SOUTHEASTERN GEOLOGY

PUBLISHED AT DUKE UNIVERSITY DURHAM, NORTH CAROLINA

VOL. 7 NO. 2 FEBRUARY, 1966

SOUTHEASTERN GEOLOGY

PUBLISHED QUARTERLY

AT

DUKE UNIVERSITY

This journal welcomes original papers on all phases of geology, geophysics, and geochemistry as related to the Southeast. Transmit manuscripts to S. DUNCAN HERON, JR., BOX 6665, COLLEGE STATION, DURHAM, NORTH CAROLINA. Please observe the following:

(1) Type the manuscript with double space lines and submit in duplicate.
(2) Cite references and prepare bibliographic lists in accordance with the method found within the pages of this journal.
(3) Submit line drawings and comples tables as finished copy.
(4) Make certain that all photographs are sharp, clear, and of good contrast.
(5) Stratigraphic terminology should abide by the Code of Stratigraphic Nomenclature (AAPG, v. 45, 1961).

Proofs will not be sent authors unless a request to this effect accompanies the manuscript.

Reprints must be ordered prior to publication. Prices are available upon request.

* * * * *

Subscriptions to Southeastern Geology are $5.00 per volume. Inquiries should be addressed to WM. J. FURBISH, BUSINESS AND CIRCULATION MANAGER, BOX 6665, COLLEGE STATION, DURHAM, NORTH CAROLINA. Make check payable to Southeastern Geology.

SOUTHEASTERN GEOLOGY

Table of Contents

Vol. 7, No. 2

1966

THE SURRY SCARP FROM FOUNTAIN TO POTTERS HILL, NORTH CAROLINA[1]

by

R. B. Daniels
Soil Conservation Service
Raleigh, North Carolina

E. E. Gamble
Soil Conservation Service
Raleigh, North Carolina

and

W. D. Nettleton
Soil Conservation Service
Riverside, California

ABSTRACT

The Surry scarp was visually traced across the Neuse River watershed in North Carolina. Its average toe elevation is 94 feet and the vertical variation is $\pm$ 2 feet. There has been no measurable deformation of the scarp. The scarp was crossed in two areas with closely spaced drill holes. In each traverse the scarp truncates surficial sediments that lie to the west. Surficial sediments east of the scarp have a base below those to the west. There is no evidence of interfingering of sediments across the scarp. The gentle arcuate outline of the east-facing scarp suggests that it has been cut by an open ocean. A fluvial counterpart of the Surry can be traced up the Neuse River and its tributaries.

The Surry scarp marks a major stratigraphic and geomorphic boundary in the Coastal Plain of North Carolina. Soil properties change across the scarp and it also marks a major pedologic boundary.

1/ Joint contribution from the Soil Conservation Service, USDA, and the Soil Science Department, North Carolina Agricultural Experiment Station, Raleigh, North Carolina. Published with the approval of the Director of Research as Paper No. 2095 of the Journal Series.

INTRODUCTION

The Surry scarp is one of the major geomorphic features in the Coastal Plain of North Carolina. Flint (1940) has traced the scarp on interstream divides from its type area in Virginia south across North Carolina. Other workers also recognized and mapped the scarp in varying degrees of detail in North Carolina (Stephenson, 1912; Mundorf, 1946; Johnson and Du Bar, 1964). Although it has been recognized for years, there is little detailed information on its relation to adjacent sediments, its slope, height, and distribution across or within a drainage basin in North Carolina. The origin of the scarp is obscure, or at least not completely understood. Our observations and ideas are given in the following paragraphs.

We have visually traced the Surry scarp from the Neuse-Tar drainage divide near Fountain in Pitt County south to the Neuse-Cape Fear drainage divide near Potters Hill in Duplin County (Figure 1). Its distribution in Toisnot Swamp and the lower part of the Contentnea Creek valleys has been mapped. We measured the slope and height of the scarp by transit and stadia rod in 11 traverses. It was crossed in two areas with closely spaced drill holes; in critical areas the drill holes were 30 to 200 feet apart. Power auger flights were pulled every 5 to 10 feet so that sediments and their contacts could be examined in the least disturbed condition.

LOCATION

The Surry scarp crosses the Neuse-Tar drainage divide at Fountain, North Carolina. It trends almost due south to the Potters Hill area, but its outline is a series of gentle arcs that are concave seaward (Figure 1). The arc between Fountain and Snow Hill has a radius of nine miles and the one between Snow Hill and Kinston a radius of 57 miles. The arcs crossed by the Trent River and Tuckahoe Swamp have radii of 16 and 6 miles. The placement of these arcs is not influenced by streams except possibly by the Neuse River because at Kinston it crosses the scarp where two arcs meet.

CHARACTERISTICS

The scarp is 9 to 27 feet high and has slopes of 0.8 to 1.4 feet per 100 feet. It is higher to the north than to the south of Kinston. North of Kinston the altitude of the nearly level surface just west of the scarp is about 110 feet. South of Kinston a series of almost level surfaces occur just west of the scarp. The highest surface has an altitude of about 120 feet, the lowest is about 100 feet. These surfaces are separated by gentle slopes or "scarps" (Figure 2) that in places could

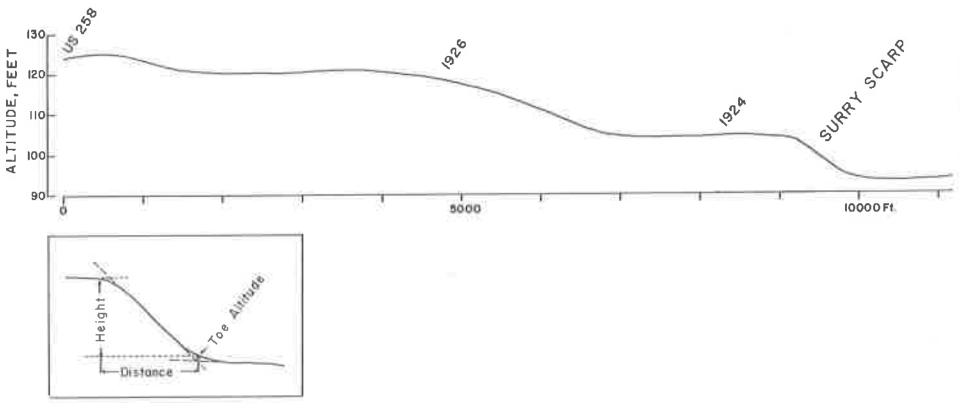

Figure 2. Profile of gentle slopes above the Surry scarp on road no. 1925, Lenoir County, North Carolina. The west end of the traverse starts at U. S. highway 258. The method of determining the toe elevation and the height of the scarp is shown in the inset.

be confused with the Surry scarp. These slopes can be traced for only two or three miles and in many places less than that. Similar features are common on the Coharie terrace of Stephenson (1912) on the Neuse-Cape Fear divide.

