CLAY MINERALS OF THE OUTCROPPING BASAL CRETACEOUS BEDS BETWEEN THE CAPE FEAR RIVER, NORTH CAROLINA, AND LYNCHES RIVER, SOUTH CAROLINA

by

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ABSTRACT

The basal Cretaceous beds of the area are subdivided into three units : the Cape Fear formation, Middendorf formation and Bladen member of the Black Creek formation. Stratigraphic position and lithology indicate that the Cape Fear is the oldest and the Middendorf is in part the landward facies of the Bladen. The Middendorf sediments are fluviatile and the Cape Fear and Bladen sediments are probably marine.

The Cape Fear and Bladen contain abundant montmorillonite, some kaolinite and lesser amounts of illite. In the Middendorf kaolinite predominates, although a few samples have small amounts of montmorillonite and illite.

Preliminary data indicate that in the Cretaceous–Tertiary sediments of the Atlantic Coastal Plain, montmorillonite occurs in abundance in the marine beds and kaolinite in the nonmarine sediments. The basal Cretaceous beds of the area studied fit into this scheme of clay mineral distribution.

The origin of the clay minerals of the Cretaceous formations studied is approached from sedimentary and empirical standpoints. The montmorillonite–marine and kaolinite-nonmarine associations strongly suggest that the montmorillonite has formed by marine diegenesis, whereas the sedimentary evidence suggests that the montmorillonite of the Cape Fear formation is detrital and the kaolinite of the Middendorf formation has formed by prolonged postdepositional weathering of a more varied clay mineral assemblage. The sediments of the Bladen unit in themselves offer little evidence as to the origin of their clay minerals. However, the predominance of kaolinite in the contemporary deltaic Bladen suggest that kaolinite was the only clay mineral supplied to the depositional area, and that in the marine part of the sedimentation area part of this kaolinite was changed to montmorillonite by marine diagnetic processes.

INTRODUCTION

Several years ago the writer undertook a study of the stratigraphy of the basal Cretaceous formations in an area between Fayetteville, North Carolina and McBee, South Carolina. To aid solution of stratigraphic problems and to gain insight into the origin of the sediments, investigation of the clay minerals of the several formations was undertaken.

This paper presents data on the stratigraphic distribution of the clay minerals within several of the basal Cretaceous formations and preliminary data on clay mineral distribution in the Cretaceous and Tertiary beds of the Atlantic Coastal Plain. Ideas are presented concerning origin of the clay minerals. A comparison is made between the ancient clay minerals of the Atlantic Coastal Plain and the modern clay minerals of the Atlantic Ocean.

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LABORATORY METHODS

The clay minerals of the basal Cretaceous beds were identified from film patterns made with a Hayes diffraction instrument. x-ray diffractograms of selected samples were made and compared with the film patterns with good verification of results; however, one diffractogram did show a very small quantity of illite that had remained undetected on the film pattern.

Field samples were dispersed and the clay size separated from the silt and sand sizes. The clay-size particles were calcium saturated and dried in a 40°C oven. The dry clay was mounted in a capillary tube and x-rayed. Many of the samples were either solvated in ethylene glycol, heated in an 550°C oven, or mounted as oriented aggregates.

SUMMARY OF THE STRATIGRAPHY

The Cretaceous formations of North Carolina have been described by Stephenson (1912), and those of South Carolina by Cooke (1936). In South Carolina Cooke recognized the Tuscaloosa, Black Creek and Peedee formations, all of upper Cretaceous age. He extended the term Tuscaloosa into North Carolina to include beds previously designated lower Cretaceous and called Patuxent by Stephenson (1912, p. 83). Berry (1914, p. 7) called certain beds in South Carolina (in the outcrop area of the Tuscaloosa formation) the Middendorf member of the Black Creek formation. The contemporary age of the Middendorf–Black Creek was based on plant fossil correlation. Dorf (1952) reconfirmed the correlation made by Berry and advocated dropping of the Tuscaloosa formation in South Carolina in favor of the Middendorf member of the Black Creek formation. A more detailed review of the history of correlation and nomenclature may be found elsewhere (Heron, 1958).

The basal Cretaceous beds of the area studied are subdivided into the Cape Fear formation, the Middendorf formation and the Bladen number of the Black Creek formation. A brief description of these formations is presented here.

