SOME ASPECTS OF THE MINERALOGY OF THE NORTHERN ATLANTIC COASTAL PLAIN

by

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ABSTRACT

Studies of the mineralogy of the northern part of the Atlantic Coastal Plain indicate that the heavy mineral content of the Cretaceous and Cenozoic sediments consists basically of two suites, a restricted mineral suite characterized by very stable minerals, and a full suite consisting of a great variety of igneous and metamorphic minerals. The restricted suite occurs in the nonmarine sediments and the full suite in the marine deposits.

The nonmarine Cretaceous deposits consist of kaolinite, with variable amounts of illite and its alteration products. Transition sediments like those of the Magothy formation contain kaolinite, illite, chloritic material and, occasionally, some montmorillonite. The marine sediments are characterized primarily by illite and montmorillonite. Thus, a limited heavy mineral suite and kaolinite are associated in nonmarine deposits, and a full suite and montmorillonite are found in marine sediments.

On the basis of available data the conclusion is reached that the different heavy mineral and clay mineral suites are a result of different source areas for the marine and nonmarine sediments.

The suggestion is made that the formational concept cannot be employed with regard to the nonmarine sediments of the northern Coastal Plain but that, instead, a new concept be adopted based on depositional conditions within the framework of the control of the heavy and clay mineral assemblages.

INTRODUCTION

During the last few years, several investigations of the mineralogy of the Cretaceous sediments of the Atlantic Coastal Plain have been made. Some of these studies were used to attempt clarification of controversial questions such as weathering in the source area vs. intrastratal solution, the mineralogy of the source area and direction of transportation of the sediments, and their environment of deposition. Other investigations had as their primary objective the subdivision of Cretaceous sediments into heavy mineral zones for stratigraphical purposes.

The present paper summarizes and evaluates the data published to date, and introduces some additional information concerning heavy minerals and clay minerals of the Cretaceous sediments of New Jersey, Delaware and Maryland. An effort is made to throw some light on the controversial questions mentioned above.

The senior writer is responsible for the presentation and interpretation of the heavy mineral data; the junior writer investigated the clay minerals. The conclusions pertaining to the environment of deposition and probable source area of the sediments are the writers' joint responsibility.

HEAVY MINERALS

Historical

Anderson *et al.* (1948) described the mineralogy, and especially the heavy minerals, of a number of cores from a deep oil test in the Salisbury, Maryland, area. In view of the lack of fossils in the sediments of the Potomac group, the boundary between the Patuxent and Arundel–Patapsco (undifferentiated) formations was selected on the basis of heavy minerals, the Patuxent being characterized by a high staurolite percentage and little or no epidote, and the Arundel–Patapsco by sparse staurolite and abundant epidote.

In the Baltimore, Maryland, area staurolite is also characteristic for the Patuxent formation, whereas the Patapsco formation lacks this mineral (Bennett and Meyer, 1952). Thus, the presence or absence of staurolite may have stratigraphic significance.

Groot (1955) investigated the heavy minerals of the Cretaceous sediments of northern Delaware. He found that the nonmarine sediments contained a lower staurolite–rich zone and an upper zircon–tourmaline–rutile zone. Later study of deep well samples revealed a lower zircon-rich zone overlying the crystalline basement and underlying the staurolite zone. Similar zones were found by McCallum (1957) in New Jersey. Thus, the nonmarine Cretaceous sediments have uniformity of mineral content in Maryland, Delaware, and New Jersey, at least along the strike. Their main characteristic is their limited suite.

The marine Cretaceous sediments of Delaware and New Jersey have a suite containing a great variety of minerals, including epidote, sillimanite, chloritoid and garnet (Groot, 1955; Reed, 1956). Thus, they have a full suite of common heavy minerals.