Flint (1940) noted a narrow range in altitude at the toe of the Surry scarp; across the Neuse basin this altitude range is four feet (Table 1). The average toe altitude is about 94 feet. There is no consistent difference in the toe altitude north or south of Kinston. This small range in altitude is evidence that differential post-Surry uplift probably has not occurred in this area.

We have mapped the Surry scarp in parts of the Neuse River, Contentnea Creek and Toisnot Swamp valleys (Figure 1). The Wicomico surface at the toe of the scarp does not increase in altitude upstream between Kinston and Goldsboro along the Neuse River or between Snow Hill and Toisnot Swamp in the Contentnea Creek valley. This suggests that the sea extended up existing valleys and that the scarp was cut by a rising sea. But in the Toisnot Swamp valley the altitude of the Wicomico surface increases from about 95 to a maximum of about 145 feet (Figure 3). At these higher altitudes the Wicomico surface has an elevation range of about 15 feet and it always slopes toward the center of the valley. The characteristics of the Wicomico surface in the Toisnot valley indicate that it has a fluvial origin in this valley. Elsewhere, such as the Neuse River valley between Goldsboro and Kinston, it may have a marine or estuarine origin.

The last identifiable remnant of the surface in the Toisnot valley is at the head of Silver Lake. Here it is about 8 to 10 feet above the flow line of Toisnot Swamp. This contrasts to the 50-foot difference between this surface and the flow line at the lower end of the valley

Table 1. Height, toe altitude, and average slope of the Surry Scarp between Fountain and Potters Hill, North Carolina

Measurement	Location	Height feet	Toe Altitude	Average Slope in feet/100 feet (percent)	minutes
1	Fountain	25	96	1.3	44
2		10	94.5	1.0	34
3		27	94	1.3	44
4		20	--	1.4	48
5		20	94.5	1.2	42
6		11	--	1.0	34
7	Kinston	10	92.5	0.8	28
8	South of Kinston	17	--	1.0	34
9		15	92	0.8	28
10		9	94	1.1	38
11		12	92	1.0	34

-- Bench marks not available for determining correct altitude.

(Figure 3). It is possible that the Wicomico surface is covered by the flood plain farther upstream.

RELATION TO SEDIMENTS

Surficial sediments west of the Surry scarp are coarsest at the base and become finer toward the top. Three kinds of the finer upper sediments occur west of the scarp (Figure 1). On the Neuse-Tar divide west of Fountain and north of Snow Hill the sediments are silty sands; mean silt content is about 19 percent. North of Fountain and south of Snow Hill the surficial sediments are fine sands. Sands from 0.250 to 0.062 mm make up 80 to 85 percent of the sample, but the silt content is less than five percent. These fine sands feel silty, probably because of the large amount of very fine sand (30 to 35 percent). One small area north of Kinston and the area south of Kinston are predominantly medium sands. We have no analytical data from this area but field estimates suggest very low silt contents and clay contents of ten percent or less. The contact between the silty sands and the fine sands is sharp. The contact between the fine sands and the medium sands is sharp in places, but it can also be gradational over a mile or more. We have not studied the sediments east of the scarp in detail and cannot properly characterize them at this time.

Two detailed drill traverses were made across the scarp, one at Fountain on the Neuse-Tar divide (Figures 4 and 1) and the other on

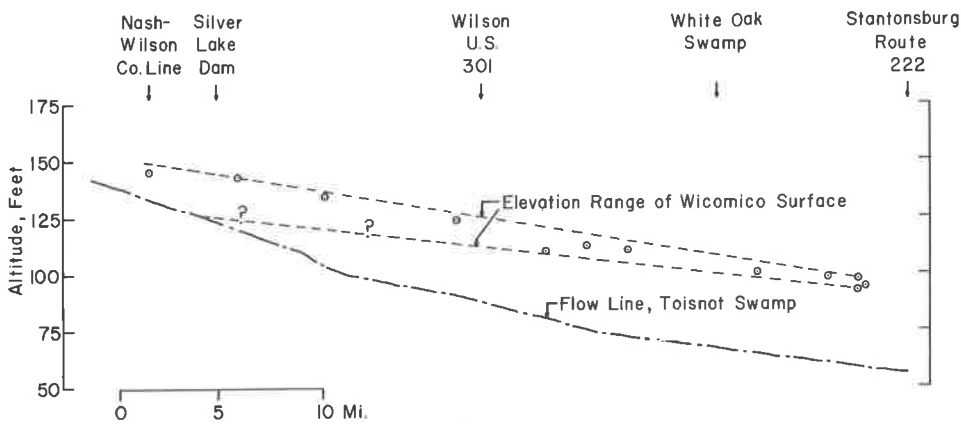

Figure 3. Elevation of Wicomico surface in Toisnot Swamp valley from Stantonsburg to the Nash-Wilson County line.

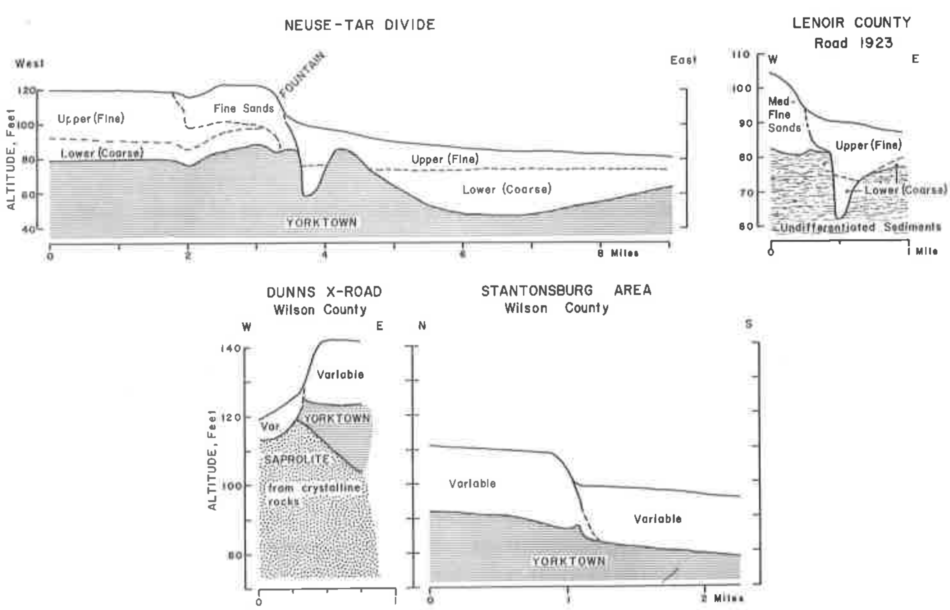

Figure 4. Relation of sediments across the Surry scarp.