The Cape Fear Formation

The name Cape Fear was first used by Stephenson (1907, p. 95) for beds exposed along the Cape Fear River near Fayetteville, North Carolina. In 1912 he grouped these beds, together with the sands and clays of the Sandhills region of North Carolina, into the Patuxent formation.

The Cape Fear as used in this paper is essentially the same as the usage by Stephenson (1907) for the rocks exposed along the Cape Fear River (Fig. 1).

Clay minerals.—Sixteen samples of clay separated from the sandstone and siltstone of the Cape Fear formation have mixtures of montmorillonite and kaolinite; no other clay minerals have been detected. According to the intensity of the basal spacings montmorillonite is commonly more abundant than kaolinite, but some samples show that the two minerals occur in equal proportions and one sample contains more kaolinite than montmorillonite.

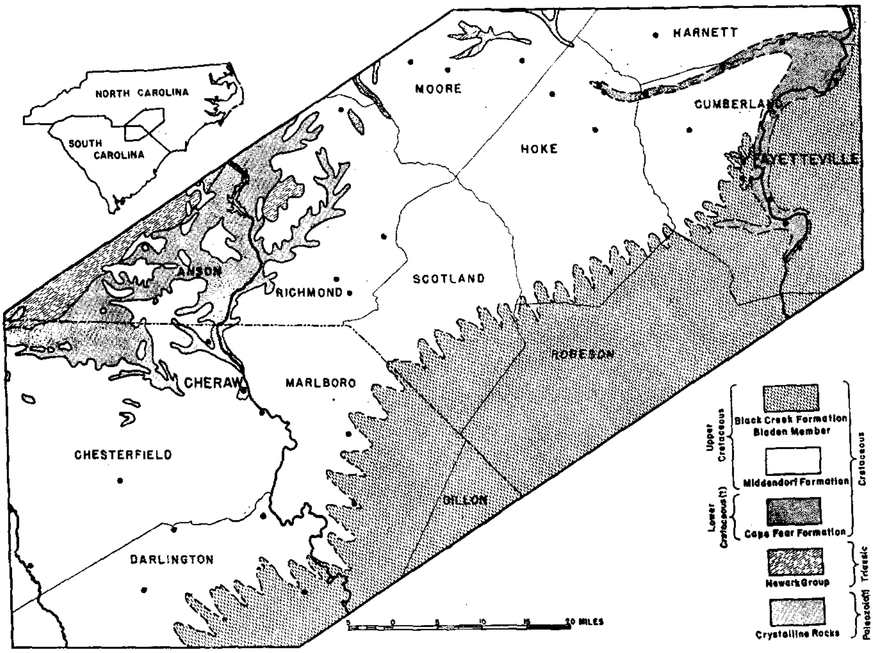

FIGURE 1.—Geologic map of basal Cretaceous outcrops between Cape Fear River North Carolina, and Lynches River, South Carolina. Contact between Black Creek and Middendorf formations is diagrammatic and interpretive. Surficial deposits that generally blanket the outcrops of all Cretaceous deposits are not shown. Black dots indicate areas where one or more clay samples have been collected for x-ray analysis.

Lithology and sedimentary structures.—The Cape Fear formation is mostly sandstone that has intercalated layers of siltstone. The sandstones are quartz wackes (Gilbert, 1954, pp. 289–290) because they are poorly sorted and contain more than 10 percent argillaceous matrix, less than 10 percent feldspar, and less than 10 percent unstable rock fragments. The siltstones are massive and show no lamination or bedding. Fig. 2 is a triangular diagram showing the size distribution of the sediments in the form of sand–silt–clay percentages.

The sedimentary structures include intraformational conglomerates composed of rounded quartz pebbles and subrounded to angular fragments of siltstone, and stratification of alternate layers of sandstone and mudstone. The mudstone layers are thinner and when traced along river bluffs eventually pinch out into the thicker sand layers.

Origin and deposition.—The sedimentary structures and the fluidity index (ratio of detrital grains to detrital matrix, Pettijohn, 1957, p. 288) may suggest that the sediments were deposited from fluids of high density (turbidity flows).

