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

REPORT OF INVESTIGATIONS NO. 55

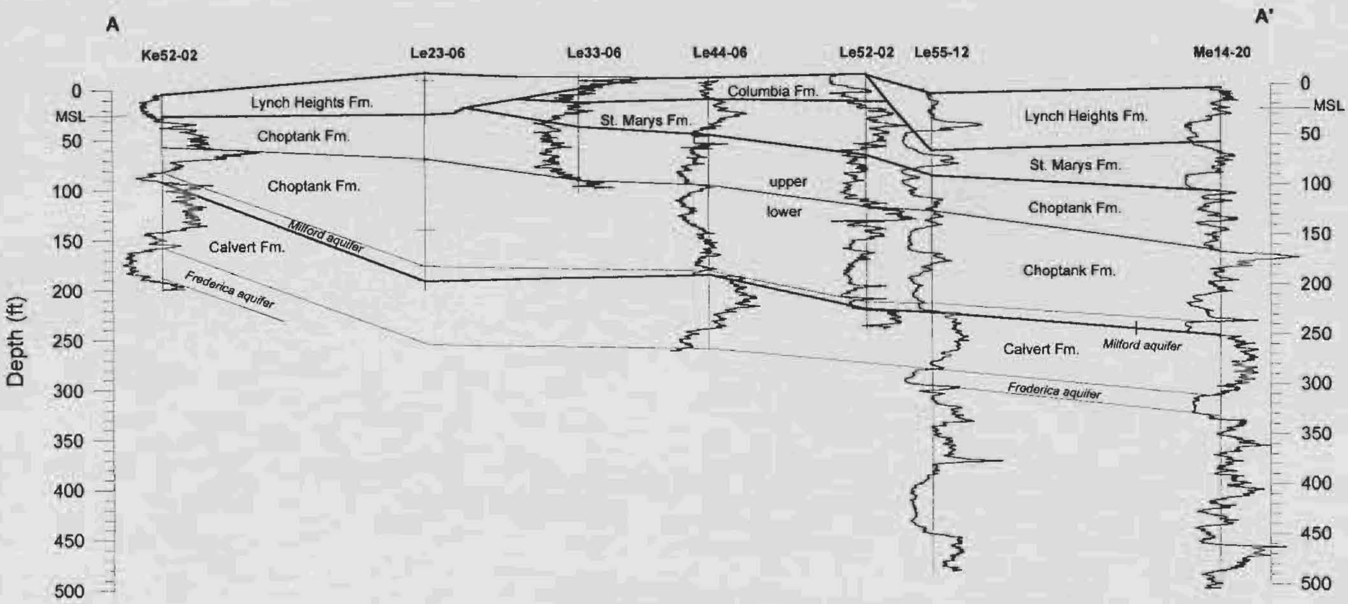
GEOLOGY OF THE MILFORD AND MISPILLION RIVER QUADRANGLES

by

Kelvin W. Ramsey

With a contribution on Palynology by

Johan J. Groot



University of Delaware
Newark, Delaware

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ABSTRACT

Investigation of the Neogene and Quaternary geology of the Milford and Mispillion River quadrangles has identified six formations: the Calvert, Choptank, and St. Marys formations of the Chespeake Group, the Columbia Formation, and the Lynch Heights and Scotts Corners formations of the Delaware Bay Group. Stream, swamp, marsh, shoreline, and estuarine and bay deposits of Holocene age are also recognized. The Calvert, Choptank, and St. Marys formations were deposited in inner shelf marine environments during the early to late Miocene. The Columbia Formation is of fluvial origin and was deposited during the middle Pleistocene prior to the erosion and deposition associated with the formation of the Lynch Heights Formation. The Lynch Heights Formation is of fluvial and estuarine origin and is of middle Pleistocene age. The Scotts Corners Formation was deposited in tidal, nearshore, and estuarine environments and is of late Pleistocene age. The Scotts Corners Formation and the Lynch Heights Formation are each interpreted to have been deposited during more than one cycle of sea-level rise and fall. Latest Pleistocene and Holocene deposition has occurred over the last 11,000 years.

INTRODUCTION

This publication accompanies Delaware Geological Survey Geologic Map No. 8 (Ramsey, 1993) and concentrates on the stratigraphy of the area covered by the Milford and Mispillion River quadrangles (Figs. 1 and 2). Knowledge of the stratigraphy is important for understanding the distribution of sand, silt, and clay bodies within the map area. These bodies control the distribution, transmission, and quality of ground water that is used for agricultural, public and private supply, and industrial purposes. Availability of mineral resources such as sand and gravel is also dictated by the distribution of these geologic units. Detailed discussion of the stratigraphy is limited to Miocene and younger lithostratigraphic units that have been penetrated by borings in the Milford and Mispillion quadrangles (Figs. 2 and 3; Appendix A). Except for the Columbia Formation, the formal units comprise two groups: the Chesapeake Group, consisting of the Calvert, Choptank, and St. Marys formations, and a newly recognized group, the Delaware Bay Group, consisting of the Lynch Heights and Scotts Corners formations. The Columbia Formation lies stratigraphically between these two groups. Informal units are the surficial Carolina Bay deposits, and the stream, swamp, marsh, shoreline, and estuarine and bay deposits. The Chesapeake Group is of Miocene age; the Columbia Formation and the Delaware Bay Group are of Pleistocene age; the Carolina Bay deposits are of probable Pleistocene and Holocene age; and the stream, swamp, marsh, shoreline, and estuarine and bay deposits are of Holocene age.

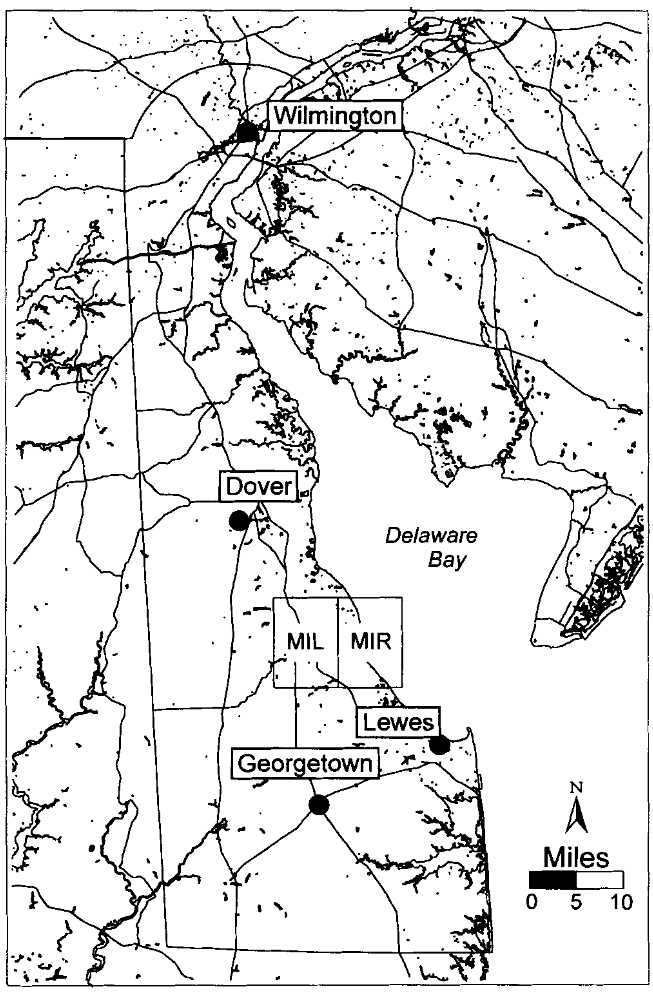

Figure 1. Location map of the Milford (MIL) and Mispillion River (MIR) quadrangles.

Acknowledgments

Thanks are to due to Alexis Richardson, Kathi Stetser, Patrick Thomas, and Stefanie Baxter for their help in the compilation of data for this report. I also wish to thank David Krantz, John F. Wehmiller, A. Scott Andres, and Robert R. Jordan for their discussions on aspects of the stratigraphy. Richard N. Benson was very helpful in working through the Miocene stratigraphy and correlations. Narendar Pendkar and Jim Maio conducted the clay mineral analyses. William S. Schenck provided help with the production of the graphics. Special thanks are due to Johan J. Groot for his efforts on unravelling the pollen stratigraphy and for his discussions on many aspects of this report. Nenad Spoljaric, Johan J. Groot, and John H. Talley provided reviews of the manuscript.

STRATIGRAPHY

Chesapeake Group

The Chesapeake Group in Delaware was described by Jordan (1962, p. 27) as "Predominantly gray and bluish-gray silt containing beds of gray, fine- to medium-grained sand and some shell beds" of Miocene age and that lie unconformably on the Piney Point Formation (Eocene) in Delaware south of Dover. The Chesapeake Group was not

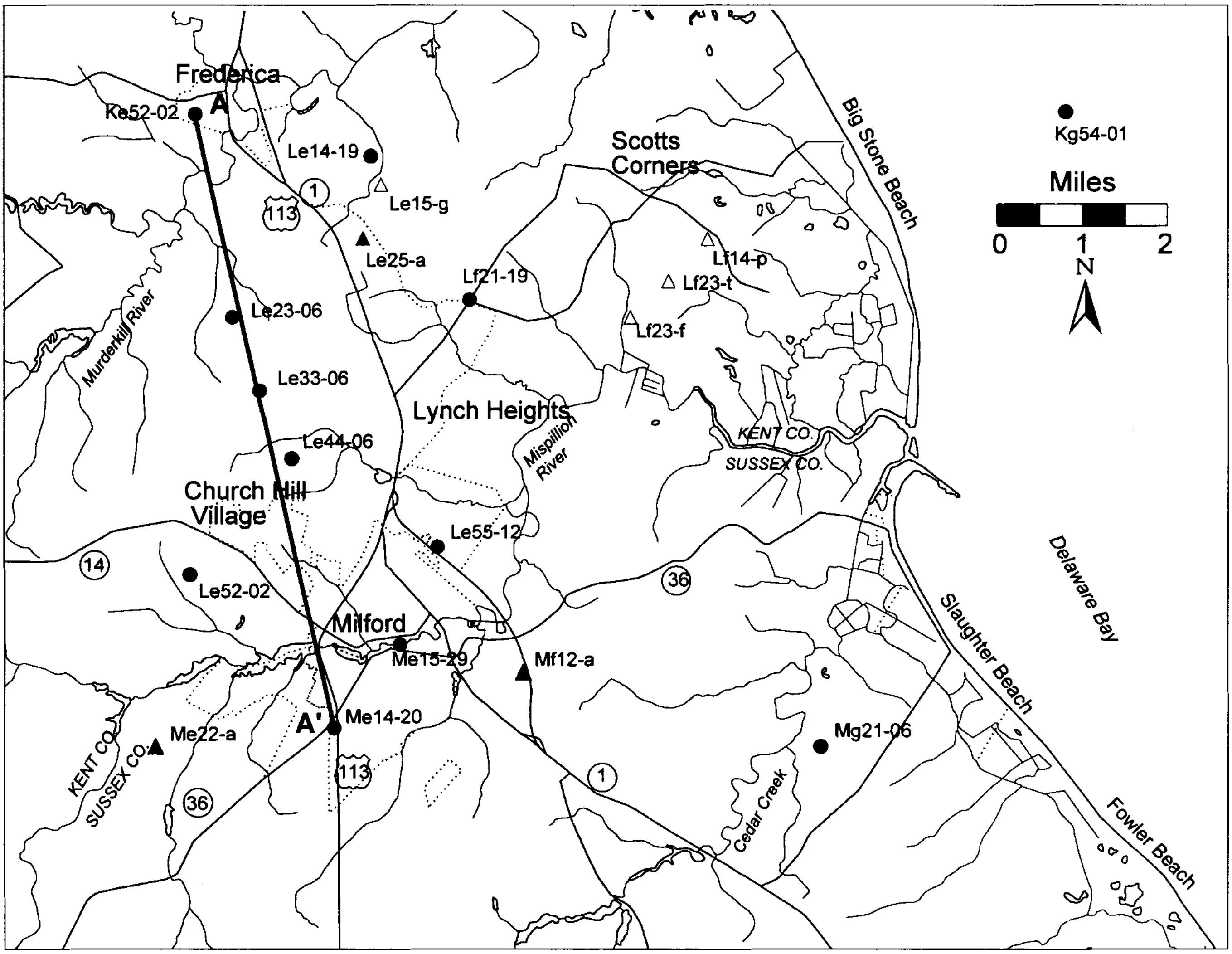

Figure 2. Location map of drill holes, cross-section, and place names in the mapping area. Filled circles- drill holes, open triangles- soil auger borings, filled triangles- outcrops.

subdivided into formations. It was described as being unconformably overlain by the Columbia Group sands and gravels. The lithologic description (Jordan, 1962) for the Group has not been greatly modified, and its usage is continued in this report. Some changes have been made to the definition of the Chesapeake Group in Delaware as to bounding stratigraphic units, the age, and the subdivision into formations. Data from drill hole Me15-29 (Fig. 4), located in Milford, indicate that the Chesapeake Group is composed of quartzose sands and silts that unconformably overlie an unnamed unit composed of glauconitic sands and silts of Oligocene age (Benson, 1990a). Three formations within the group have been recognized in the map area, in ascending order: the Calvert, Choptank, and St. Marys (Table 1). The Chesapeake Group (early to late Miocene age, Benson, 1990a) is unconformably overlain by sands, silts, and clays of the Columbia, Lynch Heights, and Scotts Corners formations. Sand bodies within the Chesapeake Group have been given informal names that refer both to their lithology and their capability to store and transmit ground water to wells. For example, the Cheswold sand refers to a series of sand bodies that are found in the lower portion of the Calvert Formation. The corresponding water-yielding unit is named the Cheswold aquifer. These units in the Milford area are discussed in a later section on aquifer recognition and nomenclature.

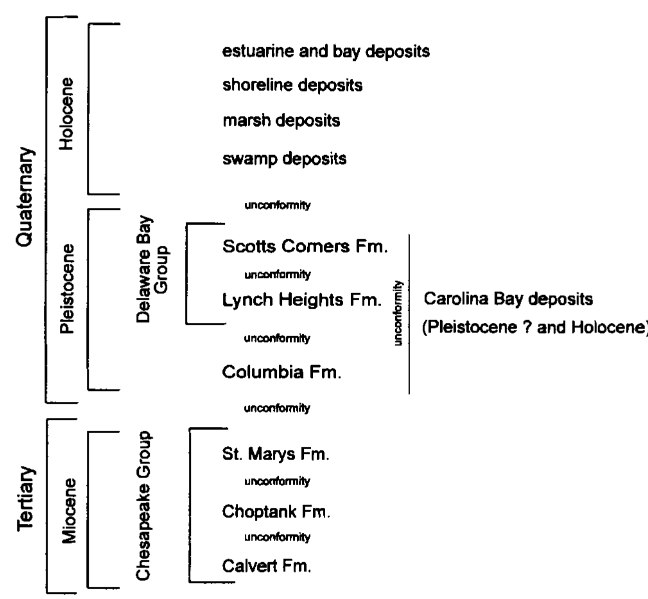

Figure 3. Miocene and younger stratigraphic units recognized within the map area.

Drill holes Me15-29 and Me14-20 (Fig. 4) are designated as reference sections for the Chesapeake Group in the Milford area. Me15-29 penetrated the entire thickness of the

Table 1

Summary of stratigraphic units of the Chesapeake Group in the map area.

FORMATION	AGE	STRATIGRAPHIC RELATIONSHIPS	LITHOLOGY	MINERALOGY	PALEO-CLIMATE	THICKNESS RANGE (FT.)
St. Marys	L. Miocene	Unconformable on Choptank Formation. Unconformably overlain by the Columbia and Lynch Heights formations.	Gray, fine to very fine sandy to clayey silt with thin sand and and shelly sand beds that grades down into or sharply overlies a gray, fine to medium sand with some shell with some coarse to granule sand and a few phosphate pebbles.	Quartzose. Percentage of feldspar & other minerals low. Quartz commonly clear. Clay minerals dominated by smectite with lesser amounts of illite , kaolinite and chlorite.	Warm temperate. Marginal marine.	0-60
Choptank	M.- L.. Miocene	Unconformable on Calvert Formation. Unconformably overlain by St. Marys, Columbia, and Lynch Heights formations. Divided into two fining-upward units informally called the upper and lower Choptank.	Basal dark gray to brown, medium to coarse to granule sand that grades upward into a fine to medium sand with abundant shell that grades upward into gray silty clay to clayey silt with scattered shell. Overlain by a gray, fine, silty, shelly sand that grades upward into a gray to greenish gray clayey silt to silty clay with scattered, thin fine shelly sand beds.	Quartzose. Percentage of feldspar & other minerals low. Quartz commonly clear. Clay minerals may be similar to those of the St. Marys and Calvert Formations. At least one sample dominated by a mixed layer assemblage. Other samples have smectite with lesser amounts of illite and kaolinite.	Warm temperate to subtropical. Marginal to open marine.	70-150
Calvert	E.-M. Miocene	Unconformably overlies a mid-Oligocene glauconitic sand. Unconformably overlain by the Choptank Formation.	Basal, gray, medium to coarse, quartzose, glauconitic sand that grades upward into gray, fine to medium, silty to shelly sand and in turn into a very fine, sandy silt. Lower unit overlain by three fining-upward units with a lower, gray, fine to medium sand that grades into a gray to dark brown, very fine sandy silt to silty clay. Shells common in the sands and silty sands.	Quartzose. Percentage of other minerals low. Clay minerals dominated by smectite with lesser amounts of kaolinite, illite, and chlorite.	Subtropical to warm temperate. Open marine.	Approx. 400-450

group and has geophysical logs (gamma and electric) and samples, and has been used in regional correlation (Benson, 1990a). Correlation between the two holes provides the basis for recognition of formational boundaries as well as intra-formational stratigraphy that was applied throughout the map area.

Calvert Formation

In drill hole Me15-29, the Calvert Formation is 414 feet thick (Fig. 4). The lowermost Calvert is a medium to coarse, quartzose, glauconitic sand about 15 feet in thickness. This sand grades upwards into fine to medium, silty to shelly, quartz sand and finally into a very fine sandy silt ("lower" in Fig. 4). Above the lower unit are three fining upward units ("1, 2, 3" in Fig. 4) with a lower, gray, fine to medium sand that grades upward into a gray to dark brown, very fine sandy silt to silty clay. Shells are common in the sands and silty sands. Drill hole Me14-20 penetrated the upper two units and was terminated in the sandy portion of the third. These units can be traced both updip toward Dover and downdip to drill hole Oh25-02 near Lewes, and to the southwest to Bridgeville (by examination of cross sections in Benson, 1990a).

Choptank Formation

In drill hole Me14-20, the Choptank Formation is 144 feet thick (Fig. 4). A similar thickness is projected for Me15-29. The Choptank is typically sandier than the underlying Calvert Formation. The contact between the Choptank and the Calvert is very distinctive, consisting of a dark gray to brown, medium to coarse to granule quartz sand overlying a compact brown clay. The clay is the uppermost Calvert and the sands are assigned to the Choptank. The position of the contact in Me15-29 differs from that of Benson (1990a, his Fig. 4) who put it at approximately 380 feet at a gamma spike on the basis of geophysical log correlation of the contact in boreholes Ni31-07 and Oh25-02 near Lewes, Delaware. In Oh25-02, he recognized the Calvert/Choptank boundary on the basis of the highest occurrences of five Calvert marker species (four molluscs and one bryozoan). In Me15-29, I place the contact stratigraphically above Benson's (1990a) pick at 225 ft (Fig. 4) at a distinct, mappable lithologic break interpreted to be a regional unconformity below which are found pollen assemblages associated with the Calvert Formation and above which are found pollen assemblages associated with the Choptank Formation (Groot, 1992; this report).

On the basis of examination of gamma log records of the formation, the Choptank was subdivided into two fining-upward units designated as the lower and upper Choptank (Ramsey, 1993). The lower Choptank consists of a basal, dark gray to brown, medium to coarse to granule sand that is commonly devoid of shells. This sand grades upward into fine to medium quartz sand with abundant shells and in turn into gray, silty clays to clayey silts with scattered shells. The top of the lower Choptank is marked by a silty clay that has a distinctively high gamma reading on the gamma-ray logs and is reported in drillers logs as being "hard" or "hard drilling." The upper Choptank also consists of a fining upward unit, but the sand is not as well developed as that of the lower Choptank and in places is thin or absent. The sand is a gray, fine-grained, silty, shelly sand that grades upward into a gray to greenish gray, clayey silt to silty clay with scattered, thin, fine shelly sand beds. In the Milford area, the lower Choptank is about 80 feet thick and the upper Choptank about 60 feet thick (Fig. 4). Updip, the upper and lower Choptank lose some of their character on gamma logs where the unit contains more sand throughout the section.

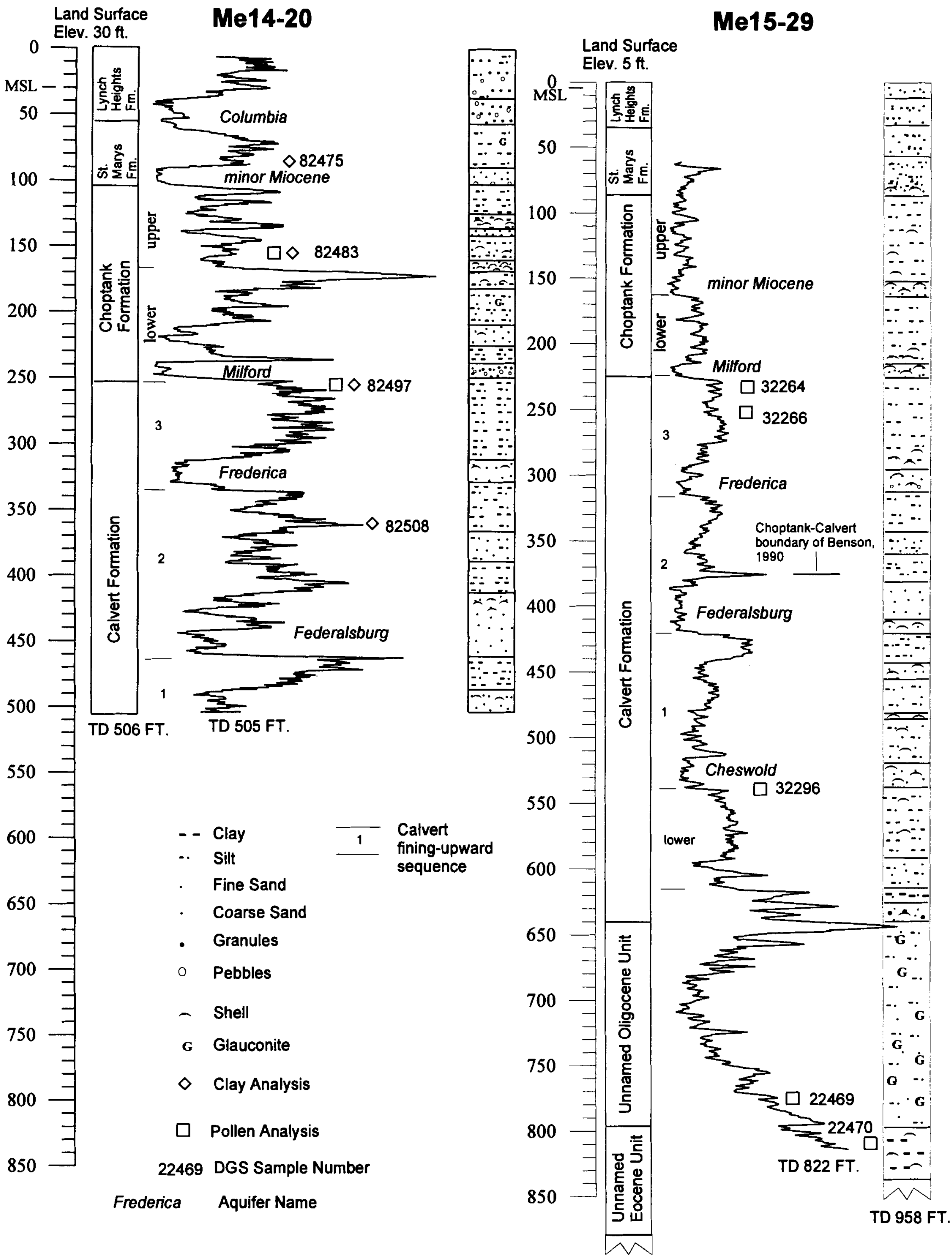

Figure 4. Stratigraphic units, gamma-ray logs, and lithologic columns for drill-holes Me14-20 and Me15-29 (reference sections for the Chesapeake Group in the Milford area).

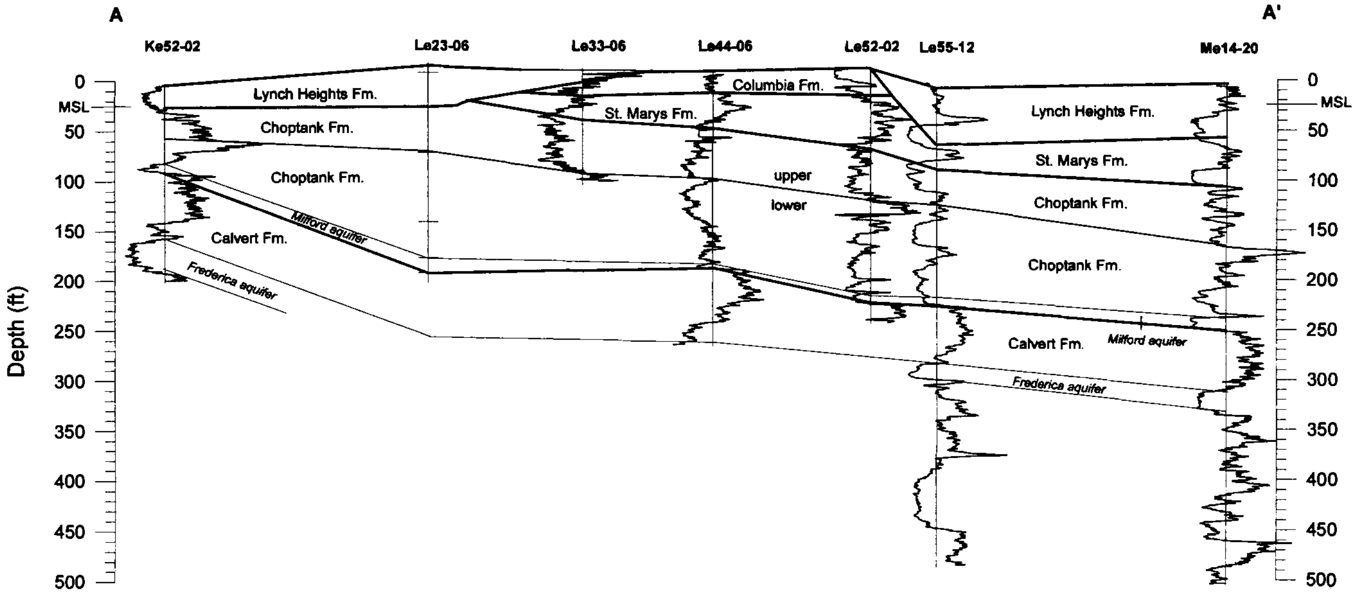

Figure 5. North-south cross-section from Frederica to Milford using gamma-ray logs. Note the Milford aquifer at the base of the Choptank Formation. See Figure 2 for location.

