PALEOENVIRONMENTAL ANALYSES OF THE KIRKWOOD FORMATION

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ABSTRACT

Palynological analyses were made on 200 samples of the Kirkwood Formation from 7 wells and 3 outcrop localities to determine the environments of deposition and climatic conditions that prevailed during its deposition.

The Kirkwood Formation consists of three surface members: the Asbury Park, Grenloch Sand and Alloway Clay. Five subsurface phases, identified and described in this study are correlated with the Early Miocene Tampa and Hawthorn Formations of South Carolina, Georgia, and Florida, and the Middle Miocene Calvert, Choptank and St. Marys Formations of Maryland, Delaware and Virginia. The Asbury Park, Grenloch Sand and Alloway Clay Members are correlated with the subsurface Calvert Phase on the basis of their palynological assemblages.

Paleobathymetric interpretations of the surface and subsurface facies of the Kirkwood Formation are made on the basis of their pollen, spore, dinoflagellate, diatom, silicoflagellate and radiolarian assemblages. These assemblages indicate nearshore environments of deposition for the Asbury Park, Grenloch Sand and Alloway Clay Members and transgressive and regressive sequences in the Tampa, Hawthorn, Calvert and St. Marys Phases.

Paleoclimatic interpretations, made on the basis of _Pinus/Picea_ ratios and changes in the regional microfloras indicate that the Asbury Park, Grenloch Sand and Alloway Clay

were deposited during a period of climatic deterioration from subtropical to temperate conditions. A period of climatic deterioration from subtropical to temperate conditions is indicated to have taken place during the deposition of the Tampa, Hawthorn and lower portion of the Calvert Phase. A period of climatic amelioration is indicated during the deposition of the upper part of the Calvert Phase and throughout the deposition of the Choptank Phase. A second period of climatic deterioration is indicated to have taken place during the deposition of the St. Marys Phase.

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PREVIOUS PALEOENVIRONMENTAL STUDIES

Paleoenvironmental interpretations of the surface samples of the Kirkwood Formation have been made by several authors on the basis of paleontological, sedimentological and mineralogical studies.

Isphording and Lodding (1970 and 1973) determined the kaolinite, illite and montmorillonite content of the Asbury Park Member and concluded that it was deposited in transitional marine environments such as marshes, lagoons or estuaries.

Richards and Harbison (1942) studied the molluscan faunas of the Shiloh Marl facies of the Alloway Clay Member and placed it in the middle neritic environment of deposition.

Isphording and Lodding (1973) reported that the Macro-kaolinite Zone of the Alloway Clay was deposited in either a lagoon, swamp or estuary that received large amounts of runoff.

Paleoclimatic interpretations of the Kirkwood Formation have been reported by Isphording (1970) and Isphording and Lodding (1973). They reported that the surface members of the Kirkwood Formation were deposited under warm, moist climatic conditions. Their interpretations were based on heavy mineral, light mineral and clay mineral suites.

Prior to the present study, paleobathymetric and paleo-climatic interpretations had not been reported on the alternating sands and clays of the Kirkwood Formation in the subsurface.

Paleonvironmental interpretations of the Kirkwood Formation in the present study are made on the basis of microfossils recovered from 200 samples from 7 wells and 3 outcrop localities. Included in these assemblages are pollen, spores, silicoflagellates, radiolaria, dinoflagellate cysts, diatoms and foraminiferal test linings.

Paleobathymetric interpretations are based on spore/dinoflagellate ratios as well as relative frequency distributions of continental and marine palynomorphs. In general, spore/dinoflagellate ratios decrease from transitional to nearshore and offshore deposits (Dunay 1969).

Previous palynological studies of other Tertiary formations of North America are limited in that their assemblages are often exclusively marine or continental. Continental assemblages are limited in that they provide short term discontinuous records of the vegetative history of the area. These assemblages often represent the flora of a limited area in the immediate area of the deposit (Groot and Groot 1966). Thus it is difficult to ascertain long term climatic fluctuations from these assemblages.

An additional problem has been the correlation of previously described, isolated palynological assemblages. The latitudinal zonation of the tundra, boreal, mixed deciduous and deciduous plant communities across North America is well documented (Potzger and Otto 1943, Goodlet 1954, Graham 1963, Davis 1969 and Elsik 1969). Because of this latitudinal zonation it is virtually impossible to correlate the continental Miocene deposits of British Columbia as reported by Piel (1969) for example with those of Louisiana as reported by Elsik (1969) on the basis of palynological assemblages alone.

Exclusively marine palynological assemblages are limited in that the asaccate paleoclimatical indicators that appear in abundance in continental assemblages are often rare to absent in marine assemblages (Dunay 1969).

Because of the absence of asaccate grains in offshore assemblages, paleoclimatic interpretations should be made on the basis of the relative frequencies of arboreal forms that produce bisaccate grains and whose distributions in modern floras are controlled by climatological factors. Paleoclimatic interpretations in this study are based on *Pinus*/*Picea* ratios as well as overall changes in the regional floras.

Modern species of *Pinus* are included in the floras of many regions throughout North America (Munn 1938, Braun 1950, Fernald 1950 and Collingwood and Brush 1964). Associated forms, including *Taxus* and *Taxodium* indicate that the species of *Pinus* that are present in palynological assemblages of the Kirkwood Formation probably had climatic tolerances and ecologic requirements similar to modern species of *Pinus* that are now included in the native floras along the Gulf Coastal Plain and the southern portion of the Atlantic Coastal Plain. These forms include *Pinus echinata* Miller, *Pinus palustris* Miller, *Pinus ellioti* Engelm, *Pinus taede Linneaus*, *Pinus* *serotina* Michaux, *Pinus virginia* Miller and *Pinus glabra* Walter (Fernald 1950 and Collingwood and Brush 1964).

Modern species of *Picea* closely follow the 10°C average July isotherm on their northern boundaries and the 23°C isotherm on their southern boundaries (Wolfe and Leopold 1967). *Picea rubens* Sargent and *Picea mariana* (Miller) are major elements of the modern floras from northern New England to the Yukon territory (Collingwood and Brush 1964). Pollen grains of these species very closely resemble the *Picea* grains that are encountered in palynological assemblages of the Kirkwood Formation. Other occurences of *Picea* in the modern floras of North America include the appearances of *Picea sitchensis* (Bongard) Carriere and *Picea breweriana* Watson in the modern flora of the Coastal Ranges from northern California to Alaska and *Picea pungens* Engelmann and *Picea engelmanni* Perry on the higher slopes of the Northern Rockies (Munn 1938, Braun 1950, Fernald 1950 and Collingwood and Brush 1964).

Increasing *Pinus/Picea* ratios in Quaternary floras indicate warming conditions. Decreasing *Pinus/Picea* ratios indicate cooling conditions (Davis 1967).

The Kirkwood Formation consists of four alternating marine and terrestrial facies in the subsurface. Widely spaced sections are correlated with each other on the basis of their palynological assemblages. Thus a continuous regional paleoenvironmental analysis may be made from samples of the Kirkwood Formation.

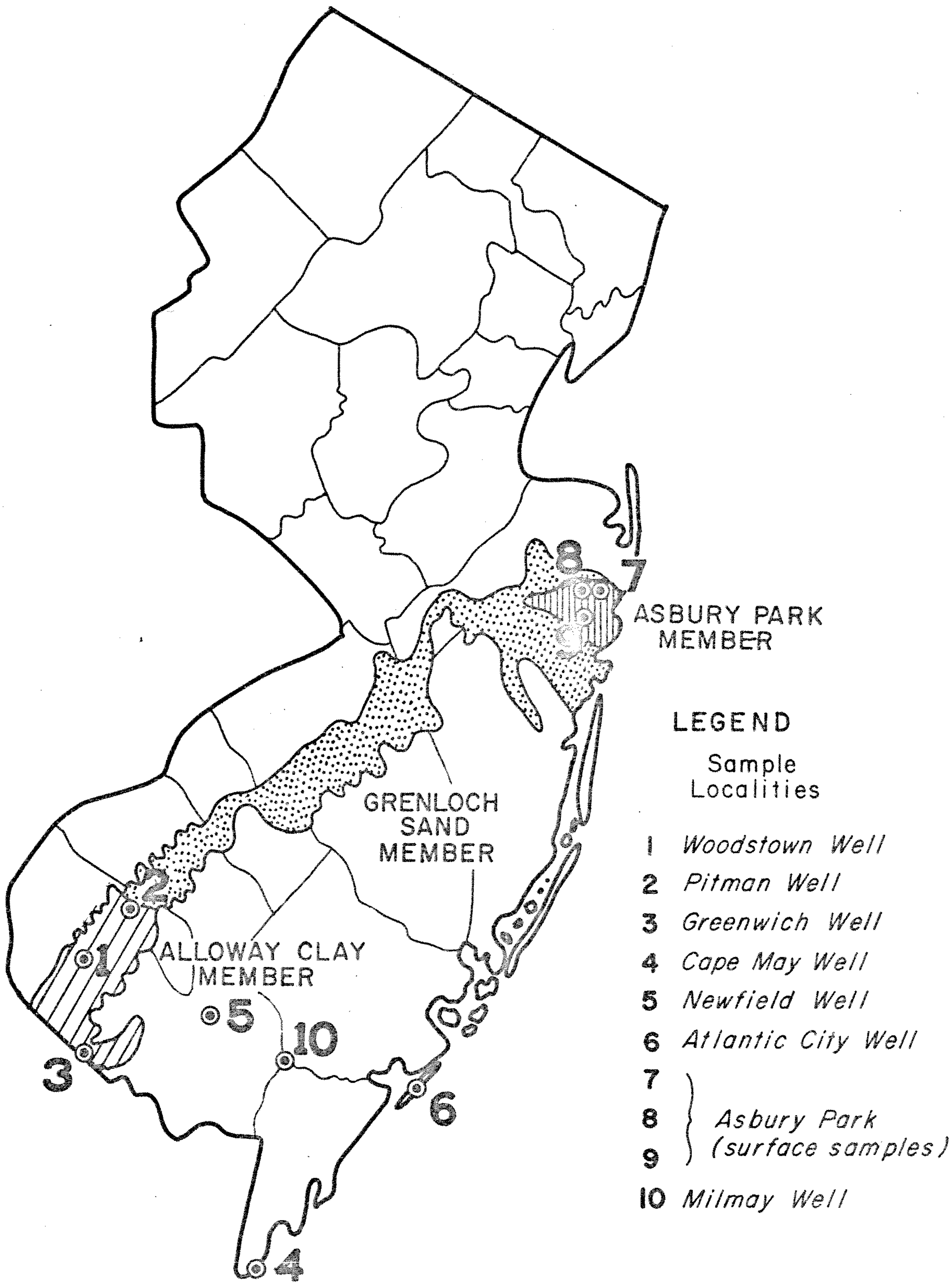

Figure 1: Outcrop map of the Kirkwood Formation including sample locations of the present study

STRATIGRAPHY OF THE KIRKWOOD FORMATION

The Kirkwood Formation outcrops in a northeast to southwest trending belt on the New Jersey Coastal Plain. The formation dips 10 to 25 feet per mile below the overlying Cohansey Formation (Barksdale 1958). The Kirkwood Formation unconformably overlies the Shark River and Manasquan Formations (Eocene) (Richards 1945 and Owens and Sohl 1973). The maximum outcrop thickness is 100 feet. The formation thickens to 790 feet in the subsurface at Atlantic City (Barksdale 1958).

The Kirkwood consists of three members, the Asbury Park, Grenloch Sand and Alloway Clay.

The Asbury Park Member outcrops in Monmouth County (Fig. 1). It consists of dark brown, often finely laminated, silty sands and micaceous clays.

The Alloway Clay outcrops in Cumberland, Gloucester and Salem Counties (Fig. 1). The clay is light brown in outcrop and dark brown to gray in the subsurface. The upper beds of the Alloway Clay near Shiloh, New Jersey are locally called the Shiloh Marl. In the vicinity of Woodstown, New Jersey, the illite and montmorillonite near the base of the Alloway Clay have been diagenetically altered to form a "macro-kaolinite zone" (Isphording and Lodding 1970 and 1973). This unit seems to be unique in the geological literature. It had for many years been mistakenly referred to as "micaceous talc-like clay" (Ries and Kummel 1904).

The Grenloch Sand is the largest of the three members in areal extent. It outcrops in portions of Monmouth, Ocean, Burlington, Camden, Gloucester and Salem Counties (Fig. 1). This member overlies and is interlayered with the Asbury Park Member to the northeast and the Alloway Clay Member to the southwest (Fig. 2). In outcrop the Grenloch Sand Member consists of fine yellow and orange sands. In the subsurface the sands are interlayered with silts and clays.

The Asbury Park, Grenloch Sand and Alloway Clay are easily recognizable in outcrop, but rapidly lose their identities downdip and cannot be differentiated lithologically in deep wells (Isphording and Lodding 1970).

In the present study subsurface sections of the Kirkwood Formation are divided into five biostratigraphic units. Units I and II are encountered in deep well sections from Greenwich, Newfield, Milmay and Cape May (Figs. 12-16). Unit I consists of gray silty clays and varies in thickness from 50 feet at Greenwich to 70 feet at Cape May. Unit II consists of gray to brown silty clays and varies in thickness from 25 feet at Greenwich to 60 feet at Cape May. Units III, IV and V are encountered in sections from Greenwich, Newfield, Milmay, Atlantic City and Cape May (Figs. 12-16). Unit III consists of alternating sands and clays and varies in thickness from 45 feet at Greenwich to 220 feet at Cape May. Unit IV consists of sands and clays and varies in thickness from 20 feet at Greenwich to 150 feet at Cape May. Unit V consists of alternating sands and silts and varies in thickness from 40 feet at Greenwich to 200 feet at Cape May.

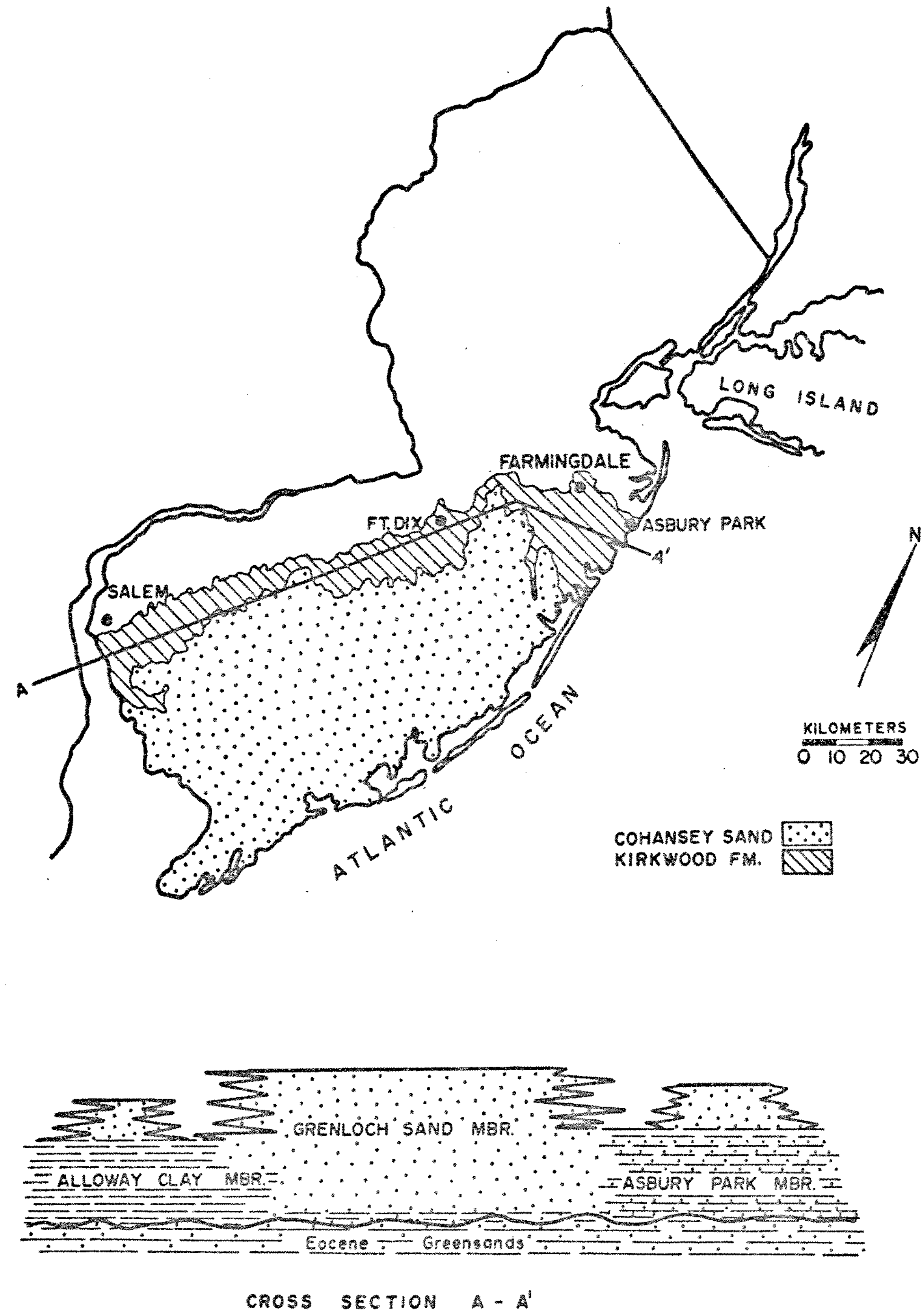

Figure 2: Facies relationships of the Asbury Park, Grenloch Sand and Alloway Clay Members of the Kirkwood Formation

RESULTS OF PALYNOLOGICAL ANALYSES OF THE SURFACE MEMBERS OF THE KIRKWOOD FORMATION

Palynological assemblages of the Asbury Park Member are dominated by nonarboreal palynomorphs including those of Chenopodiaceae, Ericaceae and Gramineae. Spores of lower vascular plants including Equisetum are abundant in most samples. Arboreal associates include Alnus, Betula, Castanea, Corylus, Cyrilla, Fagus, Juniper, Liquidambar, Picea, Pinus, Quercus, and Taxodium. Aquatic elements include dinoflagellates, diatoms and silicoflagellates. The diatom, Actinoptychus heliopelta Grunow and the dinoflagellate, Deflandrea are present in samples collected from Farmingdale, Hammonton and Howell.