Dryden and Dryden (1956) made a thought-provoking study of the heavy minerals of Cretaceous and Cenozoic sediments of the Coastal Plain from New Jersey to Alabama. After investigating hundreds of samples as well as studying data reported in previous publications, they reported the following:

> On the basis of heavy minerals, the Atlantic Coastal Plain can be divided into a northern and southern part; the boundary between the two has not been sharply defined, but it lies within a belt 100 miles wide in northern North Carolina. In both areas there is a " full " suite, containing all of the common heavy minerals of the nearby crystalline rocks, and a " limited " suite, lacking garnet, epidote, chloritoid, and hornblende. However, the distribution of these two suites is different, in time and space.
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> In the north, a limited suite is found in the (generally) older, nonmarine sediments, and a full suite in the rest of the Coastal Plain, Cretaceous to Pleistocene. In the south, a limited suite is found throughout the Coastal Plain sediments, marine and nonmarine, except for low-lying Pleistocene and certain Recent deposits.

Limited Suite

Groot (1955) and McCallum (1957) have described the limited suite in detail. The very stable minerals tourmaline, zircon and rutile are the predominant constituents, with abundant staurolite only in sediments assigned to the Patuxent formation in Maryland (Bennett and Meyer, 1952). McCallum found that, in New Jersey, the Cretaceous deposits overlying the crystalline basement contain mainly zircon ; this zircon zone is overlain by a staurolite-rich zone, which in turn is overlain by a zircon–tourmaline zone. The same sequence of mineral zones was found in a well near Delaware City, Delaware (unpublished data in the file of the Delaware Geological Survey).

Groot (1955) studied the tourmaline grains of the limited suite occurring in Delaware. He found that they are generally angular to subangular. In the stratigraphically lower portion of the nonmarine deposits, in the zircon zone and the lower part of the staurolite-rich zone, no oval-shaped, well-rounded grains occur. In the stratigraphically higher portions, however, the percentage of such grains gradually increases in progressively younger nonmarine deposits.

On the basis of available data the limited suite appears to have a wide geographic distribution because it occurs in New Jersey, Delaware, and Maryland in strata that are undoubtedly of nonmarine origin. According to Dryden and Dryden (1956) the limited suite occurs also in the nonmarine and marine deposits of Cretaceous and Cenozoic age in the southern part of the Atlantic Coastal Plain. Although this paper is primarily concerned with the northern part of the Coastal Plain, this phenomenon is mentioned because it has a direct bearing on the interpretation of the mineral suites in terms of source area.

Full Suite

The full suite is characterized by abundant epidote and the consistent occurrence of staurolite, chloritoid, sillimanite, kyanite and andalusite in addition to the very stable minerals occurring in the limited suite. The minerals of the full suite have been described in detail by Anderson *et al.* (1948), Groot (1955), and Reed (1956).

The full suite occurs in the marine Cretaceous and Cenozoic sediments of the northern Atlantic Coastal Plain, from New Jersey to northern North Carolina (Dryden and Dryden, 1956). It is also found in upper Cretaceous sediments considered largely nonmarine (Anderson *et al.*, 1948).

In a well drilled at Port Penn, Delaware, a bed of marine deposition (as indicated by the presence of glauconite and foraminifera), was found at a depth of 570–578 ft below land surface. This bed is overlain and underlain by the variegated clays and white and gray sands that are characteristic of the nonmarine Cretaceous deposits containing the limited suite. The marine bed, however, contains a full suite, including epidote, garnet, sillimanite and andalusite (data in the file of the Delaware Geological Survey).

Source Areas

The source area of the nonmarine Cretaceous sediments of the Coastal Plain is clearly located in the Piedmont and, to a smaller degree, in the Paleozoic sediments of the Appalachian Mountains. Clark, Bibbins and Berry (1911), specifically mentioned as a source area for the Patuxent and Patapsco formations the crystalline rocks lying to the west of the present Fall Line.

Dryden and Dryden (1946) noted that the majority of the tourmaline grains found in the sediments of the Potomac group are identical in varietal characteristics with those of the Wissahickon formation of Delaware, Maryland, and Pennsylvania. Groot (1955) also demonstrated that the heavy minerals occurring in the Potomac group sediments in Delaware were derived largely from the nearby Piedmont. A detailed study of tourmaline grains showed, however, that the percentage of oval-shaped, well rounded grains of second (or more) cycle origin increased in progressively younger nonmarine Cretaceous deposits. This was interpreted by Groot as an indication that the Paleozoic rocks of the Folded Appalachian Mountains supplied an increasing quantity of material to these deposits.