St. Marys Formation

Rasmussen et al. (1960) recognized the St. Marys Formation as a body of gray sand, silt, and clay that extends to depths of 200 feet in the Milford area. Ramsey (1993) subdivided this interval into the St. Marys Formation and the Choptank Formation. The St. Marys Formation ranges from a few feet thick near its updip limit to about 60 feet thick northwest and south of Milford. The St. Marys consists of a basal, gray, fine to medium sand with some shell that is gradational with, to sharply overlain by, a gray, fine to very fine, sandy silt to clayey silt. The silt contains some thin sand and shelly sand beds. Where the unit is thin to the north, shells are rare. The basal sand in a few localities contains some coarse to granule sand and a few, scattered phosphate pebbles. The gamma log signature for the St. Marys in the Milford area is not quite as distinct as that found downdip (Andres, 1986) but is still consistent enough for recognition of the formation (Figs. 3 and 4). The contact between the St. Marys and the overlying Quaternary units is irregular in topography where Quaternary-age channels cut into the unit (refer to cross-sections A-A′ and B-B′, Ramsey, 1993).

Aquifer Recognition and Nomenclature

Sand bodies within the Chesapeake Group are important resources because of their ability to store and transmit water that is used for domestic, public, agricultural, and industrial purposes. These bodies have been recognized as aquifers (Marine and Rasmussen, 1955) and have been given informal names based on their location and stratigraphic position (Rasmussen et al., 1960; Benson, 1990a). With growing demands on water resources and the entry of aquifer nomenclature into the realm of regulations and litigation, it has become increasingly important to clearly define the sand bodies in a stratigraphic context, to recognize their utility as aquifers, and to state the proper aquifer nomenclature. The nomenclature and stratigraphic context for aquifers within the Chesapeake Group in the vicinity of Milford was reviewed, and the designations for the aquifers in the area were established. This work builds upon that of Talley (1982) and includes a considerable amount of stratigraphic information and data that were not available at the time of his work. Understanding the stratigraphic position of these sand bodies is critical for correctly determining the aquifer name, especially in areas where any one of the aquifers is absent or has lost its character as a sand. For example, the Federalsburg aquifer is not everywhere present; the sand is commonly silty and in places grades to a silt. Identifying and naming aquifers up or down a section where the Federalsburg is only assumed to be present, may lead to an erroneous designation of those aquifers that are present.

There are five aquifers recognized within the Chesapeake Group in the Milford area (Figs. 4, 5, and 6). These are the Cheswold, Federalsburg, and Frederica aquifers located in the Calvert Formation, an aquifer at the base of the Choptank Formation, here named the Milford aquifer, and an unnamed aquifer system consisting of scattered sand bodies in the upper Choptank and lower St. Marys formations. The Cheswold, Federalsburg, and Frederica aquifers correspond to the three sand bodies that are part of the three upper fining-upward units of the Calvert Formation. Each may consist of one distinctive sand bed or several interconnected beds separated by scattered silty clay or clayey silt beds.

On the basis of correlation of the uppermost sand body in the Calvert Formation from Milford updip to Frederica and the paleontologic evidence that the brown clayey silts above the sand body are Calvert (Groot, 1992), the Frederica is recognized to be in the Calvert Formation (Figs. 4 and 5). Likewise, the sands that comprise the Cheswold aquifer have been traced downdip from the area of Cheswold north of Dover to Me15-29 in Milford (R. N. Benson, personal communication). The sand has also been traced updip from a deep well in the vicinity of Lewes (Benson, 1990a). Both studies place the sand bodies of the aquifer in the Calvert Formation in the positions as described above. The establishment of these two sand bodies in their proper stratigraphic context is critical for regional correlation and proper aquifer nomenclature. Both are delineated at or near their

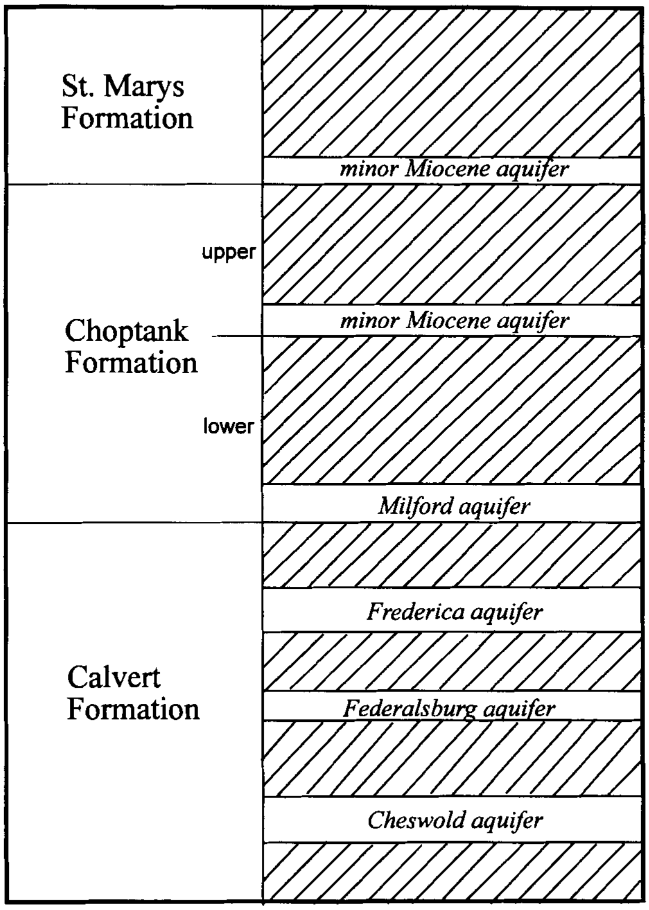

Figure 6. Schematic diagram of the position of aquifers within the Chesapeake Group in the Milford area.

type areas and traced from the type areas to the Milford area. The Federalsburg was placed by Talley (1982), between the Frederica and Cheswold aquifers, the position it was assigned by Cushing et al. (1973). A recognizable sand body occurs between the Frederica and Cheswold in the Milford area and is here called the Federalsburg (Figs. 4, 6). The Federalsburg in its type area has not been traced to Milford, however, and it cannot be stated with certainty that the type Federalsburg is the same sand body as, or connected with, that at Milford.

The regional correlation of the Cheswold and Frederica aquifers requires redesignation of aquifers in the Milford area. Rasmussen (1955) named the Frederica aquifer for sands used for water at the town of Frederica. The top of the sands was shown on a cross-section as being approximately 120 feet below sea level (see also the shallower Miocene sand in well Ke3 in Fig. 25 of Marine and Rasmussen, 1955). Correlation of the sands with wells in the Milford area placed the Frederica (shallower Miocene sand) at approximately 200 feet below sea level. This correlation was used by Cushing et al. (1973), Sundstrom and Pickett (1968, 1969) and Talley (1982). Detailed correlation in the present study, however, indicates that the Frederica actually occurs at depths of 250 to 300 feet in Milford (Fig. 5). Likewise, the Federalsburg and Cheswold aquifers are deeper than previously reported. That is, the aquifer names were assigned one sand body too high in the Milford area.

The basal sands of the Choptank Formation are a recognizable aquifer that is used extensively in the Milford area. It is here named the Milford aquifer. Its type section is drill hole Me14-20 in Milford (Fig. 4). This aquifer was previously called the Frederica aquifer in the area by Sundstrom and Pickett (1968, 1969), Cushing et al. (1973), and Talley (1982). This aquifer is found throughout the map area and a structure contour map of the base of the aquifer is shown in Fig. 7. Sand bodies in the upper Choptank and the basal St. Marys are irregularly distributed and locally produce water for domestic use. These are at present not assigned a name other than the minor Miocene aquifer of Talley (1982).

Columbia Formation

The Columbia Formation (Jordan 1964, 1974) in the Milford area is a light reddish brown to white, cross-bedded, medium to coarse sand with scattered thin beds of pebbles and gravel. Some discontinuous, thin beds of reddish brown clayey silt and medium to fine sand are present as well as rare beds of greenish gray clayey silt to silty very fine sand. The sands are quartzose with less than 25 percent feldspar (Jordan, 1964). The Columbia rests unconformably on the St. Marys Formation and, updip, the Choptank Formation. It ranges from only a few feet thick where it is truncated by the overlying Lynch Heights Formation to about 80 feet thick west of Milford where it is the surficial unit (cross sections A-A′ and B-B′, Ramsey, 1993).

Previous workers in the study area had denoted the Columbia Formation by a variety of names, Pamlico formation, Pleistocene series, or Beaverdam sand (Rasmussen et al., 1960). Owens and Denny (1979) mapped a portion of the outcrop area, here recognized as Columbia, as the Beaverdam Sand with a few patches of Pensauken Formation. The Pensauken Formation is a New Jersey and Maryland nomenclatural equivalent of the Columbia (Pazzaglia, 1993). A Tertiary age for the unit (Owens and Denny, 1979) is here considered to be incorrect. On the basis of an examination of pollen from the unit and examination of mineralogy and stratigraphic position, the Columbia Formation is considered to be early middle or early Pleistocene in age (Groot et al., 1995), in agreement with Jordan (1974), although Pazzaglia (1993) placed at least a portion of the unit in the Pliocene.

Outcrop Me22-a (Fig. 8) is here designated as a reference section for the Columbia Formation in the Milford area. A 30-ft vertical exposure in this privately-owned borrow pit shows the Columbia to be a medium to coarse, cross-bedded sand. The trough cross-bedding has abundant cut-and-fill structures in fining-upward beds that range from six inches to two feet in thickness. Pebbles and thin beds of gravel are found at the base of the cut-and-fill structures. Some of the pebble layers can be traced for lateral distances of a hundred feet or more. A few cobbles, with long axes less than a foot in length, were found in the exposure. Lithologies of the pebbles are dominated by quartz and chert. The general direction of dip of cross-beds is to the south and southeast. Two feet of greenish gray, clayey silt occur near the base of the exposure. Lithologies seen at the exposure are similar to those reported in driller's logs from the area. A summary description of the Columbia Formation is given in Table 2.

Delaware Bay Group

The Delaware Bay Group is herein named for the sand, silt, clay and organic-rich deposits found adjacent to the present Delaware Bay that comprise the Lynch Heights and

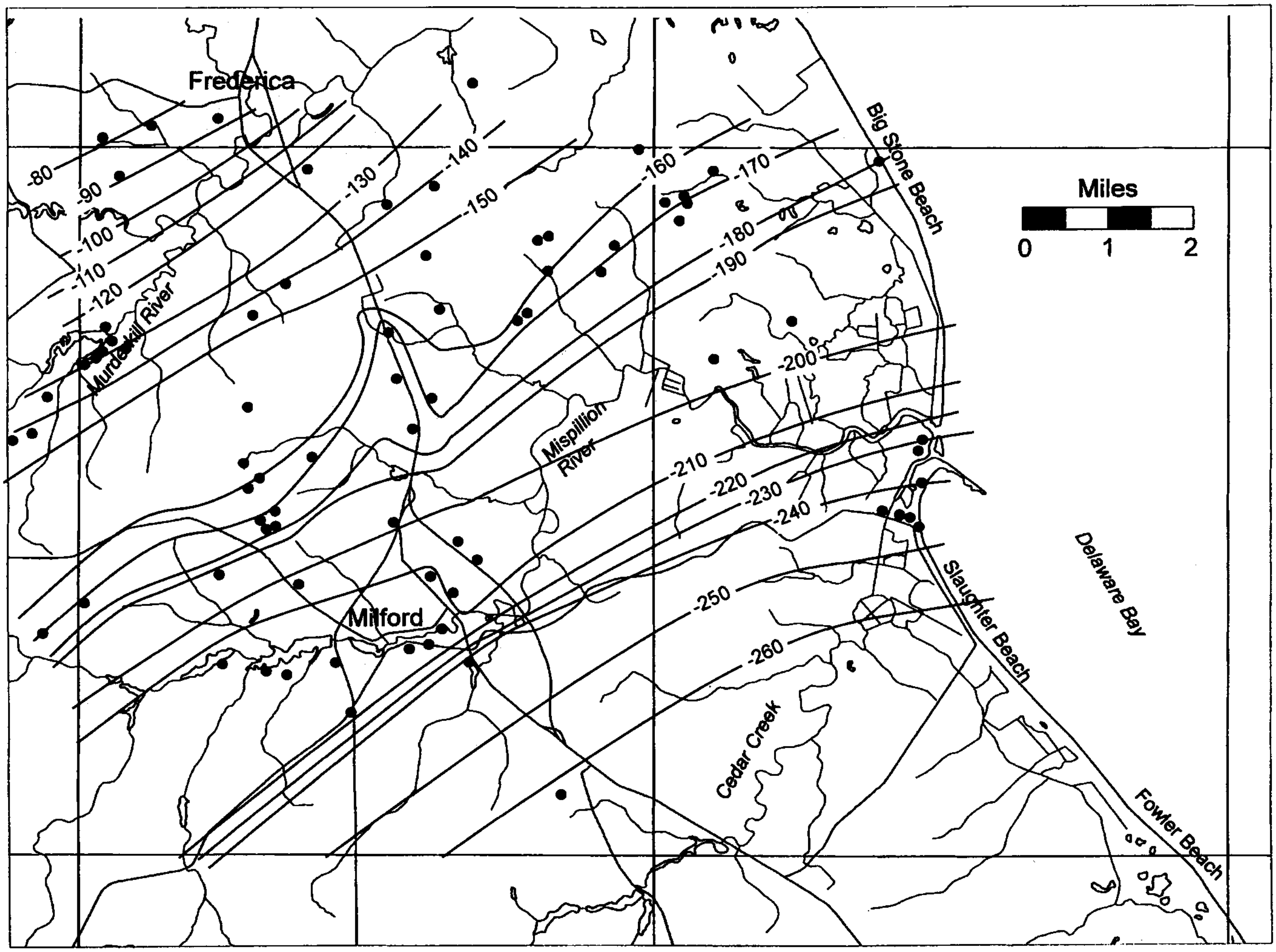

Figure 7. Structure contour map of the top of the Calvert Formation (base of the Milford aquifer) in the map area. Contour interval is 10 feet. Contour numbers are in feet below mean sea level. Filled circles represent well data points used in the construction of the map.

Table 2

Summary of stratigraphic units of Quaternary age in the map area.

FORMATION	AGE	STRATIGRAPHIC RELATIONSHIPS	LITHOLOGY	MINERALOGY	PALEO-CLIMATE/ DEP. ENV.	THICKNESS RANGE (FT.)
Scotts Corners	L. Pleistocene	Unconformable on Lynch Heights. Unconformably overlain by Holocene deposits.	Light gray to brown to light yellowish brown, coarse to fine sand with discontinuous beds of organic-rich clayey silt, clayey silt, coarse to very coarse sand, and pebble gravel	Quartzose, <10% feldspar and some muscovite. Mixed clay assemblage of kaolinite, smectite, illite, chlorite, and mixed layer clays in decreasing order of abundance. 1% vermiculite.	Temperate to warm temperate. Fresh-water stream to estuarine to bay-bottom.	0-25
Lynch Heights	M.-L. Pleistocene	Unconformable on Columbia, St. Marys and Choptank formations. Unconformably overlain by Scotts Corners Fm. and Holocene deposits	Light yellowish and light reddish brown to gray medium sand with discontinuous beds of fine to very fine silty sand, reddish brown to brown clayey silt, and organic-rich clayey silt to silty sand. Some beds of medium to coarse pebbly sand with scat. cobbles and coarse to granule sand.	Quartzose, approx. 25% feldspar. Micaceous where sands are fine to very fine grained. Mixed clay assemblage of kaolinite, illite, chlorite, smectite, and mixed layer clays in decreasing order of abundance. 1% vermiculite.	Warm temperate to cool temperate. Probably cooler than Scotts Corners. Fluvial-estuarine	0-50
Columbia	E.-M. Pleistocene	Unconformable on St. Marys and Choptank formations. Unconformably overlain by Scotts Corners and Lynch Heights fms. and Holocene deposits.	Light reddish brown to white, cross-bedded medium to coarse sand with scattered thin beds of pebbles and gravel. Some discontinuous, thin beds of reddish-brown clayey silt and medium to fine sand and rare beds of greenish-gray silt to silty very fine sand.	Quartzose, 10-30% feldspar. Mixed clay assemblage of kaolinite, smectite, illite, and chlorite. Up to 2% vermiculite.	Cool to cool temperate. Fluvial.	0-80

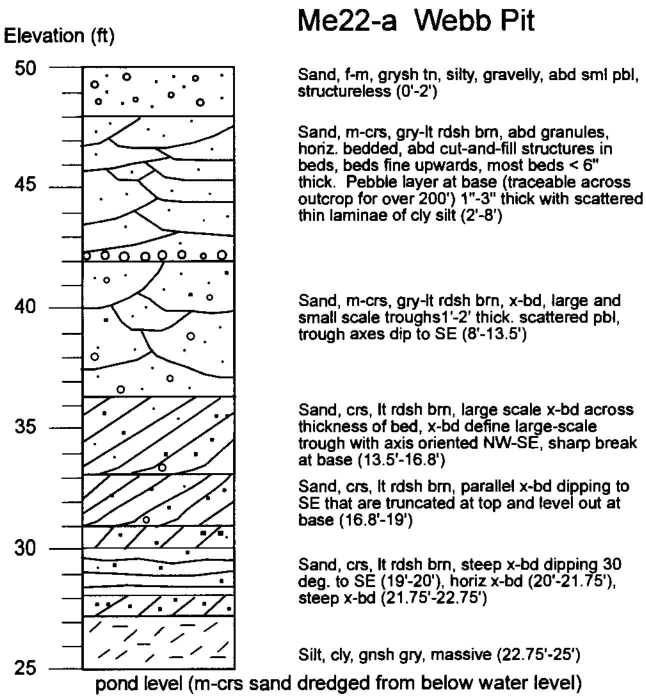

Figure 8. Lithologic description of Me22-a, reference section for the Columbia Formation in the map area. Numbers in parenthesis denote an interval of feet below land surface in which the unit described was found. Abbreviations for lithologic descriptions for this and subsequent figures are from Swanson, 1981.

Scotts Corners formations. It takes the place of an informal unit, the Delaware Bay deposits (Ramsey and Schenck, 1990). The name is taken from Delaware Bay, a large estuary located between the states of Delaware and New Jersey. It is an appropriate name for the group because the deposition and geographic and stratigraphic distribution of the sediments within the group are related to the geologic history of the estuary and are located adjacent to Delaware Bay. The Group lies unconformably above Cretaceous and lower Tertiary rocks, the Chesapeake Group, and the Columbia Formation and extends for a distance of over 50 miles between the outcrop area of the Columbia Formation and the Holocene depositional systems marginal to Delaware Bay.

The two formations comprising the Group, the Lynch Heights and Scotts Corners formations (Table 2, Fig. 3), are wedge-shaped deposits that thicken toward the present Delaware Bay. The stratigraphic position of the group is a cut-and-fill body inset into the Columbia Formation and older deposits. Each formation represents one or more periods of erosion and deposition associated with fluctuations of the margins of the Delaware River and estuary (Delaware Bay). The deposits within the group consist of light reddish brown to gray, medium to coarse sands with common beds of fine to medium sand and very fine to fine sandy silt. Also present are beds of gray clayey silt and brown, organic-rich clayey silt that are commonly found in lensoid channel-fill bodies. The sands are quartzose with varying amounts of feldspar, slightly less than that found in the Columbia Formation. The deposits are heterogeneous both vertically and laterally. The general trend within the group is that the sediments fine upward, but there are exceptions. The surficial expression of the group is that of terraces consisting of flats or treads sloping toward Delaware Bay separated by breaks in topography (scarps). The surficial contact between the Lynch Heights and Columbia Formation is associated with a subtle to distinct scarp indicative of the erosional contact between the two units. The sediments within the group were deposited in stream, swamp, marsh, estuarine barrier and beach, and offshore estuarine environments (Ramsey, 1993). Where the major channel of the ancestral Delaware River was located, fluvial deposits are also present.

Jordan (1974) summarized the history of the nomenclature of the Pleistocene units of Delaware and specifically the background and usage of the terrace-formation nomenclature within Delaware. He rejected the usage of these terms in favor of the Columbia, Beaverdam, and Omar formations. The early work of Miller (1906) and Bascom and Miller (1920) recognized a geologic unit (Talbot Formation) parallel to the present Delaware Bay that was distinct from the sand of the unit now called the Columbia Formation (their Wicomico Formation). Because of the confusion between stratigraphic and geomorphic terminology associated with the Talbot Formation (Jordan, 1962, 1974), the term is not used in Delaware. Credit must be given to these geologists, however, for recognizing what is here called the Delaware Bay Group. Ramsey and Schenck (1990) recognized the existence of these deposits adjacent to Delaware Bay and used the informal term "Delaware Bay deposits." Ramsey (1993) named two formations in the Milford and Mispillion River quadrangles the Lynch Heights Formation and Scotts Corners Formation within the area mapped previously as the "Delaware Bay deposits."

Detailed mineralogic examination of the deposits now placed within the Delaware Bay Group as well as the Columbia Formation was conducted by Jordan (1964). At the time, all the samples examined were considered to be a part of the Columbia Formation. Sample sites in and adjacent to the area of this study recorded in Jordan's original field maps and notes were examined and have been assigned to formation according to the mapping presented in this study (Table 3). These data were supplemented by visual examination of samples from the study area with a binocular microscope in order to determine gross mineralogy. No specific counts of grain mineralogy were made; rather, visual estimates of mineralogy were made based on grains

Table 3

Mineralogy of the Columbia Formation in the map area. DGSID- outcrop identifier; RRJID- locality identifier of Jordan, 1964; qtz- quartz; h.m. index- heavy mineral index (stable mineral index of Jordan, 1964; ratio of percentages of zircon+tourmaline+rutile to all other non-opaque mineral percentages); Qcl- Columbia Fm., Qlh- Lynch Heights Fm., Qsc- Scotts Corners Fm., Qcb- Carolina Bay deposits.

DGSID	RRJID	% qtz	% feldspar	h.m. index	map unit
Ke54-a	Ke-I	68	31	1.17	Qlh
Ld14-c	Ld-II	68	30	0.22	Qcl
Le22-a	Le-I	74	24	1.37	Qlh
Lf51-b	Lf-II	73	26	1.1	Qlh
Me22-a	*	61	28	0.64	Qcl
Me45-a	Me-II	89	11	0.91	Qcl
Mf12-b	Mf-I	91	10	0.96	Qlh
Mg52-a	Mg-I	96	4	0.55	Qsc (Qcb)
Ng11-a	Ng-I	96	4	1.75	Qsc
	Average	80	19	0.96	

*from Leggett (1992)

observed in several fields of view from a single sample. The visual examinations yielded similar results to the detailed mineralogy of Jordan (1964). Mineralogy of one sample from the Columbia Formation at Me22-a was examined by Pazzaglia (1993) and Leggett (1992) and is included in Table 3. The percentages of quartz and feldspar and the heavy mineral stability index are within the ranges reported by Jordan (1964) for the Columbia Formation.

This study is in agreement with Jordan (1964) that there are no discernable patterns in relation to mineralogy and elevation. In part this is due to the fact that the Columbia, Lynch Heights, and Scotts Corners formations can all be found at the same elevations (cross-section A-A′, B-B′; Ramsey, 1993). Likewise, the mineralogies for the Quaternary units, both light and heavy minerals, do not appear to be distinctive enough to separate the units solely on mineral content (Jordan, 1964). As observed by Miller (1906) and Bascom and Miller (1920), the terraces identified can not be recognized by mineralogy alone. The only general observation to be made is that the percentage of feldspar is less in the Scotts Corners Formation than in the Columbia Formation (Table 3). Unless detailed comparative mineralogy of the Quaternary units reveals otherwise, the units can not be separated using mineral content alone; however, on the basis of the geologic ages and the cut-and-fill relationship of the two formations to the Columbia, they are not the same unit.

On the basis of examination of pollen from the Scotts Corners and Lynch Heights formations and comparison with age correlative deposits along the Delaware Atlantic Coast (Groot et al., 1990; Groot, this report) and offshore New Jersey (Groot et al., 1995) dated by amino acid racemization, the Delaware Bay Group is considered to be middle to late Pleistocene in age. Age estimates suggest that the deposits are less than 500,000 years old (Groot et al., 1995). Palynologic evidence indicates some variation in climate during deposition. Most samples from these units indicate cool temperate to temperate climates, but some samples also indicate deposition during cold periods of climate (refer to the palynology section, this report). On the basis of examination of outcrop and subsurface geologic data and the geomorphic expression of the deposits, the Delaware Bay Group can be traced from inland of Cape Henlopen up the entire margin of Delaware Bay to Wilmington. It is likely that the Cape May Formation of New Jersey is a correlative unit across Delaware Bay and could be formally included within the group. Also included within the group are various units of Quaternary age that are below the waters of the present Delaware Bay (Twichell et al., 1977; Knebel et al., 1988). The group is likely coeval with the Omar Formation of southeastern Delaware (Jordan, 1974; Groot et al., 1990) and the Sinepuxent and Ironshire formations of Maryland (Owens and Denny, 1979).

Lynch Heights Formation

The Lynch Heights Formation was named after the unincorporated village of Lynch Heights just north of Milford near where the formation was first recognized from lithologic descriptions from numerous driller's logs (Ramsey, 1993). It consists of light yellowish and light reddish brown to gray medium, quartz sand with discontinuous beds of fine to very fine silty sand, reddish brown to brown clayey silt, and organic-rich clayey silt to silty sand. Lesser amounts of medium to coarse pebbly sand with scattered cobbles and coarse to granule sand also are present. Where the sands are fine to very fine grained, they are quartzose and slightly feldspathic and micaceous. The unit is up to 50 feet thick and thins from east to west.

The type section of the Lynch Heights is drill hole Lf21-19 (Fig. 9 and Ramsey, 1993). This locality as well as a borrow pit just east of Milford (here designated as reference section Mf12-a (Fig. 10) show the typical sequence found within the Lynch Heights where it is the surficial stratigraphic unit. Although there is heterogeneity of bedding within the formation, it can be subdivided into a lower medium to coarse sand, a middle interbedded clayey silt and fine to medium sand, and an upper medium sand fining upward to a fine sand to fine sandy silt. In places, the upper sand is coarse with pebbles, such as at reference section Mf12-a (Fig. 10).