Lenoir County road No. 1923 located between Kinston and the Trent River. In the drill traverse at Fountain, the sediments west of the scarp are divided into three units. An upper fine unit (silty sand) overlies a lower coarse unit (sand and fine gravel). At the scarp a fine sand unit overlies the other two units. East of the scarp the sediments are divided into an upper fine and lower coarse sand unit. Only the mean diameter (Folk and Ward, 1957) and kurtosis parameters have mean values that are statistically different (Table 2). Skewness and standard deviation of the five sediment units at Fountain (Figure 4) are not statistically different. In all measured parameters there is an overlap of values from sediments on either side of the scarp. This is to be expected because the sediments east or west of the Surry do not differ strikingly in general appearance. Only the fine sand unit at Fountain and south of Snow Hill (Figure 1) is distinctive. But patches of similar sediments can be found east of the scarp.

On the Neuse-Tar divide the Surry scarp truncates the fine sand unit (Figure 4). Its subsurface toe is cut several feet into the Yorktown Formation. The relations at Lenoir County Road No. 1923 are the same as those at Fountain. The base of the surficial sediments is lower east than west of the scarp. There are characteristic irregularities that occur in this base. The channel configuration at the immediate subsurface toe occurs at both Fountain and Lenoir County Road No. 1923.

On the Neuse-Tar divide and Lenoir County Road No. 1923 there is no interfingering of sediments across the scarp. The scarp truncates sediments to the west and it is partly buried by sediments to the east. Relations between the scarp and sediments at Dunns Crossroad and Stantonsburg (Figure 4) are similar to those on the Neuse-Tar divide and in Lenoir County. But our bore holes in these areas were too far apart for us to be sure of the exact contact between sediments.

Our interpretation of the traverses shown in Figure 4 and the laboratory data in Table 2 is that the Surry scarp was cut and then partly buried by younger sediments. In most traverses there is a slight break in slope from the surface to the subsurface scarp. The surface scarp grades to the top of the sediments to the east or toward the river. But the subsurface scarp when extrapolated upward does not coincide with the surface scarp. This is evidence that the surface scarp is slightly younger than the one in the subsurface, or that it has been modified by later erosion.

The relations between sediments across the scarp, truncation of the mappable sedimentary units west of the scarp (Figure 1), and distribution of the scarp in valleys shows that it was formed by erosion. We agree with Flint (1940) that it is difficult to see how the scarp could by formed by faulting. Other workers (Oaks and Coch, 1963; Colquhoun, 1962) also believe that the Surry scarp is an erosion feature.

Oaks and Coch (1963) interpreted the scarp as an erosional feature cut into the Kilby Formation, and they believed that sediments across the scarp were the same. Our evidence indicates separate sediments across the scarp and it agrees with the work of Colquhoun (1962), Colquhoun and Duncan (1964), and Johnson and Du Bar (1964) in South Carolina.

We could not find any areas of eolian sand associated with the scarp between Fountain and Potters Hill. Eolian sands, identified by

Table 2. Levels of statistical significance among sediments west and east of the Surry scarp at Fountain, North Carolina (see Figure 4).

		West of scarp			East of scarp	
		Upper fine	Lower coarse	Fine sandy	Upper fine	Lower coarse
	$\overline{X}$ ∅	5.98	2.67	3.06	2.72	2.25
West of scarp	Upper fine		**	**	**	**
West of scarp	Lower coarse			n. s.	n. s.	n. s.
West of scarp	Fine sand				n. s.	**
East of scarp	Upper fine					n. s.

LSD 5% = 0.54
LSD 1% = 0.73

	$\overline{X}$ Kurtosis	1.266	1.483	3.302	2.872	3.415
West of scarp	Upper fine		n. s.	**	**	**
West of scarp	Lower coarse			**	**	**
West of scarp	Fine sand				*	n. s.
East of scarp	Upper fine					**

LSD 5% = 0.328
LSD 1% = 0.439

* Significant at the 5% level
** Significant at the 1% level

dune topography, buried soils, uniform sand size, and altitudes greater than the general landscape, are mapped near the scarp in river valleys (Figure 1). These sands, however, may pre-date and post-date the scarp. In places the fine sand unit at Fountain and south of Snow Hill may have some reworked sand at the surface. This reworked sand is not associated with the Surry scarp; it is associated only with the fine sand unit.

SOIL RELATIONS ACROSS THE SURRY SCARP

The Surry scarp appears to be a major stratigraphic and geomorphic boundary in the Coastal Plain of this part of North Carolina. Soil properties also change across this scarp. Most of the soils of the silty sands on the Neuse-Tar divide west of Fountain have fragipans in their lower sola. East of the scarp at Fountain in similar materials, soils with fragipans are of very limited areal extent. Detailed soil studies at the junction of Toisnot Swamp and Contentnea Creek show that soils below the scarp have less well developed fragipans than those above the scarp. Soils below the scarp have fragipans averaging about 14 inches thick and sola 58 inches thick; those above the scarp have fragipans averaging about 33 inches thick and sola 83 inches thick. These changes often are enough to be identified at the series level and in many areas the classification of soils changes across the scarp.

DISCUSSION

The distribution of the Surry scarp in river valleys, its truncation of sedimentary units, and the change of sediments across the scarp show that it was formed by erosion. Erosion of the scarp between Fountain and Potters Hill by an open ocean is suggested by its gentle arcuate outline and the fact that it has been traced over distances of hundreds of miles (Flint, 1940). If it was cut by an open ocean, the absence of sand dunes on or near the scarp is puzzling. It seems unlikely that post-Surry erosion could destroy all traces of sand dunes. Admittedly, it is possible that the scarp has been eroded since it was cut. But this erosion must have been slight because the scarp grades to the top of the lower sediments and it seems unlikely that all traces of the sand dunes would have been destroyed. A more logical explanation is that eolian sands were never deposited on or near the scarp.

