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

REPORT OF INVESTIGATIONS NO. 50

PLANT MICROFOSSILS OF THE CALVERT FORMATION OF DELAWARE

by

Johan J. Groot

University of Delaware
Newark, Delaware

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PLANT MICROFOSSILS OF THE CALVERT FORMATION OF DELAWARE

Johan J. Groot

ABSTRACT

The Calvert Formation, deposited in a shallow sea during the late Oligocene and early to middle Miocene (15-27 million years ago), contains a very rich fossil microflora, both in terms of number of specimens and number of species. Most abundant are pollen of oak, pine, and hickory, but exotic taxa (those that no longer occur in Delaware) are present in all samples of this formation. They include pollen of *Engelhardia* type, *Manilkara, Planera* (water elm), *Alangium*(?), and palms. All of these exotics are genera of subtropical or tropical regions, some occurring now in Central America, Florida, and east Asia. The climate during the deposition of the Calvert Formation was probably subtropical and moist.

During periods of high sea level there was very little coastal plain area and, therefore, little room for swamps. During a regression, however, larger coastal plain wetlands came into being, and that this happened is indicated by few marine dinoflagellate cysts and a relatively high percentage of pollen of taxa that occur in and around swamps. On the other hand, samples with high frequencies of dinoflagellate cysts and low percentages of moisture-loving taxa suggest a high sea level. Periods of relatively low sea level occurred both in the early Miocene and the late middle Miocene; high sea levels were noted in the late Oligocene and early middle Miocene. These results correlate with determinations of relative sea level fluctuations based on studies of foraminifers from Dover Air Force Base test well Je32-04.

INTRODUCTION

The Calvert Formation, an important source of ground water in Kent County, has been the subject of considerable study in test well Je32-04 drilled at the Dover Air Force Base in 1957 (Fig. 1). That study included mineralogical, textural, and micropaleontological investigations of the Calvert and older formations and resulted in some conclusions with regard to the environments of deposition and the ages of the deposits encountered in the cores of the test well (Benson et al., 1985). The present report is intended to contribute some additional knowledge of late Oligocene and Miocene paleoenvironments in terms of continental climate and sea-level fluctuations by means of a study of the palynoflora (pollen, spores, and dinoflagellate cysts) of the Calvert Formation in samples from the Dover test well and from other test holes drilled in Kent County (indicated by five-digit numbers in Figure 1).

Acknowledgments

Thomas A. Ager of the U. S. Geological Survey provided the excellent pollen preparations of the samples of Dover Air Force Base test well. He and Norman O. Frederiksen critically reviewed the manuscript. Richard N. Benson of the Delaware Geological Survey suggested various editorial improvements to the text of this paper. Lucy E. Edwards and Debra A. Willard, both of the U.S. Geological Survey, were helpful in providing some reference slides of modern pollen for comparison with those found in the Calvert Formation. The encouragement and support by Robert R. Jordan, State Geologist and Director, Delaware Geological Survey, is gratefully acknowledged.

PREVIOUS INVESTIGATIONS

There are no reports on the palynology of the Calvert Formation of Delaware. However, Leopold (1969) mentioned about thirty taxa from the Calvert of Maryland, including several that are now foreign to the middle Atlantic area. Garner (1976) reported on sporomorphs from the formation exposed in cliffs on the west side of Chesapeake Bay and interpreted his pollen assemblages to represent a subtropical vegetation. Goldstein (1974) studied the pollen and spores of the Kirkwood Formation of New Jersey, which is, at least in part, coeval with the Calvert Formation of Delaware and Maryland. He found that *Pinus, Quercus,* and *Carya* were the dominant taxa, and that dinoflagellate cysts were common to abundant. Exotics, generally taxa that now grow in tropical or subtropical regions, were present in most samples but only as minor constituents of the palynoflora. These taxa include *Engelhardia, Platycarya, Magnolia, Melia, Planera, Cyrilla, Gordonia,* and Sapotaceae. Ager (in Owens et al., 1988) reported a *Quercus-Carya-Pinus* assemblage from the Kirkwood, with some *Fagus, Nyssa, Liquidambar, Ulmus, Tilia,* and such exotics as Sapotaceae, *Podocarpus, Pterocarya,* and *Momipites* (*Engelhardia* type).

THE PALYNOFLORA OF THE CALVERT FORMATION IN DELAWARE

In view of the fact that the purpose of this report is to contribute some knowledge to the paleoclimatology and paleoecology of the Calvert Formation, the use of form-generic names for fossil pollen has been avoided as much as possible because such names generally convey little or nothing with regard to their botanical affinity and, therefore, to their paleoecological significance. Most of the pollen encountered can be assigned to extant genera or