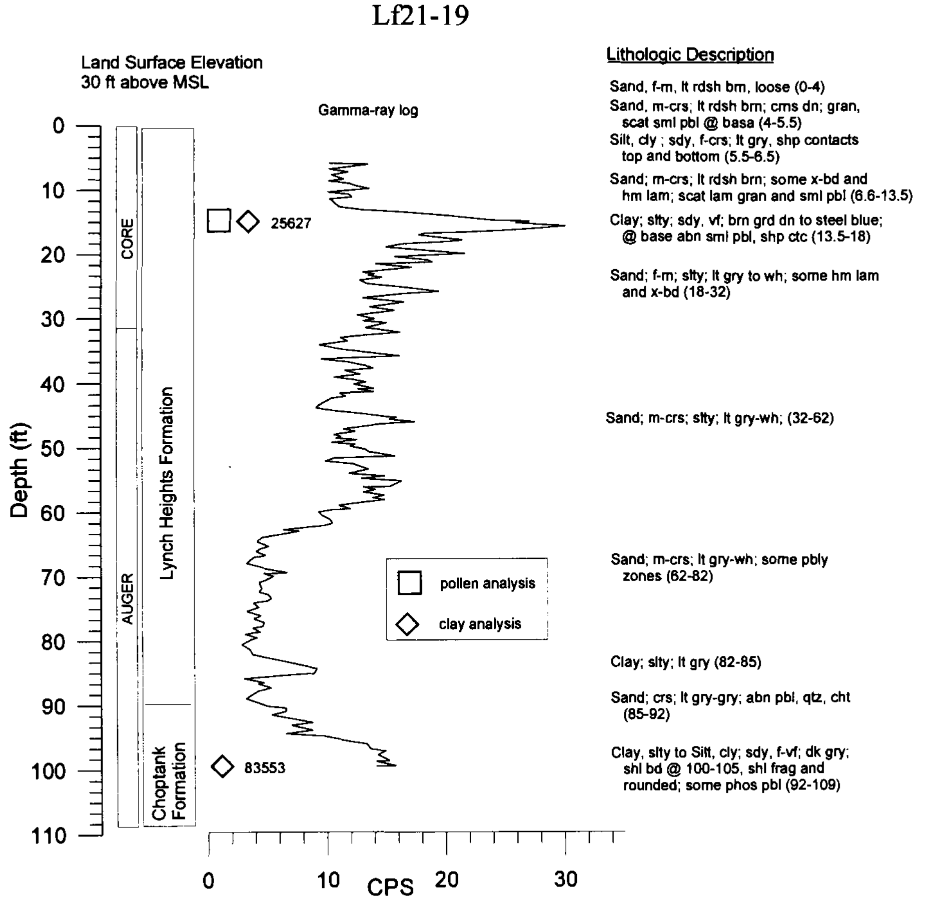

Figure 9. Gamma ray log and lithologic description of material from drill hole Lf21-19, type section of the Lynch Heights Formation. Numbers in parentheses denote an interval of feet below land surface in which the unit described was found.

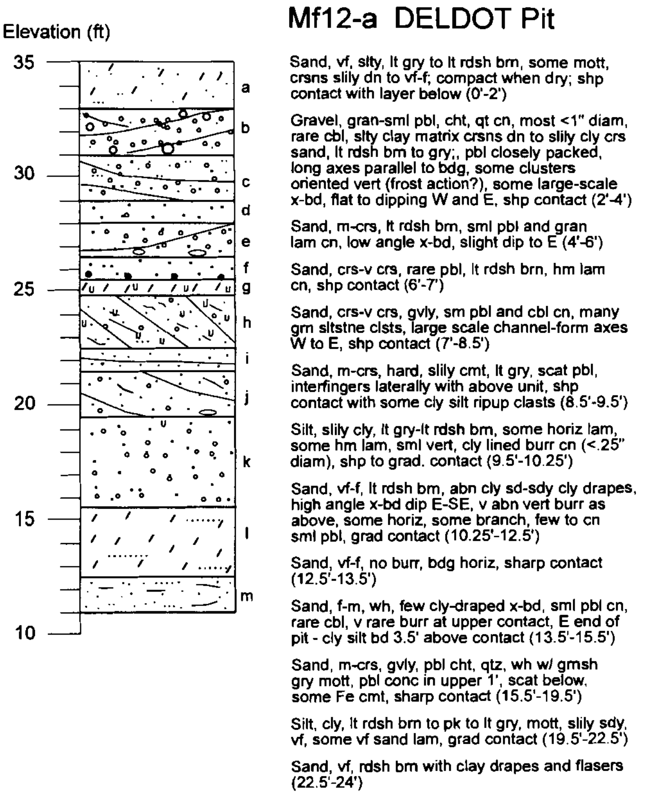

Figure 10. Lithologic description of Mf12-a, reference section for the Lynch Heights Formation. Numbers in parentheses denote an interval of feet below land surface in which the unit described was found.

The interbedded clayey silt and fine sand is commonly burrowed. In the area around Lynch Heights and to the west, this interval has a characteristic yellowish red to red color that is noted in many of the drillers' lithologic logs. To the east where the Lynch Heights is overlain by the Scotts Corners Formation, the formation is coarser, ranging from medium to coarse, but there is a trend of fining from west to east (cross section A-A´, Ramsey, 1993). Where the unit thins to the west and pinches out against the Columbia Formation, the middle, finer-grained facies is absent, and medium to fine sand overlies the coarse sands at the base of the unit. A detailed lithofacies analysis of the unit has not been conducted owing to the paucity of outcrops or exposures and cores.

The Lynch Heights rests unconformably on the St. Marys Formation, or where the St. Marys is absent, the Choptank Formation. Where the Columbia Formation is present, the Lynch Heights lies unconformably on that unit and the surficial expression of the contact between the two units is marked by a recognizable to subtle break in topography (scarp). The base of the Lynch Heights commonly contains a bed of coarse sand with pebbles that rests on the finer-grained units of the Chesapeake Group. Recognition of the contact between the Lynch Heights and Columbia is not always easy. Criteria are changes in sediment texture, color, or sorting between the two units, and a pebbly sand or an ironstone layer (iron-cemented sand) at the contact. The Lynch Heights tends to be finer-grained and better-sorted than the Columbia and has a greater variety of colors. The Columbia tends to have colors that are in the light to dark reddish brown to white range whereas the Lynch Heights ranges from light red (almost pink) to yellow to gray.

Previous work (Jordan, 1964, 1974; Talley, 1982) placed the sediments of the Lynch Heights in the Columbia Formation. It was also referred to as the Pamlico formation, Parsonsburg sand, Beaverdam sand, or Pleistocene series (Rasmussen et al., 1960). Owens and Denny (1979) in a regional map showed the area east of Milford to be underlain by the Omar Formation and to the east of the Omar, the Ironshire Formation. In Milford and to the west, the Beaverdam sand was mapped along with patches of the Pennsauken Formation. Identification of these units was attempted but the lithologies in their type areas differed markedly from those found in the Milford area. The Omar Formation of southeastern Delaware (Jordan, 1974) is in part age coeval with the Lynch Heights Formation but is lithologically distinct (characteristically finer-grained than the Lynch Heights or Scotts Corners), having been deposited in lagoon and barrier systems related to the open ocean coast (Groot et al., 1990).

Scotts Corners Formation

The Scotts Corners Formation was named after the crossroads of Scotts Corners located on Milford Neck northeast of Milford near where the formation was first recognized from numerous shallow drill holes in the Milford Neck Wildlife Area (Ramsey, 1993). It consists of light gray to brown to light yellowish brown, coarse to fine sand with discontinuous beds of organic-rich clayey silt, clayey silt, coarse to very coarse quartz sand, and pebble gravel. The unit is much thinner than the Lynch Heights, having a maximum thickness of about 25 feet. The sands are quartzose with some feldspar and muscovite. Laminae of opaque heavy minerals are common.

The type section of the Scotts Corners is auger hole Lf14-p (Ramsey, 1993). It is typical of the Scotts Corners on Milford Neck and consists of a reddish brown to gray, thin, clean to muddy, pebbly, coarse, quartz sand overlain by a brown organic-rich clayey silt. The silt is in turn overlain by a light gray, medium to coarse, cross-bedded sand that fines upward and is capped by a light gray to light reddish brown silt (Fig. 11). Numerous shallow drill holes (cross-sections C-C´, D-D´, E-E´, Ramsey, 1993) show that the organic-rich silts and clayey silts are generally associated with channel-

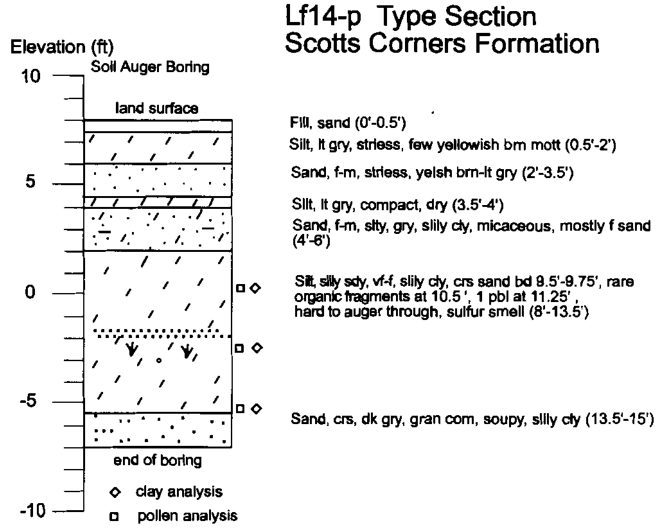

Figure 11. Lithologic description of Lf14-p, type section of the Scotts Corners Formation. Numbers in parentheses denote an interval of feet below land surface in which the unit described was found.

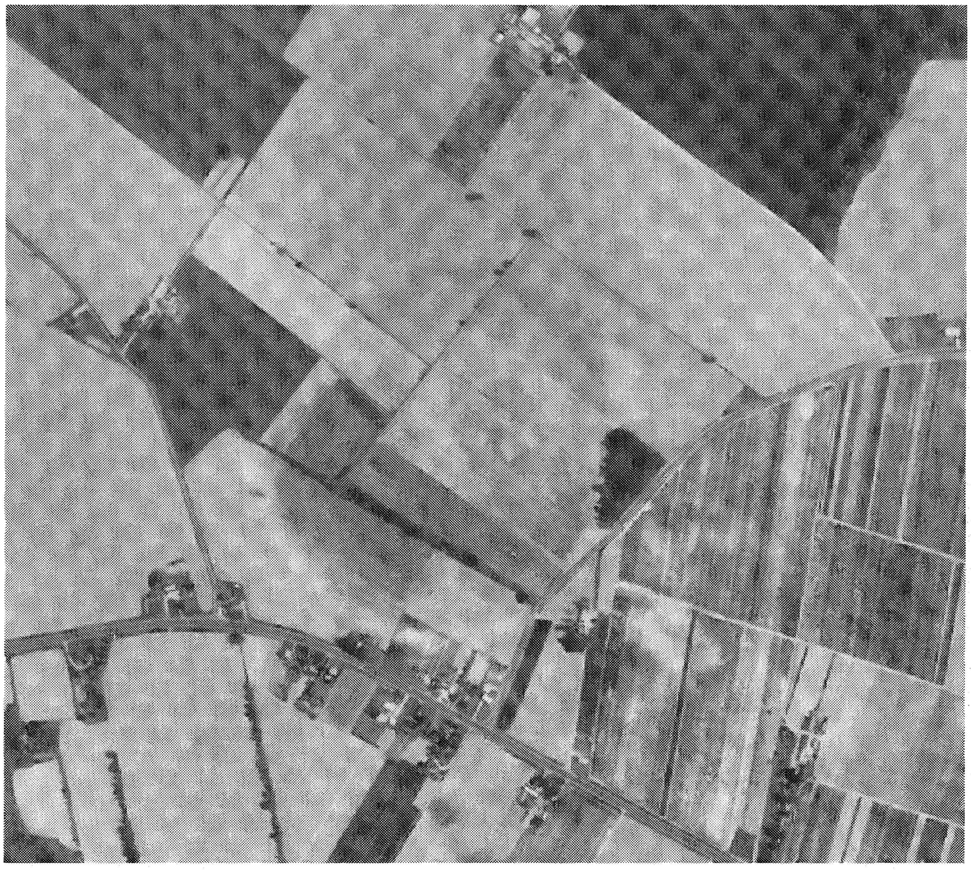

Figure 12. Aerial photograph of a Carolina Bay near Church Hill Village west of Milford (from Soil Conservation Service photo AHP2JJ-31 taken on May 7, 1968). The sandy rim shows up as a light colored circular feature most prominent on the south and southeast sides of the bay. North is to the top of the photograph.

fill features that are a part of the Scotts Corners. Where the silts are absent, the section is dominated by sand and is thinner. To the south of the Mispillion River, the Scotts Corners is sandier than on Milford Neck and mud-filled channels are rare. In places, the unit is capped by small sand dunes and sand sheets composed of fine to medium, light gray (where water-saturated) to light yellowish brown sand.

The Scotts Corners Formation rests unconformably on the Lynch Heights Formation. The surficial contact between the two units is marked by a sharp break in topography (scarp) that descends from elevations of thirty feet or more on the Lynch Heights to elevations of twenty feet or less on the Scotts Corners. The base of the Scotts Corners is commonly marked by a coarse sand to pebble gravel that overlies a compact, oxidized sand of the Lynch Heights. South of the Mispillion River, this contact in many places may be difficult to recognize where the sands of the Scotts Corners are texturally and mineralogically similar to those of the Lynch Heights. The contact is marked by a concentration of pebbles and heavy minerals in a sand that is cleaner than the slightly silty sands of the underlying Lynch Heights. An oxidized zone beneath the contact is not everywhere present, but is common.

The Scotts Corners is restricted to the area east of a break in topography (scarp) between elevations of thirty feet or more to the west and twenty feet or less to the east and to a similar area adjacent to the two major streams, the Mispillion and the Murderkill rivers. The toe of this scarp is at approximately eighteen feet. East of the scarp the land surface slopes to where it is being overridden by the present marshes at elevations just above present mean sea level. The scarp is interpreted to be an ancestral shoreline of Delaware Bay at a period when relative sea level was higher than at present (approximately 18 feet).

Carolina Bay Deposits

Elliptical- to oval-shaped shallow depressions are found scattered on the land surface throughout the map area. They vary in size from less than 500 to greater than 2500 feet in diameter. A "rim" composed of sand is characteristic of these features. The rim is best developed on the east and southeast sides of these depressions. The largest of these features is found at Church Hill Village on Route 14 west of Milford (Fig. 12). Others are found along Route 13 north of Lynch Heights, along Milford Neck Road in the Milford Neck Wildlife area, and south of Route 36 on Slaughter Neck (Ramsey, 1993).

These features have long been referred to as bays or Carolina Bays (Thornbury, 1969) and have been recognized in the Coastal Plain from New Jersey to Georgia. Rasmussen et al. (1960) recognized "bays" in Sussex County and showed an aerial photograph of three such features near Milton, just south of the map area. The origin of the bays is a matter of much debate (Thornbury, 1969). In Delaware, their formation appears to be associated with times of cold climate when vegetative cover was reduced, sea level was lower, and wind moved considerable amounts of sand around unimpeded by large tracts of tree cover. Formation may have occurred during a single span of time or may have occurred during multiple episodes. The features in the map area are formed on geologic units of differing ages, the Columbia, Lynch Heights, and Scotts Corners formations. They have been the sites of accumulation of sediment in the basin centers where standing water and organic production contribute to the deposition of organic-rich sediments. In historical times, some of these basins have been cleared and farmed. Where farmed, much of the organic-rich deposits in the basins have been oxidized and leached in the plow zone.

Sediments within the bays consist of finely laminated to structureless, dark to light gray, clayey silts to fine to medium sand. Organic matter, usually disseminated, is commonly found associated with gray clayey silts. The rims are composed of fine to coarse, yellowish brown, moderately well-sorted quartz sand. The contact with underlying deposits is difficult to recognize owing to similarities in texture and composition, and is most readily recognized in the center of the basin where fine-grained deposits overlie the sands beneath.

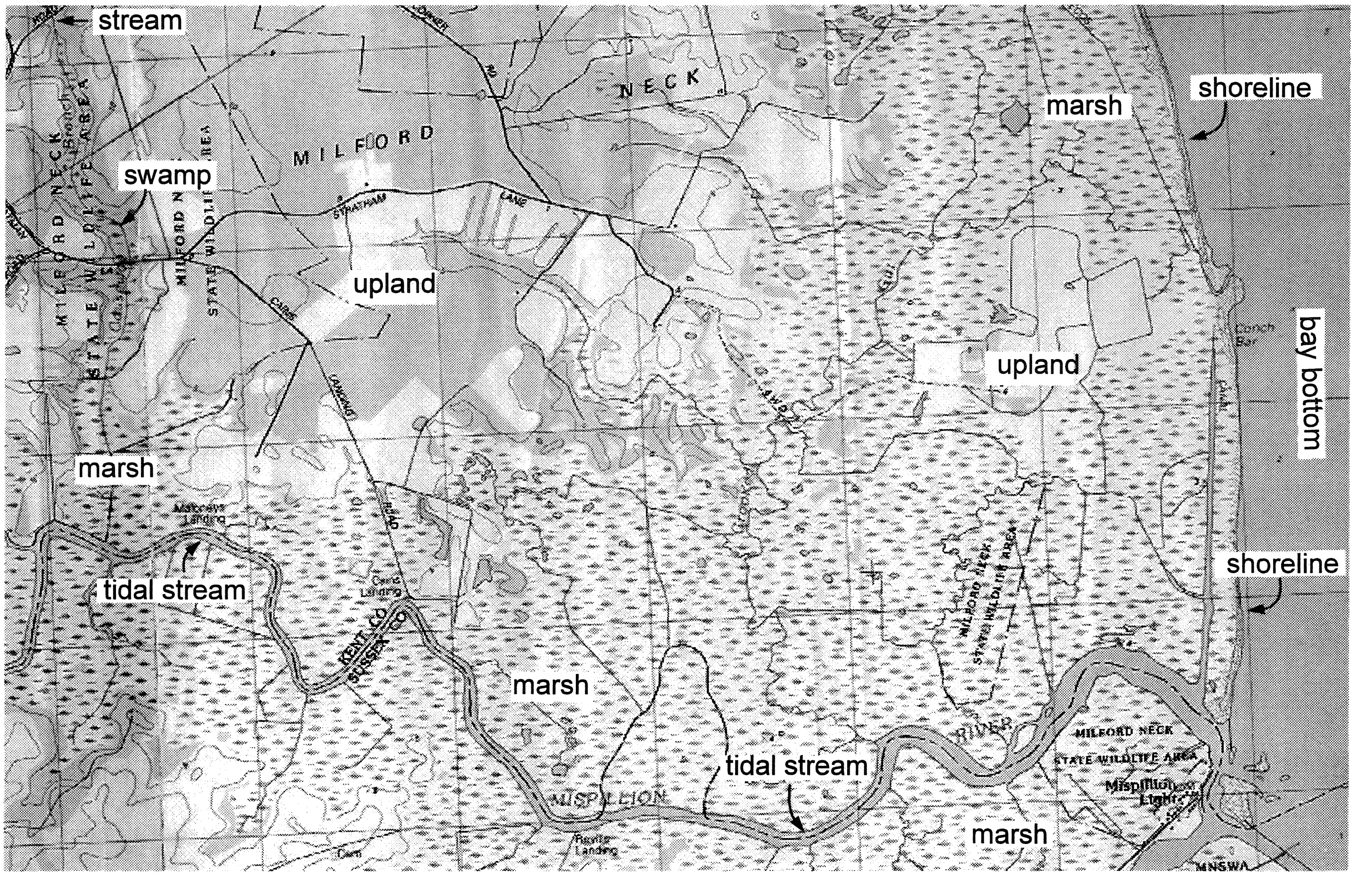

Figure 13. Schematic diagram of the distribution of Holocene depositional environments (map base from U.S. Geological Survey topographic maps of the Milford and Mispillion River quadrangles, 1993).

Holocene Deposits

The depositional systems currently active in the map area are essentially those that have been in place during the rise in sea level over the last 10,000 years. As the land has been drowned with the rise in sea level, these systems have migrated landward, each sensitive to the local topography, sediment supply, and tide and current regime. Holocene deposits within the study area are divided into three categories: nontidal, tidal, and estuarine. Nontidal deposits include streams and swamps. Tidal deposits include the marshes and tidal streams. Estuarine deposits include the shoreline (including washover, dune, and beach) and bay bottom. A schematic diagram (Fig. 13) shows the present distribution of the deposits in a system such as that of the Mispillion River. The deposits fill an antecedent topographic surface that is as much as 80 feet below present sea level in the area now covered by Delaware Bay and are as much as 50 feet thick (Figs. 14 and 15; Appendix C). Subsurface distribution of Holocene sediments is much like that found onshore. Paleovalleys (Fig. 14) are filled with stream, swamp, marsh, and tidal stream deposits. A cap of silt and fine sand bay-bottom deposits is ubiquitous. The bay deposits are thin on the paleointerfluves (usually <10 feet thick) and slightly thicker above the paleovalleys. Inspection of seismic lines does not indicate a significant thickening offshore (Fig. 15).

Stream Deposits

Stream (alluvial) deposits are restricted to the present stream valleys and paleovalleys of the antecedent topography. The deposits are commonly sand with some admixture of silt and clay. Owing to the relatively small drainage basins and the rise of sea level flooding the stream valleys, the area of deposition is somewhat restricted. On the geologic map (Ramsey, 1993), alluvial deposits were mapped with swamp deposits due to the limited distribution of the alluvial deposits.

Swamp Deposits

Swamp deposits are found in two distinct settings. The first setting is found in the present stream valleys upstream from marsh and other tidal deposits. The other setting is in flat, undrained upland areas, most notably on Milford Neck just southwest of Thompsonville. The swamp deposits contain a variety of lithologies from medium sand to an organic-rich clayey silt. The swamp deposits on the uplands tend to be less than five feet thick and consist of medium to fine sand to some clayey silt with or without organic material. The material ranges in color from yellowish brown to dark gray. Gray colors are common where water stands over a good portion of the year. The swamps in the stream valleys contain the same lithologies as the upland swamps with organic-rich sediment comprising a greater proportion of the section. Swamp deposits in the stream valleys may be up to ten or more feet thick, especially in the centers of the valleys. The deposits tend to lack sedimentary structures owing to bioturbation by tree roots and invertebrate infauna such as worms.

The upland swamps have a patchy distribution and rest unconformably on the deposits of the Scotts Corners or Lynch Heights formations. They are localized where there is a flat upland area with poor drainage. The contact with the underlying units is marked by an oxidized zone on the under-

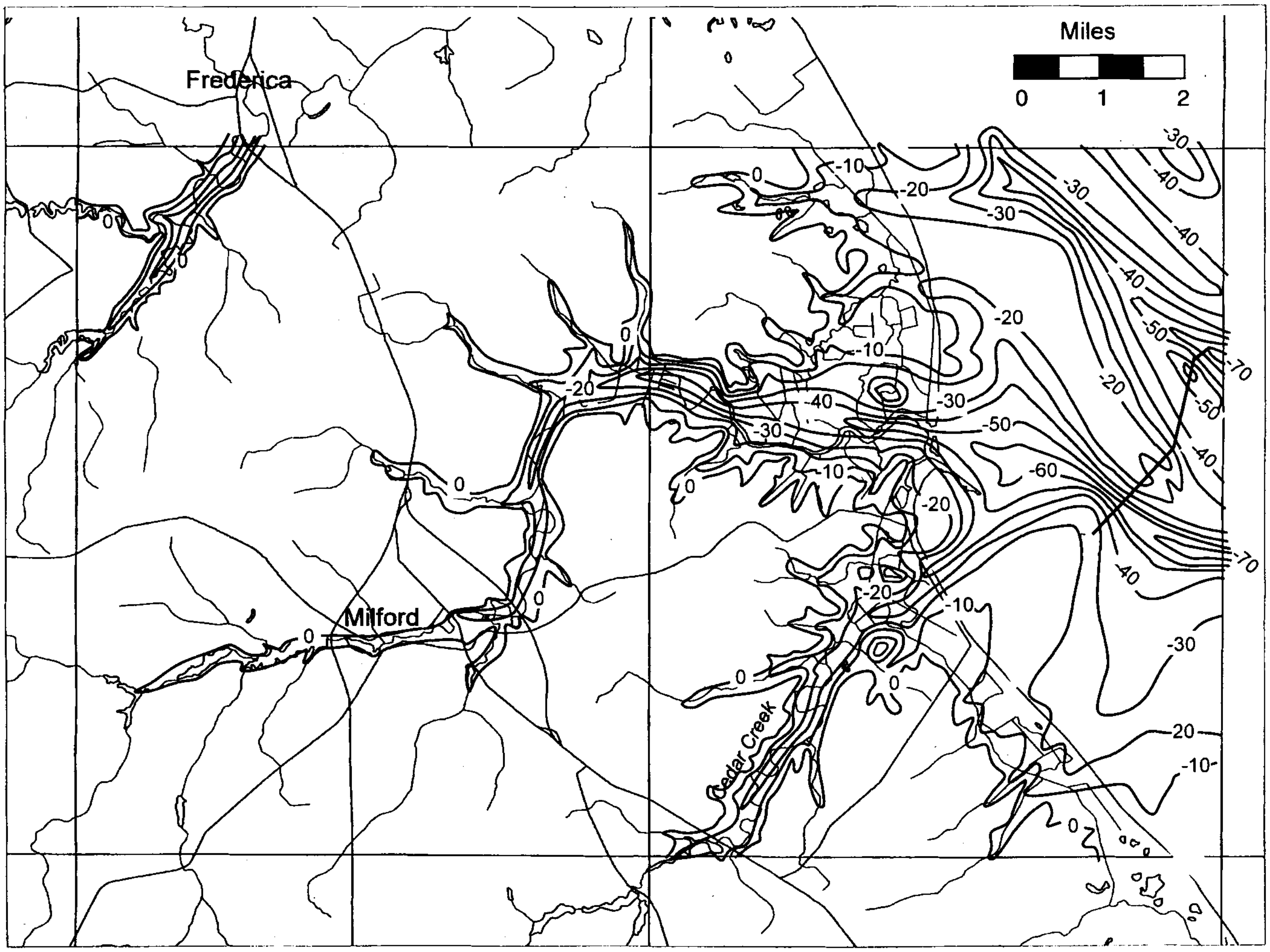

Figure 14. Structure contour map of the base of Holocene deposits in the map area. Contour interval is ten feet. Contour numbers are in feet below mean sea level. The line in the right center of the map is the location of U.S. Geological Survey seismic line number 8 (Knebel, 1989; Knebel and Circe, 1988; Knebel and others, 1988). A portion of the seismic data from that line is shown in Figure 15.

lying unit, an increase in compaction in the underlying material, and a lack of organics. The deposits pinch out laterally against local topographically higher areas. The swamp deposits within the stream valleys rest unconformably on the Scotts Corners and Lynch Heights Formations and deep within some of the stream valleys on the St. Marys Formation. The characteristics of the unconformity are the same as those of the upland swamps. In places, an interval of stream (alluvial) deposits may lie between the swamp deposits and the unconformity. These deposits interfinger laterally downstream with tidal stream and marsh deposits and upstream with stream deposits. The distribution of swamp deposits is mapped largely on the presence of trees and high shrubs on the current depositional surface as opposed to marsh deposits that are dominated by grasses and low shrubs.

Marsh Deposits

Unlike the swamp deposits, a considerable amount of research has been conducted on marsh and associated tidal stream environments (Elliott, 1972; Richter, 1974; Allen, 1977; Kayan and Kraft, 1979; Chrzastowski, 1986; Yi, 1992; John and Pizzuto, 1995). Of these Richter (1974), Kayan and Kraft (1979), and Yi (1992) conducted part of their work in the map area.