Surface samples of the Grenloch Sand are void of pollen, spores, silicoflagellates, diatoms, radiolarians, dinoflagellate cysts and foraminiferal test linings. Palynological residues of the Grenloch Sand consist of highly oxidized fragments of plant tissues.

Palynological assemblages of the Alloway Clay Member are dominated by arboreal pollen grains. Pinus, Picea, Quercus, Carya, Juniper, Fagus, Acer and Taxodium are the dominant forms. Nonarboreal palynomorphs including members of Chenopodiaceae, Ericaceae and Gramineae are present in the upper portion of this member. Aquatic elements consisting primarily of large dinoflagellate cysts, including Hystrichokolpoma and foraminiferal test linings become less abundant in the upper part of the section. Palynological assemblages of the "macrokaolinite zone" consist almost exclusively of *Pinus* grains. Marine, nonarboreal and arboreal forms including *Picea*, *Quercus*, *Carya* and *Tilia* are rare in these assemblages.

RESULTS OF PALYNOLOGICAL ANALYSES OF THE SUBSURFACE PHASES OF THE KIRKWOOD FORMATION

Subsurface sections of the Kirkwood Formation may be divided into five biostratigraphic units on the basis of their palynological assemblages. Units I and II are encountered in deep well sections from Greenwich, Newfield, Milmay and Cape May (Fig. 1). Units III, IV and V are encountered in sections from Greenwich, Newfield, Milmay, Atlantic City and Cape May (Fig. 1).

Palynological assemblages in the lower portion of Unit I are dominated by large dinoflagellate cysts including those of *Hystrichokolpoma*. *Pinus*, *Quercus* and *Carya* are the dominant arboreal forms throughout these assemblages. *Alnus*, *Betula*, *Castanea*, *Corylus*, *Cyrilla*, *Ilex*, *Nyssa*, *Platycarya*, *Pterocarya*, *Salix*, *Taxodium* and *Taxus* are minor arboreal constituents. Frequencies of nonarboreal elements including members of Chenopodiaceae, Ericaceae and Gramineae generally increase in the upper part of the section.

Palynological assemblages of the lower portion of Unit II are dominated by small spiny dinoflagellate cysts including forms closely resembling modern species of *Micrhystridium*. Arboreal and nonarboreal elements are similar in composition and distribution to those of Unit I.

Pinus, *Quercus*, *Carya* and dinoflagellate cysts dominate the palynological assemblages of Unit III. Frequencies of dinoflagellate cysts decrease in the upper part of the section with small spiny forms becoming relatively more abundant. The first major influxes of *Picea* and Gramineae occur in this unit. Minor arboreal elements include *Alnus*, *Betula*, *Castanea*, *Corylus*, *Cyrilla*, *Ephedra*, *Fagus*, *Ilex*, *Liquidambar*, *Magnolia*, *Melia*, *Nyssa*, *Platanus*, *Platycarya*, *Salix*, *Taxodium*, *Taxus* and *Tilia*. Nonarboreal forms including high frequencies of Gramineae and unidentified spores of lower vascular plants increase in the upper portion of Unit III. Foraminiferal test linings, radiolarians, diatoms and silicoflagellates including *Corbisema* and *Dichtyocha fibula* are abundant in the lower portion of this unit.

Palynological assemblages of Unit IV are dominated by *Quercus*, *Pinus* and *Carya*. Other arboreal forms include *Alnus*, *Betula*, *Castanea*, *Corylus*, *Cyrilla*, *Engelhardtia*, *Fagus*, *Juglans*, *Nyssa*, *Salix*, *Taxodium*, *Tilia* and *Ulmus*. Relative frequencies of *Picea* decrease in the upper portion of this unit. *Picea* completely disappears in the upper portion of this unit from assemblages taken from Greenwich, Milmay and Atlantic City. Nonarboreal elements including Chenopodiaceae, Ericaceae, Gramineae and spores of lower vascular plants are abundant in the central portion of this unit. Marine forms consisting primarily of small, spiny dinoflagellate cysts first decrease and then increase in the upper portion of the section.

Palynological assemblages of Unit V are dominated by *Pinus*, *Quercus* and *Carya*. Minor arboreal constituents include *Acer*, *Alnus*, *Betula*, *Castanea*, *Corylus*, *Cyrilla*, *Fagus*,

<u>Juglans</u>, <u>Liquidambar</u>, <u>Magnolia</u>, <u>Nyssa</u>, <u>Pterocarya</u>, <u>Prunus</u>, <u>Taxodium</u>, <u>Tilia</u> and <u>Ulmus</u>. <u>Picea</u> appears in low frequencies in lower portions of this unit and increases in the upper levels. The first appearance of <u>Abies</u> is noted in this unit in samples taken from Greenwich, Newfield, Atlantic City and Cape May. Nonarboreal elements including members of Chenopodiaceae, Ericaceae, Gramineae, spores of lower vascular plants, leaf hairs and Sparangium are abundant in the upper portion of this unit. The first appearance of Compositae is noted in assemblages from Greenwich, Milmay, Atlantic City and Cape May. Marine elements consisting primarily of dinoflagellate cysts generally decrease with smaller forms becoming relatively more abundant than larger forms in the upper portion of the unit.

Percentage frequency histograms of the palynological analyses are presented in Appendix II.

PALEOENVIRONMENTAL INTERPRETATIONS OF THE SURFACE MEMBERS OF THE KIRKWOOD FORMATION

Palynological assemblages of the Asbury Park Member include high frequencies of Chenopodiaceae and Ericaceae. Modern species of Chenopodiaceae are found in sandy waste soils. The phreatic waters of these soils are often saline or brackish (Fernald 1950). Modern species of Ericaceae are often found in peaty clearings and along the margins of bogs (Fernald 1950).

The dinoflagellate, *Deflandrea*, a common form in modern nearshore brackish water assemblages, is included in several palynological assemblages of the Asbury Park Member.

The association of members of Chenopodiaceae and Ericaceae with dinoflagellate cysts indicates a coastal brackish water environment of deposition similar to that reported by Martin and Rouse (1966) from the Oligocene deposits of the Queen Charlotte Islands of British Columbia.

Pinus/*Picea* ratios ranging from 7/1 to 10/1 and the presence of *Taxodium* in palynological assemblages of the Asbury Park Member indicate that these sediments were deposited under subtropical climatic conditions. Modern species of *Taxodium* are found in the native floras of the Gulf Coastal Plain and the southern portion of the Atlantic Coastal Plain (Fairchild and Elsik 1968, Fredrickson 1969, Stewart 1971 and Tschudy 1973).

Surface samples of the Grenloch Sand are void of micro-paleontologic remains with the exception of highly oxidized fragments of maceral tissues. The association of these oxidized macerals along with the relatively coarse texture of these deposits indicates a high energy, possibly littoral, environment of deposition for the Grenloch Sand Member.

Palynological assemblages of the Alloway Clay Member are characterized by decreasing frequencies of large dino-flagellate cysts and the presence of nonarboreal forms in the upper portion of the unit. These assemblages, including high frequencies of planktonic foraminiferal test linings in the lower portion of the unit, indicate a middle neritic environment of deposition becoming more shallow, possibly to inner neritic, during the final stages of its deposition (Wall 1965, Groot and Groot 1966 and Davey 1970a).

Decreasing Pinus/Picea ratios from 9/1 to 6/1 and the presence of modern subtropical forms including Taxodium in the lower portion of the Alloway Clay indicate that climate deteriorated during the deposition of this unit. It appears that the subtropical conditions that prevailed during the deposition of the lower portion of this member gave way to temperate conditions during the deposition of its upper portion, the Shiloh Marl. Increasing Pinus/Picea ratios indicate a warming trend during the final stages of the deposition of the Shiloh Marl. The presence of Taxus, limited in modern assemblages to the southern portion of Florida, in the uppermost horizon of the Shiloh Marl at

Pitman, New Jersey supports the warming trend interpretation suggested by the *Pinus*/*Picea* ratios.

The apparent lack of arboreal grains other than *Pinus* in palynological assemblages of the Macrokaolinite Zone of the Alloway Clay has been explained by Isphording and Lodding (1973) to be the result of the diagenesis that produced the macrokaolinite. They reasoned that the other pollen grains that were present in the Macrokaolinite Zone were dissolved during the diagenesis while the hardier *Pinus* varieties were unaffected. This seems not to be the case because, although rare, well preserved grains produced by *Carya*, *Picea*, *Quercus* and *Tilia* are present in these assemblages.

It is more probable that the predominance of *Pinus* is due to its anemophilous form of dispersal and the relatively large quantities of pollen that each pine tree produces. In modern palynological assemblages in the general vicinity of pine forests, frequencies of *Pinus* are over-represented from their actual numbers by a factor of from 6.6 to 1 to 22.4 to 1 (Davis, Brubaker and Beiswenger 1971).

Palynological assemblages of the Macrokaolinite Zone are similar in composition to modern assemblages of pine swamps along the southern New Jersey to Virginia coasts.

PALEOENVIRONMENTAL INTERPRETATIONS OF THE SUBSURFACE PHASES OF THE KIRKWOOD FORMATION

Palynological assemblages of the lower portion of Unit I are dominated by large dinoflagellate cysts and foraminiferal test linings. These assemblages indicate a middle neritic environment of deposition (Wall 1965). Frequencies of nonarboreal elements generally increase in the upper part of the section indicating shoaling conditions during the deposition of the upper horizons (Davey 1970a).

Pinus/Picea ratios greater than 100/1 and the presence of Platycarya, Pterocarya, Taxodium and Taxus in palynological assemblages of Unit I indicate deteriorating subtropical conditions during the deposition of this unit. Modern species of Platycarya, Pterocarya, Taxodium and Taxus are indigenous to subtropical and tropical areas of Asia and North America (Fernald 1950 and Kapp 1969).

Palynological assemblages of Unit II are similar in their overall composition to those of Unit I. Dinoflagellate cysts dominate the lower assemblages and then decrease in the upper assemblages as they do in Unit I; however the cysts of Unit II are smaller and contain more spines than do the cysts of Unit I. Also the foraminiferal test linings are less abundant in Unit II than they are in Unit I. These assemblages indicate a shoaling inner neritic environment of deposition (Wall 1965).

Pinus/*Picea* ratios vary from 50/1 to greater than 100/1 in Unit II. Relative frequencies of *Platycarya*, *Pterocarya*, *Taxodium* and *Taxus* are somewhat lower in Unit II than in Unit I. Thus the deteriorating climatic conditions during the deposition of Unit I appear to have continued throughout the deposition of Unit II.

The presence of silicoflagellates, radiolarians, dinoflagellate cysts and foraminiferal test linings in samples of Unit III indicates a middle to outer neritic environment of deposition for these sediments (Cornell 1969). Increasing nonarboreal elements in the upper portion of this unit as shown by spore/dinoflagellate ratios (Fig. 4) indicate shoaling conditions during the deposition of the upper portion of this unit (Dunay 1969).

Pinus/*Picea* ratios (Fig. 4) indicate that the climatic deterioration that began during the deposition of Unit I culminated during the deposition of Unit III. *Pinus*/*Picea* ratios varying from 9/1 to 7/1 and the presence of Gramineae and *Ephedra*, whose modern species are present in the southwestern portion of the United States, indicate the presence of cool (temperate) dry conditions along the New Jersey Coastal Plain during the deposition of Unit III.

Palynological assemblages of Unit IV contain few marine palynomorphs. Those forms that are present are small spiny dinoflagellates in the uppermost and lowermost horizons. Spore/dinoflagellate ratios (Fig. 3) are highest in the central portion of Unit IV. These assemblages indicate that the regressive conditions that began in Unit III continued into Unit IV and culminated during the deposition of the central portion of that unit. Assemblages of the upper portion of Unit IV indicate a return to nearshore conditions.

Increasing *Pinus/Picea* ratios from 10/1 to greater than 100/1 appear to indicate warming conditions throughout the deposition of Unit IV (Fig. 4). *Picea* disappears completely from some of the assemblages of the uppermost horizons. The return of *Taxus* along with lower frequencies of Gramineae and the absence of *Ephedra* apparently indicates a return to warm moist climatic conditions along the New Jersey Coastal Plain during the deposition of Unit IV.

Spore/dinoflagellate ratios (Fig. 3) indicate that the transgressive conditions that began in Unit IV culminated during the deposition of Unit V. Small spiny dinoflagellate cysts dominate the assemblages of the central portion of Unit V indicating nearshore conditions. Increasing spore/dinoflagellate ratios in the upper horizons indicate a return to shoaling conditions during the deposition of those sediments.

Decreasing *Pinus/Picea* ratios (Fig. 4) from 10/1 to 7/1 and the first appearance of *Abies* in the uppermost horizons of Unit V indicate climatic deterioration throughout the deposition of the unit. Modern species of *Abies* are generally restricted to areas north of 45° N. latitude in North America.

Species of *Abies* that are present in the Rocky and Appalachian Mountains south of 45° N. latitude are restricted to elevations above 4,000 feet (Collingwood and Brush 1964). Pollen grains produced by *Abies* in palynological assemblages of Unit V are most similar, morphologically, to those produced by *Abies balsamea* the modern distribution of which is limited to the native floras of northern New England to the Yukon territory (Collingwood and Brush 1964 and Kapp 1969).

Paleoclimatic interpretations made in this study on the basis of *Pinus*/*Picea* ratios closely match those made by Norem (1956) and Dorf (1960, 1964 and 1969) on the basis of paleobotanic remains of isolated deposits throughout North America.

Paleobathymetric interpretations made in this study on the basis of spore/dinoflagellate ratios generally match those made by Richards and Harbison (1942) and Isphording and Lodding (1973) on the basis of the molluscan faunas and clay mineralogy of the surface members of the Kirkwood formation. Prior to this study, paleobathymetric interpretations had not been made on the subsurface samples of the Kirkwood.

