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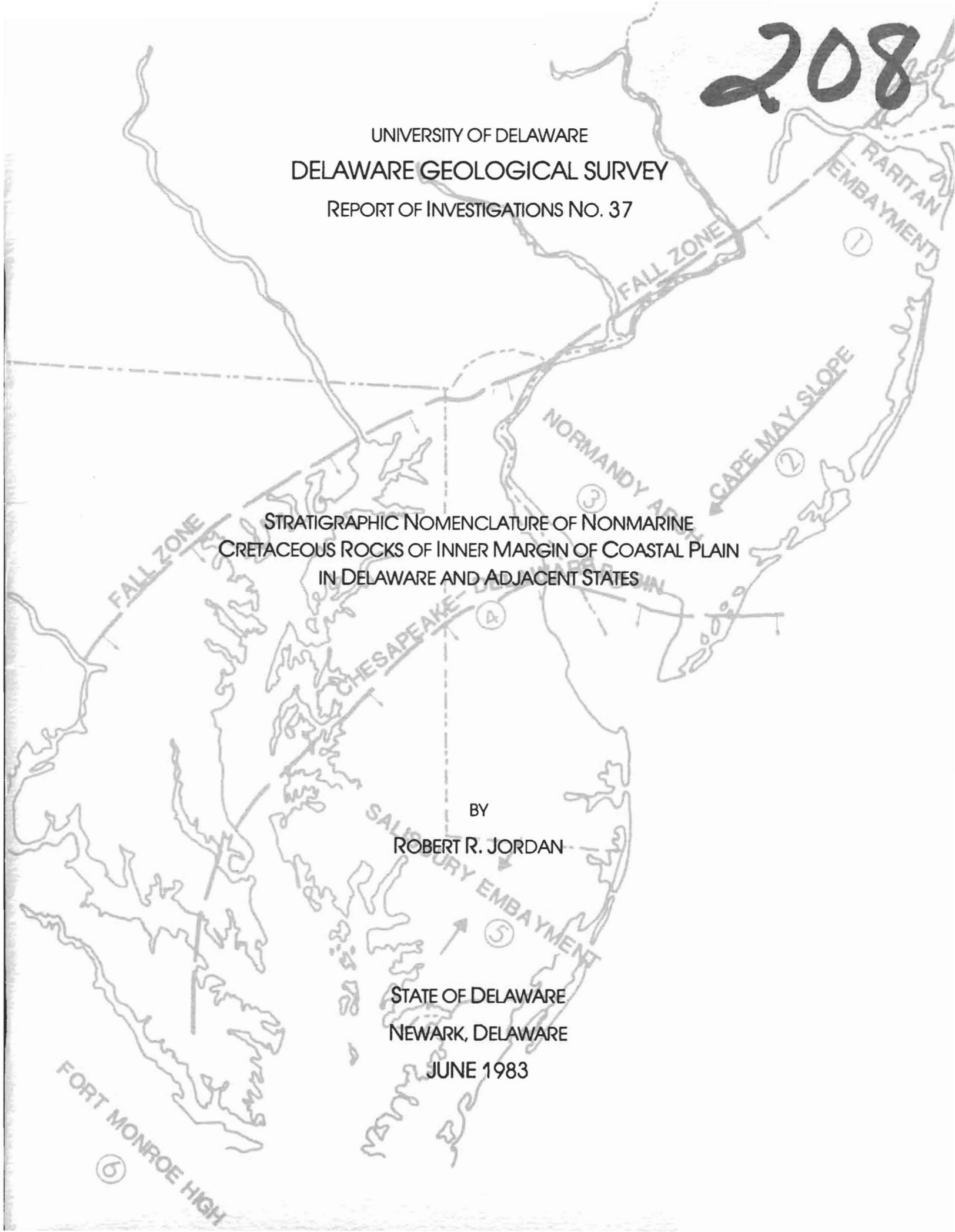

STRATIGRAPHIC NOMENCLATURE OF NONMARINE CRETACEOUS ROCKS OF INNER MARGIN OF COASTAL PLAIN IN DELAWARE AND ADJACENT STATES

BY

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STRATIGRAPHIC NOMENCLATURE OF NONMARINE CRETACEOUS ROCKS OF INNER MARGIN OF COASTAL PLAIN IN DELAWARE AND ADJACENT STATES

ABSTRACT

Rocks of Cretaceous age deposited in continental and marginal environments, and now found along the inner edge of the northern Atlantic Coastal Plain, have historically been classified as the Potomac Group and the Potomac, Patuxent, Arundel, Patapsco, Raritan, and Magothy formations. Subdivisions of the Raritan and Magothy formations have also been recognized. Lithologic characteristics and spatial relationships of the units indicate that only the Potomac Formation and the Magothy Formation can be differentiated in northern Delaware. The complex nonmarine deposits originated on an aggrading coastal plain. Their projections into the deeper subsurface on- and offshore will be important in future studies. No changes in terminology are recommended, but careful use of stratigraphic nomenclature is urged in order to avoid confusion, especially in hydrologic applications.

INTRODUCTION

Purpose and Scope

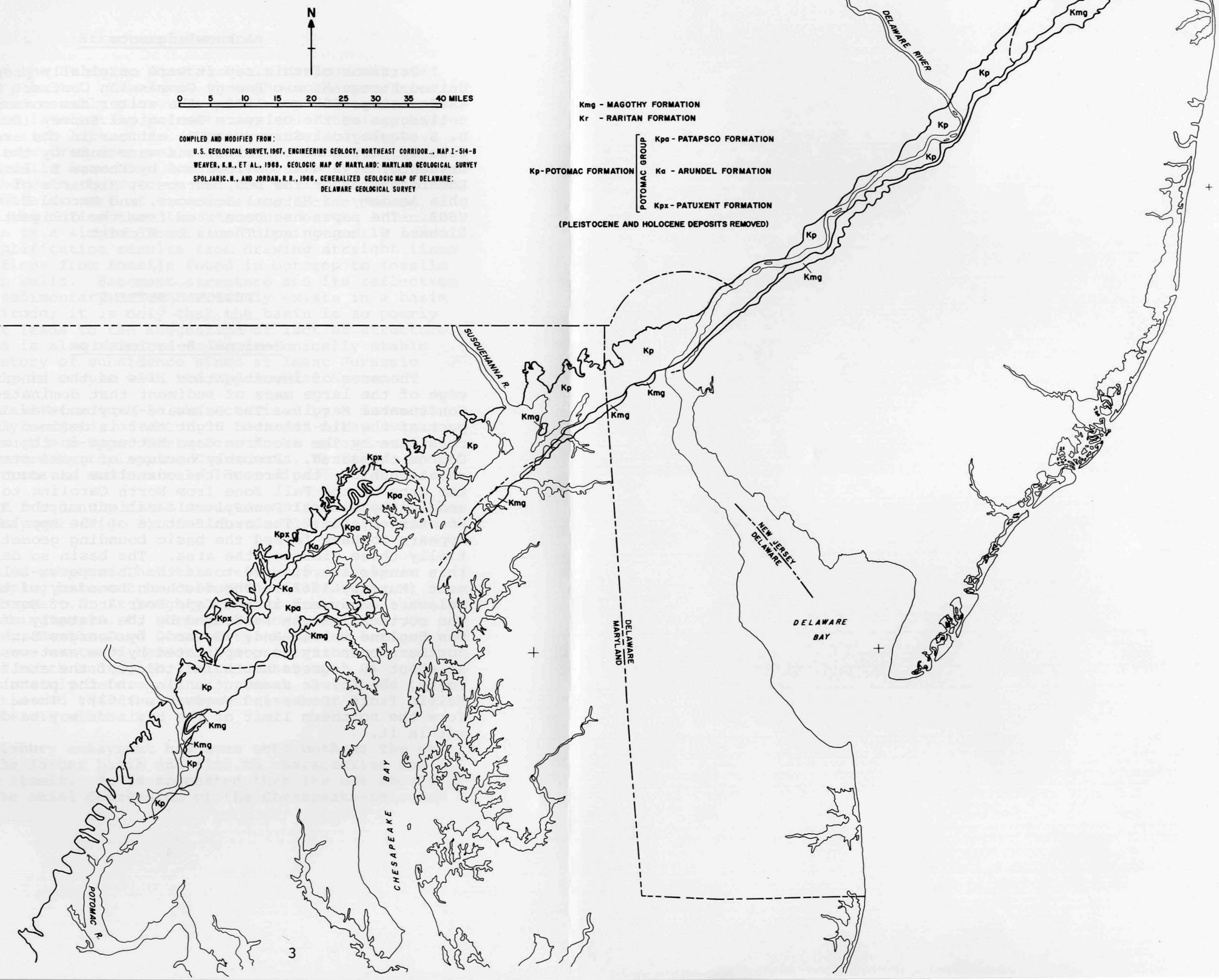
Although the nonmarine Cretaceous rocks of the inner Mid-Atlantic Coastal Plain have been investigated for a century and have a relatively simple nomenclature, difficulties are still encountered with definitions of the stratigraphic names and extents of their applications. This investigation seeks to clarify such usage through a review of the origins of the names and descriptions of the rock units.