Determination of the source area of the marine Cretaceous sediments, which contain a full suite in the northern Coastal Plain and a limited suite in the southern Coastal Plain, presents a difficult problem. It cannot be solved until fundamental questions pertaining to source-rock weathering and intrastratal solution are clarified. Dryden and Dryden (1956) dealt with these questions in their paper presented before the International Geological Congress in Mexico, and the present writers want to add some comments to the Drydens' presentation.

Source-rock Weathering and Postdepositional Weathering

The crystalline rocks of the Piedmont, which are believed to have furnished most of the material for the Coastal Plain sediments, contain a great variety of accessory minerals; these minerals should be present in the sediments.

Inasmuch as many of the accessories do not occur in the nonmarine deposits of the northern Coastal Plain and the nonmarine and marine deposits of the southern Coastal Plain (which contain the limited suite), they must have disappeared as a result of weathering. The question is only: is this limited suite a result of weathering in the source area or in the area of deposition?

Continuous severe weathering in the source area could easily explain the occurrence of the limited suite in the southern Coastal Plain, but the presence of the full suite in the marine Cretaceous and Tertiary formations of the northern Coastal Plain poses a problem. Seemingly, only two possible explanations exist:

(a) for some reason weathering in the source area of the northern Coastal Plain sediments decreased sharply during late Cretaceous time; or (b) the marine Cretaceous sediments of the northern Coastal Plain have a different source area than those of the southern Coastal Plain.

The first alternative appears to be unrealistic inasmuch as it is generally assumed that during Cretaceous time no sharp climatic difference existed in the area under consideration. Rather warm and humid climatic conditions probably prevailed throughout the area. The second alternative seems more likely, and some arguments in its favor will be presented later.

If now some thought is given to postdepositional weathering as being responsible for the limited suite, the following possibilities must be considered: (a) intrastratal solution, and (b) subaerial weathering of slowly accumulating continental sediment. Intrastratal solution, although probably effective over very long periods of time as shown by Pettijohn (1941, 1957) can hardly be responsible for the differences in mineral content observed in the Atlantic Coastal Plain. Dryden and Dryden (1956) stated:

> . . . in either area, north or south, post-depositional solution may be thought of as a potentially important factor in determining what kind of heavy mineral suite will persist. But when northern and southern areas are considered together, this explanation is seriously weakened. Each area has quite a variety of sedimentary rocks, ranging from coarse-grained, poorly-sorted, nonmarine sand and gravel to well-bedded, fine-grained, marine sand, silt and clay. If solution would have produced a limited suite in all these lithologic types in the south, it should have been just as nonselective in the north. And if in the north, its action was restricted to the earlier part of Coastal Plain history, it seems unlikely that in the south its action would have continued almost to the present. Post-depositional solution may have played a role, but apparently not the major one.

Recent observations tend to affirm this view. The occurrence of a lens of glauconitic sand in a well at Port Penn, Delaware was mentioned before. This sand contains a full suite whereas in the same area sand of the same age but of nonmarine origin contains the limited suite. This phenomenon is not consistent with the hypothesis that intrastratal solution is primarily responsible for the limited suite.

Subaerial weathering of slowly accumulating nonmarine sediments could have occurred during early and middle Cretaceous time, and this would easily explain the presence of the full suite in the marine bed of the Port Penn well, and in the marine upper Cretaceous deposits of the northern Coastal Plain. However, two questions arise which cast doubt on the validity of this type of postdepositional weathering. First, would it not be truly amazing that garnet, epidote, sillimanite and other minerals, which are common in the full suite of the marine beds, completely failed to survive weathering when accumulating as nonmarine sediments in the Coastal Plain? And, secondly, why would the marine sediments of the southern Coastal Plain have been deprived of so many minerals when those in the north escaped postdepositional weathering?