On the basis of previous work and analysis of unpublished Delaware Geological Survey core logs and data, five lithofacies are recognized in the marsh deposits: basal sand, basal organic-rich mud and sand, organic-rich mud, mud, and muddy to clean sand. These facies are similar to those recognized previously (Kayan and Kraft, 1979; Yi, 1992) but have lithic terms rather than genetic terms in their names. For example, the channel lag facies of Kayan and Kraft (1979) roughly corresponds to the basal sand lithofacies. The latter term is not as restrictive in that the basal sand lithofacies includes sands deposited in stream channel and colluvial environments as well as channel lag deposits.

The basal sand lithofacies consists of yellowish brown to gray sand, varying in texture from fine to gravel, with an admixture of silt, clay, and organic material. The predominate texture is medium to coarse sand with scattered pebbles. Some cross-bedding is present, but its nature and extent are unknown owing to a lack of exposure and limited core data. Thickness is on the order of a few feet at most. The unit represents stream deposits that have been overridden by tidal deposition. Some of the sands in steep-sided paleovalleys may be in part colluvial material partially reworked by stream and tidal deposition. The lithofacies overlies sands and muds of the Scotts Corners or Lynch Heights formations

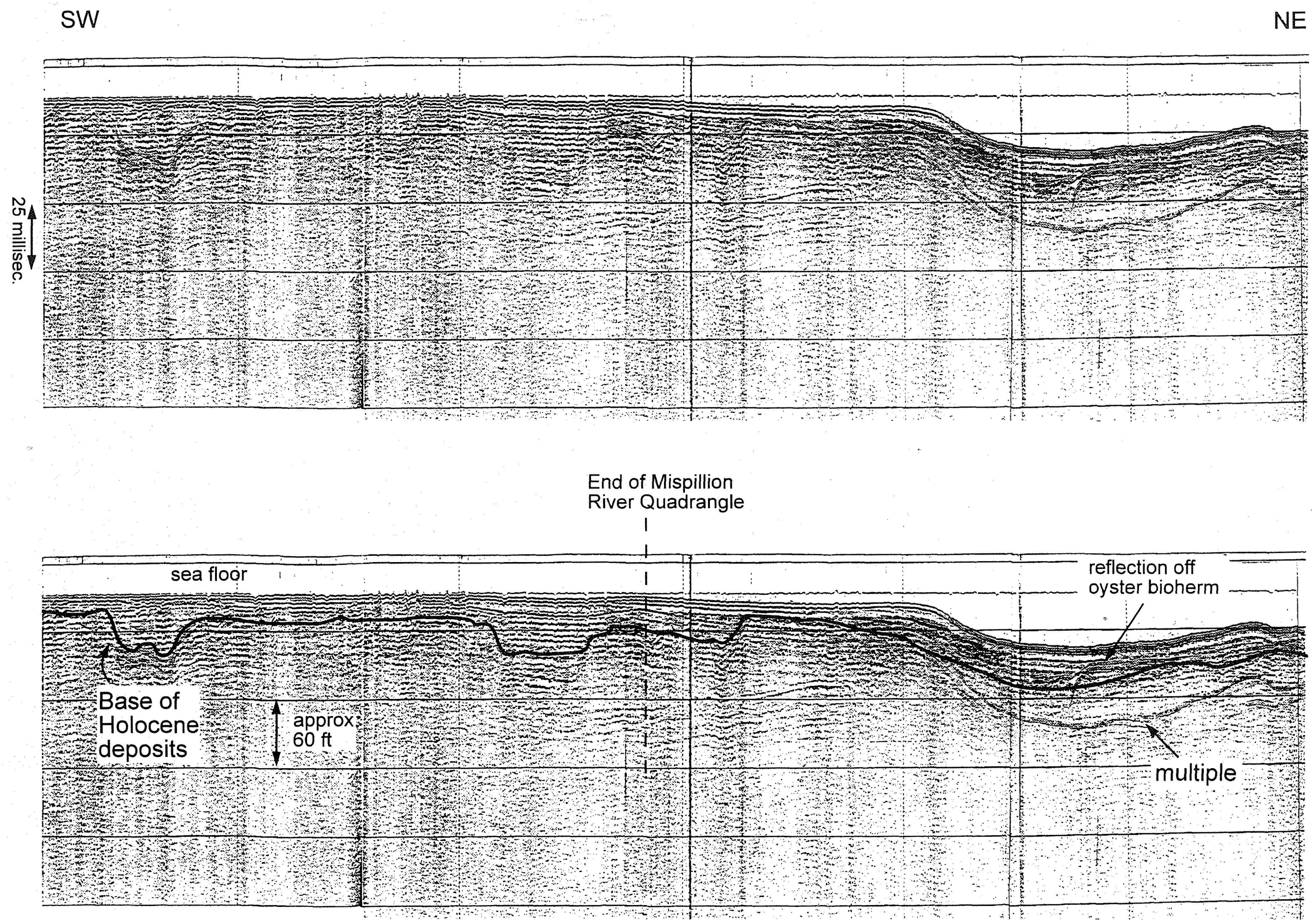

Figure 15. Uninterpreted and interpreted versions of U.S. Geological Survey seismic line number 8 showing the base of the Holocene deposits beneath the bottom of Delaware Bay offshore of the Mispillion River Inlet. Location of line shown on Fig. 14.

or clayey and shelly sands and muds of the St. Marys Formation. It is generally less compact and less oxidized than the underlying units. The basal sand lithofacies roughly corresponds to the channel lag unit of Kayan and Kraft (1979) and in part to the basal organic lithofacies of Yi (1992).

The basal organic-rich mud and sand lithofacies consists of gray to brown to black, fine to coarse sand to a sandy mud with a noticeable organic content. The organic content varies from leaves, stems, and twigs to finely disseminated material. The percentage of organic material varies but rarely reaches the 75 percent range where it could be called a peat (Yi, 1992). The unit represents deposition in swamp environments or in the leading edge of freshwater marshes that interfinger with swamp and stream channel deposits. This lithofacies corresponds to the basal peat of Kraft (1971) and in part the basal organic lithofacies of Yi (1992). The lithofacies interfingers with the basal sand lithofacies and the organic mud and mud lithofacies.

The organic-rich mud lithofacies comprises the bulk of the sediments of the marsh in the map area. It consists of gray to brown, silty clay to clayey silt. Pieces of organic material, primarily from marsh grasses, are a common constituent. In place, vertical roots of grasses are also common. Color laminations from gray to brown to black are generally present, reflecting varying amounts of organic material. It interfingers with the basal organic-rich and the mud lithofacies. The organic-rich mud lithofacies is roughly equivalent to the marsh deposits of Kayan and Kraft (1979) and the freshwater marsh, slightly brackish marsh, brackish marsh, salt marsh, scrub-shrub, salt marsh-pond, and overbank mud microfacies of Yi (1992). The microfacies of Yi (1992) are defined on the detailed analysis of plant fragments from cores to determine local depositional environment. They all have roughly the same organic-rich mud lithology and for the purposes of this report are grouped together into the organic-rich mud lithofacies. Detailed analysis of plant material is not available for most of the core descriptions from the marshes within the map area. The microfacies do show promise for detailed analysis of the marsh depositional system. No attempt has been made to compare Holocene pollen stratigraphy with the plant remains and interpreted microfacies of Yi (1992).

The mud lithofacies consists of light to dark gray clayey silt to silty clay. Some small percentages of organic material may be present, but in general the unit is devoid of visible organic matter. Sedimentary structures are not common, some burrows may be present, and faint color laminations from light to dark gray have been observed. This lithofacies was interpreted by Kayan and Kraft (1979) to be a lagoonal deposit. More likely, the muds are the product of deposition by tidal streams (Chrzastowski, 1986; Yi, 1992). The mud lithofacies corresponds to the overbank mud and tidal flat/tidal stream microfacies of Yi (1992). It interfingers and is gradational with the organic mud and muddy to clean sand lithofacies.

The muddy to clean sand lithofacies consists of gray to yellowish brown, fine to coarse sand with varying amounts of silt and clay. Pebbles and granules are also common. Sedimentary structures are common including planar to trough cross-bedding, heavy mineral laminations, and fining and coarsening upward bedding. In places, thin laminae of clay are present as well as thin laminae of organic material. The lithofacies represents those sediments deposited in environments associated with the estuarine shoreline of Delaware Bay. These include the distal portions of washover lobes of the shoreline deposits. These deposits have interlaminations and beds of organic or clayey material representing the reestablishment of the marsh on the washover lobes. In the axes of some of the main paleovalleys, the lithofacies may also have been deposited in the flood tidal deltas of the streams where they flow into Delaware Bay. The lithofacies interfingers with the offshore lithofacies and the organic-rich mud and mud lithofacies and in areas where the Holocene deposits are thin may directly overlie the basal sand or basal organic-rich mud and sand lithofacies.

Shoreline Deposits

Shoreline deposits are those sands found on the margin of Delaware Bay and consist of sediments deposited in beach, dune, and washover environments. They are analagous to the washover barrier sediments of Kayan and Kraft (1979). Shoreline deposits consist of white to dark gray, medium to coarse quartz sand with pebbles and cobbles. Laminae of opaque heavy minerals, very coarse sand, and pebbles are common. In the dunes, fine to medium sand with heavy mineral laminae is present. Scattered mud clasts ranging from pebble to cobble size are also found; many have organic fragments of marsh plants within them. *Busycon, Crepidula,* and other gastropod shells as well as the oyster *Crassostrea* are rare. Pebble lithology is dominated by quartz and chert. Many of the chert pebbles contain Paleozoic fossils. Cobble lithology is commonly quartz or quartzite. Other pebble and cobble lithologies include siltstone, sandstone, and micaceous schist. The color of the deposits is dependent upon the water saturation of the sediments, white where unsaturated such as on the beach and in the dunes and dark gray below the water table. The shoreline deposits are normally less than ten feet thick and rest sharply upon marsh deposits and interfinger with the muddy to clean sand of the marsh deposits landward. In many places, especially north of the Mispillion River, the lower contact is at or near the surf zone and at low tide, the marsh deposits crop out in the beach face forming a small 1- to 2-foot high escarpment. The deposits track the landward migration of the shoreline (refer to the position of the 1954, 1981, and 1989-90 shorelines in Ramsey, 1993).

Estuarine and Bay Deposits

Previous work in Delaware Bay in the map area includes the work of Oostdam (1971), Strom (1972), Weil (1976), Marx (1981), Maley (1981), and Knebel (1989). Most of the cores collected by Marx (1981) and Maley (1981) as well as some of the samples reported by Oostdam (1971) are housed in the Delaware Geological Survey's Core and Sample Library.

A compilation of the bottom sediment textures of the bay area of the Mispillion River quadrangle was included on the geologic map (Ramsey, 1993). The distribution of the textures as mapped was based on data from the map area as well as data from all adjacent areas. The data were compiled from unpublished DGS sources as well as from Strom (1972), Weil (1976), Maley (1981), Marx (1981), and Wethe (1984) and include a combination of bottom sediment grab samples (Appendix D) and samples from the tops of cores. Bottom sediment texture distribution does not appear to have a direct correlation with bathymetry. Shoals are coarser-grained than their surrounding areas only in the sense that they do not have a significant mud matrix. The sand fraction is the same, fine to very fine sand. Nearshore, the textures differ north and south of the Mispillion Inlet. North of the inlet, there is only a thin stretch of sand that composes the modern beach. Immediately offshore, the surface sediments are fine-grained and typically have a mud component. Around the inlet and in the breach north of the inlet are coarse gravelly sands. These in part represent the end of the littoral drift cells at the inlet and the winnowing of finer material by tidal current activity associated with the inlet. They may also represent material brought in to repair the breach north of the inlet in the 1970s, which ultimately failed, so the material was distributed as an ebb tidal delta. South of the inlet, a sandy mud is the dominant constituent to about one half mile offshore where it grades into a gravelly sand with or without a mud matrix. The sandy mud likely represents the reworking of the Holocene marsh muds deposited behind the barrier that are now exposed in the shallow depths of the nearshore and shoreface.

PALYNOLOGY

by Johan J. Groot

Introduction

The objectives of the palynological study were, (1) to determine where possible, the ages of the Quaternary and Tertiary sediments in the Milford area, (2) their environments of deposition, and (3) the climates that prevailed at the time of their deposition. The pollen assemblages found in the surficial deposits indicate a Quaternary age (Tables 4, 5). In order to understand the details of the geologic history of the area, however, it is necessary to define the ages of these sediments more precisely. A palynologic investigation of Quaternary sediments beneath the continental shelf and the upper part of the continental slope off of New Jersey recognized a sequence of alternating temperate and cold intervals (Groot et al., 1995). These intervals were interpreted in terms of oxygen isotope stages, in part in conjunction with aminostratigraphy (Groot et al., 1995). Furthermore, the stratigraphic distribution of six species of *Quercus* pollen was determined, and the results were applied to onshore deposits in Delaware (Groot et al., 1995). The age assignments of the Quaternary sediments in the Milford area are based, therefore, on recognition of the *Quercus* pollen species present in these deposits. Although such age determinations are simple in principle, they are impossible where there is a paucity of *Quercus* pollen or where they are poorly preserved. Where there is the possibility of reworking, the age of the deposit is indicated by the presence of the youngest *Quercus* pollen present. In lieu of designating ages in terms of marine oxygen isotope stages, the terms early, middle, and late Pleistocene are used (Richmond and Fullerton, 1986). This has been done to avoid suggesting

Table 4

Palynomorph assemblages of the Scotts Corners Formation. Numbers are expressed in percentages of the pollen sum. P- present (< 1%); LP- late Pleistocene, MP- middle Pleistocene, Q-Quaternary; C-cold, T- temperate, WT- warm temperate; BF- boreal forest, E-estuarine, M- marsh, TM- tidal marsh, FWM- fresh water marsh

	DGSID	Lf23-t	Lf14-b	Lf14-c	Lf14-e	Lf14-f	Lf14-m	Lf14-n	Lf14-p	Lf14-p	Lf14-p	Lf21-b	Lf23-f	Lf23-u	Lf23-x	Lf23-x	Lf23-x	Lf23-ac	Lf23-ac	Lf23-ad	Lf13-a	Lf14-a	Le14-a
	SAMPLE NO.	41422	41323	41330	41334	41336	41353	41356	14125	41431	41435	41367	41344	41464	41465	41469	41472	41482	41485	41489	40975	40976	41373
	SAMPLE ELEV. (FT.)	2	2.25	-1.5	-1.5	-1.5	-4	-4	0	-2.5	-5.25	8.5	-6.5	3.5	1	6.75	-0.25	0.5	-2	-2	2	0	2
Betulaceae	*Alnus*	P	P	4	10		3	3	P		P		P		1	1		P		1	2	4	9
	Betula	P	9	4	P	11	6	2	6		2		2	P	1	1		P		2	10	4	P
	Carpinus		1		P		P	2		P		3	6						P	P	1	3	2
Juglandaceae	*Carya*		5	4	2	1	3	6	3	7	7	3	3	6	4	3	4	14	5	8	3	4	P
Fagaceae	*Castanea*	P		2	P	1	P														1	P	
	Quercus	P	21	8	6	23	6	8	34	31	49	39	44	21	30	38	40	11	33	7	25	30	28
Aquifoliaceae	*Ilex*				2		2	P			P							P				P	6
Hamamelidoacea	*Liquidambar*			P				2		3	6		5		3	P	12	1	13			P	2
Myricaceae	*Myrica*	1	1	3	2	1	6	3							1							1	1
Nyssaceae	*Nyssa*									5	P		P	P	?	2	21	2	4				2
Ulmaceae	*Ulmus*										P	P	P										
Other				2	29		P	2		1								1?	4		1		11
Gymnosperms	*Picea, Abies*	20						P	P?	P			P		P				P	P			P
	Pinus	50	42	49	27	36	42	46	39	39	27	37	19	65	49	37	16	58	31	73	31	33	14
	Tsuga		P	1	P			2	P	11	3		P		6	6	2	4	6	P			3
	TCT		1		P	1	3						13							1	3		1
	Taxodium												P										
Herbs	*Artemesia*		1	P																P?	1		
	Chenopodiaceae		6			3	P			P		4			2		P		P	P	P	5	P
	Compositae	1	6	7	3	10	10	7	6			9	2	2		1	P	2	2	2	8	3	6
	Gramineae		1?	8	9	3	9	10				P	2		1						7	3	1
	Cyperaceae		1		4		?	?														1	P
	Ericaceae	1		P			P	2		.				2	1			P?		2	1	2	
	Hydrocharitaceae			P			P						P										4
	Typha, Sparganium			P													P?						P
	Other						2	P			P		P				P				2	6	2
Ferns, Mosses	*Lycopodium*	1																P					
	Osmunda	P				1					P												P
	Polypodiaceae		2	5	2	3	4	4	6		2	P		P		1	2	1		2	2	1	3
	Sphagnum	19		1	P	7	P	P	6	P		2		2		1				P	3	P	P
	Other																					P	
	NAP	24	17	25	18	27	28	24	17	2	3	17	5	7	4	3	4	5		8	25	22	19
	Reworked Palynomorphs					P			P	P	P		P		?	P			P	P		P	P
	Dinocysts + microforams																	3	3				
	Age	?	LP	LP	LP	LP	?	?	LP	LP	LP	LP	MP?	LP?	LP	LP	LP	LP	LP	?	Q	Q	LP
	Climate	C	T/WT	T/WT	T/WT	T/WT	T/WT	T/WT	T/WT	T/WT	T/WT	T/WT	WT	T/WT	T/WT	T/WT	T/WT	T/WT	T/WT	T/WT	T/WT	T/WT	T/WT
	Env. of deposition	BF	E	FWM	M	TM	M	M	?	?	?	E	FWM	?	E	?	E	E	E?	E	M	E	FWM
	Stratigraphic unit	Qsc	Qsc	Qsc	Qsc	Qsc	Qsc	Qsc	Qsc	Qsc	Qsc	Qsc	?	Qsc	Qsc	Qsc	Qsc	Qsc	Qsc	Qsc	Qsc	Qsc	Qsc

a degree of precision in dating the Quaternary deposits that may be more appropriate when additional data become available. Interpretation of climate was based on the floral assemblages indicated by the pollen and comparison with their current distribution in terms of climatic condition. Environmental interpretations are based on the floral assemblages indicated by the pollen and comparison with their present environmental distribution (wet/dry, upland/lowland, open area/dense forest, etc.) as well as the presence of indicators of fresh-water, brackish, or marine conditions. Locations for wells and outcrops from which samples were collected and processed for pollen are given in Appendix B.

Table 5

Palynomorph assemblages of the Lynch Heights Formation. Numbers are expressed in percentages of the pollen sum. P- present (< 1%); MP- middle Pleistocene, Q- Quaternary; CT- cool temperate, T- temperate, WT- warm temperate; E- estuarine, BF- boreal forest, M- marsh

	DGSID	Lf21-19	Le25-12	Le14-19	Le14-19	Le14-19	Le14-19	Le15-g	Le14-18	Le14-18	Le14-18	Le14-18
	SAMPLE NO.	25627-1	25639	25658-1	25658-2	25659-1	25659-2	41420	25706-1	25706-2	25707-1	25707-2
	SAMPLE ELEV. (FT.)	14.5	18.5	8	7	6	5	12.5	8	7	6	5
Betulaceae	*Alnus*	P	P	P	P	3	3		P	P	3	3
	Betula	3	1	2		1	2		2		1	2
	Carpinus				P		1			P		1
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
Aquifoliaceae	*Ilex*	1		P			1		P			1
Hamamelidoacea	*Liquidambar*											
Myricaceae	*Myrica*	3				P		1	P		P	
Nyssaceae	*Nyssa*											
Ulmaceae	*Ulmus*											
Other												
Gymnosperms	*Picea, Abies*	2	3		1			57		1		?
	Pinus	57	76	53	63	67	70	39	53	63	67	70
	Tsuga	P					P					P
	TCT	1										
	Taxodium											
Herbs	*Artemesia*		P		P	P				P	P	
	Chenopodiaceae	3	7	P					P			
	Compositae	3	P	4	7	6	3		4	7	6	3
	Gramineae	P	P	2	1	1		1	2	1	1	
	Cyperaceae		P									
	Ericaceae	2	3		1		P			1		P
	Hydrocharitaceae											
	Typha, Sparganium											
	Other			P		P		1	P		P	
Ferns, Mosses	*Lycopodium*					1					P	
	Osmunda	P					P					P
	Polypodiaceae	4	5	3	4	6	5		3	4	6	5
	Sphagnum	11	2	5	5	4	P		5	5	4	P
	Other											
	NAP	24	18	14	20	20	9	2	14	19	20	9
	Reworked Palynomorphs					P	P				P	P
	Dinocysts + microforams	?	P				?					?
	Age	MP	MP	MP	MP	MP	MP	?	Q	Q	MP	Q
	Climate	CT	CT	T	T	T	T	C	T/WT	T	T	T/WT
	Env. of deposition	E	E	E	?	?	?	BF	M?	M?	M?	?
	Stratigraphic unit	Qlh	Qlh	Qlh	Qlh	Qlh	Qlh	Qlh	Qlh	Qlh	Qlh	Qlh

Pollen Assemblages

Scotts Corners Formation

Pinus and *Quercus* pollen generally occur in high but variable frequencies (Table 4). Other arboreal pollen that are consistently present are those of *Betula* and *Carya. Tsuga* has been found in most samples of this formation. The non-arboreal component is quite variable, but pollen of the Compositae, Graminae, and Chenopodiaceae are common. These assemblages indicate a temperate or warm-temperate, moist climate like the one of today, and environments of deposition ranging from estuarine to tidal and fresh-water marsh. The age of most of the sediments, as suggested by the predominance of *Quercus* species 1 (Groot et al., 1995) is late Pleistocene (or Sangamonian). One sample (41422, Lf23-t; Table 4) differs completely from those described above; it is dominated by *Pinus* and *Picea*, indicating a cold climate and a boreal forest environment. Below and above this sample (located at +2 ft msl) in nearby sample sites, estuarine and tidal marsh sediments were laid down during temperate or warm-temperate climate intervals. The palynological data support the interpretation of the lithology that the Scotts Corners Formation was deposited in three substages of the Late Pleistocene, two relative warm intervals and one cold period.

Lynch Heights Formation

The assemblages are characterized by generally high frequencies of *Pinus*, low presentages of *Quercus* and the presence of 1 to 4 percent of *Picea* in one-half of the samples analyzed (Table 5). Consequently, it appears that this formation was deposited, at least in part, during a period somewhat cooler than that of the Scotts Corner Formation. *Quercus* pollen species suggest that the age of the Lynch Heights is middle Pleistocene. One sample (41420, Le15-g; Table 5) is dominated by *Picea* pollen indicating a very cold climate and a boreal forest environment. That sample, at an elevation of 12.5 ft (msl), is underlain by samples from other sample sites having pollen assemblages indicating a temperate or warm-temperate climate, and overlain by sediments deposited in an estuarine environment during a period of cool-temperate climate. Consequently, the Lynch Heights Formation was deposited in three stages or substages of the middle Pleistocene.

Table 6

Palynomorph assemblages of samples from offshore cores in Delaware Bay. Numbers are expressed in percentages of the pollen sum. P- present (< 1%); T- temperate; CT- cool temperate.

	DGSID SAMPLE NO. SAMPLE ELEV. (FT.)	Kg52-04 22247 -34	Kg54-01 22280	Kg54-01 22287 -60
Betulaceae	*Alnus*	1		
	Betula	P		3
	Carpinus			
Juglandaceae	*Carya*	11		
Fagaceae	*Castanea*	P		
	Quercus	54	P	9
Aquifoliaceae	*Ilex*			P
Hamamelidoacea	*Liquidambar*	3		
Myricaceae	*Myrica*	P		
Nyssaceae	*Nyssa*			
Ulmaceae	*Ulmus*			
Other				
Gymnosperms	*Picea, Abies*			1
	Pinus	10	P	73
	Tsuga	P		
	TCT			
	Taxodium			
Herbs	*Artemesia*			
	Chenopodiaceae	P		
	Compositae			4
	Gramineae	15		1
	Cyperaceae			P
	Ericaceae			
	Hydrocharitaceae			
	Typha, Sparganium	P		
	Other	P		
Ferns, Mosses	*Lycopodium*			1
	Osmunda			
	Polypodiaceae	P		4
	Sphagnum			1
	Other			P
	NAP	18		
	Reworked Palynomorphs			
	Dinocysts + microforams			
	Age			
	Climate	T		T/CT
	Env. of deposition			
	Stratigraphic unit			

Columbia Formation

No pollen analyses are available from this formation in the Milford area. However, nine samples collected in various localities throughout Delaware indicate a cool to cool-temperate climate, a fluvial environment of deposition, and a middle or perhaps early Pleistocene age. In order to determine the age of the Columbia more precisely, further study is necessary.

Delaware Bay Sediments

Three core samples were analyzed (Table 6), one of which (22280, Kg54-01) is dominated by dinocysts. Below this sample, at -60 ft (msl) *Pinus* is dominant, with some *Quercus*, Compositae and Polypodiaceae. The third sample is quite different, with *Quercus* most frequent and little *Pinus*; pollen of Gramineae (grasses) dominate the non-arboreal component. These analyses differ from those of suspended sediments in Delaware Bay (Groot, 1966) in having lower percentages of non-arboreal pollen, particularly Chenopodiaceae.

Formations of Miocene Age

Pollen assemblages of the Calvert, Choptank, and St. Marys formations are shown in Table 7. In these formations, *Quercus* pollen frequencies range from 36 to 78 percent, and *Pinus* from 4 to 33 present, with the higher *Pinus* percentages in the Calvert Formation. Exotic pollen (of taxa extinct in Delaware) are those of *Pterocarya*, *Momipites* (*Engelhardia* type), *Cupuliferoidaepollenites fallax*, *Planera*, *Cyrilla*, Sapotaceae, *Alangium*(?), *Gordonia*, *Eucommia*, *Tricolporopollenites edmundii*, Palmae, *Sequoia* type, and *Sciadopitys*. Most of these exotica are rare (except in the Calvert Formation), generally occuring in very low frequencies (less than one percent of the pollen sum) and in a few samples only. Most of the exotic pollen indicate the presence of subtropical taxa that became particularly rare in the St. Marys Formation, suggesting a cooling trend during the late middle Miocene, changing the climate from subtropical to warm-temperate. This change is indicated by the ratios of temperate and warm-temperate to subtropical and tropical taxa (Table 7). Relatively low ratios suggest a subtropical climate, as in the Calvert, and high ratios a somewhat cooler climate, as in the St. Marys.

Table 7 also shows the percentages of wetland genera for each sample. These include *Alnus*, *Ilex*, *Liquidambar*, *Nyssa*, *Planera*, *Cyrilla*, *Symplocos*, *Gordonia*, and *Taxodium*. These taxa probably occured mostly in the Coastal Plain rather than in the Piedmont. Therefore, relatively high percentages of wetland genera indicate the presence of a low, wide coastal plain, and consequently a low sea level; very low percentages are interpreted as an indication of a narrow coastal plain and a high sea level (Groot, 1992, p. 5). Table 7 suggests that sea level fluctuated during middle Miocene time.

Conclusions

(1.) The Calvert Formation differs from the overlying Choptank and St. Marys formations in having generally higher percentages of pollen of conifers, including those of the Taxodiaceae-Cuprescaceae-Taxaceae (TCT), and a somewhat greater occurrence of *Momipites* and a lower frequency of *Pterocarya*. Whereas *Tilia* is generally present in

Table 7

Palynomorph assemblages of samples from deposits of Miocene age from the map area. Numbers are expressed in percentages of the pollen sum. P- present (< 1%); WT- warm temperate, ST- subtropical.