The principal rock stratigraphic units included are the Potomac Group and Potomac, Patuxent, Arundel, Patapsco, Raritan, and Magothy formations together with the several members of the Raritan and the Magothy. The area of investigation includes the outcrop and subcrop areas of these units in the states of Delaware, Maryland, and New Jersey. The area so defined (Fig. 1) lies along the inner margin of the Atlantic Coastal Plain adjacent to the Fall Zone between Washington, D. C. and New York City. The length of this belt is approximately 210 miles; it varies in width from roughly 20 to 40 miles. The rocks represent ages ranging from Early Cretaceous into the Late Cretaceous.

The nonmarine Cretaceous deposits form the base of the inner portion of the massive prism of Cretaceous, Tertiary, and Quaternary sediments that underlies the Atlantic Continental Margin. The units extend to the east and south far beyond the limits of the present study. Only the inner belt is considered here because that is where the terminology originated and where the units are most intensively utilized, especially for water supply.

Only the Potomac Formation and the Magothy Formation are identified in Delaware. Because they are substantial parts of the rock mass of the Atlantic Coastal Plain, include important sands acting as aquifers, and are mined for clay and sand, workers have sought to subdivide the Potomac to facilitate detailed study. It is particularly important that the geologic terminology be understood so that it can be correctly compared with that used in computer-based studies of aquifers and properly translated into terms used by regulatory agencies.

Figure 1.


N
0 5 10 15 20 25 30 35 40 MILES
COMPILED AND MODIFIED FROM:
U.S. GEOLOGICAL SURVEY, 1967, ENGINEERING GEOLOGY, NORTHEAST CORRIDOR.., MAP I-514-B
WEAVER, K.N., ET AL., 1968, GEOLOGIC MAP OF MARYLAND: MARYLAND GEOLOGICAL SURVEY
SPOLJARIC, N., AND JORDAN, R.R., 1966, GENERALIZED GEOLOGIC MAP OF DELAWARE: DELAWARE GEOLOGICAL SURVEY
Kmg - MAGOTHY FORMATION
Kr - RARITAN FORMATION
Kp - POTOMAC FORMATION
POTOMAC GROUP
Kpa - PATAPSCO FORMATION
Ka - ARUNDEL FORMATION
Kpx - PATUXENT FORMATION
(PLEISTOCENE AND HOLOCENE DEPOSITS REMOVED)
DELAWARE RIVER
SUSQUEHANNA R.
POTOMAC R.
CHESAPEAKE BAY
DELAWARE BAY
NEW JERSEY
DELAWARE
DELAWARE
MARYLAND
Kr
Kmg
Kp
Kpa
Ka
Kpx

Acknowledgments

Portions of this report were originally prepared under United States Atomic Energy Commission Contract No. AT(30-1)-4887 during 1969 and 1970. The writer has consulted with colleagues at the Delaware Geological Survey (DGS) and the U. S. Geological Survey (USGS) offices in the area. Particularly pertinent contributions were made by the late Lincoln Dryden of Bryn Mawr College and by Thomas E. Pickett and Edward Custer of the DGS, Horace G. Richards of the Philadelphia Academy of Natural Sciences, and Harold E. Gill of the USGS. The paper has benefited from the diligent reviews of Richard N. Benson and Thomas E. Pickett.

REGIONAL SETTING

Regional Relationships

The area of investigation lies on the innermost feather edge of the large mass of sediment that dominates the Atlantic Continental Margin. The Delaware-Maryland-New Jersey area is part of the Mid-Atlantic Bight that is defined in the present coastline by the arc from Cape Hatteras on the south to Cape Cod on the north. Probably because of gross structural relationships, the arc of the coastline has counterparts in the arcs of the Fall Zone from North Carolina to New England and in the central Pennsylvania salient of the Appalachian Mountain System. The architecture of the Appalachian System appears to have formed the basic bounding geometry on essentially three sides of the area. The basin so defined in this manner is referred to as the Chesapeake-Delaware embayment (Murray, 1961). The southern boundary of the Chesapeake-Delaware embayment is the Cape Fear Arch of North Carolina. The northern margin is formed by the easterly offset of the New England upland and, seaward, by Georges Bank. The northern boundary is complicated by the east-west trends, at about 40 degrees north latitude, of the shelf edge contours, the Kelvin seamount chain, and the postulated Cornwall-Kelvin fault (Drake and Woodward, 1963). These features may form the northern limit of the basin or may be contained within it.

Structural Features

Study of the Atlantic Coastal Plain has concentrated on the outcrop belts. Exposures throughout the province are limited and usually poor, but proximity to centers of population and interesting paleontology and lithology have resulted in a rich literature. Opportunities to sample downdip sections from deep wells are rare; consequently, the few deep wells have been studied intensively. Too often correlation between the outcrop and the wells has been done without adequate account of structure and facies change, resulting in the notion that the structure of the Atlantic Coastal Plain is a simple "homocline" dipping gently seaward. This oversimplification results from drawing straight lines on cross sections from fossils found in outcrop to fossils found in deep wells. Basement structure and its reflection through the sedimentary column certainly exists in a basin of this magnitude; it is only that the basin is so poorly explored that leads to the suggestion of lack of structure. The same area is also referred to as tectonically stable despite a history of subsidence since at least Jurassic time, probably in couple with the Appalachian System.

The overall structure is characterized by a basement dip, generally seaward, of about 90 feet per mile, average. Jurassic through mid-Upper Cretaceous rocks onlap basement and are succeeded by toplapping Cretaceous, Tertiary, and Quaternary strata in successively lower dips.

The most frequently cited structure of the area is the Salisbury embayment (Fig. 2) of Richards (1948). He stated (page 54):

> It is proposed that this region of steeply sloping basement be called the "Salisbury Embayment." It roughly extends from Washington, D. C. through Meadows, Salisbury, Berlin, and Ocean City, Maryland and thence eastward beneath the present ocean. Its north and south limits cannot be accurately determined at present, but it is estimated that the Embayment is about 75 miles in width.

The term Salisbury embayment has been used both as the central feature of the larger basin and also to characterize the larger basin itself. It is suggested that its use should be limited to the axial depression of the Chesapeake-Delaware