The full suite could have originated as a result of active diastrophism in the source area, but we can hardly assume that this happened in the north and not in the south. Less severe chemical weathering in the north as a result of a cooler climate might also be responsible. Again, climatic differences between north and south presumably were small, humid–warm conditions prevailing. Thus, climate, diastrophism, and postdepositional weathering probably can be excluded as basic causes for the occurrence of the full and limited suites.

This reasoning, if correct, points to provenance as the main factor responsible for the two different suites. The influence of provenance could be interpreted in two ways:

(1) North and south could have received second- (or more) cycle sediments

up to Merchantville time. These second-cycle sediments would then contain a limited suite. During and after Merchantville time, crystalline source rocks were uncovered in the north, producing a full suite in the northern Coastal Plain, while the limited suite (or second-cycle suite) persisted in the south. The main objection to this interpretation is that marine-facies sediments older than Merchantville contain a full suite. In addition, most of the heavy mineral grains in the limited suite are quite angular and show no sign of long transportation. For instance, tourmaline thought to have been derived from the Wissahickon formation commonly is angular in the nonmarine Cretaceous sediments, a fact which does not point to second-cycle origin.

(2) The only other explanation seems to be that the marine Cretaceous (as well as Tertiary) sediments in the north received material from a different source than those in the south, and that this source was not available in the southern Coastal Plain (except perhaps in late Pleistocene time). This source must have contributed clastic material by means of longshore currents, and it became, therefore, not available to the nonmarine sediments which continued to consist of relatively weathered material. Thus, the full suite could be explained in the marine sediments in the New Jersey, Delaware, Maryland–Virginia area and the limited suite in the nonmarine sediments. If this explanation is correct, facies differences *per se* have nothing to do with differences in mineral suites; rather, they are a result of differences in provenance.

The above reasoning points to provenance only because other factors have been eliminated as inconsistent with the known facts. Proof of an additional source area for the full suite remains to be presented.

CLAY MINERALOGY

Clay mineral compositions in unconsolidated sedimentary formations are controlled principally by two interrelated factors: (a) the contribution from the source area and (b) differential segregation in the depositional environments. Differences in clay mineral compositions have at times been attributed to diagenesis, but this factor is considered of little importance in the sediments of the northern Atlantic Coastal Plain.

Related to the factors that determine clay mineral composition is the accompanying heavy mineral suite. The concept of the full and limited suites of heavy minerals affords opportunity for determination of change in source direction as well as an appraisal of the maturity of the contribution. It is thus possible that, for a given area of sedimentation, source area contributions may differ and preferential segregation may have been operative, and an extremely complicated pattern of clay mineral distribution may result. Because of this complexity, clay mineral analyses should be evaluated within a given heavy mineral suite (full vs. limited) to determine the contribution and segregation factors from a homogeneous source area. Only when the mineralogy of the individual suite has been evaluated may clay mineral analyses be meaningfully compared between different suites having different source areas.

TABLE 1.—QUALITATIVE CLAY MINERAL DISTRIBUTION IN SOME FULL SUITE UPPER CRETACEOUS AND TERTIARY FORMATIONS IN NEW JERSEY

Age	Formation	Kaolinite	Chlorite	Montmorillonite	Mica	Remarks
Tertiary Miocene	Cohansey	++	±	±	+	
	Kirkwood	+ +	+ +	. . +	+ +	Northeast Southwest
Eocene	Manasquan	+ . .	. . . .	++ ++	± ±	Northeast Southwest
	Vincentown	+ + . .	. . . . . .	. . + ++	+ + ±	Atlantic Highlands (NE) Quartz–sand facies Lime–sand facies (SW)
Paleocene	Hornerstown	. .	. .	+	±	
Cretaceous Monmouth Group	Red Bank	. .	±	+	+	Coastal wells only
	Navesink	. .	±	+	+	Well samples only
	Mt. Laurel Wenonah	±	+	+	+	Undifferentiated
Matawan Group	Marshalltown	+ . .	+ +	+ +	+ +	Northeast Southwest
	Englishtown	+	+	±	+	Well samples only
	Woodbury	+ +	+ +	. . +	+ +	Northeast outcrops Southwest outcrops and wells
	Merchantville	+	+	+	+	
	Magothy	+ +	+ +	+ . .	+ +	Dark marine clays Light estuarine (?) clays
	Raritan	+ ++	+ . .	. . . .	+ +	Marine transgression Nonmarine