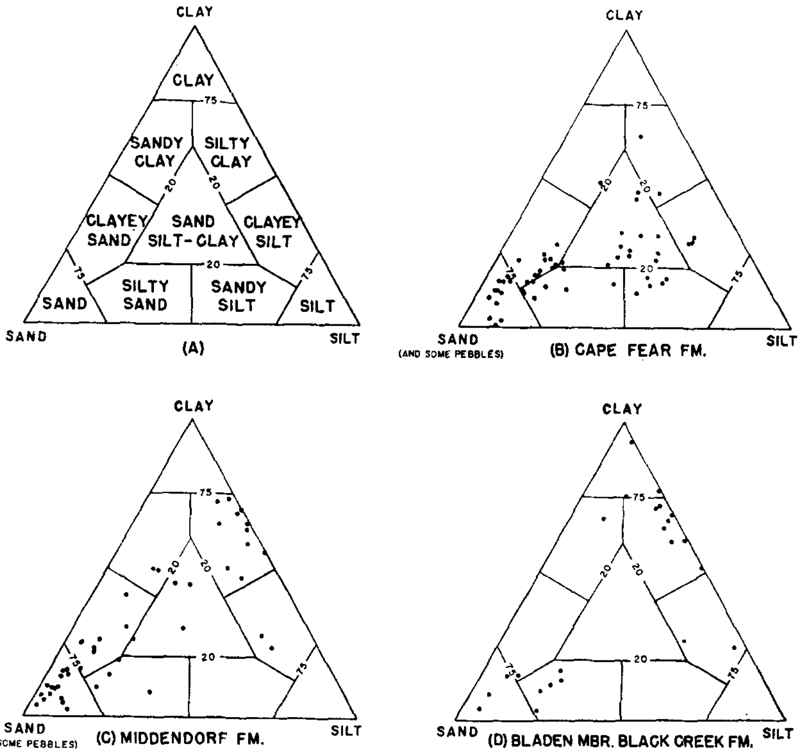

FIGURE 2.—(A) Nomenclature of sand–silt–clay percentages as presented by Shepard (1954, p. 157). (B) Fifty-four samples from the Cape Fear formation. (C) Forty-five samples from the Middendorf formation. (D) Twenty-three samples from the Bladen menber of the Black Creek formation (data for Bladen member from Powers, 1951, p. 78).

Because the Cape Fear formation is essentially nonfossiliferous, it is difficult to determine whether it was deposited in a marine or nonmarine environment. The writer has found minor amounts of lignite and one specimen of Foraminifera even though 92 samples were examined for microfossils. The overall evenness and uniformity of stratification, plus the lack of characteristic features of shallow-water marine or fluvial deposits such as well sorted sands, extensive cross-bedding, or abrupt changes in lithology, suggest that the Cape Fear sediments are marine and probably were deposited below wave base.

The Middendorf Formation

Sloan (1904) first used the name Middendorf to designate a " phase " of the basal Cretaceous of South Carolina. Berry (1914) regarded the Middendorf as a member of the Black Creek formation.

The Middendorf formation as used in this paper is essentially the same as the Tuscaloosa formation except for exclusion of the sediments in North Carolina called Cape Fear (Fig. 1).

Clay minerals.—The only characteristic clay mineral of the Middendorf formation is kaolinite, but of 27 samples x-rayed small quantities of illite were recorded in two, minor montmorillonite in one, and a trace of montmorillonite in two more.

Lithology and sedimentary structures.—The Middendorf formation consists of loose sand, poorly indurated sandstone, thin layers or lenses of mudstone, poorly sorted clayey sands, and laminated layers of sand and mudstone. The sand is locally indurated by iron oxide. The sandstones are mostly quartz wackes; however, some of them are quartz arenites inasmuch as they have less than 10 percent clay matrix. The sandstones differ from those of the Cape Fear formation in that they may contain some mineral cement, have a smaller percentage of clay matrix, and are for the most part less indurated. The finer-grained sediments of the Middendorf formation contain abundant clay-size material. The size distribution of 45 samples is illustrated by Fig. 2.

The Middendorf formation is characterized by its lack of homogeneity. Outcrops may show massive sand with thin discontinuous mudstone layers or lenses, thick mudstone lenses changing horizontally to sand, cross-bedded sands with mudstones occurring as layers, pods, balls and irregular masses, and more or less uniform layering. Cross-bedding is common in the Middendorf sands, though some sand layers lack any evidence of this structure. The cross-bedding is of medium scale (sets from 15 to 25 in. long) and the festoon type has been observed in several outcrops. Clay-ball conglomerates commonly without quartz pebbles are common adjacent to the mudstone layers.