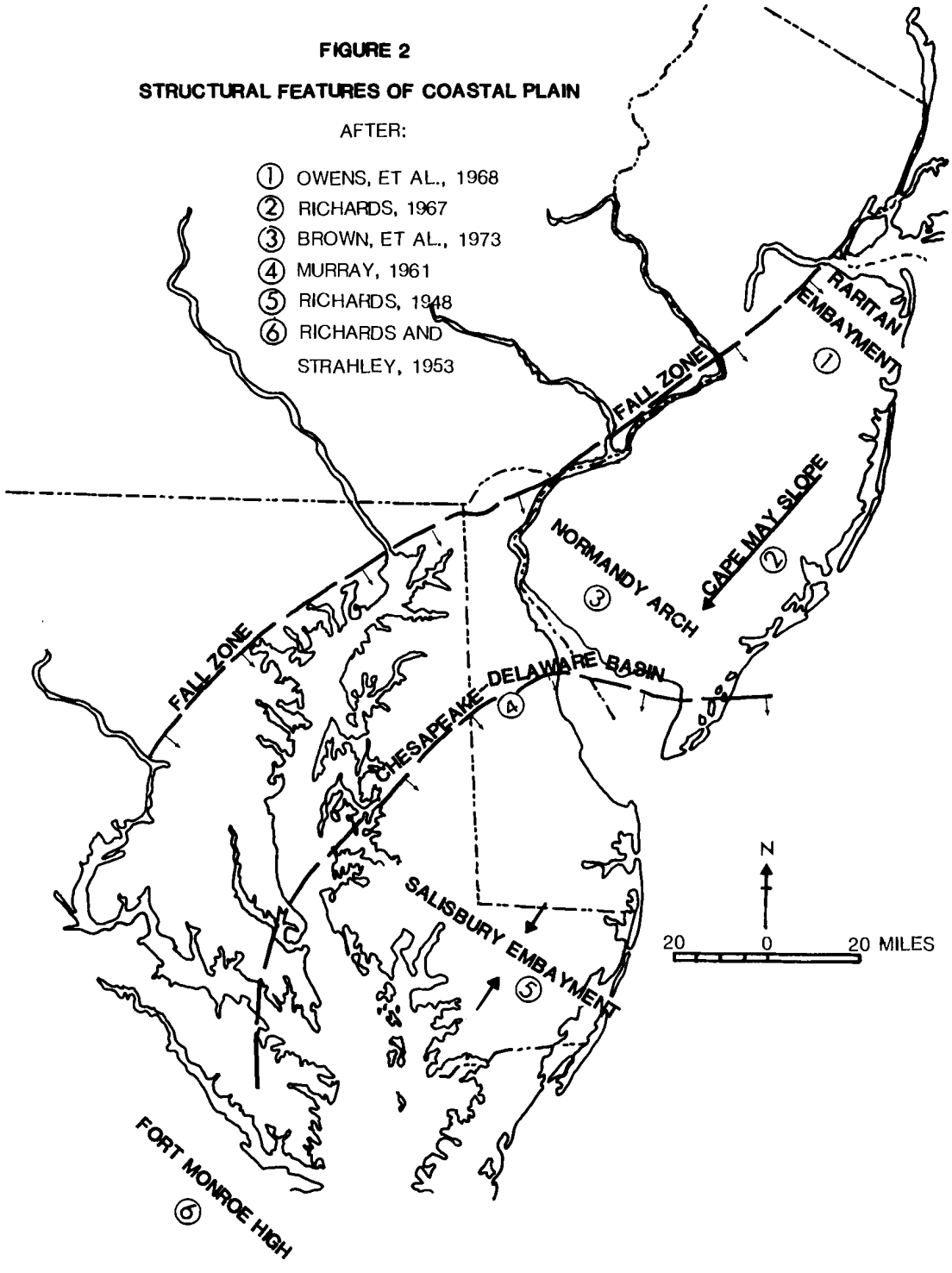


FIGURE 2
STRUCTURAL FEATURES OF COASTAL PLAIN
AFTER:
① OWENS, ET AL., 1968
② RICHARDS, 1967
③ BROWN, ET AL., 1973
④ MURRAY, 1961
⑤ RICHARDS, 1948
⑥ RICHARDS AND STRAHLEY, 1953
RARITAN EMBAYMENT
①
FALL ZONE
CAPE MAY SLOPE
②
NORMANDY ARCH
③
FALL ZONE
DELAWARE BASIN
④
CHESAPEAKE
SALISBURY EMBAYMENT
⑤
FORT MONROE HIGH
⑥
N
20
0
20 MILES

embayment. The basement depression is reflected in thicker accumulations of the older rocks and, probably, in the configuration of the younger strata (Jordan, 1963).

Murray (1961, p. 92-93) commented:

> Perhaps the most interesting structural anomaly in the Embayment is a pronounced flexure or change in the rate of dip of the basement surface and certain strata above it. Although this feature is rather well-documented in both published and unpublished reports, no really satisfactory explanation of its origin has been advanced. In the eastern Maryland region, where most data are available, the rate of dip of the basement increases from approximately 50 feet per mile to more than 100 feet per mile; the basement is slightly more than 8,000 feet below the present Eastern Maryland Shore.

To the north of the Salibury embayment Richards (1967) indicated a rather regular rise in basement which he designated the "Cape May Slope."

Apparently on this slope Owens et al. (1968) have identified the south New Jersey uplift, a transverse basement high trending northwest-southeast across the southern portion of New Jersey. To the north of this uplift Owens et al. (1968) show the Raritan embayment of northern New Jersey. Owens and Sohl (1969, p. 237) describe these features:

> ...a major trough or smaller basin is centered in the vicinity of Raritan Bay and a high occurs in southern New Jersey. ...both these large structures are actually a complex of many smaller troughs and arches (U. S. Geological Survey, 1967). Structures such as these influence sedimentary patterns in this area, particularly during Late Cretaceous time.

The arch in southern New Jersey, which bounds the Chesapeake-Delaware embayment on the north was named the Normandy arch by Brown et al. (1972). That paper provides an important synthesis of all of the major structural elements of the Atlantic Coastal Plain north of North Carolina. Regional tectonics were shown to have actively influenced depositional patterns of Coastal Plain sedimentary rocks.

South of the Salisbury embayment and beyond the area of investigation, the soutnern margin of the arch is formed by the Fort Monroe high (Richards and Strahley, 1953). Between this high and the basin-bounding Cape Fear arch lies the Pamlico basin or Hatteras low (Richards, 1967).

Details of the configuration of basement and of the local relief on its surface are known from only a few small areas, as, for example, that near Delaware City, Delaware presented by Spoljaric (1967). The basement surface appears to have local relief of tens, and in places hundreds, of feet and is not the smooth surface suggested in the original concept of the Fall Zone peneplain (D. W. Johnson, 1931). Detailed determination of relief, however, is complicated by the inconsistent reporting of "basement" as fresh crystalline rock or as the top of the weathered crystalline rock zone, which may be 50 feet or more thick.

DESCRIPTIONS OF UNITS

Historical Summary

An understanding of the various nomenclatures employed for the nonmarine Cretaceous rock is uncessary to utilize the accumulated literature. The earliest descriptive informal names used by pioneering workers such as Booth (1841), Conrad (1869), and Chester (1884) will not be discussed as they have been displaced by formal names of a more nearly modern stratigraphic character starting with the work of W J McGee in the mid-1880's.

The six formation names currently used were applied during the period 1886-1887: Potomac, Patuxent, Arundel, Patapsco, Raritan, and Magothy. The units constitute a stratigraphic association related by similar clay, silt, and sand lithologies, various nonmarine environments of deposition, and sequential, if not broadly continuous, deposition. Difficulties are primarily the result of disagreements on the ability to subdivide the Potomac into the Patuxent, Arundel, and Patapsco formations, different applications of the terms in three States, and the extension of the Raritan from the northernmost portion of New Jersey into Maryland.

The evolution of the stratigraphic nomenclature is shown in Table 1.

TABLE 1. Usage of Group and Formation Names.

(* First use of name; ** redefined name)

COOK 1869	CONRAD 1869	MCGEE 1886	MCGEE 1888			CLARK 1893
N.J.	N.J.	MD.	MD.	DEL.	N.J.	N.J.
PLASTIC CLAY SERIES: LIGNITE, POTTERS CLAY, FIRE CLAY	RARITAN CLAY*	POTOMAC FM.*	POTOMAC FM.	POTOMAC FM.	POTOMAC FM.	↑ CROSSWICKS CLAY; RARITAN FM.**

DARTON 1893	CLARK & BIBBINS 1897	CLARK 1904	WELLER 1907	BASCOM & MILLER 1920
MD.	MD.	MD.-DEL.-N.J.	N.J.	DEL.
MAGOTHY FM.*		MAGOTHY CLIFFWOOD (N.J.)	MAGOTHY FM.	MAGOTHY FM.
POTOMAC FM.	RARITAN FM.	RARITAN FM.**	RARITAN FM.	RARITAN FM.
	POTOMAC GROUP: PATAPSCO FM.*	POTOMAC GROUP: PATAPSCO FM.		PATAPSCO FM.
	POTOMAC GROUP: ARUNDEL FM.*	POTOMAC GROUP: ARUNDEL FM.		
	POTOMAC GROUP: PATUXENT FM.*	POTOMAC GROUP: PATUXENT FM.		PATUXENT FM.

SPANGLER & PETERSON 1950		MARINE & RASMUSSEN 1955			GROOT 1955
MD.-DEL.	N.J.	MD.	DEL.	N.J.	DEL.
MAGOTHY FM. "RARITAN" POTOMAC GROUP: PATAPSCO, ARUNDEL, PATUXENT	MAGOTHY FM. RARITAN (undifferentiated)	MAGOTHY FM. RARITAN FM. POTOMAC GROUP: PATAPSCO FM., ARUNDEL FM., PATUXENT FM.	MAGOTHY FM. NONMARINE CRETACEOUS SEDIMENTS	MAGOTHY FM. RARITAN FM. POTOMAC GROUP	MAGOTHY FM. RARITAN-PATAPSCO ZONE PATUXENT ZONE

JORDAN 1962			RICHARDS, OLMSTED & RUHLE 1962			RICHARDS 1967	
MD.	DEL.	N.J.	DEL.	N.J.	MD.	DEL.	N.J.
MAGOTHY FM. POTOMAC GROUP: RARITAN FM., PATAPSCO FM., ARUNDEL CLAY, PATUXENT FM.	MAGOTHY FM. POTOMAC FM.	MAGOTHY FM. RARITAN FM. PATAPSCO AND PATUXENT FMS.	MAGOTHY FM. RARITAN FM. PATAPSCO AND PATUXENT FMS. (undiff.)	MAGOTHY FM. RARITAN FM. POTOMAC GROUP	MAGOTHY POTOMAC GROUP: RARITAN, PATAPSCO, ARUNDEL, PATUXENT	MAGOTHY POTOMAC	MAGOTHY RARITAN POTOMAC

GEOLOGIC MAP OF MARYLAND 1968	HANSEN 1969	OWENS & SOHL 1969
MD.	MD.	N.J.
MAGOTHY FM.	MAGOTHY FM.	MAGOTHY FM.
POTOMAC GROUP including where differentiated		RARITAN FM.
RARITAN AND PATAPSCO FMS.	PATAPSCO FM.	POTOMAC-
ARUNDEL CLAY	ARUNDEL FM.	RARITAN (undiff.)
PATUXENT FM.	PATUXENT FM.	