	DGSID	Kf54-06	Le53-02	Le52-01	Le54-06	Me14-14	Le33-06	Le33-06	Le55-07	Me14-20	Le55-07	Me14-20	Me15-29	Me15-29	Me15-29
	SAMPLE NO.	22191	23507	23502	23504	23505	83330	83335	32904	82483	32916	82497	32264	32266	32296
	SAMPLE ELEV. (FT.)	-58	-26	-23	-29	-31	-62	-83	-161	-130	-221	-224	-230	-250	-540
Betulaceae	*Alnus*		P		2		P	P		P		P		P	P
	Betula	P	P		P		P	P		P			P		P
Juglandaceae	*Carya*	13	12	2	16	8	13	12	15	13	6	7	6	22	12
	Momipites						P?		1		1		4	P	3
	Juglans		P					P					P		
	Pterocarya	P	P		P	P	P	P	1		1				
Fagaeceae	*Castanea*									P					
	C. fallax						P?								
	Quercus type	68	57	78	44	77	57	60	44	61	76	42	46	37	36
Aquifoliaceae	*Ilex*	P	P				P		1	P	3	P	P	P	2
Hamamelidacea	*Liquidambar*	P	1	P	7		2	2	1	4	1	1	2		
Nyssaceae	*Nyssa*	P?		P									6	P	4
Tiliaceae	*Tilia*					1			P	P		P	P	3	P
Ulmaceae	*Ulmus*	P	4	2	5	P	2	2				P			
	Planera				P							P			
Cyrillaceae	*Cyrilla*							P		P?				P	P
Symplocaceae	*Symplocos*					P				P					
Sapotaceae	*Manikara*										P				
	Other	P		P?					1				2		
Alangiaceae	*Alangium* (?)							P				P			
Theaceae	*Gordonia*														P
Eucommiaceae	*Eucommia*														P
	T. edmundii		P		P										
Palmae (?)		P						P?		P?					P
Gymnosperms	*Picea, Abies*						P					P			P
	Pinus type	5	6	4	9	8	6	9	32	15	8	33	22	17	18
	Tsuga								1			P			
	Cedrus														P?
	Sequoia type				P?	P						P	P		
	Sciadopitys		P												
	TCT		6	6	3	2	9	5	1	2	1	11	10	17	16
Herbs, Ferns	Chenopodiaceae	10	P	2	3	P	9	6		1					
	Ericaceae						P?					1			P
	Polypodiaceae		P	P	P					P					
	Other	2	8	5	8	P	P	2		1	1	P	P	P	P
	Dinocysts + microforams			P	P	24	P	P		1		5			
	Temperate/Tropical ratio	86	>100	107	89?	83	91	97	22	75	40	41	11	24	9
	Wetland taxa %	2	3	2	10	1	4	3	3	5	4	3	13	3	8
	Climate	WT	WT	WT	WT	WT	WT	WT	WT/ST	WT	WT/ST	WT/ST	WT/ST	WT	ST
	Sea Level	?	?	?	?	HIGH	?	?	?	?	?	HIGH	LOW	MED	LOW
	Stratigraphic unit	St. Marys Formation					Choptank Formation				Calvert Formation				

the Calvert, *Ulmus* is found in the Choptank and St. Marys formations. Pollen of the Chenopodiaceae are consistently present in the St. Marys, have been found in some of the samples of the Choptank, but not in any sample of the Calvert Formation in the Milford area. The palynological differences between the Calvert and the overlying Miocene formations are distinct, but those between the Choptank and St. Marys are rather subtle.

(2.) The Columbia Formation contains few non-oxidized silt layers that may have preserved pollen and spores; none were encountered in the Milford area. Samples from other parts of Delaware, however, consistently have *Picea* pollen, and assemblages indicating a cool climate and a fluvial environment. The *Quercus* pollen are different from those of the Lynch Heights and Scotts Corners formations and suggest a probable middle Pleistocene age.

(3.) The environments of deposition inferred from the pollen assemblages of the Lynch Heights and Scotts Corners formations range from fresh-water marsh to estuarine; these are environments similar to those now present along the Delaware Bay coast. The main difference between the two formations is a possible slightly cooler climate at the time of deposition of the Lynch Heights (middle Pleistocene) than the Scotts Corners (late Pleistocene). The altitude of estuarine sediments of the Lynch Heights Formation, up to at least 30 ft above msl, indicates that at some time during the middle Pleistocene sea level was at least 30 ft. higher than at present, in spite of the indications of a cool-temperate climate.

(4.) Two samples, one in the Lynch Heights and one in the Scotts Corners, indicate a cold climate and a boreal forest. These samples clearly suggest that these formations were deposited in several stages of the middle and late Pleistocene, respectively.

CLAY MINERALOGY

Methods

Forty samples from the stratigraphic units in or near the map area were selected for determination of clay mineralogy (Table 8; Appendix F). Many of these samples were also split for palynomorph extraction (Appendix B). In addition, 16 samples from the Columbia Formation in Delaware were also analyzed (Appendix F) for comparison between the Columbia and younger Quaternary units found in the map area. Clay slides were prepared for x-ray analyses and were analyzed untreated, glycolated, and heated to 400° and 550° C (Spoljaric, 1971). Clay minerals were identified using standard methods of identification. Semi-quantitative determination of clay mineral percentages using peak height and width were conducted following the methodology of Moore and Reynolds (1997) in order to determine if there was any utility in this method for characterizing clay mineral suites for specific stratigraphic units.

Table 8 shows the average percentages of clay minerals from samples from the map area. Owing to the inherent variability of the composition of clay minerals and the com-

Table 8

Average percentages of clay minerals for each of the stratigraphic units from the map area. Qh- Holocene deposits, Qsc- Scotts Corners Fm., Qlh- Lynch Heights Fm., Qcl- Columbia Fm., Tsm- St. Marys Fm., Tch- Choptank Fm., Tc- Calvert Formation.

Stratigraphic Unit	Smectite %	Illite %	Kaolinite %	Chlorite %	Mixed Layer %	Vermiculite %	Number of Samples
Qh	19	40	22	20	0	0	4
Qsc	24	19	41	13	3	1	14
Qlh	13	19	46	15	8	1	5
Qcl	21	21	47	9	0	2	17
Tsm	78	14	5	3	0	0	7
Tch	30	7	2	1	60	0	3
Tc	66	8	25	1	0	0	4

plexity of x-ray diffraction patterns, these percentages should be taken as relative amounts of each mineral. The numbers are probably within five percent of an actual value in terms of precision (reproducibility of a number), especially for samples with constituent minerals of 20 percent or more (Moore and Reynolds, 1997). Accuracy (the difference between the derived number and the actual number), however, should be about ±10 percent for minerals with actual abundance greater than and ±20 percent for minerals with abundance less than 20 percent. Although these results are semi-quantitative at best, the method does indicate, at least, relative amounts of clay constituents present at an accuracy that is better than interpretive description of diffraction patterns without quantitative estimates.

Results

In general, most clay minerals are originally deposited as detrital particles transported and deposited by wind or water. Their original sources were either from freshly weathered bedrock or from soil (Eslinger and Pevear, 1988). Bedrock can produce detrital particles of mica, chlorite, and minor amounts of smectite. Most clay minerals come from soil sources, the mineralogy of which is determined by local factors such as parent material, climate, topography, drainage, duration of weathering, and other factors. Of these, climate may be the overriding factor (Eslinger and Pevear, 1988). Warm, wet climates produce kaolin-rich soils; drier climates produce smectite-rich soils. Wetting and drying of smectite soils with the presence of potassium feldspar can result in the formation of mixed-layer illite smectite minerals. Smectite is also produced by the weathering of wind-transported volcanic ash. Temperate climate areas may also produce vermiculite, and in areas of colder climates, chlorite is a common component where chemical weathering is at a minimum. These transported clay minerals are transported by wind or by rivers that deposit much of their fine-grained load near their mouths because of changes in salinity that cause the clay mineral to aggregate and drop out of suspension. Rivers from high latitudes carry abundances of unweathered chlorite and illite derived from glacial erosion of unweathered bedrock (Eslinger and Pevear, 1988).

Kaolinite and illite were identified in all the samples, albeit in trace amounts in some. Smectite is a common constituent, but is not present in every sample. Chlorite is also a common constituent. Vermiculite was identified in only one sample from the map area (Mg 21-06, 25658), a micaceous, sandy clay, but is found in the Columbia Formation elsewhere. Mixed layer clays are also present in samples from the Scotts Corners, Lynch Heights, and Choptank formations.

In addition to the clay minerals, quartz and plagioclase or potassium feldspar are also found in the clay-size fraction of the samples (Appendix F). The presence of quartz and feldspar may call into question semi-quantitative analysis because of the added disruption of orientation of particles on the slides analyzed by x-ray diffraction. Quartz, however, is common in most samples, is very difficult to completely remove, and is an aid in the identification of clay minerals (Moore and Reynolds, 1997, p. 227). It is assumed for this study that the quartz present was of small enough grain size that it did not grossly affect the semi-quantitative analysis. Inspection of data from the same stratigraphic unit (Appendix F) in which quartz was present and was not present do not indicate that the presence or absence of quartz (or feldspar) severely affected the semi-quantitative results. Calcite was also identified as well as traces of gypsum, jarosite, and lepidocrocite. Table 8 shows the average relative percentages for clay minerals from each stratigraphic unit with an accuracy of +/- 10 to 20 percent. The goal of this study was to look at populations from stratigraphic units and determine if there are any discernable differences between units based on their clay mineral populations. A sample with 30 percent kaolinite may not accurately be differentiated from a sample of 37 percent kaolinite; however, a population of samples that have 60 to 80 percent kaolinite may be differentiated from a population of samples that have 20 to 30 percent kaolinite. Obviously, more sampling is needed for a complete picture, but the relative percentages do provide an approximation of the clay mineral suites for each stratigraphic unit.

Stratigraphic units were determined by means of local and regional correlation as well as the fact that many of the samples contained fossil pollen that are indicative of floral assemblages and climate typical of a particular stratigraphic unit. There appears to be a difference between the units of Tertiary age (typically marine) and those of Quaternary age (typically fluvial to estuarine). The Tertiary units are dominated by smectite with lesser amounts of illite, kaolinite, and mixed layer clay minerals. The Quaternary units are dominated by kaolinite, followed by illite, smectite, chlorite, and mixed layer clay minerals. On visual inspection, no differentiation can be made among Quaternary units or among Tertiary units. The Choptank samples are somewhat aberrant in the high percentages of mixed layer minerals. Samples from elsewhere in the state indicate a clay mineral suite much more similar to that of the Calvert or St. Marys. Other trends seen are the marked decrease in the percentage of chlorite with older stratigraphic units, and less so, the same trend in the percentage of illite.

Trends in the clay mineral assemblages from this study are consistent with what is known of the climate, weathering, and depositional history during the time of deposition of the stratigraphic units. The major constituents (smectite with lesser amounts of illite and other minor components) of the Tertiary units (Calvert, Choptank, St. Marys) are consistent with a similar assemblage now found offshore South Carolina, Georgia, and northern Florida in a marine environment with a warm to subtropical climate (Pevear, 1972). The warmer climate of the Calvert Formation (Groot, 1992) is consistent with an increased percentage of kaolinite typical of deep weathering in such a climate. The dominance of smectite may indicate a component of volcanic ash (from western North America?) as volcanism was common during the Miocene. These observations are consistent with those of Spoljaric (1988) for the Calvert Formation.

The Holocene samples, although limited in number (4), are consistent with the clay mineral assemblage of Oostdam and Jordan (1972) both in composition and in relative abundances of mineral components. No discernable trends other than a decrease in chlorite abundance can be seen in the Quaternary units. This trend is significant, however, in the sense that chlorite is derived from the erosion of fresh bedrock, commonly by glacial action (Eslinger and Pevear, 1988). With successive glaciations, more bedrock was exposed, and there was less soil available for erosion and transport; hypothetically, chlorite percent should increase with the number of glaciations in an area. The percentages of chlorite are probably not statistically significant, so it is unknown whether the slightly smaller percentage in the Columbia Formation than in the younger units has any meaning or not. The clay mineral assemblage of the Quaternary units is consistent, however with a glaciated terrain, cold to warm temperate climates (Groot, this report), and an Appalachian bedrock source. The presence of kaolinite does present some difficulty in the fact that the Quaternary climates are not typical of those most conducive to kaolinite formation. It may be that the kaolinite is residual, formed by soils during the Tertiary and subsequently eroded and transported during the Quaternary.

The semi-quantitative method may offer an additional tool for differentiating stratigraphic units by their clay mineralogy. This becomes especially critical for units devoid of any palynomorphs or other fossil material. The problem is especially acute in regions dominated by sand that have scattered, oxidized clayey silt beds that contain no pollen, such as in the outcrop area of the Columbia Formation of northern and central Delaware, and in portions of the Beaverdam Formation found in much of Sussex County. More samples need to be analyzed before this method can be applied with any degree of confidence. Use of the method should always be employed with great caution given the reasons stated previously, but it is hoped that these results may offer another tool for understanding the geology of Delaware.

POST-OLIGOCENE GEOLOGIC HISTORY

Introduction

This report concentrates on the Miocene to recent geologic history of the Milford area, that is, the rocks for which some data have been analyzed and have been penetrated by drill holes in the area. The history of the deposition of the Chesapeake Group in the upper Delmarva Peninsula region is that of the filling of a depositional basin with marine sediments followed by estuarine to fluvial deposition during the late Miocene into the Pliocene (Andres, 1986; Groot et al., 1990). The Columbia Formation and younger deposits of the Delaware Bay Group were the result of the distribution of sediment produced by glacial outwash and the erosion and redistribution of the material during subsequent fluctuations of sea level during the last 800,000 years.

Benson and Pickett (1986), Benson (1990b), Ramsey and Schenck (1990), Benson (1994), and Benson and Spoljaric (1996) have documented faulting in the Coastal Plain of Delaware involving Miocene deposits of the Chesapeake Group. Benson and Pickett (1986) show the locations of faults by cross-sections and on the geologic map of the quadrangles immediately to the north of the Milford and Mispillion River quadrangles. Benson (1990b), on the basis of seismic data, showed the trace of a major fault zone within the map area. Ramsey and Schenck (1990), on the bases of examination of well data and the use of previous delination of structure, constructed a map showing the location of a fault in the northwestern corner of the Milford Quadrangle along the Murderkill River. Figure 7 shows a structure contour of the top of the Calvert Formation that is an unconformable surface underlying the Choptank Formation. Zones of closely spaced contours may mark the location of faults within the Chesapeake Group that have distorted this surface. These zones all trend southwest to northeast. Three possible candidates for fault zones exist: one running through the south side of Milford, one just to the north of Lynch Heights, and one just to the north of the Murderkill River (Fig. 7). There is no evidence of any fault activity or structural influence on deposition within the map area since Miocene time.

Chesapeake Group

Calvert Formation

The base of the Calvert Formation is an unconformity of regional extent (Benson, 1994) that in the Milford area was formed some time between 33 and 22 million years ago (Benson, 1990a). The lowermost Calvert at Lewes was assigned by Benson (1990) to the *Globorotalia kugleri* Zone which is correlated with the lowermost Miocene. Presumably the basal Calvert in the Milford area is of a similar age or slightly younger given the onlapping, transgressive nature of the lower Calvert. In Me15-29 (Fig. 4), the lowermost Calvert is a glauconitic sand about 15 to 20 feet thick. According to investigations of the Calvert at Lewes (Benson, 1990a) and Dover (Benson et al., 1985; Groot, 1990; Benson and Spoljaric, 1996), the lowermost Calvert was deposited during a period of rising sea level during the early Miocene. The sediments deposited were silty fine sands to clayey silts with scattered fine sand beds and some shelly zones. In Me15-29 (Fig. 4), they comprise most of the lowermost unit in the Calvert. A sample at -540 feet in Me15-29 (Fig. 4, Table 7) contains palynomorphs that indicate a relatively low sea level. This sample is from the uppermost part of the lower unit within the Calvert.

In the Milford area, the Cheswold sand forms the interval at the base of the lowermost fining-upward sequence (1 in Fig. 4; Fig. 6). Excavations into the Cheswold between Dover and Smyrna (unpublished DGS data) indicate that the sands were deposited in a shallow marine to estuarine (tidal flat) setting near a land area that was forested to the shoreline. In Me15-29, the Cheswold is found between -436 and -532 ft and consists of medium with some coarse slightly shelly to shelly sand. There are three sandy intervals that make up the Cheswold, the best developed sand being found between -508 and -532 ft. The other intervals are between -432 and -450 ft and between -472 and –490 ft. Me14-20 penetrated the uppermost sand at -425 ft. If the sedimentation response to sea level rise and fall was similar for the rest of the Calvert, then sea level fluctuated at least twice more during the deposition of the Calvert. The uppermost fining-upward sequence (3 in Figure 4) contains a well developed sand known as the Frederica sand found between -254 and -272 ft in Me14-20 and -288 to -308 ft in Me15-29. Palynomorph samples from these two wells indicate that sea level was relatively high during the deposition of the muds above the Frederica and then began to fall to some lower position (Table 7). The sandy intervals are generally medium to coarse sands with some shell material. Some of the sands are cemented. The presence of radiolarians and marine diatoms in some of the finer beds support the marine depositional environment of these units.

The history of the Calvert in the Milford area consisted of an initial rise in sea level with a transgression during the early Miocene. Sea level then fell and during a subsequent rise, the Cheswold sands were deposited. The same scenario was repeated three more times. The last of these began with the deposition of the Frederica sand across the area. The environment was marine throughout the period of the Calvert. Sands were deposited during progradational episodes followed by marine mud deposition during the subsequent high stand, then a decline, of sea level. There is no evidence that the area was subaerially exposed during this time. Minor unconformities due to marine erosion or nondeposition may be present (Kidwell, 1989) but are not readily identifiable with the data currently available. The palynomorph record indicates that the climate was subtropical to warm temperate. It is not clear whether there is any correlation between the four fining-upward sequences described here and the four unconformity-bounded sequences of Kidwell (1989). The sequences of Kidwell do not include the lowermost Calvert (Shattuck zones 1-3). The overall sea-level fluctuations and general trend of water depth do generally match the sequences described from the Milford area and the pollen and other paleontologic data relating to relative sea level from elsewhere in Delaware (Benson, 1990a; Groot et al., 1990).

Choptank Formation

The contact between the Choptank and Calvert formations is an unconformity. It is marked by a coarse to granule sand overlying the distinctive brown clayey silt of the Calvert Formation. This surface can be traced over a wide area and may be in part the product of subaerial exposure. The sands above the contact generally lack shells or other fossil material directly at the contact. This may indicate some period of non-marine deposition prior to resumption of a marine environment. Shell material becomes more common upward as the sand becomes finer. The distinctive brown silts below the contact contain gypsum, some unidentified clay-sized minerals, and, in one sample, jarosite. These minerals are not uncommon in the Calvert, but may offer some evidence of a period of subaerial weathering prior to deposition of the Choptank. The basal sand of the Choptank can be mapped throughout the study area and forms an aquifer (Milford aquifer) that is currently being utilized (Figs. 4-6).

Water depths during deposition of the Choptank were typical of a marginal marine setting (less than 100 feet; Benson, 1990a). The lower Choptank (Ramsey, 1993) fines upward to a hard clayey silt bed which in Me14-20 consists predominately of smectite (Appendix F). The lack of the land-derived clays kaolinite and illite may indicate deeper water farther away from a land source. It is possible that the deposition of this bed represents the deepest water deposition within the unit. The hardness of the bed, commonly noted by drillers, may indicate that it is in part a hard ground. A potential correlative interval was reported by Kidwell (1989) to be a "firmground." The upper Choptank consists of a less well-developed fining-upward sequence with more shelly sand and shelly sandy silt intervals than the lower Choptank. *Mercenaria* shells become very abundant in some of the beds, perhaps indicating a slightly brackish component to the deposition. The pollen record from the Choptank indicates that warm temperate to subtropical climate prevailed during most of its deposition. The lower and upper Choptank (Ramsey, 1993) could be correlative with the two members of the Choptank from the western shore of the Chesapeake Bay in Maryland as described by Kidwell (1989). There are similarities in overall sequence, water depth, and depositional pattern. The Choptank in that region is only 20 meters (70 feet) thick, whereas the unit in the Milford area is about double that thickness.

St. Marys Formation

The contact between the St. Marys and the underlying Choptank is in many places difficult to recognize. The interval at the top of the Choptank is a fining-upward sand. The sand is included within the Choptank Formation and the base of the overlying clayey silt bed is the recognized as the base of the St. Marys. The St. Marys is characterized as a clayey silt with thin silty sand beds (Andres, 1986). Shells are much rarer in the St. Marys than in the underlying Calvert or Choptank and tend to be poorly preserved. Shallow marine to estuarine conditions prevailed during the time of deposition. The pollen record indicates a warm temperate climate, definitely cooler than that which prevailed during deposition of the Calvert and perhaps slightly cooler than that of the Choptank. The clay mineral suite of the unit is still dominated by smectite, but a significant component of illite and some kaolinite and chlorite indicate that a land-derived source is present (Table 8). The St. Marys is interpreted as a phase of delta progradation and a transition from the typical marine, shallow shelf environments of the Calvert and Choptank to the deltaic, estuarine, and fluvial environments typical of the late Miocene in the region (Andres, 1986; Groot et al., 1990).

Columbia Formation

The middle Pleistocene Columbia Formation lies directly on the St. Marys Formation of late Miocene age. The sediments of late Miocene and Pliocene age likely were stripped prior to deposition of the Columbia. It is possible that some of the late Pliocene Beaverdam Formation (Groot et al., 1990) may be present in the southern part of the Milford quadrangle south of the Mispillion River. Some of the sands reported in the drillers logs are similar to those of the Beaverdam in having a silt component and a whitish color, but there is no clear evidence that they are a part of the Beaverdam. These sands are included in the Columbia until further data can shed light on their origin.

The deposits of the Columbia Formation were the product of the distribution of glacial outwash sediment across an unrestricted fluvial plain during the early Pleistocene (Jordan, 1974). The rare exposures of the unit indicate that deposition was on an accretion plain where rivers migrated back and forth depositing a large volume of coarse sediment in a sediment-choked system. The system was sand-dominated and filled and covered the underlying topography carved prior to its deposition to a depth of at least 60 feet southwest of Milford. As reported by Jordan (1964), the Columbia Formation is of fluvial origin. Sedimentary structures such as the steep cross-bedding and small to large scale cut and fill are typical of those produced by movement of large sand bedforms (Miall, 1985). At Me22-a (Fig. 8), the lower 10 feet of the formation (above the clayey silt beds) have structures that are typical of foreset macroforms deposited in large bedforms marginal to an active channel of the river system. These grade upward into smaller scale sedimentary structures commonly associated with lateral accretion deposits that spread out from the banks of the river (Miall, 1985). The section is indicative of near channel deposits that grade upward into deposits farther away from the channel (i.e., records the migration of the channel away from the area now found in the pit exposure). Exposures of the Columbia are rare in the Milford area. A detailed analysis of the depositional system in the area would require much more subsurface information than is currently available.

The pollen from the Columbia Formation elsewhere in Delaware indicate that the climate was cool-temperate (Groot et al., 1995), consistent with a period of time following a major glacial period during the Pleistocene. Given the areal extent and thickness of the Columbia and what is known about its fluvial depositional environment, it is evident that two factors were necessary for the deposition of the unit: large volumes of sediment and water to transport the sediment. Water from the melting glaciers can provide the large volumes needed for the transport and distribution of the sediment. As the glaciers moved forward, they plowed off much of the soil and some of the underlying bedrock within the drainage area. This material was moved forward with the glaciers and by meltwater coming from the glaciers. As the climate began to warm and the glaciers retreated, massive amounts of meltwater moved the sediments downstream to where the streams spread out on the Coastal Plain. The meltwater also eroded some of the older Coastal Plain sediments and in northern and central New Castle County carved deep valleys (Jordan, 1964; Spoljaric, 1974). These valleys were then filled with the outwash sediment and eventually an alluvial plain was built with further sedimentation. In the vicinity of Milford, none of these deep channels was found during the course of this investigation (Fig. 16). The sediments in the alluvial plain, however, built up 50 to 60 feet of sedi-

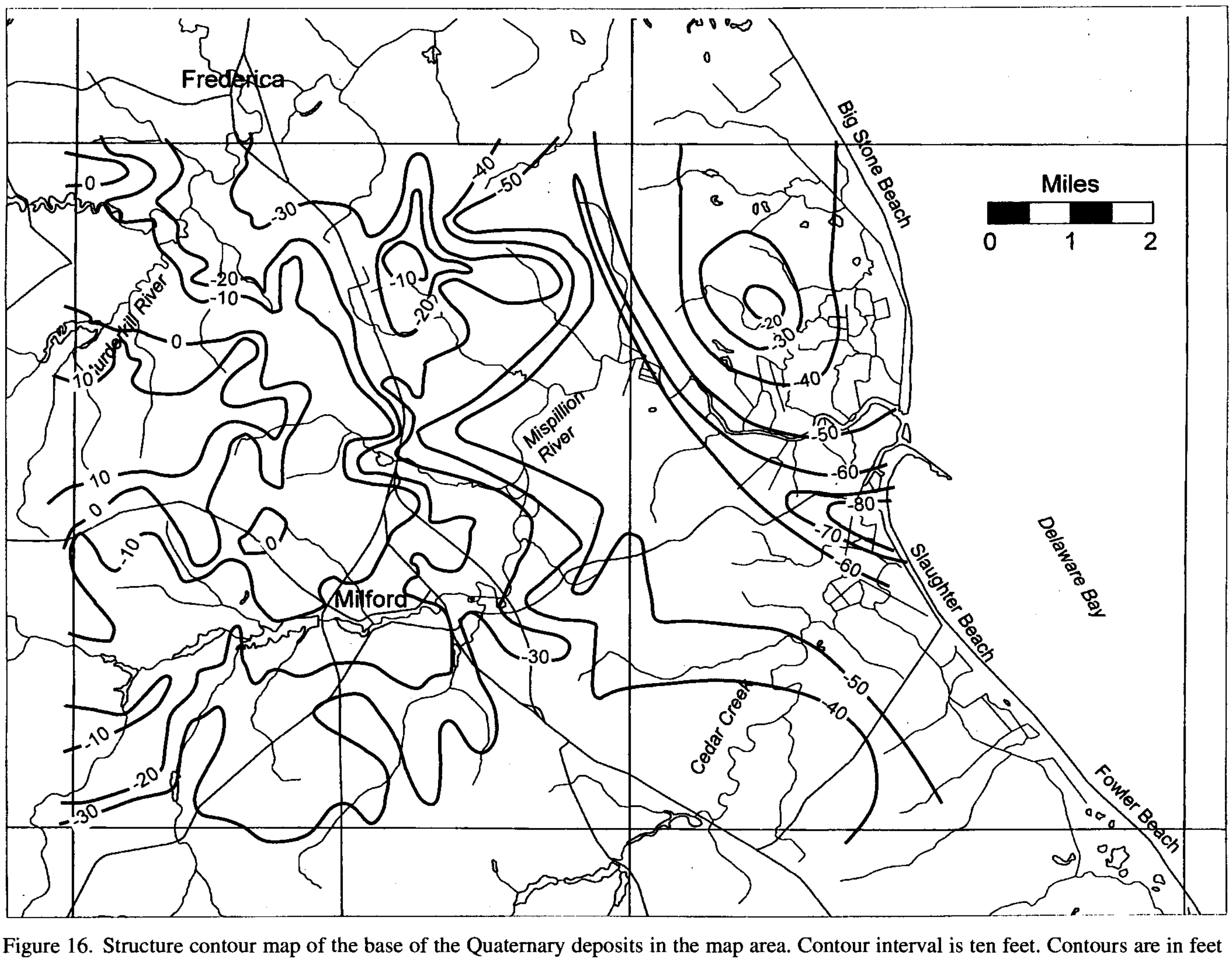

Figure 16. Structure contour map of the base of the Quaternary deposits in the map area. Contour interval is ten feet. Contours are in feet below mean sea level. Contours are drawn for a time prior to late Wisconsinan and Holocene erosion (Figure 14).

ment in the area. The relatively undissected, flat, surface (I, Figs. 17, 18) is characteristic of an alluvial plain that has been relatively uneroded since time of deposition.

