STATE OF DELAWARE
DELAWARE GEOLOGICAL SURVEY
Johan J. Groot, State Geologist
BULLETIN NO. 9

STRATIGRAPHY OF THE SEDIMENTARY ROCKS OF DELAWARE

by
ROBERT R. JORDAN

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Geologist, Delaware Geological Survey

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ABSTRACT

The stratigraphy of the Coastal Plain of Delaware is discussed with emphasis placed upon an appraisal of the stratigraphic nomenclature. A revised stratigraphic column for Delaware is proposed. Rock stratigraphic units, based mainly on data from certain key wells, are described and the published names which have been or which might conceivably be applied to those units are reviewed. In each case a name is chosen and the reasons for the choice are stated.

The relationships between the column established for Delaware and the recognized columns for adjacent states are considered. The rock units of the Coastal Plain of New Jersey, Delaware, and Maryland form an interrelated mass. However, profound facies changes do occur, particularly in the dip direction, but also along the strike. Thus, attempts to extend units established in the outcrop belt almost indefinitely into the subsurface have been unsatisfactory.

In Delaware the nonmarine Cretaceous sediments cannot be subdivided and all of these materials are included under the name Potomac Formation. The Magothy Formation, which is familiar throughout the northern Atlantic Coastal Plain, follows above. Fine-grained, micaceous marine sediments constitute the Matawan Formation in the subsurface. Near the outcrop the Matawan is divisible into the Merchantville Formation and the Wenonah Formation which together comprise the Matawan Group. Similarly, the younger marine Cretaceous sediments, which tend to be coarser in texture are called the Monmouth Formation in the subsurface and this is divided into the Mount Laurel-Navesink and Redbank Formations of the Monmouth Group near the outcrops. In the central part of Delaware the upper part of the Monmouth Formation grades into a unit which, because it has been inadequately drilled, is designated informally as unit A. A cessation of sedimentation at the end of Cretaceous time is not evident and the Cretaceous-Tertiary boundary is contained within unit A in that part of the state. Farther to the north the boundary is found within another unit which is identified, for the time being, as unit B. Above unit B is the Rancocas Formation and above that lies a rather poorly known deposit designated unit C. The time equivalent of unit B, the Rancocas, and at least part of unit C down the dip is the thick unit A. The Piney Point Formation overlies unit A in the central and south-central part of Delaware. The Piney Point, in a strikingly rapid change of facies, is lost, at least partially to unit A, just to the north of Dover. The youngest sediments involved in this sequence are upper Middle or possibly Late Eocene. The sequence is truncated by an unconformity above which are sediments of Miocene age. These varied rocks are termed the Chesapeake Group. This is undifferentiated although the manner in which it may later be divided is suggested by the presence of several informal units (aquifers). The Chesapeake Group is truncated by an unconformity. Almost the whole of the surface of the Delaware Coastal Plain is covered by materials of Pleistocene and probable Pleistocene age. The fluviatile sands of the northern portion of the state do not appear to admit to subdivision and the old name of Columbia Formation is considered to be satisfactory for them. Related deposits in the south comprise the Columbia Group which is divided into the Beaverdam Formation below and the Omar Formation, which is newly described herein.
above. A distinction is made between the rock units and the "terrace-formations." The sediments which cap some of the hills of the Piedmont have been called by many names and Bryn Mawr Formation has been selected as the most appropriate of these.

The inadequacies of the information currently available which stem mainly from a lack of deep, carefully logged, and sampled wells, suggest that the proposed system will require modifications and additions as more data become available; however, it provides a starting point.
INTRODUCTION

Purpose and Scope

This report represents an endeavor to clarify the stratigraphic nomenclature of Delaware in the light of modern stratigraphic thought and recent data, particularly from the subsurface, obtained mainly through the efforts of the present Delaware Geological Survey. Although stratigraphic columns for the State of Delaware are readily available in the literature, the names used are derived mainly from other states and applied here, sometimes only by simple analogy, with less than ideal results. Those who work in the State of Delaware and their colleagues elsewhere who wish to correlate with Delaware materials have felt the need for a clarification of Delaware stratigraphy. It is not implied that Delaware as a political entity contains a unique succession of geologic units requiring a new nomenclature but rather that the geographic area connoted by the name Delaware has inherited geologic names in a confusing fashion from neighboring areas and that this confusion can now be somewhat alleviated. The Code of Stratigraphic Nomenclature (American Commission on Stratigraphic Nomenclature, 1961) cautions about the seriousness of redefining units. It is not our purpose to redefine extant units but rather to clarify their meaning in Delaware. This is done by determining the nature of the rock units and their nomenclatural problems, establishing the reasonable and legal alternatives and stating and justifying a preference of name. The origin and history of each name is considered, not in an effort to establish a rigid order of precedence, but in order to clarify the significance of the term.

The scope of this clarification or reassessment is limited by the available data. In view of the paucity of suitable exposures, the new data are, in turn, limited mainly by the number and distribution of accurately logged, relatively deep wells. Some wells of this nature are available now in the northern two-thirds of Delaware. Information is sparse or lacking in the southern portion and as a result the Neocene and Quaternary sediments, which become thick in that area, are not as finely delineated as the older sediments in the north. Information is also lacking regarding the nature of the older units as they continue in the subsurface of southern Delaware for they lie at depths which have not been penetrated by the drill.

The description and taxonomy of rock units is but one aspect of stratigraphy. It is, however, believed to be fundamental to the interpretive work to follow.

Much remains to be studied, however the existing stratigraphic nomenclature hampers further study and we would seek to promote such efforts by providing a more useful framework.

There are three major reasons for attempting to revise the stratigraphy of Delaware at this time. First, as has been suggested, Delaware, either as a political or geographic entity, has historically had very little influence in the terminology which developed. The first Delaware Geological Survey operated from 1837 to 1838 and a memoir was published by Booth in 1841.
That Survey preceded the system of applying geographic names to geologic units and therefore has had little direct affect on stratigraphic terminology. Booth's work does, nevertheless, contribute to the understanding of the geology because of his descriptions of the many marl pits which provided fresh exposures at the time of the First Survey. The state lacked a geological facility of its own from 1839 until the establishment of the present Geological Survey in 1951. In this 112 year interval the fundamental geology of adjacent Atlantic Coastal Plain states was established and refined to a high degree. The New Jersey Geological Survey, founded earlier, has been in nearly continuous operation since 1854 and the Maryland counterpart, now known as the Department of Geology, Mines and Water Resources, was established in 1896. Workers in these and other states recognized that the geologic units of their areas did not end at political boundaries but continued sometimes into Delaware. Names were applied which were derived in places other than Delaware. There is no unit in Delaware which bears a name derived in the state. This in itself is no difficulty but the names which have been applied are based on a variety of criteria and on comparisons with different stratigraphic columns. This has sometimes resulted in confusion. Tertiary units are particularly subject to this sort of confusion because the names used in New Jersey are totally different from the names used in Maryland and terms from both of these states have been applied in centrally located Delaware. Similarly, difficulty arises with the Cretaceous units because the Matawan and Monmouth designations are used in Maryland for formations and in New Jersey for groups with a total of nine formations and the problem of resolving the relationships falls to Delaware. The intermediate position dictated to Delaware by geography and history requires that its stratigraphic nomenclature be precise.

A second reason for presenting this reassessment at this time stems from a belief in the evolutionary nature of applied stratigraphy. In regions where geologists are active new data are continually brought forth. New data do not necessarily imply obsolescence of the older nomenclature but, more often, add depth and scope to our understanding of the units. The nomenclature of the northern Atlantic Coastal Plain units was derived from surface exposures and information obtained relatively recently from the subsurface must be added to the older concepts to achieve an understanding of the units in three dimensions. In some cases the terminology applied at the surface cannot express the relationships adequately when the subsurface situation is known. Drilling has increased the width of the study area and downdip facies relationships must now be taken into account. The extension, as on cross sections, of the thin Coastal Plain formations almost indefinitely into the subsurface without closely spaced control wells may be misleading. Because a greensand, for example, is present below a silt in outcrop does not necessarily mean that a similar sequence 50 or 100 miles down the dip involves the same units even if the ages are approximately the same.

A third reason evolves partially from the second: data presently being collected in Delaware cannot be properly systematized nor efficiently utilized in the present system. A basic reason for using names is so that we do not have to completely describe a unit each time that we refer to it. If a name does not serve its purpose as a noun, or if several names must be used to convey a concept, then clarification is in order.
Acknowledgments

Discussions with many of the other geologists who are interested in the stratigraphy of the Atlantic Coastal Plain have been valuable to the writer in formulating the thoughts contained herein. Particular recognition is due Dr. Johan J. Groot, State Geologist of Delaware, for his support throughout this study and especially for his aid in the preparation of those portions dealing with rocks of Cretaceous age.

The stratigraphic columns shown for New Jersey and Maryland on the correlation chart (fig. 3) are modified from columns published by the geological surveys of those states following the suggestions of Dr. Kemble Widmer, State Geologist of New Jersey and Mr. Turbit H. Slaughter of the Maryland Department of Geology, Mines and Water Resources.

The cooperation of the many well drillers and well owners who have contributed to the knowledge of the basic geology of Delaware is gratefully acknowledged.

METHODS AND PRINCIPLES

The Delaware Geological Survey wishes to declare its acceptance of the Code of Stratigraphic Nomenclature (American Commission on Stratigraphic Nomenclature, 1961) and its intent to comply with these rules in all matters of stratigraphic nomenclature. Clearly the advantages of a uniform code outweigh any possible objections by individuals to specific points contained in the code.

Formations are regarded as units having lithologic identity, i.e., rock stratigraphic units. The degree of variation which can be tolerated if the formation is to retain its identity is a somewhat subjective matter. However, it is clear that some formations are "better" than others; their boundaries have been chosen in such a manner that they have a distinctive identity and can be distinguished by the trained observer in outcrop and in well cuttings or cores and on geophysical well logs. In this sense "good" formations are practical formations. The units proposed herein have been tested for practicality and found to be useful.

It is also considered as basic that whatever scheme be selected for a given area it should harmonize with the fundamental geology of the area and the surrounding region. The Atlantic Coastal Region is now, and has been for a considerable portion of geologic time, an elongate sedimentary basin. The basin is not of the same depth at all points and may be subdivided into related and interconnected basins divided by transverse structural ridges. Delaware is located in a division bordered on the west by the Appalachian Piedmont, as is the entire province, and on the south by the Cape Fear Arch. In the north the basin is largely submerged and curves to the east north of Long Island. An eastern boundary of sorts, at least to the miogeosynclinal sequence, may exist in the form of a geanticline at the edge of the continental shelf (Drake, Ewing, and Sutton, 1959). The basin has been called the Salisbury Embayment or Basin and the Baltimore Embayment. Murray (1961) has proposed the name Chesapeake-Delaware Embayment for this feature and this will be adopted here as it seems most satisfactory.
The present outcrop belts of the relevant Coastal Plain sediments flank the Piedmont and extend to the southeast a few tens of miles into the Coastal Plain. That part of the basin which received the greatest mass of sediment was located somewhat farther to the southeast as is indicated by the very great thicknesses of sediment recorded by geophysical means and in wells. The axial or central portion of a sedimentary basin may be rather indefinite and may change position in geologic time, as do the margins, but the present surface exposures tend toward the landward periphery of the basin as opposed to its center. Environmental variations, particularly those related to sea level and the supply of clastic sediment, will usually be more strongly reflected in the type of sediment deposited at the periphery of a basin than at the center. A change in relative sea level of a few feet will have a profound effect upon the nature of the deposition near the shore but may have no discernible effect upon the sediments accumulating contemporaneously in several hundred feet of water. Stated generally, lithologic variation will tend to be greater near the margins than at the center of a basin. It seems probable that more formations are named in areas where the present outcrop belt more closely approaches the margin of the old basin. The axial portion of the basin and the outcrop belt are not everywhere equidistant and so this effect may obtain in the present strike direction as well as in a dip direction.

Relations between facies are obscured or complicated by the indiscriminate use of names from shallow water facies, as seen in outcrop, in wells which penetrate the deeper water facies down the dip. It is not necessary, indeed it is unlikely, that a unit retain lithologic identity from the beach to the edge of the continental shelf.

The present data are derived from the subsurface by means of wells. Although many well logs have been collected only a very few are sufficiently deep or accurate to provide data useful to the establishment of a stratigraphic framework. The log of each well which penetrates a given formation adds something to our knowledge of that formation, but by far the greatest contribution is made by the few wells which have been logged by geologists, sampled by means of cores, and logged geophysically. These wells are guideposts and provide the framework into which less reliable data are fitted. Ten such wells have been used to establish the cross section shown as plate 3. These wells particularly have served to establish the presence of the units whose nomenclature will be discussed. Written and electric and/or gamma-ray logs and ditch samples are available for all of these wells. Cores have been taken in several of them. Detailed studies of individual major wells will be published separately. In addition to the logs, the mineralogy, mechanical composition, heavy mineral content, pollen and spores, and Foraminifera have been studied where reliable samples (cores or ditch samples of undisputed origin) were available.

GENERAL GEOLOGY

The State of Delaware encompasses portions of two physiographic provinces - the Appalachian Piedmont and the Atlantic Coastal Plain. The sedimentary rocks of the state are the subject of this study. All of the rocks of the Coastal Plain are included in this category. Those of the Piedmont are excluded because they are all metamorphic or igneous types.
Only a small portion of the state, that part north of a line drawn roughly between Wilmington and Newark, lies in the Piedmont Province. This area is characterized topographically by its gently rolling hills. The greater part of the area is underlain by the Wissahickon Schist. The underlying Cockeysville Marble is exposed in two small areas at the crests of unroofed anticlines. The Cockeysville and the Wissahickon are metasediments and belong to the Glenarm Series which is of great extent in the Appalachian Piedmont. The severe metamorphism to which these rocks have been subjected has obscured evidence of their ages. They were once generally regarded as Precambrian but later studies strongly favor a Paleozoic age (Watson, 1957).