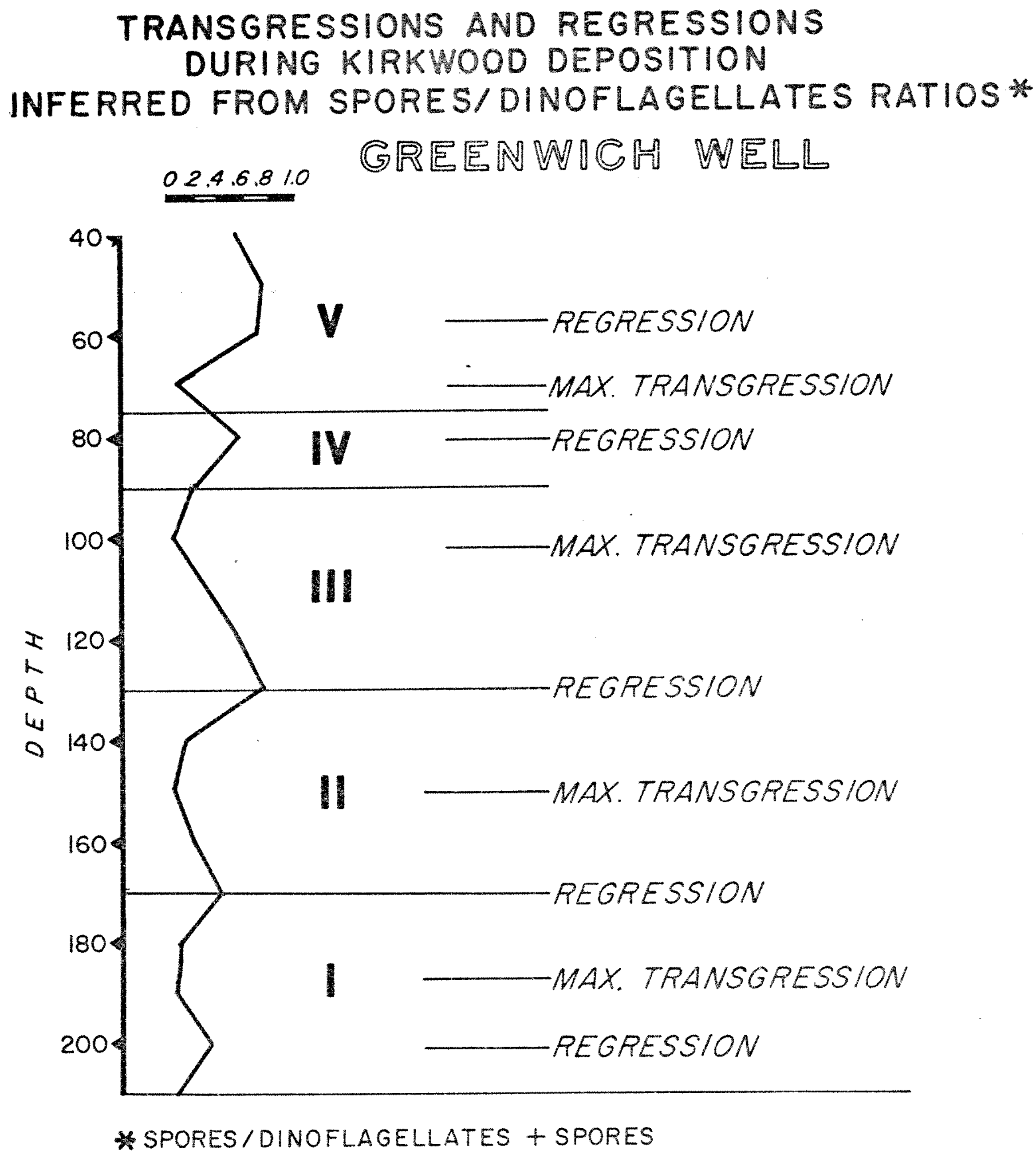

Figure 3: Spore/dinoflagellate ratios of the Kirkwood Formation at Greenwich, New Jersey

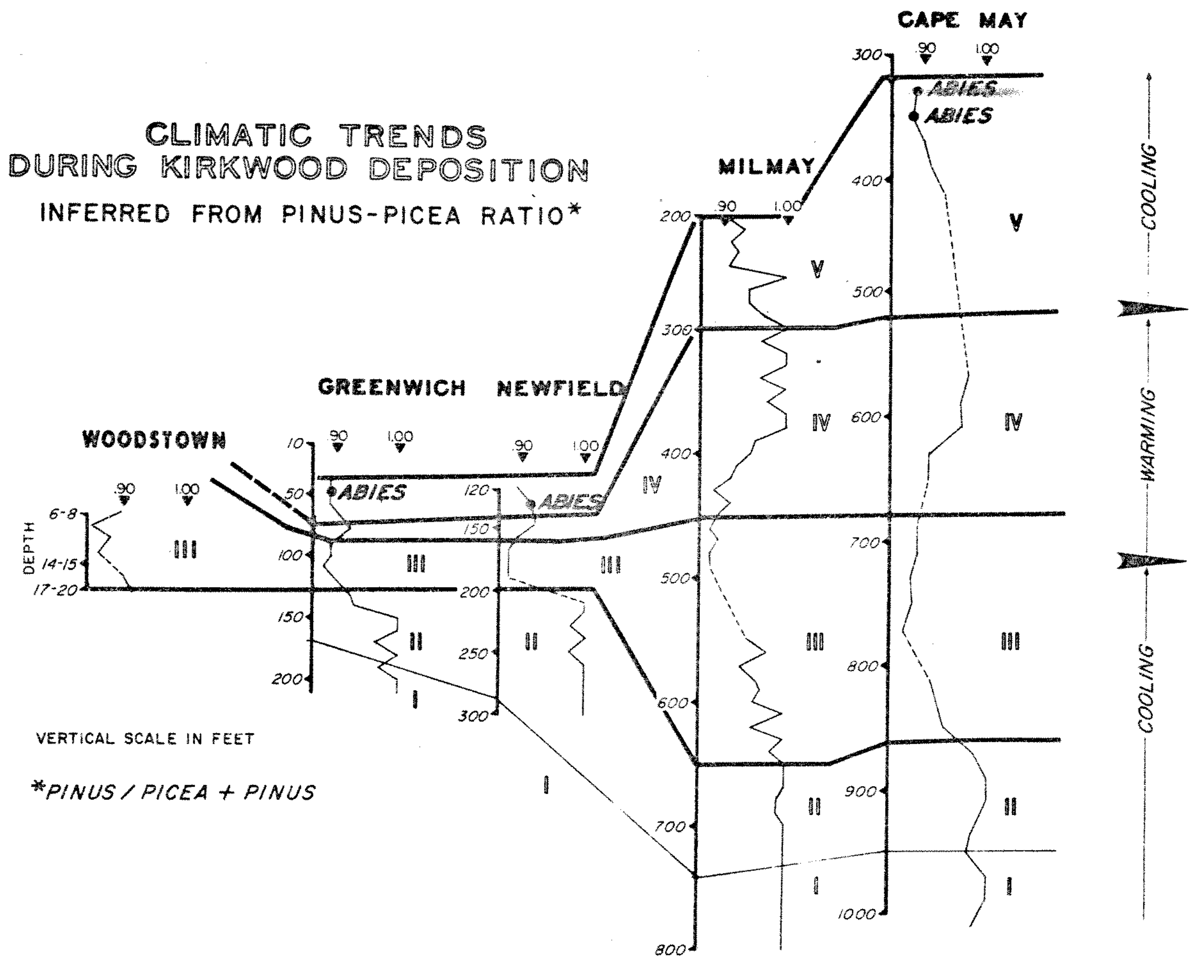

Figure 4: Pinus/Picea ratios of the Kirkwood Formation at Woodstown, Greenwich, Newfield, Milmay, and Cape May, New Jersey

CORRELATION OF THE SUBSURFACE PHASES OF THE KIRKWOOD FORMATION WITH OTHER FORMATIONS ALONG THE ATLANTIC COASTAL PLAIN

The Miocene sediments of New Jersey were assigned to the Kirkwood Formation by Knapp (1904). Prior to this, these sediments were referred to as the Chesapeake Formation because of the similarity of its molluscan fauna to that of the Chesapeake Group of Maryland, Delaware and Virginia (Clark 1893, Whitfield 1894, and Salisbury 1895, 1896 and 1898).

Richards and Harbison (1942) correlated the Asbury Park and Alloway Clay Members with the Middle Miocene Calvert Formation, the basal member of the Chesapeake Group, on the basis of their molluscan faunas and the diatom, *Actinoptychus heliopelta* Grunow. Subsequent correlations by Dorsey (1948), Gardner (1948), Lohman (1948), Johnson and Richards (1952), Gernant (1970) and Owens and Sohl (1970) agree with those of Richards and Harbison (1942).

Foraminiferal assemblages of Units I and II of the present study including *Cassigerinella chipolensis*, *Globigerina bradyi*, *Globigerina ouachitaensis ciperoensis*, *Globigerina praebuloides*, *leroyi*, *Globigerina* cf. *quinqueloba*, *Globigerina venezuelana*, *Globigerinita dissimilis*, *Globigerinoides triloba* and unidentified species of *Globorotalia* indicate that these units were deposited during the Early Miocene (*Globorotalia kugleri* Zone).

Unit III of the present study can be correlated with the Calvert Formation on the basis of the silicoflagellates, Corbisema sp. and Dictyocha fibula. These forms identified from the 120 foot interval in the Greenwich Well are diagnostic forms of the Calvert Formation (Tynan 1957).

Richards (1945) reported the presence of Bulliopsis integra (Conrad) and Terebra inornata Whitfield in the 400 to 450 foot interval (Unit V of the present study) of the Anchor Gas Well in Cape May. Bulliopsis integra (Conrad) and Terebra inornata Whitfield are diagnostic of the Middle Miocene St. Marys Formation, the youngest member of the Chesapeake Group.

Four transgressive sequences are interpreted from palynological assemblages on the basis of spore/dinoflagellate ratios (Fig. 3) and relative frequency distributions of continental and marine palynomorphs. The two Lower Miocene transgressions (Unit I and II) are correlated with the Tampa and Hawthorn transgressions of South Carolina, Georgia and Florida. The Middle Miocene transgressions (Units III and V) are correlated with the Calvert and St. Marys transgressions of Maryland, Delaware and Virginia. Unit IV is correlated with the Choptank Formation of Maryland, Delaware and Virginia on the basis of their stratigraphic positions and paleoenvironmental interpretations. Gernant (1970) reported that the lower portion of the Choptank Formation represents a continuation of the shoaling that began in the Calvert, whereas the upper strata were deposited in slightly deeper water that represented the onset of the St. Marys transgression. The same paleoenvironmental interpretations are reported in this study for the sediments of Unit IV on the basis of their palynological assemblages.

Correlations of the subsurface phases of the Kirkwood Formation with other formations along the Atlantic Coastal Plain are presented in Figure 5.

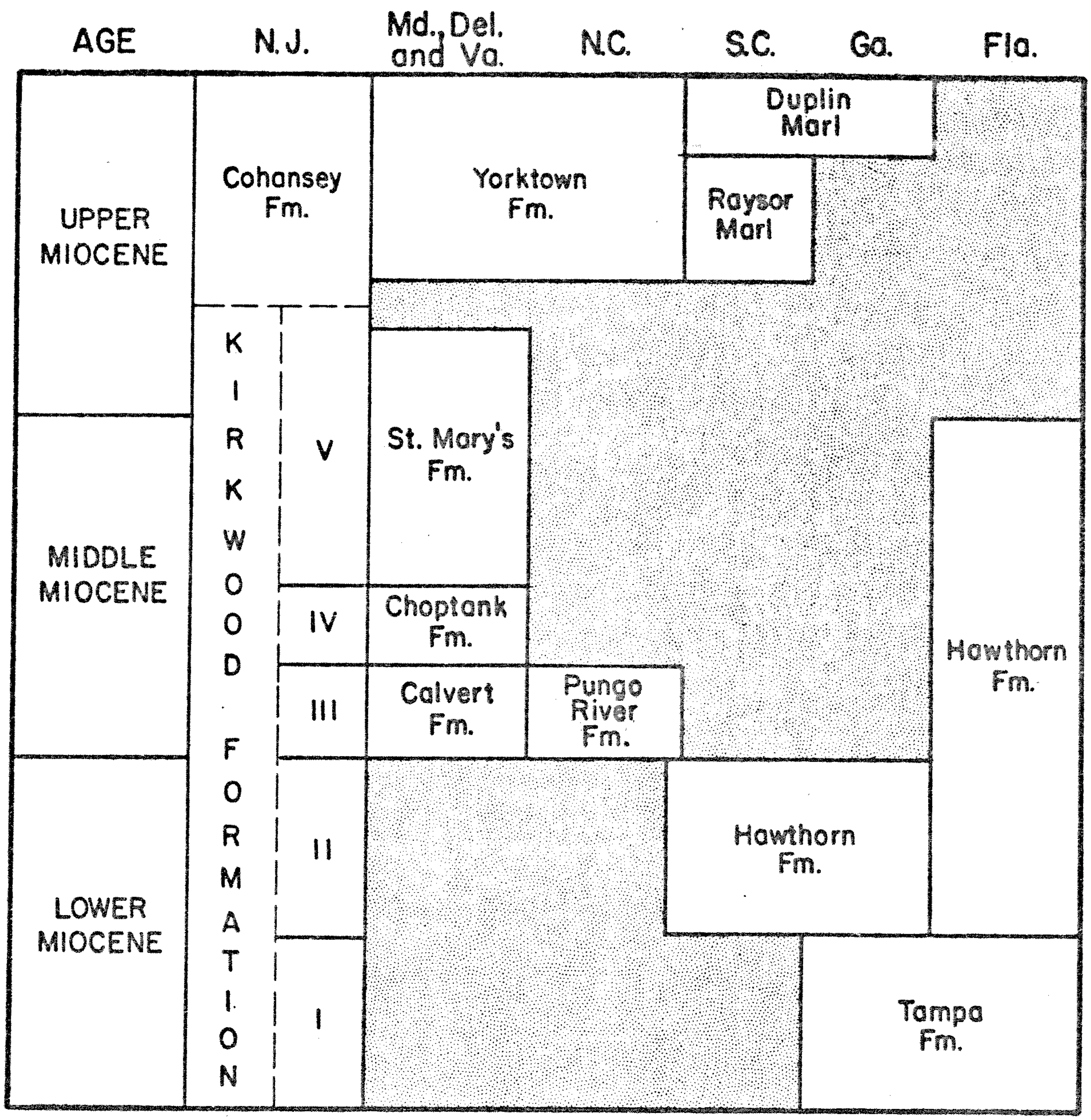

Figure 5: Correlation of the subsurface phases of the Kirkwood Formation with other formations along the Atlantic Coastal Plain

CORRELATION OF THE SURFACE MEMBERS AND SUBSURFACE PHASES OF THE KIRKWOOD FORMATION

The Asbury Park and Alloway Clay Members are correlated with Unit III (Figs. 6 and 7) on the basis of their *Pinus/Picea* ratios, spore/dinoflagellate ratios, abundances of Gramineae and lack of Compositae and/or *Abies* in their palynological assemblages. The diatom, *Actinoptychus heliopelta* Grunow that is diagnostic of the Calvert Formation in Maryland, Delaware and Virginia is present in assemblages of Unit III as well as in those of the Asbury Park and Alloway Clay.

Surface samples of the Grenloch Sand Member are void of palynomorphs due to their coarse grain sizes and highly oxidized state. This member is correlated with Unit III of the Kirkwood Formation in the subsurface because of its interfingering stratigraphic relationship with the Asbury Park and Alloway Clay Members (Fig. 2).