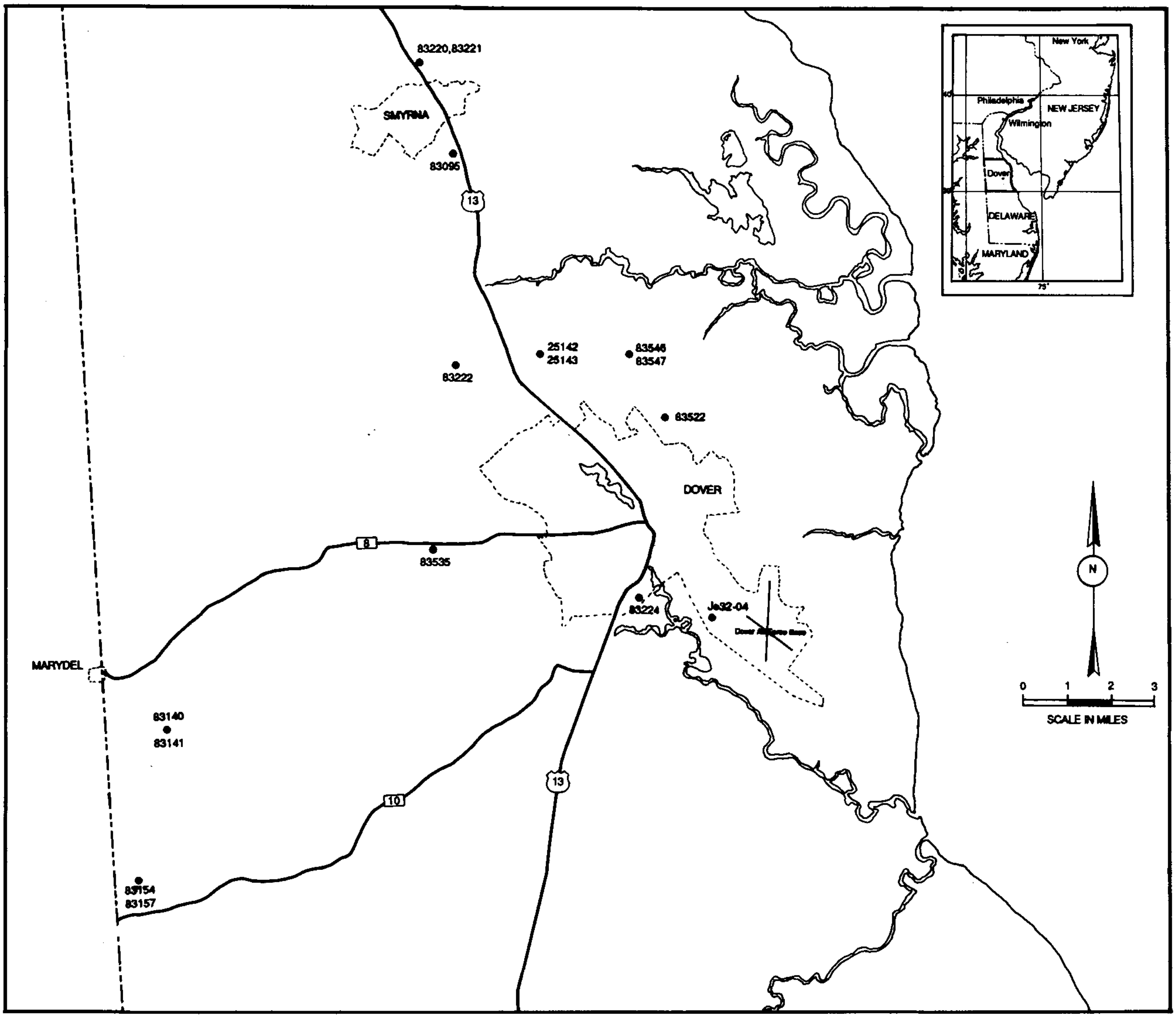

Figure 1. Location of samples used for palynological analyses.

families. Traverse (1988, p. 310) stated "Not until about 20 million years ago (Muller, 1981, personal communication) do all angiosperms encountered belong to extant families. Beginning about 10 million years ago almost all angiosperms were referable to extant genera."

The oldest part of the Calvert Formation in the Dover test well is of late Oligocene age (Benson et al., 1985) approximately 27 or 28 million years before present, and it appears that nearly all pollen grains can be assigned to extant families, and many to extant genera, even if some of the latter no longer occur in the mid-Atlantic coastal area but in subtropical or tropical regions of Central America or elsewhere. However, when perusing the palynological data presented in Table 1 and in Figure 2, it is necessary to exercise some caution in their interpretation. Some of the palynomorphs are illustrated in Plates 1-3.

The category "*Quercus* type" in Table 1 and Figure 2 encompasses many different tricolpate, scabrate pollen grains which probably belong to the Fagaceae, but which are not necessarily all *Quercus*, although many cannot be readily distinguished from Quaternary oak pollen.

The identification of vesiculate pollen grains was hampered by many of them having lost their sacci. In determining the percentages of *Pinus* type pollen, two sacci were counted as one vesiculate pollen. However, with detached sacci it is not possible to distinguish *Pinus* from *Picea, Abies, Cedrus,* and *Podocarpus.* The percentages of these other four genera may therefore be somewhat higher than indicated in Table 1 and Figure 2.

Sequoia type pollen are those with a papilla. They may represent *Sequoia* or another genus of the Taxodiaceae. Inaperturate pollen that split open (*Inaperturopollenites hiatus*) may represent *Taxodium* or *Glypostrobus*(?). They are included in the category TCT (Taxodiaceae-Cupressaceae-Taxaceae).