Igneous and metagniegeous rocks are found to the southeast of the Glenarm Series between Philadelphia and the Susquehanna River. In Delaware these rocks underlie Wilmington and its northern and western environs and a belt trending to the southwest from there through Newark. This rock mass is referred to as the Wilmington Complex. It has recently been described in detail by Ward (1959). Ward found that most of the Complex consists of a "banded gneiss." Other prominent rock types include gabbro, amphibolite, and granite. The Wilmington Complex is younger than the Glenarm Series and appears to be intruded itself at its southwestern margin by the Port Deposit Granodiorite which is an extensive unit in nearby Maryland.

Physiographically the border of the Piedmont with the Coastal Plain Province is marked by the Fall Zone. In this zone the gradients of streams entering upon the easily eroded Coastal Plain sediments from the Piedmont increase and rapids form. The crystalline rocks extend far to the east beyond the Fall Zone to make up the basement on which the Coastal Plain sediments have been deposited.

The sediments of the Coastal Plain generally dip gently toward the Atlantic Ocean to the southeast. Successively younger units dip less steeply and most units tend to thicken in the downdip direction, at least in the area in which well data are available. Maximum total thickness reaches approximately 8000 feet in the southeastern corner of the state.

The oldest sediments known from the Delaware Coastal Plain are of Aptian-Albian age. It is possible that older sediments are present (personal communication, Johan J. Groot). Deposition of these continental materials continued into the Upper Cretaceous. The marine transgression is considered to have occurred in the Turonian. Marine deposition continued thereafter with little or no interruption at least until the Late Eocene. No Oligocene sediments are known from the northern Atlantic Coastal Plain. Deposition resumed in the latter part of the Miocene and was interrupted again by a period of non-deposition during the Pliocene and perhaps part of the Pleistocene. Pleistocene fluvial, estuarine, and near-shore deposits cover almost the entire surface of the Delaware Coastal Plain. Except for the outcrops of the marine Cretaceous units in the banks of the Chesapeake and Delaware Canal and the numerous sand and gravel pits in the Pleistocene deposits, the sedimentary rocks are very poorly exposed in Delaware. Therefore, geologic investigations are mainly concerned with the subsurface,
POTOMAC FORMATION

Description: White, gray, and rust-brown quartz sands with some gravel; variegated white, yellow, and red silts and clays, and some beds of gray clay containing finely disseminated carbonaceous matter and lignite. These are generally irregularly interbedded.

General statement. - The crystalline rocks of the Piedmont are overlain in the Coastal Plain by variegated silts and clays interbedded with sands of varying texture. Individual beds of sand or silt or clay are generally restricted in areal extent and thickness. Thus lithologic variability in both vertical and horizontal directions is a characteristic of the unit.

Sediments such as these have a wide geographic distribution within the Atlantic Coastal Plain. They are present in the subsurface of Long Island and in the subsurface and outcrops of New Jersey, Delaware, Maryland, the District of Columbia, and Virginia.

W J McGee (1886a,b) applied the name Potomac Formation as the first formal name to be used for these sediments. McGee studied the Potomac Formation in the District of Columbia and in adjacent parts of Maryland and Virginia and described it as follows (McGee, 1886b, p. 474):

The most extensive formation in the District is that hitherto known as “Newer Mesozoic” in Virginia, and “Iron Ore Clays” in Maryland. It is denominated the Potomac formation. In structure and composition it is bipartite, the upper portion consisting of highly colored mottled and banded clays, with intercalations of sand and quartzose gravel, and the lower of sand and gravel with intercalations of clay. In both divisions stratification is inconstant and often absent and the materials are sometimes indiscriminately intermingled.

Later McGee (1888) treated the Potomac Formation in more detail. He pursued its investigation in the northern Coastal Plain and traced it from North Carolina to New Jersey and thus introduced the name Potomac into Delaware. At places McGee discerned two “members” which were not named. The lower division was discriminated as being predominantly sandy whereas the upper was mostly clay.

Divisions of the Potomac. - Clark and Bibbins (1897) discussed the stratigraphy of the Potomac sediments in some detail. Working in Maryland, they were able to divide the Potomac into the Patuxent, Arundel, Patapsco, and Raritan Formations in ascending order. The Potomac was raised to group rank.

The Patuxent Formation was described as consisting of sand which may be arkosic or gravelly. In addition it should be noted that, “Frequently the sands pass over into sandy clays and these in turn into more highly argillaceous materials which are commonly of light color, but at times become lead-colored, brown or red, and not unlike the variegated clays of the Patapsco formation.” (Clark and Bibbins, 1897, p. 482).
The Arundel formation was described as follows (p. 485): "The deposits consist of a series of large and small lenses of iron ore-bearing clays which occupy ancient depressions in the surface of the Patuxent formation."

The Patapsco Formation was said to (p. 489), "...consist chiefly of highly colored and variegated clays which grade over into lighter colored sands and clays, while sandy lenses of coarser materials are sometimes inter-stratified."

The field work of Clark and Bibbins stopped at the Maryland-Delaware state line and the above units were not actually traced into Delaware. The uppermost formation of the Potomac Group, the Raritan, was described as consisting of sands and clays and its extent was given as from New Jersey to Maryland, thus implying its occurrence in Delaware. The Potomac Group itself was thought to be essentially the equivalent of the Red Clay Formation which Booth (1841) had described in Delaware.

Clark, Bibbins, and Berry (1911) and Clark (1916) studied the nonmarine sediments of Maryland in some detail. The Patuxent, Arundel, Patapsco, and Raritan Formations were mapped. Bascom and Miller (1920) traced these sediments into Delaware, but recognized only the Patuxent, Patapsco, and Raritan Formations. It is instructive to note the descriptions of the lithologic characteristics of these formations as given by Bascom and Miller. The Patuxent Formation is described as follows (p. 9):

The materials composing the Patuxent formation are extremely variable but are prevalingly arenaceous. Abrupt alternations, both vertical and horizontal, of sand, gravel, and clay may be seen in almost every well-exposed section.

The sands are described as typically white and consisting of angular to sub-angular grains of clear quartz. However, in "...numerous small areas the sand grains are covered with a thin coating of iron or manganese oxide, which imparts a pink, salmon or purplish color." The clays are "...commonly light in color, though locally they are highly colored by iron compounds."

The Patapsco Formation in Delaware according to Bascom and Miller (p. 9) "...is composed chiefly of highly colored and variegated clays, inter-bedded with sandy clays, sands and gravels, the materials of different kinds grading into each other both horizontally and vertically." The variability of the formation is apparent when one considers that at some localities the clays are predominantly white rather than variegated, and that in other localities it consists of white to buff cross-bedded sand, which was described previously as a characteristic of the Patuxent.

Bascom and Miller found (p. 10) that the Raritan Formation "...consists of variable materials similar to those that form the Patuxent and Patapsco formations." The Raritan is further described as "...predominantly arenaceous, in this respect resembling the Patuxent, although the sands are less arkose." Clay lenses were found to be common, but "...there is an almost complete absence of the highly colored variegated beds that form so prominent a feature of the Patapsco." This criterion does not appear to be
definitive, however, for Bascom and Miller recognized that "Raritan deposits cannot everywhere be separated with ease from the underlying Patapsco strata."

Attempts to distinguish between the various nonmarine formations in wells in Delaware have proved futile. In sections where hundreds of feet of these materials are penetrated, and with the aid of cores and geophysical logs, units of formational status cannot be traced in the subsurface. Well sections consist predominantly of silt and clay, much of it variegated, with relatively thin beds of sand interspersed. Its character is demonstrated by the well log shown as plate 1. The only feature which suggests the possibility of eventual subdivision is a tendency for the unit to become more sandy for a few tens of feet above the crystalline basement. This too is only a tendency and does not provide a reliable basis for subdivision.

Groot (1955) and Groot and Penny (1960) have stressed the difficulty of dividing the Potomac sediments into smaller units. The problem of recognizing these subdivisions in Delaware has been clearly stated by Groot (1955, p. 25):

> These formations are so similar in lithology and so devoid of recognizable fossils in this area, that it is not clear on what basis Miller differentiated them. In fact, the question arises whether or not they deserve to be called formations at all. If the definition of the term "formation" involves a mappable geologic unit with definite contacts (i.e. the top and bottom of a sedimentary formation), recognizable and capable of being traced in the field, then the Patuxent, Patapsco and Raritan can hardly be called formations.

From the time of Groot's publication the Delaware Geological Survey has referred to the sediments in question as the "nonmarine Cretaceous sediments."

One thing common to all descriptions of the Potomac materials is recognition of their great variability. All of the proposed subdivisions of the Potomac contain white and variegated silts and clays and cross-beded quartz sands and in all there are rapid changes in lithology. Although these materials may be locally subdivided elsewhere, it is here preferable to consider them as belonging to one unit and to apply to it the original name given by McGee (1886a, b), the Potomac Formation.

**Age of Potomac.** - The age of the outcropping Potomac Formation ranges from Early Cretaceous to early Late Cretaceous as shown by the work of Berry (in Clark et al. 1911, 1916) and Dorf (1952) on plant megafossils and of Groot and Penny (1960) and Groot, Penny, and Groot (1961) on plant microfossils. "Formations" based on discriminations between the Early and Late Cretaceous deposits have been employed by some but these are not formations in the present sense. The study of Groot and Penny (1960) demonstrated the independence of lithology from age within the Potomac.
MAGOTHY FORMATION

Description:  White and buff, angular to subangular quartz sand, frequently cross-bedded, and beds of gray and black clayey silt containing abundant finely disseminated organic matter and lignite.

The Potomac Formation is unconformably overlain by the Magothy Formation. The Magothy is one of the most clearly defined units in the Coastal Plain and its taxonomy is perhaps the least complicated. The association within the formation of well-sorted white sands and dark silty clays is distinctive. The individual beds are rather thin, usually not more than two or three feet, but they are laterally persistent. The Magothy differs from the underlying Potomac in this respect and also in that its sands are coarser and, perhaps most obvious, it lacks the variegated or white clays which are so distinctive in the Potomac Formation. The thickness of the Magothy is comparatively constant at a few tens of feet both in outcrop and in the subsurface.

Excellent exposures of the Magothy Formation are found in the banks of the Chesapeake and Delaware Canal near the Delaware-Maryland state line. Its characteristic lithology has been encountered in the key wells at Middletown, Deakyneville, and Dover (see plate 3). Anderson (1948) records its presence in deep testwells on the Eastern Shore of Maryland directly south of Delaware and about 100 miles from the outcrop belt. The Magothy is a time-transgressing unit which heralded the submergence reflected in the succeeding marine units. The age of the outcropping Magothy is Late Cretaceous, probably late Turonian to early Senonian (Dorf, 1952; Groot, Penny, and Groot, 1961).

The Magothy Formation was first described and named by Darton (1893), who found it well exposed along the Magothy River of Maryland. He presented a map showing its distribution in Maryland (p. 409) and, although he did not work north of Maryland, he stated his belief that the formation continued into Delaware (p. 410). That the Magothy was clearly recognized as such farther north is not evident until the results of later studies by Clark were published in 1904. Clark (1904, p. 435-438) reviews the taxonomy of equivalent beds in New Jersey and states (p. 438) that he has traced these "...alternating beds of dark clays and light sands... almost continuously from the western shores of the Chesapeake Bay in Maryland to the Raritan Bay in New Jersey."

Bascom and Miller (1920) mapped the Magothy in Delaware, and since the publication of their work all subsequent papers concerned with the geology of Delaware, to the writer's knowledge, have recognized it as a distinct lithologic unit.

MATAWAN FORMATION AND GROUP

Description:  Dark gray to bluish-gray, micaceous, slightly glauconitic sandy silt. In outcrop divisible into a dark gray to dark blue, micaceous, glauconitic sandy silt and silty sand-
low (Merchantville Formation) and a gray and rust-brown, fine to very fine grained, well sorted, micaceous, sparingly glauconitic quartz sand above (Wenonah Formation).

General statement. - The Matawan Formation is traced in the subsurface of Delaware at least as far as south as Dover Air Force Base (see plate 3 and figure 2). It is well exposed in the banks of the Chesapeake and Delaware Canal where it can be divided into two formations designated the Merchantville, below, and the Wenonah, above. Where these units are present it is necessary to elevate the Matawan to group status. The Merchantville and Wenonah Formations can only be differentiated in the subsurface for a short distance from the outcrop (see plate 3 and figure 2) and beyond this, where the bulk of the Matawan sediments are to be found, the unit does not admit to subdivision in Delaware. Where the single lithic unit is present the rank must be that of formation (see Code of Stratigraphic Nomenclature, Articles 9a and 9c).

In New Jersey the Matawan is given group status and includes the Merchantville, Woodbury, Englishtown, Marshalltown, and Wenonah Formations. In Maryland no subdivisions of the Matawan are recognized and it is considered a formation. The Matawan was originally considered to be a formation in Delaware although later usage has made it a group.

The Matawan beds were originally known in New Jersey under the name Clay Marl which was proposed by G. H. Cook. The very early history of the investigations of the unit was given by Clark in 1893. The following year Clark revised the older classification of New Jersey Coastal Plain units and proposed the name Matawan Formation for the Clay Marl as follows (Clark, 1894a, p. 335-336):

On account of the extensive and typical development of the Clay Marls on the shore of the Raritan bay, in the vicinity of Matawan creek, and along the banks of the latter stream, the name Matawan formation is proposed for the deposits of this horizon.

The greensand is a less pronounced feature than in the overlying formations. The deposits consist, for the most part, of dark-colored clays with interbedded layers of sand, the latter becoming very pronounced in the upper portion of the formation. At some points beds of green-sand appear, but they are generally thin and of very narrow geographical extent. The deposits are largely fragmental, with here and there an admixture of carbonate of lime, derived from the shells of organisms.