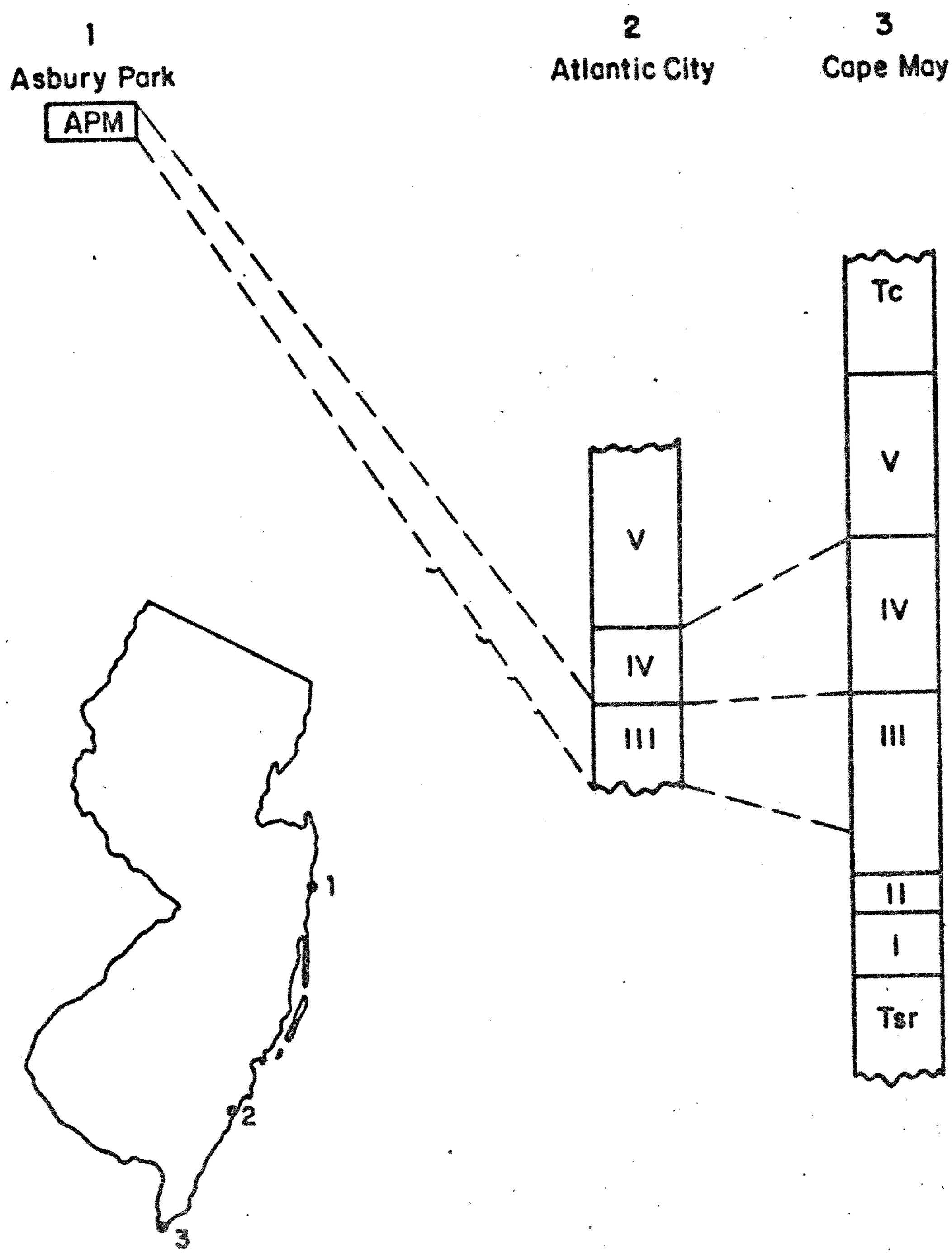

Figure 6: Correlation of the Asbury Park Member with the subsurface phases of the Kirkwood Formation

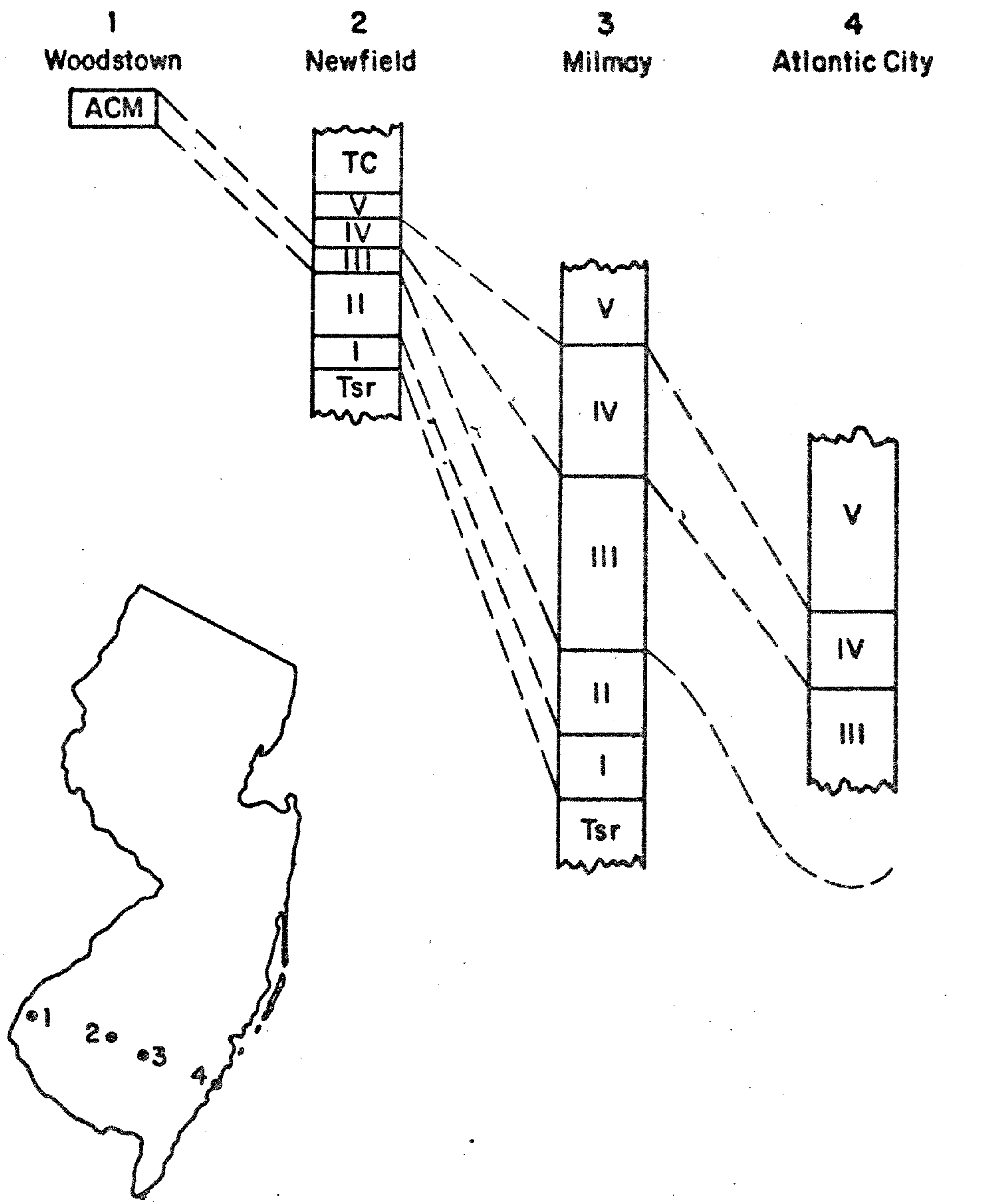

Figure 7: Correlation of the Alloway Clay Member with the subsurface phases of the Kirkwood Formation

SUMMARY OF THE SURFACE MEMBERS OF THE KIRKWOOD

MEMBER	DESCRIPTION
Asbury Park	1) Calvert Equivalent 2) Deteriorating Climate (Subtropical to Temperate) 3) *Actinoptychus heliopelta* Grunow Is Present. 4) Coastal Brackish Water Environment of Deposition
Grenloch Sand	1) Calvert Equivalent 2) Deteriorating Climate (Subtropical to Temperate) 3) Void of Palynological Remains 4) High Energy, Possibly Littoral, Environment of Deposition
Alloway Clay	1) Calvert Equivalent 2) Deteriorating Climate (Subtropical to Temperate) 3) *Actinoptychus heliopelta* Grunow Is Present 4) Pine Swamp Environment of Deposition, Deepening to Middle Neritic and then Shoaling, Perhaps to Inner Neritic

SUMMARY OF THE SUBSURFACE PHASES OF THE KIRKWOOD FORMATION

ZONE	DESCRIPTION
V	1) St. Marys Equivalent 2) Deteriorating Climate (Subtropical to Temperate) 3) First Appearances of Compositae and _Abies_ 4) Transgressive Sequence That Began In Zone IV Continues Into Zone V Followed By A Regressive Sequence
IV	1) Choptank Equivalent 2) Ameliorating Climate (Temperate to Subtropical) 3) Picea Becomes Rare In Upper Horizons 4) Regressive Sequence That Began In Zone III Continues Into Zone IV Followed By A Transgressive Sequence
III	1) Calvert Equivalent 2) Deteriorating Climate Becoming Slightly Warmer In The Later Stages (Subtropical to Temperate) 3) First Major Influxes Of _Picea_ and Gramineae 4) Transgressive Sequence Followed By A Regressive Sequence
II	1) Hawthorn Equivalent 2) Deteriorating Climate (Subtropical) 3) Low Frequencies of _Picea_ and Gramineae 4) Transgressive Sequence Followed By A Regressive Sequence
I	1) Tampa Equivalent 2) Deteriorating Climate (Subtropical) 3) _Globorotalia kugleri_ Zone 4) Transgressive Sequence Followed By A Regressive Sequence

CONCLUSIONS

1) Subsurface sections of the Kirkwood Formation may be divided into five biostratigraphic units.

2) These units are correlated with the Lower Miocene Tampa and Hawthorn Formations of South Carolina, Georgia and Florida and the Middle Miocene Calvert, Choptank and St. Marys Formations of Maryland, Delaware and Virginia.

3) Spore/dinoflagellate ratios and relative frequencies of continental and marine palynomorphs indicate transgressive and regressive sequences in the Tampa, Hawthorn, Calvert and St. Marys Phases.

4) *Pinus*/*Picea* ratios and changes in the regional microfloras indicate that climatic deterioration from subtropical to temperate conditions took place during the deposition of the Tampa, Hawthorn and lower portion of the Calvert Phase followed by climatic amelioration during the deposition of the upper part of the Calvert Phase and throughout the deposition of the Choptank Phase. A second period of climatic deterioration is indicated during the deposition of the St. Marys Phase.

5) The Asbury Park Member is correlative with the subsurface Calvert Phase. It was deposited in a coastal brackish water environment of deposition under subtropical to temperate climatic conditions.

6) The Grenloch Sand Member is correlative with the subsurface Calvert Phase. It was deposited in a high energy, possibly littoral, environment of deposition under subtropical to temperate climatic conditions.

7) The Alloway Clay Member is correlative with the subsurface Calvert Phase. It was deposited in a low energy nearshore environment of deposition under subtropical to temperate climatic conditions.

GEOLOGIC AGE AND CHESAPEAKE GROUP
EQUIVALENTS OF THE KIRKWOOD FORMATION, N.J.

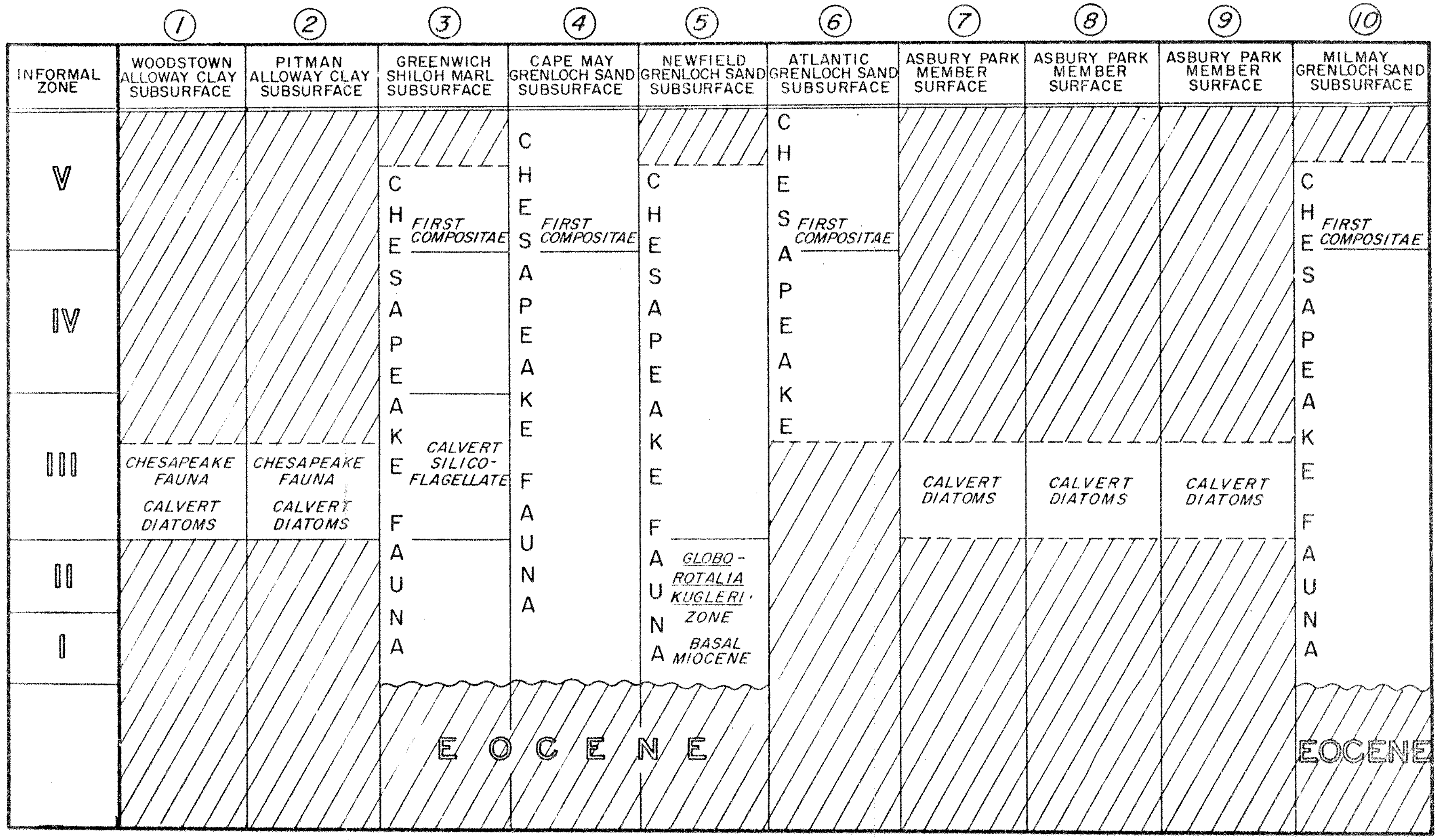

Figure 8: Geologic ages and Chesapeake Group equivalents of the surface and subsurface facies of the Kirkwood Formation

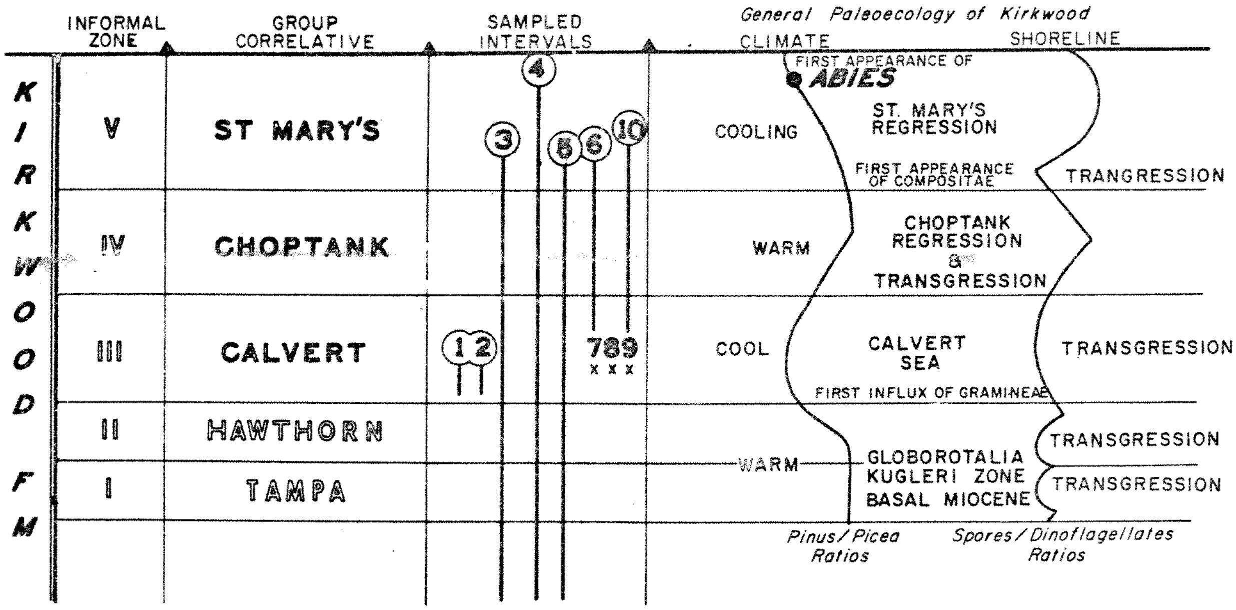

Figure 9: Correlations and paleonvironmental inferences of the surface and subsurface facies of the Kirkwood Formation