Full Suite Variations

The simplest example is that of marine Cretaceous and Tertiary sediments. In these sediments the heavy mineral association indicates a full immature suite and is accompanied by an immature clay mineral suite. The clay minerals are kaolinite, mica, chlorite and montmorillonite in varying proportions that are dependent principally upon the segregation factors of preferential settling and flocculation for the different environments of deposition. These mechanisms should result in the concentration of the coarser kaolinite particles in shore facies and the finer montmorillonite particles in more marine facies. Distribution of micaceous components, chlorite and mica, should occur between the two extremes.

The qualitative clay mineral distribution for most of the full suite upper Cretaceous and Tertiary formations in New Jersey is shown in Table 1. Where data were available, variations within a single formation are shown. The limited suite nonmarine Raritan formation is included for completeness.

No nonmarine full suite sediments are present and the variations for the limited suite nonmarine Raritan clays may not have direct application to the full suite marine sediments because the nature of the contribution for each suite may have been totally different. However, nonmarine sediments are composed dominantly of kaolinite and mica; brackish water embayment clays of the Raritan (upper Woodbridge clays) and the light colored estuarine (?) clays of the Magothy formation contain kaolinite–mica–chlorite assemblages; and marine clays contain montmorillonite as well as the other components. The clay mineral contribution for the full marine suite was thus a kaolinite–mica–chlorite–montmorillonite assemblage, and it is assumed that had nonmarine full suite sediments been present they would have shown the preference towards kaolinite–mica and kaolinite–mica–chlorite assemblages.

Seemingly two environments are present for the limited suite Raritan formation: (a) a possible deltaic–lacustrine–fluviatile nonmarine environment containing kaolinite and mica; (b) an estuarine–lagoonal environment containing kaolinite, mica and chlorite. The first observed effects of marine or brackish water conditions is the appearance of chlorite in the typically nonmarine assemblage of the Raritan formation. Unfortunately, no marine limited suite sediments were available for study, and it cannot be determined whether the Raritan formation shows clay mineral variations in marine members or the kaolinite–mica–chlorite contribution actually observed was the sole contribution from the source area.

With the advent of true marine conditions in late Magothy and Merchantville times, montmorillonite is added to the kaolinite–mica–chlorite assemblage. This four-component assemblage is diagnostic for what is here called the inner neritic environment and indicates a marine transgression that evidently was widespread in Merchantville time because no variation in assemblage was noted from either outcrop or well samples.

A marine regression evidently occurred in some areas during Woodbury and Englishtown times inasmuch as montmorillonite is not invariably present, and environments varied, therefore, between estuarine–lagoonal and inner neritic. Montmorillonite is not found in Woodbury clays in outcrops and shallow wells to the northeast, but is present in wells down dip and in outcrops to the southwest. Seemingly, the waters shallowed toward a northwest source. Englishtown samples are from wells and show inner-neritic compositions. Shallower water facies are indicated by the absence of montmorillonite nearer the outcrop.

Marshalltown clays show a second marine transgression with deeper water conditions to the southwest than those existing in Merchantville time. Deeper water is indicated by the prevalence of montmorillonite and the absence of kaolinite. Kaolinite is found only to the northeast (inner neritic). The montmorillonite–mica–chlorite association to the southwest is referred to as the middle-neritic environment. Thus the formation shows marine conditions similar to those of the Merchantville in the northeast, but to the southwest deeper water conditions are found.