More detailed study of the Upper Cretaceous rocks led to the publication of two very similar papers by Clark, Bagg, and Shattuck (1897) and by Clark (1898). These papers provide a thorough review of previous geologic work on the marine Cretaceous sediments. The Matawan Formation was recognized in Delaware and beyond it as far as the Potomac River. Clark, Bagg, and Shattuck presented maps showing the distribution of the Matawan in New Jersey, Delaware, and Maryland. It was found that lithologic variation in the northern part of New Jersey warranted the division of the Matawan into the Crosswicks Clays, below, and the Hazlet Sands, above. These units could not be differentiated in the southern portion of New Jersey or in Delaware or Maryland. The characteristic micaceous nature of both the sands and the clays was noted in these reports.
Related units in New Jersey. - The various formational names which are now included in the Matawan of New Jersey were introduced by G. N. Knapp (reported by Salisbury, 1899). Salisbury stated (p. 35):

The several beds have been named by Mr. Knapp as follows, commencing below: the Merchantville bed (marly clay); the Woodbury bed (dove-colored clay); the Columbus bed (sand); the Marshalltown bed (marly-clay sand), and the Wenonah bed (sand).

The name Columbus was later found to be preoccupied and the name Englishtown was substituted for it by Kümmel (in Weller, 1907). Weller (1905a,b) had used, in essence, the modern terminology for the New Jersey Coastal Plain formations. Weller's chart which traces the evolution of the terminology employed in New Jersey is presented as figure 1.

The correlation of the Matawan sediments of New Jersey and similar sediments in Delaware is well established. The name Matawan, designating either formation or group, has been used in Delaware by such workers as Clark (1904), Bascom and Miller (1920), Stephenson, Cooke, and Mansfield (1932), Carter (1937), Spangler and Peterson (1950), and Groot, Organist, and Richards (1954). Disagreement has occurred among authors regarding which of the subdivisions recognized in New Jersey may be present in Delaware. This question has centered about the materials which are exposed in the banks of the Chesapeake and Delaware Canal. In the subsurface, as is indicated in plate 3 and figure 2, the Matawan of Delaware constitutes a single lithic unit which is designated the Matawan Formation. In outcrop facies changes affecting mainly the upper part of the unit result in two distinct units, the Merchantville and the Wenonah Formations, which are discussed below. Where these units are present the Matawan is considered to include them and thus to be of group rank.

Merchantville Formation

In a study of the rocks of Cretaceous age exposed in the banks of the Chesapeake and Delaware Canal, Groot, Organist, and Richards (1954) described the oldest of the marine units as consisting of dark blue to black, micaceous, glauconitic silt and dark greenish-brown, micaceous, glauconitic, very fine quartz sand containing considerable admixtures of silt and clay. This unit, because of its evident similarity to the type material in New Jersey, was called Merchantville. The details of this decision are given in Groot et al. (1954). This designation has been used since that time by the Delaware Geological Survey and others (for example see Murray, 1961, p.357) and it appears that no substantial evidence in opposition is forthcoming.

The Woodbury, Englishtown, and Marshalltown Formations which are present in the Matawan Group of New Jersey are not known in Delaware. Although Carter (1937) believed that the Englishtown and Marshalltown are present in the canal exposures and Spangler and Peterson list the Woodbury and Marshalltown as present at the same locality, the study by Groot, Organist, and Richards is, in the writer's experience, definitive and its findings are accepted here.
<table>
<thead>
<tr>
<th>Upper Marl</th>
<th>Middle Marl</th>
<th>Red Sand</th>
<th>Blue shell Marl</th>
<th>Marl and Clay Marl</th>
<th>Marl</th>
<th>Laminated Sands</th>
<th>Clay Marl</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow Sand</td>
<td>Yellow lime-sand and shell layer</td>
<td>Shell layer</td>
<td>Mixed clay</td>
<td>Red sand Marl</td>
<td>Red sand Marl</td>
<td>Red sands Marl</td>
<td>Lime sand and shell layer</td>
</tr>
<tr>
<td>Upper Marl</td>
<td>Middle Marl</td>
<td>Red Sand</td>
<td>Blue shell Marl</td>
<td>Marl and Clay Marl</td>
<td>Marl</td>
<td>Laminated Sands</td>
<td>Clay Marl</td>
</tr>
<tr>
<td>Yellow Sand</td>
<td>Yellow lime-sand and shell layer</td>
<td>Shell layer</td>
<td>Mixed clay</td>
<td>Red sand Marl</td>
<td>Red sand Marl</td>
<td>Red sands Marl</td>
<td>Lime sand and shell layer</td>
</tr>
<tr>
<td>Upper Marl</td>
<td>Middle Marl</td>
<td>Red Sand</td>
<td>Blue shell Marl</td>
<td>Marl and Clay Marl</td>
<td>Marl</td>
<td>Laminated Sands</td>
<td>Clay Marl</td>
</tr>
<tr>
<td>Yellow Sand</td>
<td>Yellow lime-sand and shell layer</td>
<td>Shell layer</td>
<td>Mixed clay</td>
<td>Red sand Marl</td>
<td>Red sand Marl</td>
<td>Red sands Marl</td>
<td>Lime sand and shell layer</td>
</tr>
</tbody>
</table>

**Figure 1. Early stratigraphic nomenclature of units in the coastal plain.**
Wenonah Formation

At the Chesapeake and Delaware Canal a rust-brown to gray, rather well sorted, micaceous, slightly glauconitic, fine quartz sand conformably overlies the Merchantville Formation. A distinctive lithologic feature of this sand is the presence of numerous tube-like structures which have been called Halymenites major Lesquereux. Carter (1937) considered this unit to be the equivalent of the Englishtown of New Jersey, but it has since been pointed out by Spangler and Peterson (1950) and by Groot et al. (1954) that no Englishtown is present in the canal and that the unit is actually the Wenonah Formation. Not only does the gross lithology of the unit support correlation with the New Jersey Wenonah but Halymenites major is also characteristic of that formation.

The Wenonah and the Merchantville per se are of very limited extent in Delaware and cannot be distinguished in wells even a few miles south of the outcrops at the canal. As is common in the Coastal Plain these formations represent facies where lithologic differentiation has taken place in relatively shallow water while sediments being deposited contemporaneously in deeper water (the so-called down-dip facies such as the Matawan Formation as used herein) are essentially unaffected.

In recognition of the relatively insignificant mass of the preserved Merchantville and Wenonah sediments in Delaware as compared to the bulk of the Matawan in the subsurface the possibility of reducing the outcropping Matawan to formation rank with the Merchantville and Wenonah as members was given consideration. This was not done, however, because the units can be mapped at a scale of 1:25000 (cf. Code of Stratigraphic Nomenclature) and because the Matawan in Delaware is generally known as a group among present geologists and the concept of the smaller units as members would be strange.

MONMOUTH FORMATION AND GROUP

Description: Fine to medium-grained glauconite and quartz sand. In outcrop a group divisible into a dark greenish-brown to almost black, highly glauconitic sandy silt and silty sand below (Navesink-Mt. Laurel Formation) and a reddish-brown, fine to medium-grained, slightly micaceous and glauconitic quartz sand above (Redbank Formation).

General statement. - In Delaware the Matawan sediments, which are mostly silt and very fine sand, are conformably overlain by and grade into the Monmouth sediments which are distinguished chiefly by their greater coarseness. In a manner somewhat analogous to the Matawan, the Monmouth sands form a single lithic unit in the subsurface but in and near the outcrop may be divided into a glauconitic unit below and a quartzose unit above. These divisions are, respectively, the Mount Laurel-Navesink and the Redbank Formations. Where these two formations can be distinguished, in the banks of the eastern portion of the Chesapeake and Delaware Canal and for a few miles south of the canal, the term Monmouth has been considered to be of group rank. However, in the subsurface of Delaware, where but a single lithology is represented, the Monmouth must be ranked as a formation for a group cannot exist without its component formations.
Figure 2. Schematic representation of the stratigraphy of Delaware. Time lines are essentially horizontal. Not to scale.
The name Monmouth was originally presented in the very similar publications of Clark, Bagg, and Shattuck (1897) and Clark (1898) where, in each case, it was presented "for the first time." The following is found on page 331 of the former paper and page 181 of the latter:

The deposits of the Monmouth formation are variable, but sands largely predominate. As different types of materials to a large extent characterize the subdivisions, a more accurate description will be given of them in that connection. In general the sands are highly ferruginous and to a large extent glauconitic, becoming also at times very argillaceous toward the south. The sand deposits are frequently indurated either by iron or by carbonate of lime, the latter being furnished by the fossil shells which at time crowd the beds.

The name Monmouth was taken from Monmouth County, New Jersey. The Monmouth was stated to extend into Delaware and beyond to the Patuxent River of Maryland. Clark, Bagg, and Shattuck (1897) presented a map of the Monmouth in Delaware.

Related units in New Jersey. - In its original description the term Monmouth was used for a formation but was stated to include the previously described (Clark, 1894) Navesink and Redbank Formations and the newly introduced Mount Laurel Sands. The Tinton Formation which is considered to be a part of the Monmouth Group of New Jersey was later introduced by Weller (1905a,b). The divisions of the Monmouth will be more fully discussed below.

Since the time of the introduction of the name the Monmouth sediments have been recognized in Delaware. Clark (1904), Bascom and Miller (1920), Stephenson, Cooke, and Mansfield (1932), Carter (1937), Spangler and Peterson (1950), and Groot, Organist, and Richards (1954) have all confirmed its presence. Tracing of the Monmouth in the significant wells of Delaware by the Delaware Geological Survey has led to the conclusion that, through changes in lithology, the divisions recognizable in the outcrops are lost in the subsurface (see plate 3 and figure 2) although the Monmouth materials, retaining their predominantly sandy, glauconitic character, can be traced at least as far as the Dover Air Force Base well.

One of the better known fossil zones of the Upper Cretaceous, that of *Exogyra cancellata* Stephenson (Stephenson, 1933) is found in the lower part of the Monmouth (Mount Laurel-Navesink) in outcrops in Delaware. A recent detailed study of the Foraminifera of the outcrops led Mumby (1961) to conclude that these sediments are of upper Campanian to lower Maestrichtian age.

Although there is general agreement on the presence of the Monmouth in Delaware, there have been divergent views regarding the proper terminology to be applied to the divisions distinguished in outcrop. This problem has been discussed in detail by Groot, Organist, and Richards (1954) and is briefly reviewed in the following sections.
Mount Laurel-Navesink Formation

The Navesink Formation of New Jersey was defined by Clark (1894a,b) who considered its essential characteristic to be its sandy, glauconitic nature, in short, a greensand. The Mount Laurel sands were later separated from the Navesink and described as grayish or greenish-gray, more or less glauconitic sands which weather to a red color (Clark, 1898; Clark et al., 1897). Although most investigators of the outcrops of the Chesapeake and Delaware Canal have agreed at least approximately with the correlation of glauconitic sediments in Delaware with the lower portion of the Monmouth Group of New Jersey, there have been several views expressed regarding which of the names used in New Jersey is most appropriate for Delaware. Current, and, it is believed, most proper use in Delaware follows Groot et al. (1954) in using the combined name Mount Laurel-Navesink. The unit in Delaware shares characteristics with both the Mount Laurel and the Navesink of New Jersey; however, Groot et al. determined that (1954, p. 27), "...no basis can be found for separating them in Delaware either lithologically or faunally. Therefore, they are treated here as one unit."

Redbank Formation

In the eastern part of the Chesapeake and Delaware Canal the Mount Laurel-Navesink Formation may be observed to grade upwards into a fine- to medium-grained quartz sand known as the Redbank. The transition is accomplished by the loss, in a zone a few feet thick, of some of the silt and clay and glauconite of the Mount Laurel-Navesink. Because of the similarity of the sand in the canal to the Redbank of New Jersey, Groot et al. (1954) employed that name. They noted that this was in agreement with Clark, Bagg, and Shattuck (1897) and the earlier recognition by Chester (1884a) of his "Red Sand."

As has been mentioned above, the Mount Laurel-Navesink and the Redbank are not distinguishable as separate lithologic units for more than a few miles in a down-dip direction from the outcrops. The distinctive Redbank characteristics disappear with particular rapidity and the facies is not present in wells in the vicinity of Port Penn only two to three miles southeast of the exposures at the canal.

UNIT A

Description: Light gray to bluish-gray, moderately glauconitic silt and clay.

Unit A is entirely a subsurface unit which is known primarily from the one cored well which completely penetrates it at the Dover Air Force Base (see plate 3). In that well it is almost 500 feet thick. It appears to consist of the finer-grained facies of both the upper part of the Monmouth Formation and the informal units B and C which are described below. It occupies roughly the interval of time which is represented in the Deakyneville well, the next very deep well to the north 17 miles from the Air Force Base, by the upper part of the Monmouth, unit B, the Rancocas, and unit C, i.e., Upper Cretaceous (Maestrichtian) to about lower Middle Eocene. Because of the lack of data in the interval between Dover Air Force Base and Deakyneville the relationship of unit A with the others mentioned is not completely understood and it seems
best to designate it as a separate unit at this time. An informal designation is proposed because not enough data, particularly regarding lateral extent, are available at this writing to establish a formal formation.

The well at the Dover Air Force Base (Je32-4 in the state-wide well numbering system) provides the type section of unit A. A preliminary report on this well has been presented by Rasmussen, Groot, and Depman (1958). That paper contains written, electric, and gamma-ray logs of the well. The geophysical logs are reproduced here as plate 2. Rasmussen et al. (1958) believed that the present unit A consisted of a part of the "Brightseat (?)," the "Monmouth Group," and the upper part of the "Matawan Group." Later work has shown that there is no basis for dividing the A interval into more than one unit and that the names used originally designated somewhat different rock types (see p. 9, 13).

In addition to the well at the Dover Air Force Base, unit A has been found in wells at Dover, Woodside, and Felton. At these locations, however, the drill penetrated only far enough to establish the presence of the silt and clay.