Momipites, the most common of the exotic taxa, may be *Engelhardia* or another genus of the Juglandaceae, e.g. *Alfaroa.* The next in frequency is *Alangium*(?); the species present in the Calvert is morphologically similar to *Alangium barbatum,* although much smaller.

It appears that the Calvert Formation contains very few reworked pollen, but one grain of *Casuarinidites* and one of

Thomsonipollis were probably derived from Upper Cretaceous or Paleogene deposits.

The assemblages are either dominated by pollen of the Fagaceae (*Quercus* type) or are composed of *Quercus* type, Pinaceae, and *Carya*. These three taxa comprise nearly 80 percent of the palynoflora (excluding dinocysts and "microforams"). Minor elements (in terms of percentages) are *Liquidambar, Nyssa, Ilex, Ulmus, Tilia, Cyrilla,* TCT, and a variety of exotics, subtropical or tropical taxa no longer present in the area of investigation. The commonest of these exotics are *Momipites* (*Engelhardia* type), *Alangium*(?), and Sapotaceae, including *Manilkara.* Exotics that occur in some samples include *Planera, Gordonia, Sequoia* type, *Podocarpus, Cedrus*(?), Palmae(?), and some pollen of unknown affinity. Pollen of herbaceous taxa and spores are either absent or present in very low percentages. Dinocysts have been found in all but six of the 45 samples studied. They range in frequency from less than one percent to twenty percent.

The palynoflora of the Calvert Formation of Delaware is quite similar to that of the Kirkwood formation of New Jersey described by Goldstein (1974) and Ager (in Owens et al., 1988), except that *Platycarya* is reported in the Kirkwood and has not been found in the Calvert of Delaware. The pollen assemblages of the Calvert Formation of Maryland and Delaware also share the same taxa.

The taxa present in the Miocene of Massachusetts (Frederiksen, 1984) are the same as those of the Calvert Formation of Delaware, but they are rather different in the frequencies in which they occur. For instance, the percentage of *Pinus* is twice as large as that of *Quercus* in the Massachusetts Miocene, whereas the opposite prevails in Delaware. Furthermore, the *Picea* percentage is much higher in Massachusetts than in the Delaware Miocene, and *Tsuga* and *Sciadopitys* are very rare. This suggests that there was a definite latitudinal temperature gradient during the Miocene.

ENVIRONMENT OF DEPOSITION

The environment of deposition of the Calvert Formation ranges from marginal marine to outer neritic (Benson et al., 1985). Therefore, all sporomorphs are allochthonous, transported to the site of their deposition by streams and currents, as well as winds. They do not represent local plant communities but reflect the vegetation of an area of unknown size. However, the great majority of the pollen grains probably represents the vegetation of coastal areas. Sporomorphs that are sparse or present only in a few samples may have been derived from vegetation at some distance from the site of deposition, e.g., the Piedmont or the Appalachians; may represent a minor constituent of the vegetation near the shore; or perhaps they were derived from plants producing small quantities of pollen.