Because the stratigraphic evidence indicates that in this area of North Carolina sediments east of the scarp post-date those to the west, the toe altitude is controlled by deposition, not erosion. Sediment at the toe of the scarp could have been deposited above or below sea level. Thus the toe altitude does not necessarily represent a former stand of sea level.

Flint (1940) did not attempt to date the Surry scarp but he believed that there was some evidence suggesting that it was cut in interglacial rather than glacial times. Oaks and Coch (1963) tentatively placed the cutting of the Surry as later than the Kilby Formation but earlier than deposition of the Nansemond Formation. According to their dating of these formations, the Surry was cut in later Pliocene or early Pleistocene.

Flint (1940) stated that "the term scarp is misleading" when applied to something as gently sloping as the Surry scarp. We agree. The term scarp generally means a steep slope or abrupt declivity separating two levels. In defense of the term, it must be admitted that the Surry has more slope than the almost level surfaces east and west of it. Anything with a slope of 60 feet per mile will stand out in an undissected area with average slopes of 2 to 3 feet per mile or less. The term scarp is firmly entrenched in Coastal Plain literature and it should be retained. It should be pointed out, however, that the term scarp when used in conjunction with the Coastal Plain of North Carolina generally refers to a gentle slope separating two areas of different altitudes.

The sediments, age of the geomorphic surface, and soil properties change across the Surry scarp. These changes probably are related. The stratigraphic and geomorphic evidence shows that the surfaces west of the scarp are older than surfaces east of the scarp. Thicker soils and stronger soil horizon development should be expected on the older surfaces (Ruhe, 1956). But soil properties also change in response to changes in sediment properties. Thus, not all the changes in soils across the scarp can be related only to age or to change in sediments. Some change in soil properties should be expected at every major change in stratigraphy and geomorphology on the Coastal Plain because soils are products of their environment and they reflect the history of their landscape.

REFERENCES

Colquhoun, D. J., 1962, On surficial sediments in central South Carolina - A progress Report: Geologic Notes, Div. of Geology, State Development Board, Columbia, South Carolina, v. 6, p. 63-80.

Colquhoun, D. J. and Duncan, D. A., 1964, Rock-stratigraphic distribution of sediments laying northwest of the Surry scarp in central South Carolina: Southeastern Geology, v. 5, p. 119-142.

Flint, R. F., 1940, Pleistocene features of the Atlantic Coastal Plain: Am. Jour. Science, v. 238, p. 756-787.

Folk, R. L. and Ward, W. C., 1957, Brazos River bar: A study in the significance of grain size parameters: Jour. Sed. Petrology, v. 27, p. 3-26.

Johnson, H. S., Jr., and Du Bar, J. R., 1964, Geomorphic elements of the area between the Cape Fear and Pee Dee Rivers, North and South Carolina: Southeastern Geology, v. 6, p. 37-48.

Mundorf, M. J., 1946, Ground water in the Halifax area, North Carolina: North Carolina Dept. Conserv. and Dev., Division of Min. Res. Bull. 51.

Oaks, R. Q., Jr., and Coch, N. K., 1963, Pleistocene sea levels, Southeastern Virginia: Science, v. 140, p. 979-983.

Ruhe, R. V., 1956, Geomorphic surfaces and the nature of soils: Soil Sci., v. 82, p. 441-455.

Stephenson, L. W., 1912, The Quarternary formations, in Clark, Wm. B., Miller, B. L., Stephenson, L. W., Johnson, B. L., and Parker, H. N., The Coastal Plain of North Carolina: N. C. Geol. and Economic Survey, v. 3, 372 p.

CLAY MINERALOGY, STRATIGRAPHY, AND STRUCTURAL SETTING OF THE HAWTHORN FORMATION, COOSAWHATCHIE DISTRICT, SOUTH CAROLINA

by

S. Duncan Heron, Jr.
Duke University

and

Henry S. Johnson, Jr.
Division of Geology
S. C. State Development Board

ABSTRACT

In Jasper and Beaufort Counties, South Carolina, the Miocene Hawthorn Formation can be subdivided into phosphatic sand, clayey quartz sand, and sandy clay lithologies. A clay unit called the Coosawhatchie clay overlies the other units, possibly unconformably. The Coosawhatchie clay or one of the other Hawthorn units is overlain by marine Pleistocene sediments. The Hawthorn Formation unconformably overlies the Eocene Santee Limestone. The Oligocene Cooper Marl, present updip, is absent in the Coosawhatchie district.

The phosphatic sand of the Hawthorn Formation is mostly confined to a east-northeast trending basin herein called the Ridgeland Basin. This basin is bounded on the southeast by the Beaufort High, in which the Santee Limestone has been uplifted a minimum of 80 feet.

Clay minerals in the Coosawhatchie clay are highly montmorillonitic with kaolinite and illite in small amounts up to 5 or 10 percent. Clay size minerals in the Hawthorn units are montmorillonite, attapulgite (palygorskite), and sepiolite. Clinoptilolite occurs sparingly in one Hawthorn sample. Dolomite or calcite is present in most Hawthorn samples. The insoluble residue of one sample from the top foot or so of the Santee Limestone contains montmorillonite, illite, and trace amounts of kaolinite, the same clay suite as in the Hawthorn Formation. Clinoptilolite also was found in one Santee sample.

The origin of attapulgite and sepiolite is briefly reviewed. The presence of clinoptilolite in the South Carolina Hawthorn Formation suggests that volcanic ash may have contributed to the formation of the attapulgite and sepiolite. Another possibility is that the source area may have been a factor in supplying to the sea the necessary alumina and silica to form attapulgite and sepiolite. Magnesium could come from the normal magnesium content of the ocean or from the land. The phosphatic sand and the attapulgite-sepiolite probably accumulated under restricted conditions in the Ridgeland Basin.

INTRODUCTION

In 1962, the Division of Geology, South Carolina State Development Board, discovered the presence of phosphate-bearing sands and attapulgite clays in Miocene sediments in Jasper County, South Carolina (Figure 1). Since that time considerable exploration activity has been centered in Jasper and adjacent Beaufort County. This area is known as the Coosawhatchie district.

Approximately 200 holes have been drilled in various exploration programs. Samples from seven widely spaced holes (Figure 1) have been examined by X-ray diffraction methods. The purpose of this paper is to outline the general stratigraphic section and to report on the clay mineralogy of the sediments.

Acknowledgements

Pine Hall-Pomona Corporation provided clay samples from several drill holes. Mr. William Crow processed many of the samples for X-ray diffraction studies.

STRATIGRAPHY

Cooke (1936, p. 101) was the first to apply the name Hawthorn to lower Miocene sediments in southern South Carolina, thus extending the formation named by Dall (1892) from exposures near Hawthorn, Alachua County, Florida.