Origin and deposition.—The sediments of the Middendorf formation probably represent an environment that was dominantly fluvial: (1) the sands commonly show current bedding or festoon bedding as if deposited by swift currents. (2) The sands are commonly relatively free of clay as if deposited by a river (Pettijohn, 1957, p. 284). (3) The sands containing a moderate amount of clay matrix (from 10 to 25 percent) may indicate deposition by turbid waters on a river floodplain. (4) The relatively pure clay bodies having the shape of small basins may represent deposition on a floodplain such as the filling of an abandoned meander. (5) The abrupt horizontal and vertical changes in lithology are not necessarily indicative of a marine environment (an exception would be parts of the submerged Mississippi Delta, Shepard, 1956, p. 2621) and so by default must be considered as continental and probably fluvial. (6) One microgastropod from the type section near Middendorf, South Carolina, is considered by K. V. W. Palmer (personal communication) to be from a fresh-water or brackish-water environment.

One outcrop at Cheraw, South Carolina, contains a depauperate fauna of Foraminifera (Siple, Brown and LeGrand, 1956, p. 1757) and so must be considered marine.

Black Creek Formation, Bladen Member

Sloan (1907) named the Black Creek formation for beds exposed along Black Creek in Darlington and Florence Counties, South Carolina. Stephenson (1907) designated beds of similar lithology and age in North Carolina as the Bladen formation, but in 1912 (p. 112) he recognized the priority of Sloan's Black Creek. In 1923 (p. 9), Stephenson called the uppermost beds of this formation the Snow Hill calcareous member of the Black Creek formation. For the sake of precision and brevity, the lower unnamed member of the Black Creek formation is called Bladen member in this report (Fig. 1).

Clay minerals.—Montmorillonite and kaolinite are the only clay minerals in 12 samples of clay from the updip portions of the Bladen member of the Black Creek formation. Thirty samples of the Bladen member from the Cape Fear River bluff exposures in Cumberland and Bladen Counties, North Carolina (x-rayed by Powers, personal communication) average 75 percent montmorillonite, 15 percent illite and 10 percent kaolinite.

Lithology and sedimentary structures.—The Bladen member of the Black Creek formation consists of dark shale layers and lenses, loose light-gray sand masses, and laminated or thin-bedded shale and clean sand. The dry, slightly weathered shale typically has a flaky fissility, but some of the mudstone is massive and has conchoidal fracture. Lignite fragments and logs form an important constituent of the member. Fig. 2 is a triangular diagram of the sand–silt–clay composition of the Bladen sediments. The Bladen, like the Middendorf, has abundant clay. The " light " mineral grains are predominantly quartz. Feldspar is absent or present only in small amounts. Glauconite occurs at some horizons, especially near the top of the member. The sands have not been studied in thin section, but many of them would be classed as quartz arenites because they are well sorted and relatively free of clay matrix.

The most conspicuous sedimentary structures of the Bladen member are stratification and cross-bedding. The stratification is complex as both even bedding and lensing intertonguing sand–clay masses may be found. Small scale stratification in the form of laminated and thinly bedded shale or sand layers is typical of the member. The laminated sand masses may be inclined from the horizontal to form cross-bedding, commonly on a grand scale with individual sets measuring 100 ft or more.

Origin and deposition.—Of the modern sediments, those of the Mississippi Delta (Fisk, McFarlan and Kolb, 1954; Shepard, 1956) seem to have more in common with the Bladen member than any other. The features in common include (1) " large changes in grain size within short distances laterally and vertically " (Shepard, 1956, p. 2621), (2) " presence of laminated zones with alternating fine and coarse sediments " (Shepard, 1956, p. 2620), (3) " high content of land plants " (Shepard, 1956, p. 2620), (4) paucity of fauna (Shepard, 1956, pp. 2670, 2620), and (5) presence of glauconite at least in certain environments of the delta (Shepard, 1956, pp. 2581, 2582). All or parts of these Mississippi Delta features are found most commonly in the topset bed environments, but some are found on the pro-delta slopes and the recent delta influence shelf.