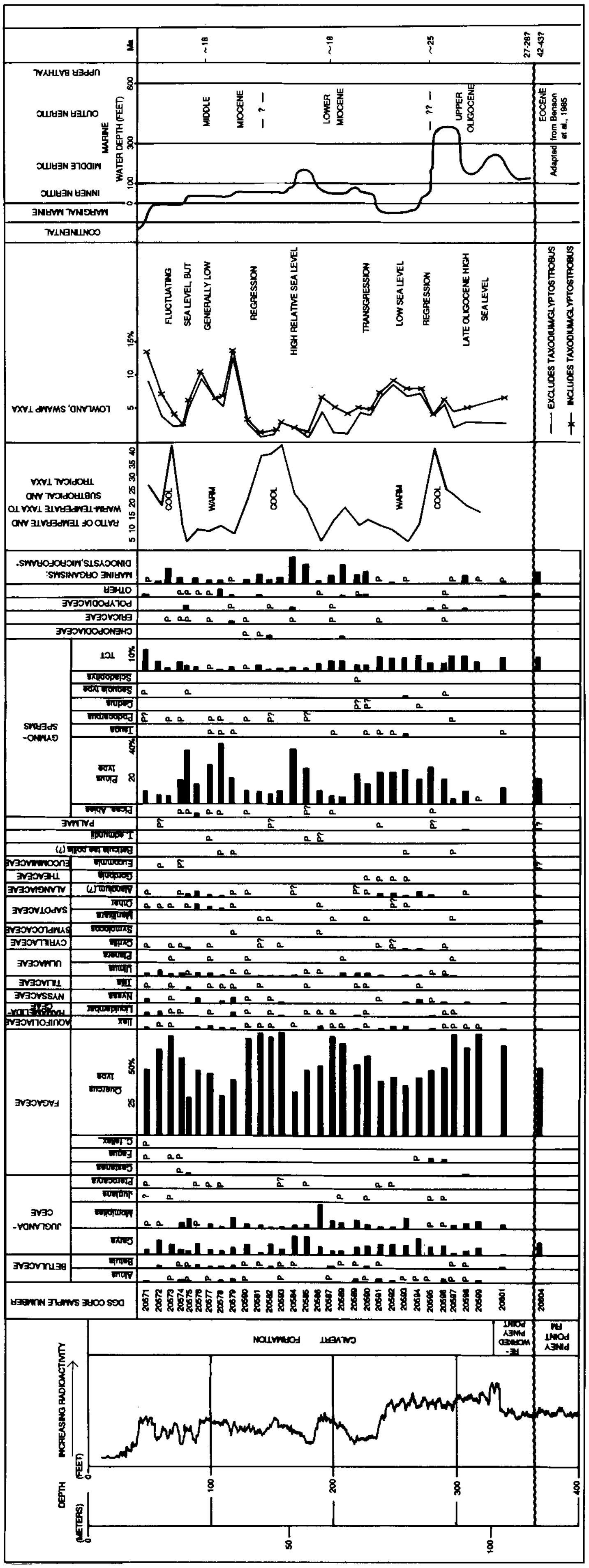

Figure 2. Pollen assemblages of the Calvert Formation in test well Je32-04, Dover Air Force Base.

Table 1.

Pollen assemblages of the Calvert Formation in various test wells in Kent County expressed as percentages of the pollen sum.

			Betulaceae		Juglandaceae				Fagaceae				Aquifoliaceae	Hamamelidaceae	Nyssaceae	Tiliaceae	Ulmaceae		Cyrillaceae	Symplocaceae	Sapotaceae		Alangiaceae	Theaceae	Eucommiaceae	
Sample No.	Well or Outcrop No.	Altitude (ft/m.s.l.)	*Alnus*	*Betula*	*Carya*	*Momipites*	*Juglans*	*Pterocarya*	*Castanea*	*Fagus*	*C. fallax*	*Quercus* type	*Ilex*	*Liquidambar*	*Nyssa*	*Tilia*	*Ulmus*	*Planera*	*Cyrilla*	*Symplocos*	*Manilkara*	Other	*Alangium* (?)	*Gordonia*	*Eucommia*	*T. edmundii*
83220	Hc24-05	+ 24	3	1	8	2		P		2?		55	2	P		P	2			?		P	P			
83221	Hc24-05	+ 12	1		5	2		P	P			56	2	P		P						P				
83095	Hc44-08	+ 3	1	1	5	1						51	1	1	1		1			1		1	P			
25142	Id32-42	+ 15.75		1	12	11						42	4			P										
25143	Id32-42	+ 15	2	P	10	5		1		2?		26	5			P	2									
83222	Ic45-02	+ 16	2	2	4	5		P	P	?	P	63	5	P		P			P			P	P			
83224	Jd24-03	- 5	2	P	3	3		P		P?	P	66				P	P						P	P		
83140	Jb53-02	- 5		P	9	7		P				33	2		2		P						P			
83141	Jb53-02	- 11	4	8	4	20		P		1		22	6		2	1			3	1		1	P		1	
83154	Kb32-28	+ 29		1	31	P	P	1				29	P	7	2							P	P			
83157	Kb32-28	- 23	2	2	4	P						67	P	P		P	P			P?			P			
83546	Id34-02	+ 1	P	P	9	2			P			56	3	P		P						2	P			
83547	Id34-02	- 3	1	3	7	4		P	P			55	5	2		P						P				
83522	Id45-03	- 8	P	2	2	P						41	3		P	2							P			
83535	Jc24-03	+ 28	3	1	11	1				1?		58	5	1		1						1	P			

At present, pollen assemblages in the bottom and suspended sediments of the Delaware estuary clearly represent the regional vegetation of the Delaware River Basin (Groot, 1966). The consistent presence in these sediments of *Tsuga*, common in northern Pennsylvania, is an indication of long distance transport of pollen by water currents. Assuming that in early and middle Miocene time geomorphological conditions were similar to those of the present, it is to be expected that at least some part of the pollen assemblages represents an upland vegetation.

Terrestrial Paleoenvironments and Sea-Level Changes

The vast majority of the palynomorphs found in the Calvert Formation are those produced by taxa that now grow in the Coastal Plain of Delaware and generally thrive in temperate and warm-temperate climates. The fact that *Quercus, Pinus,* and *Carya* were abundant in late Oligocene and Miocene times as well as at present indicates the basic persistence of the vegetation, at least at the generic and family level, with the important exception of the dramatic disruptions during Pleistocene glaciations. However, in addition to these genera, other taxa that now are mainly restricted to the Coastal Plain of Virginia, the Carolinas, and Georgia, or to subtropical and tropical regions, are present in all samples, although in highly variable percentages. These taxa include *Momipites* (*Engelhardia* type), *Alangium*(?), Sapotaceae (including *Manilkara*), *Cyrilla, Planera, Gordonia, Symplocos, Podocarpus, Sequoia* type, *Taxodium* or *Glyptostrobus,* and Palmae(?).

Genera that grow in or on the border of swamps or streams in temperate, subtropical, or tropical regions include *Alnus, Ilex, Liquidambar, Nyssa, Planera, Cyrilla, Symplocos, Gordonia,* and *Taxodium* or *Glyptostrobus.*

Momipites may represent mainly *Engelhardia.* If so, does it indicate a moist subtropical upland habitat or a lowland swamp environment? At present, *Engelhardia* lives mainly in the mountains of subtropical and tropical regions, but in the Paleogene it was abundant in lowland peat swamps of North and Central America and in Europe (Frederiksen, 1985). It is possible that during the Miocene *Momipites* occurred in both these environments.

