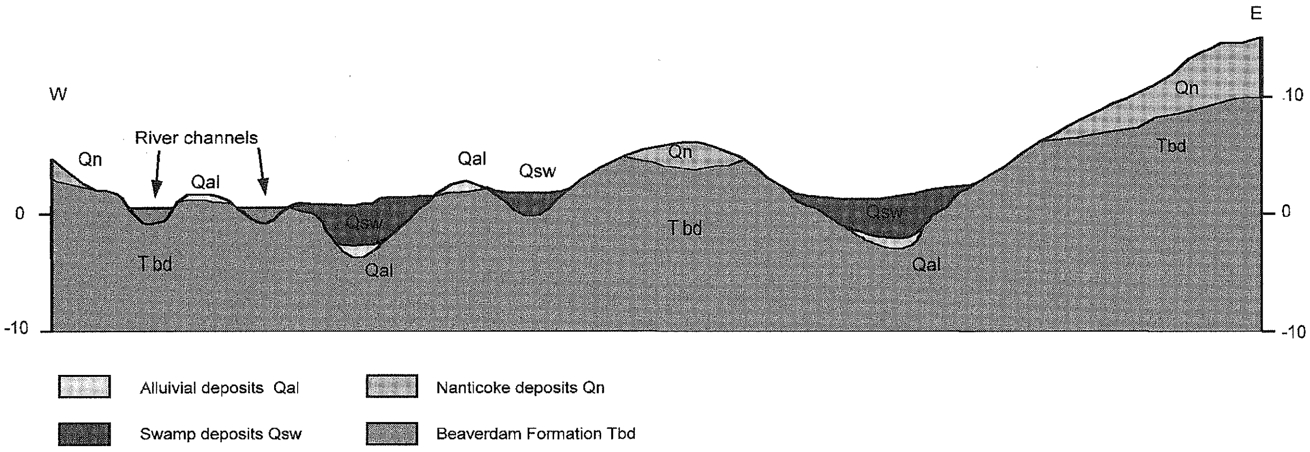
State of Delaware
DELAWARE GEOLOGICAL SURVEY
Robert R. Jordan, State Geologist

REPORT OF INVESTIGATIONS NO. 53

GEOLOGY OF THE SEAFORD AREA, DELAWARE

by

A. Scott Andres
and
Kelvin W. Ramsey



With a contribution on palynology by
Johan J. Groot

University of Delaware
Newark, Delaware
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Delaware Geological Survey Report of Investigations No. 53, *Geology of the Seaford Area, Delaware* by A. Scott Andres and Kelvin W. Ramsey, with contrtibution on palynology by Johan J. Groot, 1996.

Following release of the report, it was found that there were several errors in the text. This errata sheet is intended to correct these errors.

Page 7, column 2, paragraph 4 under *Composition and Textures*, and
Page 14, column 2, paragraph 4 under *Palynomorph Assemblages of the Quaternary Sediments*

(Chenopodeaceae) **should read** (Chenopodiaceae.)

Page 15, column 2, paragraph 1
(early Pleistocene) **should read** (early or middle Pleistocene)

Pages 16-19, Table 3 Title should read
Pollen assemblages expressed in percentages of the pollen sum.

Page 17, Table 3

Sample number 84834 -	(Remarks) Sanquisorba? **should read** Sanguisorba?
Sample numbers 42270, 42266 -	(Age) **should read** Q1
Sample number 84662 -	(Age) **should read** Q
Sample number 83836 -	(Remarks) **should be** Polygonaceae, Gordonia
Sample number 83947 -	(Remarks) **should be** *T, edmundii*, few Paleozoic spores
Sample numbers 22793, 22782 -	(Age) **should be** Q11, 13
Sample number 22826 -	(Remarks) **should be** *T. edmundii*, Onagraceae

Page 19, Table 3

Sample number 84473 -	(Remarks) **should be** Larix; reworked
Sample number 84472 -	(Remarks) should be P

Page 19, Under Key to Table 3

Column heading	**Genus**
P	Other dicotyledons

Climate

Column heading	**Explanation**
sub	subtropical

GEOLOGY OF THE SEAFORD AREA, DELAWARE

A. Scott Andres and Kelvin W. Ramsey

ABSTRACT

This report supplements the map "Geology of the Seaford Area, Delaware" (Andres and Ramsey, 1995). The map portrays surficial and shallow subsurface stratigraphy and geology in and around the Seaford East and Delaware portion of the Seaford West quadrangles. The Quaternary Nanticoke deposits and Pliocene Beaverdam Formation are the primary lithostratigraphic units covering upland surfaces in the map area. Recent swamp, alluvial, and marsh deposits cover most of the floodplains of modern streams and creeks. The Miocene Choptank, St. Marys, and Manokin formations occur in the shallow subsurface within 300 ft of land surface.

The Choptank, St. Marys, and Manokin formations were deposited in progressively shallower water marine environments. The Beaverdam Formation records incision of underlying units and progradation of a fluvial-deltaic system into the map area. The geologic history of the Quaternary is marked by weathering and erosion of the surface of the Beaverdam and deposition of the Nanticoke deposits by the ancestral Nanticoke River. Depositional environments in the Nanticoke deposits include fresh water streams and ponds, estuarine streams and lagoons, and subaerial dunes.

INTRODUCTION

Purpose and Scope

This report documents the results of investigations of the surficial and shallow subsurface geology in and around the Seaford East (SEE) and Delaware portion of the Seaford West (SEW) quadrangles (Fig. 1). Additional geologic data not shown on the Seaford area geologic map (Andres and Ramsey, 1995) and supporting documentation for stratigraphic interpretations are presented. A reproduction of the map is shown in Fig. 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 and occurrence of mineral resources such as sand and gravel are also dictated by the distribution of sand, silt, and clay bodies.

Location

The study area (Fig. 1) is located within the Atlantic Coastal Plain physiographic province. The largest incorporated towns are Seaford and Bridgeville. The major hydrographic features are the Nanticoke River basin and portions of the Marshyhope Creek basin. Land surface elevations range from sea level along the tidal portion of the Nanticoke River to just above 50 ft along the drainage divide between the Nanticoke and Marshyhope basins and along the Delmarva Peninsula drainage divide in the northeastern part of the Seaford East quadrangle.

Previous Work

Previous geological investigations in and around the Seaford area were typically conducted for regional geologic interpretation or water resources evaluations and included subsurface units deeper than those covered in this investigation. An important characteristic of many of these earlier studies is that they drew from a relatively small number of geographically scattered subsurface observations.

Many of the earlier studies combined new observations with evaluations of the data and interpretations of prior work to generate new theories and models of subsurface geologic conditions and geologic history. In several cases, new sets of observations led to new and sometimes significantly different interpretations. Interested readers are referred to Jordan (1962; 1964; 1974), Owens and Denny (1979), and Hansen (1981) for reference lists and discussions of earlier geologic research and controversies.

The relationships between stratigraphic sections established by previous and current workers are shown in Fig 3. Earlier workers in the area of Seaford assigned surficial deposits to the Pleistocene without formational designation (Marine and Rasmussen, 1955). Rasmussen et al. (1960) recognized near-surface units including the Parsonsburg sand, the Pamlico formation, the Beaverdam sand, and the Brandywine formation. Of these units, only the Beaverdam has been retained for usage in Delaware (Jordan, 1974). Jordan (1964, 1974) assigned near-surface geologic units in the map area to the Columbia Group, which in southern Delaware consisted of the Beaverdam and Omar formations. Jordan (1964, 1974) also recognized sandy deposits in the Nanticoke River Valley that were associated with a topographic feature called the Nanticoke Ridge as well as subsurface deposits that were unassigned to a particular stratigraphic unit but were considered to be Pleistocene in age. Owens and Denny (1979, fig. 5) extended stratigraphic units recognized in Maryland and New Jersey into Delaware; these include the Beaverdam Sand and the Pensauken Formation, the latter in a small band southeast of Bridgeville. Denny et al. (1979, Fig. 1) mapped the Parsonsburg Sand in the southern area of the Seaford East map and the Kent Island Formation in the area of the floodplain of the Nanticoke River. Ramsey and Schenck (1990) mapped the Columbia Formation in the northwestern portion of the map area, the Beaverdam Formation over most of the map area, and an informal unit, the Nanticoke deposits along the Nanticoke River valley. Andres (1994a) and Andres and Ramsey (1995) used the nomenclature of Ramsey and Schenck (1990) but modified some of the lithologic descriptions to reflect newer, more detailed observations.

A consensus of those who have worked in the area is that the Beaverdam Formation is present (Rasmussen et al., 1960; Jordan, 1974; Owens and Denny, 1979; Ramsey and

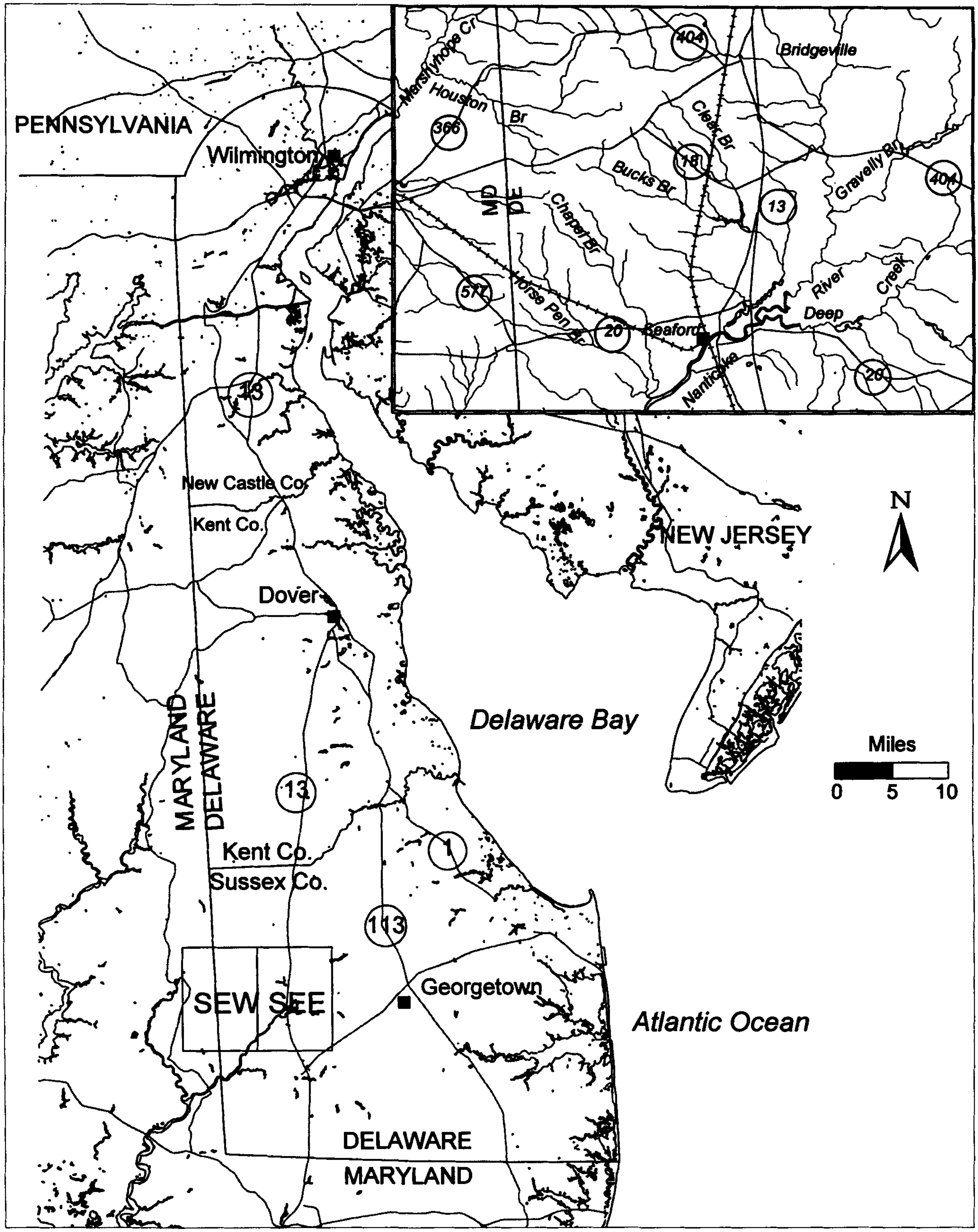

Figure 1. Map showing area of the Seaford East and Seaford West quadrangles.