Features of the Bladen member that seem to be absent in the Mississippi Delta include (1) large-scale current cross-bedding, (2) deposits of large wood pieces, and (3) lack of sand grains larger than fine size.

STRATIGRAPHIC RELATIONS

The stratigraphic relationships of the outcropping Cape Fear formation, the Middendorf formation, and the Bladen member of the Black Creek formation are open to several interpretations. It is not the purpose of this paper to explain the alternate possibilities or defend in detail the interpretation presented here, but a brief account of the stratigraphic relations is necessary to understand the clay mineral distribution.

The Middendorf is considered the updip facies of the Bladen member of the Black Creek formation and both of these formations have overlapped the Cape Fear formation. Berry (1914, p. 7) called the Middendorf the updip facies of the Black Creek (Bladen) for the South Carolina area. Stephenson (1923, p. 7) accepted this correlation, and it was reiterated by Dorf (1952, p. 2184). Both Berry and Stephenson said that the formation underlying, the Black Creek–Middendorf is the " Patuxent " formation (Stephenson 1923, p. 3). Dorf (1952, p. 2184) referred such beds to the Lower Cretaceous? (undifferentiated).

In the Fayetteville area the combined Bladen–Middendorf overlies the Cape Fear formation. In South Carolina the Cape Fear is absent or not exposed at the surface. If the Cape Fear formation is absent, then the Bladen is underlain by the main body of the Middendorf so that only the upper part of the Middendorf is a facies of the Bladen, or the Bladen–Middendorf has overlapped a formation of lithology similar to the Middendorf.

ORIGIN OF THE CLAY MINERALS IN THE LIGHT OF SEDIMENTARY EVIDENCE

In general one can choose between two views for the formation of clay minerals: (a) clay minerals reflect the conditions in the source land such as degree, intensity and length of time of weathering, plus the nature of the parent material, or (b) clay minerals respond to the changing environments brought about by transportation, deposition, and post-depositional changes.

The origin of the clay minerals of the basal Cretaceous beds of the area studied will be examined first from the standpoint of sedimentary evidence that points to the nature of the source land, method of transportation, environment of deposition and nature of postdepositional changes, then a comparison will be made with clay mineral associations of the other Cretaceous formations as well as the Tertiary strata found in the Atlantic Coastal Plain.

Origin of the Clay Minerals of the Cape Fear Formation

Several possible origins for the montmorillonite and kaolinite of the Cape Fear formation must be considered: (1) All the clay minerals are detrital. (2) Montmorillonite was the only detrital mineral deposited. Kaolinite has formed from a part of the montmorillonite because of active leaching of the montmorillonite by circulating ground waters. (3) Kaolinite and possibly other clay minerals other than montmorillonite were the only clay minerals deposited at the depositional site. Montmorillonite has formed by diagenesis from the kaolinite or from other clay minerals because of the introduction of the necessary divalent metal cations either from marine waters or from circulating ground water. (4) The kaolinite came from well weathered rocks of the source land and the montmorillonite from halmyrolysis of volcanic ash that fell directly into the basin of deposition.

Any of these possibilities may be at least partly right, but the sedimentary evidence indicates that both kaolinite and montmorillonite probably were brought in from the source land.

(a) The poorly sorted Cape Fear sediments do not permit rapid circulation of ground water, and thus slow down and perhaps stop formation of kaolinite from montmorillonite by leaching. Conversely, the poor circulation would also be detrimental to the formation of montmorillonite from kaolinite by addition of metallic bivalent cations.

The sediments of the Cape Fear formation are compact and relatively impervious. Stephenson and Johnson (1912, p. 395) recognized that in the vicinity of Fayetteville these rocks are poor aquifers. Montmorillonite and kaolinite occur in the sandstones in about the same relative abundance as in the mudstones. If the clay minerals had been altered by circulating ground waters, it would be expected that the abundance of the two minerals would be different in each lithologic type.

(b) The turbidites are deposited so rapidly that the clays should not be subjected to much syngenetic change. However, a finely divided ash could have been rapidly changed to montmorillonite. If an ash fall, or series of ash falls, did occur, there is no evidence in the sediments.

If the montmorillonite and kaolinite of the Cape Fear formation are detrital minerals then there are two possible sources for these minerals: (1) Montmorillonite came from the *B* and *C* soil horizons and kaolinite from the *A* horizon of the source land (Keller, 1956, pp. 2701–2702). (2) Kaolinite came from well-weathered rocks of the source land and montmorillonite came from erosion of associated Cretaceous land-deposited tuffs.