In the well at the Air Force Base unit A extends from a depth of 615 feet to 1100 feet (datum elevation 24 feet) and was cored every 10 feet throughout this interval. The cores are stored at the Delaware Geological Survey. Mechanical analyses show that the sediments are mostly silts with some true clays and a thin bed of very fine sand. Most median grain sizes fall between 7 and 8 phi. Glauconite content ranges from about one percent to 30 percent and, in one exceptional sample as high as 52 percent. A thin layer of bentonite has been reported in the cores of unit A (Jordan and Adams, 1962).

As indicated above, unit A represents the great span of geologic time from Late Cretaceous to Middle Eocene. The Cretaceous-Tertiary boundary has been placed within the unit at about 980 feet at the Dover Air Force Base (Jordan, 1962). The presence of any break in the sedimentation associated with the boundary is not demonstrable in this well.

UNIT B

Description: Gray to greenish- or brownish-gray, sandy and clayey, glauconitic silt with some very silty and clayey, glauconitic, fine sand.

In the wells at Deakyneville and Smyrna this thin (31 feet at Deakyneville and 45 feet at Smyrna) glauconitic silt was found to overlie the Monmouth Formation. It appears to be in conformable, probably gradational contact with the Monmouth. North of the Smyrna area the silt is not easily traced using the existing well logs but the logs, except at Middletown, are few and of questionable quality. It is thought that a similar silt found at Middletown (elevation 65 feet) from approximately 92 feet to 115 feet is the same unit that is present near Smyrna. To the south, as is shown in the well at the Dover Air Force Base this silt becomes finer grained and loses its identity as the immediately sub- and superjacent units change to similar lithologic facies. This results in the thick clay and silt of unit A.
Few cores have been taken in the unit B. It is known mainly from ditch samples and its characteristics on geophysical well logs. Because of the lack of detailed data the informal designation "B" is proposed. The Deakyneville well may be considered as containing the type section. Cores and cuttings supporting the unit are retained at the Delaware Geological Survey. The electric logs of Deakyneville well are shown in plate 1.

Foraminifera of earliest Tertiary age have been recovered from ditch samples and a core from the upper part of the unit. These Foraminifera define the Globorotalia compressa - Globigerinoides daubjergensis zone described by Loeblich and Tappan (1957a,b). Cretaceous Foraminifera have been found in samples taken from near the base of the silt. The silt contains, or straddles, the Cretaceous-Tertiary boundary.

Proof of the continuity of the silt is lacking at present. It is a thin unit in the southern part of New Castle County and is not easily traced except in carefully logged wells. Unit B is not known to be exposed at the surface.

RANCOCAS FORMATION

Description: Green and grayish-or slightly brownish-green, fine to medium-grained, silty, glauconitic sand. In weathered outcrops indurated by limonite.

General statement. - This unit may be seen in isolated outcrops along Drawyer's Creek, Appoquinimink Creek, Silver Lake, and Noxentown Pond. In outcrop it is usually weathered and unfossiliferous, however, fresh exposures occur rarely. In the subsurface it is best known in the well at Deakyneville (elevation 21 feet) where it occupies the interval from 150 to 295 feet. It is present in the well near Smyrna (elevation 35 feet) from 215 to 355 feet. Although there are no good wells between the Deakyneville-Smyrna area and the Odessa-Middletown area it is probable that similar sediments in a similar sequence at Middletown belong to the same unit. The greensand extends southward an unknown distance beyond the Deakyneville-Smyrna area but does not extend as far as Cheswold. Between Smyrna and Cheswold, a distance of about 7 miles along the dip direction, it grades into a silt which is in part its time equivalent and in part superjacent and younger. This silt is unit C described below. In the Cheswold area a few thin layers of greensand are reported on driller's logs but none are of sufficient thickness to be considered aquifers. These are thought to be tongues of greensand projecting downdip into the silt. Thus the greensand which crops out in southern New Castle County (Rancocas) is not the same as that which is present in the vicinity of Dover from approximately 300 to 550 feet (Pinney Point).

The lower contact of the Rancocas is known only from wells, where it appears to be in conformable, gradational contact with the underlying unnamed silt. In outcrop it is overlain unconformably by the Pleistocene sands. In the subsurface it is overlain conformably by the silt into which it eventually grades.
Where they are present, as in the cores from the well at Deakyneville and the ditch samples from the well near Smyrna, Foraminifera from the greensand belong to the Globigerina-keeled Globorotalia zone of upper Paleocene age (Loeblich and Tappan, 1957a) or early Eocene age (Olsson, 1960). Relatively few fossiliferous samples have been obtained and the age of the greensand is not known with greater precision.

Related units in New Jersey and Maryland. - In New Jersey and Maryland the names Rancocas Group (including Hornerstown and Vincentown Formations) and Pamunkey Group (including Aquia and Nanjemoy Formations), respectively, have been used for greensand bodies in similar, but not identical, stratigraphic position. Each of these names has been applied, by one author or another, to units within the State of Delaware and each must be tested for the validity of its claim upon the greensand described above. In an investigation of the early usage of these terms it must be remembered that the Rancocas was most often thought of as Cretaceous age by the early workers and that the Pamunkey has generally been regarded as of Eocene age. It remained for Cooke and Stephenson (1928) to point out the now generally accepted Eocene age of the New Jersey sediments.

The name Pamunkey was first used by Darton in 1891 for a unit which he described as follows (Darton, 1891, p. 439):

The formations consist of a homogeneous sheet of fine-grained materials, glauconitic sands mainly, usually profusely fossiliferous. Excepting a few local beds of clay, secondary limestones, and some gravels at its base, the formation does not comprise stratigraphic components. Wherever the formation has been bared of overlying formations its glauconitic constituent is either weathered out, leaving fine light-colored sands; or decomposed and the iron redeposited as a red or brown stain and in crusts and concretions. This weathered phase is general in the northern part of the region beyond the edge of the overlying Chesapeake formation, along the western margin in Virginia, and in all old outcrops.

The extent of the Pamunkey was given as from Virginia to Delaware. Darton states (p. 441), "...I have studied the river banks and traced the Pamunkey formation up the Chester river past Chestertown and up the Sassafras river past Georgetown into Delaware nearly to Nockimixon pond, where it thins out and the Severn and the Chesapeake formations come together," The Severn Formation as then used included the Cretaceous marine sediments and the Chesapeake Formation referred to the Miocene. The implied exclusion of the outcrops at Noxentown Pond (="Nockimixon pond") and farther northeast near Odessa may be significant.

W. B. Clark, in 1894, found it necessary to replace the older names used in New Jersey by G. H. Cook which were derived from lithologic terms. The term Rancocas Formation was proposed as a replacement for the term Middle Marl Bed. The following table is taken from Clark, 1894a, p. 334:
<table>
<thead>
<tr>
<th>Age</th>
<th>Formation</th>
<th>Economic Equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pleistocene</td>
<td>Columbia Formation</td>
<td></td>
</tr>
<tr>
<td>Neocene</td>
<td>{ Lafayette Formation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chesapeake Formation</td>
<td></td>
</tr>
<tr>
<td>Eocene</td>
<td>Shark River Formation...</td>
<td></td>
</tr>
<tr>
<td></td>
<td>{ Manasquan Formation</td>
<td>Upper Marl Bed</td>
</tr>
<tr>
<td></td>
<td>Rancocas Formation...</td>
<td>Middle Marl Bed</td>
</tr>
<tr>
<td></td>
<td>Redbank Formation...</td>
<td>Red Sand</td>
</tr>
<tr>
<td>Cretaceous</td>
<td>{ Navesink Formation</td>
<td>Green-sand Series</td>
</tr>
<tr>
<td></td>
<td>Matawan Formation...</td>
<td>Clay Marls</td>
</tr>
<tr>
<td></td>
<td>Raritan Formation...</td>
<td>Plastic Clay</td>
</tr>
</tbody>
</table>

Clark described the Rancocas Formation as consisting mainly of greensand although much more glauconitic in the lower part than the upper. The upper half is calcareous and may form "limestone ledges." Clark stressed the characteristic presence of Terebratula harlani "...the most persistent fossiliferous zone in the State."

The two divisions of the Rancocas Formation recognized by Clark in 1894 were formally named by Clark, Bagg, and Shattuck (1897) as the Sewell Marls, below, and Vincentown Lime-Sands above. The name Sewell was later found to be preoccupied and Clark (1907) substituted Hornerstown Marl in its place. Clark, Bagg, and Shattuck state that the Rancocas Formation extends from Raritan Bay to the Severn River of Maryland and present a map showing its presence in Delaware in a belt including Odessa and Middletown. They recognized that the Rancocas undergoes some lithologic change southward and state (p. 338): "The Rancocas formation throughout New Jersey admits of subdivision upon both lithologic and paleontologic grounds, into two members, but beyond the Delaware River in Delaware and Maryland the distinctions so clearly marked in the north, are gradually lost."

The term Aquia was introduced by Clark in 1895 as the Aquia Creek Stage. Continued usage and more detailed explanation is found in two papers published in 1896 (Clark, 1896a,b). Clark makes it very clear that he recognizes the difference between lithologic ("geological") units and biostratigraphic ("paleontological") units. The Aquia Creek Stage was named as a biostratigraphic unit. Clark states in his conclusions (1896b, p. 374):

1. The Eocene deposits of the middle Atlantic slope constitute a single geological unit already described under the name Pamunkey formation.

2. The deposits are remarkably homogeneous, consisting typically of glauconitic sands and clays which reach a thickness of nearly 300 feet.

3. Two clearly defined faunal zones are formed, viz: the Aquia Creek Stage and the Woodstock Stage.
Clark found that the Pamunkey Formation was present in the southern portion of New Castle County, Delaware.

The Pamunkey Formation was subdivided into two units based on lithologic distinctions by Clark and Martin in 1901. The subdivisions were deemed (p. 58), "...sufficiently distinct as regards their lithologic and faunal characteristics to be distinguished readily everywhere by the geologist in the field."

The Eocene of Maryland was divided as shown in the following table quoted from p. 58:

<table>
<thead>
<tr>
<th>Group</th>
<th>Formations or Stages</th>
<th>Members or Substages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pamunkey</td>
<td>Nanjemoy</td>
<td>Woodstock</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Potapaco</td>
</tr>
<tr>
<td></td>
<td>Aquia</td>
<td>Paspotansa</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Piscataway</td>
</tr>
</tbody>
</table>

The lithologically and paleontologically defined units were found to coincide throughout the section.

**Rancocas Formation in Delaware.** - In the Dover Folio, Miller (1906) mapped the greensands of the Middletown-Odessa area as Rancocas. Miller refers to Booth’s (1841) description of the marl pits at Noxentown Pond where great numbers of shells were found. The shell beds were not found by Miller and are not known today. Booth mentions *Gryphaea vomer*, *Gryphaea mutabilis*, *G. convexus*, and *Terebratula fragilis*. Miller, in reference to these, uses *Ostrea* (*Gryphaeostrea*) *vomer*, *Gryphaea vesicularis*, and *Terebratula harlani* var. *fragilis*. Although the nature of the fossil assemblage is not entirely clear the point must be considered that *Terebratula harlani* is quite distinctive and that this may be an extension of the shell bed referred to by Clark (1894) and found in the middle of the Rancocas in New Jersey. Whiffenfield (1885) confirms that *Terebratula harlani* had been found in the State of Delaware. In passing, it should also be noted that Booth, speaking of the "Shelly Green Sand" in the vicinity of Cantwell’s Bridge (now Odessa), the Appoquinimink Creek, and Noxentown Pond states (p. 54): "...when we observe its southern position relative to the remainder of the green sand region, its peculiar organic contents, and the amount of lime which it contains, we may view it as a continuation of the yellow limestone noticed in the survey of New Jersey, with which it lies in the same geological bearing."

Of the names which might be considered as eligible for the Delaware sediments, Hornerstown Marl and Vincentown Lime-Sand are rejected because they refer to facies which are distinctive only in New Jersey, and these probably only "up-dip," and individually they are not satisfactorily descriptive of the lithology of the materials present in Delaware. The name Pamunkey Formation is also rejected. Its original description is too broad to be useful here as it includes the overlying finer-grained materials now known as Nanjemoy which occupy a higher stratigraphic position than the Delaware greensand.

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An overruling consideration in relation to these names and particularly to the term Aquia, which in its description as a rock unit is satisfactory, is that the term Rancocas has precedence in Delaware as a clearly defined rock unit. Aside from Booth's suggested correlation in 1841 the materials in question were mapped as Rancocas by Clark, Bagg, and Shattuck (1897) and Miller (1906), in the former case before the Aquia was considered a formation. The alternative possibility of proposing a new name exists but this would set aside an established name, which action is undesirable, and in any case does not appear to be necessary.

UNIT C

Description: Green and gray, sandy and clayey, glauconitic silt.

General statement. - This formation is present in southern New Castle County and northern Kent County. It is not known to crop out. In wells near Smyrna this silt is thin and overlies the greensands of the Rancocas Formation. Between Smyrna and Cheswold it thickens, partly at the expense of the Rancocas, and from that point south it represents, in part, the finer facies of the Rancocas. At Deakyneville this silt and the greensand of the Rancocas constitute a 190 foot thick sequence lying below the Miocene sediments, of which the upper 50 feet is silt. At Cheswold only silt and thin lenses of glauconitic sand are present for 235 feet below the base of the Miocene. The next well to the south which reaches a well defined marker below the possible position of the Rancocas is at Dover Air Force Base where almost 500 feet of silt and clay, here called Unit A, overlie the Monmouth Formation and are, in turn, overlain by the Piney Point Formation, a greensand which lies above the unnamed silt. This situation is summarized in the cross section, plate 3. It can be seen that the silt under discussion is in part younger than, and in part the down-dip equivalent of the Rancocas Formation. The contact between the two units is gradational and they interfinger. Further to the southeast, just north of Dover in the line of the cross section, the upper part of the silt grades into the lower part of the greensand that constitutes the Piney Point Formation.

Mechanical analyses of cores of the unit C silt from the well at Deakyneville show that the sediment is mostly silt but that its median grain size ranges into fine sand.