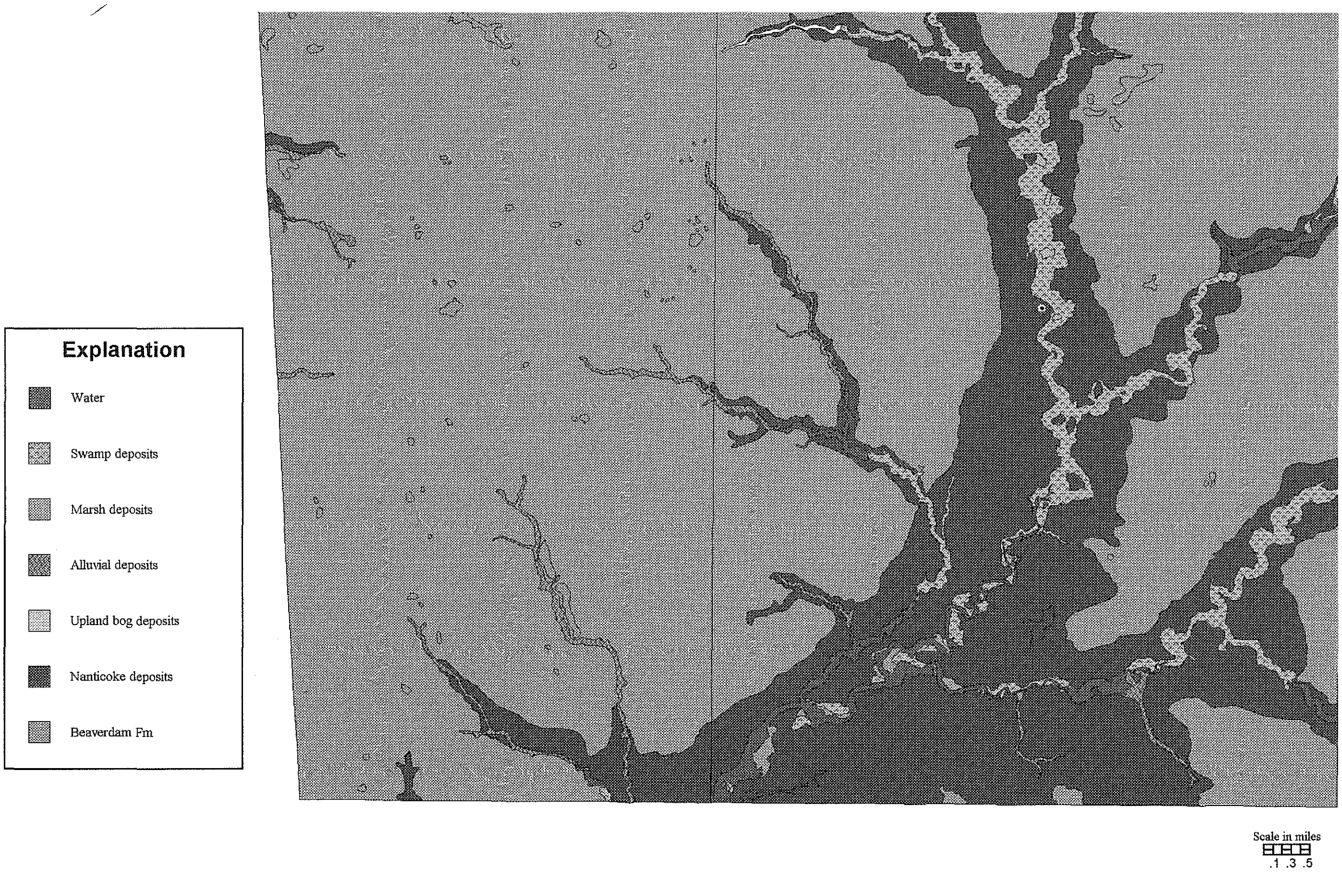

Figure 2. Geologic map of the Seaford area, Delaware.

	Rasmussen et al. (1960) Sussex County	Jordan (1962) Delaware	Owens and Denny (1979) Central Delmarva	Seaford area This Report
Recent	undifferentiated			Swamp, alluvial, and marsh deposits
Pleistocene	Parsonburg sand Pamlico and Talbot formations Walston silt Beaverdam sand	Columbia Gp: Omar Fm Beaverdam Fm	Kent Island Fm and Parsonburg Sand	Upland bog deposits Nanticoke deposits
Pliocene	Brandywine formation		Walston Silt Beaverdam Fm	Beaverdam Fm
Miocene	Cohansey sand: Upper aquiclude Pocomoke aquifer Lower aquiclude Manokin aquifer St. Marys Fm Choptank Fm	Chesapeake Gp	Pensauken Fm Pocomoke beds Manokin beds Chesapeake Gp undivided	Chesapeake Gp: Manokin Fm St. Marys Fm Choptank Fm

Figure 3. Comparison of stratigraphic column in the Seaford area (this report) with those of previous workers.

Schenck, 1990; Andres, 1994a). Other than Ramsey and Schenck (1990), no Columbia Formation had been mapped this far south. On the basis of the detailed work done for the Andres and Ramsey (1995) map, we no longer recognize the Columbia in the map area.

On the bases of lithologic and stratigraphic criteria, Jordan (1974) hypothesized that the Beaverdam and Omar formations were downdip facies of the Columbia Formation and included the Beaverdam with the Omar in the Columbia Group. He acknowledged that a definite Pleistocene age, except for the Omar Formation in southeastern Delaware, could not be proven. Lithologic and stratigraphic evidence suggested that the Columbia Formation was of Pleistocene age and that, by correlation, the Beaverdam also was of Pleistocene age. In addition, the interpretation that the Omar and Beaverdam were stratigraphically correlative provided additional support for the Pleistocene age of the Beaverdam. No surficial exposures of the Beaverdam were recognized in Delaware at that time.

Recent investigations (Ramsey and Schenck, 1990; Groot et al., 1990; Groot et al., 1995; J. J. Groot, written communication) and field work for this map indicate that (1) the Omar Formation is not present in the map area; (2) the Nanticoke deposits, the probable age equivalent of the Omar, are restricted to the valley and valley margins of the Nanticoke River and do not blanket the entire area; (3) the Beaverdam Formation is a surficial deposit in the map area; (4) the Beaverdam Formation, where palynologic data have been

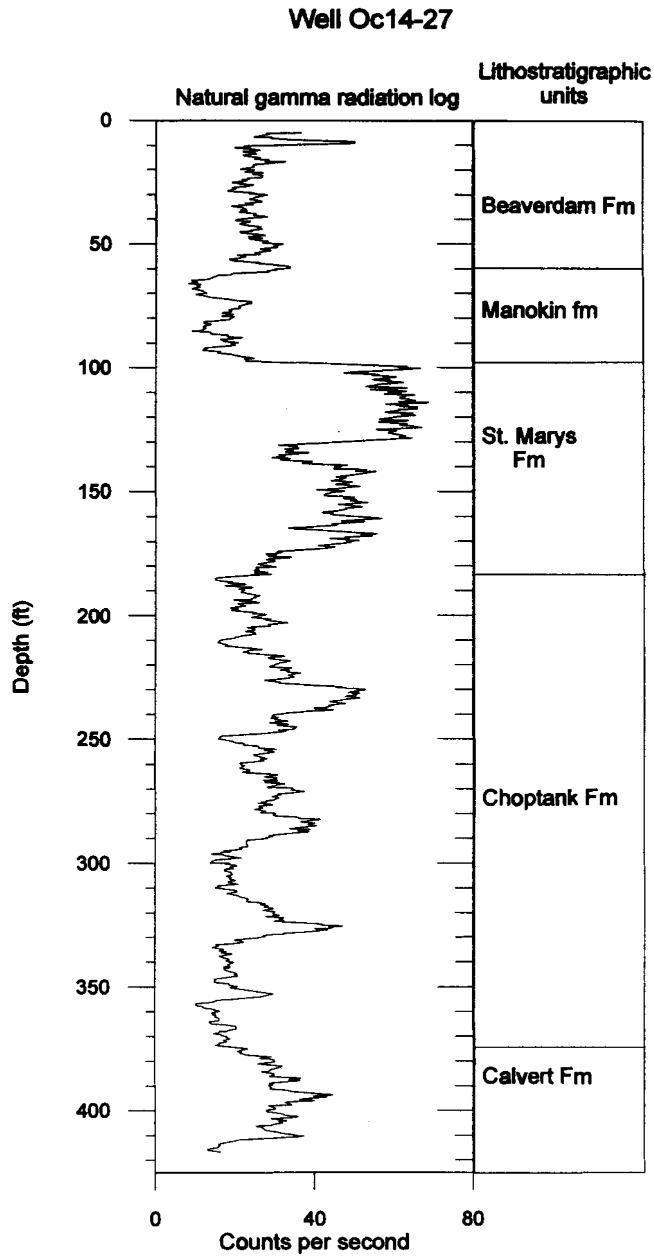

Figure 4. Well log showing lithostratigraphic units and natural gamma radiation log from well Oc14-27 (latitude 38° 44' 12" , longitude 75° 36' 11") in Bridgeville.

analyzed, including within the map area, is of Pliocene age with a flora characteristic of a temperate climate; and, (5) the Columbia Formation, where palynologic data have been analyzed, is of early to middle Pleistocene age with a flora reflective of a cool climate. Given the differences in age, lithic character, and fossil content, the Beaverdam is no longer considered to be a downdip facies of the Columbia Formation. The Beaverdam/Columbia contact is inferred to be unconformable and lies to the north of this map area.

Acknowledgments

We thank Dr. Johan J. Groot for his palynological investigations of the map area and for his discussions of the stratigraphy and geologic history. Robert R. Jordan, Richard N. Benson, and Robert B. Mixon reviewed this manuscript. C. Scott Howard supervised a large part of the drilling operations, performed light mineral analyses, and assisted final map compilation. James A. Maio and Narender Pendkar performed clay mineral analyses. Jennifer E. Athey, Bruce W. Brough, William F. Daniels, and Dawn A. Denham also deserve recognition for their contributions to field and laboratory operations. T. S. Smith and Sons, City of Seaford, The Nature Conservancy, Inc., Earth Movers, Inc., Palmer Corey and Sons, Inc., and Kaye Construction, Inc. are thanked for allowing access to their properties.

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METHODS

Unless described otherwise, the methods used in this study are described in Andres et al. (1995). This study concentrated on mapping of near-surface lithostratigraphic units, with investigation of deeper units for interpretations of structure and stratigraphic correlation. A general lack of exposure necessitated that data be drawn mainly from boreholes. There were a number of coreholes and man-made exposures in borrow pits and drainage ditches. Data used for this investigation include lithologic and geophysical logs and textural, mineralogic, and paleontologic analyses of samples.

STRATIGRAPHY

References will be made to mineralogic and palynologic data in the following discussions of the composition of lithostratigraphic units. Summaries of clay mineral, light mineral, and palynologic data are presented in tables 1, 2, and 3, respectively.

Chesapeake Group

Jordan (1962, p. 27) described the Chesapeake Group in Delaware as "Predominantly gray and bluish-gray silt containing beds of gray, fine- to medium-grained sand and some shell beds." that are of Miocene age. No formal subdivisions of the Group in Delaware were made at that time. In general, the lithologic description and age of the Group have not been greatly modified and hence the name is used in this report. Individual units within the Chesapeake Group were recognized and described by Benson and Pickett (1986), Benson (1990), and Ramsey and Schenck (1990). This report concurs with subdivision of the Group into formations (Figs. 3 and 4) and includes more detailed compositional and textural descriptions.

Choptank Formation

Rasmussen and Slaughter (1955) and Rasmussen et al. (1960) listed the Choptank Formation in their stratigraphic columns. Jordan (1962) included this formation in the Chesapeake Group, undifferentiated. Sundstrom and Pickett (1970) followed Jordan's (1962) usage. Benson and Pickett (1986) reintroduced the name Choptank Formation in Delaware, and the name has been used in subsequent publications (Andres, 1986, 1994a; Benson, 1990; Ramsey and Schenck, 1990; and, Ramsey, 1992, 1993).