In the Coosawhatchie district, the Hawthorn can be subdivided into three dominant lithologies and the Coosawhatchie clay. The Coosawhatchie clay overlies the typical Hawthorn, possibly unconformably (Figure 2).

A phosphatic sand lithology occurs as two widespread beds. Both units are slightly clayey to clayey dark greenish brown fine to medium quartz sand with sand-size to pebble size phosphate grains. The lower bed rests on the Santee Limestone of Eocene age and the upper bed usually rests on a sand lithology. Both beds lack sharp boundaries except where they are in unconformable contact with beds below (lower unit) or above (upper unit). The conformable contacts are not sharp and are somewhat arbitrarily drawn using the BPL (bone phosphate of lime) content of the sediment to differentiate them.

The clay lithology is dark green and often contains up to 50 percent sand. Interbedded clayey sand layers may be as much as 2 or 3 cm thick. Some layers of relatively pure clay may be as thick as 100 cm. Phosphate grains occur in the clay lithology but the BPL content seldom exceeds 2 percent.

The sand lithology is similar to the clay lithology except that there is a larger percent of sand. The clay layers in the sand are

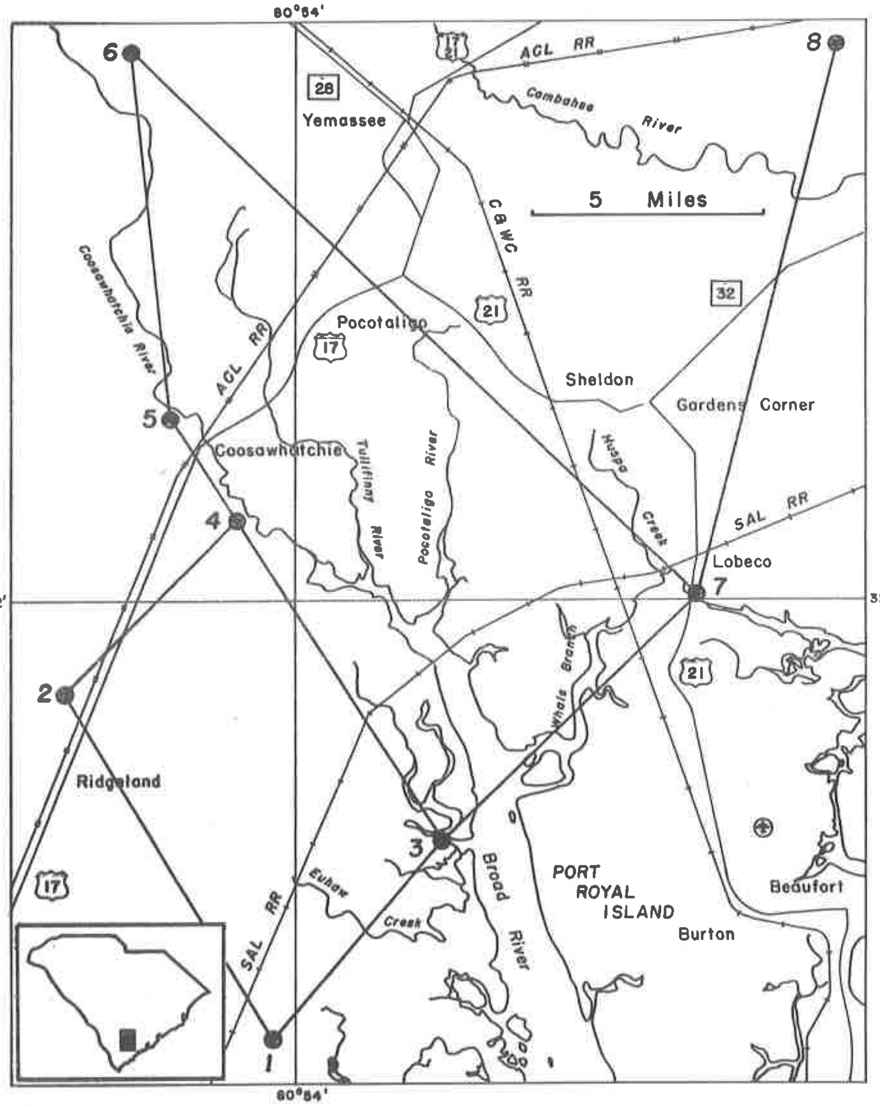

Figure 1. **Index map of Coosawhatchie district showing location of 8 drill holes studied. Lines connecting drill holes are the sections shown on the panel diagram of Figure 2.**

commonly less than 2 cm thick but they may be as thick as 10-20 cm. Clayey sand sequences without any pure clay splits may be up to 15 feet thick. Phosphate grains are common in the sand lithology but the BPL content seldom exceeds 5 percent.

The youngest unit overlying the phosphatic sand, clay, and sand lithologies has been informally termed the Coosawhatchie clay (Heron, Robinson, and Johnson, 1965, p. 24). It is very high in clay size material, has a cheesy texture, a yellow gray to light blue color, and has no preferred breaking direction.

Various sands and clays of Pleistocene age generally overlie the Hawthorn Formation.

STRUCTURE

The sediments of the South Carolina Coastal Plain generally dip seaward at a rate of 6-15 feet per mile. But, in detail, there are reversals of dip and even suggestions of relatively complex structures.

Underlying the Coosawhatchie district is the Eocene Santee Limestone (Figure 2). The limited subsurface data available suggest that the limestone surface is uneven and contains local basins and swells. An east-northeast trending basin with an axis passing near the towns of Ridgeland and Coosawhatchie is indicated by a greater thickness of Hawthorn Formation in this area and a structural high that brings the Santee Limestone near the surface eastward in Beaufort County. In one well near Brickyard Point (Beaufort County) the Santee rises to 19 feet below sea level. A few miles to the west in the Coosawhatchie district the limestone is at an elevation of -80 to -100 feet. The east-northeast trending basin is herein termed the Ridgeland Basin and the structurally high area to the east is called the Beaufort High.

A problem related to the structure and stratigraphy of the area is the absence of the Oligocene Cooper Marl in the Coosawhatchie district. Northeastward in its outcrop area the Cooper Marl overlies the Santee Limestone. No lithology assignable to the Cooper Marl has been recognized in well cuttings from the Coosawhatchie district. There are several possible explanations: (1) the Cooper has been cut out to the southwest by erosion prior to deposition of the Hawthorn, (2) the Cooper lithology changes southwestward into Hawthorn lithology, or (3) the Cooper lithology changes southwestward into Santee lithology. If (1) is correct then uplift to the southwest could have been caused by faulting or by a linear welt trending approximately west-northwest. If (2) or (3) are correct then the age assignments of all units are subject to question and revision. A detailed regional study will be necessary to resolve the problem. Structural elements of the area are shown schematically in Figure 3.