Related units in New Jersey. - In southern New Castle County and in northern Kent County, Delaware the Early Eocene greensand referred to herein as Rancocas is followed above and down the dip by finer grained sediments which still contain abundant glauconite. The similarity between this situation and the situations in Maryland, where the finer grained Nanjemoy Formation overlies the Aquia Formation, and in New Jersey, where the relatively fine grained Manasquan Marl and Shark River Marl overlie the Rancocas Group, should be noted. With these analogous relationships present in neighboring states we must consider the applicability of the names used in those states to Delaware.

The first of these units to be named was the Shark River Marl. T. A. Conrad writing in 1865 was the first to use this term. His description of the unit follows (Conrad, 1865, p. 71):
<table>
<thead>
<tr>
<th>Quaternary</th>
<th>New Jersey</th>
<th>Delaware</th>
<th>Maryland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pleistocene</td>
<td>Cape May Fm.*</td>
<td>Columbia Fm.</td>
<td>Parsonsburg Sand†</td>
</tr>
<tr>
<td></td>
<td>Pensauken Fm.*</td>
<td>Omar Fm.</td>
<td>Pamlico Fm.†</td>
</tr>
<tr>
<td></td>
<td>Bridgeton Fm.*</td>
<td>Beavertown Fm.</td>
<td>Talbot Fm.†</td>
</tr>
<tr>
<td>Pliocene (?)</td>
<td>Beacon Hill Gravel*</td>
<td>Brandywine Fm. (?)</td>
<td>Walsdon Silt†</td>
</tr>
<tr>
<td>Miocene</td>
<td>Cohassey Sand</td>
<td>Aquifers: Pocomoke, Manokin, Frederica, Cheswold</td>
<td></td>
</tr>
<tr>
<td>Tertiary</td>
<td>Kirkwood Fm.</td>
<td>Chesapeake Gr.</td>
<td></td>
</tr>
<tr>
<td>Oligocene</td>
<td>Piney Point Fm. (?)</td>
<td>Piney Point Fm.</td>
<td></td>
</tr>
<tr>
<td>Eocene</td>
<td>Shark River Fm.</td>
<td>Chickahominy Fm.</td>
<td></td>
</tr>
<tr>
<td>Paleocene</td>
<td>Vincentown Fm.</td>
<td>Monmouth Fm.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rancocas Gr.</td>
<td>Brightseat Fm.</td>
<td></td>
</tr>
<tr>
<td>Cretaceous</td>
<td>Hornerstown Fm.</td>
<td>Unit A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tinton Fm.**</td>
<td>Rancocas Fm.</td>
<td></td>
</tr>
<tr>
<td>Upper</td>
<td>Redbank Fm.</td>
<td>Unit B</td>
<td></td>
</tr>
<tr>
<td>Cretaceous</td>
<td>Navesink Marl</td>
<td></td>
<td>Monmouth Fm.</td>
</tr>
<tr>
<td></td>
<td>Mt. Laurel Sand</td>
<td>Redbank Fm.</td>
<td></td>
</tr>
<tr>
<td>Cretaceous</td>
<td>Wavenah Fm.</td>
<td>Monmouth Fm.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Marshalltown Fm.</td>
<td>Mt. Laurel - Navesink Fm.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Englishtown Sand</td>
<td>Wavenah Fm.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Woodbury Clay</td>
<td>Merchantville Fm.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Merchantville Fm.</td>
<td>Magothy Fm.</td>
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<tr>
<td></td>
<td>Magothy Fm.</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Raritan Fm.</td>
<td>Patapsco Fm.</td>
<td></td>
</tr>
<tr>
<td>Lower</td>
<td>Patuxent and Patapsco Fms.</td>
<td>Potomac Fm.</td>
<td></td>
</tr>
<tr>
<td>Cretaceous</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3. Correlation chart of the Coastal Plain units in New Jersey, Delaware, and Maryland. The section for New Jersey is adapted from Kasoboch and Scudder (1961) and Kummel (1940). The Maryland section is adapted from Rasmussen and Slaughter (1955).

*Not always separable into formations and may be collectively termed "yellow gravel series".

**Monmouth County only.

†Divisions recognized only in part of the Eastern Shore.
At present the marine beds of this era (Eocene-R.R.J.) are found to lie close to the Atlantic and in Oregon they skirt the shore; but estuary deposits were observed by Meek and Hayden in Upper Missouri. The Shark River marl is an indurated clay, with disseminated grains of green sand, which are often smooth and shining, and the shells are all in the form of casts, which are distorted more or less. Portions of this clay are indurated, making it as difficult to break as the hardest limestone. Its thickness is unknown.

This description is somewhat inadequate. Indeed, the intention of Conrad to formally name a unit may be questioned from the manner of presentation. Clark (1893, p. 208) adds: "The Shark River Marl is a marked greensand, with a slight admixture of argillaceous materials, while a hardened stoney layer is commonly found directly at the top." Clark states that the Shark River Marl is equivalent to the Blue Marl of the Upper Marl Bed of Cook. Its thickness is given as twelve feet.

Clark (1893) goes on to name the Manasquan Marl which he described as follows (p. 206-207):

It is a greensand, highly quartzose in the lower part, and at times argillaceous in the upper layers. The lower quartzose member is about forty feet in thickness and the upper glauconitic member about twenty-five feet, so that the entire thickness of the Manasquan Marl is approximately sixty-five feet. At the base of the upper member there is frequently a layer of lime clay, which has been described under the name of "fuller's earth."

From these descriptions the modern use of Shark River for the more clayey and Manasquan for the less clayey greensands is derived.

The statements of several authors regarding the extent of the Shark River Marl are summarized by Klimmel (1940, p. 128):

This formation is limited in outcrop to small areas near Long Branch and Farmingdale in Monmouth County, where a mixture of greensand (glaucite) and light colored earth 11 feet in thickness and carrying Eocene fossils rests without apparent unconformity upon the "ash" marl of the Manasquan.

Fox and Olsson have stated (1960, p. 9):

Well cores in the Manasquan River area, however, indicate that the interval between the Vincentown and the Kirkwood is represented by alternations of greensand (Manasquan) with light gray argillaceous glauconite sand and glauconitic clay (Shark River). This lithologic unit should probably be considered one formation.
John K. Adams (personal communication) concluded that the Shark River is a local, fine grained facies of the Manasquan.

The name Shark River has not been used in Delaware. The unit is apparently restricted to Monmouth County, New Jersey. Its status as a formation has been questioned in the light of subsurface data. Although the general lithology of the Shark River Marl resembles the Delaware materials and the name is very old, only disadvantages can be seen in attempting to introduce such a questionable term into usage in Delaware.

The southern extent of the Manasquan Marl is difficult to determine from the literature. Clark, Bagg, and Shattuck (1897) thought that both the Shark River and the Manasquan did not extend into southern New Jersey.

The name Manasquan, to the writer's knowledge, has not been used in Delaware. In Delaware the materials in question are known only from the subsurface. Mechanical analyses indicate that they are mainly silt. It is evident that the name Manasquan refers to a glauconitic sand and that the relationship between that sand and the Delaware silts is poorly understood. For these reasons the term Manasquan cannot be used for the sediments of unit C in Delaware.

Related units in Maryland. - Turning to the Maryland sequence, the name Nanjemoy Formation deserves consideration. The Nanjemoy was named in 1901 when the Pamunkey Formation was divided into lithologic and paleontologic units by Clark and Martin as has been related above regarding the Aquia Formation. The description of the Nanjemoy given by Clark and Martin (1901, p. 64) follows:

The Nanjemoy formation, so called from Nanjemoy Creek, which enters the Potomac river from the Maryland side in Charles County, just below Maryland Point, is composed of greensand, often highly argillaceous, and less frequently calcareous than the lower beds, and with here and there layers containing abundant crystals and crystalline masses of gypsum. The thickness of the deposits is about 125 feet.

Mechanical analyses presented by Otton (1955) and by Dryden and Overbeck (1948) indicate that the Nanjemoy Formation is predominantly sand. The relationship between the unit in question in Delaware and the Nanjemoy in Maryland is analogous to the Delaware and New Jersey sediments. Conditions may have been very similar in New Jersey and Maryland but different toward the center of the basin in Delaware.

The use of the name Nanjemoy for the Delaware material is rejected because it is not accurately descriptive of the sediments of unit C in Delaware. In addition to the more important textural difference it may be noted that the gypsum which is referred to by several authors as characteristic of the Nanjemoy has not been reported in Delaware, nor has the distinctive Marlboro Clay (Darton, 1948).
The formal designation of unit C is deferred until such time as cores are available from it in the area of its most characteristic development, that is in the vicinity of Cheswold, Delaware.

**PINEY POINT FORMATION**

**Description:** Green, medium and fine grained, glauconitic sand.

The Piney Point Formation is known in Delaware in central and southern Kent Count and is thought to be present farther to the south, at least into the northern portion of Sussex County. The Piney Point is present in the well at the Dover Air Force Base between 340 and 615 feet. Detailed information about it is derived mainly from cores taken in this well. It is traced in wells north through the City of Dover to a point about a mile north of Dover. At this northern point it is only about 80 feet thick. The greensand changes facies rapidly just north of Dover and is, in part, the time equivalent of the silt of unit C discussed above. The upper part of the greensand does seem to be somewhat younger than unit C. The Piney Point is known to extend south through Woodside, where it is 220 feet thick, and Felton, where it is approximately 185 feet thick. Throughout this area the greensand constitutes an important aquifer. Less reliable well data indicate that the Piney Point probably is present as far south as Milford and Bridgeville.

The Piney Point Formation appears to grade downward into the unit A silt. In the area in which it has been studied in Delaware the Piney Point is truncated sharply above by the unconformity at the base of the Miocene Series. Using the wells at the Dover Air Force Base, Woodside, and Felton the interface between the Piney Point and the overlying Miocene sediments has been determined to strike N 47° E and dip to the southeast at 19 feet per mile.

In the well at the Dover Air Force Base, the greensand is rather uniform in texture and mineral composition. The median grain size shows little deviation either way from 2 phi (0.25 mm). The quartz content of the greensand ranges between 40 and 50 percent and the glauconite content ranges from 25 to 45 percent. Most of the remaining material is clay.

The nature of the Piney Point as an aquifer has been discussed by Rasmussen, Groot, and Depman (1958). It was in that paper that the name Piney Point was first applied in Delaware.

Sediments of Jacksonian (Late Eocene) age had been reported previously from wells at Brandywine Lighthouse (in Delaware Bay), Cape May, New Jersey and Atlantic City, New Jersey (Richards, 1945). No name had been applied to the Late Eocene material of Delaware and New Jersey however; this was probably because so little was known about it. Rasmussen, Groot, and Depman (p. 29) considered the greensand in the Air Force Base well to be Jacksonian in age but recognized the need for additional palaeontological work. The age of that unit has not yet been established precisely but later work has suggested that much of it is Middle Eocene in age. The amount removed by the pre-Late Miocene erosion is undetermined.
The name Piney Point was first used by Otton (1955). Unfortunately his determination of the unit was based to a great degree on its age. Reference is made by Otton (1955, p. 85) to "...the characteristic Jackson lithology..."

The name was actually applied as follows (p. 85):

The hitherto unnamed glauconitic sands and inter-spersed shell beds of Jackson age lying above the Nan-jemoy formation and below the Calvert formation are herein named the Piney Point formation from their typical development in a well at Piney Point along the north bank of the Potomac River in St. Marys County.

The use of the name Piney Point was extended to the Eastern Shore of Maryland by Rasmussen and Slaughter (1957) in a report dealing with Caroline, Dorchester, and Talbot Counties. They state (p. 61): "The Piney Point formation is an extensive quartz sand slightly to moderately glauconitic, ranging from brown, olive-green, to green in color."

Regarding the unit described in the Dover Air Force Base well Rasmussen, Groot, and Depman (1958, p. 29) state:

In central Delaware the sediments of Jackson age consist mostly of fine to medium glauconitic sand and thin interbedded clay lenses. On the basis of lithology, micro-fossils, and semi-continuous tracing in wells, this sand is correlated with the Piney Point formation of southern Maryland (Otton, 1955, p. 85) and the Eastern Shore (Rasmussen and Slaughter, 1957, p. 3, 61-67, pl. 9).

Although the age of the unit has received too much emphasis and a detailed description in the type area is lacking, it is established that a glauconitic sand underlies the Miocene sediments of the southern part of the Maryland Coastal Plain, the central portion of the Eastern Shore and central Delaware. Owing to the deficiencies mentioned the name Piney Point is not entirely satisfactory, however, it does fill a need and because of its stratigraphic relationships the unit is not likely to be confused. Indeed, an attempt to establish another name to be used in Delaware would create confusion.

CHESAPEAKE GROUP

Description: Predominantly gray and bluish-gray silt containing beds of gray, fine- to medium-grained sand and some shell beds.

General statement. - The sediments of the Chesapeake Group form a wedge-shaped mass in Delaware with the thin edge in the southern part of New Castle County. In the southeast under Fenwick Island, it reaches its maximum thickness in the state of 1550 feet (Rasmussen et al., 1960). These sediments are best known in central and southern Kent County where widely used aquifers are present.

The sediments of the Chesapeake Group are all of Miocene age. They lie unconformably on unit B, and farther south on the Piney Point Formation. They are truncated by an erosional unconformity above which sediments of Pleistocene age are found.
In the central part of Delaware, as has been pointed out by Marine and Rasmussen (1955), the Miocene series consists of three units of silt separated by two relatively thin sand bodies. The sands are named the Cheswold aquifer (deeper Miocene) and Frederica aquifer (shallower Miocene). The sands are rather irregular in thickness but are consistently fine- to medium-grained quartz sand. The silts may also contain lenses of fine sand. The division of these sediments into two sand aquifers and three silt aquicludes is a generalization but it may be reasonably stated that a well drilled in the southern two-thirds of Kent County can be expected to pass through a silt-sand-silt-sand-silt sequence in the Miocene sediments.