Since there are no known ash deposits in the basal Cretaceous beds of North Carolina, nor any evidence for Cretaceous ash deposits in the source land, the likelihood of direct volcanic ash origin of the montmorillonite cannot be proved.

The composition of the Cape Fear sediments partly supports the idea of derivation of montmorillonite and kaolinite from the various soil horizons of the source land. The presence of comparatively fresh feldspar in the sediments suggest that they were derived by erosion of the *C* horizon, where the feldspars would remain comparatively fresh. However, feldspar makes up less than 5–10 percent of the sediments and has less than 2 percent associated rock fragments, suggesting that erosion of fresh rock or rock from the *C* horizon was volumetrically far less than erosion of the *A* and *B* horizons where feldspar and rock fragments would not be found.

A few x-ray patterns of the clay-size material in the *C* horizon of deeply weathered Carolina Slate Group (a Piedmont rock of lower Paleozoic(?) age that probably was derived mainly from volcanic ash) contains a large amount of montmorillonite and little or no kaolinite. Such weathered rock could have supplied a part of the montmorillonite to the Cape Fear basin of sedimentation.

Although there are many variables, the sedimentary evidence indicates that the clay minerals of the Cape Fear formation were formed in the source land, transported and deposited with little or no diagenetic change. The montmorillonite appears to have been derived from the *B* and *C* soil horizons and kaolinite from the *A* horizon.

Origin of the Clay Minerals of the Middendorf Formation

The Middendorf formation is composed largely of kaolinite, but locally contains montmorillonite and illite. The kaolinite of the Middendorf formation could have been derived from a deeply weathered source land that would give rise to the formation of kaolinite with virtual exclusion of other clay minerals, particularly montmorillonite. Even in an area that has undergone long weathering one would expect to find some montmorillonite in the *C* horizon. Occasional deep erosion would remove some of the montmorillonite to the basin of deposition.

Kaolinite could have formed from other clay minerals as a result of prolonged weathering and leaching of the Middendorf sediments inasmuch as the near-surface exposures of Middendorf sediments contain considerable amounts of iron as stain, cement and concretions. Even the less permeable sediments, such as the silty clay at the Middendorf type section, have iron oxide stringers and veins. The leaf fossils in this claystone have been replaced by ferric oxides. Angular feldspar grains commonly are weathered completely to clay. Their sharp corners prove that they were transported in the unweathered state. In general, the sediments of the Middendorf are permeable and would permit circulation of waters capable of breaking down montmorillonite to kaolinite.

However, the iron deposits and weathered feldspar grains may indicate only secondary weathering that is genetically unrelated to the kaolinite origin. Kesler (1956, p. 550) demonstrated that the Tuscaloosa formation (probably equal to the Middendorf formation) of Georgia and the Aiken area, South Carolina, contains thick kaolinite beds that could not have been formed entirely by secondary leaching. These commercial kaolinite deposits are believed by Kesler (1956, p. 553) to represent weathering of feldspar sands on a deltaic plain and subsequent transportation of the kaolinite to nearby lakes, probably oxbows. There are no large kaolinite deposits in the area described in this paper and there is no reason to believe that the exact method of kaolinite formation proposed by Kesler would necessarily apply in this region.

Then the sedimentary characteristics shed little evidence on the origin of the clay minerals of the Middendorf formation, although there remains the possibility that the kaolinite has formed by excessive postdepositional leaching.

Origin of the Clay Minerals of the Bladen Member of the Black Creek Formation

The Bladen member contains montmorillonite, kaolinite and illite; montmorillonite is most abundant. Essentially the same clay minerals except for illite are found in the Cape Fear formation, but the evidence that suggests a detrital origin for the minerals in the Cape Fear formation does not apply to the Bladen unit because of differences in depositional history of the two formations.

The writer sees no evidence in the sediments for either an allogenic or an authogenic origin for the clay minerals in the Bladen unit; however, the relationship between the Bladen and Middendorf units suggest several problems.