CLAY MINERALOGY

Fifty-three samples of the Hawthorn Formation, seven samples of the Pleistocene sediments, and four samples of the Santee Limestone were studied by X-ray diffraction. All samples were acid treated when necessary to remove carbonates, dispersed, separated at 2 microns, magnesium saturated, and sedimented onto glass slides from a thick slurry. Some samples were ground, sieved to less than 325 mesh, and mounted as a powder for X-ray diffraction. Samples were ethylene glycol solvated and heat treated to verify the various mineral components identified. No attempt was made to study relative amounts of the mineral components except when the montmorillonite, illite, and kaolinite groups were the only minerals found.

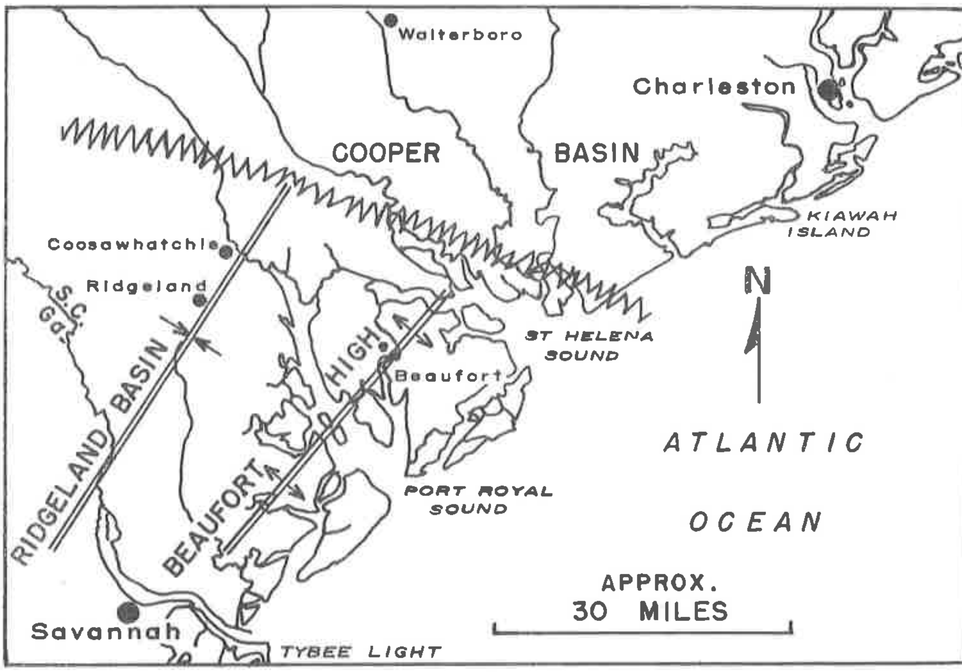

Figure 3. Structural elements of southern South Carolina.

Pleistocene Sediments

The clayey sediments of the Pleistocene contain dominant montmorillonite with subordinate kaolinite and a trace of illitic material. The samples close to the surface usually show the effects of weathering by having a high content of kaolinite and dioctahedral vermiculite or mixed layer materials. These clays agree in kind and amount with those of similar marine Pleistocene sediments elsewhere in the state (Heron, Robinson, and Johnson, 1965, p. 29).

One sample from hole 7 shows sepiolite as a major constituent along with montmorillonite. Sepiolite is abundant in the underlying Hawthorn, but it has not been detected elsewhere in the Pleistocene sediments. The sepiolite in the Pleistocene may have been eroded from the updip part of the Hawthorn. Buie and Gremillion (1963, p. 24-25) report that attapulgite is unstable in an acid environment, such as may be encountered in the weathering zone, and the attapulgite in Florida and Georgia readily weathers to montmorillonite and then to kaolinite. Rogers, Martin, and Norrish (1954, p. 537) report both attapulgite (palygorskite) and sepiolite in a rendzina soil overlying an attapulgite-bearing dolomite in Queensland. Apparently where basic conditions can be maintained during weathering, attapulgite and sepiolite may be carried over into the soil. If erosion were fast enough the sepiolite of the

Hawthorn could have been transported a short distance and deposited without serious alteration of the structure. This would be especially true if the erosion and deposition took place in a marine and hence slightly basic environment. The Pleistocene sediments in this area are of nearshore marine origin.

Coosawhatchie Clay

The dominant clay mineral of the Coosawhatchie clay is montmorillonite. Kaolinite and illite usually occur in small amounts, to as much as 5 or 10 percent. The clay has a very distinctive appearance. Its characteristic mineralogy, stratigraphic position, and apparent unconformable relationship to the underlying units indicate that this unit is genetically unrelated to the underlying sediments.

Hawthorn Lithologies

The clay mineral suites of the phosphatic sand, clay, and sand lithologies are very similar, although the X-ray patterns indicate that the amounts of the various minerals vary both horizontally and vertically.

Montmorillonite. - Every sample from the Hawthorn sediments contains montmorillonite. Often this mineral dominates the clay size material. The magnesium saturated samples have a basal spacing of about 14.5 Å that usually expands to 17 Å with ethylene glycol solvation. However, a few of the samples would not expand beyond about 16 Å. The only other prominent peak of the oriented sample is at 3.35 Å.

Attapulgite (Palygorskite). - As with montmorillonite, attapulgite is present in all samples of the Hawthorn Formation below the Coosawhatchie clay. It is especially abundant in and below the upper phosphatic sand unit. Montmorillonite and attapulgite alternate in relative abundance, but neither mineral appears to be dominant in one lithology or the other.

Figure 4 shows a characteristic X-ray diffraction pattern of attapulgite and Table 1 presents the X-ray data.

Sepiolite. - The three typical Hawthorn lithologies commonly contain sepiolite. In many samples the strong 12 A spacing of sepiolite is well developed and associated with the ubiquitous montmorillonite and attapulgite. No pure samples of sepiolite have been found. The minor X-ray diffraction peaks do not fit published data on sepiolite but do match fairly well the poorly crystalline sepiolite described by Brindley (1959, p. 448-499) and the variety pilolite (ASTM card 2-0034), an aluminum rich sepiolite. Espenshade and Spencer (1963, p. 21) report "questionable loughlinite and sepiolite" from the Hawthorn Formation of northern peninsular Florida. Buie and Gremillion (1963, 1964) report sepiolite associated with attapulgite in the Hawthorn Formation of southwest Georgia and panhandle Florida.

