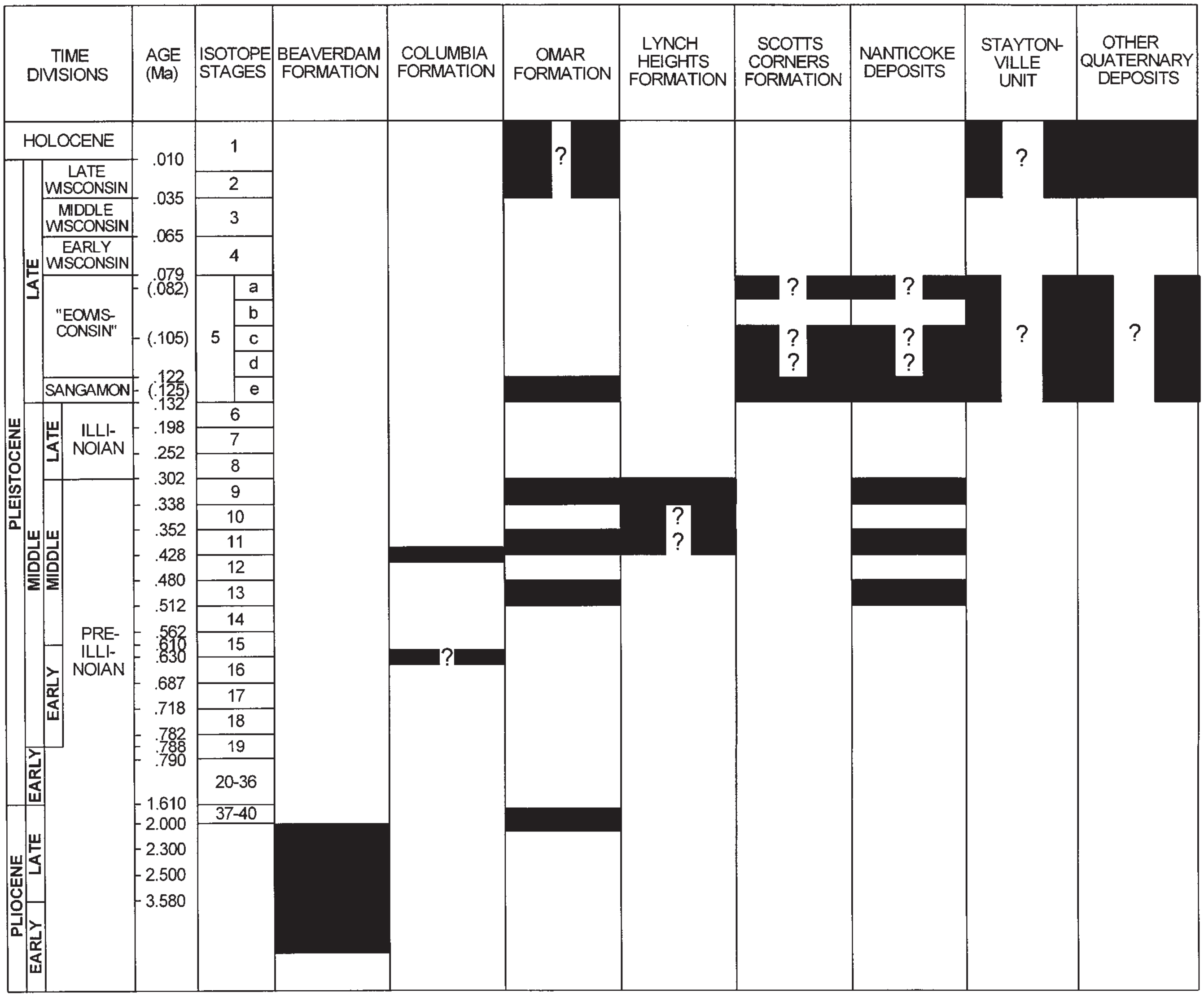


Figure 5. Palynologically determined ages of post-Miocene stratigraphic units of Delaware. Time divisions, age (Ma), and isotope stages after Richmond and Fullerton (1986).

Davis, R.B. and Webb, T.H., 1975, The contemporary distribution of pollen in eastern North America: A comparison with the vegetation: Quaternary Research, v. 5, p. 395–434.

Demicco, P.M., 1982, Hydrogeology of the southern half of the Marydel Quadrangle, Delaware: Newark, Del., University of Delaware, M.S. thesis, 243 p.

Denny, C.S., Owens, J.P., Sirkin, L.A., and Rubin, M., 1979, The Parsonsburg Sand in the central Delmarva Peninsula, Maryland and Delaware: U.S. Geological Survey Professional Paper 1067, 16 p.

Flint, R.F., 1940, Pleistocene features of the Atlantic Coastal Plain: American Journal of Science, v. 238, p. 757–787.

Groot, J.J., 1991, Palynological evidence for late Miocene, Pliocene, and early Pleistocene climate changes in the middle U.S. Atlantic Coastal Plain: Quaternary Science Reviews, v. 10, p. 147–162.

Groot, J.J., Benson, R.N., and Wehmiller, J.F. 1995, Palynological, foraminiferal, and aminostratigraphic studies of Quaternary sediments from the U.S. middle Atlantic upper continental slope, continental shelf, and Coastal Plain: Quaternary Science Reviews, v. 14, p. 17–49.

Groot, J.J., Organist,, D.M.., and Richards, H.G., 1954, Marine Upper Cretaceous formations of the Chesapeake and Delaware Canal: Delaware Geological Survey Bulletin No. 3, 64 p.

Groot, J.J., Ramsey, K.W., and Wehmiller, J.F., 1990, Ages of the Bethany, Beaverdam, and Omar formations of southern Delaware: Delaware Geological Survey Report of Investigations No. 47, 19 p.

Imbrie, J., Hays, J.D., Martinson, D.G., McIntyre, A., Mix, A.C., Morley, J.J., Pisias, N.G., Prell, W.L., and Shackleton, N.J., 1984, The orbital theory of Pleistocene climate: Support from a revised chronology of the marine $\delta^{18}O$ record, *in* Berger, A.L, Imbrie, J., Hays, J., Kukla, G., and Saltzman, B., eds., Milankovitch and climate, Part 1: Boston, D. Reidel Publishing Company, p. 269–305.

Jordan, R.R., 1962, Stratigraphy of the sedimentary rocks of Delaware: Delaware Geological Survey Bulletin No. 9, 51 p.

___ 1964, Columbia (Pleistocene) sediments of Delaware: Delaware Geological Survey Bulletin No. 12, 62 p.

___ 1974, Pleistocene deposits of Delaware, *in* Oaks, R. Q., Jr., and DuBar, J. R., eds., Post- Miocene stratigraphy, central and southern Atlantic Coastal Plain: Logan, Utah, Utah State University Press, p. 30–52.

Jordan, R.R., and Talley J.H., 1976, Guidebook, Columbia deposits of Delaware: Delaware Geological Survey Open File Report No. 8, 49 p.

Mountain, G.S., Miller, K.G., Blum, P., et al., 1994, 7. Site 903, *in* Mountain, G.S., Miller, K.G., Blum, P., et al., Proceedings of the Ocean Drilling Program, Initial Reports, v. 150: College Station, Tex. (Ocean Drilling Program), p. 129–205.

Mixon, R.B., Szabo, B.J., and Owens, J.P., 1982, Uranium-series dating of mollusks and corals, and age of Pleistocene deposits, Chesapeake Bay area, Virginia and Maryland: U.S. Geological Survey Professional Paper 1067-E, 18p.

Nickmann, R.J., and Demarest, J.M., II, 1982, Pollen analysis of some mid-Pleistocene interglacial lagoonal sediments from southern Delaware: Quaternary Research v. 17, p. 93–104.