If *Momipites* represents *Engelhardia* growing in or around swamps, low frequencies of this taxon would be expected at times of relatively high sea levels, and high percentages at intervals of low sea levels. However, the percentages of *Momipites* do not appear to be related to those of other wetland genera, or to transgressions and regressions. This lack of a clear relationship suggests that

Palmae (?)	Gymnosperms								Herbs, Ferns				Dinocysts plus Microforams*	Ratio of temperate and warm-temperate to subtropical and tropical taxa	Wetland taxa(%)	Paleoenvironmental Interpretation		Remarks
	Picea, Abies	*Pinus* type	*Tsuga*	*Podocarpus*	*Cedrus*	*Sequoia* type	*Sciadopitys*	TCT	Chenopodiaceae	Ericaceae	Polypodiaceae	Other				Climate	Sea Level	
		7	P	P		P	?	15					P	21.8	5.5	cool	medium	
P		6						19			2	1		25.4	3.5	cool	high	
1		6				1		21	1		1	4	2	16.8	5.0	medium	medium	
		25						3				2	20	5.1	4.0	warm?	high	High percentages of *Momipites*
		38						3			P	3	19	8.2	7.0	warm	medium	
P		7	P					2			P	1	2	11.1	8.0	warm	low	
		5				P		14		P		P	P	17.2	2.0	cool	high	
		37	P	P		P		6				P	P	6.1	4.0	warm	medium	
		22						4				2		1.3	16.0	warm?	low	very high percentages of *Momipites*
		26		P				P				P		46.3	9.5	very cool	low	
P		8						11			2		P	36.0	3.5	cool	high	
		16						4			2		6	15.2	4.0	medium	medium	
		18						3			1		1	15.3	8.0	medium	low	
		44		P				P			2	1	P	46.5	4.0	very cool	high	
		10						7					4	30.0	9.0	cool	low	

* as a percentage of the pollen sum

Momipites represents an upland vegetation, as *Engelhardia* does at present. For this reason, *Momipites* has not been included in the frequencies of wetland genera.

Relatively high percentages of wetland genera suggest the presence of a low, flat coastal plain and, consequently of a relatively low sea level; very low percentages are interpreted as an indication of very little coastal plain and a high sea level. High sea levels are suggested in the late Oligocene-earliest Miocene and in late early Miocene time. High sea levels also are indicated by high (up to 20% of the pollen sum) frequencies of dinocysts. A low sea level is indicated in the early part of the early Miocene. Fluctuating, but generally low sea levels characterized most of the middle Miocene.

Figure 2 shows a water-depth curve prepared by Benson (Benson et al., 1985, Plate 2). These water depths "...should not be taken literally..." but "...provide some magnitude of the range of water depth..." (Benson et al., 1985, p. 49). This curve suggests high sea levels in the late Oligocene and the late early Miocene; it indicates low sea levels in early early Miocene and most of middle Miocene times. Thus, there is a general agreement regarding the occurrences of transgressions and regressions interpreted from two entirely different sets of data: palynomorphs of continental provenance, and marine organisms (radiolarians, foraminifers, and dinocysts). Haq et al. (1987) indicated a world-wide transgression in the earliest Miocene, about 25 Ma ago, a regression about 21 Ma ago, another transgression 20 to 17 Ma before present, followed by a general regressive trend, with fluctuations, for the remainder of the middle Miocene. Their interpretation of global sea-level changes is not different from that based on the palynological evidence from Delaware, considering the limits of accuracy of the chronology.

Paleoclimate

The dominance of *Quercus* type pollen and the generally high percentages of *Pinus* and *Carya* indicate that oak, pine, and hickory were important components of the coastal vegetation. Assuming that the climatic requirements of these genera are not very different from those of the present, a temperate or warm-temperate climate is indicated. However, the persistent presence (although mostly in low percentages) of taxa that now grow in subtropical or tropical regions and the paucity of cold-climate indicators show that the climate during deposition of the Calvert

Formation was warm-temperate or subtropical and moist, probably similar to that which now prevails in the coastal region of Georgia or northern Florida. The diversity and abundance of the palynoflora representing trees and shrubs and the near absence of pollen of herbs suggest a dense forest growing right up to the coast.

In order to determine whether or not the palynological record indicates changes in climate during the deposition of the Calvert Formation, the ratio of temperate-warm temperate taxa to subtropical-tropical taxa was determined for each sample investigated. The former include *Carya, Quercus, Liquidambar, Nyssa,* and *Ilex,* and the latter *Momipites, Cyrilla,* Sapotaceae and *Alangium*(?). High ratios occur where *Quercus* frequencies are high and subtropical-tropical taxa are present in low percentages. Thus, high ratios indicate relatively cool intervals, and low ratios warm intervals.

A curve connecting these ratios is shown in Figure 2. During high sea-level stands these ratios are generally high, suggesting a relatively cool climate, and during low sea-level stands the ratios are low, indicating a warmer climate. However, if sea-level fluctuations were eustatically controlled owing to changes of ice volumes in Antarctica, the opposite might be expected, assuming that climate changes in the southern and northern hemispheres would be contemporaneous and of the same tendency.