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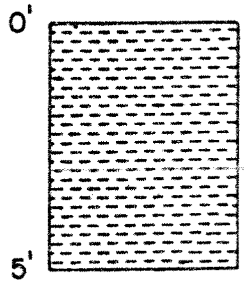
APPENDIX I

Surface and Subsurface Sections of the Kirkwood Formation

Farmingdale Sample

1 1/4 miles north of Farmingdale, about 200 yards east of the railroad tracks, at an elevation of approximately 15 feet above sea level



(Unit III)

Black Clay

Chenopods, *Equisetum*, Ericaceae, *Osmunda*, and Polypodium dominate assemblages

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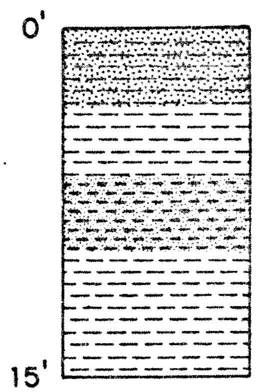
Hammonton Sample

south side of Hammonton Road, about 2 miles east of Route 9, at an elevation of approximately 25 feet above sea level



(Unit III)

Light Gray Sands and Clays--Low Frequencies of Palynomorphs

Light Gray Clay--Low Frequencies of Palynomorphs

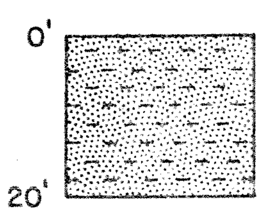
Dark Black Silty Clay--Nonarboreal elements dominate assemblages

Light Gray Clay--Low Frequencies of Palynomorphs

Light Gray Clay--Low Frequencies of Palynomorphs

Howell Sample

landfill site, about 3 miles east of Route 9 and 1 mile north of the Ocean County Line, at an elevation of approximately 40 feet above sea level



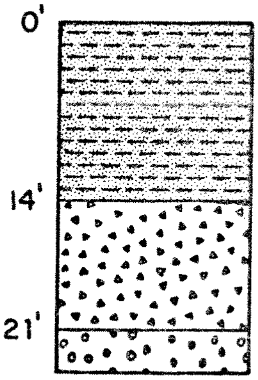
(Unit III)

Red Sands with small Gray Clay Inclusions--Low Frequencies of Palynomorphs and *Actinoptychus heliopelta*

Figure 10: Surface Samples of the Asbury Park Member

Woodstown Sample

(Unit III)



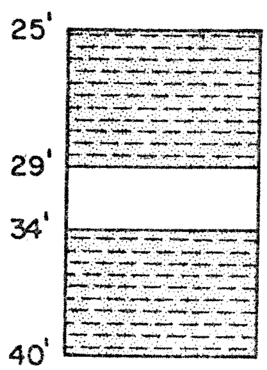
Brown to Gray Silty Clay--Decreasing Frequencies of Dinoflagellate Cysts and Foraminiferal Test Linings in the Upper Portion of the Section, *Actinoptychus heliopelta* is present in these assemblages.

"Macrokaolinite Zone"--Very High Frequencies of *Pinus*, Few Dinoflagellates

Glauconitic Sands (Eocene)

Pitman Sample

(Unit III)



Brown to Gray Silty Clay--High Frequencies of Dinoflagellate Cysts and Foraminiferal Test Linings

Samples Not Available

Brown to Gray Silty Clay--High Frequencies of Dinoflagellate Cysts and Foraminiferal Test Linings

Figure 11: Subsurface Samples of the Alloway Clay Member

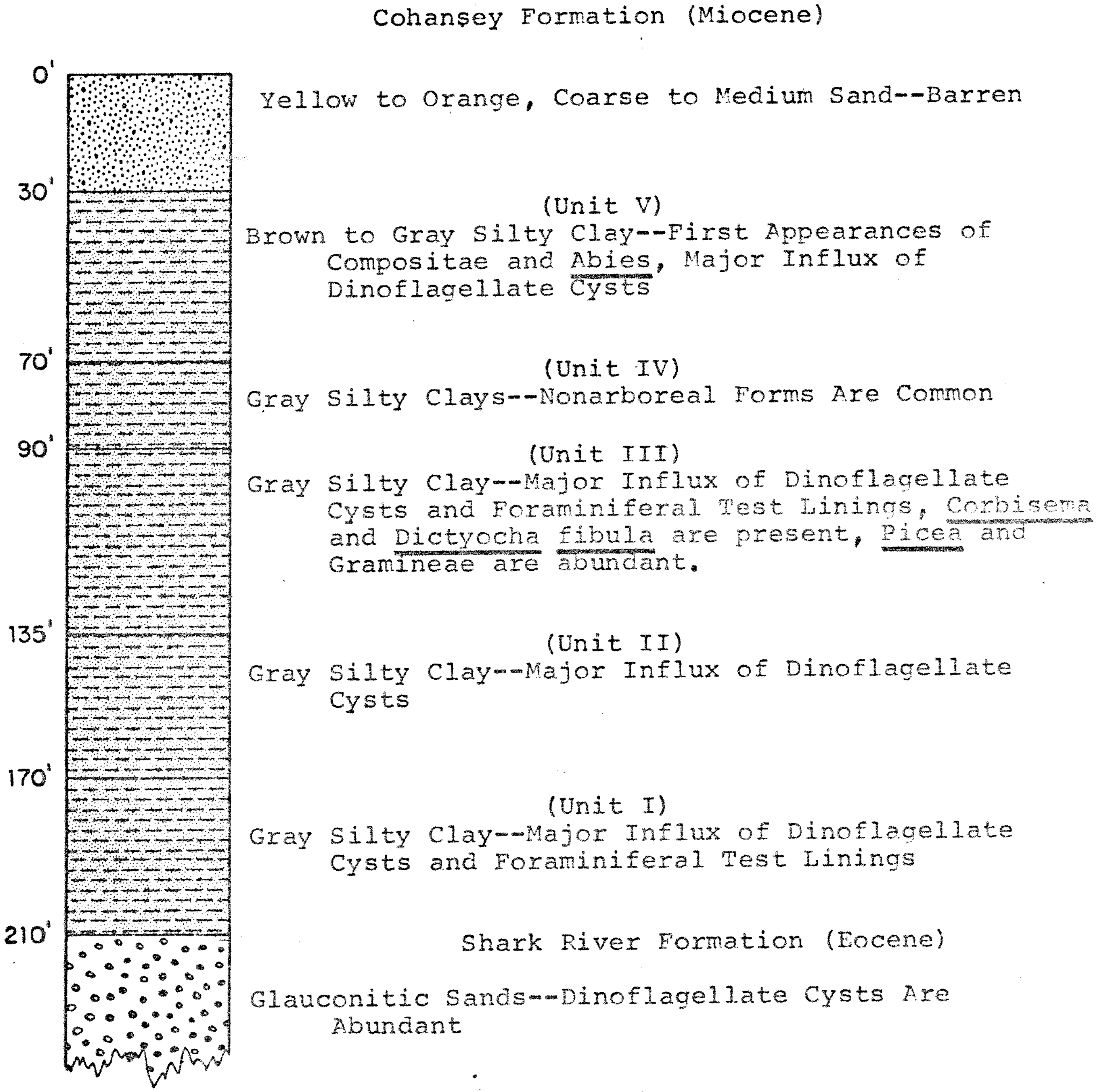
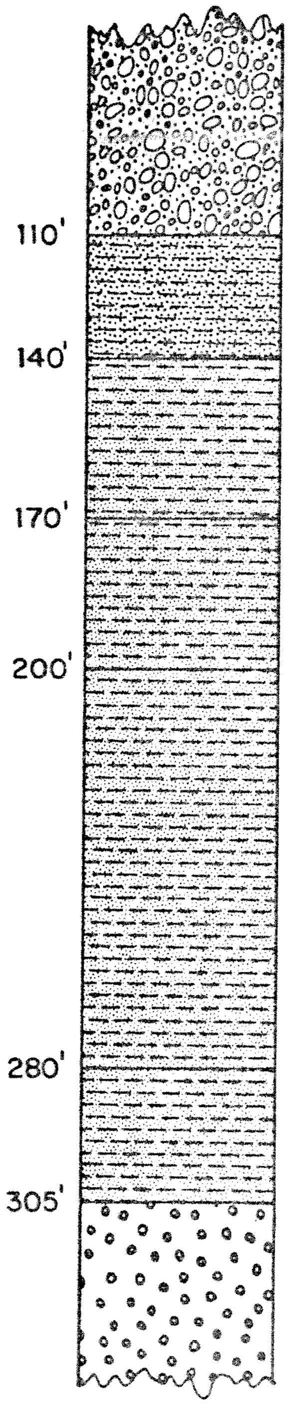


Figure 12: Subsurface Section of the Kirkwood Formation From Greenwich, New Jersey



Cohansey Formation (Miocene) and Quaternary Deposits

Yellow, Orange and Brown Sands and Gravels--Void of Palynological Remains

(Unit V)

Brown Sands and Clays--First Appearance of *Abies*

(Unit IV)

Gray Silty Clay--Spores are abundant

(Unit III)

Gray Silty Clay--First Major Influxes of *Picea* and Gramineae

(Unit II)

Compact, Gray Silty Clay--Major Influx of Dinoflagellate Cysts and Foraminiferal Test Linings, *Globorotalia kugleri* Zone

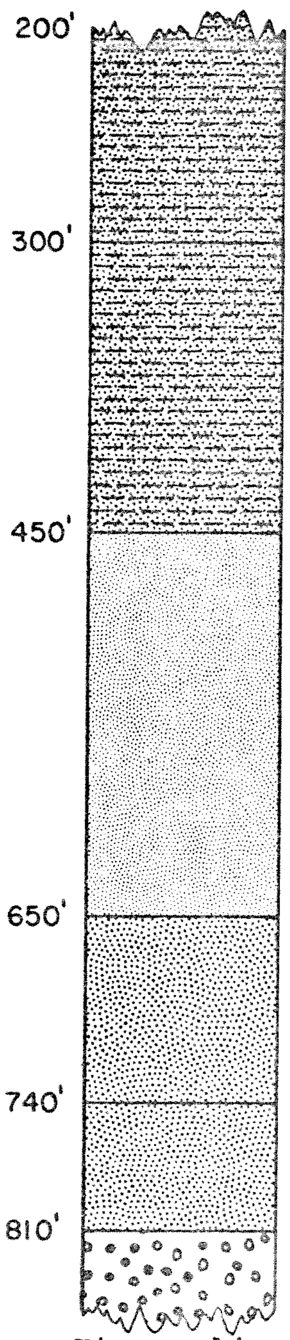
(Unit I)

Compact, Gray Silty Clay--Major Influx of Dinoflagellate Cysts and Foraminifera

Shark River Formation

Glauconitic Sands--Few Dinoflagellate Cysts

Figure 13: Subsurface Section of the Kirkwood Formation from Newfield, New Jersey



(Unit V)
Brown to Gray Sands and Silts--First Appearance of Compositae

(Unit IV)
Brown to Gray Sands and Silts--Spores are abundant

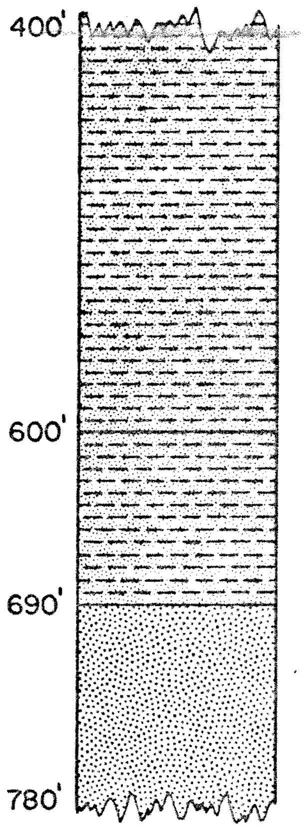
(Unit III)
Brown to Gray Fine Sands--Major Influx of Dinoflagellate Cysts and Foraminiferal Test Linings

(Unit II)
Yellow to Brown Sands--Major Influx of Dinoflagellate Cysts

(Unit I)
Yellow to Brown Sands--Major Influx of Dinoflagellate Cysts and Foraminiferal Test Linings

Shark River Formation
Glauconitic Sands--Dinoflagellates are common

Figure 14: Subsurface Section of the Kirkwood Formation from Milmay, New Jersey



(Unit V)

Gray Silty Clays--First Appearances of <u>Abies</u> and Compositae, Major Influx of Dinoflagellate Cysts

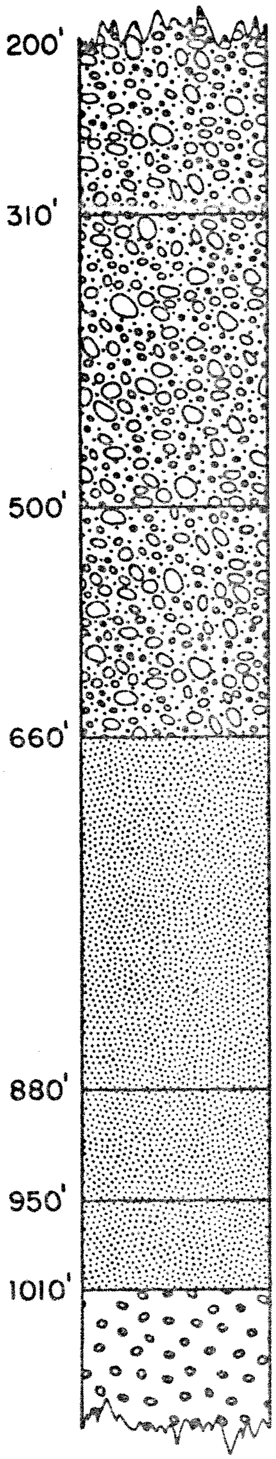
(Unit IV)

Brown Silty Clays--Spores are abundant

(Unit III)

Brown to Brownish Gray Sands--Major Influx of Dinoflagellate Cysts and Foraminiferal Test Linings

Figure 15: Subsurface Section of the Kirkwood Formation from Atlantic City, New Jersey



Cohansey Formation (Miocene)
Dark Gray Sands and Gravels--Few Palynomorphs are present

(Unit V)
Gray Sands and Gravels--First Appearances of *Abies* and Compositae, Major Influx of Dinoflagellate Cysts

(Unit IV)
Gray Sands and Gravels--Spores are abundant.