In the southern part of Delaware few wells penetrate through the Quaternary sands and pass into the underlying sediments. Rasmussen et al. (1960) state, referring to Sussex County: "Wells at only three sites in the county (Milford, the oil tests near Bridgeville, and Seaford) have been drilled through the entire Miocene section" (p. 86). It is in this area that the sediments of Miocene age in Delaware are thickest.

Related units in New Jersey. - In New Jersey sediments of Miocene age are described under the names Kirkwood Formation and Cohansey Formation.

Kirkwood appears to have been first used by Knapp in 1904 to describe a significant sand aquifer of the New Jersey Coastal Plain. The Kirkwood of New Jersey consists of fine quartz sand with some clay beds. More clay is present in the southern part of that state (Kümmel, 1940). From the meager well logs available Richards (1945) believed that portions of the wells at Lewes and Bridgeville, Delaware belong to the Kirkwood Formation. Many authors have indicated that the Kirkwood is roughly correlative with the Chesapeake Group of Maryland. It is probable that this sequence is continuous through Delaware. The application of proper terminology remains a difficult problem because the lithologic characteristics of some of the units are not clearly defined and because the southern Delaware subsurface has not been explored in sufficient detail to enable distinctions between the several formations to be made.

In the southern and eastern portions of Sussex County the sediments which have been identified as belonging to the Chesapeake Group are overlain by additional beds of sand and silt which have been referred to the Cohansey Formation by Richards (1945) and by Rasmussen et al. (1960). Richards, referring to the interval between 125 feet and 294 feet in the deep well at Lewes, wrote (p. 900), "The upper part of the section assigned to the Cohansey may include some early Pleistocene (Pensauken?), while the material below 268 feet is definitely Cohansey." Rasmussen et al. identified as "Cohansey, Miocene(?) Series" sediments above the St. Marys in a number of wells in Sussex County. They divided the Cohansey into two silt and two sand units, and designated the sands as the Manokin and Pocomoke aquifers as a "...provisional working hypothesis" (p. 89).

The term Cohansey was originated by Kümmel and Knapp (Reis and Kümmel, 1904). This was the result of dividing the Beacon Hill Gravel into two units of which the Cohansey was the lower. It is described (p. 138) as:
...a bed of coarse quartz sand, with occasional small pebbles. Locally, the sand is cemented into beds of sandstone. The lower member also contains lenses of clay, which are frequently of considerable economic importance.

The correlation of the silts and fine sands of Sussex County with the Cohansey, based on its type description from the outcrop area, on a lithologic basis seems tenuous. The extension, into southern Delaware, of equivalents of the sediments described by the name Cohansey in New Jersey is likely. The materials found in Delaware, however, so far as is known, represent a finer grained facies than the Cohansey as described and the propriety of retaining the name is questioned.

The Cohansey sand and its equivalents do not belong to the Chesapeake Group but they do constitute a related stratigraphic problem because, until each unit is better defined by wells the top of one and the bottom of the other cannot be defined. As stated by Rasmussen et al. (1960, p. 89):

Few wells penetrate more than a few tens of feet into the formation, and fewer still have logs that have received careful study. The subdivision of the Cohansey sand in Delaware is a project worthy of detailed geologic investigation.

Related units in Maryland. - The Maryland Miocene has been studied mainly at the excellent exposures of the Calvert Cliffs on the western shore of the Chesapeake Bay. Unfortunately, investigators seem to have been overwhelmed with the fossil content of these outcrops and the lithologic descriptions have been neglected. Darton (1891) applied the name Chesapeake Formation to these sediments and discussed their lithology as follows (p. 443):

The formation is diverse in composition, consisting of sands, clays, marls, diatomaceous beds, and shell fragments, in all several hundred feet in thickness. The lower beds consist mainly of dark-colored clays and fine, mealy sands containing the extensive and well-known diatomaceous deposits. These are succeeded by lighter-colored clays and sands with occasional local inclusions of blue marl. The upper beds are coarser-grained and consist chiefly of white beach sands containing shells and deposits of shell fragments, and occasional argillaceous members. These three series intergrade in zones, which vary somewhat in stratigraphic position and vertical extent, and all the members rapidly thicken seaward, apparently reaching a thickness of nearly 1,000 feet at Fort Monroe.

Darton found an exposure of the lower unit near Clayton, Delaware.

In the U. S. Geological Survey Correlation Papers Dall and Harris (1892) expanded on Darton's use of the term Chesapeake. They stated (p. 123):
For the strata bordering on the Chesapeake in Maryland and Virginia which belong to the Miocene, Darton has proposed the name of the Chesapeake formation. This term as used by him is equivalent to "Miocene" as heretofore understood in these states, and is the stratigraphic homonym of the chronologic "Yorktown epoch" of Dana.

The term Chesapeake group, as independently suggested, here includes as typical Darton's Chesapeake formation and also all other beds belonging to the same horizon and containing the same general fauna on the Atlantic and Gulf coasts of the United States.

The use of the term Chesapeake has not been popular beyond the area mentioned by Darton.

The usage of Chesapeake Group in Delaware is well established. Darton implied its use in the paper containing the original description of the group by his mention of the outcrop at Clayton. Delaware is certainly included in the interpretation of Dall and Harris. Examples of the continued usage of Chesapeake in Delaware may be found in Richards (1945) and Clark, Mathews, and Berry (1918).

The lack of exposures and the paucity of deep wells has made it difficult to trace individual formations found in Maryland (or New Jersey) into Delaware. The applicability of formational names, as defined in Maryland requires careful consideration.

The names Calvert, Choptank, and St. Marys were first used by Shattuck in 1902. The only record of this in print, however, is in an abstract in which the names are used but not defined (Shattuck, 1902). The names were used shortly thereafter by Clark, Shattuck, and Dall (1904) and by Shattuck (1907). Clark, Shattuck, and Dall divided the Calvert Formation into the Fairhaven diatomaceous earth which is "...characterized by the presence of a large proportion of diatoms imbedded in a very finely divided quartz matrix" (p. lxxii) and the Plum Point marls which, "...consist of a series of sandy-clays and marls in which are imbedded large numbers of organic remains including diatoms" (p. lxxxiv). The same authors state that the overlying Choptank Formation is variable and consists of "...fine, yellow, quartz sand, bluish-green sandy clay, slate-colored clay and, at times, ledges of indurated rock" (p. lxxx). The St. Marys Formation is also described (p. lxxxv):

The materials composing the St. Marys formation consist of clay, sand and sandy clay. As exposed in Maryland, it is typically a greenish-blue sandy clay bearing large quantities of fossils and resembling very closely the sandy clay of the Calvert formation described above.

To the writer's knowledge evidence for the use of these formational names in Delaware has been presented only by Rasmussen, Wilkins, and Beall (1960) although the names have been used previous to the publication of that paper by, for example, Clark, Mathews, and Berry (1918) and Richards (1945). The tracing of these units to the east and northeast from Maryland into Delaware is implied by Shattuck's map (Clark, Shattuck, and Dall, 1904) but the geologic symbols end at the Maryland-Delaware state line and no evidence is offered for the continuation of the formations into Delaware.
The drilling of deep oil test wells on the Eastern Shore in the 1940's provided an opportunity to investigate the occurrence of these and other units in the vicinity of Delaware. Anderson (1948) has recorded the presence of the Calvert, Choptank, and St. Marys Formations in the deep wells near Salisbury, Berlin, and Ocean City, Maryland. Rasmussen and Slaughter in ground water investigations on the Eastern Shore (1955, 1957) also traced these units. The stratigraphic investigations of Spangler and Peterson (1950) also contain descriptions of these formations which are presumably applicable in Delaware. From the descriptions of these authors it is evident that the Calvert Formation is essentially a silt which is diatomaceous. The Choptank Formation is predominantly a quartz sand and the St. Marys Formation consists mainly of silt and clay. Some dissent is noted in Anderson's description of the St. Marys Formation in the well near Salisbury (1948, p. 19): "In that portion of the well assigned to the St. Marys, fine to coarse sand and some gravel are very abundant." It is interesting to note also that Spangler and Peterson state that the Calvert formation is present in Delaware and characterize the unit in the Maryland outcrop as (p. 77), "...two diatomaceous clay zones which are approximately equal in thickness and which are separated by a fairly conspicuous shell zone."

In central Delaware the silt-sand-silt-sand-silt sequence mentioned above is not readily referable to any of these units. The Delaware materials occupy a position in time which is roughly equivalent to the Calvert Formation but this does not imply correspondence of the rock units. It may be pointed out in passing that the diatomaceous earth which figures so prominently in the lithology of the Calvert has not been recovered in cores of the Miocene sediments at Deakyneville or Dover Air Force Base. Diatoms commonly are numerous but are not major rock constituents any more than are the Foraminifera or Radiolaria which are also present.

In the southern portion of Delaware the Miocene series has been drilled through at only three sites. An electric log of the deep well at Bridgeville is presented by Rasmussen et al. (1960) but the Miocene formations are not identified on the log. In the text of that report the authors indicate that "...the section between 357 and 738 feet below land surface may be the Calvert" (p. 87). The Choptank Formation is "indistinct" in this well (p. 88). Only driller's logs are available for the other deep wells in Sussex County. As noted by Rasmussen et al. it is difficult to distinguish individual formations from the log of the well at Seaford. A copy of this log appears in Marine and Rasmussen (1955, p. 242-243) as well Pc 7. The deep well at Lewes was discussed by Woolman (1899) and a log and paleontological notes are presented by him (p. 83-87). The only indication of formational divisions in that log appears to be the presence of diatoms between 407 and 772 feet and between 950 feet and the bottom of the well at 1080 feet. If the diatoms of the Calvert Formation are diagnostic of the lithology of that formation, its presence is suggested at Lewes. A review of these and other, shallower wells which reach the Chesapeake in Sussex County is given by Rasmussen et al. (1960). It is evident that their effort to correlate the sediments of Sussex County, as well as the present effort and all earlier ones, suffers from a lack of adequate well information.
Chesapeake Group in Delaware. - Rocks are present in Delaware that are the equivalents of the outcropping Miocene rocks of Maryland. The Maryland sediments have been correlated with those of New Jersey but differ in lithology. It would seem that at least some of the lithologic change must be accomplished in the subsurface of Delaware. It is submitted that in this critical area formational names should be used with precision that is not available at this time.

In summary it may be stated that in central Delaware, where well control is comparatively good, the expected Calvert Formation is not, as yet, clearly defined. In Sussex County, where the Miocene of Delaware is well developed control by deep wells is almost lacking. Lithologic subdivisions do exist but the present information appears to be inadequate to warrant formal subdivision of these rocks. Thus the entire mass is best represented by the name Chesapeake Group (undifferentiated).

Informal divisions. - The designation of such informal units as the Nanticoke, Cheswold, Frederica, Manokin, and Pocomoke aquifers (Rasmussen et al., 1960) indicates that the thick wedge of Miocene sediments in Delaware can be subdivided on the basis of lithology. The tentative distribution of the aquifers through the "formations" derived from Maryland and New Jersey further suggests that those units are not chosen on the basis of the most obvious lithologic boundaries available. The informal units may form the best foundation for the designation of formal units because they are readily recognized, in sequence, on the basis of lithologic characteristics.

Because of our meager knowledge of the Miocene of Delaware its subdivision into formal units might be done in some less than ideal manner at this time and therefore such action is deferred until more information is available. The informal names of the various aquifers adequately fill the need for designation of practical smaller units at this time.

**BRYN MAWR FORMATION**

**Description:** Red and brown, poorly sorted sand with large admixtures of silt and clay and, almost always, fine gravel. Thoroughly oxidized and often cemented by limonite.

The materials discussed here have been called by several names and are sometimes known as the "high-level" gravels. They have been mapped in Delaware by Bascom and Stose (1932) and by Ward and Groot (1957). These deposits differ from the other sediments discussed in this report in that they are found not in the Coastal Plain but, rather, rest on the crystalline rocks of the Piedmont. In Delaware they are restricted to a relatively small area to the north of Wilmington where they are mapped as occurring in patches. According to Ward and Groot (1957) the Bryn Mawr may reach a maximum thickness of 70 feet.

The unique characteristics of these sediments are their degree of oxidation and their occurrence on hill tops in the Piedmont Province. The greater degree of oxidation of the Bryn Mawr has been suggested by some authors as confirmation of the greater age of these materials than the Columbia sediments which concept is called for by the theory of terrace-formations. The U. S.
Geological Survey's age designation of the Bryn Mawr is "Pliocene (?)." It should be noted that no evidence other than the very questionable criterion of topographic position exists for the age of the Bryn Mawr Formation.

The name Bryn Mawr Gravel was used first by Lewis in 1881 for the upland gravels that he had noted previously in the vicinity of Philadelphia. He described the Bryn Mawr as follows (Lewis, 1881a, p. 269):

Upon the summits of some of the highest hills in the gneissic region back of Philadelphia, and at elevations of from 325 to 450 feet above it, there are isolated patches of an ancient gravel, different from any yet described, to which we have given the provisional name of the "The Bryn Mawr Gravel." It can always be recognized by the presence of sharp or partially rounded fragments of a hard, heavy iron sandstone or conglomerate. Such fragments are often covered by a brownish-black iron glaze.

Shortly thereafter Lewis (1881b) found that the Bryn Mawr continued south into Delaware and described several localities where it occurs to the north and northwest of Wilmington.

Bryn Mawr was superseded, at least in popularity, by the names Appomattox, Lafayette, and Brandywine which were used successively for many years until Bryn Mawr was reinstated by Miss Bascom in 1924. The history of this succession of names is reviewed in that paper from which the following is quoted (Bascom, 1924, p. 117):

In 1888 the term "Appomattox" was used by McGee for the "older terrace sediments," and in 1891, in conference with Hilgard and others, McGee correlated these sediments with the deposits of Lafayette County, Mississippi, which had been assigned to the early Quaternary and which were then called the "Lafayette formation." Since that date the term "Lafayette" has been very generally used. Recent work, however, has shown that the "Lafayette formation" of the type locality in the Gulf region is not Quaternary but of Wilcox Eocene age. A new name was therefore proposed in 1915 for the Atlantic coast deposits by Clark, who called them the Brandywine formation, from a type locality in the vicinity of Brandywine village, Prince Georges County, Md. The name was defined to cover all the gravels that lie above the Sunderland formation at 200 feet, in Maryland reaching an altitude of 480 feet and having a width from northwest to southeast of 40 miles.