I suggest that the Columbia Formation represents the major introduction of sediment into the region during the Quaternary. This may have been the result of a single glaciation, or more than one glacial advance. Later depositional events in large measure have resulted in the erosion and redistribution of the Columbia and older sediments with only minor contribution of new sediment into the region.

Delaware Bay Group

Introduction

The major development that influenced the geology of the region after deposition of the Columbia Formation was the establishment of the Delaware River at or near its present course in the Coastal Plain. Presumably this occurred after the major source of sediment supply (pre-glacial regolith) from the Appalachian glaciers was depleted. In addition, periglacial action (freeze-thaw) has contributed to movement of material downslope and to the production of new material, but has also created a stable landscape that contributes little sediment for transport by streams during times of temperate climate (Braun, 1989). The depletion of sediment supply and perhaps a lowering of sea level greater than that experienced previously with the continuation of a contribution of glacial meltwater resulted in the entrenchment of the river somewhere near its present course. With a lowered sea level during the glaciation and continuing into the period when the glaciers were melting, glacial meltwater from the Delaware River would have poured into the area of the previously deposited Columbia Formation and have deeply incised a major river channel into the Columbia and older sediments. The subsequent rise in sea level to levels higher than had been experienced since perhaps the latest Pliocene or earliest Pleistocene began the modification of the Columbia sediments and older deposits (mainly the Beaverdam Formation) into the recognizable coastal configuration of today.

Knebel and Circe's (1988) profiling in Delaware Bay revealed two late Pleistocene drainage systems beneath Delaware Bay; one pre-Sangamonian (late Illinoian?) in age, and the other Wisconsinan. Whether the initial, post-Columbia valley of the Delaware is that identified as the pre-Sangamonian by Knebel and Circe (1988) is unknown. It is the most northerly of the identifiable paleovalleys and has a path underneath Cape May, New Jersey. If the progressive development of cutting and filling paleovalleys by the Delaware is similar to that of the Susquehanna (Colman and

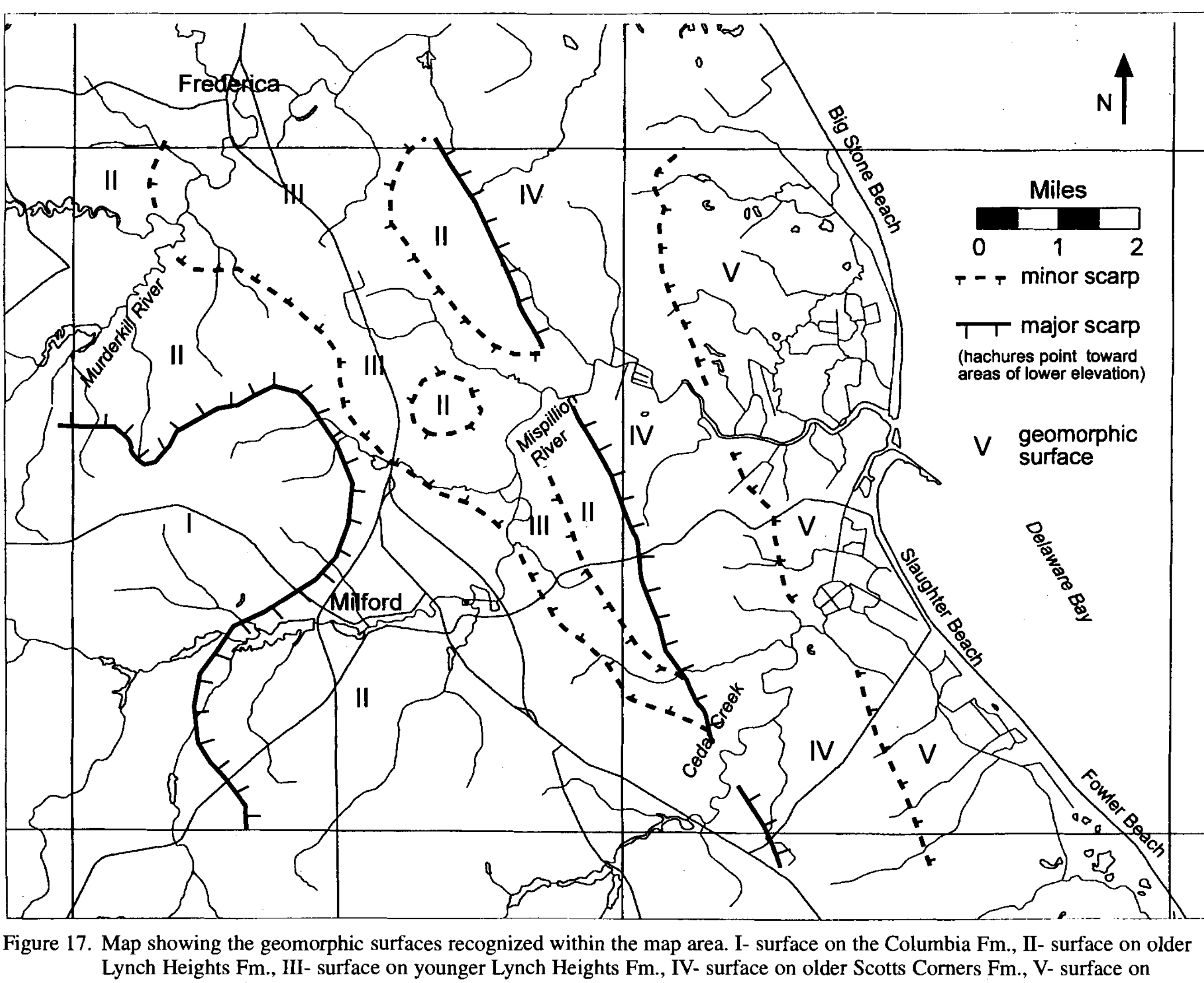

Figure 17. Map showing the geomorphic surfaces recognized within the map area. I- surface on the Columbia Fm., II- surface on older Lynch Heights Fm., III- surface on younger Lynch Heights Fm., IV- surface on older Scotts Corners Fm., V- surface on younger Scotts Corners Fm.

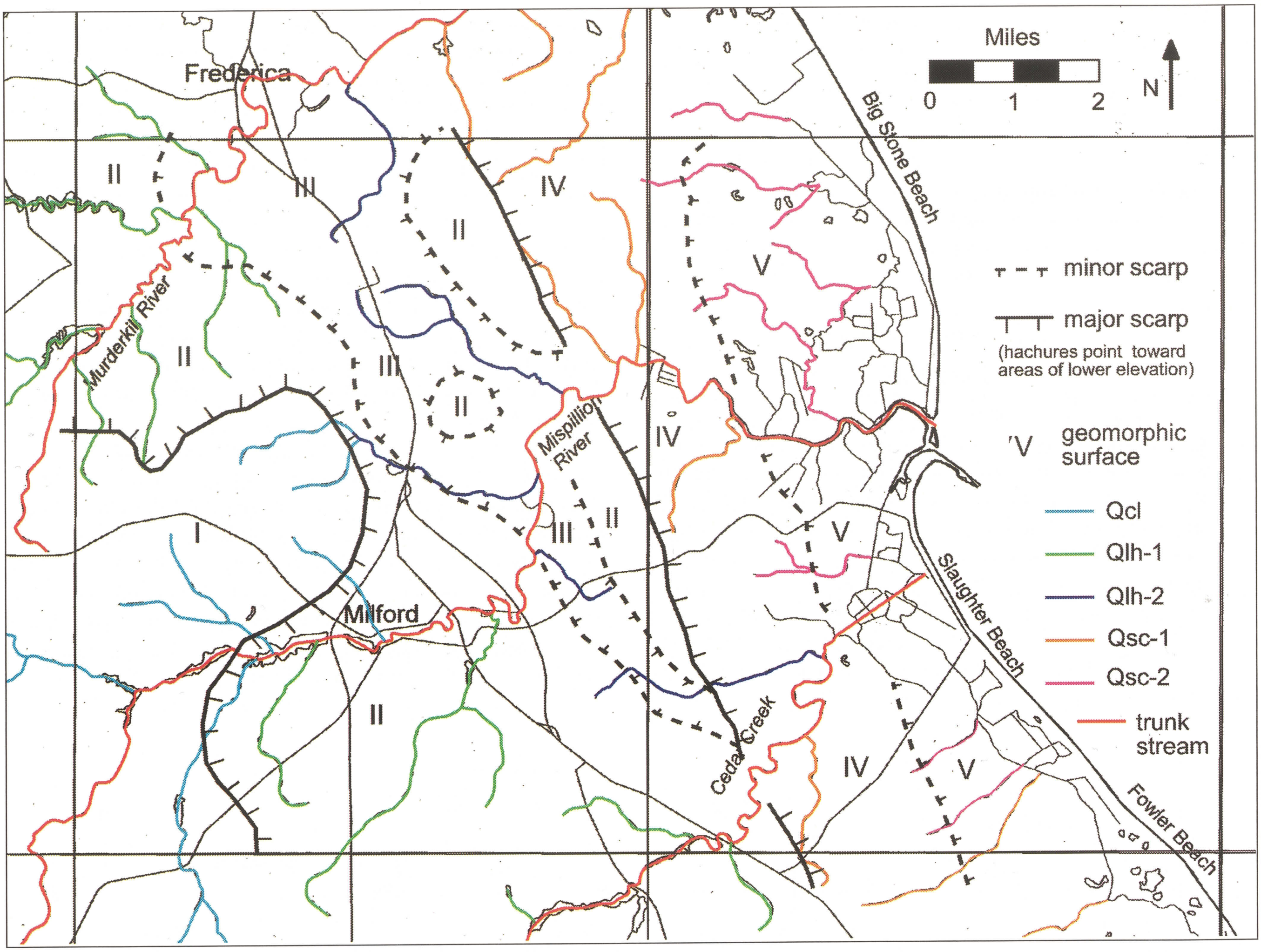

Figure 18. Map showing generations of stream development within the map area as influenced by the geomorphology (Figure 17). Qcl-Columbia Fm., Qlh- Lynch Heights Fm., Qsc- Scotts Corners Fm. Roman numerals represent surfaces depicted in Figure 17.

Mixon, 1988), then a trend of oldest to the north and youngest to the south would be expected. In the Susquehanna drainage (Chesapeake Bay), Colman and Mixon (1988) identified three drainage systems with paleo-valleys correlated in age from youngest to oldest with oxygen isotope stages 2, 6, and 8 or 12. Given the proximity of the drainage basins and the shared geologic framework of the region, the Quaternary history of cutting and filling of the rivers should be similar. Recent seismic profiling on the Delaware and southernmost New Jersey Atlantic inner shelf deposits indicates at least four distinct channel systems that appear to extend into Delaware Bay can be recognized (David E. Krantz, personal communication, 1996). The relative ages of these channel systems can be determined, but outside of the channel associated with the last glacial period erosion and Holocene fill, the age of the others cannot be determined with certainty at this time due to a lack of core data. I assume that the paleovalley systems found in the Delaware should correlate with those of the Susquehanna and that there are probably three or four distinct Quaternary paleovalley systems: one associated with the Lynch Heights that in part is found on land in the Mispillion River Quadrangle; one associated with the Scotts Corners that is underneath the present Delaware Bay; one associated with the Wisconsinan that is currently being filled, and one of indeterminate age that runs beneath Cape May (northern paleovalley of Knebel and Circe, 1988).

Prior to deposition of the Lynch Heights Formation, the Columbia Formation and correlative deposits formed a wide alluvial plain that stretched from the western shore of Maryland to New Jersey only interrupted by rivers that were feeding sediments onto the plain. With an ensuing glaciation, a drop in sediment supply, and a fall in sea level, the two major rivers in the region, the Susquehanna and the Delaware, began carving valleys in the Coastal Plain at or near their present courses. The sediments of the Columbia began to be eroded, redistributed locally, and transported to the continental shelf. A drainage system on the old alluvial plain of the Columbia began to be developed but because of the flatness of the plain was poorly developed. Adjacent to the major rivers, headward erosion of tributary streams occurred as an adjustment to the volume of water being carried in the glacier-fed rivers (White, 1978).

Lynch Heights Formation

In the Milford and Mispillion River quadrangles, the deposition of the Lynch Heights began after the Delaware River carved a valley that cut into the St. Marys and Choptank formations and in places completely removed the St. Marys (cross-section A-A´, Ramsey, 1993). This valley was approximately parallel to the present course of the Delaware and its base was about 70 feet below present sea level. A structure contour map of the base of the Quaternary (Fig. 16) shows the western margin of the valley was relatively steep rising from the elevations of -40 feet northwest of Spring Hill to +20 feet along Bluejay Lane to the southwest within the distance of about a mile (cross-section A-A´, Ramsey, 1993). Within this valley, fluvial sediments consisting of coarse sand with some gravel were deposited on the underlying Tertiary units. Most of the sand and gravel was derived locally from the Columbia Formation. No exposures of this portion of the Lynch Heights have been found. Samples from drill cuttings consist mainly of a medium to coarse sand with scattered pebbles. Thicknesses of these fluvial deposits probably range from a few feet to a few tens of feet. This unit is the lower sand as described in the section on stratigraphy.

The middle interbedded sand and clayey silt unit is typical of tidal flats associated with a sandy estuary (Reineck and Singh, 1980). The sequence at reference section Mf12-a (Fig. 10) is a transgressive sequence going from very fine sand with clay drapes and silt of a lower subtidal flat, in turn cut into by medium to coarse sands deposited in tidal channels. These sands are overlain by burrowed fine sands and clayey silts deposits on the margins of the channel. The fine-grained deposits are in turn overlain by coarse to very coarse cross-bedded sands, likely associated with a migrating barrier or spit complex. The sequence is capped by muddy coarse sands and gravel that likely were deposited just offshore in the estuary proper; much like that found off of Slaughter Beach today. The very fine sand cap may be offshore sands, or more likely aeolian sands deposited after sea level fell after deposition of the Lynch Heights. The medium to fine sand and silts of the upper portion of the Lynch Heights were the sediments deposited in the estuary and estuary margin during the highest stand of sea level. The subtle break in topography at the surficial contact between the Lynch Heights and the Columbia is the remnant of an eroding shoreline at the maximum extent of the estuary. The original surface of the Lynch Heights (II, Fig. 17) sloped gently to the east from this contact toward an ancestral Delaware Bay.

Geomorphic evidence (Fig. 17) suggests a period of erosion cut into and modified the Lynch Heights surface prior to deposition of the Scotts Corners Formation. A flat area of approximately 25 feet in elevation extends along Rt. 113 from the northern border of the map area south-southeastward to east of Milford on Cedar Neck. This flat (III, Fig. 17) separates higher areas that are up to 40 feet in elevation in an topographic outlier to the east from the Lynch Heights to the west at similar elevations (II, Fig. 17). The high area to the east is probably not a barrier or spit (i.e., likely topographically high features in a coastal setting). From drillers' log descriptions, these deposits in the outlier consist of a variety of lithologies from coarse sand to silty sand with a core of gray clayey silts and organic silts.

The flat area to the west of the outlier has a distinctive silt cap (cross-sections A-A´ and B-B´, Ramsey, 1993) unlike the rest of the Lynch Heights. One excavation in a drainage ditch (Le25-a) showed the material to be a sandy silt of one to three feet in thickness that thickens from east to west and overlies a coarse pebbly sand. The silt cap represents some period of deposition in a relatively low energy environment (tidal?). It is unknown how much of the sands below the silt also are a part of this feature.

Evidence of cold climate deposition at the base of the silt-capped flat within the Lynch Heights is documented by a pollen sample from a site in the Milford Neck Wildlife area (Le15-g). The pollen collected from this site at about 10 feet below the present land surface indicate that a boreal forest vegetation existed in the area at the time of deposition of the sediment. The age of this deposit is unknown, but is apparently related to the deposition of the Lynch Heights (based on the depth beneath the surface and its location in a broad, flat area) rather than later deposition. It likely represents a bog on a relict land surface associated with the erosion of the Lynch Heights prior to the deposition of the sands and silt cap of the flat area.

Most of the Lynch Heights deposition had an estuarine or tidal influence. The pattern of sedimentation was similar to that occurring at present. An estuary was developing and enlarging with a rising sea level. On the margins of the estuary, nearshore and tidal deposits were being laid down. As sea level rose, deposition was confined to the paleovalley with a fining toward the east (toward the paleoestuary center) and along the valley margin. Some mud-filled paleovalleys have been recognized, the largest one of which trends from just west of Wesley Church to beyond Herrings Corners. Pollen from within the deposits of this channel indicate estuarine and marsh conditions in a cool-temperate climate. The middle interbedded sand and clayey silt unit began to develop extensively when the paleovalley margins began to be flooded and the flat-lying uplands inundated. The area provided a new source of sediment, and because larger land area was flooded, sedimentation rates may have slowed allowing for finer-grained deposition. The lower slope may have also allowed for the development of tidal flat deposition such as that at the reference section exposure Mf12-a (Fig. 10). A similar sequence is found at other exposures and is recognized from drill hole logs in the area. The unit is characterized by a fining-upward section found beneath a coarsening-upward sequence. The Lynch Heights at its westward extent is capped by a sandy unit that is in part shoreline deposits and in places an aeolian unit (fine to medium well-sorted sands) mapped with the Lynch Heights, but may be of a separate depositional event and younger age than the Lynch Heights. Maximum flooding reached a relative position of 42 to 45 feet above present sea level. Because flooding was on a relatively flat-lying surface, the shoreline was not cliffed, and only a subtle scarp was produced between the Lynch Heights and the Columbia.

After maximum flooding, sea level fell to at least a relative position of 15 feet above present. The Lynch Heights was eroded by a fluvial(?) system that cut out at least thirty feet of the deposits in a valley that ran along the present Route 113 from the north to just south of Lynch Heights and then turned to the northeast close to the present course of the Mispillion River. This valley was filled with silt and fine sand to elevations of between 25 and 30 feet (Fig. 17, III) to form the present flat (fine-grained deposits at land surface in cross-section A-A´ from Le34-06 to Le35-34 and in B-B´ from Le23-04 to Le15-03, Ramsey, 1993). These deposits are interpreted to be estuarine and marsh deposits filling the paleovalley. The paleovalley was probably a tributary to the main channel of the Delaware River owing to its narrow width and limited depth of erosion. After deposition of these sediments, sea level fell and the main channel of the Delaware shifted to the east somewhere beneath the present Delaware Bay. It is possible that during the erosional and depositional event just described that the main channel could have existed somewhere along the present location of the Scotts Corners Formation and had removed much of the Lynch Heights to the east above present sea level and in part created the scarp that forms the boundary between the Lynch Heights and Scotts Corners Formations. Otherwise, it is difficult to account for the volume of sediment removed from a thick Lynch Heights Formation and deposited in a thin Scotts Corners Formation with just estuarine shoreline processes for removal and transport of the sediment.

The time between the two phases of the Lynch Heights is not known. The contact between the two at Le25-a has the characteristics of an unconformity. The most compelling evidence is a pollen sample (Le15-g) from 10 feet below the present land surface that indicates a cold climate and a boreal forest vegetation deposited in a bog prior to deposition of the second phase. Presumably, the bog would have been located on the surface eroded prior to deposition of the second phase and during a glacial episode. If so, a glacial period occurred between the two phases of Lynch Heights deposition.

After the first phase of Lynch Heights deposition, a drainage network began forming that was the predecessor of the modern drainage. Older streams that had previously been formed on the Columbia Formation may have been captured by this system that established streams flowing from the drainage divide between the Susquehanna and Delaware Rivers toward the Delaware River. The older streams flow out from the area underlain by the Columbia Formation (Fig. 18). These include the Mispillion and Murderkill rivers and perhaps Cedar Creek. A secondary system developed on the oldest Lynch Heights surface became integrated with this system. These streams have their head near the Columbia-Lynch Heights contact. A similar system developed on the surface of the younger Lynch Heights deposits with streams with their heads near the older and younger Lynch Heights contact. After the second phase of Lynch Heights deposition, sea level fell and the larger streams were incised into the underlying deposits (Fig. 17, 18).

There are small scale sand sheets and dunes composed of loose fine to medium sand scattered on the surface of the Lynch Heights. These features are too small to be mapped on a scale of 1:24000 without intensive field investigation that was beyond the scope of this study. These features are commonly found adjacent to present streams on their north or east sides. An example are small dunes found on the north side of Williamsville Road, north of Griffith Lake, and east of Holly Hill Road (Ramsey, 1993). These appear on the topographic map as small linear features. Presumably, these features are related to colder climate periods that postdate the Lynch Heights where vegetation was less abundant and sand easily was moved and deposited by wind (Denny and Owens, 1979). Dates from radiocarbon dating of similar deposits elsewhere in Delaware range from 10,000 to 30,000 yrs BP and possibly older (Denny and Owens, 1979; Ramsey and Baxter, 1996).

Scotts Corners Formation

The Scotts Corners compared to the Columbia Formation and the Lynch Heights Formation is a thin unit (less than 15 feet thick over most of the map area) and is interpreted to represent transgressive tidal, shoreline, and estuarine sediments. The Scotts Corners is separated from the older Lynch Heights by a prominent topographic feature (scarp) that was the estuarine shoreline during the Scotts Corners depositon (Fig. 17). The shoreline may in part be a reoccupation of an older shoreline (fluvial or estuarine) that was associated with the younger Lynch Heights deposition or even a younger estuarine shoreline which has had almost all correlative deposits stripped by the Scotts Corners transgression. At least one pollen sample (41344; Lf23-f) from the area mapped as Scotts Corners has yielded a palynomorph assemblage that appears to be older than Scotts Corner and unlike that of the Lynch Heights both in terms of floral content and climate. In addition, one pollen sample (41422; Lf23-t) indicates a cold climate with boreal forest vegetation. This sample lies at the base of the Scotts Corners beneath 5 feet of coarse to medium sand with pebbles interpreted as shoreface or slightly offshore sands capped by a thin layer of silt. This sample was likely deposited in a bog during a cold climate period prior to Scotts Corners deposition. If so, the surface upon which the Scotts Corners was deposited was exposed during a glacial period and the Lynch Heights in the area had already been removed.

On the bases of the stratigraphy and distribution of lithologies within the Scotts Corners, the lower pebble gravel and coarse sands represent reworking along the contact with the underlying Lynch Heights as marshes and tidal channels migrated inland with rising sea level. The organic muds are the remains of the marshes and organic muds deposited on the flanks of the tidal channels. These deposits gave way to the medium to coarse sands that represent the migration of a beach-barrier system across the area and grade up into silts that were deposited offshore in the bay bottom. The tidal channel and organic silts were preserved only where channeling was deep. As the barrier beach system migrated through an area, much of the back barrier sediments were removed by erosion in the shoreface and just offshore. A modern example occurs in the same area at Fowlers Beach where the erosion along the present shoreline is removing most or all of the back barrier marsh deposits. South of the present Mispillion River on Cedar Neck and Slaughter Neck, the deep channels were rare (as they are near the present shoreline, exclusive of Cedar Creek) and the Scotts Corners is dominated by sand deposited in the shoreface and just offshore. The source of sediment was most likely reworked from the underlying sandy Lynch Heights Formation.

As with the Lynch Heights, deposits now recognized as the Scotts Corners Formation were previously included in the Columbia Formation (Jordan, 1964) and also included in the Pamlico formation, Parsonsburg sand, or Pleistocene series (Rasmussen et al., 1960). In a regional map, Owens and Denny (1979) showed to the east of Milford the Ironshire Formation over an area currently mapped as the Scotts Corners. Identification of this unit was attempted, but the lithologies of the unit as described differed markedly from that of the deposits found in the Milford area. The Scotts Corners is in part coeval with the Omar Formation of southeastern Delaware and possibly with the Sinepuxent Formation of Maryland (Owens and Denny, 1979). The Scotts Corners along Delaware Bay occupies a similar geomorphic position as these deposits (east of a topographic break, i. e., an old shoreline, and with land surface elevations of twenty feet or less). Palynostratigraphic data also indicate that these units were deposited under similar climatic conditions and are probable age equivalents (palynology section of this report).

The Scotts Corners represents two periods of deposition, each associated with rising sea level. Geomorphic evidence from topography and stream patterns indicate the possiblity of two shorelines and periods of stream generation. Evidence from the pollen record within the unit also consist of two distinct floral assemblages within the formation. In addition to the prominent scarp that marks the landward extent of the Scotts Corners, another more subtle feature is found to the east marking a break between elevations of ten feet or greater (IV, Fig. 18) and those of five feet or less (V, Fig. 18). The toe of this scarp is at approximately seven feet above present sea level. The feature is not particularly well developed over much of the area and is partly obscured by modern human activity (agricultural plowing). On Milford Neck, closely spaced borings indicate that organic rich sediments thin out against this feature (cross sections C-C´ and E-E´, Ramsey, 1993). These sediments have a pollen assemblage distinct from that of the rest of the Scotts Corners.

In addition, numerous small streams that flow into the present marshes and are not tributary to other streams have their head at this feature, suggesting that an independent drainage system was developed that flowed to the east prior to the current rise in sea level. The fact that the streams are not integrated with the rest of the drainage on the surface of the Scotts Corners suggests that these features developed on a younger surface (V, Fig. 18) exposed after sea-level fell and the shoreline scarp within the Scotts Corners was cut (Figs. 17, 18). The indication that the organic deposits pinch out against the feature argues for the generation of the deposits during a rise in sea level rather than a stillstand during the fall of sea level after the deposition of the majority of the Scotts Corners. A stillstand deposit would normally consists of prograding sand bodies or an eroded shoreline without the deposition of organics. Deposits such as those along the Delaware Bay shoreline today are associated with a rising sea level and are similar to those seen in this younger Scotts Corners feature. The mappability of this feature and associated deposits is difficult and at present the deposits are included within the Scotts Corners Formation.

Small scale dunes and sand sheets composed of fine to medium sand found on the surface of the Scotts Corners Formation are similar to those on the Lynch Heights. A sample (Lf23-t, 41422) beneath one of these sand sheets at the contact with the underlying Scotts Corners Formation yielded a palynoflora typical of a boreal forest climate. It was likely deposited in a bog on top of the Scotts Corners prior to being covered by the sand. These sand bodies are small and scattered and are mapped with the Scotts Corners even though they may be of a younger and completely separate phase of deposition.