If, as the stratigraphic evidence seems to indicate, the Bladen is the down-dip facies of the Middendorf, then the presence of a considerable amount of montmorillonite would stand in opposition to such a correlation, especially when one follows the suggestions of Weaver (1958) who points out the inter-relations of clay mineral suites between formations that are facies of each other and those derived from similar sources. However, if as previously suggested, leaching has destroyed the montmorillonite in the Middendorf and not in the Black Creek, then the anomaly is more apparent than real. Why has the Black Creek montmorillonite not been destroyed by the same leaching processes? Perhaps protection by some lately removed overburden would have been sufficient. Yet, another explanation is apparent. The montmorillonite in the Bladen may not be detrital but may have formed by marine diagenesis of a predominantly kaolinitic detritus. This hypothesis would explain more adequately the Middendorf–Bladen clay mineral distribution and it agrees with the hypothesis suggested by the clay mineral associations in the Atlantic Coastal Plain.

CLAY MINERAL ASSOCIATIONS IN THE ATLANTIC COASTAL PLAIN

Empirical observation (based on comparatively few but widespread samples) indicates that in the Cretaceous and Tertiary beds of the Atlantic Coastal Plain there is a definite clay mineral difference between marine and nonmarine sediments. In general, beds that contain a rather large fauna and are known to be marine have a large percentage of montmorillonite; whereas beds that are nonmarine (especially fluvial) all have a large percentage of kaolinite. So far as the writer knows this was first suggested for North Carolina by Reves (1956, p. 12) and for the Northern Atlantic Coastal Plain by Groot and Glass (1959). Pryor and Glass (1958) found the same relationship in the Cretaceous and Tertiary clays of the Upper Mississippi Embayment; however, there is no reason to believe that all Cretaceous and Tertiary beds show such a clay mineral relationship.

Specific examples are as follows: The nonmarine Potomac Group of the Northern Atlantic Coastal Plain contains kaolinite with subordinate amounts of illite or illite mixed-layer clay (Anonymous, 1958, pp. 17, 31, 35, 40). The Tuscaloosa formation around Aiken, South Carolina, is generally regarded as nonmarine and it contains extensive bodies of almost pure kaolinitic clays (Kesler, 1956, p. 549). The known Cretaceous (and older Cenozoic) marine beds of the Northern Atlantic Coastal Plain contain high percentage of montmorillonite (Anonymous, 1958, pp. 21, 24, 30), although Groot and Glass (1959) report that the marine sediments have illite and kaolinite where glauconite is absent and montmorillonite where glauconite is present. In North Carolina the Cretaceous marine Peedee formation (Reves, 1956, p. 12) contains much montmorillonite. The Cenozoic beds of North Carolina exclusive of the so-called terrace deposits all contain dominant montmorillonite (Reves, 1956, pp. 15–19).

The clay minerals of the three basal Cretaceous formations in the area studied fit into the scheme of clay mineral distribution in the Atlantic Coastal Plain. Both the Cape Fear and Bladen sediments which are judged to be marine have abundant montmorillonite, whereas the nonmarine Middendorf sediments contain dominant kaolinite.

The predominant clay minerals of the modern marine Atlantic Coast sediments are illite and chlorite with minor kaolinite and montmorillonite (Powers, 1954; Murray and Sayyab, 1955). Weaver (1958, p. 256) points out that these are the same as those clay minerals found in the Appalachian area source land to the west and that they are the same minerals being supplied to the ocean by present-day rivers. Yet they stand in contrast to the sediments of the basal Cretaceous beds, which certainly had the same source, in the area studied. Illite has been found in only two samples of the Middendorf, not at all in the Cape Fear, and only in small quantities in the Bladen. Chlorite or a chloritelike mineral (14 Å mineral described by Reves, 1956) does occur in the so-called terrace deposits of North Carolina, but it has not been detected in the Cape Fear, Bladen or definite Middendorf beds. Kaolinite, which seems to be minor in the Atlantic sediments, is dominant in the Middendorf and plentiful in the Cape Fear and Bladen. Montmorillonite, which is very minor in the Atlantic, is abundant in the Cape Fear and Bladen.