TABLE 1

Summary of clay mineral data. Average, minimum, and maximum values reported in percent to the nearest whole number. Readers should consult Brown and Brindley (1980), Moore and Reynolds (1989), or other source regarding the precision of x-ray diffraction measurements.(Note: nd = none detected)

UNIT	Number of Samples	Smectite	Illite	Kaolinite	Chlorite	Vermiculite	Illite crystal-linity index
	Average values						
Beaverdam	29	6	11	71	10	3	4
Nanticoke	16	20	8	44	25	4	3
Manokin	7	29	27	31	12	nd	10
St. Mary	13	42	27	22	9	nd	12
Choptank	5	52	19	23	6	nd	9
	Minimum values						
Beaverdam		nd	nd	21	nd	nd	nd
Nanticoke		nd	nd	9	nd	nd	nd
Manokin		8	14	7	3	nd	3
St. Marys		4	9	9	nd	nd	3
Choptank		17	11	10	nd	nd	3
	Maximum values						
Beaverdam		34	45	100	63	42	22
Nanticoke		81	40	100	64	35	17
Manokin		71	43	58	19	nd	16
St. Marys		69	54	38	28	nd	38
Choptank		71	30	39	14	nd	15
	Standard deviation						
Beaverdam		8.24	13.81	25.30	15.21	8.51	5.93
Nanticoke		21.61	9.61	34.77	21.90	8.76	4.87
Manokin		24.62	9.69	15.93	6.26	nd	4.43
St. Marys		22.76	11.83	8.68	8.48	nd	8.69
Choptank		21.22	7.22	11.09	4.71	nd	3.94

The Choptank Formation consists of multiple fining-upward sequences of olive-gray, gray, and brown-gray, fine to coarse quartz sand and shelly and gravelly sand, that grade into green-gray, brown-gray, and blue-gray, sandy, clayey, shelly silt. Analyses of samples from the map area show that smectite is the dominant clay mineral in the Choptank Formation. There are lesser amounts of kaolinite and illite, followed by chlorite (Table 1). The unit, which ranges from 160 to about 200 ft thick, is completely penetrated by only a few drill holes in the map area. The Choptank rests unconformably on the Calvert Formation in the map area. The lower contact is typically recognized in borehole logs where grayish to brownish fine to medium sands of the Choptank rest on a mud to sandy mud in the Calvert that is usually described as brown to chocolate brown.

St. Marys Formation

Rasmussen and Slaughter (1955) and Rasmussen et al. (1960) recognized the first fine-grained unit overlying the Choptank Formation as the St. Marys (?). They included the query because the unit could not be definitively traced from its type locality on the western side of Chesapeake Bay to the Delmarva Peninsula. On the bases of macrofaunal remains the unit was considered to be of Miocene age. Jordan (1962) and Sundstrom and Pickett (1970) included this interval in the undifferentiated Chesapeake Group. As additional subsurface data became available, many workers (Weigle, 1974; Owens and Denny, 1979; Hansen, 1981; Andres 1986, 1994a; Benson, 1990; Ramsey and Schenck, 1990; Ramsey, 1992, 1993; and Achmad and Wilson, 1993) used the term St. Marys with or without the query. The unit is considered to be of late Miocene age (Owens and Denny, 1979; Benson, 1990; Ramsey, in press), although no fossil remains have been found in the unit in the map area to confirm this interpretation.

The St. Marys consists of blue-gray, green-gray, or gray sandy (fine) silt and silty clay with beds of fine to medium sand, and fine to medium gravel in a mud matrix. The term mud is used, herein, as an indeterminate mixture of silt and clay. In the northern portion of the map area, the upper one to three feet of the unit are commonly oxidized and colored hues of yellow, orange, and red. Analyses of samples from the map area show that smectite is the dominant clay mineral in the St. Marys Formation. There are lesser amounts of kaolinite and illite, followed by chlorite (Table 1).

The St. Marys is present throughout the map area, and thickness ranges from about 80 to about 100 ft. On the basis of natural gamma radiation log analysis, Hansen (1981), Andres (1986), and Achmad and Wilson (1993) placed the contact at the bottom of the predominately muddy St. Marys where mud overlies a thin sandy interval. In many borehole logs, the contact is marked by a sharp peak of natural gamma radiation, possibly indicating concentrations of phosphatic material (Hansen, 1981). Because of these lithologic and gamma radiation characteristics, the boundary between the St. Marys and the underlying Choptank Formation is interpreted as an unconformity that represents erosion or non-deposition.

Manokin Formation

The name Manokin was used by Rasmussen and Slaughter (1955) to describe an aquifer near Manokin, Maryland. They considered the Manokin aquifer to be a part of the Miocene-age "Yorktown(?) and Cohansey(?) Formation." Rasmussen et al. (1960) extended the use of the name into Delaware. Jordan (1962) and Sundstrom and Pickett (1970) interpreted the Manokin aquifer to occur within the undifferentiated Miocene-age Chesapeake Group. Owens and Denny (1979) used the term "Manokin beds" and also reported a Miocene age. Hansen (1981) continued to use the term Manokin and considered it to be of Miocene age, but he referred to it as an aquifer.

On the basis of regional well-log analysis and correlation, Andres (1986) proposed the Manokin formation as an informal lithostratigraphic unit within the Chesapeake Group. This unit has the same stratigraphic position and generally the same composition and texture as the "Manokin beds" and "Manokin aquifer." Benson (1990) continued the use of the informal term "Manokin formation." Ramsey and Schenck (1990), Ramsey (1992), Andres (1994a), and Andres and Ramsey (1995) recognized a lower siltier facies (Manokin A) and an upper sandy facies (Manokin B). This study continues to use the informal name Manokin formation in the sense of Andres (1986) and Ramsey and Schenck (1990). The Manokin is considered to be a member of the Chesapeake Group, and palynologic (Table 3) and other paleontologic data indicate a late

Miocene age in Maryland for the correlative section (Benson, 1990).

The Manokin formation consists of a coarsening-upward sequence informally subdivided into two subunits, A and B. The lower unit (A) consists of gray, blue-gray, and brown-gray silty clayey sand and silty sand. Where exposed to oxidizing conditions the lower unit is yellow to red. In some locations, the lower subunit is not present. The upper unit (B) consists of light to medium gray or yellow-orange to red-orange (where weathered), medium to fine and coarse sand with common beds of gravelly sand and rare beds of clayey to silty sand.

Analysis of two samples in this study show the Manokin to be dominated by monocrystalline quartz with only 3 percent each of potassium feldspar and plagioclase (Table 2). The feldspar tends to be more weathered than that observed in the overlying Beaverdam Formation. Leggett (1992) reports similar results from five samples collected outside of the map area. The clay mineral suite consists of relatively similar amounts of smectite, illite, and kaolinite with lesser amounts of chlorite. The Manokin has a clay mineral suite similar to that of the St. Marys Formation (Table 1). The illite crystallinity index is higher than that of the Beaverdam Formation and Nanticoke deposits (Table 1).

Thickness ranges from a feather-edge to as much as 50 ft. The Manokin is truncated by the overlying Beaverdam Formation in parts of the northern portion of the map area. Throughout most of the map area, the contact between the St. Marys and lower muddy unit of the Manokin (A) is gradational and represents a transition from shallow marine to marginal marine environments (Hansen, 1981; Andres, 1986; Achmad and Wilson, 1993). In some locations, the upper sandy unit of the Manokin (B) directly overlies the St. Marys (Fig. 4). The sharp changes in natural gamma radiation shown in Figure 4 and associated lithologic characteristics indicate an erosional contact. The contact is arbitrarily set where the shale percentage is calculated from natural gamma radiation logs to be 50 percent (Asquith, 1982, p. 91). The exact location of the contact is not certain in some boreholes where no natural gamma radiation log is available and the gradation zone is represented by a thick sequence of interbedded muddy sands, sandy muds, and mud (Andres and Ramsey, 1995).

Beaverdam Formation

Relation to Previously Recognized Units

The Beaverdam Sand was originally recognized in Wicomico County, Maryland, by Rasmussen and Slaughter (1955) and assigned a Pleistocene age. Rasmussen et al. (1960) used this nomenclature. Jordan (1964, 1974) interpreted the Beaverdam as a downdip facies of the Quaternary-age Columbia Formation and assigned it to the Columbia Group. Owens and Denny (1979) interpreted an unconformity between the Columbia Formation and the Beaverdam and assigned a Pliocene age to the Beaverdam based on fossil palynomorphs. Owens and Denny (1986) used this nomenclature on a geologic map of adjacent Caroline County, Maryland. Groot et al. (1990, 1995), Benson (1990), and Ramsey and Schenck (1990) agreed with the Pliocene age. On the bases of more extensive data coverage, Ramsey and Schenck (1990) expanded the lithologic definition of the unit and renamed it the Beaverdam Formation. In this publication, we use the nomenclature of Ramsey and Schenck (1990), Ramsey (1992), Andres (1994a), and Andres and Ramsey (1995).

Composition and Textures

The Beaverdam Formation consists of two lithofacies: a lower light gray to light yellow-orange, medium to coarse sand, gravelly sand, and sandy gravel with rare beds of dark gray or blue- to green-gray silty clay to clayey silt; and an upper yellow-orange, light brown, and light gray, silty fine to medium sand, sandy silt, clayey sandy silt, and clayey silt with a white to light yellow silt or clay matrix. Carbonized tree branches and herbaceous remains have been found in scattered locations in the upper lithofacies at depths greater than 10 ft below land surface. Rare cobbles and boulders are found in the lower lithofacies. Where weathered, the Beaverdam is brightly colored white, red, and orange, with

TABLE 2

Summary of light mineral data. Values reported as counts to the nearest whole number. Percentages can be determined by dividing the counts by 2.

Unit	Number of samples	Total Quartz	Monocrystalline Quartz	Polycrystalline Quartz	Straight Quartz	Undulatory Quartz	Lithic grains	Potassium Feldspar	Plagioclase Feldspar	Total Feldspar
Mean values										
Beaverdam	12	162	142	20	111	51	10	22	4	26
Nanticoke	7	177	163	15	118	60	3	12	7	18
Manokin	2	186	151	36	111	76	1	6	6	12
Minimum values										
Beaverdam		144	100	6	81	8	0	9	0	9
Nanticoke		161	137	3	95	48	0	1	0	1
Manokin		178	147	31	104	74	0	5	1	6
Maximum values										
Beaverdam		188	160	46	151	100	35	43	12	43
Nanticoke		195	192	30	145	93	7	28	16	31
Manokin		194	154	40	117	77	2	8	12	17
Standard deviation										
Beaverdam		12.79	15.33	11.56	18.97	26.49	10.82	9.92	4.33	11.69
Nanticoke		12.55	19.43	8.13	16.46	14.25	2.36	9.11	5.60	11.37
Manokin		2.49	4.50	2.16	16.54	18.08	9.02	11.03	4.83	12.34

highly weathered grains of feldspar and degraded kaolinitic clays. Figure 4 shows a typical natural gamma radiation log from a well that penetrates the Beaverdam Formation.

The results of light mineral analyses of 12 samples show the Beaverdam to consist of 72 to 94 percent quartz, 4.5 to 22 percent feldspar, and trace amounts of lithic fragments (Table 2). Monocrystalline quartz and potassium feldspar are the predominate forms of these minerals. Sand grains, pebbles, and granules found near land surface are usually very friable and chalky, with a distinctive white color. X-ray diffraction analysis of these grains show poorly crystalline quartz and feldspar. Pebble- to boulder-sized clasts are mainly quartz and quartzite, with less common sandstone, chert, metamorphic rocks, and conglomerate. Many of the larger clasts are highly weathered. The clay mineral suite is dominated by kaolinite with lesser amounts of illite, vermiculite, and chlorite. There tends to be more kaolinite and vermiculite and a lower illite crystallinity index from samples collected near land surface. X-ray diffraction analyses of matrix and grain coatings from samples collected from the weathering profile show either disordered kaolinite, or some other non-crystalline material. It is possible that some of the non-crystalline material is amorphous silica or iron oxide.

Thickness, Distribution, and Bounding Relationships

The Beaverdam is the geologic unit occurring at land surface over much of the map area. Data are not sufficient for mapping a detailed basal configuration or thickness. Where data are available, it can be shown that the basal surface is highly irregular with as much as 40 ft of relief. The upper unit can be as much as 35 ft thick, the lower 70 ft, and total thickness ranges from 55 to 100 ft. The Beaverdam Formation is exposed in the bottom of the Nanticoke River in some locations. It unconformably overlies the Manokin and St. Marys formations.

Nanticoke Deposits

Relation to Previously Recognized Units

We use the informal name Nanticoke deposits in the sense of Ramsey and Schenck (1990), Andres (1994a), and Andres and Ramsey (1995). The Nanticoke deposits occur in the same general geographic and stratigraphic positions as the dune field noted by Booth (1841), the Parsonsburg sand of Rasmussen et al. (1960), and the dune features and Nanticoke Ridge of Jordan (1964, 1974) and Jordan and Talley (1976). The Nanticoke deposits, as recognized in this study, are thinner and have a composition different from that of the Parsonsburg sand of Rasmussen et al. (1960). It appears that some of what Rasmussen et al. (1960) identify as the Parsonsburg sand would be included in the Beaverdam Formation of this study. The Nanticoke deposits include some of what Jordan (1964, 1974) called the Nanticoke Ridge.