A detailed explanation of the very broad correlation of the Lafayette Formation was presented by McGee in 1891 and the reader is referred to that paper for specific information concerning the nature and taxonomy of the unit. To the writer's knowledge the term Lafayette has not been used explicitly in Delaware and is considered here only as the vague predecessor of the name Brandywine. The reasons for the change to Brandywine are detailed by Clark (1915).
Miller (1906) used "Lafayette" but did not map any in that part of Delaware covered by the Dover Folio. Bascom et al. (1909) also preferred to use "Lafayette" on the Philadelphia Folio but found that it did not extend into Delaware. In 1920, on the Elkton-Wilmington Folio, Bascom, and Miller mapped the "Brandywine formation" but it too occurred only in the Maryland portion of the area. It was here that it was possible to separate those deposits of the Brandywine which occur at higher elevations ("early Brandywine") from those restricted to lower elevations ("later Brandywine"). In 1924 Bascom proposed (p. 117), "...to restrict the term Brandywine formation to the late or lower-level deposits of the type locality, and to reinstate the old term Bryn Mawr gravel for the early or high-level deposits of Pennsylvania, Delaware, and Maryland (Cecil County)."

In the Coatesville-West Chester Folio (Bascom and Stose, 1932) areas in the vicinity of Fairfax, Talleyville, and Brandywine, Delaware were mapped as Bryn Mawr and an area south of Carrcroft, at a lower elevation, was mapped as Brandywine.

The Bryn Mawr Formation, despite its temporary retirement about the beginning of this century, has been restored as an acceptable term. It is regrettable only that elevation has come to play such an important role in the identification of the unit.

The Brandywine Formation, which was distinguished by Miss Bascom from Bryn Mawr on the basis of topographic position in the Piedmont, was not identified in later work in northern Delaware by Ward and Groot (1957). The name Brandywine has, however, been recently used for a unit in the Coastal Plain, first in Maryland by Rasmussen and Slaughter (1957) and then in Delaware by Rasmussen et al. (1960). In these studies the name has been applied to the "red gravelly sand" first described from the southern Eastern Shore counties of Maryland by Rasmussen and Slaughter (1955).

"Brandywine" was originated by Clark (1915) for a part of the previously used and very broadly defined Appomattox and Lafayette Formations which is particularly well developed in Prince Georges County, Maryland. Topographic criteria, which were not a part of Clark's description, were later applied to identification of the unit by Bascom (1924) and Bascom and Stose (1932). The Brandywine Formation of these authors was confined to upland areas. Rasmussen et al. (1960) followed peg model studies of Rasmussen and Slaughter (1955, 1957) in correlating a coarse, oxidized sand from the subsurface of southern Delaware with the upland unit. This correlation is reinforced by the concept of the Brandywine as an alluvial fan which would, presumably, be found at lower elevations in southern Delaware than in the Piedmont or the higher parts of the Maryland Coastal Plain.

The Brandywine Formation in Sussex County, Delaware is described by Rasmussen et al. (1960, p. 91) as "...orange, red, or brown sand, containing a few layers of clay and some gravel." The cored well studies of the Delaware Geological Survey in the southeastern part of Sussex County have failed to reveal this unit and the writer is not acquainted with it in Delaware. However, Rasmussen et al. (1960) indicate that its distribution may be patchy, particularly in the eastern part of Sussex County.
The age of the Brandywine is not precisely known. Like the Bryn Mawr, it has been assigned to the Pliocene or Pliocene (?) by many authors. It must be noted that aside from topographic and stratigraphic position, which are not definitive, there is no evidence upon which an age determination may be based.

COLUMBIA FORMATION AND COLUMBIA GROUP

General statement. - Almost the entire Coastal Plain of Delaware is underlain by a veneer of clastic sediments. These surficial deposits rest unconformably on the truncated surfaces of the other Coastal Plain units in order from older to younger to the southeast of the Fall Zone. As a result of transportation by several agencies and deposition in a number of environments many diverse types of sediments are present.

The thickness of the surficial deposits is variable as they have been deposited on an erosion surface and have themselves been subjected to erosion. In New Castle and Kent Counties they have, in places, been stripped away and the older rocks exposed. Over-all, however, the thickness of these sediments increases to the southeast, away from the Fall Zone, and reaches a maximum, in Delaware, of 150 feet or more in Sussex County.

This deposit is of special interest because of its importance as an aquifer and because almost all recharge to underlying aquifers must pass through it.

It is known from water wells in certain channels in New Castle County and throughout Sussex County where it is almost the only aquifer in use. It may be studied in outcrop in the banks of the Chesapeake and Delaware Canal and in many gravel pits distributed about the state.

Although a Pleistocene age is generally accepted for these sediments it is often difficult to prove at a particular locality because fossils are very rare. In Delaware fossils are not known outside of Sussex County. Richards (1936) found Pleistocene marine megafossils at several localities in eastern Sussex County. In the west, near Laurel, a Pleistocene oyster bed has been found (Shuster, 1960). Investigations of the Delaware Geological Survey, as yet unpublished, have recovered pollen and spores and diatoms from wells in southern Sussex County and gastropods and Foraminifera from the locality near Laurel.

For reasons which are detailed below, the name Columbia is retained for the surficial sediments. Columbia was first used in reference to a single formation identified near the Fall Zone of the northern part of the Coastal Plain. When various "terrace formations" were recognized the Columbia was elevated to the rank of group.

The term "Columbia Group" is very inclusive and has been applied to all of the surficial sediments of Delaware. However, a group may not exist without component formations (Code of Stratigraphic Nomenclature, Article 9a,c) and must be lowered to formational rank outside of the area where more than one lithic unit is found.
It is possible at this time to designate but one rock stratigraphic unit in northern Delaware but at least two may be discerned in the southern portion of the state. Columbia Formation is recognized as the proper designation of the surficial sediments where they comprise only one unit. Related sediments in the south, which include the Beaverdam Formation and the newly described Omar Formation, constitute the Columbia Group.

General consideration of the origin and application of "Columbia" will be found in the following section designated Columbia Group. Also considered under that heading are stratigraphic terms that have been used for materials included by various authors in the Columbia Group in the State of Delaware. An attempt has been made to avoid names which have not been applied in this state. Following this the presently recognized formations of the Columbia Group are discussed under the headings Beaverdam Formation and Omar Formation. Data pertaining specifically to the Columbia Formation of northern Delaware are found under the heading Columbia Formation.

Columbia Group

Origin of the term Columbia. - The term Columbia Group has been used sporadically for many years to refer to all of the surficial deposits of the Middle Atlantic Slope which are presumed to be of Pleistocene age. It may be noted that one of its attributes is that it designates these related rocks by a means other than their inferred age.

Columbia was first used by W J McGee as a formation name in a Report of the Health Officer of the District of Columbia (McGee, 1886a), the geologic part of which also appeared in the American Journal of Science (McGee, 1886b). In these papers the name was applied to a unit found in the "amphitheater" of hills about Washington, D.C. McGee (1886b, p. 473) stated:

Within the amphitheater and rising about its periphery (except on the east) to an altitude of about 100 feet is a well defined Quaternary deposit to which the name Columbia formation is applied. Its upper portion consists of loam or brick-clay, and its lower of sand, gravel, boulders (up to four or five feet in diameter), or all combined. Its thickness is variable, the upper member ranging from almost nothing to perhaps 20 or 30 feet, and the lower from perhaps 1 to 20 feet. The deposit is more or less distinctly stratified throughout, particularly in the lower division; and at the base it frequently becomes a simple bed of boulders and gravel, without considerable admixture of finely comminuted materials.

McGee later extended the use of the name Columbia to include the surficial deposits of much of the Coastal Plain. In 1887 he included deposits of the Delaware River in a discussion of the Columbia formation. The Delaware materials were included more specifically by McGee the following year (McGee, 1888, p. 378):

As shown by the researches of Lewis and Chester, at Philadelphia and in northern Delaware respectively, the Delaware river and bay are flanked on the west from Philadelphia to Dover by a deposit of brick-clay or loam
passing into gravel below the Philadelphia Brick Clay and Red Gravel of the former author, and the Delaware Gravels of the latter. The deposits have been described in detail by these authors, and it will suffice to add that not only in general characters but in less conspicuous features detectable on minute examination they are indistinguishable from their homologues in corresponding position of the Susquehanna and Potomac;...

McGee used "Columbia" to include all of these materials. He conceived of the unit as being of great extent. It was considered to be one of the three formations of the "Middle Atlantic Slope."

Other names used for the Quaternary Series. - The conspicuous surficial deposits had received attention from still earlier workers and McGee (1888, p. 449-455) provides a fine review of the work done prior to his own. A few of these works are pertinent to Delaware but none has had a lasting effect on the nomenclature.

Booth (1841) mentioned the surficial materials of southern Delaware but he did not provide a name for them other than "Lower Clays," "Upper Sands," and "River Deposits," all of which are included, at least in part, in the present concept of the Omar Formation. Chester (1884b) discussed the deposits of northern Delaware and noted that the Philadelphia Clay and Red Gravel described earlier by Lewis (1881a) graded into one unit in Delaware and stated (p. 190): "Considering these facts it seems proper that the two indistinct units, i.e., the Philadelphia Clay and the Red Gravel should be included under one head, which we shall hereafter call the Delaware Gravels."

The Delaware Gravels were found to pass into finer, lighter colored sands in southern Delaware and in Chester's study of the following year (Chester, 1885) these sediments were designated the Estuary Sands.

The names used by Booth, Lewis, and Chester, were apparently lost in the larger concept of McGee's Columbia. The names have not been used by subsequent authors. No purpose will be served by attempting to reinstate names not used for so long. Indeed, additional objections are found in the use of lithologic terms as formation names and also because "estuary" in a formational name is misleading and because "Delaware" has been applied to other units (Wilmarth, 1938, p. 591-594).

It must be emphasized here that Booth, Lewis, Chester, and McGee described lithic units to which geomorphological features were incidental.

The nomenclature of the Quaternary sediments of the Atlantic Coastal Plain has become very complex. Clearly there is a great variety of rock types to be considered but the situation has become unduly complicated by failure to distinguish between formations and terraces or by the intentional combination of the two features under one name, i.e., terrace formations. It has been pointed out by Dryden and Overbeck (1948) that the heterogeneity of the rocks prompts recourse to geomorphic criteria in order to subdivide the Columbia. It is abundantly clear that formations are to be defined as lithic units (Code of Stratigraphic Nomenclature) and the writer cannot, therefore, reconcile terraces with formations. The various names defined and
accepted as designating terraces (for examples see papers of Shattuck and Cooke) properly belong to terraces and, in order to avoid confusion, should not be used for rock units. Frye and Willman (1962) have recently drawn attention to the ambiguity of formations based on surface expression. They suggest that a class of "morphostratigraphic units" be created to accept such features as moraines and terraces.

Additional remarks by Frye (1962) give some indication of the difficulties which may be anticipated when attempting time correlation of Coastal Plain terraces with the glacial section of the interior as has been done in the past by some authors.

The use of the names of Atlantic Coast terraces in Delaware seems particularly inappropriate because of the general lack of agreement regarding the position and extent of the terraces and in some areas, including Delaware, their very existence. Apart from their influence on the geologic nomenclature the problems connected with terraces are not within the scope of this study and the reader is referred to the work of Flint (1940, 1941, 1947) and Cooke (1930, 1936, 1941, 1945) and their references for discussions of other aspects of Quaternary terraces on the Eastern Seaboard.

Shattuck (1901, 1906) elevated the Columbia to the rank of group and included in it the Sunderland, Wicomico, and Talbot "terrace formations." These units are shown as extending into Delaware on Shattuck's map of 1906. Shattuck makes it clear that these units were not distinguished by lithologic criteria and it appears that he did not consider it possible to do so because of the similarity of the materials.

The studies of Cooke lead him to apply the names of the many terraces which he found along the East Coast to almost all of the Atlantic Coastal Plain (1930). Of Cooke's terraces, Rasmussen et al. (1960) state that the Silver Bluff, Princess Anne, Pamlico, Talbot, and Penholoway may be present in Sussex County. Under Cooke's concept it is presumed that these and possible other, higher terraces, where the land elevation is sufficient, are suspected of being present in Delaware. The present writer again would stress that these features are terraces and not formations.

Rasmussen and Slaughter (1955, 1957) were able to establish several units in the Pleistocene deposits of Maryland in counties adjacent to Delaware. Recently these names, Parsonsburg Sand, Pamlico Formation, Walston Silt, and Beaverdam Sand, were used by Rasmussen et al. (1960) in tables and on plates representing the geology of Sussex County, Delaware.

A continuing study of the Columbia Group in Sussex County by the Delaware Geological Survey has shown that not all of the terms from Maryland can be applied successfully in Delaware. The study of this Survey is designed as a stratigraphic study and it has included the drilling of five test wells in the southern part of Sussex County and three additional wells in New Castle County. A total of 130 cores were taken in these wells and additional samples have been obtained from other wells and from outcrops. The study has included investigation of mechanical composition, mineralogy, and paleontology, including micropaleontology and palynology. The area of detailed investigation is limited but it includes areas where the names Parsonsburg, Pamlico,
and Beaverdam have been applied by Rasmussen et al. The Walston Silt as recognized by those authors is not indicated as being present in the area of the detailed investigation.

The Walston Silt was defined by Rasmussen and Slaughter (1955) in Maryland south of Sussex County. They stated (p. 116): "The Walston silt, here named from the Walston Branch, is a lenticular unit of sand, silty sand, sandy silt, silt, clayey silt, silty clay, and clay, with organic material, overlying unconformably the Beaverdam sand, and underlying, unconformably, the Parsonsburg sand." The presence of this unit in Delaware is not documented by Rasmussen et al. (1960) except that the name is given to intervals in several wells on the basis of drillers' descriptions. The presence of the unit is not actively challenged but neither can it be accepted unqualifiedly until more adequate wells are drilled and specific aspects of its lithology and extent demonstrated.