WOLFE & PAKISER 1971		ROBBINS *et al.* 1975	
MD.	N.J.	MD. & DEL.	N.J.
MAGOTHY FM.	MAGOTHY FM.**	MAGOTHY FM.	RARITAN FM.
	RARITAN FM.**		
BEDS AT ELK NECK PATAPSCO FM. ARUNDEL FM. PATUXENT FM.		ELK NECK BEDS PATAPSCO FM. ARUNDEL FM. PATUXENT FM.	POTOMAC GP.

PETTERS 1976	JORDAN & SMITH 1983		
N.J.			N.J.
MAGOTHY FM. RARITAN FM. BASS RIVER FM.*	MAGOTHY FM. POTOMAC GP. PATAPSCO FM. ARUNDEL & PATUXENT FMS.	MAGOTHY FM. POTOMAC FM.	MAGOTHY FM. RARITAN FM. BASS R. FM. POTOMAC GP.

Potomac Formation

Nomenclature

The name Potomac Formation was first used by W J McGee (1886a, b), who studied the deposits in the District of Columbia and adjacent parts of Maryland and Virginia which must now be considered its generalized type locality. The original description is taken from 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, banded and mottled 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.

Extent

Further investigation by McGee (1888) extended the Potomac Formation from North Carolina to New Jersey, thus introducing the name in those states including Delaware. McGee noted that in places the lower portion of the Potomac Formation was predominantly sandy and the upper portion mostly clayey. He indicated that these subdivisions were "members," but did not name them.

The Potomac of Maryland was subdivided by Clark and Bibbins in 1897 into the Patuxent, Arundel, Patapsco, and Raritan formations. Only "Raritan" was not a new name, having been extended from New Jersey. The term Potomac was retained and raised to group rank in order to include these four formations.

Thus, in Maryland the term Potomac has been used to designate a group consisting of four formations, although there has been controversy about just how to differentiate the formations (some authors have included only the lower three formations in the group, omitting the Raritan). It appears to have been established that the distinctions can

be made only over a portion of the Maryland Coastal Plain centering about Baltimore. Within this area the Potomac is of group rank and outside it it is a formation including the entire section equivalent to that of the group (Weaver et al., 1968; Hansen, 1969b).

Bascom and Miller (1920) traced the Potomac Group into Delaware, recognizing the Patuxent, Patapsco, and Raritan formations. However, more recent workers in Delaware have rejected the idea that the Potomac can be subdivided into the formations found in Maryland and have persisted in using the term Potomac Formation for the entire stratigraphic interval (Groot, 1955; Jordan, 1962). During the period of equivocation on the question of subdividing the Potomac in Delaware, the term "nonmarine Cretaceous" was used for the interval as, for example, by Marine and Rasmussen (1955).

In New Jersey the term Potomac has not been as widely used as in the other States. Spangler and Peterson (1950) used Raritan (undifferentiated) to designate the nonmarine Cretaceous stratigraphic interval in New Jersey and did not feel it necessary to extend the Potomac designation that far north. However, Richards et al. (1962) used the designation Potomac Group (also undifferentiated) and showed that it underlies the Raritan of New Jersey. This general usage of the term Potomac to designate older deposits underlying the Raritan of New Jersey appears to have become general practice as exemplified by Richards (1967), Owens and Sohl (1969), and Petters (1976).

Lithology

The original lithologic definition of the Potomac Formation by McGee (1886a, b) has been restated in substantially its original form for Delaware by Jordan (1962, p. 6): "White, gray, and rust-brown quartz sands with some gravel; variegated white, yellow, and red silts and clays, with some beds of gray clay containing finely disseminated carbonaceous matter and lignite. These are generally irregularly interbedded." This description appears to be in accordance with those of other workers throughout the region as, for example, in New Jersey by Barksdale et al. (1958), and Owens and Sohl (1969); in Delaware by Marine and Rasmussen (1955), Groot (1955), and Sundstrom et al. (1967); and in Maryland by Weaver et al. (1968), Glaser (1968, 1969), and Hansen (1968, 1969b).

Sands constitute about 45 percent of the total thickness of the Potomac in Delaware (Jordan, 1968). Hansen (1969b) found about 60 percent sand in the Potomac Group (less the Arundel clay) in the Baltimore area, decreasing to about 20 percent in southern Maryland.

The clays of the Potomac are usually very fine and dense. As is the case with most "clays," they actually contain mostly silt. Groot (1955) provides several mechanical analyses of clay from the upper portion of the section in Delaware showing median grain sizes of 6Ø to 8Ø and Inman (1952) sorting coefficients between about 3 and 5. In outcrop the clays are not indurated, but are very "sticky." In deeper wells the clays are semi-indurated, approaching fine-grained mudstone.

Many mechanical analyses of the Potomac sands of Delaware are given by Groot (1955). The sands of the lower part of the Potomac ("Patuxent zone") are coarse to medium and generally well-sorted. They are positively skewed, except for the coarsest, and some are bimodal. Higher in the section ("Patapsco-Raritan zone") the sands are somewhat finer and siltier, more variable than below, and tend to be positively skewed and bimodal. Small amounts of gravel are reported from the basal Potomac in Delaware. More substantial gravel deposits are present in the basal units of Maryland (Darton, 1939) and in New Jersey (Owens and Sohl, 1969).

Cementation of sands and gravelly sands by limonite in thin ledges is common throughout the region. Such zones of induration may build to thicknesses of several feet. Cemented zones usually occur at the base of a sand overlying a dense clay, apparently as a result of local perching of ground water due to contrasts in permeability.

The clay mineralogy of the nonmarine Cretaceous deposits of the general area is characterized by Groot and Glass (1960) as dominantly kaolinite with illite and its alteration products. It was emphasized that other clay minerals are essentially absent. Owens and Sohl (1969, p. 270) found that: "The pattern is not as simple as that proposed by Groot and Glass (1960). For example, montmorillonite occurs in the Raritan near Trenton..." The "Raritan near Trenton" and the "Raritan Formation-Potomac Group(?) undifferentiated" of Owens and Sohl appear to be within the Potomac Formation as currently understood. Their table indicates a predominantly kaolinitic clay mineral suite with illite, but with some montmorillonite and mixed-layer clay as well.

There is agreement that the clay mineral suite of all of the nonmarine Cretaceous deposits of Delaware, Maryland, and New Jersey is dominated by kaolinite. Owens et al. (1961) report the clay minerals of the Raritan Formation near Trenton, New Jersey (Potomac?) are kaolinite with mica and those of the Magothy Formation of New Jersey are also kaolinite with mica, plus "...mixed-layered mica, montmorillonite and (or) chlorite..." In Maryland Knechtel et al. (1961, p. 7) described the clay minerals of the nonmarine Cretaceous as "...mixtures of kaolinite with illite and highly illitic mixed-layered clay."

Knechtel and others were able to distinguish a dominant highly colored "facies" from a smaller volume of duller clays, and attributed the former to ferric iron and the latter to iron in a reduced state. The brightly colored facies indicates oxidizing conditions and was found to contain little organic matter. It was postulated that these materials have undergone "...little or no chemical alterations since deposition..." The darker strata contained wood and reflect reducing conditions. These are lenticular and are distributed within the other facies, but seem to correlate with the Arundel Formation and also, presumably, with the Magothy Formation. The clay mineralogy of the two facies is similar except the darker one shows a slightly higher kaolinite content.

The sands of the Potomac are quartzose. Through the years authors have repeatedly referred to at least some of the sands as arkosic. The feldspar component is reported to be particularly prominent in the basal beds (e.g. Darton, 1939; Spangler and Peterson, 1950; Murray, 1961). Actual determinations of the feldspar content are very limited. Groot (1955, p. 27), dealing with the lower part of the section in northern Delaware, reported: "The sands contain varying amounts of feldspar, although, in Delaware, never enough to warrant the term arkose." Glaser (1968) states: the Patuxent Formation sands (and, by implication those of the Patapsco) are "...essentially orthoquartzitic." A detailed investigation by Glaser (1969) demonstrated that the "arkosic" Potomac sands are fallacious, except for the lower beds in Virginia for which he presents paleocurrent evidence of transport from a significantly different, more granitic, source terrain. It may be that the clay clasts frequently observed in the Potomac (and described by Glaser) have been mistakenly interpreted in the past.