Owens, J.P., and Denny, C.S., 1979, Upper Cenozoic deposits of the central Delmarva Peninsula, Maryland and Delaware: U. S. Geological Survey Professional Paper 1067-A, 28 p.

Owens, J.P., and Minard, J.P., 1979, Upper Cenozoic sediments of the lower Delaware Valley and northern Delmarva Peninsula, New Jersey, Pennsylvania, Delaware, and Maryland: U.S. Geological Survey Professional Paper 1067-D, 47 p.

Ramsey, K.W., 1993, Geologic map of the Milford and Mispillion River quadrangles: Delaware Geological Survey Geologic Map No. 8, Scale 1:24,000.

Ramsey, K.W., 1997, Geology of the Milford and Mispillion River quadrangles: Delaware Geological Survey Report of Investigations No. 55, 40 p.

Ramsey, K.W., and Baxter S.J., 1996, Radioarbon dates from Delaware: A compilation: Delaware Geological Survey Report of Investigations No. 54, 18 p.

Ramsey, K.W., and Schenck, W.S., 1990, Geologic map of southern Delaware: Delaware Geological Survey Open File Report No. 32, scale 1:100,000.

Rasmussen, W.C., Groot, J.J., Martin, R.O.R., McCarren, E.F., Behn, V.C., and others, 1957, The water resources of northern Delaware: Delaware Geological Survey Bulletin No. 6, 223 p., 8 pls.

Rasmussen, W.C., and Slaughter, T.H., 1955, The water resources of Somerset, Wicomico, and Worcester counties: Maryland Department of Geology, Mines and Water Resources, Bulletin 16, 114 p.

Richmond, G.M., and Fullerton, D.S., 1986, Summation of Quaternary glaciations in the United States of America, *in* Šibrava, V., Bowen, D.Q., and Richmond, G.M., eds., Quaternary glaciations in the Northern Hemisphere: Quaternary Science Reviews, v. 5, p. 183–196.

Shackleton, N.J., 1987, Oxygen isotopes, ice volume and sea level: Quaternary Science Reviews, v. 6, p. 183–190.

Sirkin, L.A., Denny, C.S., and Rubin, M., 1977, Late Pleistocene environment of the central Delmarva Peninsula: Geological Society of America Bulletin, v. 88, p. 139–142.

Sirkin, L.A., and Owens, J.P., 1976, Applied pollen stratigraphic studies in the Delmarva Peninsula [abs.]: Geological Society of America Abstracts with Programs, v. 8, Northeastern Section, p. 268.

Smart, P.L., and Richards, D.A., 1992, Late Quaternary high sea-stands: Quaternary Science Reviews, v. 11, p. 687–696.

Stanford, S.D., 1997, Pliocene-Quaternary geology of northern New Jersey: An overview, *in* Stanford, S.D., and Witte, R., eds., Pliocene-Quaternary geology of northern New Jersey; Guidebook for the 60th Annual Reunion of the Northeastern Friends of the Pleistocene: Trenton, p. 1.1–1.26.

Toscano, M.A., 1992, Record of oxygen-isotope stage 5 on the Maryland inner shelf and Atlantic Coastal Plain—a post-transgressive highstand regime, *in* Fletcher, C.H., III, and Wehmiller, J.F., eds., Quaternary coasts of the United States: Marine and lacustrine systems: SEPM (Society for Sedimentary Geology) Special Publication no. 48, p. 88–99.

Toscano, M.A., Kerhin, R.T., York, L.L., Cronin, T.M., and Williams, S.J., 1989, Quaternary stratigraphy of the inner continental shelf of Maryland: Maryland Geological Survey Report of Investigations 50, 116 p., 5 pls.

Traverse, A., 1988, Paleopalynology: Boston, Unwin Hyman, 600 p.

Ward, R.F., and Groot, J.J., 1957, Engineering materials of northern New Castle County: Delaware Geological Survey Bulletin No. 7, 103 p., 5 pls.

Wehmiller, J.F., and Belknap, D.F., 1982, Amino acid age estimates, Quaternary Atlantic Coastal Plain: Comparison with U-series dates, biostratigraphy, and paleoclimatic control: Quaternary Research, v. 18, p. 311–336.

Wehmiller, J.F., Belknap, D.F., Boutin, B.S., Mirecki, J.E., Rahaim, S.D., and York, L.L., 1988, A review of the aminostratigraphy of Quaternary mollusks from United States Atlantic Coastal Plain sites, *in* Easterbrook, D.L., ed., Dating Quaternary sediments: Geological Society of America Special Paper 227, p. 69–110.

PLATE 1

Microslide number follows taxon name. Bars are 20 μm long.

1. *Tricolporopollenites edmundii*, 20959 IIA, Beaverdam Formation, Pliocene.
2. *Momipites*, 20756-1, Omar Formation, Pliocene.
3. *Pterocarya*, 42203(1), Beaverdam Formation, Pliocene.
4. *Symplocos*, 20772-2, Omar Formation, late Tertiary or Quaternary.
5. *Sciadopitys*, 20775 II, Omar Formation, Pliocene.
6. *Ulmus serotina*(?), 20770-3, Omar Formation, Quaternary.
7. *Pinus*, 22782, Nanticoke deposits, Quaternary.
8. *Alnus*, 40463-1, Quaternary.
9. *Betula*, 22782, Nanticoke deposits, Quaternary.
10. *Quercus* sp. 1, 22711, Nanticoke deposits, Quaternary.
11. *Quercus* sp. 3, 40463-1, Quaternary.
12. *Quercus* sp. 5, 22782, Nanticoke deposits, Quaternary.