In the detailed investigation it has been determined that the Pamlico Formation and the Parsonsburg Sand are not clearly distinguishable lithologic units in Delaware. The Pamlico was defined by Rasmussen and Slaughter (1955, p. 117) as "...gray, sandy, clayey silt, with lenses of fine to medium-grained sand and some gravel." Unfortunately prior usage has established the Pamlico as a terrace. According to Wilmarth (1938, p. 1595) Pamlico was first used by L. W. Stephenson in an unpublished manuscript. The name was first published by Clark (1910, p. 651) who wrote, regarding the Talbot terrace: "In North Carolina it divides into two terraces, constituting the Chowan and Pamlico Formations." Pamlico has been used in regard to Delaware by Richards (1936) for he considered that (p. 1643): "The Pamlico terrace and formation appear to be continuous from Delaware to Florida." Objection is raised to the use of Pamlico in Delaware because it carries the connotation of a terrace and, more significantly, because the studies in progress indicate that the well intervals labeled Pamlico by Rasmussen et al. are not clearly defined lithologic units. The latter is also the basis of the objection raised to the Parsonsburg Sand. It is apparently this unit which we cannot distinguish from the Pamlico. Rasmussen and Slaughter, when defining the Parsonsburg wrote (1955, p. 118):

The Parsonsburg sand is the name given here to the veneer of sand and associated deposits which compose the rims, and in places, the interior of the "Maryland Basins."

The Parsonsburg sand is composed predominantly of medium-grained sand, but it is poorly sorted, the materials ranging from the size of small boulders (rare), through cobbles, gravel, very coarse to very fine sand, silt and clay. In color it is buff, tan, orange, or brown. This formation also appears to be distinguished by the fact that it occupies a particular morphologic position.

In the area investigated by this Survey alternating silts and sands were found above a relatively thick sand. Individual sands and silts could not be traced from well to well and the upper materials could not be classified into formations of silt or of sand, rather there is but one unit which is characterized by the heterogeneity of its alternating sediments. This unit will be de-
fined below as the Omar Formation. It would appear to include the materials designated by Rasmussen et al. as the Parsonsburg Sand and the Pamlico Formation in Delaware.

The quartz sand which underlies the alternating silts and sands constitutes the second formation of the Columbia Group which is recognized at present in the State of Delaware. In their studies in Maryland Rasmussen and Slaughter recognized this unit and named it the Beaverdam Sand. Rasmussen et al. (1960) extended the unit into Delaware. Details of its occurrence are presented below.

Beaverdam Formation

The original description of the Beaverdam by Rasmussen and Slaughter (1955, p. 113) follows:

The Beaverdam sand is composed of unconsolidated, white to buff, medium-grained, quartz sand, with small quantities of coarse and fine sand, pebbles and granules, and a minor admixture of white silt. It is named for Beaverdam Creek, the east branch of the Wicomico River, because of its prominent occurrence in and beneath the drainage basin of that stream.

The reference locality is a well two miles east of Salisbury, Maryland.

As stated above, the area in which detailed information is available in Delaware is limited to the southeastern portion of Sussex County and, although there are many water wells and sand pits in other parts of Sussex County which suggest that the Beaverdam is an extensive unit, the remarks made here apply specifically to the smaller area and should be extended from it only on the basis of firm data.

Three logs of the cored wells drilled in Sussex County by this Survey have been interpreted independently and published by Rasmussen et al. (1960, p. 216-217, 222-225; well nos. Qh44-l, Rg22-l and Rg23-l). We concur in the presence of the Beaverdam in these wells but may differ by insignificant amounts regarding its vertical limits. In order that the Beaverdam Formation may be unequivocally established in Delaware additional data pertaining to the formation follow.

The logs of the cored wells drilled by this Survey, including the electric logs, are presented in plate 4. Mechanical analyses of 38 samples from five cored wells disposed roughly along a line between Omar and Whitesville, a distance of more than 13 miles, demonstrate that the Beaverdam is a rather uniform, fairly well sorted, medium sand. Statistical parameters based on the formulae of Inman (1952) yield an average median grain size ($Mdd$) of 1.37 and a sorting coefficient ($\sigma_c$) of 1.135. Average figures have some significance here because the sand is fairly uniform. The median grain size is almost invariably in the medium sand range (1-2$\phi$) and the extreme values found are -1.2$\phi$ to 2.82$\phi$, the coarser of these samples was exceptional. Skewness values ($\alpha$) are rather low and positive and fairly uniform. It is
particularly evident from the electric logs that thin beds of fine sand or even silt may be found within the Beaverdam Formation. Granules are common and some gravel is also found. The sands consist almost entirely of quartz. A small amount of chert is present and is particularly evident among particles larger than coarse sand. A large suite of heavy minerals is present but in total they comprise a very minor portion of the sand.

The gross characteristics of the sand from the wells in Delaware are similar to those of sand exposed in the drainage basin of Beaverdam Creek in Wicomico County, Maryland, which is the reference area for the Beaverdam Formation according to Rasmussen and Slaughter (1955). Outcrop samples from Maryland actually examined by the writer are slightly more rounded and finer-grained than the core samples in Delaware. However, the rather poor outcrops may not be entirely representative and reliance must be placed upon a mechanical analysis of a sample from the subsurface of Wicomico County which shows the Beaverdam to be a medium sand (Rasmussen and Slaughter, 1955, p. 113).

In the five wells the Beaverdam sand is 92, 105, 64, 60, and 106 feet thick. It is probable that this formation underlies a large part of Sussex County but in order that it may remain a reliable unit the name Beaverdam should not be used without ample justification.

The present concept of the Beaverdam Formation would seem to include, at least in part, the sands referred to by Booth and the Estuary Sands of Chester.

The Beaverdam appears to be the oldest formation of the Columbia Group in southern Delaware. It overlies, unconformably, blue-gray silts and fine sands, which are tentatively classified as part of the Chesapeake Group. The Beaverdam has been assumed to be of Quaternary age and seems to be related to the overlying sparsely fossiliferous Pleistocene sediments but it must be noted that it is unfossiliferous and, although there seems to be no reason to doubt its Quaternary age, neither can it be demonstrated at present.

Omar Formation

As has been indicated above, a satisfactory name for the sediments which overlie the Beaverdam Formation in southeastern Sussex County is lacking. These sediments have been sufficiently studied so that a formal name may be given to them. The name Omar Formation is here proposed to designate taken from a small village about two miles east of the town of Frankford in Sussex County, Delaware. Omar is the town nearest to well number Qh44-1 which provides the type section of the formation (see map on plate 4),

The Omar Formation directly underlies a large portion of southeastern Sussex County. Due primarily to a lack of relief it is very poorly exposed in outcrop. It may be seen in some shallow road cuts and in drainage ditches but these expose only a fraction of the unit. Beds of silt and sand of varying texture are found in the banks of the Assawoman Canal about 6 miles to the east of the type locality. Again, not enough of the section is exposed to be definitive but well logs between the canal and Omar suggest, if they do not prove, the continuity of the sequence of alternating sands and silts which com-
prise the Omar Formation. Recourse is had to well sections in order to characterize the entire formation. The wells which provide the major part of the control on the Omar Formation are those cored and logged wells already mentioned in conjunction with the Beaverdam Formation. These wells provide control along a line from a point 2 1/2 miles east of Frankford, through Cedar Swamp to a point one mile northeast of Whitesville, a distance of more than 13 miles. The formation may be extended with confidence several miles from this line to the east and to the north and south on the basis of descriptions from drillers' logs, which also confirm its continuity between cored wells. To the west, even in the cored well near Whitesville, it becomes more difficult to distinguish the Omar. The formation may not be limited to the area described but because of a lack of data it would not be prudent to extend it beyond the area at this time.

The interval from 1/2 foot below land surface (in order to eliminate the thin soil zone) to a depth of 45 feet in well Qh44-1 located at the junction of Delaware Route 26 with County Road 353 2 1/2 miles east of Frankford, Sussex County, Delaware is designated as the type locality of the Omar Formation. The other wells of the series, specifically Rg23-1 and Rg22-1 are to be considered also as providing representative reference sections as indicated in plate 4 which includes descriptive and electrical logs.

The Omar Formation consists of interbedded, gray to dark gray, quartz sands and silts. Individual beds range in thickness from a few inches to more than 10 feet. Thinner layers of clay or silt, some only a few millimeters thick have been found in sand beds. The sands are variable in texture but tend to be fine and may be well sorted or only moderately well sorted. The silts tend to be medium silts but this varies depending on the quantity of admixed sand. The silts generally contain some plant matter and some dark silts might be termed "organic." The sands commonly contain woody fragments some of which are lignitic. Contacts between individual beds may be sharp or gradational over several inches. The extreme range of textures recorded is from 0.75 to 7.60 in 36 samples studied. Sorting values (a<phi>) range from 0.48 to 3.88. The sands show consistently lower values than do the silts. Skewness values (a<phi>) also have a considerable range but only a few are negative and most values are moderate.

The Omar Formation overlies the Beaverdam Formation. The presence of an unconformable relationship between the two units is suggested although it is not established. Such a feature would seem to represent a change in environment of deposition rather than a long period of non-deposition.

The sands of the Beaverdam Formation are more homogeneous than the Omar Formation. The Beaverdam in general is coarser, better sorted, lighter in color and lacking in organic matter in comparison to the sandy part of the Omar although thin individual beds of the Omar may approach the appearance of the Beaverdam. The silts of the Omar contrast strongly with the almost entirely arenaceous Beaverdam.

In the five wells the Omar is 50, 44, 54, 38, and 40 feet thick.

Plant remains dominate the fossil content of the Omar in the reference wells. The occurrence of woody material and lignite has been mentioned. Plant microfossils are also present, particularly in the finer grained portions.
of the formation. Pollen and spores indicate that the Omar Formation was deposited under climatic conditions which include both moderate and cold temperatures. Diatoms are also present but have not been studied. Richards (1936) obtained mollusks from the Assawoman Canal. Although paleontologic data are still meager, the Pleistocene age of the Omar Formation has been established.

Samples, logs, and microfossils obtained from the Omar Formation are deposited at the Delaware Geological Survey.

Although it may play no role in the definition of the formation, brief and generalized mention of its implied history may serve to clarify the relationship between its diverse sediments. It is suggested that the Omar was deposited near the shore and that it represents a number of the distinct but intimately related environments of deposition associated with a shore of sandy beaches. Sediments of the beach, of lagoons and possibly of pre-existing estuaries are represented. It is suggested that the incursion of the beach sands upon the lagoon and perhaps upon the landward side of the lagoon is recorded as occurring not once but several times in an irregular fashion. Substantiation of this, or the development of a more adequate explanation, is the objective of a continuing study of these deposits.

Columbia Formation

The surficial sediments of southern Delaware have been shown to be divisible into at least two formations (the Beaverdam and the Omar). These two formations comprise the Columbia Group. The sediments of the southern part of the state were derived primarily from two sources: materials distributed along the shore by the waves and currents of the Atlantic and materials transported by streams essentially from the north. The latter are probably the ultimate source of the former and are thought to be dominant in Delaware.

In New Castle County evidence from wells and from artificial exposures in pits and in the banks of the Chesapeake and Delaware Canal clearly indicate that the surficial materials of the northern Delaware are of fluvial origin. Between the familiar sands and gravels of the north and the sands and silts of the south there exists an area (essentially Kent County) in which little is known about these sediments. In this area and probably in the southern portion of this area, near the Kent-Sussex County line, the transition is made from the fluvial sands to dominantly littoral, lagoonal, estuarine, and inner neritic sediments of the south. Inferred history indicates that the relationship of the sediments from New Castle County to those in Sussex County may be very complex due to the repeated changes in sea level and stream regimen during the Pleistocene.

For the purposes of stratigraphy we note that the sands and gravels of the north have not been formally subdivided, indeed they do not appear to be divisible into lithologic units. Thus the name Columbia Group will be used in southern Delaware where it includes the Beaverdam and the Omar formations and possibly others but the group passes north into the Columbia Formation as originally used by McGee. This includes the Delaware River Gravels of Chester.

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The Columbia Formation of northern Delaware may be described as yellow to dark reddish-brown, mostly coarse, moderately sorted, quartz sand, with a considerable admixture of gravel and commonly containing cobbles and, in some places, boulders. Thin silts may be present but are uncommon. It is generally cross-bedded but the bedding may be contorted. Limonite is common as thin ledges and as a stain or coating on other particles. A variety of lithic types is recognizable among the larger fragments, including especially quartzose sandstone and quartzite, some of which contain Paleozoic fossils.

The occurrence of the Columbia Formation in channels has already been alluded to. The characteristics of the formation are best demonstrated where the channels cross the Chesapeake and Delaware Canal. Some of the channels extend below the sea level. Descriptions of the formation and the results of an electrical resistivity study with emphasis on the channels is found in Groot and Rasmussen (1954). The channels have also received the attention of Rasmussen et al. (1957).

The names Sunderland, Wicomico, and Talbot have been used on geologic maps which have included northern Delaware by Miller (1906), Bascom and Miller (1920), and Bascom and Stose (1932). These names have been used as parts of the Columbia Group in the first two papers. Objections to such terms have been catalogued above and are again applied here. It is to be noted that Miller (1906, p. 6) has stated: "On purely lithologic grounds it is impossible to separate the three formations composing the Columbia Group,..." A similar statement is found in Bascom and Miller (1920, p. 13).

A small strip of sand and gravel along the west bank of the Delaware River in extreme northeastern Delaware was mapped by Bascom et al. (1909) as the Cape May Formation. Cape May was originated by Salisbury (1898) for the latest Pleistocene sediments of New Jersey. These same sediments had been considered much earlier by Lewis and by Chester and had been included by McGee in the Columbia Formation which, as we have indicated, appears to be the oldest acceptable name.
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