The heavy mineral suite of the Potomac Formation is relatively simple, but discussions of its origin have been complicated. The suite is dominated by zircon, tourmaline, rutile, staurolite, and kyanite, i.e., the most resistant minerals plus an admixture of tough metamorphic minerals. The components of the suite have been established by several studies having compatible results: Groot (1955), northern Delaware; McCallum (1956), New Jersey; Glaser (1966, 1969), Maryland; Bennett and Meyer (1952), Baltimore area; Anderson (1948), deep subsurface; Dryden and Overbeck (1948), southern Maryland; and Owens and Sohl (1969), New Jersey.

The staurolite and kyanite are concentrated in the lower beds of the Potomac. Groot (1955) identified this as a staurolite-kyanite-tourmaline-zircon zone. In contrast, he found the upper portion of the Potomac to contain a tourmaline-zircon-rutile zone. These two zones were called, respectively, the Patuxent and Patapsco-Raritan zones. This distribution of heavy mineral suites is substantially confirmed elsewhere by the authors cited.

The younger rocks of the Atlantic Coastal Plain contain additional species of heavy minerals that contrast with the lack of variety within the nonmarine Cretaceous. Thus, Dryden and Dryden (1960) have described "limited" and "full" suites. The classification of particular suites and related stratigraphic units as limited or full and the possible relationship of the two types of suites to provenance and environment of deposition have generated significant discussion exemplified by Dryden and Dryden (1960), Groot and Glass (1960), and Owens and Sohl (1969).

In simplification the limited suite belongs to older, continental units (including those discussed in this paper) and the full suite is found in younger, marine strata. In the southern part of the Atlantic Coastal Plain the limited suite prevails throughout. Genetic implications of the full and limited suites can be found in possible relationships to tectonics, climate, paleogeography, source-rock composition, and diagenesis. Regardless of their origins, trace mineral zones should not be equated with rock stratigraphic units.

There is a contradiction between supposedly feldspar-rich sands and the postulated severe weathering necessary to reduce heavy mineral suites. The "arkosic" nature of the Potomac sands may be somewhat exaggerated in the literature although variations may be considerable and the trend toward greater amounts of feldspar in the lower sands may be valid.

Patuxent Formation

Nomenclature

Clark and Bibbins (1897) may have recognized the same sandier basal portion of the Potomac that was referred to earlier by McGee when they differentiated and named the Patuxent Formation. The Patuxent was described as a sand that is generally arkosic or gravelly.

"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).

Extent

Bascom and Miller (1920) mapped the Patuxent Formation in northern Delaware, but noted the highly variable lithology that made it difficult to distinguish within the Potomac Group.

In 1955, Groot reported several heavy mineral zones, one of which he named the Patuxent zone. Some confusion has arisen from this by other workers attempting to use the heavy mineral zone as an extension of the Patuxent Formation. For example, Kasabach and Scudder (1961) noted the occurrence of the Patuxent Formation in New Jersey. It appears this recognition is not widely accepted (Richards *et al*., 1962; Richards, 1967; Owens and Sohl, 1969).

In current usage it appears that the Patuxent Formation is distinguishable and limited to the area in the vicinity of Baltimore, Maryland where it is recognized and mapped by Glaser (1968, 1969), Hansen (1969a, b), and USGS (1967). This is related to the presence of the guide horizon represented by the Arundel Formation.

Lithology

The Patuxent Formation was described by Hansen (1969b, p. 1927) as: "Light-gray to orange-brown, cross-bedded, argillaceous quartzose sand with moderately sorted, angular, medium to coarse grains, and sub-rounded quartz gravel;

relatively thin, pale-gray to red silt and clay bands are interbedded."

The Patuxent Formation represents the basal part of the Potomac and is relatively sandier, coarser, and, supposedly, more feldspar-rich than the overlying beds. It appears to be differentiated from the Patapsco Formation by being sand and clay as opposed to clay and sand. The original description of the Patuxent by Clark and Bibbins (1897, p. 482) was based on such a distinction.

Arundel Formation

Nomenclature

Clark and Bibbins (1897) stated that in Maryland the Arundel Formation "...consists 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 Arundel was recognized as a clay that separates the sandy underlying Patuxent Formation from the clayey overlying Patapsco Formation.

Extent

Although the Arundel has sometimes been mapped throughout Maryland (Clark et al., 1911), it was not mapped in Delaware by Bascom and Miller (1920) or later workers, nor has it been recognized in New Jersey. Only Spangler and Peterson (1950) appear to have extended the Arundel Formation as far north as Delaware.

Current usage restricts the Arundel Formation to the vicinity of Baltimore, Maryland. Its importance as a marker horizon may be judged from the fact that where it is not present to separate the Patuxent and Patapsco formations, those units evidently cannot be distinguished from each other (Glaser, 1969). It is interesting to note that the most recent maps (Weaver et al., 1968; USGS, 1968) agree with Clark et al. (1911) in that the Arundel is not extended north of the vicinity of Aberdeen, Maryland.

Lithology

Clark and Bibbins description of the Arundel was revised by Hansen (1969b, p. 1927): "The Arundel Formation is a dark-gray to red lignitic clay containing abundant siderite concretions." It has been noted above that the dark colors considered indicative of reducing conditions by Knechtel *et al*. (1961) are correlated with the Arundel Formation.

Patapsco Formation

Nomenclature

The Patapsco Formation was originally found to "...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 interstratified..." (Clark and Bibbins, 1897, p. 489).

Extent

This upper unit has been mapped throughout the Coastal Plain of Maryland, as, for example, by Clark *et al*. (1911) and was recognized in Delaware by Bascom and Miller (1920). Spangler and Peterson (1950), in treating the stratigraphy of Maryland and Delaware as one entity, also used the Patapsco Formation in Delaware. Subsequent workers in Delaware, however, have been unable to distinguish the Patapsco as a separate unit (Groot, 1955; Jordan, 1962).

In a manner similar to that of the Patuxent Formation discussed above the term Patapsco has been used on occasion in New Jersey, but it is not clear how the Patapsco is differentiated there from other nonmarine Cretaceous units. It appears that the Patapsco can be reliably differentiated as a formation only where the underlying Arundel is present to separate it from the other materials of the Potomac Group.

Lithology

Hansen (1969b, p. 1927) provides a description of the Patapsco from its type area: "The Patapsco Formation in the Baltimore-Washington, D.C. area is a sequence of interbedded variegated (gray, brown, red) silt and clay and lenticular

cross-bedded, argillaceous, sub-rounded, fine- to medium-grained quartzose sand."

The Patapsco Formation, where it can be distinguished, corresponds to the upper portion of the Potomac Formation to the north which contains, in general, finer sands and more clay than the older beds below. Groot (1955) designated a heavy mineral assemblage as the "Raritan-Patapsco Zone," which should not be confused with rock stratigraphic units.

Raritan Formation

Nomenclature

The name Raritan is taken from Raritan Bay at the northernmost end of the study area. It was first applied to the deposits of that region by Conrad in 1869. The modern usage of the Raritan Formation and its various subdivisions in northern New Jersey is clarified by Owens and Sohl (1969, p. 238-239):

> At the type locality of the Raritan at Raritan Bay, the formation is exposed in a large number of pits, mainly south of the Raritan River. Ries, Kummel, and Knapp (1904), later modified by Berry (1906), divided these beds into several units:
>
> The Amboy stoneware clay
> Number 3 sand - chiefly quartz
> The South Amboy fire clay
> Number 2 sand - including beds of so-called "feldspar" and "kaolin"
> The Woodbridge, clay-fire [sic.], stoneware, and brick clays
> Number 1 sand - in part fire sand
> The Raritan clay-fire and terra-cotta clays
>
> Barksdale *et al*. (1943) named the Number 1, 2, and 3 sands the Farrington sand, Sayreville sand, and Old Bridge sand members, respectively, and this is the usage followed by the U. S. Geological Survey. The other

> names used by Ries, Kummel, and Knapp (1904) apply to economic beds and are considered informal terms by the U. S. Geological Survey.
>
> The beds listed above are chiefly interstratified light-colored sands and dark or variegated clayey silts or silty clays which vary in texture, composition, and thickness within short distances.