Denny et al. (1979) map the Parsonsburg sand in the southern portion of the map area. The Parsonsburg sand, as described by Owens and Denny (1979, 1986) and Denny et al. (1979) has some of the same textural and compositional elements as the Nanticoke deposits in the Seaford area; however, the differences in lithologies, fossil content, and mapped distributions between the Parsonsburg sand and the Nanticoke deposits indicate that the two units are not the same and are not considered to be equivalent.

Composition and Textures

The Nanticoke deposits consist of light to medium brown to light gray, fine to medium quartz sand with scattered coarse sand, granules, and pebbles, and gray to brown, clayey sandy silt and silty clayey sand, commonly containing granule- to pebble-sized, irregularly shaped, rusty-colored mottles and weakly cemented concretions. When dry, the muddy beds have a friable, hackly texture. Woody and herbaceous plant debris has been found in muddy beds in scattered locations. Shells and shell fragments have been reported in a few unpublished drill-hole logs from borings along the Nanticoke River in the southern portion of the map area and to the south of the map area. The muddy beds tend to increase in thickness and frequency of occurrence toward the south. Beds of fine to medium gravel and medium to coarse sand are rarely found at the base of the unit. The sand is usually much better sorted and less silty and compacted than the underlying Beaverdam Formation, so that the contact is easily detected in boreholes and outcrops.

A sequence typical of the Nanticoke deposits consists of a lower, thinly planar-bedded to structureless, fine to medium sand, and an upper high-angle, high-amplitude cross-bedded to structureless, fine to medium sand (Fig. 5). Structureless sands are most often found within 3 ft of land surface, hence it is likely that soil-forming processes have destroyed bedding. Dark red-orange iron-stained lamellae are common below land surface. The upper portion of the soil profile is very sandy and light colored. Much of the area mapped as Nanticoke deposits is mapped as Evesboro Soil by Ireland and Matthews (1974). Less common muddy beds are typically laminated to thinly bedded.

Evidence of soft-sediment deformation has been observed in the map area. One example is shown in Figure 6. Groot (Table 3) reports cold-climate (taiga) palynomorphs in a few samples from the Nanticoke deposits in the area. The authors have observed similar structures in Kent and New Castle counties and interpret them to have formed in seasonally frozen ground.

The results of light mineral analyses on seven samples show the unit to contain over 90 percent quartz, with 2.5 to 8.5 percent feldspar (Table 2). The pebble-sized clasts are dominated by quartz and quartzite, with few ironstone clasts. Pebbles are typically rounded to sub-rounded. Many clasts are highly weathered. Clay mineral compositions of samples collected in and around the map area show two types of assemblages. One is a kaolinite, +/- illite and vermiculite typical of the light gray unfossiliferous beds; the other is a kaolinite, illite, smectite, chlorite, +/- vermiculite assemblage. The second type of assemblage is more common where mud beds are thicker and more numerous in the southern part of the map area and areas to the south and is commonly associated with estuarine fossils (Chenopodeaceae pollen and *Crassostrea* shells).

Composition indicates that much of the Nanticoke deposit sediments in the map area are most likely derived by local reworking of the underlying weathered Beaverdam. The clay and fossil composition of thicker mud beds with estuarine fossils indicate that clay-sized sediments were

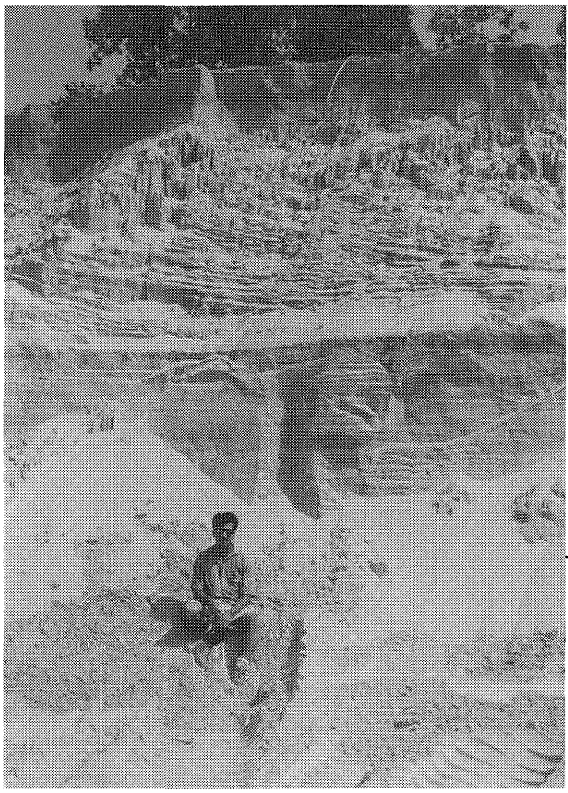

Figure 5. A typical sequence of Nanticoke deposits at outcrop Od43-a2 (for location see Fig. 10). View to the northeast. The high-angle cross bedding in the uppermost unit dips toward the southeast.

transported into the area from an estuary connected to an external sediment source.

Thickness, Distribution, and Bounding Relations

Within the map area, the Nanticoke deposits usually are less than 15 ft thick. Their thickness tends to increase in a down-valley direction where thicknesses greater than 25 ft have been found in drill holes located to the south of the map area.

The outcrop pattern of the Nanticoke deposits tends to parallel the Nanticoke River and larger tributary streams. Throughout most of the map area the Nanticoke deposits unconformably overlie the Beaverdam Formation. In addition, small outliers of Nanticoke deposits protrude 5 to 15 ft above the floodplain of the Nanticoke River and larger tributary streams in a few locations. In these outliers, the Nanticoke deposits are less than five feet thick and overlie the Beaverdam Formation (Fig. 7).

In most locations, the base of the Nanticoke deposits is an irregular surface that gently slopes toward the floodplain of the present Nanticoke River. Where observed in stream valleys it usually occurs above the local base level of current drainage (see Fig. 7). In the vicinity of Seaford and to the south along the Nanticoke River, however, Nanticoke deposits containing estuarine fossils are found below the local base level of current drainage. It is likely that the Nanticoke deposits in these areas represent another phase of erosion and deposition; however, because the unit has no recognizable surface expression, it is mapped as part of the Nanticoke deposits.

Other Quaternary Deposits

Marsh Deposits

Marsh deposits consist of structureless to finely laminated, gray, black, and brown organic-rich silty clay with discontinuous beds of peat. In place or transported fragments of marsh grasses are common. Marsh deposits are differentiated from swamp and alluvium by their cover of marsh grasses and scrub bushes and a lack of large trees. Composition was determined from review of logs of borings done for the Rt 13 crossing of the Nanticoke River and by correlation with marsh deposits observed along Delaware Bay.

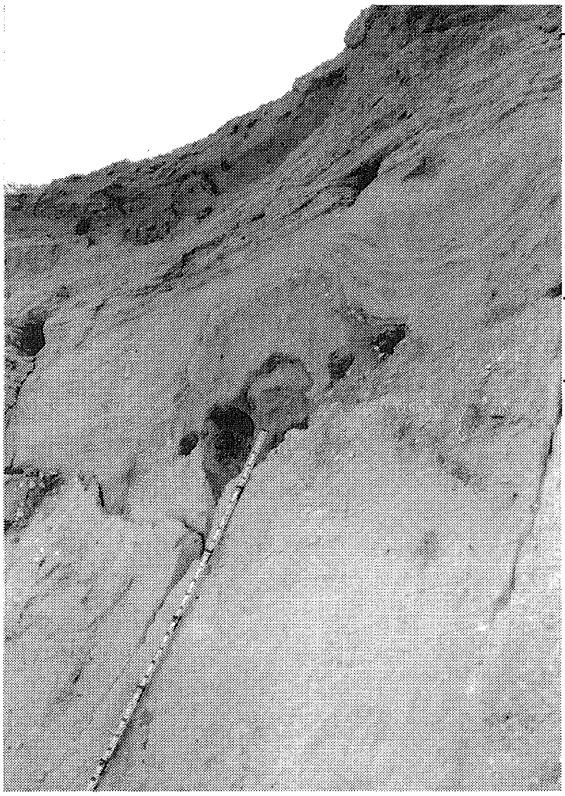

Figure 6. Soft sediment deformation (above ruler) in the Nanticoke deposits at outcrop Od43-a1 (for location see Fig. 10). The mixed zone contains materials derived from the Nanticoke deposits and the Beaverdam Formation.

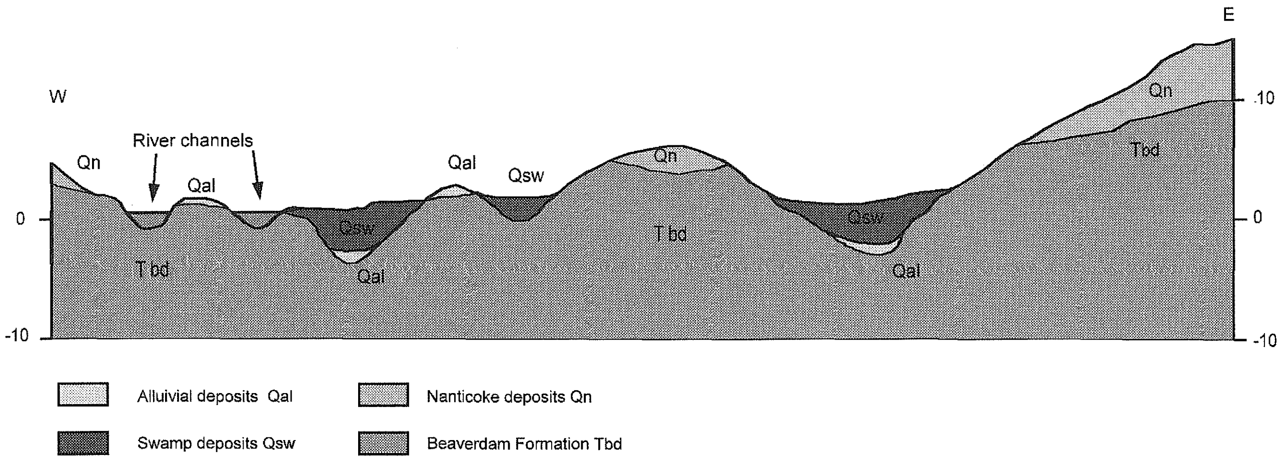

Figure 7. Cross section showing geology and geomorphology of the floodplain and valley walls. The location of this cross section is shown in Fig. 8.

Marsh deposits unconformably overlie the Beaverdam Formation and the Nanticoke deposits. Up valley, they interfinger with swamp and alluvial deposits.

Marsh deposits are found adjacent to the Nanticoke River and Broad Creek in the southern portion of the map area. According to boring logs, they are as much as 25 ft thick where Rt 13 crosses the Nanticoke River. There are insufficient data to describe the thickness of the unit elsewhere.

Swamp and Alluvial Deposits

Swamp deposits are composed of gray, brown, and black organic-rich silty clay to medium quartzose sand with discontinuous beds of brown organic silt and peat. Transported fragments (twigs to large trunks) of woody material are common along the Nanticoke River. Alluvial deposits consist of brown, light yellow orange, and gray fine to coarse quartzose sand, silt, clay, and fine to medium sand and gravel. Swamp and alluvial deposits were observed in closely spaced hand auger borings and Dutch cores done in the floodplains of the Nanticoke River and tributary streams in a number of locations in the map area.

Swamp and alluvial deposits occur within the current floodplain of the Nanticoke River and its tributaries. Figure 7 illustrates the distribution of floodplain swamp and alluvial deposits in the Middleford area. Swamp deposits also occur on poorly drained upland surfaces. Swamp deposits in the floodplains are recognized by topographic expression, high organic-material content, and forest cover. On poorly-drained upland surfaces they are recognized by negative topographic expression, forest cover, and distribution on topographic maps.

Thicknesses of swamp and alluvial deposits range from less than 1 ft to at least 15 ft. In some locations within the floodplain, alluvial deposits less than 2 ft thick directly overlie the Beaverdam Formation. The base of these units extends as much as 10 to 15 ft below current local base level. The basal surface is irregular with as much as 15 ft of relief within 100 ft. Known thicknesses of upland swamp deposits are less than 10 ft.