(Unit III)
Gray Sands--First Major Influxes of *Picea* and Gramineae, Major Influx of Dinoflagellate Cysts and Foraminiferal Test Linings

(Unit II)
Gray Sands--Major Influx of Dinoflagellate Cysts

(Unit I)
Gray Sands--Major Influx of Dinoflagellate Cysts and Foraminiferal Test Linings

Shark River Formation (Eocene)
Glauconitic Sands--Dinoflagellates are abundant

Figure 16: Subsurface Section of the Kirkwood Formation from Cape May, New Jersey

APPENDIX II

Percentage Frequency Pollen Histograms of the Kirkwood Formation

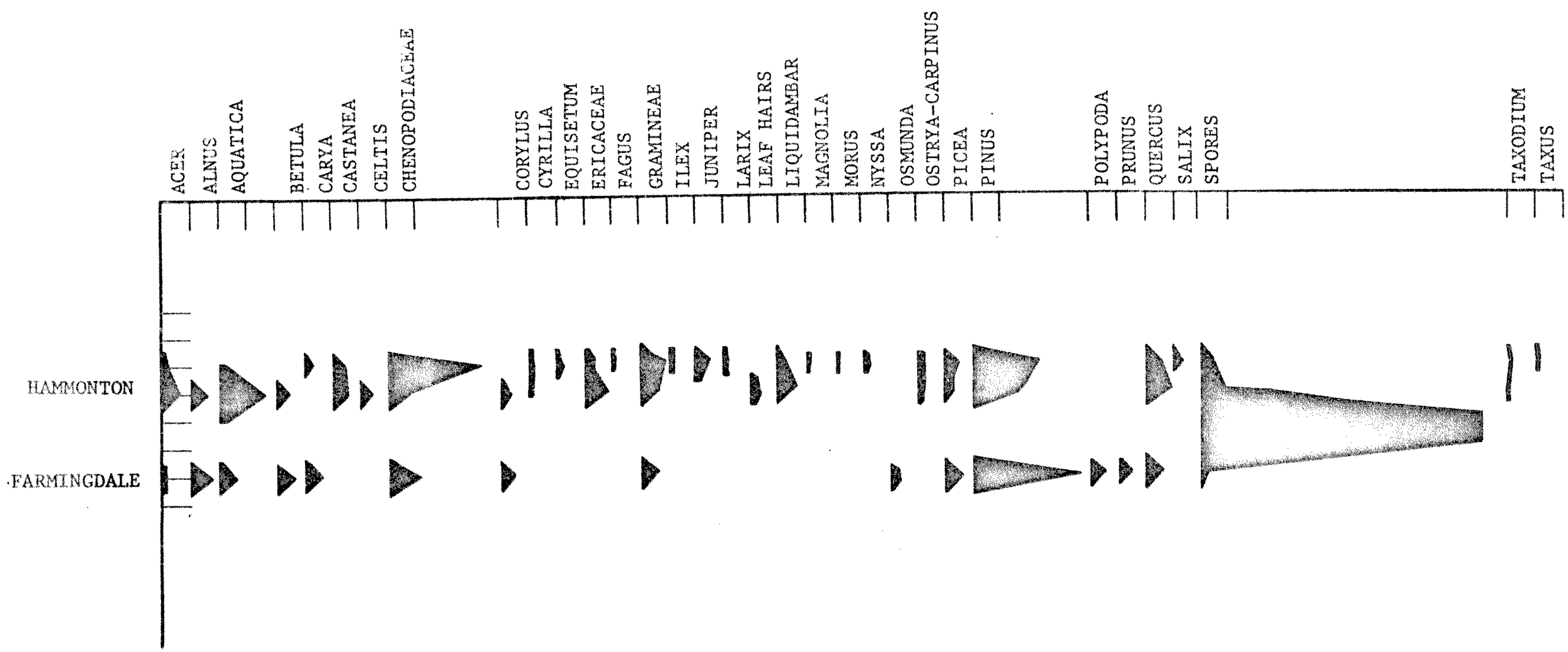


Figure 17: Percentage Frequency Pollen Histograms of the Asbury Park Member from Farmingdale, Hammonton and Howell, New Jersey

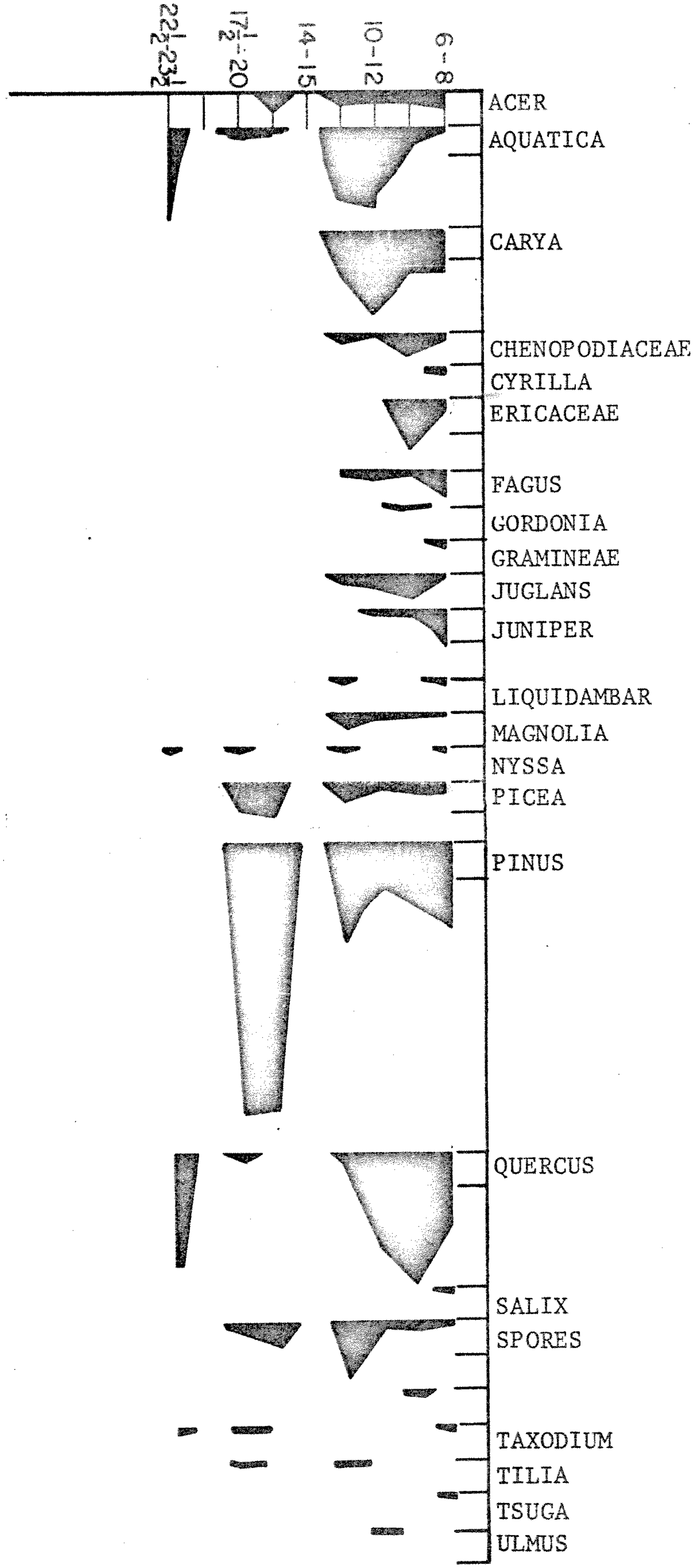


Figure 18: Percentage frequency pollen histogram of the Alloway Clay Member from Woodstown, New Jersey

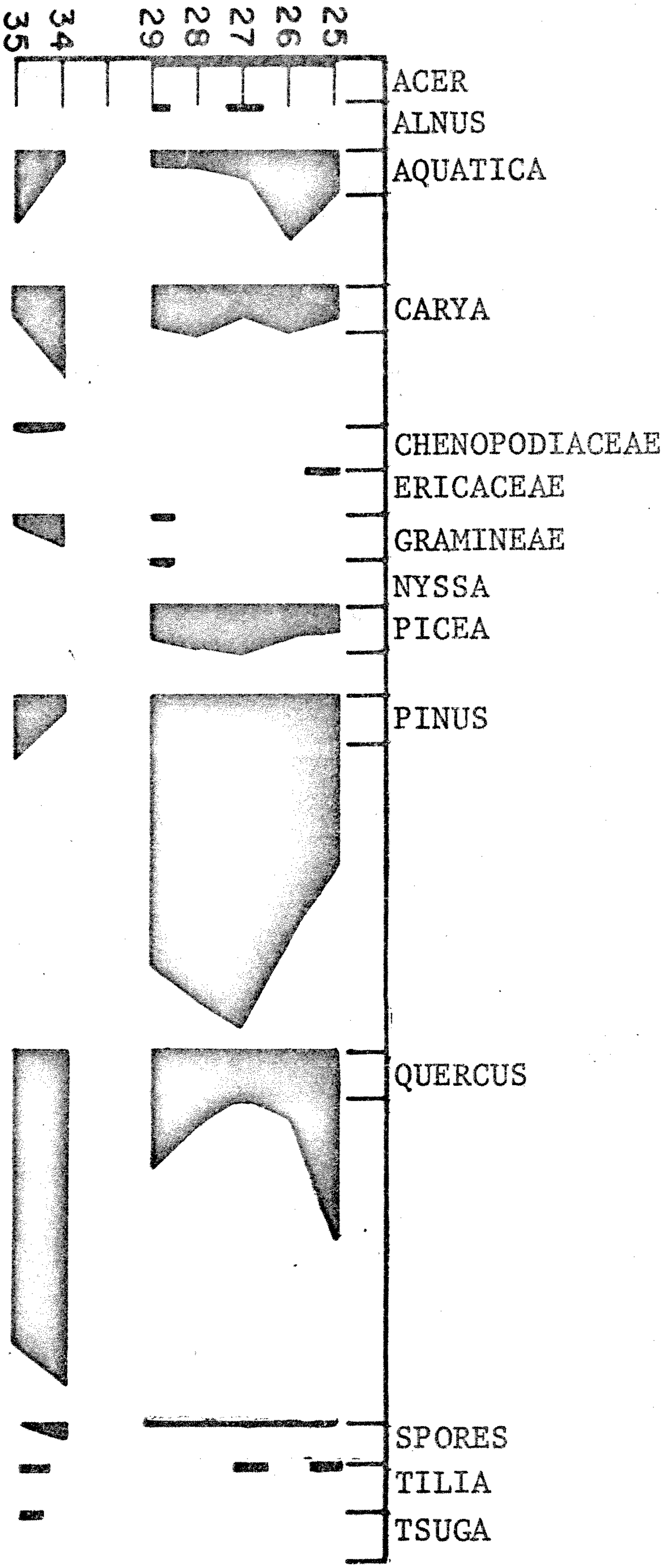


Figure 19: Percentage frequency pollen histogram of the Alloway Clay Member from Pitman, New Jersey

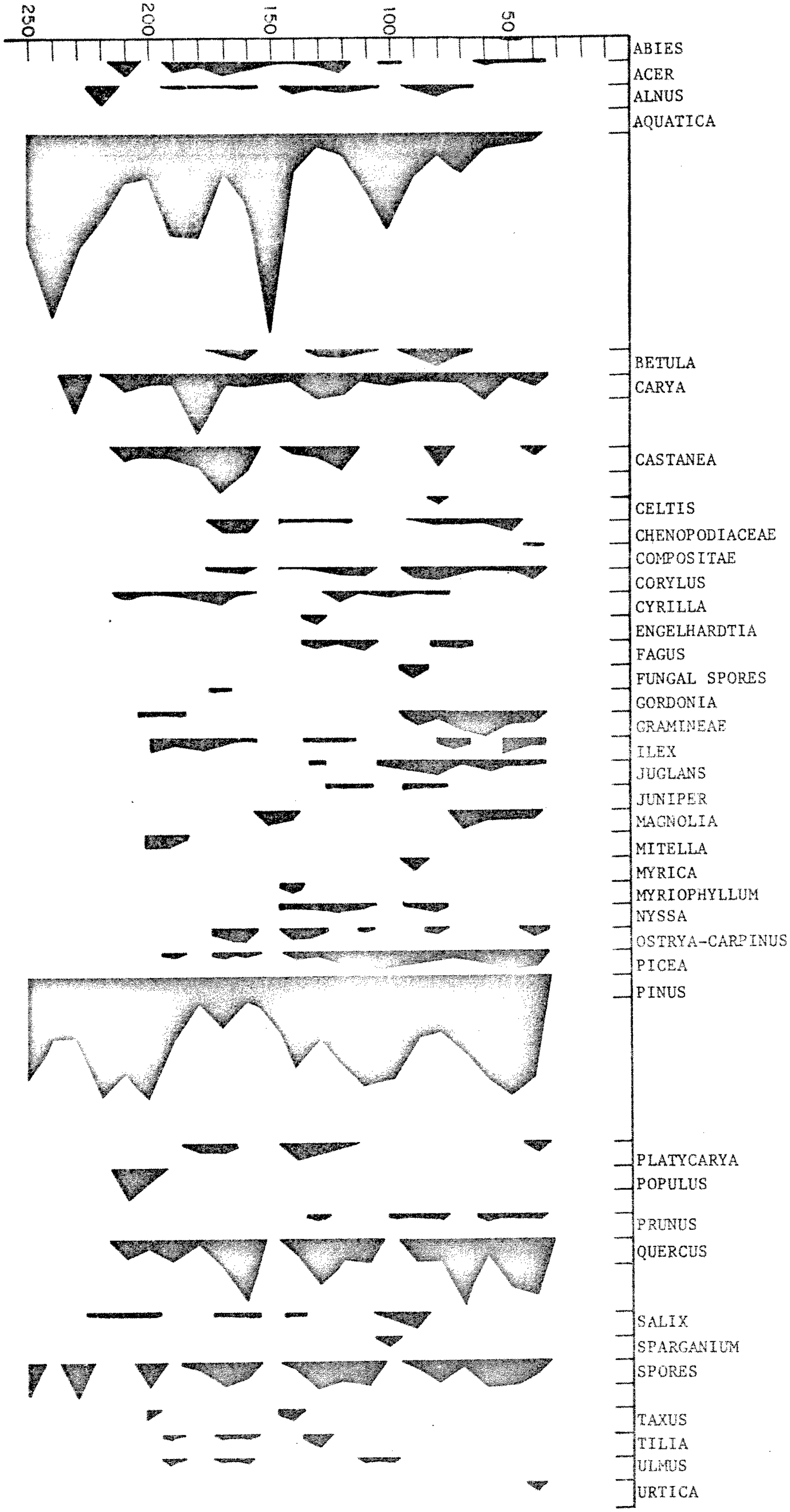


Figure 20: Percentage frequency pollen histogram of the Kirkwood Formation from Greenwich, New Jersey

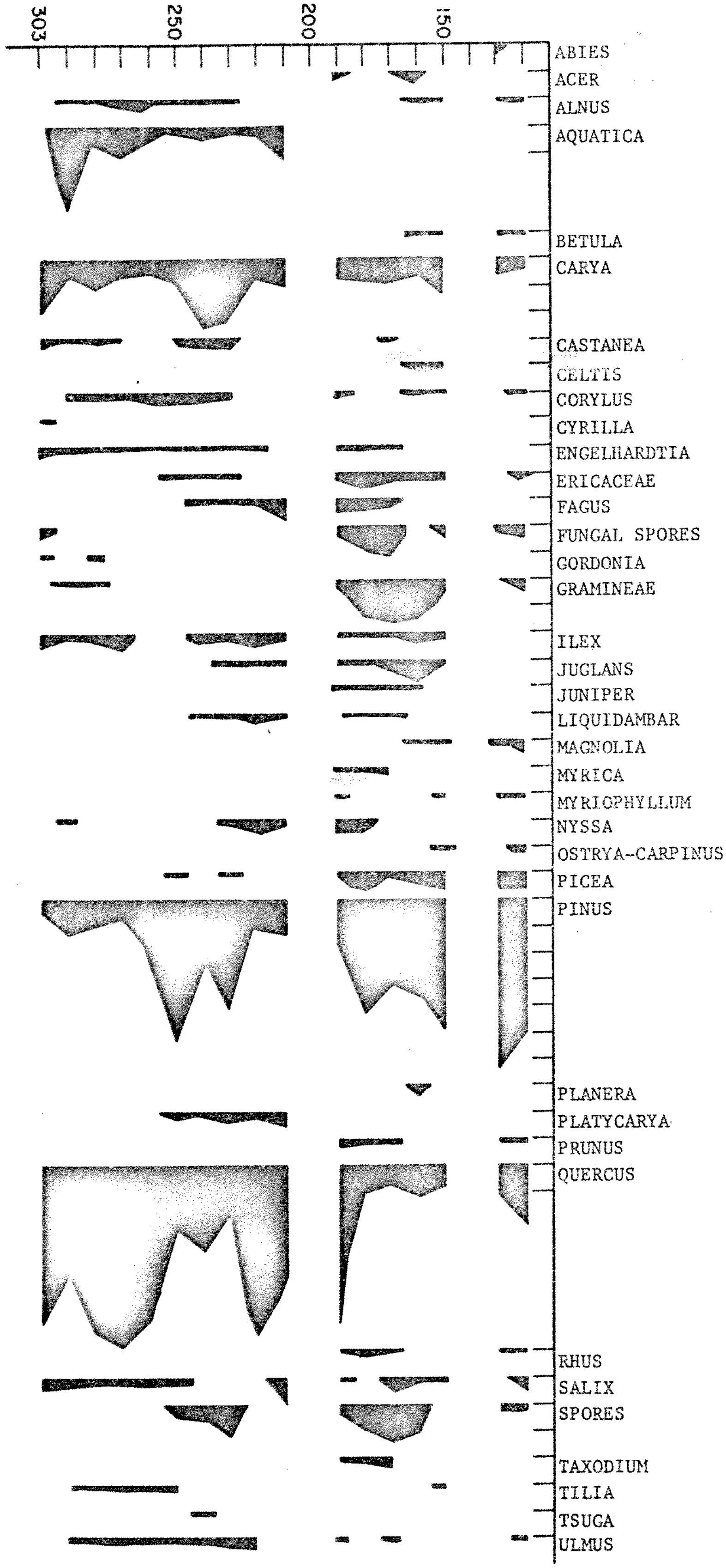


Figure 21; Percentage frequency pollen histogram of the Kirkwood Formation from Newfield, New Jersey