Owens and Sohl relegate the Amboy clay to the overlying Magothy Formation and place the top of the Raritan at the Old Bridge sand member. Wolfe and Pakiser (1971) assigned the Old Bridge sand member to the Magothy on the basis of continuity of the flora. Thus, in current usage the Raritan of the northern New Jersey type area is divided into the Raritan fire clay, Farrington sand member, Woodbridge clay, Sayreville sand member, and South Amboy fire clay.

Extent

Use of the term Raritan in New Jersey was extended away from the type locality to include the nonmarine sands and clays found throughout the State below the Magothy Formation (M. E. Johnson, 1950). Owens and Sohl (1969) found:

> A different facies of the Raritan occurs in the Delaware River Valley. Here the formation consists largely of thick interbeds of light-colored sands (similar to the sand of the Old Bridge and Sayreville members) and massive to thick-bedded variegated (shades of red, white, and yellow) silty clay (Greenman and others, 1961). Thick black clays containing abundant siderite concretions (Woodbridge clay) are absent. ...the sands have large-scale cross-stratification and abundant gravel (p. 239).

Bascom and Miller (1920) mapped the Raritan Formation farther south, into Delaware, but noted difficulty in differentiating the Raritan from the underlying Patapsco.

Clark _et al_. (1911) and Clark (1916) extended the use of the term Raritan into Maryland, applying it to the uppermost beds of the Potomac deposits. The problems inherent in

extending the Raritan so far from its type locality have been pointed out by Spangler and Peterson (1950), Groot and Penny (1960), Owens (1969), and Hansen (1969b) among others. Hansen summarized (p. 1924):

> Historically the uppermost nonmarine Cretaceous strata in southern Maryland were assigned to the Raritan Formation (Clark and Berry, 1916). Those beds, however, are lithologically indistinct from the underlying Patapsco Formation and apparently do not contain diagnostic fossils. As a result, many recent workers have included them in the Potomac Group without differentiating them from the Patapsco Formation (Weaver et al., 1968).

The use of the term Raritan in Maryland appears to have been rejected as it had been previously in Delaware (Groot, 1955; Jordan, 1962). The regional geologic map interpretation of the U. S. Geological Survey (1967) restricts the Raritan Formation to the area of its original designation in northern New Jersey.

Petters (1976) identified the downdip equivalent of portions of the Raritan Formation and the uppermost part of the "Upper Potomac Group" in New Jersey as the Bass River Formation. As the Bass River is entirely subsurface, it is beyond the scope of the present discussion.

Lithology

The restricted Raritan Formation is most completely described by Owens and Sohl (1969, p. 239) in terms of its component members: The Woodbridge clay is mostly dark silt and clay. "It is largely a thin- to thick-bedded sequence of micaceous silts and clays, containing an enormous amount of woody fragments and siderite concretions." Marine fossils and organic borings are found.

> The South Amboy clay is thinner (maximum thickness of 35 feet) and less widespread (lenses rapidly) than the Woodbridge clay and lacks siderite concretions as well as marine fossils.
>
> The Sayreville and Old Bridge Members [sic., Old Bridge later considered to be part of

> Magothy Formation] are largely light-colored, medium-grained sands which locally have interbeds of light- to dark-colored clayey silts. Not uncommonly, the silty strata are disrupted forming intraformational breccias. Coarse sandy beds are abundant in both members, but gravel is rare. The sandy beds in both members are extensively cross-stratified with the scale of the planar beds varying from a few inches to several feet. The larger scale cross-strata appear to be more common in the Old Bridge than in the Sayreville. The Old Bridge is thicker and more persistent at the surface and in the subsurface than the Sayreville (Barksdale and others, 1943, fig. 3).

Owens and Sohl also reported that the Raritan contains only zircon, tourmaline, and rutile as heavy minerals. Their analyses of the clay mineralogy show primarily kaolinite, usually with illite, plus rare mixed-layer, mica-glauconite mixture, and montmorillonite clays.

Magothy Formation

Nomenclature

Of all of the units considered the Magothy Formation is the most clearly defined and its taxomony the least complicated. The name derives from the Magothy River of Maryland where the unit was first described by Darton (1893).

Extent

Clark (1904, p. 438) stated that he 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." All subsequent authors appear to have had little difficulty in agreeing on the nature of the Magothy and in identifying its distinctive lithology throughout the area. It is mapped at the Chesapeake and Delaware Canal in Delaware by Pickett (1970).

Only in the Raritan Bay area of New Jersey has the Magothy been subdivided. Owens and Sohl include in the Magothy the Amboy stoneware clay, the Morgan beds, and the Cliffwood beds. Wolfe and Pakiser (1971) added the Old Bridge Sand member,

originally considered part of the Raritan Formation, as the basal member of the Magothy Formation. These units cannot be distinguished outside of the Raritan Bay area. As stated by Owens and Sohl (1969, p. 242):

> Southwest of the Raritan Bay area, in the vicinity of Trenton, the Magothy thins to approximately 50 feet and the three subdivisions of the Magothy are no longer evident. Here the formation consists of rapidly lensing dark clays and light-colored sands.

Lithology

The Magothy Formation consists, at its simplest, of the alternating dark clays and light sands that were described and named by Darton in the valley of the Magothy River of Maryland in 1893. Other authors have provided additional detail.

Weaver et al. (1968) described the Magothy in Maryland as "loose, white, cross-bedded, 'sugary', lignitic sands and dark gray, laminated silty clays; white to orange-brown, iron-stained, subrounded quartzose gravels in western Anne Arundel County; absent in outcrop southwest of Patuxent River; thickness 0-60 feet."

In Delaware Jordan (1962, p. 9) found the Magothy to be "white and buff, angular to subangular quartz sand, irregularly cross-bedded, and beds of gray and black clayey silt containing abundant finely disseminated organic matter and lignite."

In New Jersey Owens and Sohl (1969, p. 239) described the Magothy at Raritan Bay as "...intercalated dark carbonaceous-rich silty clays or clayey silts and light-colored sands." They include the Amboy stoneware clay, dark, micaceous silt with abundant carbonaceous matter, in the Magothy. They further recognized the "Morgan beds" and "Cliffwood beds" as subdivisions of the Magothy. The former consists of dark clays and silts and light sands and the latter are dominantly sands also containing dark clays. Carbonaceous materials are common throughout. The Old Bridge sand member later included in the Magothy was described by Owens and Sohl (1969) as "largely light-colored medium-grained sands which locally have interbeds of light- to dark-colored clayey silts." (p. 239).

The sands of the Magothy Formation are predominately medium to fine and well-sorted. The lighter colored sands are generally cleaner. Gravel is sometimes present in small amounts. Cross-bedding is common and often outlined by concentrations of heavy minerals. Gray and buff sands are siltier and clayier than the white ones. The dark units commonly referred to as clays are generally quite silty. Bedding is frequently very thin and usually individual beds do not exceed a few feet in thickness. In total there is probably somewhat more sand than clay in the formation. The dark color is caused by finely divided and disseminated particles of carbonaceous material. Pieces of lignite and fresh-appearing wood up to the size of large tree limbs are found in the Magothy. Siderite, pyrite, and marcasite are found as concretions or as replacements of or coatings on lignite.

The sands are very dominantly quartzose, with feldspar appratently present only as a minor admixture. Glaser (1969) lists no feldspar in four samples of the Magothy from Maryland.

The heavy minerals of the Magothy Formation are subject to much of the discussion that has been described in connection with the heavy minerals of the Potomac Formation. Groot (1955) classifies the Magothy heavy minerals as belonging to a staurolite-tourmaline zone. He notes that the suite is very similar to that described as the Patuxent zone, but that the Magothy contains even more abundant staurolite. In addition to staurolite, tourmaline, zircon, and rutile, Groot found anatase, kyanite, and epidote sometimes present in small amounts. The Magothy appears to represent the transition between the limited and full heavy mineral suites of the Atlantic Coastal Plain (Dryden and Dryden, 1960; Groot and Glass, 1960). Sohl and Owens (1969) described heavy minerals from the Magothy Formation of northern New Jersey where they found the suite dominated by zircon, tourmaline, and rutile, and also containing staurolite, garnet, sillimanite, kyanite, chloritoid, and epidote. They noted that the number of heavy mineral species increases upward through the Magothy Formation and they defined it in the Raritan Bay area. This transition in mineral suites through the Magothy appears to be another indication of the correlation of the limited suite with nonmarine rocks and the full suite with marine beds.

Groot and Glass (1960) described the clay minerals of the Magothy as a kaolinite-mica-chlorite assemblage which

contains montmorillonite in some cases, especially in the upper part of the formation. Kaolinite and illite also dominate the clay mineral assemblage of the Magothy Formation in northern New Jersey according to Owens and Sohl (1969) and some variable amounts of mixed layer, vermiculite, and montmorillonite clays are found.