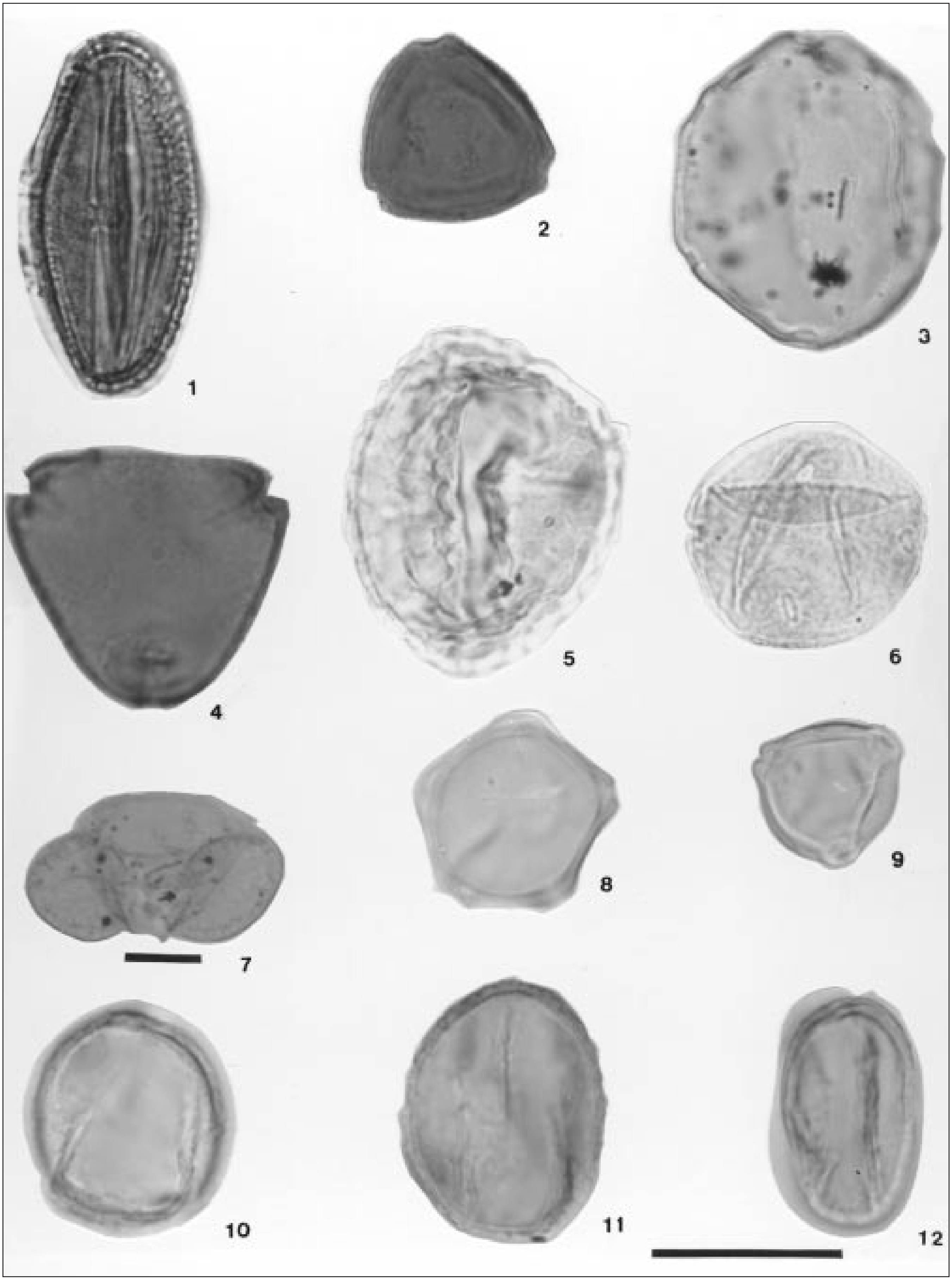

1
2
3
4
5
6
7
8
9
10
11
12

PLATE 2

Microslide number follows taxon name. Bar is 20 μm long.

13, 14. *Quercus* sp. 6, 22782, Nanticoke deposits, Quaternary.
15. Taxodiaceae, Cupressaceae, Taxaceae (TCT), 20959 INIA, Beaverdam Formation, Pliocene.
16. Compositae, 40463, Quaternary.
17. *Tsuga*, 42203(1), Beaverdam Formation, Pliocene.
18. *Nuphar*, 20767-6, Omar Formation, Quaternary.
19. *Ilex*, 84769(1), Quaternary.
20. Caryophyllaceae, 40000, Quaternary.

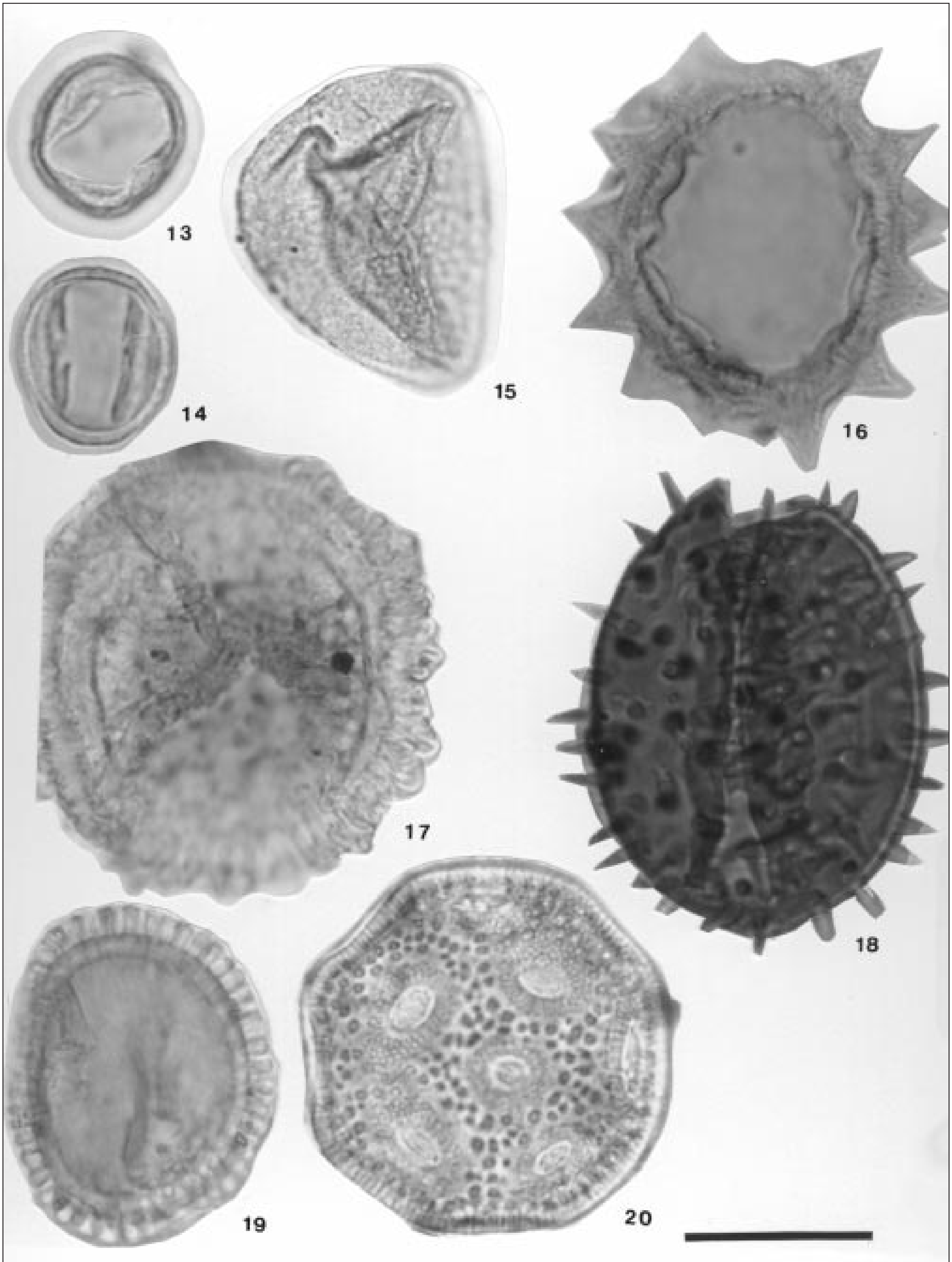
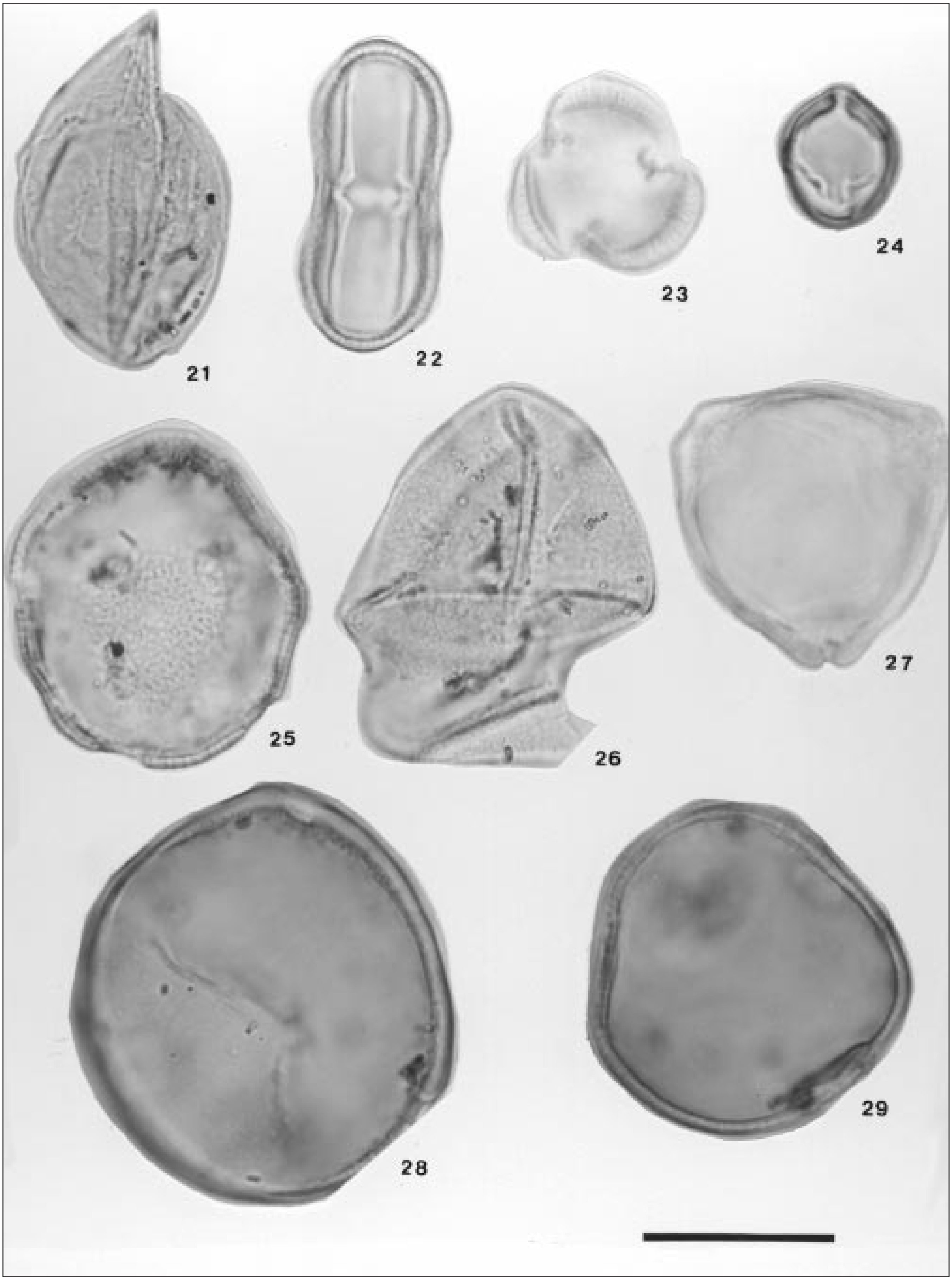