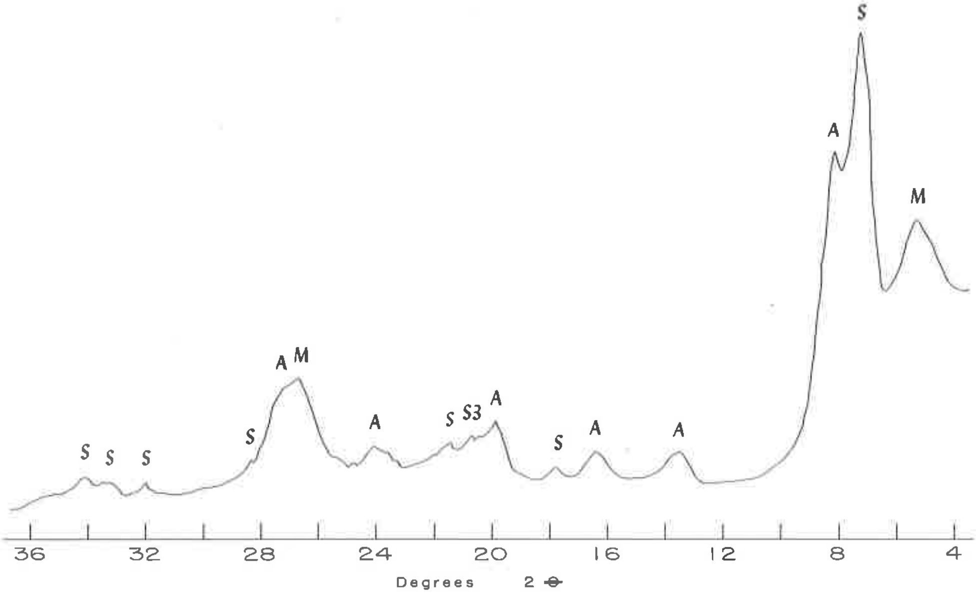

Figure 4. Typical X-ray diffraction tracing showing montmorillonite (M), attapulgite (A), and sepiolite (S) peaks. Sample is from the outcrop of the Hawthorn Formation at Sisters Ferry bluff on Savannah River, Georgia.

The South Carolina sepiolite always shows some of the characteristic hkl reflections for attapulgite associated with the 12 Å sepiolite peak, even where there is a poor development of the 10.6 Å peak. The 12 Å peak of sepiolite is still present after heating to 400° C for 12 hours. It is absent after heating for 8 hours to 550° C.

Other minerals. - Illite and related minerals are rare in the Hawthorn lithologies. Several samples showed poorly developed humps or weak peaks at about 10.2 Å.

A sample from the Hawthorn and one from the Santee Limestone, immediately beneath the Hawthorn, showed a small diffraction peak at 9.0 Å. The mineral is probably clinoptilolite rather than heulandite as it is thermally stable after heating above 450° C (Mumpton, 1960, p. 368). Clinoptilolite has been identified by the authors in other Coastal Plain units including the phosphatic lower Miocene in North Carolina, Miocene sediments of the Chesapeake Group in Virginia, and the Cooper Marl (Oligocene ?) in South Carolina. Rooney and Kerr (1964, p. 166) have recognized the mineral as an important constituent of the North Carolina phosphate deposits.

Samples processed as whole samples show the presence of either dolomite or calcite associated with the Hawthorn sediments. Dolomite occurs as small sand size crystals in both the sand and clay lithologies. Calcite occurs in thin limestone layers and in one sample

Table 1. -- d Spacings of Sepiolite and Attapulgite

Sepiolite Sample 27-12-3 Savannah River		Sepiolite Brindley (1959) Asia Minor		Attapulgite Sample 7 Hole 7	
(17)	s			(14.25)*	5
12.0	vs	12.3	60	10.65	vs
(10.81)	s			6.40	w
(6.53) B	w	7.6	5	5.42	w
(5.41)	w			4.99	vw
5.0	vw	4.9	6B	4.48	w
(4.46)	w	4.5		3.66	w
			20NR		
4.33	vw	4.3		(3.33)	mw
4.28	vw			3.22	mw
4.13	vw			3.05	vw
(3.72) B	w	3.746	20B	2.788	w
(3.34)	w	3.49	5	2.690	w
(3.24)	w	3.34		2.614	w
			20NR, B		
3.15	vw			2.240	w
2.796	vw	2.98			
2.69	vw	2.67			
		2.56	40NR, B		
2.625	vw	2.49			
		etc.			

Extra lines in (   )
B = Broad, NR = not resolved
Half Bracket = Broad hump with peaks indicated
* Poor expansion with ethylene glycol to as much as 16.21 Å
Both samples less than 2 microns size, oriented slides, 1°2θ per minute.

within the clay lithology. Calcite and dolomite appear to be mutually exclusive.

No attempt has been made to identify the phosphate mineral in the phosphatic sand lithology by measurement of the unit cell. The X-ray diffraction pattern of a phosphate pebble from the upper phosphatic sand unit (Locality 27-3, Jasper County) is almost identical to that given by Malde (1959, p. 43) for a phosphate pebble from Charleston, South Carolina. He tentatively identified the mineral as carbonate-fluorapatite based on the amount of fluorine, carbonate, and P_2O_5. Carbonate-fluorapatite has been identified as the primary phosphate mineral in North Carolina (Rooney and Kerr, 1964, p. 166) and in Florida (Altschuler and others, 1952, p. 1231).

Santee Limestone

One sample of insoluble residue obtained from the Santee Limestone contains 73% montmorillonite, 25% illitic material, and 2% kaolinite. Three other samples from the Santee Limestone immediately below the basal Hawthorn phosphatic sand unit show montmorillonite, sepiolite and/or attapulgite, illitic material, and in one case clinoptilolite. The first sample is probably more representative of the Santee Limestone as a whole because it fits the picture as developed elsewhere (Heron, Robinson, and Johnson, 1965, p. 23). The other three samples may represent contamination in drilling, filling of small cracks and holes in the limestone with overlying Hawthorn sediments, or partial replacement of the limestone by magnesium rich solutions.