It is possible that the different percentages of subtropical and tropical genera do not indicate climate changes but changes in the provenance of the palynomorphs. During times of high sea level many pollen grains were derived from the vegetation of the Piedmont and perhaps from the Appalachians, regions of higher elevation than the Coastal Plain and, therefore, a little cooler and with fewer subtropical or tropical plants. During intervals of low sea level the Coastal Plain vegetation would be the main contributor of palynomorphs and produce more pollen from subtropical or tropical taxa.

SUMMARY AND CONCLUSIONS

The plant microfossils of the Calvert Formation of Delaware indicate the preponderance of temperate and warm-temperate taxa (*Quercus, Pinus,* and *Carya*), but also the consistent presence of taxa representing a subtropical or tropical vegetation, e.g., *Momipites,* Sapotaceae, and *Alangium*(?). These assemblages indicate a climate similar to that now prevailing in the Coastal Plain of Georgia or Florida.

Differences in the frequencies of pollen representing a wetland vegetation are interpreted in terms of transgressions and regressions. The sea-level changes indicated by palynomorph assemblages of continental provenance, by marine organisms (Benson et al., 1985), and by seismic stratigraphy (Haq et al., 1987) appear to coincide within the limits of accuracy of the chronology.

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PLATES 1-3

Selected pollen taxa from the Calvert Formation

PLATE 1

Figure

1.	*Podocarpus*	Sample 20581	120.8 x 29.1[1]	70μ
2.	*Cedrus*?	Sample 20590	124.5 x 23.1	74μ
3.	T.C.T.	Sample 20597	125.2 x 38.9	31μ
4.	T.C.T.	Sample 20590	125.5 x 19.1	25μ
5.	*Sciadopitys*	Sample 20589	125.2 x 32.3	40μ
6.	*Sequoia* type	Sample 83140(1)	123.8 x 30.8	23μ
7.	*Alnus*	Sample 20571	123.6 x 31.8	20μ
8.	*Betula*	Sample 20571	126.1 x 32.8	20μ
9.	*Myrica*	Sample 20597	123.9 x 30.5	20μ
10.	*Carya*	Sample 20574	122.7 x 35.0	38μ

[1] Coordinates (Leitz microscope)

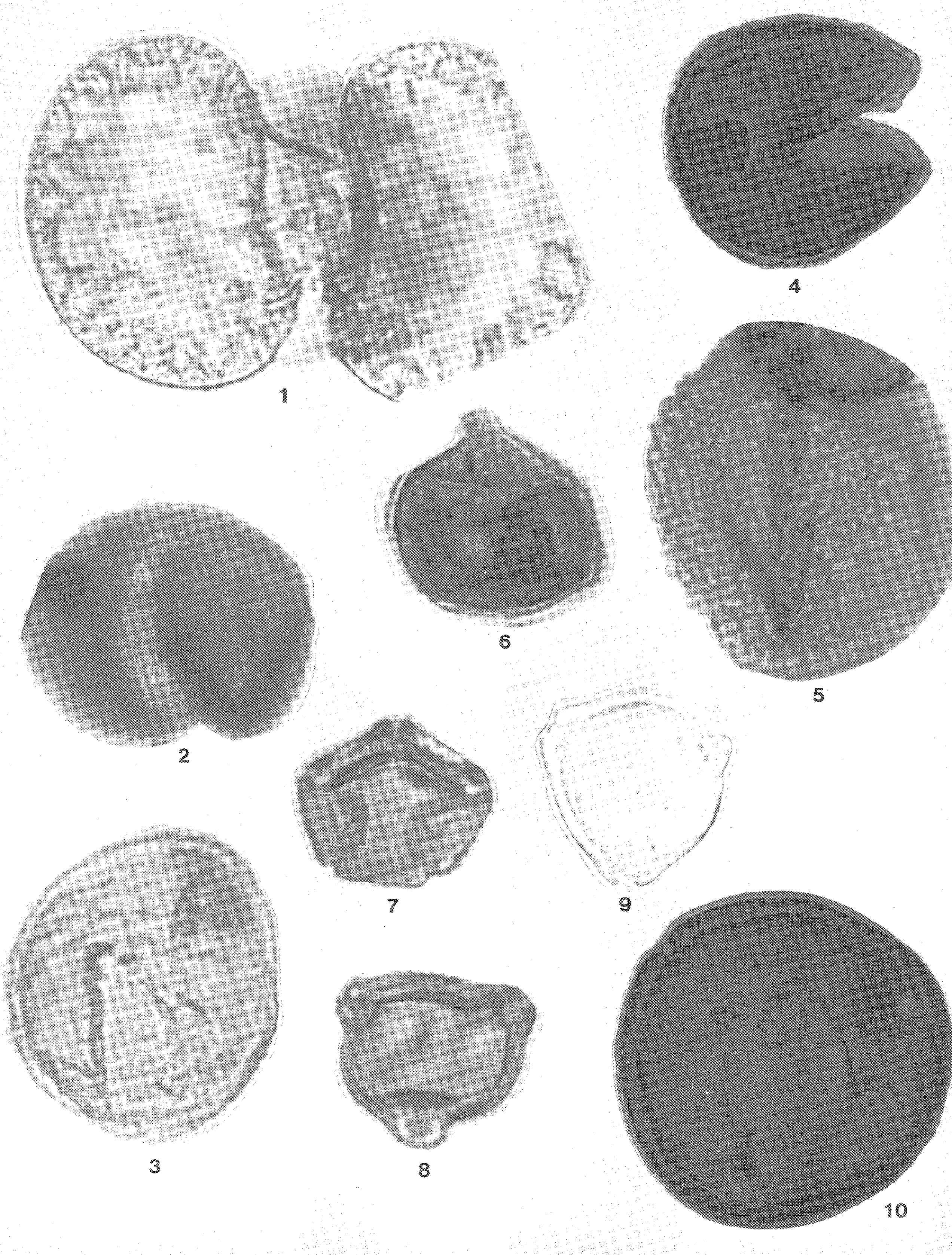
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PLATE 2