13
14
15
16
17
18
19
20

PLATE 3

Microslide number follows taxon name. Bar is 20 μm long.

21. TCT (*Taxodium*?), 84770(1), Nanticoke deposits, Quaternary.
22. Umbelliferae, 84769(1), Nanticoke deposits, Quaternary.
23. *Artemisia*, 84769(1), Nanticoke deposits, Quaternary.
24. *Cyrilla*, 42203(1), Beaverdam Formation, Pliocene.
25. *Liquidamber*, 42203(1), Beaverdam Formation, Pliocene.
26. Cyperaceae, 84770(1), Nanticoke deposits, Quaternary.
27. *Myrica*, 84769(1), Nanticoke deposits, Quaternary.
28. *Carya*, 84770(1), Nanticoke deposits, Quaternary.
29. Gramineae, 84770(1), Nanticoke deposits, Quaternary.


21
22
23
24
25
26
27
28
29

Appendix 1. Locations of wells and outcrops (DGSIDs) sampled.

DGSID	LATITUDE	LONGITUDE	DGSID	LATITUDE	LONGITUDE
Db31-60	393725	754434	Nh44-a	384612	751159
Db34-a	393702	754139	Nh45-02	384612	751012
Fb34-09	392716	754133	Nj51-02	384520	750456
Hc24-05	391840	753639	Ob24-a	384342	754140
Hd13-02	391924	753203	Oc15-08	384446	753558
Hd34-01	391720	753117	Od32-c	384229	753345
Hd41-03	391614	753448	Od43-03	384106	753251
Id22-a	391308	753355	Od43-a	384152	753256
Id25-a	391302	753059	Oe34-02	384247	752620
Id32-a	391206	753315	Og45-01	384145	751543
Id34-a	391207	753159	Oh25-10	384345	751055
Id45-a	391147	753040	Pb34-04	383745	754106
Jb33-a	390740	754213	Pb55-03	383543	754059
Kb42-01	390147	754318	Pc25-04	383834	753548
Ld44-c	385622	753138	Pc41-01	383619	753954
Le14-18	385934	752624	Pc43-01	383624	753711
Le14-a	385919	752617	Pc51-01	383554	753923
Le15-g	385941	752550	Pd21-07	383850	753521
Le25-12	385814	752536	Qb15-01	383432	754006
Le44-09	385613	752638	Qb23-01	383353	754202
Lf13-a	385912	752240	Qc24-06	383317	753626
Lf14-a	385901	752120	Qf45-04	383129	752006
Lf14-b	385932	752153	Qf54-08	383006	752108
Lf14-c	385934	752142	Qg31-01	383226	751904
Lf14-e	385940	752135	Qg31-03	383232	751901
Lf14-j	385929	752134	Qg32-06	383221	751830
Lf14-m	385931	752117	Qg33-02	383253	751846
Lf14-n	385935	752126	Qg34-08	383206	751624
Lf14-p	385906	752133	Qg52-01	383038	751856
Lf21-19	385822	752442	Qg54-a	383056	751621
Lf21-b	385855	752413	Qh34-09	383239	751107
Lf23-ac	385818	752203	Qh35-04	383251	751050
Lf23-ad	385827	752222	Qh35-08	383254	751055
Lf23-f	385812	752232	Qh35-09	383233	751059
Lf23-t	385834	752201	Qh41-a	383136	751448
Lf23-u	385822	752207	Qh44-01	383054	751130
Lf23-x	385817	752202	Qi11-a	383457	750918
Lf24-02	385834	752106	Qi51-04	383041	750932
Mc45-03	385150	753549	Qi54-02	383042	750631
Md54-07	385025	753154	Rg13-01	382934	751731
Me45-a	385137	752503	Rg22-01	382845	751806
Mf51-a	385051	752450	Rg23-01	382822	751714
Mg21-06	385348	751959	Rh24-a	382833	751105
Nc15-a	384936	753503	Rh34-a	382754	751105
Ng45-01	384652	751517	Ri13-a	382937	750753

Appendix 2. Scientific and common names of plant taxa occurring in post-Miocene sediments of Delaware

Scientific Name	Common Name	Scientific Name	Common Name
Acer	Maple	*Ulmus*	Elm
Alnus	Alder	*Pterocarya*	Wingnut
Betula	Birch	*Cyrilla*	Ironwood
Carpinus	Hornbeam	*Symplocos*	Sweetleaf
Carya	Hickory	*Abies*	Fir
Castanea	Chestnut	*Picea*	Spruce
Fagus	Beech	*Pinus*	Pine
Fraxinus	Ash	*Tsuga*	Hemlock
Ilex	Holly	*Taxodium*	Baldcypress
Juglans	Walnut	Caryophyllaceae	Pink family
Liquidambar	Sweetgum	Chenopodiaceae	Goosefoot family
Myrica	Waxmyrtle	Compositae	Sunflower or daisy family
Nyssa	Tupelo	Gramineae	Grass family
Ostrya	Hophornbeam	Cyperaceae	Sedge family
Populus	Poplar	Ericaceae	Heath family
Quercus	Oak	*Typha*	Cattail
Salix	Willow	*Sparganium*	Bar reed
Tilia	Linden	Polypodiaceae	A fern family

Appendix 3. Pollen assemblages of the Beaverdam Formation expressed in percentages of the pollen sum.