ENVIRONMENTS OF DEPOSITION

The subaerial deposition of almost all of the materials under consideration has long been accepted. The predominantly red, yellow, and brown colors, conspicuous plant remains, sedimentary structures, and frequent abrupt lithologic transitions are satisfactory evidence of continental, as opposed to marine, deposition. The framework is an alluviating plain spreading in multiple fan-like fashion along the margin of the Appalachian Highlands. The relationships of the distal portions of the deposits with the bordering sea and, indeed, the nature of the continental margin itself is important but beyond the scope of this paper.

Evidence for shifting deltaic complexes has been noted by several authors. Hansen (1969b) presented the analogy of the Potomac Group of Southern Maryland with the delta of the Niger River. Owens et al. (1968) and Owens and Sohl (1969) have emphasized the deltaic evolution of the Raritan section of northern New Jersey. Gill, Sirkin, and Doyle (1969) have described four deltaic masses, localized by basement tectonics, from Delaware to northern New Jersey.

In Delaware, Groot (1955, p. 103) found the environment of deposition of the Potomac Formation was "... a low-lying, swampy coastal plain in which fluviatile bimodal sediments were deposited, some in brackish, swampy lagoons and estuaries, and some in stream channels and flood plains." He noted also the presence of pyrite and marcasite with lignite fragments and related this to the presence of brackish water. Spoljaric (1967) identified fluvial sand bodies in the subsurface in the form of "shoestring channels." Among others, Rima et al. (1964), Sundstrom et al. (1967), and Jordan (1968) have written about the distribution and probable complex continuity of the sandy channels in Delaware.

Hansen's (1968, 1969b) studies of geophysical logs, lithologies, and hydrology concluded that a huge delta system spread south and southeast from a "major axial river system" debauching on the Coastal Plain near Baltimore. He differentiated braided and meandering delta sand channels and, assuming the latter would be downstream, traced sands of the Potomac and Patapsco formations away from the source stream. In concentric array he found a flood plain characterized by meandering streams bordered beyond by a "fringing swamp zone." The Arundel Formation was considered a paludal facies intervening between the Patuxent and Patapsco formations.

Glaser's (1969) study of the Maryland materials indicated that Patuxent deposition was dominated by braided streams. There were probably several principal channels spaced some miles apart and the major streams might be expected to shift channels from time to time. The Arundel Formation was considered a back swamp deposit on the plain. The Patapsco appeared to have been deposited by meandering streams on a low deltaic plain. Glaser found the Magothy to be estuarine and marginal deltaic, with some channels.

The Magothy of both Maryland and Delaware is recognized as transitional to marine conditions (Groot, 1955; Glaser, 1968). It contains some fluvial channels, but its more continuous and widespread sands suggest lagoonal or estuarine conditions. Its abundant flora indicate swampy coastal conditions. It may be that the "fluvial" channels were at least in part, tidal. This interpretation appears satisfactory as far north through New Jersey as the Trenton area.

In the Trenton-Raritan Bay area detailed studies by Owens et al. (1968, 1969) have characterized the environments of deposition of the subdivisions of the Raritan and Magothy formations. The oldest unit, the Raritan fire clay, was deposited subaerially on a deltaic plain. The cross-bedded sands in the Raritan, the Farrington, Sayreville, and Old Bridge members, represent fluvial channels and the accretion of coarse detritus in point bars or channel bars. The Woodbridge clay was deposited in "marginal-marine mangrove-type swamps." It contains abundant plant remains, shallow marine fossils, perhaps of brackish affinities, and Callianassa-type intertidal burrows. "Slack water" subaerial deposits on the delta plain are present in the form of the South Amboy fire clay and also the Amboy stoneware clay placed in the Magothy Formation. Overbank interbedded sands and clays of flood plains predominate in the Morgan beds and are also found in parts of the Woodrbidge and Old Bridge. The uppermost

Cliffwood beds represent distributary channels with a significant marine influence.

In summary, many terms have been used to characterize the paleogeomorphic features and depositional environments of the Potomac and Magothy formations in and near Delaware. The scale of the features identified and the precision of terminology has varied. "Delta" has been persistantly used to describe the general environment of deposition of the Potomac. Because of the predominance of fluvial, continental features in the Potomac of Delaware, "delta," which connotes deposition into a body of water, is somewhat misleading. It is suggested that the general paleoenvironment represented by the Potomac in Delaware is an alluvial plain, or more precisely, an aggrading coastal plain in the sense that term is used by Galloway (1982).

The transition from nonmarine to marine deposition to the east must have been an irregular boundary that shifted through time. "Marine" beds in the sediment complex have been reported, mostly from wells. The faunas are indicative of shallow, and even brackish, marine conditions and probably relate to marginal deltaic and estuarine environments.

AGES

Most age information on the nonmarine Cretaceous rocks is determined from paleobotanical studies. The earliest of these emphasized plant fragments and later efforts have employed palynology. Reducing conditions favor preservation of woody materials, pollen, and spores, so studies tend to concentrate on the darker units. However, small lenses of dark clay seem to be present in sufficient quantities throughout the section and area to permit general study of the entire sequence.

The paleobotanical investigations by Berry (1911), Dorf (1952), Groot and Penny (1960), Groot, Penny, and Groot (1961), Brenner (1963), Doyle (1969, 1977), Wolfe and Pakiser (1971, and Doyle and Robbins (1977) are the bases for this discussion of the ages of the several units. These authors are in agreement that the time interval represented by the rocks from the basal Potomac through the Magothy straddles the Early/Late Cretaceous time division. Unfortunately, age assignment to Early or Late Cretaceous has been used by some to differentiate between "formations," especially the Arundel and Patapsco and

the Patapsco and Raritan, a practice that is no longer acceptable.

The paleobotanists agree that the Potomac Formation (or group) ranges from Barremian through Albian. Doyle (1969) suggests that the basal beds may not be older than Aptian and, together with Groot and Penny (1960), would extend the sequence into the Cenomanian.

Where the Potomac is subdivisible in Maryland, the Patuxent Formation is taken by Berry (1911), Dorf (1952), and Brenner (1963) to be restricted to the Neocomian, although Doyle finds it somewhat younger, mostly Aptian.

The Arundel was included in the late Neocomian by Berry and in the Aptian by Dorf. Brenner considers it Barremian-Aptian and Doyle, Aptian-Albian.

The authors generally agree on an Albian age for the Patapsco, with Doyle (1969, 1977) indicating it as a bit younger than the others and extending into the Cenomanian.

The Raritan Formation is considered to be Cenomanian to Early Turonian.

There appears to be less agreement on the age of the Magothy than on the other units. Berry (1911) and Richards (1967) cited as Late Cenomanian-Early Turonian. At the other extreme, Doyle (1969, 1977) considers it to be Santonian. Dorf (1952) gives a Coniacian age and Groot, Penny, and Groot (1961) Late Turonian to Early Coniacian.

All of the units may be considered facies in a single depositional sequence and, as such, may be expected to be time transgressive. Not only may ages vary with location, but the difficulty or inability to distinguish lithologic units in sampling (Groot and Penny, 1960) adds to the spread in these age determinations.

A major unconformity lies between the basal Potomac beds and the crystalline basement of Precambrian or Early Paleozoic age. At the extreme northern and southern ends of the study area the "basement" rocks are Triassic red beds (Spangler and Peterson, 1950; USGS, 1967). The major basal unconformity of the Atlantic Coastal Plain sequence corresponds to the Fall Zone peneplain of Appalachian terminology (D. W. Johnson, 1931).

The Patuxent-Arundel contact is described by Clark and Bibbins (1897) in a manner suggesting an erosional unconformity; however, the paleobotanical evidence cited above emphasizes the similarity of the Patuxent and Arundel floras and none of the paleobotanists has suggested a significant unconformity.

Berry (1911) indicated a hiatus equivalent to the Aptian occurring between the Arundel and Patapsco formations. Brenner (1963) found that the unconformity between the Arundel and Patapsco is relatively minor. Other paleobotanists have felt that no break exists or that it is of insignificant magnitude.

Only Dorf favored an unconformity between the Patapsco and Raritan formations. However, it is not clear in all cases whether the writers were dealing with the Raritan that has been extended through New Jersey, Delaware, and Maryland or only with the Raritan of northernmost New Jersey. As explained above the "Raritan" of Maryland is now included with the Patapsco Formation and must be considered a continuous unit. The Raritan in the restricted sense appears to be significantly younger than that of Maryland and lies unconformably on the uppermost Potomac of New Jersey (Doyle, 1969; Owens and Sohl, 1969).

An unconformity between the Magothy Formation as a traditional transgressive marine unit and the underlying Raritan or Potomac Formations is to be expected (Jordan, 1962). Dorf and Doyle both consider this break to be a hiatus of considerable length. On the other hand, Groot, Penny, and Groot (1961) state that it is a minor unconformity.