Deposition of the Scotts Corners within the map area began during sea level rise when local base level began to be affected. Where tidal processes were present, fresh water and brackish water marsh deposits developed. These initially were restricted to pre-existing stream valleys (primarily along the ancestral Murderkill or Mispillion Rivers). The actual paths of these streams during that time are difficult to determine. Filled channels are recognizable on Milford Neck (cross section D-D´; Ramsey, 1993); whether they represent the ancestral Mispillion River has not been determined. With continued sea level rise, the old stream valleys were filled and wide-spread marshes developed on the flooded interfluves. The transgression appears to have continued until the shoreline reached the position of the scarp. It is unknown how much scarp retreat occurred during the maximum high stand. Deposition along the pre-existing stream valleys behind the shoreline (such as along the Mispillion) indicates that these streams were in existence and being flooded at this time in a similar setting to that currently found in Blackbird Creek adjacent to the Delaware River in New Castle County. Sands, silts, and muds found at the land surface throughout the map area of the Scotts Corners were deposited as estuarine (bay bottom) and nearshore deposits during the maximum transgression. Sands were likely contributed by shoreface erosion of the underlying Lynch Heights as well as from the Lynch Heights where the shoreline intersected the scarp. Analysis of pollen samples from the Scotts Corners shows that the climate was temperate to warm temperate.

After the maximum transgression, sea level fell and a drainage system began to form on the exposed surface. The streams had their head near the contact with the Lynch Heights (primarily at the toe of the scarp) and became integrated with the major streams flowing from the west (Mispillion and Murderkill rivers and Cedar Creek; Fig. 18). As with the Lynch Heights, there is some evidence that indicates a second phase of Scotts Corners deposition. There is a subtle scarp that runs roughly parallel to the present Delaware Bay that marks a break between the Scotts Corners surface that is about 10 feet above sea level (IV, Fig. 18) and rises to about 20 feet above sea level to the west and a flat area around 5 to 7 feet above sea level (V, Fig. 18) that slopes eastward underneath the present marsh (Figs. 17, 18). Streams that flow out into the present marsh toward Delaware Bay and that are not integrated with the major drainage system originate at or near this scarp (Fig. 18). Given the pattern of stream development on the other geomorphic surfaces at or near stratigraphic breaks associated with shorelines, another shoreline and stratigraphic break is suggested. On Milford Neck (cross-sections C-C´ and E-E´, Ramsey, 1993), an organic-rich deposit (the muds at the base of the Scotts Corners) pinches out against sandier deposits to the west and a coarse sandy unit (shoreface deposits) ramps up near the subtle scarp. Pollen samples from the organic-rich muds indicate fresh-water to brackish marsh environments that are rare in the rest of the Scotts Corners. They also have a higher non-arboreal pollen (NAP) percentage than the rest of the Scotts Corners and have a common component of *Myrica* that is not present or is present in amounts of one percent of the arboreal pollen in the rest of the Scotts Corners. Taken together, the geomorphology, stratigraphy, and palynology indicate that there were two separate depositional events within the Scotts Corners Formation.

After deposition of the younger Scotts Corners, sea level fell, and a drainage pattern developed on the exposed surface. These small streams tend to originate at the subtle scarp and trend east into the present marshes behind the Delaware Bay barrier. The larger streams cut across these deposits and carved the valleys that are filled with Holocene deposits or are currently being filled with recent sediments.

Ages of the Columbia, Lynch Heights, and Scotts Corners Formations

The ages of the Columbia, Lynch Heights, and Scotts Corners formations are interpreted on the bases of the relative stratigraphic position of the units, palynologic data from the map area as compared to elsewhere in Delaware and in the nearby region, and aminostratigraphic data from Delaware and the neighboring mid-Atlantic region.

Stratigraphic Position

A cross-section across the map area (Ramsey, 1993, cross-section A-A′) shows that the Columbia, Lynch Heights, and Scotts Corners have cut-and-fill relationships with each other. The Columbia Formation is stratigraphically the oldest unit. It is cut into by the Lynch Heights Formation which is in turn cut into by the Scotts Corners Formation. The three units, then, are from oldest to youngest, the Columbia, Lynch Heights, and Scotts Corners formations.

Palynologic Data

Previously published data on the palynology of the Quaternary units of Delaware (Groot et al., 1990, 1995) and of the Columbia, Lynch Heights, and Scotts Corners formations in this report provide some age information. First, on the bases of available data from Delaware all three units are of Pleistocene age. Second, the populations of *Quercus* (oak) species found within the units (this report) compared with those found in offshore sediments (Groot et al., 1995), indicate the Columbia Formation is of middle or possibly early Pleistocene age. The boundary between the early and middle Pleistocene is approximately 770,000 yrs BP (Engel et al., 1996). Likewise, the Lynch Heights Formation is considered to be of middle Pleistocene age (between 770,000 and 132,000 yrs BP), and the Scotts Corners to be of late Pleistocene age (younger than 132,000 yrs BP; Engel et al., 1996; Richmond and Fullerton, 1986). Because of the prevalence of two forms of *Quercus* (species 1 and 3; Groot et al., 1995) in the Scotts Corners Formation, it is interpreted to have been deposited during oxygen isotope stage 5 (between 79,000 and 132,000 yrs BP).

Aminostratigraphic Data

No shell material from the map area was found for amino acid racemization analysis. Aminostratigraphy relies upon the observation that amino acids contained in fossilized shell material undergo racemization during diagenesis. Racemization produces D- (right-handed) amino acids from the original L- (left-handed) amino acids. The degree of racemization is determined by measurement of D/L values for one or more amino acids in the total amino acid mixture of a fossil. For more information on this technique, refer to Groot et al., (1990, 1995). The simplest approach to using data from this technique is as a stratigraphic tool whereby age estimates are assigned to recognized clusters of D/L values (aminozones) from samples within a region of similar temperature histories (racemization is temperature dependent). Previously published data from Delaware and the mid-Atlantic region (Groot et al., 1990, 1995) does provide information that can be used in interpretation of the Quaternary units under discussion.

Amino acid racemization data from shells from the Omar Formation of the Atlantic Coast of Delaware have clustered in three aminozones: IIa, IIc, and IId which have been assigned age estimates of roughly 100,000, 200,000, and 500,000 years BP respectively (Groot et al., 1990). More recent kinetic modeling has suggested that the IIc aminozone is more likely to be in the range of 250,000 to 400,000 years, or a mid-point of about 325,000 years (Mirecki et al., 1995). On the bases of comparison with other onshore and offshore sites in the region, a tenative correlation with the oxygen isotope stages of IIa with stage 5, IIc with stages 7 and 9, and IId with stages 11, 13, or 15 was proposed (Groot et al., 1995).

Given these age estimates, there appears to be at least three aminozones in Delaware represented by shell material. These are a unit at an age of about 100,000 years that can be correlated with aminozone IIa (oxygen isotope stage 5), a unit at an age between 250,000 and 400,000 years that can be correlated with aminozone IIc (oxygen isotope stage 9 or possibly as young as 7), and a unit that is around 500,000 years (or as old as 800,000, Mirecki et al., 1995) which can be correlated with aminozone IId (stages 11, 13, or 15). Deposits containing aminozone IIc have also been found across Delaware Bay in New Jersey where geomorphic and aminostratigraphic evidence suggest that stage 9 is a likely candidate for correlation (J. F. Wehmiller, personal communication, 1997).

Ages of the Units

The Omar Formation of the Atlantic Coast of Delaware is correlative to the Scotts Corners and Lynch Heights formations along the margins of Delaware Bay and was deposited during several glacial/interglacial cycles during the Quaternary (Groot et al., 1990). It stands to reason that high stands of sea level that have a sedimentary record of lagoonal and estuarine deposits along the Atlantic Coast would also have a record along the margins of Delaware Bay; therefore, it is likely that the Lynch Heights and Scotts Corners formations as records of the these high stands are coeval with the respective Omar cycles. On the bases of the pollen record from both the Omar and the Delaware Bay Group deposits and the aminostratigraphic age estimates from shells from the Omar Formation, some age estimates of the Scotts Corners and Lynch Heights formations can be suggested.

Fig. 19 shows tenative correlations between the Scotts Corners, Lynch Heights, and Omar cycles by assuming the oxygen isotope curve (Shackleton et al., 1984) as a proxy for changes in sea level that would have affected Delaware. The interpreted positions of sea level during deposition of the Scotts Corners, Lynch Heights, and Omar formations are indicated by the solid portions of the sea level curve on the bases of the actual range of elevations at which they are currently found.

Holocene deposits range back to about the last 10,000 years in age for this region. The shape of the Holocene part of the curve shown in Fig. 19 reflects the data from radiocarbon dates as reported by Ramsey and Baxter (1996).

The Carolina Bay deposits overlie the Scotts Corners Formation and must be younger than that unit. The time of deposition is unknown but likely occured after 79,000 years ago, possibly during the cold intervals of stages 2 and 4 (Fig. 19).

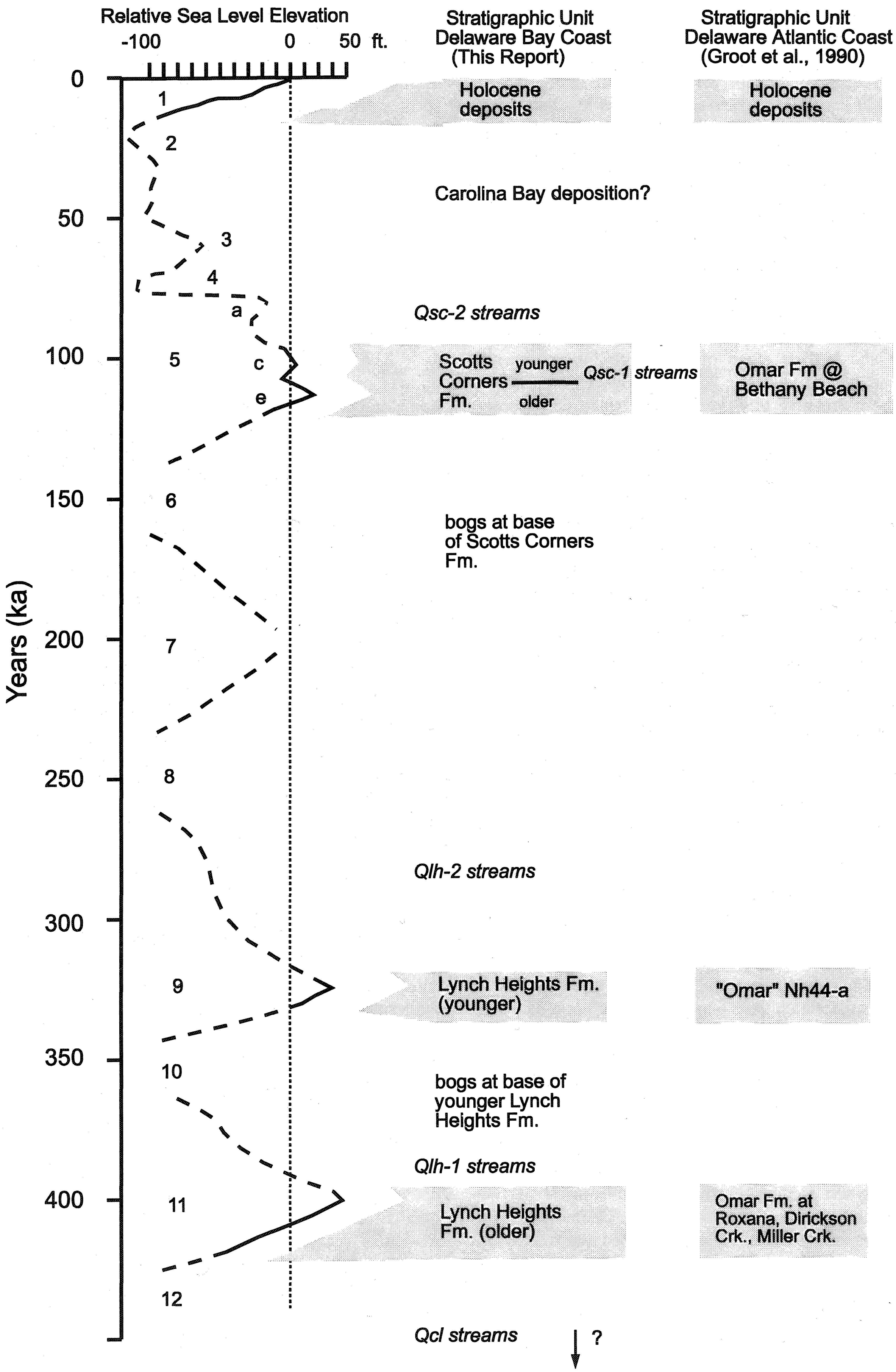

Figure 19. Schematic diagram of relative sea-level changes and interpretation of distribution of Quaternary and Holocene units in the map area. Also shown are possible correlations with stratigraphic units found along the Atlantic Coast of Delaware. Numbers within curve refer to oxygen isotope stages (Shackleton et al., 1994).

The Scotts Corners Formation has been divided into two parts, younger and older. Geomorphic evidence indicates that relative sea level was 18 to 20 feet above that at present during deposition of the older Scotts Corners and then fell to at least 10 feet below present sea level and then rose to about 8 feet above present sea level during deposition of the younger Scotts Corners. Palynologic evidence indicates that the two periods of deposition were separated by a cool to cold climate interval. Correlation both by pollen flora indicates that the Scotts Corners is age equivalent to the Omar Formation found at Bethany Beach (Groot et al., 1990). By correlation, aminostratigraphic age estimates place the age of the Scotts Corners at about 100,000 yrs BP. I suggest that the older Scotts Corners was deposited during oxygen isotope stage 5e (approx. 120,000 yrs BP), the most extensive and highest stand of sea level during stage 5 (Shackleton et al., 1984). The younger Scotts Corners could possibly be correlative to oxygen istope stage 5c (approx. 100,000 yrs BP), which also is thought to have had a sea level high above that at present (Shackleton et al., 1994). Two depositional periods during stage 5 is in agreement with the innner Atlantic continental shelf record of deposition off Maryland (Toscano et al., 1989; Toscano and York, 1992). Evidence from correlative units in the middle Atlantic Coastal Plain (Colman and Mixon, 1988; Toscano and York, 1992) indicate the possibility of two periods of deposition within stage 5. Global sea level records for the period (Smart and Richards, 1992) all show that the most prominent sea-level stand was that of the 125,000-year period (stage 5e) and was above present sea level by about 6 meters. The general consensus is that most of the last interglacial deposits in the Delmarva region are correlative with stage 5e, deposited about 125,000 yrs B. P. (Colman and Mixon, 1988; Toscano and York, 1992). Stage 5c (at about 100,000 yrs B. P.) appears to be the most likely candidate for the younger Scotts Corners deposits. Toscano and York (1992) report that stage 5c sea levels in the Maryland shelf may have reached to as much as 2 meters above present sea level based on water depth tolerances of ostracodes found in deposits correlated with stage 5c and on the elevation of correlative emerged deposits on the Atlantic coast of Maryland and Virginia (Sinepuxent Neck and Wachapreague, respectively). These elevations agree well with the younger Scotts Corners deposits which have a maximum elevation of 7 feet (2.1 meters).

Pollen-bearing sediments were found at the base of the Scotts Corners that were deposited in bogs during a period of cold climate and a lower sea level interval between the deposition of the Lynch Heights and that of the Scotts Corners. Within the Omar Formation are also deposits indicating a cold climate.

The Lynch Heights Formation also consists of two parts separated by a cold climate deposit. Geomorphic and stratigraphic evidence that sea level dropped and rose again between deposition of the two parts. Palynologic evidence indicates that at least a portion of the younger Lynch Heights correlates with aminozone IIc (this report; Groot et al., 1995). It would also by correlation be consistent with the presence of a shelly deposit attributed to the Omar Formation just to the south of the map area (Nh44-a; sample 41142, Table 5 in Groot et al., 1995) and underlies the Scotts Corners Formation which was tenatively placed in oxygen isotope stage 7 (Groot et al., 1995). On the basis of more recent kinetic modeling of amino acid racemization, deposits at Nh44-a (Fig. 19) are probably older, at least stage 9 (J. F. Wehmiller, personal communication, 1997). Also the oak species from Nh44-a are consistent with those from the Lynch Heights.

At the base of the younger Lynch Heights at one locality (Le15-g, Table 5) a bog deposit contains pollen that indicates a boreal forest climate. A severe cold period must have occured between the deposition of the older and younger Lynch Heights. Aminostratigraphic data indicate that there is an older aminozone in the Omar, IId, that can be correlated with oxygen isotope stages 11, 13, or 15 (Groot et al., 1995). I suggest that the older Lynch Heights correlates with stage 11.

The Delaware Bay Group deposits (Lynch Heights and Scotts Corners formations) were the result of the sedimentation along the margins of an ancestral Delaware Bay estuary. This estuary was the result of drowning of a river valley cut through the Columbia Formation. At least one cycle of lowered sea level during a glacial period must have occurred between the final deposition of the Columbia Formation (during an interglacial period) and the deposition of the Lynch Heights Formation. If the older Lynch Heights is at least as old as stage 11, then the Columbia, must be at least as old as stage 13 (approx. 500,000 yrs BP) and could well be older.

According to Richmond and Fullerton (1986), the oldest glaciation in the eastern New York, Pennsylvania, New Jersey for which there is a till record, covers a period of time from stages 14 through 12 (between about 562,000 and 428,000 years BP). Engel et al. (1996) document glacial deposits in the same area at least as old as stage 22 (approx. 820,000 years BP). Seismic evidence off of Long Island and New England indicate a glacial record going back at least as far as stage 21 (Richmond and Fullerton, 1986). The Columbia Formation is likely the result of one or more of these glacial events, but cannot be definitively tied to any one of them.

Holocene Sea-Level and Depositional History

Figure 20 is a local sea level plot of eight radiocarbon dates from the map area and additional dates from the southwestern Delaware Bay area (Appendix E; Ramsey and Baxter, 1996). The material dated came from tidally-influenced organic-rich sediments (tidal swamp or marsh) incorporating plant remains that grew within the tidal range. The radiocarbon dates reflect the time at which sea level was at a particular elevation (the present elevation from which the sample was taken) relative to present sea level. The plotting of these dates versus elevation (Fig. 20) tracks the relative rise of sea level within the region and the deposition of sediments related to the sea level rise. The plot is an approximation of sea level change. There are many factors to be considered that add uncertainty. Among these are compaction of sediments, uncertainty range within the radiocarbon dates, and problems with reworking of organic material (Fletcher, 1986). The dates have been calibrated (Ramsey and Baxter, 1996) to calendar years using the computer model "CALIB" of Stuiver and Reimer (1993).

By about 9500 years BP, the antecedent topography began to be flooded as sea level rose. The rise continued at a relatively constant rate until about 6,000 years BP where the slope of the curve steepens, indicating a more rapid relative rise of sea level. Although many local factors may have contributed to the apparent increase in the rate of rise (antecedent topography configuration, changes in sediment supply, etc.), catastrophic ice sheet collapse and rapid sea level rise at about 7600 years BP (documented in Caribbean coral reefs; Blanchon and Shaw, 1995) may have also been an influence.

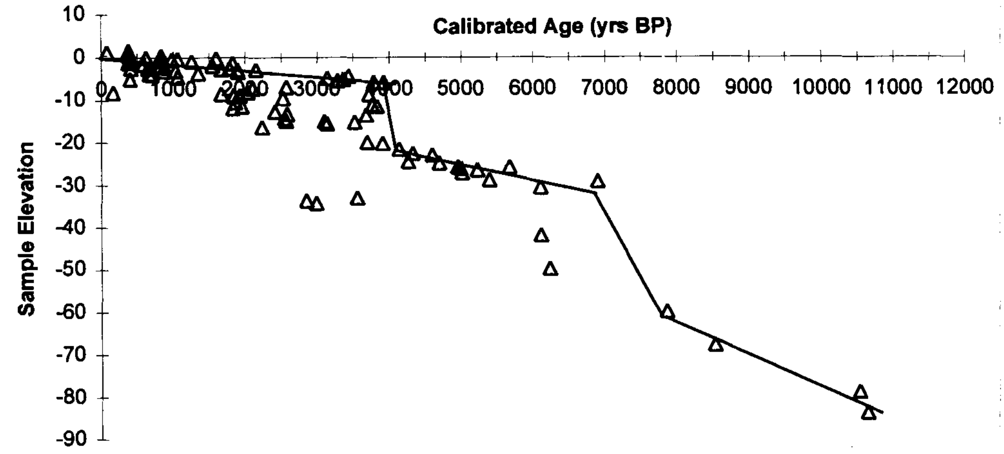

Figure 20. Distribution of calibrated radiocarbon dates for southeastern Delaware Bay. Line represents a generalized sea-level curve for the Holocene within the area drawn on the earliest incursion of sea level within the region.

Another increase in slope at about 2800 years BP indicates another increase in sea level rise. After that there is distinct flattening of the curve to the present or a decrease in the rate of sea level rise. It is unknown whether the interval of more rapid rise is to be attributed to local or other factors. The flattening of the curve was noted by Belknap and Kraft (1977) and was attributed to a change in the rate of subsidence due to hydro-isostatic compensation. The change in slope, however, may be simply the function of a change from flooding and deposition in the paleovalleys to overtopping and flooding of the broad, flat interfluves. The broad interfluves begin at approximately 10 to 20 feet below present sea level at about the same elevation as the change in slope of the curve (Fig. 20). Inundation of a broad, flat area takes a longer period of time per unit volume of water than a narrow, steep-sided valley. The relative rate of sea-level rise apparently slows down, reflected as a decrease in the slope of the curve, controlled by the antecedent topography rather than larger scale external forces.

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Appendix A

Geophysical Logs from the Milford and Mispillion River Quadrangles

MIL-Milford Quadrangle
MIR- Mispillion River Quadrangle
GAM- Gamma Log
SPE- Single Point Electric Log
IND- Induction Log
GGL- Gamma Density Log
MPE- Multiple Point Electric Log

DGSID	QUAD	Elevation (ft)	Hole Depth (ft)	Log Start Depth (ft)	Log Stop Depth (ft)	Log Type
Ke52-02	FRE	22	200	5	200	GAM
Le14-19	MIL	19	83	5	81	GAM
Le25-12	MIL	30	30	5	26	GAM
Le33-06	MIL	42	130	5	118	GAM
Le35-12	MIL	26	70	6	43	GAM
Le44-06	MIL	37	290	5	288.5	GAM
Le51-03	MIL	50	400	5	196	GAM
Le51-04	MIL	50	208	5	204	SPE
Le52-01	MIL	42	65	5	64	GAM
Le52-02	MIL	47	260	0	258	GAM
Le52-02	MIL	47	260	0	258	SPE
Le53-02	MIL	38	85	5	79	GAM
Le53-03	MIL	42	280	5	280	SPE
Le54-02	MIL	38	145	5	143	SPE
Le54-04	MIL	41	493	10	493	SPE
Le54-06	MIL	35	65	5	60	GAM
Le54-11	MIL	42	84.5	5	79	GAM
Le55-07	MIL	21	336	5	325	SPE
Le55-12	MIL	35	485	5	485	GAM
Le55-12	MIL	35	485	5	485	SPE
Lf13-06	MIR	9	284	5	273	GAM
Lf21-19	MIL	30	109	5	99	GAM
Lf24-02	MIR	7	103	5	101	GAM
Lg41-08	MIR	5	263	5	246	GAM
Lg41-08	MIR	5	263	10	247	GGL
Lg41-08	MIR	5	263	5	215	GRS
Lg42-02	MIR	2	304	304	136	MPE
Lg42-02	MIR	2	304	140	304	SPE

DGSID	QUAD	Elevation (ft)	Hole Depth (ft)	Log Start Depth (ft)	Log Stop Depth (ft)	Log Type
Lg42-02	MIR	2	304	224	3	GAM
Me13-03	MIL	27	160	5	127	GAM
Me14-07	MIL	20	106	10	101	SPE
Me14-14	MIL	35	66	5	64	GAM
Me14-20	MIL	30	506	5	505	GAM
Me14-20	MIL	30	506	5	500	SPE
Me14-20	MIL	30	506	5	505	GAM
Me14-20	MIL	30	506	5	500	SPE
Me14-23	MIL	30	263	5	255	GAM
Me14-29	MIL	25	260	5	232	GAM
Me15-29	MIL	7.3	955	60	822	GGL
Me15-29	MIL	7.3	955	50	822	IND
Me15-31	MIL	25	200	10	200	SPE
Me22-04	MIL	32	260	5	242	GAM
Me23-04	MIL	42	65	5	64	GAM
Me24-04	MIL	33	90	10	83	SPE
Me24-07	MIL	38	110	5	103	GAM
Me24-08	MIL	39	71.5	5	68	GAM
Me24-12	MIL	35	250	5	240	GAM
Me25-04	MIL	32	80	5	75	GAM
Me34-03	MIL	40	125	5	104	GAM
Mf21-07	MIL	34	105	5	105	GAM
Mf21-10	MIL	28	170	5	160	GAM
Mg21-06	MIR	10	118	5	114	GAM

Appendix B

Location Data and Sample Numbers for Pollen, Clay, and Mineral Samples Used in this Study

Cly- Clay Sample
Pollen- Pollen Sample
Min- Sample used for mineralogy

DGSID's with last two digits as numbers are wells or borings
DGSID's with last digits as lower-cased letters are outcrops or soil auger borings

DGSID	Sample No.	Analysis	Latitude	Longitude
Db31-60	25411	Cly	393725	754434
Ec11-a	41748	Cly	393442	753935
Ec11-a	41749	Cly	"	"
Ec31-a	41689	Cly	393203	753906
Ec31-a	41691	Cly	"	"
Ec31-a	41693	Cly	"	"
Fb25-a	40974	Cly	392815	753945
Fb34-09	32541	Cly	392716	754133
Fb55-04	25462	Cly	392547	754011
Fc12-a	41362	Cly	392925	753820
Hc24-05	83219	Cly	391840	753640
Hc35-a	41500	Cly	391750	753548
Ke54-a		Min.	390001	752629
Kf54-06	22191	Cly, Pollen	390012	752131
Kg52-04	22247	Pollen	390014	751819
Kg54-01	22280	Pollen	390010	751648
Kg54-01	22287	Pollen	"	"
Ld14-c		Min.	385916	753140
Ld44-c	41000	Cly	355623	753138
Ld44-c	41003	Cly	"	"
Le14-18	25706-2	Pollen	385934	752654
Le14-18	25706-1	Pollen	"	"
Le14-18	25707-2	Pollen	"	"
Le14-18	25707-1	Pollen	"	"
Le14-18	83557	Cly	"	"
Le14-19	25658-2	Pollen	385955	752601
Le14-19	25658-1	Pollen	"	"
Le14-19	25659-2	Pollen	"	"
Le14-19	25659-1	Pollen	"	"
Le14-a	41372	Cly	385919	752617
Le14-a	41373	Pollen	"	"
Le15-g	41420	Cly, Pollen	385941	752550
Le22-a		Min.	385833	752848
Le25-12	25639	Pollen	385814	752536
Le33-06	83330	Cly, Pollen	385728	752725
Le33-06	83335	Cly, Pollen	"	"
Le52-01	23502	Cly	385523	752814
Le52-01	23502	Pollen	"	"
Le53-02	23507	Pollen	385517	752706
Le54-06	23504	Pollen	385502	752654
Le55-07	32876	Cly	385530	752527
Le55-07	32882	Cly	"	"
Le55-07	32904	Cly, Pollen	"	"
Le55-07	32916	Cly, Pollen	385530	752527
Le55-07	32934	Cly	"	"
Le55-a	41325	Cly	385556	752512
Lf13-a	40975	Cly, Pollen	385912	752240
Lf14-a	40976	Cly, Pollen	385901	752120

DGSID	Sample No.	Analysis	Latitude	Longitude
Lf14-b	41323	Pollen	385932	752153
Lf14-b	41324	Cly	"	"
Lf14-c	41330	Pollen	385934	752142
Lf14-e	41334	Pollen	385940	752135
Lf14-f	41336	Pollen	385941	752134
Lf14-m	41353	Pollen	385931	752117
Lf14-n	41356	Pollen	385935	752126
Lf14-p	41425	Cly, Pollen	385906	752133
Lf14-p	41431	Cly, Pollen	"	"
Lf14-p	41435	Cly, Pollen	"	"
Lf21-19	25627-1	Pollen	385822	752442
Lf21-19	25627	Cly	"	"
Lf21-19	83553	Cly	"	"
Lf21-b	41367	Pollen	385855	752413
Lf23-ac	41482	Cly, Pollen	385818	752203
Lf23-ac	41485	Cly, Pollen	"	"
Lf23-ad	41489	Pollen	385827	752222
Lf23-f	41344	Pollen	385812	752232
Lf23-t	41422	Cly, Pollen	385834	752201
Lf23-u	41464	Cly, Pollen	385822	752207
Lf23-x	41465	Cly, Pollen	385817	752202
Lf23-x	41469	Cly, Pollen	"	"
Lf23-x	41472	Cly, Pollen	"	"
Lf42-01	25403	Cly	385608	752348
Lf51-b		Min.	385513	752446
Mc22-a	41001	Cly	385304	753310
Mc45-03	83160	Cly	385150	753549
Me14-14	23505	Pollen	385411	752650
Me14-20	82475	Cly	385401	752625
Me14-20	82483	Cly, Pollen	"	"
Me14-20	82497	Cly, Pollen	"	"
Me14-20	82508	Cly	"	"
Me15-29	32264	Pollen	385458	752516
Me15-29	32266	Pollen	"	"
Me15-29	32296	Pollen	"	"
Me22-a		Min.	385348	752846
Me22-a	41417	Cly	"	"
Me45-a		Min.	385138	752503
Mf12-b		Min.	385434	752352
Mg21-06	25658	Cly	385348	751959
Mg52-a		Min.	385023	751816
Ng11-a		Min.	384944	751905
Nh13-28	70371	Cly	384930	751212
Nh13-29	70375	Cly	384942	751219
Nh25-03	70362	Cly	384853	751043

Appendix C

Data Related to the Base of the Holocene Deposits
(Figure 14)

LOCALID refers to designation given in original reference or report.