Figure				
1.	*Pterocarya*	Sample 20571	123.3 x 30.5	28μ
2.	*Momipites*	Sample 20574	125.5 x 24.0	24μ
3.	*Momipites*	Sample 20574	127.0 x 42.0	19μ
4.	*Quercus* type	Sample 83222	123.2 x 43.1	18x12μ
5.	*Quercus* type	Sample 83157	127.0 x 28.3	23x15μ
6.	*Quercus* type	Sample 83222	121.8 x 42.9	25x18μ
7.	*Ilex*	Sample 20593	123.2 x 30.2	28x23μ
8.	*Liquidambar*	Sample 20571	123.3 x 26.4	30μ
9.	*Tilia*	Sample 20575	127.2 x 37.3	38μ
10.	*Ulmus*	Sample 20571	122.8 x 37.9	24μ
11.	*Planera*	Sample 20577	120.2 x 32.6	27μ
12.	*Cyrilla*	Sample 20575	126.0 x 27.3	15μ
13.	*Cyrilla*	Sample 20577	125.2 x 38.4	20μ

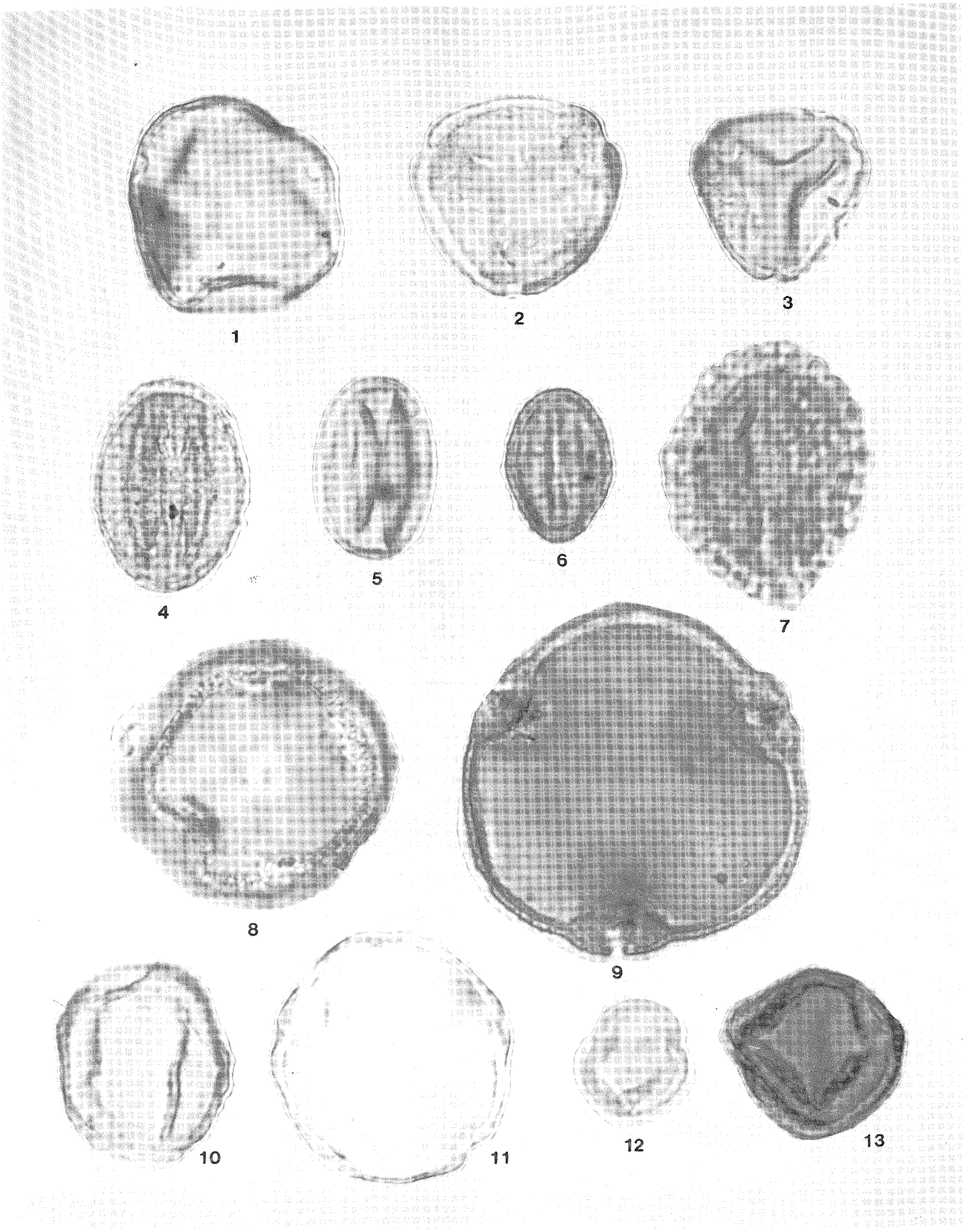
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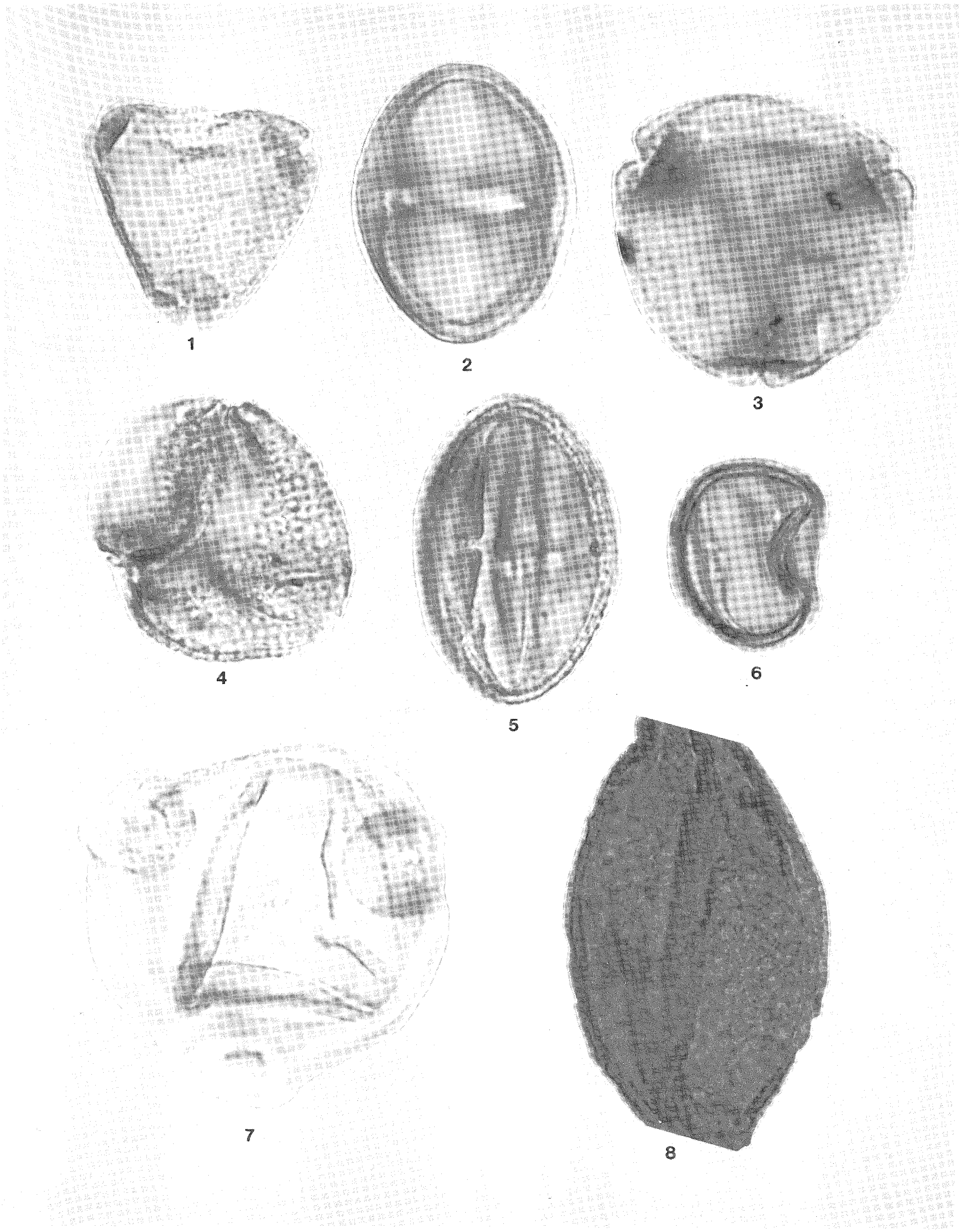
PLATE 3

Figure				
1.	*Symplocos*	Sample 20579	124.0 x 26.3	27μ
2.	*Manilkara*	Sample 20577	127.8 x 38.2	33x25μ
3.	*Alangium*(?)	Sample 83095	118.0 x 49.2	34μ
4.	*Gordonia*	Sample 20590	126.2 x 40.3	32μ
5.	*Tricolporopollenites edmundii*	Sample 20577	122.4 x 29.8	35x23μ
6.	*Eucommia*	Sample 20574	125.7 x 23.2	23x18μ
7.	Onagraceae	Sample 20578	124.9 x 31.9	40μ
8.	*Liriodendron*	Sample 20576	125.2 x 19.5	55μ



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