Swamp deposits interfinger with alluvial deposits upstream and along the stream channel margins and with marsh deposits downstream on a scale of tens of feet. Swamp and alluvial deposits unconformably overlie the Nanticoke deposits and the Beaverdam Formation.

Upland Bog Deposits

Upland bog deposits consist of light brown, fine to medium quartzose sand and silty sand, and gray to black, laminated, organic-rich, sandy silt. Upland bog deposits have not been previously mapped in Delaware. Limited data indicate that these deposits are thin, ranging from 1 to 5 ft. Upland bog deposits occur only on the outcrop area of the Beaverdam Formation, and are mapped only where the land surface is clear of forest vegetation. Key features are negative topographic expression and presence of standing water during late winter and spring months.

Upland bog deposits unconformably overlie the Beaverdam Formation. The precise nature of the relationship between upland bog and Nanticoke deposits is uncertain. It is possible that they may be preserved under the Nanticoke deposits.

GEOMORPHOLOGY

Landforms within the map area can be divided into two general categories, those associated with the floodplains of the Nanticoke River and its tributaries and those found on upland surfaces. These landforms, although modified by human activity, provide information regarding the geologic history of the region and the lithologies and stratigraphic units underlying the landforms.

Floodplains

The geomorphology of the floodplains has been significantly modified by human activities. Field observations, aerial photograph analysis, and discussions with staff of the U. S. Natural Resources Conservation Service, DGS, residents, and others confirm that the existing morphology of the drainageways should be interpreted with caution. For example, the Nanticoke River and its adjacent floodplain have been significantly modified by dredging and filling upstream of the gaging station located just east of Bridgeville. Road and pond construction and borrow operations have modified the Nanticoke River and its tributaries at a number of locations. Dams have been constructed on a number of tributary streams creating some of the larger ponds in the map area.

Some of the reaches of the Nanticoke River, Deep Creek, Gravelly Branch, and several other small tributaries

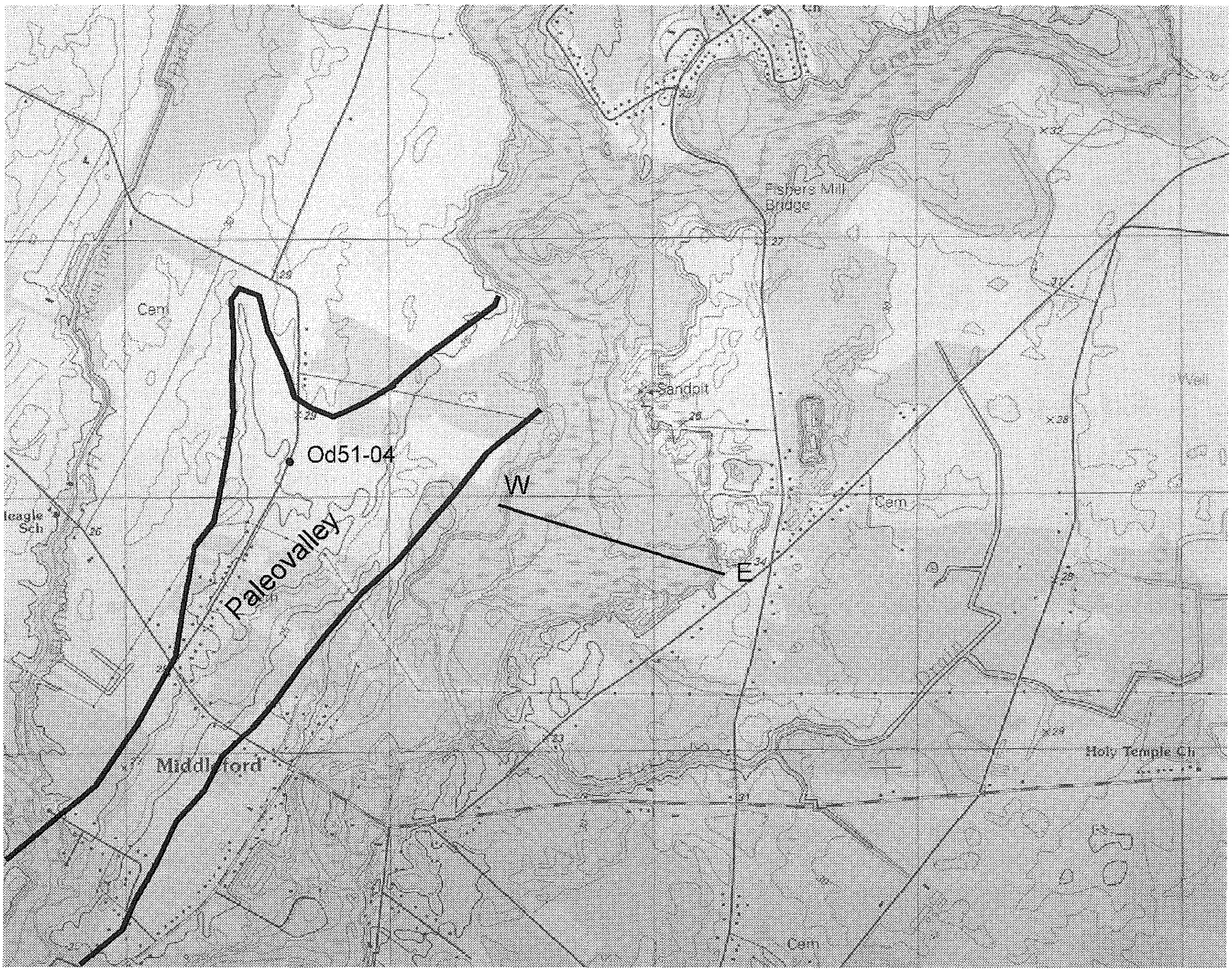

Figure 8. Map of Middleford area showing location of the cross section in Fig. 7. The map also shows a paleovalley within the Nanticoke deposits located west of the Nanticoke River. The paleovalley underlies a surface that has a negative topographic expression and indicates possible stream capture.

are interpreted to be in natural settings. These streams are characterized by swampy floodplains and multiple channels. Most fair-weather stream flow occurs in one channel, with the other channels containing slack water. Following significant precipitation, all channels carry significant flows, and flood flow covers the entire floodplain.

Figure 7 is a cross-section across the Nanticoke River floodplain to the northeast of Middleford, Delaware (Fig. 8). The lateral boundaries of the floodplain are commonly marked by distinctive breaks in slope and change in vegetation. Alluvial deposits form sandy ridges and mounds extending 2-3 ft above the surrounding swamp and typically have a different vegetative cover than the adjacent swamp. Although not shown in Figure 7, swamp surfaces have many small pits and hummocks around uprooted trees. Other portions of the floodplains are shown in Figures 9a, 9b, 10a, and 10b.

Valley walls (Figs. 8, 9b, and 10b) have sinuous patterns and relatively steep slopes compared to upland surfaces. These characteristics indicate that streams have meandered within their floodplains as the valleys were eroded into underlying units.

Upland Surfaces

Mapped lithostratigraphic units on upland surfaces include the Nanticoke deposits, Beaverdam Formation, swamp deposits, and upland bog deposits. Geomorphology and land cover are key characteristics for distinguishing these units.

Numerous, small, irregularly shaped to rounded, undrained depressions are found on the outcrop surface of the Beaverdam Formation (Figs. 11a and 11b). The sizes of these features typically are less than 10 acres and the edges (rims) are not raised above the surrounding landscape. These features are here referred to as upland bogs to distinguish them from slightly similar landforms mapped as Carolina Bays by Ramsey (1993). Upland bogs also include some of the bays and basins of Rasmussen et al. (1960). Aerial photographs commonly show a distinctive surface texture consisting of light and dark mottles (Figs. 9 and 11). The light and dark mottling is due to differences in soil-moisture content and is likely related to soil texture differences. Most of the outcrop area has been cleared and drained and under agricultural production for decades so that it is not possible to be certain if the appearance of any

Figure 9. Aerial photograph and topographic map of part of the outcrop area of the Nanticoke deposits. A distinctive grain of light and dark colored soils developed on the Nanticoke deposits is oriented sub-parallel to present drainage associated with ridge and swale topography (a. Aerial photograph - ANH 1N 14 1954, and b. Seaford East topographic map, U. S. Geological Survey, 1992).

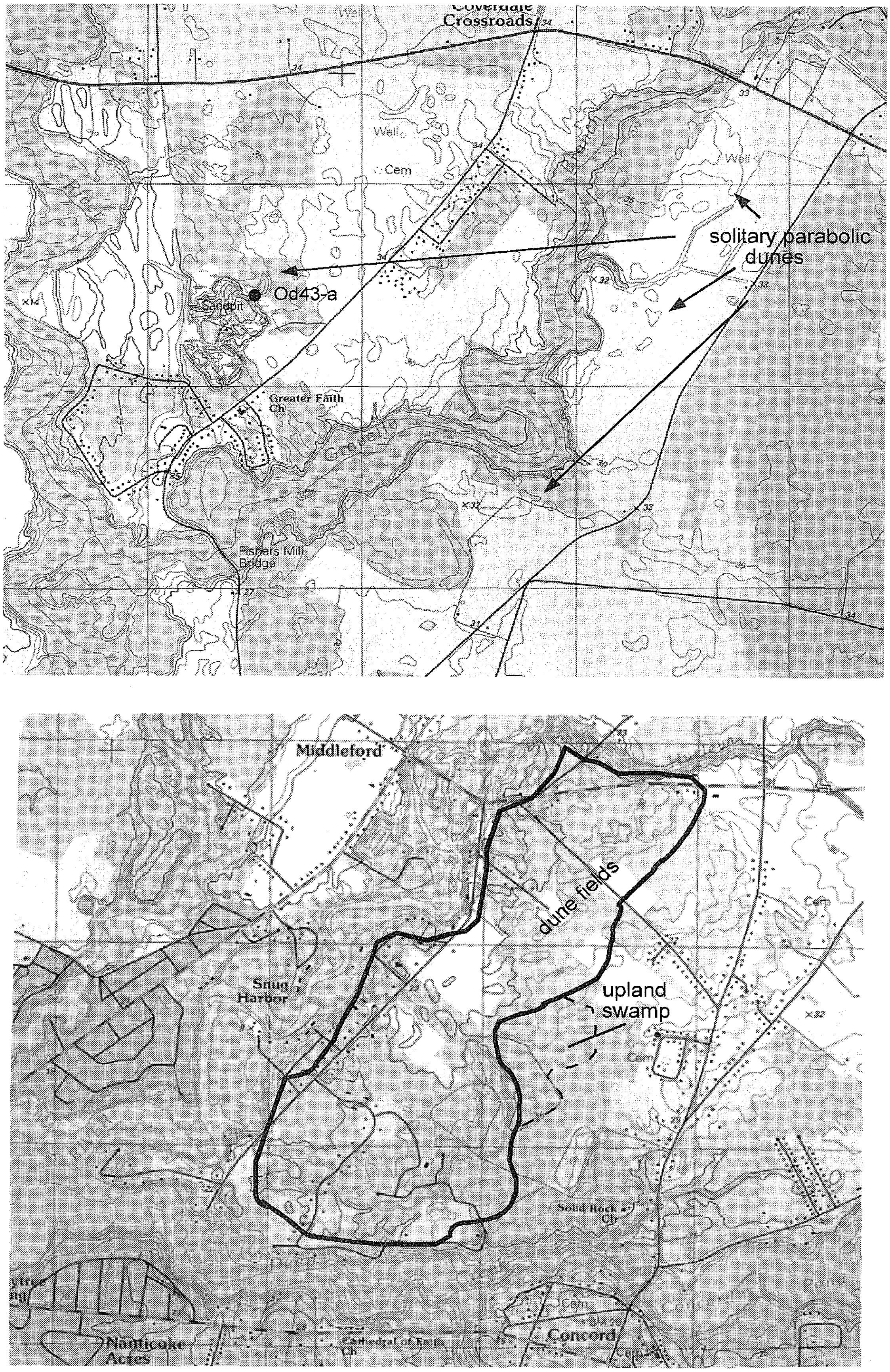

Figure 10. Dune deposits in the Nanticoke River valley. a. Solitary parabolic dunes are most common north of the juncture of the Nanticoke River and Gravelly Branch, where the thickness of Nanticoke deposits typically is less than 10 ft. Although no systematic measurements have been made, visual analysis indicates that the concave side of almost all dunes faces northwesterly. The approximate location of the photographs from figs. 4 and 5 is shown as Od43-a. b. Dune field located between Gravelly Branch and Deep Creek containing parabolic and other complexly shaped dunes. Note the upland swamp.