In the Atlantic Coastal Plain Correlation Chart prepared for the COSUNA project of AAPG (Jordan and Smith, 1983), the "Potomac Group (undifferentiated)" of New Jersey and "Potomac Formation" of Delaware, in outcrop areas, are shown as mid-Aptian to Lower Cenomanian. In the outcrop areas of Maryland the Potomac is presented as Barremian to Albian or Cenomanian. Unconformities are shown at all contacts.

On the same chart, the Raritan Formation of New Jersey is considered to range from Early Cenomanian to mid-Turonian. It is not considered to be present in the inner Coastal Plain of Delaware or Maryland.

The COSUNA chart shows the Magothy of New Jersey ranging through the Santonian to the lowermost Campanian. In the

outcrop area of Delaware it is considered restricted to the uppermost Santonian. In the type area of Maryland it is shown as mid-Santonian to mid-Campanian. The authors of the COSUNA chart indicate that the Magothy approximately retains its age downdip, except that it may be as young as lowermost CAmpanian in coastal New Jersey. In the deep subsurface of southeastern New Jersey and coastal Delaware and Maryland the base of the Potomac is considered to lie in the Jurassic.

SUBDIVISIONS AND CORRELATIONS

The subdivision of the Potomac Formation into the Patuxent, Arundel, and Patapsco formations in a part of Maryland has been described, as have the components of the Raritan and Magothy formations found near Raritan Bay, New Jersey. The ability to distinguish subdivisions in these localities is enhanced by exposure and relatively dense well control. In Delaware, the thick Potomac Formation with its various sand and clay beds begs subdivision, which would be advantageous to geologic study, especially to applied hydrology, in order to correlate within the Potomac on a valid and consistent basis. The great number and similarity of individual lenses of sand and clay have, thus far, generally precluded the identification of units and impeded the correlation of single beds between even closely spaced wells in Delaware. The basic problems of correlation internal to the Potomac Formation have been discussed by Spoljaric (1967), Jordan (1968), and Hansen (1969a, b). Referring to northeastern Maryland, Owens (1969, p. 91) found "...There is no compelling evidence to support a tripartite division within the Potomac Group."

Spoljaric (1967) studied a small part of New Castle County, Delaware having comparatively good well control. He constructed lithofacies maps for seven "slices," based on statistical considerations, of an approximately 900-foot thick Potomac section. He concluded that deposition was continuous throughout Potomac time; that the geometry of the sands is channel-like and their trends persistent through time; that basement configuration strongly influenced initial deposition; and that erosion has removed the uppermost Potomac deposits. If adequate control can be provided, this method seems promising for following specific lithologies within the heterogeneous sedimentary package.

In Maryland, Hansen (1969a) was able to extend and correlate subdivisions of the Patapsco Formation by relating

subsurface geometry to a perspective point based on a method described by Haites (1963). Both this and Hansen's (1969b) subsurface correlations of the Potomac Group in southern Maryland based on interpretations of facies generated by environmental controls are substantiated by hydrologic data.

Jordan (1968) and Sundstrom et al. (1967) plotted the occurrences of sand and clay within the Potomac in New Castle County, Delaware relative to basement datum. Zones of high and low sand/shale ratios were defined by graphing the percentages of wells having sand or clay at a given interval above basement. Sandy and clayey zones so defined provide correlation and agree with empirical hydrologic testing of the aquifers.

At least within northern Delaware, where the Potomac is heavily used for ground-water supplies, correlation of individual bodies of sand or silt for even short distances between wells is difficult. Marker horizons that might indicate the internal geometry of the rock mass have not been found. Many sands of similar lithology are imbedded in a complex, poorly understood, three-dimensional pattern within a matrix of rather uniform variegated silt. It is likely that the original architecture of the mass has been modified by compaction, which should have been differential depending on the sand/clay ratios of specific columns.

The relationships of the lithostratigraphic units discussed, as currently understood, is shown in Figure 3. It does not seem that additional formal lithostratigraphic subdivision of the Potomac Formation in northern Delaware is liekly or warranted. However, definition of lithologic zones, trends, and aquifers through statistical and geometric applications may be accomplished. It is also probably that greater age control can be achieved through palynology and that significant advances will be made in the interpretation of paleoenvironment.

Care should be exercised, however, to avoid comparison between formal lithostratigraphic nomenclature and other means of stratigraphic subdivision.

This study has been restricted to the inner margin of the Coastal Plain where the stratigraphic terminology has originated historically from investigations of outcrops and shallow wells. The rocks identified there as Potomac and Magothy formations extend far to the east into the deep subsurface of the Coastal Plain and have equivalents in its

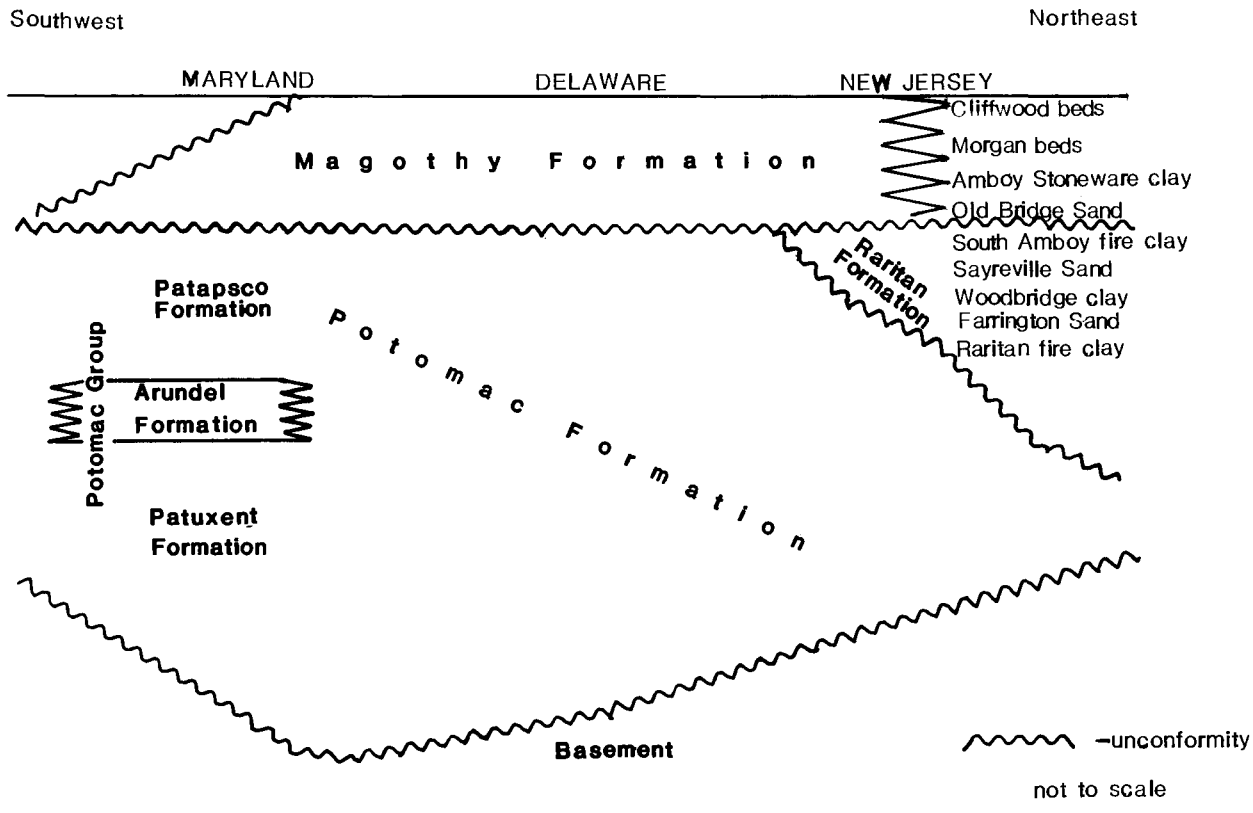


Figure 3. Schematic diagram of lateral and vertical relationships of nonmarine Cretaceous deposits. Compiled and modified from: Doyle, 1967; Jordan, 1962; Owens and Sohl, 1969; U.S.G.S. 1967; Weaver, et al., 1968.

offshore extension, the Baltimore Canyon Trough. Information from offshore is adding markedly to knowledge of the stratigraphy of the entire region. The gap of 200 miles from the outcrop belt to the sites of recent petroleum exploration is incompletely bridged with seismic profiles and sparse well control. Interpretation of information across that gap, which should be possible because of apparent continuity of some strata and the genetic relationships of others, offers promise for development of a regional stratigraphic framework.

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