Samples from the Mt. Laurel and Wenonah formations were not stratigraphically differentiated. Clay mineral data, therefore, are inconclusive but suggest that conditions ranged between inner neritic (kaolinite present) and middle neritic (kaolinite absent). The so-called " bentonite " of the Mt. Laurel–Wenonah reported by Stevenson (1936) probably is only a concentration of the normal nonbentonitic montmorillonite component of the formations.

Well samples from the Navesink and Red Bank formations indicate marine conditions having deeper water than those of Marshalltown time: kaolinite is absent and chlorite is present locally. The montmorillonite–mica association defines the outer neritic environment and represents the deepest water environment for these sediments. Environments sampled ranged from middle to outer neritic for these formations.

Glauconite may be found in any neritic environment. Mica may be present in all environments but has greatest abundance in the near-shore environments. The wide depositional range of mica probably is due to its large variation in particle size. The constant association of glauconite and montmorillonite indicates that the two minerals may be genetically related.

The clay mineral assemblages of the various environments, from the kaolinitic nonmarine environment to the outer neritic marine environment, involve: (a) addition of chlorite; (b) addition of montmorillonite; (c) loss of kaolinite; (d) loss of chlorite. The clay mineral associations and their probable environments are listed in Table 2. It is believed that the observed

TABLE 2.—CLAY MINERAL ASSOCIATIONS AND THEIR PROBABLE ENVIRONMENTS

Suggested Environment	Kaolinite	Chlorite	Montmorillonite	Mica	Glauconite
Deltaic, Lacustrine, Fluviatile	+ +	. .	. .	+	. .
Estuarine, Lagoonal	+	+	. .	+	. .
Neritic					
inner	+	+	+	+	+
middle	. .	+	+	+	+
outer	. .	. .	+ +	±	+

distribution of clay minerals is in accord with published data gathered from observations and experiments on the settling and flocculation of clay minerals that occur with changing salinity and distance from shore.

Paleocene and Eocene clays are characterized by dominance of montmorillonite, presence or absence of small amounts of kaolinite and mica, and absence of chlorite. For the Manasquan and Hornerstown formations, the outer neritic environment is indicated. The Vincentown formation, which shows a marine regression in some areas, is known to change in outcrop from northeast to southwest from a quartz-sand facies to a bryozoan limesand facies. Table 1 shows the change in clay mineral assemblage with changing facies, kaolinite being found to the northeast and montmorillonite to the southwest. The formation shows considerable variation along the strike and again the northern or northwest source is indicated.

The Miocene Kirkwood formation also is extremely variable along its outcrop, and montmorillonite is present only to the southwest. Again, the typical deeper water environment probably is to the southwest.

For the full suite marine sediments (Merchantville to Kirkwood), the depositional environment is suggested by the clay mineral assemblage, which implies that a constant contribution of four clay mineral constituents was being supplied from a source area possibly to the northwest, and that preferential segregation occurred with deposition. It is unfortunate that no nonmarine full-suite sediments are present in New Jersey. However, the ideal case for full-suite sediments with environments ranging from nonmarine to outer neritic may be observed for Cretaceous and Tertiary sediments of the Upper Mississippi embayment, which have been studied recently by Pryor and Glass (1959).

If a group of sediments contain a full suite of heavy minerals, and the suite remains constant for environments ranging from nonmarine to marine, it is then possible by determining the clay mineral changes for the different environments to establish the nature of the source area contribution and the segregation factors affecting the contribution. In New Jersey, however, the determination of contribution and segregation factors was based principally on full suite marine formations, for the nonmarine full suite sediments are not present. By analyses of limited suite nonmarine sediments, from the information supplied by preferential segregation for the full suite sediments, and from observations in areas having both marine and nonmarine full suite sediments, it may be inferred that the missing full suite nonmarine sediments may have been kaolinitic.