DGSID	LOCALID	Latitude (N)	Longitude (W)	Surface Elevation (ft)	Elevation Base of Holocene (ft)
Lf32-02	CHF 16	385724	752328	-6.5	-10
Lf33-01	68	385740	752239	2	>-8
Lf33-03	HY18P	385732	752205	3	-3
Lf34-03	69	385740	752130	2	
Lf35-01	70	385705	752031	2	-48
Lf41-02	1	385614	752412	5	-43
Lf42-01	CHF 17	385608	752348	-6.5	-12
Lf44-03	HY17P	385657	752122	2	-46
Lg11-01	CR 124	385957	751938	3	-14
Lg11-04		385955	751936	3	-18
Lg11-05	8	385903	751901	1	-12
Lg11-06	9	385908	751903	1	-10
Lg11-07	10	385912	751905	1	-9
Lg11-08	11	385916	751908	1	-5
Lg14-01	PRM 18	385903	751618		-20.5
Lg22-01	PRM 20	385848	751842	-2.49	-4
Lg22-02	7	385802	751844	1	-5
Lg22-03	6	385804	751844	1	-5
Lg22-04	5	385806	751844	1	-14
Lg22-05	4	385808	751845	1	-8
Lg22-06	3	385810	751845	1	-6
Lg22-07	2	385812	751845	1	-6
Lg22-08	1	385822	751848	1	-10
Lg22-09	0	385824	751849	1	-15

DGSID	LOCALID	Latitude (N)	Longitude (W)	Surface Elevation (ft)	Elevation Base of Holocene (ft)
Lg22-10	1	385830	751850	1	>-20
Lg22-11	2	385834	751851	1	>-20
Lg22-12	3	385839	751852	1	-16
Lg22-13	4	385844	751853	1	-15
Lg22-14	5	385849	751855	1	-16
Lg22-15	6	385853	751856	1	-10
Lg22-16	7	385858	751858	1	-15
Lg23-01	PRM 38	385854	751736	-12.01	-15
Lg31-01	71	385705	751926	2	-40
Lg32-01	PRM 21	385700	751848	-0.25	>-21
Lg32-02	KCB 08	385700	751848	-3.5	>-33.5
Lg32-03	KCB 13	385708	751834	0	>-10
Lg32-04	KCB 15	385750	751834	0	>-10
Lg32-05	A	385705	751849	1	>-18
Lg32-06	B	385725	751849	1	>-8
Lg32-07	14	385741	751843	1	>-20
Lg32-08	13	385743	751843	1	-15
Lg32-09	12	385749	751843	1	-3
Lg32-10	11	385753	751843	1	-3
Lg32-11	10	385725	751844	1	-3
Lg32-12	9	385758	751844	1	-6
Lg32-13	8	385760	751844	1	-5
Lg41-04		385607	751912	3	-13
Lg41-06		385606	751923	3	-7

DGSID	LOCALID	Latitude (N)	Longitude (W)	Surface Elevation (ft)	Elevation Base of Holocene (ft)
Lg41-08		385610	751908	5	-2
Lg41-11	1	385642	751907	4	-13
Lg41-12	2	385642	751907	4	-13
Lg41-13	1	385605	751927	2	-1
Lg41-14	2	385605	751928	3.2	0
Lg41-15	3	385605	751927	3.5	-3
Lg41-16	4	385605	751924	3.4	0
Lg41-17	CR 36	385626	751917	4	-26
Lg41-18	78	385628	751914	2	-15
Lg41-20	HYMSIV	385638	751908	2	-1
Lg41-22	KAYAN5	385534	751920	3	-10
Lg41-23	KAYAN4	385536	751924	3	-7
Lg42-01		385650	751857	2	-36
Lg42-02		385648	751858'	5	-36
Lg42-03	PRM 25	385600	751848	-1.25	>-14
Lg42-04	KCB 09	385659	751847	0	>-32
Lg42-05	KCB 11	385648	751834	0	>-10
Lg42-06	KCB 12	385648	751834	0	>-10
Lg44-01	PRM 14	385606	751651	-7.32	>-27
Lg51-01	PRM 04	385554	751903	0	>-12
Lg51-02	77	385542	751931	2	-25
Lg51-03	HY20P	385506	751925	2	-30
Lg52-05	PRM 13	385518	751806	-4.33	~-13
Lg52-06	SB01	385527	751801	-5.25	>-12

DGSID	LOCALID	Latitude (N)	Longitude (W)	Surface Elevation (ft)	Elevation Base of Holocene (ft)
Lg52-09	HY57G	385514	751843	3	-11
Lg52-10	HY58G	385512	751847	3	-15
Lg52-11	HY59G	385510	751849	3	-7
Lg52-12	HY60G	385508	751853	3	-16
Lg52-13	HY61G	385506	751856	3	>25
Lg53-01	SB 05	385504	751728	-6.23	>-14
Lg53-02	SB 02	385507	751756	-6.56	>-10.5
Lg53-03	TB 01	385506	751742	0	-30
Lg53-04	SB 03	385516	751740	-4.6	~-10
Lg53-05	TB 02	385520	751753	0	no log
Lg53-06	TB 02A	385523	751747	0	no log
Lg53-07	TB 02B	385528	751743	0	no log
Lg55-01	PRM 12	385512	751536	-8.27	>-32
Mf15-01	73	385403	752029	2	
Mf15-02	HY21P	385430	752006	3	>-10
Mf25-02	HY22P	385336	752042	3	>-10
Mf34-01		385235	752137	0.5	-12.5
Mf34-02	DB 1	385239	752135	3	-18.5
Mf34-03	2	385239	752135	-3	-13
Mf34-06	72	385241	752132	2	-17
Mg11-01	75	385456	751912	2	
Mg11-02	76	385457	751948	2	-23
Mg12-02	AG 85	385442	751817	7	>-5
Mg12-03	74	385433	751826	2	>-1.0?

DGSID	LOCALID	Latitude (N)	Longitude (W)	Surface Elevation (ft)	Elevation Base of Holocene (ft)
Mg12-05	1	385426	751831	4	-2
Mg12-06	2	385427	751831	3.5	-4
Mg13-01	SB 04	385453	751743	-8.2	>-13
Mg13-02	SB 06	385440	751725	-8.86	-14
Mg13-03	SB 07	385450	751708	-7.55	-12
Mg13-04	SB 08	385419	751710	-6.73	>-14
Mg13-06	PRM 03	385418	751742	0	-16
Mg13-08	KAYAN2	385417	751747	3	>-7
Mg14-01	PRM 09	385412	751636	-10	>-17.5
Mg14-02	SB 09	385426	751658	-8.2	>-18
Mg14-03	SB 10	385432	751649	-8.2	>-10
Mg25-01	C370	385309	751554	-5	>-9.5
Mg25-02	C470	385315	751515	-7	-9.5
Mg25-03	C570	385330	751521	-10	-11
Mg34-02	KM 23	385254	751611	-1.31	-1
Mg34-03	79	385248	751619	2	2
Mg34-04	HY65G	385352	751612	3	2
Mg34-05	HY66G	385350	751616	3	2
Mg34-06	HY67G	385348	751618	3	2
Mg34-07	HY68G	385348	751611	3	2
Mg34-08	HY69G	385348	751613	3	2
Mg34-10	HY71G	385345	751619	3	-5
Mg34-12	HY73G	385346	751612	3	1
Mg34-13	HY74G	385344	751610	3	-1

DGSID	LOCALID	Latitude (N)	Longitude (W)	Surface Elevation (ft)	Elevation Base of Holocene (ft)
Mg34-14	HY75G	385342	751607	3	>-7
Mg34-15	HY76G	385341	751605	3	-2
Mg34-16	HY77G	385340	751602	3	-2
Mg35-01	KM 14	385250	751526	-3.28	-5
Mg35-02	jw24	385244	751557	0	-1
Mg35-03	jw25	385236	751547	0	-1
Mg35-04	HY78G	385339	751559	3	-2
Mg35-05	HY79G	385336	751555	3	>-6
Mg35-06	HY80G	385335	751554	3	>-2

Appendix D

Data Related to the Bottom Sediment Textures in Delaware Bay
(shown in Ramsey, 1993)

Data from Weil, 1976

Gvl- gravel
Sd- sand
Slt- silt
Cly- clay

DGSID	LOCALID	Latitude	Longitude	Elevation (ft)	Gvl%	Sd%	Slt%	Cly%	Mud%	Site Designation (Weil, 1976)
Lg15-a	SGS72-201	385954	751500	-27	0.0	81.7	18.3	0.0	18.3	W-214-76
Lg14-a	SGS72-101	385906	751654	-14	0.0	86.5	8.4	5.1	13.5	W-213-76
Lg25-a	SGS72-113	385818	751506	-13	0.4	81.1	11.1	7.4	18.5	W-203-76
Lg34-a	SGS72-112	385733	751618	-9	0.0	85.3	14.7	0.0	14.7	W-202-76
Lg45-a	S-116	385627	751503	-19	0.0	90.2	9.8	0.0	9.8	W-191-76
Lg52-a	S-151	385548	751830	-1	0.0	47.9	44.5	7.6	52.1	W-185-76
Lg55-c	S-118	385548	751548	-12	0.0	97.7	2.3	0.0	2.3	W-189-76
Lg54-a	S-119	385530	751603	-13	0.0	81.8	14.2	4.0	18.2	W-188-76
Lg53-a	S-147	385524	751712	-7	0.0	66.5	27.6	5.9	33.5	W-183-76
Lg55-b	S-107	385518	751521	-7	0.0	96.5	3.5	0.0	3.5	W-160-76
Lg45-b	S-117	385515	751521	-13	0.0	61.9	32.5	5.6	38.1	W-190-76
Lg52-b	S-150	385509	751809	-2	0.0	85.0	12.4	2.6	15.0	W-184-76
Lg54-b	S-120	385524	751618	-10	0.0	74.4	19.7	5.9	25.6	W-187-76
Lg55-a	S-106	385500	751548	-8	0.0	96.6	3.4	0.0	3.4	W-159-76
Lg53-b	S-148	385500	751727	-7	0.0	70.5	23.7	5.8	29.5	W-182-76
Mg14-c	S-105	385445	751615	-9	0.0	81.3	15.2	3.5	18.7	W-158-76
Mg13-a	S-149	385436	751745	-2	0.7	94.3	3.8	1.3	5.1	W-181-76
Mg14-b	S-104	385424	751639	-9	0.0	84.7	3.4	1.1	4.5	W-157-76
Mg25-c	S-95	385339	751700	-10	23.3	70.4	5.5	0.8	6.3	W-140-76
Mg14-a	S-103	385412	751700	-2	1.8	86.9	8.5	2.9	11.3	W-156-76
Mg25-b	S-94	385321	751536	-6	2.0	97.6	0.3	0.0	0.3	W-139-76
Mg25-a	S-93	385309	751554	-6	0.0	99.4	0.6	0.0	0.6	W-138-76
Lg43-a	S-152	385500	751757	-4	3.2	96.6	0.2	0.0	0.2	W-186-76

Appendix E

Data Related to Radiocarbon Dates from the Southeastern Delaware Bay Region
(Figure 20)

(from Ramsey and Baxter, 1996)

DGS #	DGSID	Calibrated Date (yrs BP)	Sample Elevation (feet)	Sample Type
205	Ie31-a	1351	-3.75	sediment
206	Ie31-a	2106	-7.35	sediment
207	Ie31-a	1830	-11.9	sediment
211	Ie31-e	3680	-13.55	sediment
210	Ie31-f	1670	-8.55	sediment
209	Ie31-g	401	-5.15	sediment
208	Ie31-h	589	-1.65	sediment
49	If51-01	3104	-15	basal peat
133	If51-02	2549	-14.4	basal peat
104	Jd35-14	1841	-8.84	fiber mat
108	Je31-23	3721	-8.82	wood
105	Je31-33	1837	-9.02	mud
106	Je31-33	1038	-3.12	mud
107	Je31-33	984	-0.49	mud
163	Jf21-a	3698	-20	tree stump
51	Jg31-03	4596	-23	basal peat
70	Jh25-01	2851	-33.7	shell
71	Jh25-01	2993	-34.3	shell
35	Jj41-a	2237	-16.5	peat
45	Kf22-04	3563	-33	peat
46	Kf22-04	6234	-50	peat
47	Kf22-04	8533	-68	peat
48	Kf22-06	10534	-79	peat
40	Kf22-26	1865	-10.5	peat
42	Kf22-26	3136	-15.5	peat
39	Kf22-39	3522	-15.2	basal peat
36	Kf23-07	2573	-15	peat
41	Kf32-04	1898	-3	peat
37	Kf32-05	1902	-3.5	peat
38	Kf32-07	2154	-3	peat
90	Lg41-22	1603	-0.281	peat
132	Lg51-01	1958	-11.5	peat
91	Lg51-05	379	1.458	peat
93	Lg52-08	5232	-26.528	peat&mud
94	Lg52-08	6108	-30.62	shell
50	Lg52-15	6110	-42	basal peat
95	Mf34-01	164	-8.227	peat
92	Mg13-08	662	-2.58	peat
34	Mg25-01	2575	-7	basal peat
134	Mh41-07	3832	-11.5	peat
68	Mi45-01	10648	-84	plant
27	Nh23-06	1926	-9	peat
28	Nh35-20	2528	-9.6	basal peat
99	Nh35-a	400	0	shell
186	Nh35-b	79	1.2	basal peat
187	Nh35-c	833	0.4	basal peat
188	Nh35-d	621	-0.1	basal peat
189	Nh35-e	822	-0.7	basal peat
190	Nh35-f	1064	-0.4	basal peat
191	Nh35-g	1262	-1	basal peat
192	Nh35-h	1547	-1.9	basal peat
32	Nh45-21	2584	-13.3	peat
33	Nh45-22	2418	-12.8	peat
1	Ni31-25	396	-0.5	peat
6	Ni35-03	7860	-60	peat
161	Ni44-a	706	-4.1	*Spartina sp.*
162	Ni44-a	881	-2.4	*Spartina sp.*
26	Ni45-a	372	0.5	wood
165	Ni53-a	1673	-2.85	palustrine marsh peat
166	Ni53-a	3149	-4.9	*Spartina patens*
167	Ni53-a	3289	-5.53	palustrine marsh peat
168	Ni53-a	3368	-5.2	palustrine marsh peat
169	Ni53-a	3786	-5.83	palustrine marsh peat
170	Ni53-a	3925	-5.9	palustrine marsh peat
171	Ni53-b	1783	-2.57	palustrine marsh peat
172	Ni53-b	1831	-1.4	*Spartina alterniflora*
173	Ni53-b	3441	-4.48	*Spartina patens*
176	Ni54-a	3914	-20.3	palustrine marsh peat
177	Ni54-a	4326	-22.6	*Spartina patens*
178	Ni54-a	4262	-24.6	palustrine marsh peat
179	Ni54-a	5674	-25.9	palustrine marsh peat
180	Ni54-a	5018	-27.2	*Spartina patens, Distichlis*
181	Ni54-a	6905	-29.2	palustrine marsh peat
164	Ni54-b	4998	-26.2	palustrine marsh peat
174	Ni54-c	3766	-11.3	*Spartina patens*
175	Ni54-c	5394	-28.9	marsh peat
182	Ni54-d	2034	-8.2	palustrine marsh peat
183	Ni54-d	4139	-21.7	palustrine marsh peat
184	Ni54-d	4695	-24.9	*Juncus gerardii*
185	Ni54-d	4954	-25.9	*Sp. cyno, Sc. robustus*
153	Ni55-a	863	-3.3	*Spartina sp.*
154	Ni55-b	375	-1.3	*Spartina sp.*
155	Ni55-b	408	-2.6	*Spartina sp.*
156	Ni55-b	1064	-4.6	*Spartina sp.*
157	Ni55-b	1035	-3.1	*Spartina sp.*
158	Ni55-c	823	-2	*Spartina sp.*
159	Ni55-c	670	-3.9	*Spartina sp.*
160	Ni55-d	650	-2.6	*Spartina sp.*
89	Ni55-e	818	-2.4	basal peat

Appendix F

Clay Mineral Data

plag- plagioclase feldspar
kspar- potassium feldspar
smec- smectite
arag- aragonite
gyp- gypsum
jaro- jarosite
chlor- chlorite

Sample Number	DGSID	Depth (ft.)	Depositional Environment	Stratigraphic Unit
25402*	Lf42-01	0.5-0.6	Marsh	Holocene
25403	Lf42-01	6.7-6.8	Tidal Channel	Holocene
70362	Nh25-03	8-8.1	Estuarine	Holocene
70371	Nh13-28	7-7.1	Estuarine	Holocene
70375	Nh13-29	3.3-3.4	Estuarine	Holocene
41420	Le15-g	9.5-9.75	Bog	Scotts Corners
41422	Lf23-t	9-9.25	Bog	Scotts Corners
41425	Lf14-p	8-8.25	Lagoon/Marsh	Scotts Corners
41431	Lf14-p	10.5-11	Lagoon/Marsh	Scotts Corners
41435	Lf14-p	13.25-13.5	Lagoon/Marsh	Scotts Corners
40975	Lf13-a	7-7.25	Marsh	Scotts Corners
40976	Lf14-a	7.25-7.5	Marsh	Scotts Corners
25658	Mg21-06	20-22	Estuarine	Scotts Corners
41464	Lf23-u	7-7.25	Marsh	Scotts Corners
41465	Lf23-x	8-8.25	Estuarine	Scotts Corners
41469	Lf23-x	10-10.25	Estuarine	Scotts Corners
41472	Lf23-x	11-11.25	Estuarine	Scotts Corners
41482	Lf23-ac	9-9.5	Marsh,bog	Scotts Corners
41485	Lf23-ac	11	Marsh,bog	Scotts Corners
32876	Le55-07	40-45	Fluvial	Lynch Heights
41324	Lf14-b	6-6.5	Marsh/Swamp	Lynch Heights
41325	Le55-a	7.25-7.5	Marsh/Swamp	Lynch Heights
41372	Le14-a	13-13.25	Swamp/Marsh	Lynch Heights
25627	Lf21-19	14-16	Estuarine	Lynch Heights
41417	Me22-a	20-20.5	Fluvial	Columbia
32882	Le55-07	70-75	Marine	St. Marys
22191	Kf54-06	63-68	Marine	St. Marys
23502	Le52-01	65	Marine	St. Marys
22191	Kf54-06	63.5-68.5	Marine	St. Marys
82475	Me14-20	82-92	Marine	St. Marys
83330	Le33-06	103-104	Marine	St. Marys
83335	Le33-06	124-125	Marine	St. Marys
83553	Lf21-19	102-103	Marine	St. Marys
83557	Le14-18	90-91	Marine	St. Marys
32904	Le55-07	180-185	Marine	Choptank
82483	Me14-20	156-166	Marine	Choptank
32916	Le55-07	240-245	Marine	Calvert
32934	Le55-07	330-335	Marine	Calvert
82497	Me14-20	256-266	Marine	Calvert
82508	Me14-20	356-366	Marine	Calvert

*Sample yielded insufficient amounts of clay for analysis

Strat. Unit	DGSID	Sample #	Smectite %	Illite %	Kaolinite %	Chlorite %	Vermiculite %	Mixed Layer %	Illite C.I.	Mixed Layer Type	Quartz	Feldspar	Other
Qm	Lf42-01	25403	8	31	44	17	0	0	7.3		yes		
Qb	Nh13-28	70371	25	35	18	22	0	0	6.9		yes	plag+kspar	
Qb	Nh13-29	70375	18	44	18	20	0	0	5.8			plag	
Qb	Nh25-03	70362	24	50	9	18	0	0	7.8		yes	plag	
Qsc	Le15-g	41420	0	10	66	24	0	0	1.3				lepidocrocite
Qsc	Lf13-a	40975	29	34	29	8	0	0	11.3		yes		
Qsc	Lf14-a	40976	51	18	27	4	0	0	5.0				
Qsc	Lf14-b	41324	17	25	37	8	0	12	9.5	Smec/Illite	yes		
Qsc	Lf14-p	41425	29	14	48	0	0	9	3.8	Smec/Illite			
Qsc	Lf14-p	41431	14	29	44	13	0	0	3.1				
Qsc	Lf14-p	41435	16	29	34	21	0	0	5.6		yes	plag	
Qsc	Lf23-ac	41482	19	23	37	21	0	0	9.6		yes	kspar	
Qsc	Lf23-ac	41485	43	19	20	17	0	0	10.3		yes	kspar	
Qsc	Lf23-t	41422	18	5	35	9	0	32	3.8	Smec/Illite	yes		
Qsc	Lf23-u	41464	28	18	44	10	0	0	11.3		yes	kspar	lepidocrocite
Qsc	Lf23-x	41465	36	22	25	17	0	0	7.3		yes		
Qsc	Lf23-x	41469	36	21	24	19	0	0	6.9		yes		
Qsc	Lf23-x	41472	0	24	61	14	0	0	6.8		yes	plag+kspar	lepidocrocite
Qsc	Mg21-06	25658	11	5	75	0	9	0	2.8				
Qlh	Le55-a	41325	0.5	11	59	30	0	0	2.8	Smec/Illite	yes		
Qlh	Le55-07	32876	41	24	28	6	0	0	10.7		yes		
Qlh	Lf21-19	25627	4	29	41	26	0	0	12.2				
Qlh	Le14-a	41372	0	3	67	4	0	26	6.3	Illite/Smec			
Qcl	Db31-60	25411	20	31	25	25	0	0	8.4				
Qcl	Ec11-a	41748	0	20	39	21	20	0	1.0				
Qcl	Ec11-a	41749	0	8	92	0	0	0	1.3				
Qcl	Ec31-a	41689	6	34	55	0	5	0	25.0				
Qcl	Ec31-a	41691	0	59	31	10	0	0	12.0				
Qcl	Ec31-a	41693	0	28	72	0	0	0	4.8				
Qcl	Fb25-a	40974	66	15	19	0	0	0	7.0				
Qcl	Fb34-09	32541	46	17	23	14	0	0	7.6				
Qcl	Fb55-04	25462	66	8	26	0	0	0	5.5				
Qcl	Fc12-a	41362	0	41	40	19	0	0	16.0				

Strat. Unit	DGSID	Sample #	Smectite %	Illite %	Kaolinite %	Chlorite %	Vermiculite %	Mixed Layer %	Illite C.I.	Mixed Layer Type	Quartz	Feldspar	Other
Qcl	Hc24-05	83219	0	13	57	30	0	0	8.0				
Qcl	Hc35-a	41500	60	15	18	7	0	0	7.3				
Qcl	Ld44-c	41000	0	16	84	0	0	0	10.0				
Qcl	Ld44-c	41003	19	7	74	0	0	0	3.4				
Qcl	Mc22-a	41001	0	9	91	0	0	0	5.0				
Qcl	Mc45-03	83160	32	23	21	23	0	0	7.0				
Qcl	Me22-a	41417	44	18	29	9	0	0	0.0				
Tsm	Kf54-06	22191	94	5	1	0	0	0	5.0				
Tsm	Le14-18	83557	64	19	3	14	0	0	6.0		yes		
Tsm	Le33-06	83330	94	5	1	0.5	0	0	5.3		yes		
Tsm	Le33-06	83335	88	9	3	0.5	0	0	10.3		yes		
Tsm	Le52-01	23502	88	8	4	0	0	0	5.6		yes		jarosite
Tsm	Le55-07	32882	48	26	17	9	0	0	13.0		yes		jarosite
Tsm	Me14-20	82475	69	24	7	0	0	0	4.7		yes		
Tch	Le55-07	32904	0	6	5	0	0	90	4.7	Chlor/Smec	yes		calcite,arag
Tch	Lf21-19	83553	0	7	1	1	0	91	9.3	Smec/Chlor	yes		
Tch	Me14-20	82483	90	7	2	1	0	0	5.7		yes		
Tc	Le55-07	32916	69	7	24	0	0	0	2.2		yes		gyp,jaro,calc
Tc	Le55-07	32934	62	10	28	0	0	0	4.0		yes		calcite,arag
Tc	Me14-20	82497	69	6	25	0	0	0	5.0		yes	trace	
Tc	Me14-20	82508	63	9	22	5	0	0	3.0				
0.5=trace.													

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