	DGSID	Pc43-01	Pc43-01	Qb15-01	Ob24-a	Pd21-07	Og45-01	Qi11-a	Qi11-a	Qi11-a	Ob25-10
	SAMPLE NO.	22826	22827	84440	42203	83166	85203	41109	41110	41111	83438
Betulaceae	*Alnus*		P		3	P	P	1	1		
	Betula	2	1		3	P	5	6	4	3	9
	Carpinus	1			P		P	P	1	P	1
Juglandaceae	*Carya*	11	14	37	6	36	13	34	8	5	P
	Pterocarya	1	P		1		1	P	P	P	
Fagaceae	*Castanea*				2						
	Quercus	69	66	14	41	55	31	28	26	25	44
Aquifoliaceae	*Ilex*				4						
Hamamelidaceae	*Liquidambar*	1	2	14	P	P	P				
Myricaceae	*Myrica*				1		1				P
Nyssaceae	*Nyssa*		1		P						
Tiliaceae	*Tilia*	1	1		P	2	P	2	1	4	
Ulmaceae	*Ulmus*					P	1	P	5	P	P?
Cyrillaceae	*Cyrilla*				P	P?					
Symplocaceae	*Symplocos*				P						
	Other	3		1	3		5	2			1
Gymnosperms	*Picea, Abies*				P		2	P	P	1	4
	Pinus	1	2	23	23		15	6	5	15	14
	Tsuga		P	1	P						
	Sciadopitys		1	1		2	P				P
	TCT	11	6	4	2	2	3	2	5	4	1
	Taxodium		1						P		
Herbs	*Artemisia*										P
	Caryophyllaceae										
	Chenopodiaceae						2		6	2	
	Compositae			1			4	11	22	22	13
	Gramineae			1			2	P		1	2
	Cyperaceae				1		P			1	
	Ericaceae				1						
	Hydrocharitaceae								P		
	Typha, Sparganium										
	Other								P	4	
Ferns,	*Lycopodium*						P	P			P
Mosses	*Osmunda*						P				P
	Polypodiaceae	2	3	3	2	P	5	5	6	8	4
	Sphagnum				P		P		P	2	P
	Other		1								
NAP		2	4	5	4	P	16	18	36	40	24
Reworked Palynomorphs		P			P			P	P	P	
Dinocysts + microforams			?		2			P		P	

Appendix 4. Pollen assemblages of the Columbia Formation, expressed in percentages of the pollen sum.

	DGSID	Db31-60	Fb34-09	Fb34-09	Fb34-09	Hc24-05	Mc45-03	Id45-a
	SAMPLE NO.	25411	32541	22695	22696	83219	83160	41686
Betulaceae	*Alnus*	6	3	3	P	3	2	1
	Betula	5	2		P		2	P
	Carpinus	1	P		1			
Juglandaceae	*Carya*	1	1	3	1			1
	Pterocarya							
Fagaceae	*Castanea*	1	P					
	Quercus	14	3	4	1	2	2	13
Aquifoliaceae	*Ilex*				P	P		P
Hamamelidaceae	*Liquidambar*							
Myricaceae	*Myrica*	P						
Nyssaceae	*Nyssa*							
Tiliaceae	*Tilia*	P	1	1				
Ulmaceae	*Ulmus*	P	P	P			P	
Cyrillaceae	*Cyrilla*							
Symplocaceae	*Symplocos*							
	Other	2	P	1	2	P		P
Gymnosperms	*Picea, Abies*	6	7	5	17	4	4	4
	Pinus	36	70	71	67	75	85	57
	Tsuga		2	2	7			
	Sciadopitys							
	TCT	3	1	1	P		P	
	Taxodium	?						
Herbs	*Artemesia*	2	P			P		2
	Caryophyllaceae							
	Chenopodiaceae		P		P		P	
	Compositae	8	4	2	1	1	P	8
	Gramineae	6	1	P		P		
	Cyperaceae		?	P		4		P
	Ericaceae	P	1	P		4	P	
	Myriophyllum	P	1	P		P		
	Typha, Sparganium	P						
	Other	P		1			P	P
Ferns, Mosses	*Lycopodium*	1	P	P			P	
	Osmunda							
	Polypodiaceae	2	1		P			P
	Sphagnum	P		2			4	2
	Other							
NAP		21	9	9	2	11	6	21
Reworked Palynomorphs		P	1					
Dinocysts + microforams								

Appendix 5. Pollen assemblages of the Omar Formation expressed in percentages of the pollen sum

	DGSID	Qh35-04	Qh35-08	Qh35-09	Nh44-a	Qh41-a	Ri13-a	Qi51-04	Qi51-04	Qi51-04	Qi51-04	Qi54-02	Rg23-01
	SAMPLE NO.	85652	85709	85711	41142	40962	40969	25046	25047	25049	25050	25197	20735
Betulaceae	*Alnus*		17	6	4	3	1		P		8		1
	Betula	4	2	5	20	11	2	1	1		6	P	P
	Carpinus	P	P	3	P	P	2				2	2	
Juglandaceae	*Carya*	16	3	2	1	2	8	5	2	5	9	2	P
	Pterocarya												
Fagaceae	*Castanea*												
	Quercus	26	13	11	34	61	17	16	13	26	25	34	P
Aquifoliaceae	*Ilex*										P		
Hamamelidaceae	*Liquidambar*	8	4	P	1				P	3	4	8	
Myricaceae	*Myrica*		P	P	3	P							P
Nyssaceae	*Nyssa*	2	7						1		6	4	
Tiliaceae	*Tilia*												
Ulmaceae	*Ulmus*				1			1	2		P		
Cyrillaceae	*Cyrilla*												
Symplocaceae	*Symplocos*												
	Other dicots	P	3		1	1		1	P		2		
Gymnosperms	*Picea, Abies*	P			P					1	2		7
	Pinus	29	30	42	5	8	51	67	55	59	27	43	63
	Tsuga		3	1			1		3	2	4	2	
	Sciadopitys												
	TCT	P	P		6	1	2	1	4	3			P
	Taxodium	P	P									P	
Herbs	*Artemisia*			P	P		3						
	Caryophyllaceae								P	1			
	Chenopodiaceae	6	3	3		P	4	6	3		3	P	P
	Compositae	2	4	3	19	3	6		6		P	P	2
	Gramineae	2	2	5		2		1	P		P		P
	Cyperaceae	P	2	P									13
	Ericaceae			2		P					P		3
	Hydrocharitaceae										P		
	Typha, Sparganium												P
	Other herbs		2			P							
Ferns, Mosses	*Lycopodium*										P		
	Osmunda			P								P	
	Polypodiaceae	1	2	12			P	1	2	P	P		P
	Sphagnum		1		3	2			1	1	P	P	4
	Other Pteridophytes						P		P		P		P
NAP		12	15	27	22	8	14	8	14	3	8	3	25
Reworked palynomorphs					2						P		
Dinocysts + microforams			2	2		8	6	21	6			20	

Appendix 5. Pollen assemblages of the Omar Formation expressed in percentages of the pollen sum