The Limited Suite Clays

Nonmarine Cretaceous sediments of Long Island, New Jersey, and Delaware, in outcrop and in the shallower wells, contain a limited suite of heavy minerals and are composed of dominantly kaolinitic clays, compatible with our interpretation of a nonmarine environment. However, analyses are lacking for limited suite marine sediments that are presumed to be present down dip. Well samples of nonmarine Cretaceous sediments from Salem

County, New Jersey, to 650 ft depth and Delaware samples to the basement at about 800 ft have revealed no change from the kaolinitic composition of the outcrops. Therefore, it cannot be determined whether or not the full and limited suite clays had different contributions. For the limited suite clays, the marine members, if present, have not been analyzed; thus reconstruction of contribution and segregation factors is impossible. All that is known is that the different suites had different source areas and different heavy and clay mineral compositions.

The data available, however, show an interesting contrast. Limited suite nonmarine clays are all dominantly kaolinitic with no montmorillonite and full-suite marine clays always contain montmorillonite. This observation appears to have important stratigraphic and environmental value, and it must suffice until marine limited-suite clays are analyzed. No evidence contradictory to the inverse kaolinite–montmorillonite environmental relationship for nonmarine and marine sediments has been found.

Certain generalizations may be made. If intense or long-continued weathering in the source area results in the development of a limited suite of heavy minerals, then it is possible that the development of clay minerals at the source should also be affected. Source area mineral assemblages may well be indications of maturity of weathering for all available materials for transport and deposition.

The clay minerals accompanying the nonmarine limited heavy mineral suite are dominantly kaolinite with varying amounts of muscovite-crystallization mica and dioctohedral vermiculite, the weathering alteration product from muscovite-type mica. Noteworthy is the absence of chlorite and montmorillonite. Therefore, two possible explanations exist for this association: (a) the kaolinitic sediments represent the nonmarine assemblage, chlorite and montmorillonite being found in the more marine members; (b) for mature weathering sources, the kaolinite–mica–vermiculite association was the only contribution.

Limited Suite Variations

As all clays of nonmarine origin analyzed are dominantly kaolinitic, minor variations in heavy and clay mineral composition may be difficult to evaluate because variation may occur within short distances. Because of this complexity, interpretations made where there is agreement between heavy and clay mineral changes will be the most successful.

A relationship of this type was observed for limited suite sediments in Delaware. Sediments from 630 to 760 ft deep at Delaware City are characterized by a zircon suite of heavy minerals and kaolinite and vermiculite clay minerals. Mica is conspicuously absent, a rarity in Coastal Plain clays. From 255 to 610 ft a zircon–tourmaline–staurolite suite of heavy minerals was observed and the clay mineral assemblage was found to consist of kaolinite, abundant mica and vermiculite. The change in total mineralogy is abrupt at the contact and perhaps a change in weathering intensity is recorded.

Although no data on heavy minerals were available, Long Island Cretaceous clays at Glen Cove show a striking difference from those in New Jersey and Delaware. Although dominantly kaolinitic, the Long Island clays contain no vermiculite and are characterized by the presence of both muscovite and paragonite micas. A local northern source is suggested because paragonite is common in the metamorphic rocks of the New England Upland.

In Middlesex County, New Jersey, the Raritan formation has been subdivided into four clay beds. Although all contain a limited suite of heavy minerals and are dominantly kaolinitic, each bed has sufficient clay mineral characteristics for precise identification.

(1) Amboy stoneware clay: kaolinite, mica, ±chlorite.
(2) South Amboy fire clay: kaolinite, ±vermiculite, ±mica.
(3) Upper Woodbridge clay: kaolinite, mica, chlorite.
Lower Woodbridge clay: kaolinite ± mica.
(4) Raritan fire clay: kaolinite, mica.

The lowermost fire clay occupies depressions in Triassic shale and the kaolinite is well crystallized, the only example of such crystallinity found in New Jersey.