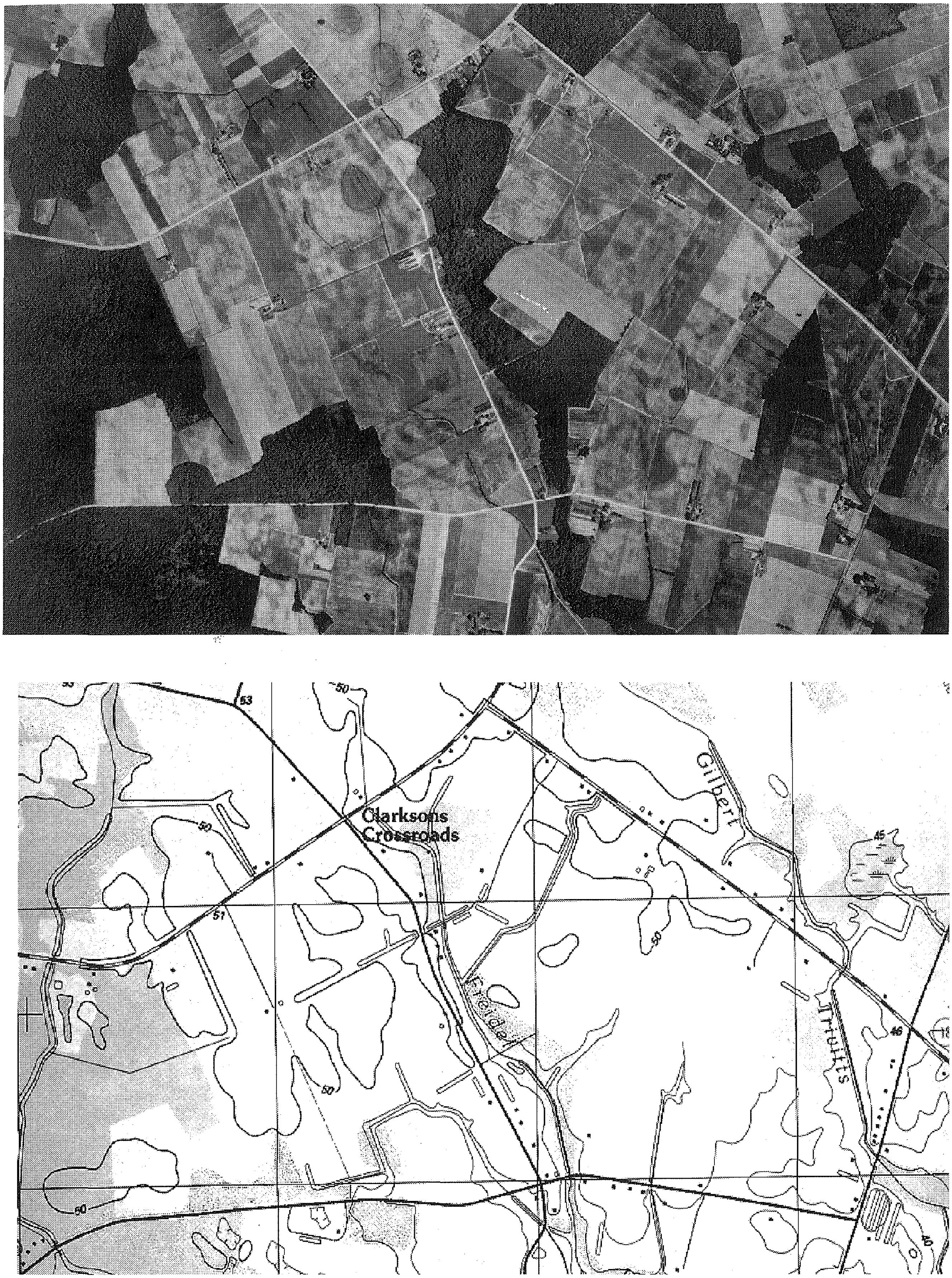

Figure 11. Aerial photograph and topographic map of an area with upland bog deposits. Upland bog deposits occur in small, irregularly shaped to rounded, undrained depressions on upland surfaces. They are mapped only in the outcrop area of the Beaverdam Formation (a. Aerial photograph ANH 1N 106 1954, and b. Seaford West topographic map, U. S. Geological Survey, 1992)

area is natural or due to human influence. For example, Ireland and Matthews (1970) indicate that the soils mapped in these areas are susceptible to formation of tillage pans, so it is probable that some of these features have been caused by land-tilling practices. In addition, tilling, ditching, and other drainage modifications probably have modified the shapes of these features. As a result, selecting a mapping scale for these features is problematic. The upland bogs shown by Andres and Ramsey (1995) differ from other, smaller, closed depressions in that current topographic relief exceeds 3 to 5 ft, and aerial photographs taken in springtime usually show standing water.

Swamps located on upland surfaces have distinctive geomorphic expression, land cover, and lithologies, hence, they are mapped as distinct lithostratigraphic units. Where observed, upland swamp surfaces are flat with pits and hummocks around uprooted trees. One such upland swamp occurs within a dunefield between Gravelly Branch and Deep Creek (Fig. 10b). A review of aerial photographs and topographic maps produced over the past 40 years shows that upland swamps have been extensively modified by ditching and clearing.

The outcrop areas of the Nanticoke deposits have gently rolling to hummocky topography. Aerial photographs and topographic maps commonly show an association of a distinctive pattern of light and dark colored soils and ridge and swale topography oriented sub-parallel to present drainage (Figs. 8 and 9).

Sand dunes are commonly occur on the south and east sides of the Nanticoke River and larger tributaries (Fig. 10). Solitary parabolic dunes are most common north of the juncture of the Nanticoke River and Gravelly Branch, where the thickness of Nanticoke deposits is typically less than 10 ft. Between Gravelly Branch and Deep Creek, a dune field contains parabolic and other complexly shaped dunes. The Nanticoke deposits are greater than 10 feet thick in this area. There is an upland swamp within this dune field.

We agree with earlier workers that these features have an eolian origin. Dune-axis orientations indicate that the prevailing wind direction during formation was from the northwest as suggested by Denny and Owens (1979) and Carver and Brook (1989). In this regard, the dunes probably have an origin similar to those studied by Markewich and Markewich (1994) in North Carolina, South Carolina, and Georgia.

PALYNOLOGY OF THE SEAFORD AREA

Johan J. Groot

General Observations

In view of the near absence of fossils, except palynomorphs, in the surficial sediments of the Seaford area, it was considered necessary to conduct a palynological investigation. Its purposes were to determine the ages of the sediments, their environments of deposition, and the paleoclimates at the times of deposition. Seventy samples were analyzed; the results are shown in Table 3. It should be noted that some samples are from outside the map area; their locations are shown in the table by latitude and longitude.

Palynomorph Assemblages of the Beaverdam Formation

The assemblages are dominated by *Quercus* (oak), generally accounting for more than 50 percent of the pollen sum. Other frequently occurring pollen are those of *Carya* (hickory) and, to a smaller extent, those of *Pinus* (pine) and various conifers of the Taxodiaceae-Cupressacene-Taxaceae (TCT) group. Characteristic exotics are *Sciadopitys, Pterocarya,* and, in some samples *Momipites* (Engelhardia type), *Cyrilla* (ironwood), and *Tricolporopollenites edmundii.* A few dinocysts were found in the Beaverdam indicating a marine or estuarine environment. This assemblage is the same as the one reported for the Bethany and lower Beaverdam formations of eastern Sussex County (Groot et al., 1990) and is considered to be of latest Miocene or Pliocene age. The climate at that time was warm-temperate, warmer than the present climate.

Palynomorph Assemblages of the Quaternary Sediments

The ages of the Quaternary deposits have been determined by the stratigraphic distribution of six species of *Quercus* pollen as reported by Groot et al. (1995) in upper continental slope and shelf sediments off the New Jersey coast and in some samples of the Quaternary of Sussex County, Delaware. In the Seaford area, *Quercus* pollen species suggesting marine oxygen isotope stage 5 (Sangamonian) are most common, but other species indicating stages 7, 9 (?) and 11-13-15, or perhaps older have also been identified (see Table 3).

Although these age determinations are simple in principle, they are impossible where there is a paucity of *Quercus* pollen, as in assemblages indicating a cold climate, or where pollen preservation is poor; therefore, Table 3 shows several samples the ages of which are unknown except being Quaternary.

The Quaternary pollen assemblages indicate a variety of environments of deposition. Of the 40 Quaternary samples that have been interpreted in terms of environment, nearly one half were deposited in an estuary during temperate climate intervals, 35 percent in or bordering a freshwater body or marsh, and some in bogs during cold or cool-temperate intervals.

Estuarine and brackish marsh sediments are generally deposited in shallow water, and their occurrence is therefore an indication of approximate sea level. There are too few samples to allow drawing firm conclusions regarding relative sea levels during the past five million years. The limited data do suggest, however, that late (stage 5) and middle to early Pleistocene (stages 7, 9 and 11, 13, 15 or older) sea levels were at least 20 ft above that of the present, and a latest Miocene-early Pliocene sea level reached +40 ft in the Seaford area. Two samples of auger hole Ob23-07, 84846 and 84847 (Table 3), have predominantly *Quercus* sp. 1 pollen and common Chenopodeaceae pollen, indicating a stage 5 age, an estuarine environment of deposition, and therefore suggesting a sea level of approximately 31 ft. As this is about 10 ft higher than observed elsewhere in Sussex County, the Ob23-07 site should be investigated again.

SUMMARY - GEOLOGIC HISTORY

Tertiary

The St. Marys and Choptank formations were deposited in inner neritic environments during the Miocene (Andres, 1986; Benson, 1990). Andres (1986) described the St. Marys environment as transitional from quiet water to slightly higher energy delta front portions of a prograding deltaic system. As such, the St. Marys signals the start of a new depositional phase in southern Delaware. Palynological data indicate a warm sub-tropical to warm-temperate environment during this time (Table 3).

The Manokin formation was deposited in inner neritic to lower delta plain environments during the middle to late Miocene (Owens and Denny, 1979; Hansen, 1981; Andres, 1986; Benson, 1990; Achmad and Wilson, 1993). Geophysical log facies analysis indicate deposition occurred in a prograding delta front environment (Andres, 1986; Achmad and Wilson, 1993). The Manokin deposits represent a significant influx of sand into the area. Where the gradation zone between the Manokin and St. Marys consists of a thick sequence of interbedded muddy sands, sandy muds, and mud, evidence does not clearly indicate whether the depositional environment was interdistributary or prodelta. Palynological data indicate a warm sub-tropical to warm-temperate environment during deposition of the Manokin (Table 3).

During the late Miocene, most of the deposition in the region was south and east of the map area (Andres, 1986; Ramsey, 1993). Part of the Manokin formation was eroded for a period of time during this period.

The Beaverdam Formation was deposited in fluvial, estuarine, and deltaic environments during the Pliocene. The irregular basal contact, coarse-grained basal beds, and fining-upward lithologic character of the lower Beaverdam represents incision and subsequent progradation of a fluvial system into the map area. Ramsey (1992) suggested that that there may have been some wave and tidal reworking of the lower Beaverdam. The heterogeneous assemblage of fine- and coarse-grained beds in the upper Beaverdam represents deposition in small channels and on adjacent floodplains, probably within a delta plain environment. A few samples from the upper Beaverdam contain pollen assemblages that indicate a warm-temperate to temperate estuarine, environment (Groot et al., 1990; Groot, this report).

Quaternary

The geologic history of the Quaternary in the Seaford area is a record of the modification of the surface of the Beaverdam Formation and deposition of sediments in fluvial, estuarine, and eolian environments. Deposition was controlled by changes in sea level and climate during glacial and interglacial periods (Groot et al., 1990, 1995). The record is preserved as an informal stratigraphic unit called the Nanticoke deposits and as recognizable landforms that shape the surface of the Nanticoke deposits and the Beaverdam Formation. The primary modifications of the surface of the Beaverdam Formation were development of a deep weathering profile and incision of the drainage of the Nanticoke River and its tributaries.

Following deposition of the Beaverdam Formation, sea level has fluctuated in response to Pleistocene and perhaps Pliocene glacial-interglacial cycles (Groot et al., 1990; 1995). During this time, there were incision and filling of the valleys of the Nanticoke River and larger tributaries and weathering and reworking of upland surfaces underlain by the Beaverdam Formation. Throughout this time upland bogs and swamps also formed and disappeared in response to changing drainage patterns. Deposition of the Columbia Formation (early Pleistocene) occurred to the north and east of the Seaford area (Ramsey, 1992).