	DGSID	Qh44-01	Qh44-01	Qh44-01	Qh44-01	Qh44-01	Qh44-01	Qh44-01	Qh44-01	Qh44-01	Qh44-01	Qh44-01	Qh34-09	Qh34-09
	SAMPLE NO.	20763	20765	20766	20767	20768	20769	20770	20771	20773	20774	20775	85678	85679
Betulaceae	*Alnus*		P	9	7	P	2	2	10	3	P	P	P	
	Betula	2	1	2	2	2	P	5	3	2	2		P	P
	Carpinus		P	P		12		P				2	2	
Juglandaceae	*Carya*	3	8	4	7	34	P	11	8	8	8	23	6	7
	Pterocarya								1?					
Fagaceae	*Castanea*			P	4				P					
	Quercus	4	8	2	6	11	P	11	16	8	19	23	28	26
Aquifoliaceae	*Ilex*				P	P			P	P				
Hamamelidaceae	*Liquidambar*	3				6		2	P	3	4	9		
Myricaceae	*Myrica*	3	2	8			2	2	4					
Nyssaceae	*Nyssa*	10	P			12				3	6	17		
Tiliaceae	*Tilia*	P												
Ulmaceae	*Ulmus*				P			P				P		
Cyrillaceae	*Cyrilla*									P	P	P		
Symplocaceae	*Symplocos*								P					
	Other dicots			P	3	3			1		2	P	1	
Gymnosperms	*Picea, Abies*		2	P	P		22	P		1	P		2	P
	Pinus	3	61	30	21	3	33	54	30	51	44	13	53	60
	Tsuga				1			1	P	1		2	P	2
	Sciadopitys											P		
	TCT	3		2	5	2		1	8	2	5			P?
	Taxodium							2				P		
Herbs	*Artemisia*		1								P			
	Caryophyllaceae			P										
	Chenopodiaceae		2	2			2		P		P	2	P	2
	Compositae	14	2	12	5		P	3	2	6	2	P	2	2
	Gramineae	2		5	31	4		1	2	1	1	2	2	P
	Cyperaceae				2	P	P	1		2	P	2?		
	Ericaceae	2	2	1	P			1	1	P	P			P
	Hydrocharitaceae	1		P							P			
	Typha, Sparganium		1	2	2	4	2	2				P		
	Other herbs				1				2	3				
Ferns, Mosses	*Lycopodium*	1	2				5	P	P					P
	Osmunda	2							P					
	Polypodiaceae		2	13	4	2	23	P	6	1	3	P	2	
	Sphagnum	43	5	5			6		2	P	2			P
	Other Pteridophytes									1				
NAP		67	17	41	45	11	39	9	16	15	11	8	7	6
Reworked palynomorphs														
Dinocysts + microforams													5	2

Appendix 5. Pollen assemblages of the Omar Formation expressed in percentages of the pollen sum

	DGSID	Rg23-01	Rg23-01	Rg23-01	Rg23-01	Rg23-01	Rg22-01	Rg22-01	Rg22-01	Rg22-01	Rg22-01	Rg22-01	Rg22-01	Rg22-01
	SAMPLE NO.	20737	20738	20739	20740	20741	20749	20750	20751	20752	20753	20754	20755	20756
Betulaceae	*Alnus*	P	2	6	1	2	P	2	4	8	17	3	P	P
	Betula	P	3	1	P	2		2	3	4	20	2	3	1
	Carpinus		P		?							P		P
Juglandaceae	*Carya*	4	14	12	4	6			P			12	12	17
	Pterocarya												?	P
Fagaceae	*Castanea*													P
	Quercus	P	34	27	6	18	25	P	2	P	P	3	50	51
Aquifoliaceae	*Ilex*			P	2	2	7				1	1		1
Hamamelidaceae	*Liquidambar*			P	P	2	1					P	P	P
Myricaceae	*Myrica*	1		P	4	5			2	3	18	4	P	
Nyssaceae	*Nyssa*		1	7	8	4	2					P		P
Tiliaceae	*Tilia*					P	P							P
Ulmaceae	*Ulmus*		P	P			P						P	P
Cyrillaceae	*Cyrilla*		1?			1?								P
Symplocaceae	*Symplocos*													
	Other dicots	5	P				1	2		P	P	P		P
Gymnosperms	*Picea, Abies*	P	1	P	3			4	11	5	1	2	P	P
	Pinus	44	24	27	28	21	10	75	52	23	12	46	30	20
	Tsuga		P	P		P						1	P	
	Sciadopitys													?
	TCT	P	4	3	P	P	10							
	Taxodium						P							P
Herbs	*Artemisia*													
	Caryophyllaceae				P	P		1			P			
	Chenopodiaceae		3	P		1		P				P	P	
	Compositae	10	4	3	6	1	6	1	8	4	5	4	P	1
	Gramineae	22		2			P	P	1	1	2	P		3
	Cyperaceae	7					8	9	3	14	3	2		
	Ericaceae		1	P	5	6	2			2	3	1		P
	Hydrocharitaceae	P												
	Typha, Sparganium	P										P		
	Other herbs	P								P	8	P		
Ferns, Mosses	*Lycopodium*					P			P	P				
	Osmunda					P	9							
	Polypodiaceae		3	P	P	3			1			1	P	P
	Sphagnum	1	3	7	26	27	14	1	8	35	6	12		
	Other Pteridophytes	?			1			2		P	P			
NAP		42	14	14	39	37	39	15	21	57	29	22	3	5
Reworked palynomorphs									2					
Dinocysts + microforams		?												P

Appendix 6. Pollen assemblages of the Lynch Heights Formation expressed in percentages of the pollen sum.

	DGSID	Lf21-19	Le25-12	Mg21-06	Mg21-06	Lf24-02	Lf24-02	Le15-g	Le14-18	Le14-18	Le14-18	Le14-18	Le44-09	Le44-09
	SAMPLE NO.	25627-1	25639	25658-1	25658-2	25659-1	25659-2	41420	25706-1	25706-2	25707-1	25707-2	85436	85439
Aceraceae	*Acer*												P	
Betulaceae	*Alnus*	P	P	P	P	3	3		P	P	3	3	P	2
	Betula	3	1	2		1	2		2		1	2	5	16
	Carpinus				P		1			P		1		
	Corylus												P	
Juglandaceae	*Carya*	2	1	7	3	1	6		7	3	1	6		
Fagaceae	*Castanea*													
	Quercus	5	1	22	11	6	7		22	11	6	7	10	7
Aquifoliaceae	*Ilex*	1		P			1		P			1		
Hamamelidaceae	*Liquidambar*													
Myricaceae	*Myrica*	3				P		1	P		P			
Nyssaceae	*Nyssa*													
Ulmaceae	*Ulmus*													
Other														
Gymnosperms	*Picea, Abies*	2	3		1			57		1		?	4	3
	Pinus	57	76	53	63	67	70	39	53	63	67	70	49	37
	Tsuga	P					P					P		
	TCT	1												
	Taxodium													
Herbs	*Artemisia*		P		P	P				P	P		1	2
	Chenopodiaceae	3	7	P					P				3	1
	Compositae	3	P	4	7	6	3		4	7	6	3	9	13
	Gramineae	P	P	2	1	1		1	2	1	1		7	6
	Cyperaceae		P										1	1
	Ericaceae	2	3		1		P			1		P		
	Hydrocharitaceae													
	Typha, Sparganium													
	Other			P		P		1	P		P			2
Ferns, Mosses	*Lycopodium*					1					P			2
	Osmunda	P					P					P	P	2
	Polypodiaceae	4	5	3	4	6	5		3	4	6	5	1	2
	Sphagnum	11	2	5	5	4	P		5	5	4	P	4	1
	Selaginella												P	
Blue green/green algae													10	
	Other													
NAP		24	18	14	20	20	9	2	14	19	20	9	30	33
Reworked Palynomorphs						P	P				P	P		
Dinocysts + microforams		?	P				?					?		1

Appendix 7. Pollen assemblages of the Scotts Corners Formation expressed in percentages of the pollen sum.