The lower member of the Woodbridge clay contains no chlorite and is nonmarine. The Upper Woodbridge clay contains a kaolinite–mica–chlorite assemblage and is shown from paleontological evidence to be of brackish water environment. Upper Woodbridge-type clays also have been found in wells at Runyon, Fort Dix, and Clementon, New Jersey, indicating that the marine transgression in upper Woodbridge time was fairly widespread. The South Amboy fire clay is characterized by kaolinite and little or no mica and vermiculite. This assemblage is prevalent for almost all outcrop localities sampled southwest of Middlesex County in New Jersey and may constitute a " norm " for Raritan-type clays. The clay mineral composition of the Amboy stoneware clay resembles the Upper Woodbridge clay and is transitional in composition to the light-colored clays of the Magothy formation. Hawkins (1935) has presented evidence for a northwest source for the Raritan formation in New Jersey.

The above example of clay mineral variations for the limited suite may have some value in interpreting the complex stratigraphy of the Cretaceous nonmarine sediments. The homogeneity of sedimentation, lithologic characteristics, absence of fossils and limited range of mineral assemblages merely emphasize a long-standing problem. Formational assignments for the Potomac group have been made on separate paleobotanical, stratigraphic, lithologic, or heavy mineral studies. Integrated studies of all possible methods of analysis are needed.

The Mineralogic–Stratigraphic Problem

Of special interest are the reported nonmarine sediments which contain a full suite of heavy minerals and dominantly montmorillonite clay minerals. Analyses of Patapsco–Arundel clay samples from the 3091–3178 ft interval in the Hammond no. 1 well at Salisbury, Maryland, showed a composition almost entirely of montmorillonite with minor amounts of kaolinite and mica. Heavy mineral analyses indicate an immature full suite (abundant epidote minerals) and the sediments are considered nonmarine (Anderson, 1948). The heavy mineral analyses are at variance with analyses of nonmarine sediments of Patapsco–Arundel age to the north in Delaware where a limited suite of heavy minerals is accompanied by dominantly kaolinite clay minerals. On the other hand, the heavy and clay mineral analyses are in agreement with those of the marine upper Cretaceous sediments of Delaware.

It should be apparent that the difference in heavy mineral suite and clay mineralogy between the sediments to the north and those in the Hammond well cannot be explained as a result of preferential segregation of kaolinite and montmorillonite. If segregation were operative, there should be no essential variation in heavy mineral suite between the kaolinitic and montmorillonitic clays.

Thus, Salisbury sediments seemingly must have had a different source area that was more immature than that of the limited suite sediments to the north. Why are the montmorillonite–epidote sediments considered nonmarine whereas the same assemblage in the upper Cretaceous of Delaware is marine? If the sediments are marine, of which there is no evidence except for the high montmorillonite content, then a kaolinite–epidote assemblage should be found in the shoreward nonmarine sediments. However, there is as yet no evidence that kaolinitic clays occur with any but a nonmarine limited heavy mineral suite. On the other hand, there is no evidence that montmorillonitic clays occur with any but a marine full heavy mineral suite. Until evidence is found to the contrary, it must be assumed that the source area contribution for the Hammond well sediments was dominantly the montmorillonite–epidote assemblage and the sediments could be marine.

A mineralogic–stratigraphic problem exists in that the sediments that contain a montmorillonite–epidote assemblage are called Patapsco–Arundel, and the same stratigraphic name is given to sediments that contain a kaolinite–zircon–tourmaline–staurolite assemblage. The difference cannot be attributed to a facies change for then the same heavy mineral suite should persist, as has been observed for the facies of the Vincentown formation in New Jersey where kaolinitic clays to the north give way to montmorillonite to the south while maintaining a full suite of similar heavy minerals. The drastic difference in mineral assemblages in Maryland and Delaware indicates different source areas, and if the idea of different facies cannot be accepted, then the sediments must be considered different stratigraphic units.

In the light of such problems as outlined above, it is possible that new and modern methods of stratigraphic analyses and a re-evaluation of stratigraphic philosophy and nomenclature are needed for classifying the unconsolidated sediments of the Atlantic Coastal Plain. It is suggested that the mappable unit formational concept for these limited suite sediments has little actual application and that it be discarded and a new concept be adopted based on depositional conditions within the framework of the control of the heavy and clay mineral assemblages.

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