DISCUSSION

Two genetic implications are suggested by the kaolinite–nonmarine and montmorillonite–marine associations found in the Cretaceous–Tertiary beds of the Atlantic Coastal Plain. The first is that montmorillonite because of its smaller particle size has been by-passed into the marine environment while the kaolinite because of its larger particle size has been deposited in the fluviatile environment. To the writer such a hypothesis is completely untenable. River-deposited sediments eventually must be eroded and finally reach the sea. After equilibrium is established, the rate of river deposition should equal the rate of erosion. Consequently the clay minerals, even if locally separated, eventually must be remixed. Whereas by-passing may be locally important, it seems unlikely that any widespread clay mineral distribution could result from such a process.

The second genetic implication is that the clay minerals have responded to the marine or nonmarine character of the sedimentary basin. This would imply that regardless of the nature of the clay minerals supplied to either environment, the end product should be kaolinite or montmorillonite. The sedimentary evidence found in the Cape Fear and Middendorf formations indicates an exact opposite interpretation, for it appears that the Cape Fear clay minerals are detrital, and that the Middendorf kaolinite has been formed partly by extensive leaching. The Bladen sediments do not in themselves offer any substantial indication of the origin of its clay minerals.

To reconcile the two different answers found by the two different means of approach is not possible at this time ; however, certain weaknesses must be pointed out :

(1) The observations on clay mineral distribution in the Atlantic Coastal Plain may be biased on several accounts : (a) insufficient number of samples ; (b) an unrecognized secondary relationship that is controlled by lithology and mineral assemblages ; (c) lack of information on nonmarine Tertiary beds (the kaolinite nonmarine association is based only on basal Cretaceous nonmarine sediments ; this may mean that " lower " Cretaceous climate was responsible for the extensive formation of kaolinite) ; and (d) different sources for the marine and nonmarine sediments (Groot and Glass, 1959, indicate that this may be true for the Northern Atlantic Coastal Plain).

(2) The sedimentary evidence that indicates the nature of transportation, deposition, salinity of the depositional basin, and extent of postdepositional changes is far from impeachable. At best, it represents intelligent guesses, for far too little is known about the nature of the " unfossiliferous marine " sediments. Both the Cape Fear and Bladen units actually may represent a largely nonmarine environment.

The clay minerals of the modern marine Atlantic Coast sediments also stand in contrast to the observed clay mineral distribution in the Cretaceous and Tertiary beds of the Atlantic Coastal Plain; therefore, of course, they also contrast with the clay mineral distribution in the Cape Fear, Middendorf, and Bladen units. The paucity of montmorillonite in the modern Atlantic Ocean sediments indicates that the weathering and erosional history of the Appalachians was very different in Cretaceous and Tertiary time from what it is today, and consequently climate is the most important factor in the high montmorillonite content of the older Coastal Plain sediments, or else postdepositional changes modified the clay minerals supplied to the depositional site.

SUMMARY

(1) The Cape Fear formation is judged to be marine. It contains montmorillonite and kaolinite with montmorillonite usually dominant. Sedimentary evidence indicates that the clay minerals may be detrital.

(2) The Middendorf formation is nonmarine and contains mostly kaolinite with local occurrences of illite or montmorillonite. The sediments themselves offer little indication as to the origin of the kaolinite, but it may be in part secondary owing to excessive leaching.

(3) The Bladen member of the Black Creek formation is judged to be marine. It contains montmorillonite and kaolinite in the updip portions and some illite is reported to occur further downdip. The sediments offer little evidence as to the origin of the clay minerals, but if the Bladen unit is the downdip marine equivalent of the Middendorf, then the possibility of the montmorillonite forming by diagenesis from a predominantly kaolinitic detritus is strong.

(4) Clay mineral assemblages in the Cretaceous–Tertiary sediments of the Atlantic Coastal Plain show that montmorillonite dominates in marine beds and kaolinite dominates in nonmarine beds.

(5) The clay minerals of the modern Atlantic sediments are illite and chlorite with lesser amounts of kaolinite and montmorillonite.

(6) The clay minerals of the Cape Fear, Middendorf and Bladen units are similar to clay mineral associations found in the rest of the Cretaceous–Tertiary beds of the Atlantic Coastal Plain.

(7) The clay mineral associations of the Cretaceous–Tertiary beds strongly suggest that montmorillonite has formed by diagenesis. If this is so then the detrital origin suggested by the sediments for the montmorillonite of the Cape Fear formation is incorrect.

(8) Interpretations of clay mineral origin based on sedimentary evidence should be at least tempered with regional studies of clay mineral associations.

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