	DGSID	Lf23-t	Lf14-b	Lf14-c	Lf14-e	Lf14-j	Lf14-m	Lf14-n	Lf14-p	Lf14-p	Lf14-p	Lf21-b	Lf23-f	Lf23-u	Lf23-x
	SAMPLE NO.	41422	41323	41330	41334	41336	41353	41356	41425	41431	41435	41367	41344	41464	41465
Betulaceae	*Alnus*	P	P	4	10		3	3	P		P		P		1
	Betula	P	9	4	P	11	6	2	6		2		2	P	1
	Carpinus		1		P		P	2		P		3	6		
Juglandaceae	*Carya*		5	4	2	1	3	6	3	7	7	3	3	6	4
	Juglans														
Fagaceae	*Castanea*	P		2	P	1	P								
	Quercus	P	21	8	6	23	6	8	34	31	49	39	44	21	30
Aquifoliaceae	*Ilex*				2		2	P		P	P		1		
Hamamelidaceae	*Liquidambar*			P				2		3	6		5		3
Myricaceae	*Myrica*	1	1	3	2	1	6	3	1	P		P			1
Nyssaceae	*Nyssa*									5	P		P	P	?
Ulmaceae	*Ulmus*										P	P	P		
Other				2	29		P	2		1					
Gymnosperms	*Picea, Abies*	20						P	P?	P	1		P		P
	Pinus	50	42	49	27	36	42	46	39	39	27	37	19	65	49
	Tsuga		P	1	P			2	P	11	3		P		6
	TCT		1		P	1	3						13		
	Taxodium												P		
Herbs	*Artemisia*		1	P			P				P	P			
	Chenopodiaceae		6			3	P			P		4			2
	Compositae	1	6	7	3	10	10	7	6			9	2	2	
	Gramineae		1?	8	9	3	9	10				P	2		1
	Cyperaceae		1		4		?	?							
	Ericaceae	1		P			P	2			1			2	1
	Hydrocharitaceae			P			P						P		
	Typha, Sparganium			P											
	Other						2	P			P		P		
Ferns, Mosses	*Lycopodium*	1										P			
	Osmunda	P				1		P			P		P		
	Polypodiaceae		2	5	2	3	4	4	6		2	P		P	
	Sphagnum	19		1	P	7	P	P	6	P		2		2	
	Other														
NAP		24	17	25	18	27	28	24	17	2	3	17	5	7	4
Reworked Palynomorphs						P			P	P	P		P		?
Dinocysts + microforams								?					?		

Appendix 7. Pollen assemblages of the Scotts Corners Formation expressed in percentages of the pollen sum.

	DGSID	Lf23-x	Lf23-x	Lf23-ac	Lf23-ac	Lf23-ad	Lf13-a	Lf14-a	Le14-a	Ng45-01	Ng45-01	Ng45-01	Nh45-02	Hd13-02	Hd13-02
	SAMPLE NO.	41469	41472	41482	41485	41489	40975	40976	41373	87467	87465	87466	25044	86317	86319
Betulaceae	*Alnus*	1		P		1	2	4	9	2			P	2	1
	Betula	1		P		2	10	4	P	6	7	7	2	2	5
	Carpinus				P	P	1	3	2			4?			
Juglandaceae	*Carya*	3	4	14	5	8	3	4	P	P	P	2		5	2
	Juglans												P		
Fagaceae	*Castanea*						1	P							
	Quercus	38	40	11	33	7	25	30	28	29	20	28	34	9	7
Aquifoliaceae	*Ilex*			P				P	6	P		1			
Hamamelidaceae	*Liquidambar*	P	12	1	13			P	2				5		
Myricaceae	*Myrica*							1	1					P	
Nyssaceae	*Nyssa*	2	21	2	4				2				2		
Ulmaceae	*Ulmus*														
Other				1?	4		1		11	P					1
Gymnosperms	*Picea, Abies*				P	P			P	17	7	7		7	5
	Pinus	37	16	58	31	73	31	33	14	17	28	19	25	52	68
	Tsuga	6	2	4	6	P			3						1
	TCT					1	3		1	P	2	1	P		
	Taxodium										1?				
Herbs	*Artemisia*					P?	1								
	Chenopodiaceae		P		P	P	P	5	P	3	2		3	2	
	Compositae	1	P	2	2	2	8	3	6	17	28	26	3	3	
	Gramineae						7	3	1		2		5		
	Cyperaceae							1	P			1			
	Ericaceae			P?		2	1	2		2	P		P	2	2
	Hydrocharitaceae								4						
	Typha, Sparganium		P?						P						
	Other		P				2	6	2						
Ferns, Mosses	*Lycopodium*			P								1		P	1
	Osmunda								P				P		
	Polypodiaceae	1	2	1		2	2	1	3	2	2			7	5
	Sphagnum	1				P	3	P	P	1		1		6	2
	Other							P			P	1	2	1	
NAP		3	4	5		8	25	22	19	24	35	31	14	22	10
Reworked Palynomorphs		P			P	P		P	P		P	2	P		
Dinocysts + microforams				3	3										

Appendix 8. Pollen assemblages of the Nanticoke Deposits expressed in percentages of the pollen sum.

	DGSID	Pc51-01	Pc51-01	Pc51-01	Qb23-01	Qb23-01	Qc13-01	Pc41-01	Pc25-04	Pc25-04	Od43-a3	Pb55-03	Pb55-03	Pb55-03	Od32-c	Pb34-04
	SAMPLE NO.	22713	22712	22711	84434	84431	22774	22782	22793	22792	41495	84659	84658	84655	42199	84098
Betulaceae	*Alnus*	11	9	3		7	3	7		1	1	2	5	P	2	
	Betula	3	3	1		3	3	5	2	13	1	6		P	2	P
	Carpinus						4	3		P	P	1				
Juglandaceae	*Carya*	6	7	3	8	P	10	4	2	5	2	6	2		P	
	Pterocarya															
Fagaceae	*Castanea*															
	Quercus	58	46	33	25	14	45	15	48	23	13	22	12	6	12	2
Aquifoliaceae	*Ilex*		P	2		1			1	P	P			1		
Hamamelidaceae	*Liquidambar*	2	P	2		1							1		P	
Myricaceae	*Myrica*	2	2	P		3		P	1	2		P	P	4	P	
Nyssaceae	*Nyssa*	2	P	3		P		P							P	
Tiliaceae	*Tilia*															
Ulmaceae	*Ulmus*					P	2									
Cyrillaceae	*Cyrilla*															
Symplocaceae	*Symplocos*															
	Other dicots			1			P		2		P	P				
Gymnosperms	*Picea, Abies*				1					1	2	P	2	8		
	Pinus	6	13	25	40	21	19	62	31	31	54	35	70	36	70	75
	Tsuga		P	P											P	
	Sciadopitys															
	TCT	P		1			4	P		1	1	4	2			
	Taxodium						2	P			1					
Herbs	*Artemisia*		P				1					1		P		P
	Caryophyllaceae													2		
	Chenopodiaceae	3	P	8	P	4		P	4	4	3	6			P	4
	Compositae	4	11	11	14	34	4	P	4	P	2	6	1	29	3	2
	Gramineae		P			1	2	P		P	2	1	1?	1	P	
	Cyperaceae					4					P			3	P	4
	Ericaceae		P		P				3		1			6	3	
	Hydrocharitaceae		P	1	3			P								
	Typha, Sparganium				P	P	2		1		1	2		P	P	
	Other				2			P					2			
Ferns, Mosses	*Lycopodium*									P	P		1			
	Osmunda		P								P					
	Polypodiaceae	2	P	1	4		2	P	1	4	4	5			P	
	Sphagnum	P		P					1	7	7	3	1		2	3
	Other															
NAP		10	16	22	25	46	12	5	14	18	22	24	6	43	12	19
Reworked Palynomorphs						2				?	2					
Dinocysts + microforams																

Appendix 9. Pollen assemblages of the Staytonville Unit expressed in percentages of the pollen sum.