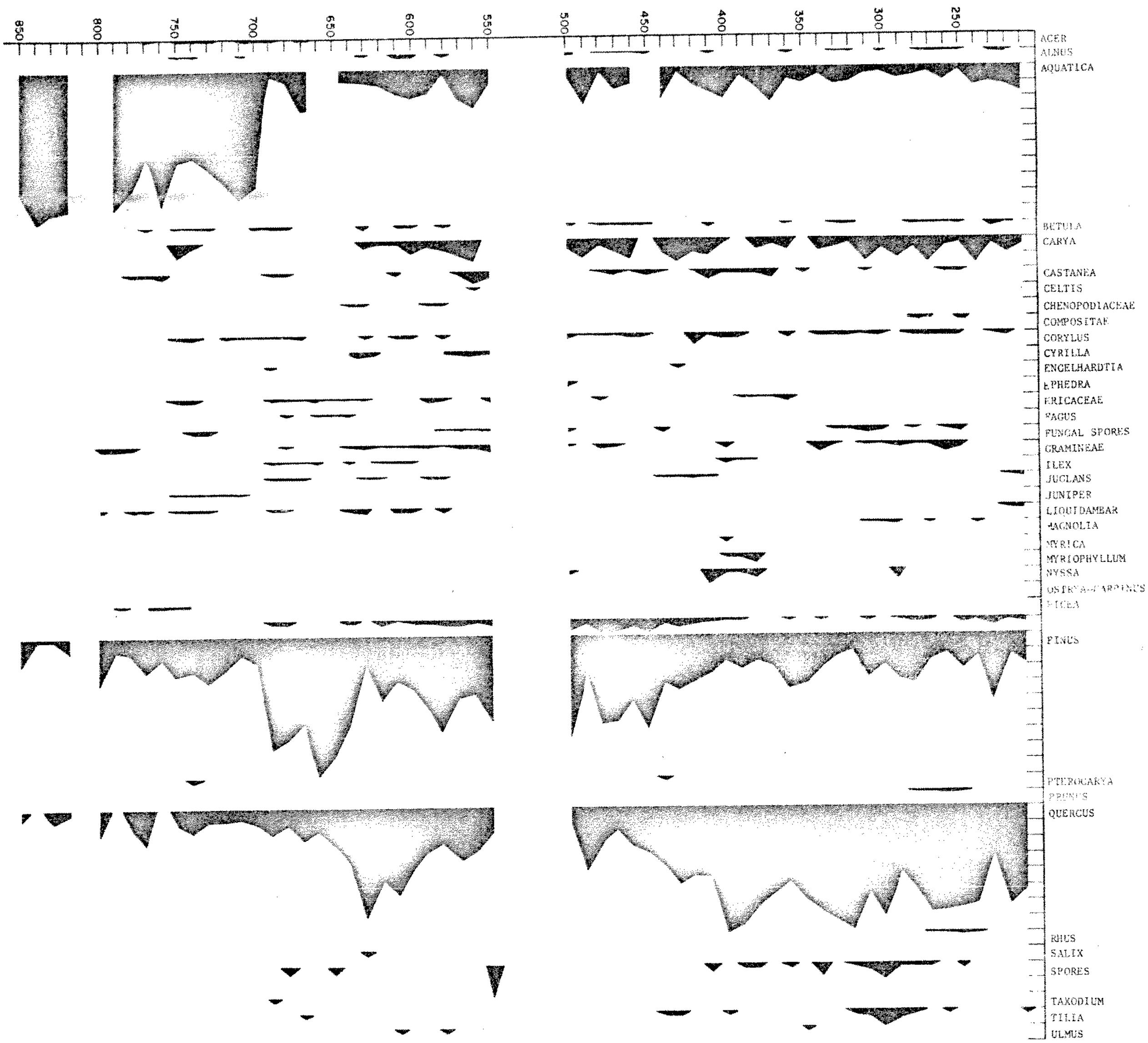


Figure 22: Percentage Frequency Pollen Histograms of the Kirkwood Formation from Milmay, New Jersey

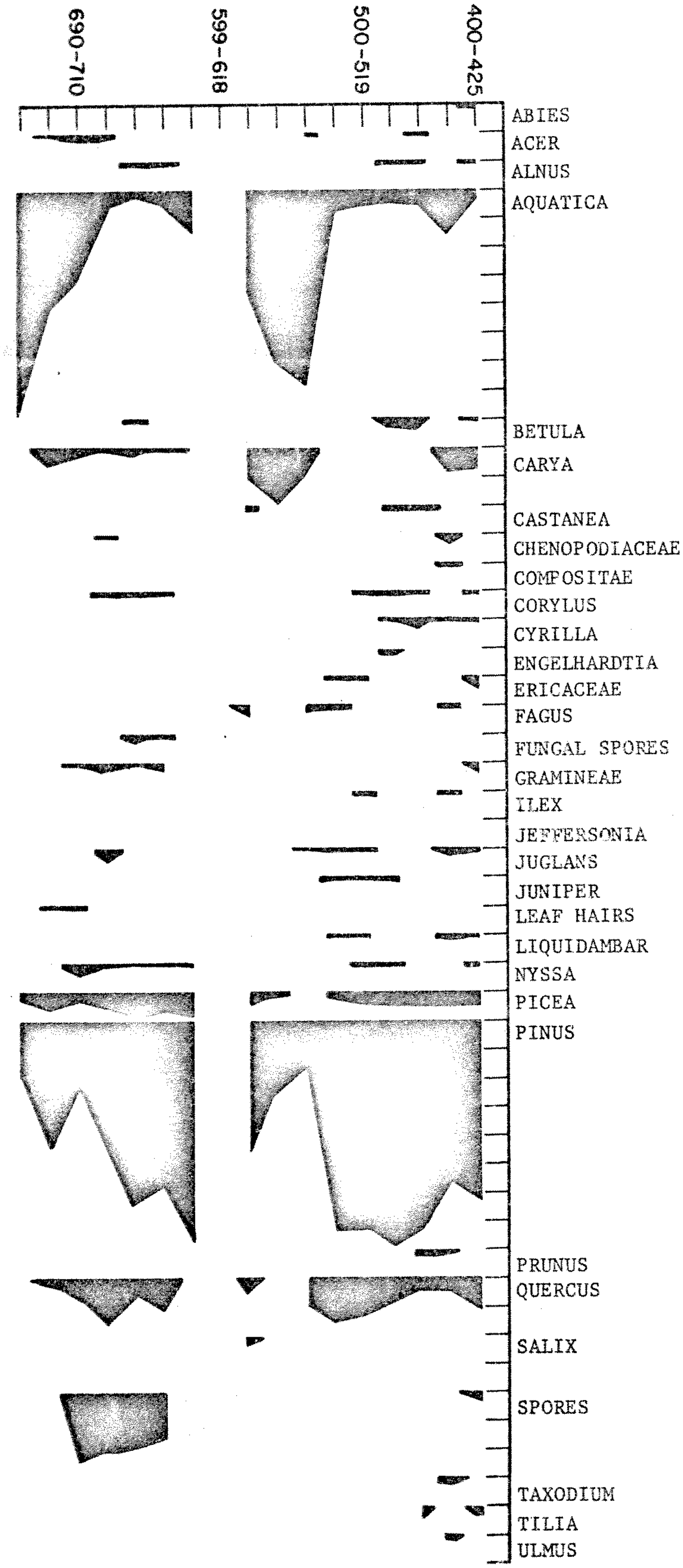


Figure 23: Percentage frequency pollen histogram of the Kirkwood Formation from Atlantic City, New Jersey

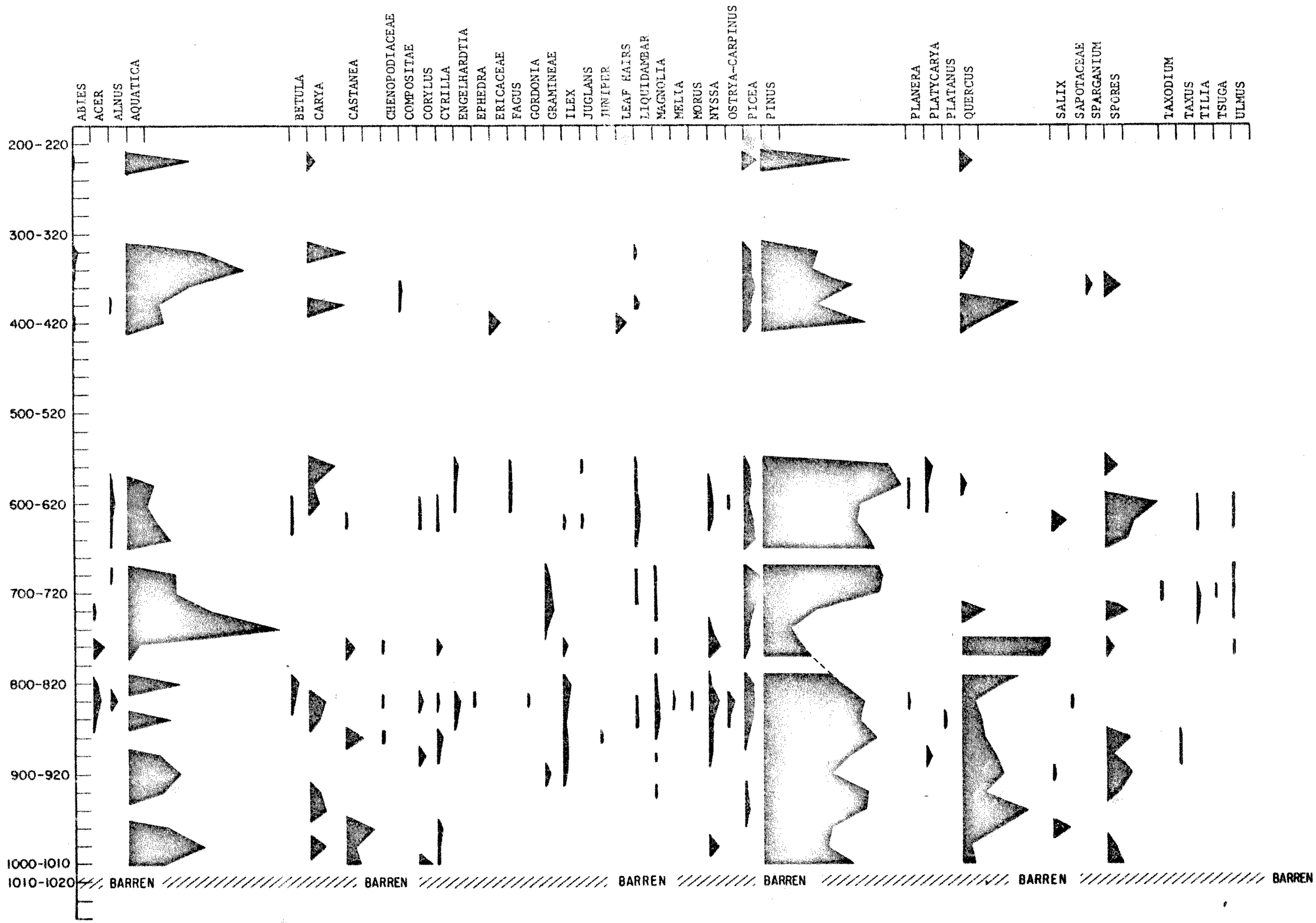


Figure 24: Percentage frequency pollen histogram of the Kirkwood Formation from Cape May, N. J.

APPENDIX III

Absolute Frequency Counts of Palynomorphs and other Microfossil Groups of the Kirkwood Formation

ASBURY PARK MEMBER

	ACER	ALNUS	BETULA	CARYA	CASTANEA	CELTIS	CHENOPODIACEAE	CORYLUS	CYRILLA	DIATOMS	DINOFLAGELLATES	EQUISETUM	ERICACEAE	FAGUS
HAMMONTON 1										3				
2														
3A	4			5	9		64		1			4	6	2
3B	9	10	9		10	7	9	6			33		16	
4														
5														
FARMINGDALE 6	2	17	6	10			21	8		4	11			
HOWELL 7										25				

	FORAMINIFERAL TEST LININGS	GRAMINEAE	ILEX	JUNIPER	LARIX	LEAF HAIRS	LIQUIDAMBAR	MAGNOLIA	MORUS	NYSSA	OSMUNDA	OSTRYA-CARPINUS	PICEA	PINUS
HAMMONTON 1														
2														
3A		19	2	10	1		5	2	1	1		1	7	45
3B	1	14				5	13					2	4	33
4														
5														
FARMINGDALE 6		11		6							4		8	79
HOWELL 7														

	POLYPODIUM	PRUNUS	QUERCUS	SALIX	SPORES	TAXODIUM	TAXUS	TOTAL	PALYNOMORPHS COUNTED PER SLIDE
HAMMONTON 1								3	2
2					1			1	2
3A			8	4	9	1	1	212	53
3B			17		16	1		215	27
4					31			31	16
5					26			26	13
FARMINGDALE 6	8	7	11		5	2		213	53
HOWELL 7								25	13
								722	

Figure 25: Absolute Frequency Count of Palynomorphs and other Microfossil Groups of the Asbury Park Member from Hammonton, Farmingdale and Howell, New Jersey

WOODSTOWN, NEW JERSEY

	ACER	CARYA	CHENOPODIACEAE	CYRILLA	DIATOMS	DINOFLAGELLATES	ERICACEAE	FAGUS	FORAMINIFERAL TEST LININGS	GORDONIA	GRAMINAE	JUGLANS	JUNIPER	LIQUIDAMBAR	MAGNOLIA	NYSSA	PICEA	PINUS	QUERCUS	SALIX	SPORES	TAXODIUM	TAXUS	TILIA	TSUGA	ULMUS	TOTAL	PALYNOMORPHS PER SLIDE
6-8	9	22	1	2			5	19			7		21	2	2	1	6	49	45	2	2	3	1		1		200	200
8-10	5	23	10		4	10	22				1	11	3		3		7	35	76		5	3					217	43
10-12	4	47				39		3	3			8	5		4		4	30	53		3					1	204	68
12-14	4	29				38			3			5	2	1	7	2	10	63	7		29			1			207	104
14-15																												
15-17½	6				1												18	165			13						203	36
17½-20		5			2											1	15	166	5		4		1	1			200	67
																											1,231	

Figure 26: Absolute Frequency Count of Palynomorphs and other Microfossil Groups of the Alloway Clay Member from Woodstown, New Jersey

PITMAN, NEW JERSEY

	ACER	ALNUS	CARYA	CHENOPODIACEAE	DIATOMS	DINOFLAGELLATES	ERICACEAE	GRAMINEAE	NYSSA	PICEA	PINUS	QUERCUS	SPORES	TILIA	TSUGA	TOTAL	PALYNOMORPHS PER SLIDE
25	1		15		3	19	2			15	79	91	1	1		227	227
26	2		23			48				21	122	29	1			246	246
27	1	1	18							31	215	24	1	1		305	305
28	1		21			6				19	139	27	1			213	213
29	1	1	40			8		2	1	34	249	102	1			439	439
34			54	1		3		20			6	203	6			283	283
35			11	2		31		1		1	24	127	2	1	1	201	201
																1,914	

Figure 27: Absolute Frequency Count of Palynomrphs of the Alloway Clay Member from Pitman, N. J.