It is probable that the area mapped as Beaverdam Formation includes younger, thin surficial units. For example, during wetter periods in the Quaternary, upland bogs and swamps undoubtedly covered larger areas than they do at present, and there may have been small streams associated with them. However, all of the organic material has oxidized, and the non-organic material deposited in them was derived from the surrounding Beaverdam Formation. Agricultural activity has further disturbed the land surface. As a result, there are no recognizable unconformable contacts, or lithologic or geomorphic differences between the Beaverdam Formation and the younger non-organic bearing alluvial, swamp, and bog deposits.

The Nanticoke deposits represent several cycles of erosion and deposition in a variety of environments during the middle to late Pleistocene. Palynological remains (Table 3) and C^{14}-dated fossil Crassostrea shells, along with lithology and geomorphology, indicate deposition occurred prior to 40,000 years ago under climatic conditions that ranged from cold to warm temperate, and environments that included freshwater bogs and ponds, freshwater and brackish streams, and eolian dunes (Ramsey and Baxter, 1996; Groot, this report; Jordan, 1974). The Nanticoke deposits of eolian origin appear to have similar morphology, lithology, and geologic history with inland dune deposits described by Markewich and Markewich (1994) in Georgia and the Carolinas.

Upstream from Middleford along the Nanticoke River, the Nanticoke deposits represent erosion of the underlying Beaverdam, reworking of the sediment with removal of most fine-grained material, and deposition in bogs and small freshwater and brackish streams. Some of the sands were subsequently or concurrently reworked by eolian processes that built sand dunes. All of these deposits occur above the current local base level and, hence, indicate a period when sea level was higher than now.

Downstream from Middleford, the Nanticoke deposits are thicker, mud beds are more common and thicker, and sand dunes occur in dune fields. The greater mass of the Nanticoke deposits in this area likely represents the distal end of one or more fluvial systems where the sediment load was dumped into a low-energy estuarine environment. The size and morphology of the dune fields indicates they may have been formed during multiple periods of eolian deposition (Markewich and Markewich, 1994).

Within the Nanticoke deposits, *Crassostrea* shells and shell fragments were recovered from a borehole just east of Seaford (Pc25-04, sample no. 22793) at elevations between 15 and 25 ft above present sea level (Jordan, 1974; Jordan and Talley, 1976). Amino acid data from this sample fall

TABLE 3

Palynological data. Results given as grain counts. A key follows the table.

Sample Number	DGSID	Land surface elevation	Sample elevation	Latitude	Longitude	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
83904	Ob23-02	41	-6	384305	754251		P					12	P		P							3	71					1			2
83901	Ob23-02	41	9	384305	754300	P	5	P?				12			P	P	P				P	4	58			P		2		P	4
84833	Ob23-04	40	33	384336	754222		3	2				1	3		1						2	12	22								11
84834	Ob23-04	40	31	384336	754222	4	1						2								1	18	34					P			9
84846	Ob23-07	38	31.5	384339	754247																										
84847	Ob23-07	38	31	384339	754247	2	2		2			15			P			P					58							3	8
42203	Ob24-a	45	42.5	384342	754140					P									P	P											
84003	Ob55-03	37	-5	384001	751005	1		1	26			53		3									10			1					3
42182	Oc15-b	38	30	384452	753510	2	3		P			P										16	30					P			2
42177	Od11-b	30	25.5	384450	753459	20	P		P		P	27		P		P		P			P		3					P			10
83186	Od32-04	30	26	384233	753345				3			3										1	80	P							1
42199	Od32-c	32	26	384229	753345	2	2		P			12		P	P	P							70	P						P	3
84765	Od41-02	29	5	384115	753401																										
84764	Od41-02	29	5.5	384115	753401																										
84763	Od41-02	29	6	384115	753401																										
84762	Od41-02	29	6.5	384115	753401																										
41495	Od43-a3	30	22	384152	753256	1	1	P	2			13	P				P				P	2	54			P	P	P		3	3
41729	Od44-c	32	27.5	384124	753129																										
84771	Od51-04	27	3.5	384038	753404	8	5	1	3		3	33	1	1	1						2	P	15			6	2				10
84768	Od51-04	27	10	384038	753404	7	3	1	P		P	9	P		P						P	P	62			1		P			3
84769	Od51-04	27	8	384038	753404	6	4		3			16		P	P				P?		P	P	42			P	P	P			9
84770	Od51-04	27	6.5	384038	753404	8	P	P	2		P	24	P	P	1			P			1		26	P		P		P		P	12
42270	Od52-g2	5	-2	384032	753318	10	2					35		2		3		P					33	3						P	3
42266	Od52-i	5	-4	384029	753223	7	6	1				8	1		P						1	P	67	4							P
83196	Oe11-02	39	-30	384416	752925	P			5			62		1			1		P?		2		17			3					1
84101	Pb34-04	36	20	383743	754106							P											95								P
84096	Pb34-04	36	33	383743	754106																										
84098	Pb34-04	36	25	383743	754106		P					2											75					P		11	2
84104	Pb34-04	36	11	383743	754106		2		P													P?	86							3	2
84099	Pb34-04	36	23	383743	754106		2		1			7		P		P						P	65			P					9
84662	Pb45-04	32	17	383615	754038	5	6					P			1							8	52								4
84660	Pb45-04	32	24	383615	754038	13	g	P				5	P		7							P	26					3			14
84661	Pb45-04	32	22	383615	754038	3	5		P			2			2						2	1	30							1	2
84663	Pb45-04	32	12	383615	754038	3	5	1				3			3							2	43								3
84650	Pb53-02	26	12	383505	754212	3	3	1	10			23	3	P	P	1					P	4	35	1							4
84658	Pb55-03	32	16	383543.9	754060	5			2			12		1	P							2	70			2?					1
84655	Pb55-03	32	25	383543.9	754060	P	P					6	1		4							8	36					P	2		29
84659	Pb55-03	32	18	383543.9	754060	2	6	1	6		P	22			P							P	35			3		1		6	6
83836	Pc14-03	34	-93	383956	753644				13	1		49	P	1		P	P		P		3		31			2				P	P
83947	Pc14-04	21	-39	383941	753647		P		9	2		75	2				P				2		5			2					P
22793	Pc25-04	25.7	14.8	383834	753548		2		2			48	1		1						2		31							4	4
22792	Pc25-04	25.7	17.2	383834	753548	1	13	P	5			23	P		2								31			1				4	P
22782	Pc41-01	22.6	12.5	383619	753954	7	5	3	4			15			P	P							62			P	P			P	P
41866	Pc41-a	26	17.5	383657.5	753938.6		2		P			5										P	86					P			4
22826	Pc43-01	25.2	-10	383624	753711		2	1	11	1		69		1			1				3		1			11					

TABLE 3

Palynological data. Results given as grain counts. A key follows the table. (continued)

Sample Number	DGSID	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	Age	Unit	Climate	Environment of deposition	Remarks
83904	Ob23-02	P		1			P	P		2	3		10	P		Q11,12	Qn	cool/temp	?	*Larix* 3%, *Nuphar*
83901	Ob23-02	P	2	1			1	P		3	1		15	P		Q7-9?	Qn	cool/temp	est?	
84833	Ob23-04	5		2		1	P	22		4	4	4	53	P		Q	Qn	cool/cold	sph bog	
84834	Ob23-04	3		1			11	10			1		35			Q	Qn	cold	bor/fst	*Sanquisorba?*
84846	Ob23-07															Q5?	Qn	temp	est	
84847	Ob23-07	4	P	2			1			2			21			Q5?	Qn	temp	est	
42203	Ob24-a														P	Plio	Tbd	warm/temp moist	est	
84003	Ob55-03	1						?					4			Plio	Tbd	temp	?	percentages approximate
42182	Oc15-b	P	38	P				2			2	P	47			Q	Qn	cold	msh	
42177	Od11-b	3	3				P		15	7	3	P	43			Q	Qn	temp	riv/lake	border of river or lake
83186	Od32-04	1		5				P		3	3		10			Q5?	Qn	temp?	pine fst	acid soil
42199	Od32-c	P	P	3			P			P	2		12			Q?7-9	Qn	temp	fluv/est	
84765	Od41-02															Plio	Tbd	warm/temp moist	?	poor preservation
84764	Od41-02															Plio	Tbd	temp		*Sciadopitys* common
84763	Od41-02															Plio	Tbd	warm/temp		*Sciadopitys/Momipites*
84762	Od41-02															Plio	Tbd	temp		*Sciadopitys*
41495	Od43-a3	2	P	1		P?	2	P	P	4	7		22		3	Q	Qn	temp./cool temp	est	
41729	Od44-c															?	?	?	?	green algal cysts, fungal hyphae
84771	Od51-04	2	1	1							2		17			Q5?	Qn	temp or warm/temp	stream	border of stream
84768	Od51-04	3	4				2			1			13			Q5	Qn	temp/moist	riv/pond	border of river or pond
84769	Od51-04	5	5	P			3			P	2	P	23			Q5	Qn	temp/moist	riv/pond	border of river or pond
64770	Od51-04	8	4	P		P	1			1	3		36	P?		Q5	Qn	temp/moist	fshw msh	
42270	Od52-g2	P	P			P		P	2	3			11	P	P	Q5a Q1	Qs	temp	?	10,070 years bp 1.4
42266	Od52-i		P				P			2			4	P		Q5 Q2 Q1	Qs	temp	fshw?	10,090 years bp 1.23
83196	Oe11-02			1	1		1		1			1	6			Plio/Mio	Tbd	warm/temp	?	*Momipites*
84101	Pb34-04		P				1			2			4			Q	Qn	temp	pine fst	Onagraceae
84096	Pb34-04															Q	Qn			
84098	Pb34-04		4								3		19			Q	Qn	temp	est?	
84104	Pb34-04			P						2	3		10			Q	Qn	temp	est?	some green algal cysts
84099	Pb34-04	4	P	P			2	P		1	4		22			Q	Qn	temp	fshw	*Nuphar*
84662	Pb45-04		1				2				21		28			Q5	Qn	cool or cold	sph bog	
84660	Pb45-04	6	4	3		3	3	P		P	3		38			Q	Qn	temp	stream	border of stream
84661	Pb45-04	2	5	1							43		54			Q	Qn	temp?	sph bog	*Larix*?, poor preservation
84663	Pb45-04	P	P	4			P				29		38			Q	Qn	cool/temp	sph bog	
84650	Pb53-02	2		1		P	4			P			13			Q5	Qn	temp	fshw	*Myriophyllium* 4%
84658	Pb55-03		1				2	1			1		6			Q	Qn	temp	?	poor preservation
84655	Pb55-03	1	3	6		P							43		P	Q	Qn	cool/temp	fshw?	
64659	Pb55-03	1				2				5	3		24			Q	Qn	temp	est	poor preservation
83836	Pc14-03									P			2			Mio	Tsm	warm/temp or sub	?	Polygonace, *Gordonia*
83947	Pc14-04									P			1	P		Plio/Mio	Tbd	warm/temp	?	*T. edmundii*; few paleozoic spore
22793	Pc25-04			3		1				1	1		13	P		Q11.13	Qn	temp	est	reworked Paleozoic spore
22792	Pc25-04	P		P			1	P		4	7		19	?		Q11,13	Qn	temp	est	poor preservation
22782	Pc41-01		P		P		P			P			4			Q11,13	Qn	warm/temp	fluv	
41866	Pc41-a	P	P							P			6			Q5	Qn	temp	?	
22826	Pc43-01									2			2	P		Plio	Tbd	temp or warm temp	?	*T. edmundii*, Onagracea

TABLE 3

Palynological data. Results given as grain counts. A key follows the table. (continued)