	DGSID	Md54-07	Nc15-a
	SAMPLE NO.	26337	40464
Betulaceae	*Alnus*	3	17
	Betula	P	3
	Carpinus		P?
Juglandaceae	*Carya*	9	P
	Pterocarya		
Fagaceae	*Castanea*		
	Quercus	61	3
Aquifoliaceae	*Ilex*		
Hamamelidaceae	*Liquidambar*	3	
Myricaceae	*Myrica*		
Nyssaceae	*Nyssa*		
Tiliaceae	*Tilia*		
Ulmaceae	*Ulmus*		
Cyrillaceae	*Cyrilla*		
Symplocaceae	*Symplocos*		
	Other dicots		
Gymnosperms	*Picea, Abies*		14
	Pinus	7	34
	Tsuga	4	
	Sciadopitys		
	TCT		
	Taxodium		
Herbs	*Artemisia*		
	Caryophyllaceae		2
	Chenopodiaceae		
	Compositae	10	8
	Gramineae		3
	Cyperaceae	P?	
	Ericaceae		
	Hydrocharitaceae		
	Typha, Sparganium, Nuphar		P
	Other		
Ferns, Mosses	*Lycopodium*		6
	Osmunda		
	Polypodiaceae	2	3
	Sphagnum		2
	Other		
NAP		13	25
Reworked Palynomorphs			
Dinocysts + microforams		10	

Appendix 10. Pollen assemblages from other Quaternary deposits, expressed in percentages of the pollen sum.

	DGSID	Nj51-02	Rh34-a	Jb33-a	Kb42-01	Db34-a	Qg54-a	Qg54-a	Rh24-a	Hd34-01	Hd41-03	Id22-a
	SAMPLE NO.	21468	41005	40822	41391	41020	41053	41054	41055	86330	86348	42368
Betulaceae	*Alnus*	39		5	P					2		1
	Betula	P		24	3	4	2		1	5		1
	Carpinus			P								
Juglandaceae	*Carya*											
	Pterocarya											
Fagaceae	*Castanea*											
	Quercus			2		1				5	2?	2
Aquifoliaceae	*Ilex*	P		P								
Hamamelidaceae	*Liquidambar*											
Myricaceae	*Myrica*			2			P	1	1			
Nyssaceae	*Nyssa*											
Tiliaceae	*Tilia*											
Ulmaceae	*Ulmus*			P?								
Cyrillaceae	*Cyrilla*											
Symplocaceae	*Symplocos*											
	Other dicots	P	1	P	P	1	P	1				P
Gymnosperms	*Picea, Abies*	8	25	16	8	22	25	36	33	7	40	14
	Pinus	38	55	33	17	58	58	48	56	37	47	57
	Tsuga											
	Sciadopitys											
	TCT				P	1						
	Taxodium											
Herbs	*Artemisia*		4	P	1	2						2
	Caryophyllaceae					2						
	Chenopodiaceae			P		1						
	Compositae	3		P	3	4				2	2	1
	Gramineae	6		P	14	2	2	1		1		3
	Cyperaceae	P	2	2	40		2	3	2			9
	Ericaceae		6	2	P	1	7	3	7	8	2	1
	Hydrocharitaceae											
	Typha, Sparganium				P	1						
	Other		3	7	9		P				2	3
Ferns, Mosses	*Lycopodium*	4		P	P	1		1			2	1
	Osmunda											
	Polypodiaceae	1	P							1		P
	Sphagnum				P		2			32	2	3
	Other		3		1		P					P
NAP		15	16	15	70	13	14	10	9	44	10	24
Reworked Palynomorphs								P				
Dinocysts + microforams												

Appendix 10. Pollen assemblages from other Quaternary deposits, expressed in percentages of the pollen sum.

	DGSID	Id22-a	Id34-a	Oc15-08	Oe34-02	Qf45-04	Qf45-04	Qf54-08	Qg33-02	Qg34-08	Qg52-01	Rg13-01
	SAMPLE NO.	42369	41493	43371	87684	84885	84886	84960	84921	84908	84985	85160
Betulaceae	*Alnus*	P		8	1			3	9	2	8	8
	Betula	P	4	9	1					2		2
	Carpinus								P?			
Juglandaceae	*Carya*							1				P
	Pterocarya											
Fagaceae	*Castanea*											
	Quercus				1			2	P	2		1
Aquifoliaceae	*Ilex*								P	1	2	
Hamamelidaceae	*Liquidambar*							1				
Myricaceae	*Myrica*	1	3	8		P		1	P		2	3
Nyssaceae	*Nyssa*											
Tiliaceae	*Tilia*											
Ulmaceae	*Ulmus*											
Cyrillaceae	*Cyrilla*											
Symplocaceae	*Symplocos*											
	Other dicots	P						P	P	P	2	
Gymnosperms	*Picea, Abies*	11	5	21	42	8	8	11	19	13	30	13
	Pinus	39	42	33	44	30	53	26	39	43	37	37
	Tsuga											
	Sciadopitys											
	TCT	P										
	Taxodium											
Herbs	*Artemisia*	3		2				2	2			
	Caryophyllaceae		P	P				1				
	Chenopodiaceae											
	Compositae	4	2	3	5			6	6		5	4
	Gramineae	4		P		P		7		1	2	P
	Cyperaceae	13		8		61	40	13	11	32	2	5
	Ericaceae		3	2	1			1			P	3
	Hydrocharitaceae	1										
	Typha, Sparganium	1										
	Other	4	P	P				1	P		2	P
Ferns, Mosses	*Lycopodium*	2	P	2	3			5		1	P	
	Osmunda	P						1				
	Polypodiaceae	2	P									
	Sphagnum	6	40	2	P			10	7		6	22
	Other	2				P	P	8		1		
NAP		43	47	21	10	62	41	55	26	35	19	34
Reworked Palynomorphs												
Dinocysts + microforams												

Appendix 10. Pollen assemblages from other Quaternary deposits, expressed in percentages of the pollen sum.

	DGSID	Rg13-01	Qg31-01	Qg31-03	Qg32-06	Id25-a	Id32-a	Ld44-c	Me45-a	Mf51-a
	SAMPLE NO.	85161	85579	85592	85654	41631	41517	40999	40000	40001
Betulaceae	*Alnus*	6	7	3	1	3				P
	Betula	2	1	2	4					
	Carpinus			P						
Juglandaceae	*Carya*			P		3	3	5	1	P
	Pterocarya									
Fagaceae	*Castanea*									
	Quercus	2	1	P	1	20	38	12	7	11
Aquifoliaceae	*Ilex*									
Hamamelidaceae	*Liquidambar*						8	5	P	2
Myricaceae	*Myrica*	5		5						
Nyssaceae	*Nyssa*						3			P
Tiliaceae	*Tilia*									
Ulmaceae	*Ulmus*									
Cyrillaceae	*Cyrilla*									
Symplocaceae	*Symplocos*									
	Other dicots	P			1			2		
Gymnosperms	*Picea, Abies*	10	28	20	30					P?
	Pinus	35	40	39	42	52	9	34	44	51
	Tsuga						1	1		
	Sciadopitys									
	TCT							2	3	5
	Taxodium									
Herbs	*Artemisia*	P	2	1	2	P				
	Caryophyllaceae					1		1	5	
	Chenopodiaceae						2	P	3	2
	Compositae	3	4	7	6	11	27	40	28	24
	Gramineae	4	1	P		2	1		2	2
	Cyperaceae	6	2	11	7			1	1	
	Ericaceae	P	3	2		1				
	Hydrocharitaceae									
	Typha, Sparganium									
	Other	3	2				4		P	
Ferns, Mosses	*Lycopodium*		3		3				1	
	Osmunda					P				
	Polypodiaceae			P		4	2		1	P
	Sphagnum	25	5	5	3	3	1		P	
	Other		1	P					P	
NAP		40	23	28	21	22	36	42	45	29
Reworked Palynomorphs						3				
Dinocysts + microforams							2			

Delaware Geological Survey
University of Delaware
Newark, Delaware 19716