GREENWICH, NEW JERSEY

	ABIES	ACER	ALNUS	BETULA	CARYA	CASTANEA	CELTIS	CHENOPODIACEAE	COMPOSITAE	CORYLUS	CYRILLA	DINOFLAGELLATES	ENGELHARDTIA	FAGUS	FORAMINIFERAL TEST LININGS	FUNGAL SPORES	GORDONIA	GRAMINEAE	ILEX	JUGLANS	JUNIPER	MAGNOLIA	MITELLA	MYRICA	MYRIOPHYLLUM	NYSSA	OSTRYA-CARPINUS	PICEA	PINUS	PLATYCARYA	POPULUS	PRUNUS	QUERCUS	RADIOLARIAN	SALIX	SILICOFLAGELLATES	SPARGANIUM	SPORES	TAXUS	TILIA	ULMUS	URTICA	TOTAL	PALYNOMORPHS COUNTED PER SLIDE
40	1	2			9	6				6		7						7	6	2		7					6	11	90	6		1	45					7				6	225	38
50		1			1			8	1	1		9						11	7	1		8						13	109			2	40					21					240	30
60		5			22			1		1		10						21	11	4		10						11	92			4	12					21					226	28
70			1	1	6			4		5		33						18		2		16						6	65				54					3					214	27
80			8	11	5	18	7	4		9	1	18		1				9	10	9	1					4	5	4	49			5	18					18					214	27
90			5	4	6			2		6	2	35		3		5		13	5	6	1			3		3		7	56			2	17		11			7					200	25
100		1			9						5	79			3					1								11	90			1			7						1		208	26
110			1	1	7					4	1	43			2						1					2	1	14	95				18			1	5	17			1		216	27
120			6	6	18	19		1		4	6	16		4					2		1					5		9	81	1			17	3		5		18					223	48
130			4	5	23	11		1		1		11	3	6					2	1						3	1	4	54	4			35					23		9			201	25
140			6		6	7		2		2		32		3								7				2	6	6	81	9			11	1	2	3		6	3				195	49
150					8							150			3							13			3				40														219	28
160		1	1	7	11	20		9		5	1	63							1								9		15				53		1			9		2	1		210	30
170			1	2	8	39		10		1	11	32					1		1								2	1	45	4			23		1			18		3	2		195	32
																																						3					212	30
180		1	1		55	14					6	89			3				7										25	5			3			1								
																																								1	2		212	42
190		1	1		7	10					2	85			5				8				4					2	60		4		17											
																																						21	4				217	54
200					8	9					1	38						1	10				4						109				9		2									
																																									1		198	25
210		12			14	15					4	43			2			1											88		3		13		2									

Figure 28: Absolute Frequency Count of Palynomorphs and other Microfossil Groups of the Kirkwood Formation from Greenwich, New Jersey

NEWFIELD, NEW JERSEY

	ABIES	ACER	ALNUS	BETULA	CARYA	CASTANEA	CELTIS	CORYLUS	CYRILLA	DINOFLAGELLATES	ENGELHARDTIA	ERICACEAE	FAGUS	FLANKTONIC FORAMINIFERA	FORAMINIFERAL TEST LININGS	FUNGAL SPORES	GORDONIA	GRAMINEAE	ILEX	JUGGANS
120			3	1	7			1				2				7		6		
130	4		2	2	16			1								5		1		
140																				
150			1	1	29		4	3				5				6		4	1	1
160		3	2	1	16		7	6										28	4	15
170					19	2		1			1	7	4			21		31	1	7
190					18						1	8	7			17		29	2	3
190		5			17			2			1	5	9			4		2	2	1
200																				
210					21					24			8		2				3	2
220					14					7	1		1	1					6	1
230		1	2	1	45	4		1		6	1	3	1		1				4	1
240			1	2	54	7		2		9	1	2	2						4	
250		2	1	2	16	1		4		6	1	2		3	1					
260			4	5	11			1		8	2			117	1					
270			5	4	14	1		4		20	1			17					8	
280			1	6	18	1		1		9	1			14	2		1	1	2	
290			1	2	13	1		2		63	1			29	3			1	3	
303					41	4			1		4					5			6	

	JUNIPER	LIQUIDAMBAR	MAGNOLIA	MYRICA	MYRIOPHYLLUM	NYSSA	OSTRYA-CARPINUS	PICEA	PINUS	PLANERA	PLATYCARYA	PRUNUS	QUERCUS	RHUS	SALIX	SPORES	TAXODIUM	TILIA	TSUGA	ULMUS	TOTAL	PALYNOMORPHS COUNTED PER SLIDE
120			7		1		1	16	107			1	49	1	7	3				1	221	111
130			2		1			17	139			1	23	1		5					220	110
140																						
150			1		1		1	14	111				20		2			2			207	104
160	1		1					9	73	3			22		3	22					216	43
170	1	2		5				6	50			1	16	1	6	27	7			4	220	55
190		1		2		7		13	94			2	19	4		18	3				248	62
190		2		3	1	9		4	33			4	123	2	3	7	3			1	243	122
200																						
210		1		1		3			26		4		87		19		2				203	34
220		5		2		10			23		1		137				10			9	228	76
230		1		1		3		1	90		2		31			19	5			4	228	114
240		2		2	1		2		46		1		67			10	2		1	1	219	110
250							2	1	110		2		48		3	7	3	2		1	218	107
260							1		35				147		2		2	2		1	337	110
270		4		1			3		15				137		2		8	5		1	250	233
280							2		21				131		2		3	1		1	218	204
290		2		1		1	1		25				73		1		2	1		1	227	99
303							1		6		4		128		1						200	25
																					3,903	

Figure 29: Absolute Frequency Count of Palynomorphs and other Microfossil Groups of the Kirkwood Formation from Newfield, New Jersey

MILMAY, NEW JERSEY

	ACER	ALNUS	BETULA	CARYA	CASTANEA	CELTIS	CHENOPODIACEAE	COMPOSITAE	CORYLUS	DINOFLAGELLATES	ENGELHARDTIA	EPHEDRA	ERICACEAE	FAGUS	FORAMINIFERAL TEST LININGS	FUNGAL SPORES	GRAMINEAE	ILEX	JUGLANS	JUNIPER	LIQUIDAMBAR	MAGNOLIA	MYRICA	MYRIOPHYLLUM	NYSSA	OSTRYA-CARPINUS	PICEA	PINUS	PTEROCARYA	PRUNUS	QUERCUS	RHUS	SALIX	SPORES	TAXODIUM	TILIA	ULMUS	TOTAL	PALYNOMORPHS COUNTER PER SLIDE
200				4						34									4		5						5	37			107					5		205	68
		[illegible]	[illegible]	18					4	27									1		2						3	26			113							196	94
		1	6	6					1	22					1												3	84			71							200	67
				31						25												2					2	24			116	1						201	50
250		2	2	7	3			1	2	6						6	7										4	43		1	107	1		7				199	50
		3	2	10	2				5	18						3	10											24		1	120	1				4		203	102
		3	1	31				1	4	8							3					1					3	31		1	117			5				209	70
		1	3	10				1	2	11						3	1										4	60			95			4		5		200	67
				25						14							5					2			13		1	57			83			5				205	68
300		1		16					3	8						2	1					1						38			129							199	50
				27	3				1	10						7	1					1					1	53		1	106			11				222	111
		1	2	7					5	21						1												20			135			5		3		200	50
		1	3	12					4	22						1	1											29			130					2		205	103
				15					4	10					1		10										1	44			113			14				212	212
																																					2	201	100
350					4					21											1							63			110						2	201	100
		2	1	12				5		16			3														2	68			84			4				197	99
				6	9					32			3															40			108							198	66
				11	3					21			2					[illegible]							5			35			115			5				198	198
					4				5	10			1					[illegible]							2		1	42			129			4				199	100
400				5	5				4	41							7	4						1	2		2	34			121			3		3		232	116
		1	2	20	7				1	34								1	1				1	1	9		5	46			67			11				207	104
		1	3	39	1				21	44				1				2	1		2		1				12	118			153			7		1		407	409
				27						4	1							1	2								8	69			89							201	101
				18	1					41					1	2			1				2	1			7	60	2		58					1		195	66
450					1		1			1																	14	118			60			1		4		200	40
460		1	2	25	3				4	22							1	1					1				11	81			51			2				205	103
		2	3	16	4				3	27					1		3										14	110			26							209	105
		1	1	9	1				3	4			3				4										16	113			43							198	66
			1	22		1			1	28									1							1	6	45			78							184	92
500		1	2	13					4	15						5	1								3		14	125			21							204	102
550										18		1	4			2	9										7	104			12			40				197	66
				24	4					41						1	4								1		5	73			54							207	69
			2	21	14					30						2	5										6	78			61							219	55
		4	3	15	4				3	1			1			3	3			1	4						6	120			45							213	107
		1		11						31			4				4			2							5	91			51							200	67
600		2	1	14					2	36							1	3			3						4	68			62							196	66
		3	2	5	2				2	32							1	1									1	57			92							198	40
			1	4						20							2	1		1	2				4		5	83			79			3				205	103
		1	4	9					1	19			1				4			1	1				3			33			116	2		4				199	199
										16			2	1			3	2							4		1	112			64			5				212	111
650																												151			42			10				203	68
										1			1															173			28			3				206	41
									2	44			2							2					1			110			37					2		200	20
					1				3	17			3	2		1				1	1				2		2	131			21			11				196	49
					1				3	10	1		3							1	3						2	143			28				1			196	65
700	1								1	149																		35			19							205	41
	1	1							2	164										1								24			13							206	34
									3	144										1								43			14							205	51
			2							113						4				2	2					1		59			14							197	49
		3	3	6					2	99			5			5				1	1				4	1		47	2		29							208	69
750		1	3	18					1	101			4							3	2					2		48			19							202	40
					2					166																1		29			3							201	38
										110																		45			44							199	20
		1			1					152							1				1					1		24			23							204	51
										172							4											21						4				201	20
800					1					111							3				2							60			31			5				213	43
										89					1													9			2							101	50
										91					1													3			6							101	34
										97					2													3			6							102	34
										78																		17			5							100	20
																																						11,579	

Figure 30: Absolute Frequency Count of Palynomorphs and other Microfossil Groups of the Kirkwood Formation from Milmay, New Jersey

ATLANTIC CITY, N. J.

	ABIES	ACER	ALNUS	BETULA	CARYA	CASTANEA	CHENOPODIACEAE	COMPOSITAE	CORYLUS	CYRILLA	DINOFLAGELLATES	ENGELHARDTIA	ERICACEAE	FAGUS	FUNGAL SPORES	GRAMINEAE	ILEX	JEFFERSONIA	JUGLANS	JUNIPER	LEAF HAIRS	LIQUIDAMBAR	NYSSA	PICEA	PINUS	PRUNUS	QUERCUS	SALIX	SPORES	TAXODIUM	TILIA	ULMUS	TOTAL	PALYNOMORPHS COUNTED PER SLIDE
400-425	1		1		15				2	2	3		6			5			1			3	1	11	125		21		3		4		204	51
425-446					16		7	1		3	28			2			3		4			2		8	112	1	10			5		1	203	104
464-482		2	2	4		3			3	4	11									1				10	145	2	10				4		201	100
482-500			1	1		2			3	3	9								2	2			1	10	156		17						208	52
500-519									2		12		3						1	1		2	2	8	144		27						202	40
519-539											15		2	1			1		1			3		7	143		28						201	25
539-559		2			19						125			5											31		18						200	100
559-579																																		
579-599					23	3					66			4										9	94		10	3					212	71
599-618																																		
618-637					3						28												2	17	152								202	67
637-656			1		3				3		11				2	4							3	14	119		22		30				212	53
656-676			1	1	4				2		5				5	3							1	16	125		11		36				209	70
676-690		4			1		1		1		12					4			6				1	13	94		32		39				208	42
690-710		3									62					1					1		6	9	63		14		45				204	34
730-758		2			10						83										2			13	89		6						205	68
750-760											33													2	15								50	25
																																	2,921	

Figure 31: Absolute Frequency Count of Palynomorphs of the Kirkwood Formation from Atlantic City, N. J.

Cape May

	ABIES	ACER	ALNUS	BETULA	CARYA	CASTANEA	CHENOPODIACEAE	COMPOSITAE	CORYLUS	CYRILLA	DINOFLAGELLATES	ENGELHARDTIA	ERICACEAE	FAGUS	FUNGAL SPORES	GRAMINEAE	ILEX	JEFFERSONIA	JUGLANS	JUNIPER	LEAF HAIRS	LIQUIDAMBAR	NYSSA	PICEA	PINUS	PRUNUS	QUERCUS	SALIX	SPORES	TAXODIUM	TILIA	ULMUS	TOTAL	PALYNOMORPHS COUNTED PER SLIDE
400-425	1		1		15				2	2	3		6			5			1			3	1	11	125		21		3		4		204	51
425-446					16		7	1		3	28			2			3		4			2		8	112	1	10			5		1	203	104
464-482		2	2	4		3			3	4	11									1				10	145	2	10				4		201	100
482-500			1	1		2			3	3	9								2	2			1	10	156		17						208	52
500-519									2		12		3						1	1		2	2	8	144		27						202	40
519-539											15		2	1			1		1			3		7	143		28						201	25
539-559		2			19						125			5											31		18						200	100
559-579																																		
579-599					23	3					66			4										9	94		10	3					212	71
599-618																																		
618-637					3						28												2	17	152								202	67
637-656			1		3				3		11				2	4							3	14	119		22		30				212	53
656-676			1	1	4				2		5				5	3							1	16	125		11		36				209	70
676-690		4			1		1		1		12					4			6				1	13	94		32		39				208	42
690-710		3									62					1					1		6	9	63		14		45				204	34
730-758		2			10						83										2			13	89		6						205	68
750-760											33													2	15								50	25
																																	2,921	

Figure 32: Absolute Frequency Count of Palynomorphs and other Microfossil Groups of the Kirkwood Formation from Cape May, New Jersey

Fredric Robert Goldstein

1944	Born May 11 in Brooklyn, New York
1962	Graduated from Abraham Lincoln High School, Brooklyn, New York
1962-66	Attended Brooklyn College, Brooklyn, New York
1966	B.S. in Geology, Brooklyn, New York
1966-68	Attended Miami University, Oxford, Ohio
1966-68	Teaching Assistantship, Miami University
1967	June-August, Instructor, Department of Geology, Brooklyn College
1968	Publication: A Geological Guide of the Bronx Park, New York Zoological Publication
1968	M.S. in Geology, Miami University
1968-69	Attended Cornell University, Ithaca, New York
1968-69	Teaching Fellowship, Cornell University
1969-74	Graduate Work in Geology, Rutgers University, New Brunswick, New Jersey
1969-71	Teaching Assistantship, Rutgers University
1970	Abstract: Initial Results of the Palynology of the Kirkwood Formation, Presented at the Annual Meeting of the New Jersey Academy of Science, Princeton University, Princeton, New Jersey
1971-72	Instructor, Science Department, Lakewood High School, Lakewood, New Jersey
1972-73	Instructor, Department of Earth, Space and Environmental Sciences, Western Connecticut State College, Danbury, Connecticut
1973	Abstract: The Palynology of the Kirkwood Formation, Presented at the Northeastern Sectional Meeting of the Geological Society of America, Allentown, Pennsylvania
1973	Abstract: The Pleistocene Stratigraphy of Southwestern Ohio, Presented at the Northeastern Sectional Meeting of the Geological Society of America, Allentown, Pennsylvania
1973-	Assistant Professor, Department of Chemistry, Trenton State College, Trenton, New Jersey
1974	Ph.D. in Geology, Rutgers University