Sample Number	DGSID	Land surface elevation	Sample elevation	Latitude	Longitude	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
22827	Pc43-01	25.2	-15	383624	753711	P	1		14	P		66		2		1	1						2	P	1	6	1				
22713	Pc51-01	6	-14	383554	753923	11	3		6			58		2	2	3							6			P				3	4
22711	Pc51-01	6	-3.7	383554	753923	3	1		3			33	2	2	P	3					2		25	P		1				8	11
22712	Pc51-01	6	-9	383554	753923	9	3		7			46	P	P	2	P							13	P				P		P	11
83171	Pd21-07	30	-140	383850	753421	1			14	P		70		1			2	2				1	7			2					
83168	Pd21-07	30	-80	383850	753421	P	2		20			59		1				P			3	P	7			3	1				1
83166	Pd21-07	30	-40	383850	753421	P	P		36			55		P			2	P	P?						2	2					
83169	Pd21-07	30	-100	383850	753421	2		P	13	2		63		P	2	P		2					2		P	7				3	3
83170	Pd21-07	30	-120	383850	753421				7	P		72		P				P			P		17			2					
84473	Pf42-02	47	25	383643	752342		P	P	P			16										P	38							5	25
84472	Pf42-02	47	28	383643	752342																										
84428	Qb14-04	11	-11.5	383412	754135		2		27			46	P	P						P			16	1		2					2
84426	Qb14-04	12	1	383412	754135		5		1			16											68					1			4
84440	Qb15-01	5	-19	383432	754006				37			14		14							1		23	1	1	4		1			1
84434	Qb23-01	6	-6	383353	754202				8			25										P	40							P	14
84436	Qb23-01	6	-11.5	383353	754202	2	P	2	9			18		2		3					2	P	42	P							15
84431	Qb23-01	6	2	383353	754202	7	3		P			14	1	1	3	P					2		21							4	34
40139	Qb34-b	25	16	383239	754136	P			5													9	68	P							2
84633	Qb45-01	30	18	383156	754012		3		2			13	P	P		P						P	69								2
84613	Qb45-05	45	30	383122	753519	3	1					3			3							18	26			P		P			12
84420	Qc22-07	25	1.5	383336	753829																										
84418	Qc22-07	25	7.5	383336	753829																										
22774	Qc23-01	20	11	383345	753705	2	3	4	10			45										19				4	2	1			4
41867	Qc45-05	26	15	383657.5	753938.6	2	2		2			10			P							P	70			P?					6
84356	Qd33-04	33	13	383230	753218	9	2		2			15									P	?	37								17
84380	Qd34-01	31	19	383248	753213	P	P	3	3		P	8	16	P	4	3						P	41								P
84329	Qe42-05	40	23	383117	752823		1		1			1	3									10	57					1	P		7

TABLE 3

Palynological data. Results given as grain counts. A key follows the table. (continued)

Sample Number	DGSID	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	Age	Unit	Climate	Environment of deposition	Remarks
22827	Pc43-01									3		1	4		?	Plio	Tbd	temp	?	*Sciadopitys, Pterocarya*
22713	Pc51-01									2	P		10			Q5	Qn	temptemp	est	
22711	Pc51-01				1					1	P		22			Q5	Qn	temp	est	fshw algae
22712	Pc51-01	P		P	P				P	P			16			Q5	Qn	temp	fluv/est	fshw algae
83171	Pd21-07						P			P		P	2			Mio	Tsm	?	?	Ditch samples
83168	Pd21-07	1								4			6	P		Mio	Tm	warm/temp to sub	?	*Momipites, T. edmundii*
83166	Pd21-07									P			P		P?	Plio/Mio	Tbd	temp	?	Ditch samples
83169	Pd21-07	P		P								P	7		P	Mio	Tm	warm/temp	?	Ditch samples
83170	Pd21-07															Mio	Tm	?	?	Ditch samples
84473	Pf42-02	P		1		P	P			4	3		41	P		Q7-9?	Tm	temp	est	*Larix* reworked
84472	Pf42-02															Q>5	Tm	temp/moist	est	
84428	Qb14-04		1					P		P			4			Q5?	Tm	temp	?	
84426	Qb14-04		2	2	1		1			1			10		P	Q5	Tm	temp	fshw deposit	
84440	Qb15-01	1								3			5			Plio	Tbd	temp	?	*Momipites*
84434	Qb23-01			P	3	P				4			25	P		Q5	Qn	temp	fsh/bckw	
84436	Qb23-01	2					P	P		P			19			Q5	Qn	temp	?	
84431	Qb23-01	1	4			1	2						46	P	P	Q5	Qn	temp	est	a flood of 10 micron dinocysts
40139	Qb34-b	4			1			2	1	6	5	2	17			Q	Qn	cool/temp	?	similar to Columbia Fm
84633	Qb45-01	2		4			P			P			11			Q5	Qn	temp	?	
84613	Qb45-05	5	3	2	P	P	2	3	P	2	12	P	45	P		Q	Qn	cold	fshw	K, pre-K spores
84420	Qc22-07															Q	Qn	?	?	
84418	Qc22-07															Q	Qn	?	fshw deposit	
22774	Qc23-01	2			1	1				2			12			Q7,9?	Qn	warm/temp	fluv/est	
41867	Qc45-05	2					2				P		13		P	Q5	Qn	temp	?	*Thalictrum*
84356	Qd33-04	P	2				P		4			P	26			Q	Qn	temp	pond/riv bot	
84380	Qd34-01		P	12		P					5		20			Q	Qn	temp/moist	?	acid soil
		1					3	9		2	3		17			Q	Qn	cool/cold/dry	?	percentages approx.

Key to Table 3.

Column heading	Genus
A	*Alnus*
B	*Betula*
C	*Carpinus*
D	*Carya*
E	*Pterocarya*
F	*Castanea*
G	*Quercus*
H	*Ilex*
I	*Liquidambar*
J	*Myrica*
K	*Nyssa*
L	*Tilia*
M	*Ulmus*
N	*Cyrilla*
O	*Symplocos*
P	Other dicotyledon
Q	*Picea and Abies*
R	*Pinus*
S	*Tsuga*
T	*Sciadopitys*
U	TCT
V	*Taxodium*
W	*Artemisia*
X	Caryophyllaceae
Y	Chenopodiaceae
Z	Compositae
AA	Gramineae
AB	Cyperaceae
AC	Ericaceae
AD	Hydrocharitaceae
AE	*Typha/Sparganium*
AF	Other herbs
AG	*Lycopodium*
AH	*Osmunda*
AI	*Polypodiaceae*
AJ	*Sphagnum*
AK	Other ferns/mosses
AL	NAP
AM	Reworked palynomorphs
AN	Dinocysts, microforams

Column heading	Explanation
Age	
Q	Quaternary
11	Oxygen isotope stage
Mio	Miocene
Plio	Pliocene
Climate	
temp	temperate

Environment and Remarks	
est	estuarine
bor	boreal
fshw	fresh water
msh	marsh
fst	forest
riv	river
bot	bottom
sph	sphagnum
fluv	fluvial
K	Cretaceous

within aminozone IIa (Groot et al., 1990). Aminozone IIa has been correlated with oxygen isotope stage 5, indicating 75,000 to 130,000 years BP (Groot et al., 1990; 1995). Palynomorphs from this sample indicate a warm temperate environment (Table 3).

Palynomorphs of Chenopodiacea and *Crassostrea* shells, indicating estuarine deposition, have been recovered from the Nanticoke deposits to the south of Seaford at elevations near sea level to 10 ft below sea level. These estuarine deposits may represent the limit of headward erosion. Alternatively, they may represent two or more periods of incision and deposition. If so then the estuarine deposits occurring at and below sea level may be the time-equivalent of the Kent Island Formation of Owens et al. (1979).

Palynomorphs indicating cold and cool temperate climates occur in samples collected from the Nanticoke deposits at depths less than 10 ft near Brights Branch (blocks Ob22, Ob23), near the Nanticoke River just east of Bridgeville (Oc15), and from areas just south of the map area. The floral assemblages indicate a range of freshwater environments including bogs, taiga, and boreal forest (Table 3).

The areas underlain by marsh, swamp, and alluvial deposits represent active depositional settings. The locations and boundaries of these environments have shifted over time in response to the rise and fall of sea level, salinity of the Nanticoke River as related to long-term climatic conditions, human influences, and the supply of clastic sediment from up valley and the valley margins.

Swamp deposits rich in organic material (peat and disseminated organics) from 7 to 10 ft beneath the floodplain of the Nanticoke River (Od52-g2, -i, -18) give dates of 9100 to 9680 C^{14} age years BP (before present). Ramsey and Baxter (1996) report dates of 10,070 to 10,770 calibrated C^{14} years for these samples. The location of the sample yielding the 10,770+ 90 years BP calibrated date (Od52-18) indicates that the river channel has migrated laterally about 800 ft. Palynological data from these samples show the paleoenvironment was a temperate-climate fresh-water body (Table 3). Swamp and alluvial deposits occurring 15 ft or more below current base level were penetrated by hand-augered boreholes, but samples adequate for carbon dating could not be obtained. The presence of marsh, swamp, and alluvial deposits below current base level demonstrates infilling of the Naticoke River valley. This valley was likely cut in response to low sea level stands during the Wisconsinan and possibly during earlier glacial periods. During the Holocene, the valley has been filling with sediment as sea level has risen.

It is likely that upland bog and swamp environments once covered much larger areas than at present. Climatic changes, land clearing, agricultural practices, and drainage modifications have created oxidizing conditions and exposed the deposits to erosion. These processes would tend to destroy organic matter, concentrate sand, and modify the geomorphology making recognition and mapping of the deposits nearly impossible.

Quaternary Depositional Model

The interpretation of the depositional history of the Nanticoke deposits within the framework of the Quaternary history of the central Delmarva Peninsula depends largely on the stratigraphic position of the unit and its relationship to the landforms that are a surficial expression of the unit. Jordan (1974) and Jordan and Talley (1976) concluded that the eolian portion of the Nanticoke deposits represented the landward portion of a shoreline complex that they named the Nanticoke Ridge. This complex represented the landward extent of a high stand of sea level during the Pleistocene, younger than the Columbia Formation. It was marked by beach and dune deposits that roughly parallel the Nanticoke River, the dune deposits being positive topographic features (ridges) traceable from Mardella Springs, Maryland, to Concord, Delaware. The northeastward extension of the shoreline across the state was postulated from reconnaissance observations of dune-like features. Landward (northwest) of the shoreline complex, lagoons were interpreted to have formed and upon subsequent lowering of sea level were the sites in which the present streams and tidal rivers such as the Nanticoke were formed. Southward stepwise progradation of these shorelines with subsequent rises and falls of sea level were suggested by the asymmetrical drainage and shape of the Delmarva Peninsula.

Geologic mapping in Sussex County (Andres and Ramsey, 1995; Andres, 1994b; Andres and Howard, 1995), along Delaware Bay (Ramsey, 1993), within the area occupied by the Chesapeake Bay (Colman and Mixon, 1988), and of lagoonal deposits along Delaware's Atlantic Coast (Chrzastowski, 1986) provide evidence for a different depositional history for the Nanticoke deposits than that described by Jordan (1974) and Jordan and Talley (1976). The Beaverdam Formation, of Pliocene age, forms the primary surficial deposit within the region (Ramsey and Schenck, 1990; Andres and Ramsey, 1995). The deeply weathered surface of the Beaverdam indicates that it has been at land surface since deposition ceased. Streams such as the Nanticoke River and its tributaries occupy valleys incised into the Beaverdam. The Quaternary record of deposition along tributaries of the Chesapeake Bay (Susquehanna River drainage) has been the filling, erosion, and reoccupation of these valleys (Colman and Mixon, 1988). Along Delaware Bay, shoreline deposits are found along erosional shoreline features that are roughly parallel to the present configuration of the Bay, not in a perpendicular configuration as suggested by the shoreline complex position indicated by Jordan (1974) and Jordan and Talley (1976).

Deposition of sediment in estuarine bodies of water such as lagoons and estuarine streams is the process by which the valleys are filled. In this model, the sedimentary deposits post-date erosion of the valley (Chrzastowski, 1986). Estuarine deposits within the map area are restricted to the valley of the Nanticoke. They are not found on or beneath upland surfaces to the west of the Nanticoke valley which would be expected if there were lagoonal deposits behind the Nanticoke Ridge. The dune deposits interfinger with and/or sharply overlie the stream deposits (fresh water and tidal) indicating that they post-date the formation of the stream valley and the depositional fill. We have observed that the position of the dune deposits is common to the region in central and southern Delaware. Dune deposits are common on the south side of many streams; they are not restricted to linear trends as shown by Jordan (1974). These dunes are attributed to an available source of sand and conditions supporting eolian transport of sand (Markewich and Markewich, 1994), a lack of vegetation during cool to cold climate periglacial conditions (Groot et al., 1995), and a prevailing wind from the northwest (Carver and Brook, 1989). The Nanticoke deposits, then, fit into a regional context of modification of the Beaverdam Formation by valley incision and filling and further modification of the Nanticoke deposits by processes associated with sea level changes and climatic changes during the Quaternary.

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