DISCUSSION

The sedimentary origin of attapulgite and sepiolite is not yet completely known and perhaps is polygenetic. Experimental studies by Mumpton and Roy (1958, p. 142) led them to believe that a calcium environment is one important factor in the formation of attapulgite or sepiolite. Siffert and Wey (1962, p. 1461) found that sepiolite could be synthesized below 100°C if the initial pH was above 10 and the final pH above 7.8. Both minerals need a magnesium environment. The formation of sepiolite is perhaps more likely to occur in a high magnesium environment since it contains more magnesium in its structure than does attapulgite. Mumpton and Roy have demonstrated that sepiolite and attapulgite are metastable with respect to montmorillonite, and Buie and Gremillion (1963) have shown how montmorillonite may form from attapulgite in an acid weathering environment. Therefore, it appears that attapulgite and/or sepiolite are not formed from the modification of a previously existing mineral (such as montmorillonite) but rather that the necessary SiO_2, MgO, and Al_2O_3 are combined along with H_2O in a calcium environment or in a high pH environment to form one or the other <u>or</u> both minerals.

There are two possible sources for the basic components necessary to form the minerals, halmyrolysis of volcanic ash or lateritic weathering of the land. A hybrid source would be weathering of land deposited volcanic ash.

Grim (1933) appears to be one of the first to suggest that the Georgia-Florida Hawthorn attapulgite clays were formed from volcanic ash. Carr and Alverson (1959, p. 66) and Espenshade and Spencer (1963, p. 20) seem to favor a volcanic ash origin. Buie and Gremillion (1963, p. 25) strongly favor a volcanic ash origin for the same attapulgite and sepiolite clays of Georgia-Florida. Grim (1933) and Buie and Gremillion (1963) report volcanic shards from the Hawthorn. Espenshade and Spencer (1963, p. 20-21) found no shards and commented on possible misidentification of shards. If the commercial attapulgite deposits of Florida and Georgia formed from volcanic ash it would seem that glass shards are likely to have been destroyed in the process.

Hathaway and Sachs (1965, p. 864-865) suggest volcanic ash as a possible contributing factor to the formation of sepiolite on the Mid-Atlantic Ridge. They attribute the source of the Mg ions to nearby serpentine or to normal Mg in sea water. Presence of abundant clinoptilolite associated with the sepiolite is taken as the cause of the high pH Siffert and Wey (1962) found to be important in the synthesis of sepiolite. Hathaway and Sachs consider the clinoptilolite, associated quartzose chert, and montmorillonite as alteration products of the volcanic ash.

Millot (1962a, b) favors a land source of the Mg, Si, and Al necessary for formation of attapulgite and sepiolite. The ions are produced during lateritization of both mafic and felsic rocks (1962a, p. 161). As evidence for a land source of various ions, Millot (1962b) summarizes the works of several groups in the Senegalese Basin of West Africa. Here kaolinite, montmorillonite, attapulgite, and sepiolite form a regular sequence from nearshore to deeper waters near the center of the basin. Nearshore kaolinite is interpreted as detrital whereas the authigenic montmorillonite, attapulgite, and sepiolite increase seaward in that order. This represents a basinward increase in the MgO/Al_2O_3 ratio.

Buie and Gremillion (1964, p. 1) report that in the Georgia-Florida attapulgite district the mineralogy changes in a southwest direction along strike and in the direction of the plunge of the Gulf Trough of Georgia. They found an increase in carbonate (presumably magnesium carbonate) and an increase in attapulgite/montmorillonite ratio to the southwest (basinward) with a corresponding decrease in diatoms and sepiolite. This is similar to the finding of Millot except for the decrease in sepiolite basinward which is opposite to his observation.

Espenshade and Spencer (1963, p. 18) found that in the Hawthorn of northern peninsular Florida a lower phosphatic dolomite unit contains attapulgite with some montmorillonite, whereas an upper phosphatic clayey sand unit contains montmorillonite and only rarely some attapulgite. Sepiolite is reported in a few samples from the lower phosphatic dolomite. No trend in the distribution of these minerals was noted by the authors, although the phosphate units do change thickness in various directions and the dolomite unit thickens basinward. It appears, therefore, that the attapulgite/montmorillonite ratio increases basinward. This is similar to findings of Millot and Buie and Gremillion.

Decrease in aluminum and increase in magnesium basinward is in keeping with the mobility of these ions, the less mobile aluminum would be tied up in compounds more quickly than the more mobile magnesium.

The origin of attapulgite-sepiolite in the South Carolina Hawthorn Formation appears compatible with the volcanic ash theory. Although shards have not been searched for in the South Carolina Hawthorn, the presence of small quantities of clinoptiloite is strong evidence for volcanic ash. This zeolite has always been attributed to alteration of volcanic ash (reviewed in Hathaway and Sachs, 1965, p. 864). The small quantities of clinoptilolite in the Hawthorn would not fulfill the postulated requirement for high pH, but the presence of carbonates fulfills the possible need for CaO. Volcanic ash might also provide the phosphorous necessary to fertilize the sea and eventually form the associated phosphate grains.

North Carolina phosphate deposits (Brown, 1958) occur in the same age rocks as the Hawthorn of South Carolina. Rooney and Kerr (1965, p. 165-166) report glauconite, montmorillonite, and abundant clinoptilolite as the dominant material in the clay fraction associated with the phosphate. Dolomite grains and carbonate cemented phosphate pellets are also reported. They associate the origin of the phosphate with volcanic activity as suggested by the abundant clinoptilolite. It is strange that the North Carolina phosphate deposits, with age, stratigraphic relationships, and basic mineralogy similar to the South Carolina Hawthorn Formation, contain no reported attapulgite or sepiolite. What were the conditions that led to the formation of attapulgite-sepiolite in one place and no attapulgite-sepiolite in another place?

The question cannot be answered definitely, but an intriguing possibility is that some ingredients of the attapulgite, sepiolite, and montmorillonite came from the land via rivers to the oceans in a manner similar to that described by Millot (1962b) and combined perhaps with other elements also present to form the various minerals. The major difference between the North Carolina and the South Carolina-Georgia-Florida area is the outcrop of highly kaolinitic beds of Cretaceous and perhaps early Tertiary age in the vicinity of the more southerly area. Lateritic weathering of these beds (reported for early Tertiary beds by Cooke and MacNeil, 1952, p. 23) may have supplied silica and some alumina to the basin of sedimentation. Magnesia could have come from the normal magnesium content of the ocean or from lateritic weathering of magnesium-bearing Piedmont rocks. Volcanic ash could help the process, but it would not be strictly necessary. The observed basinward increase in MgO/Al_2O_3 ratio would be compatible with a land source for the ions. The phosphorous source could be from volcanic ash or from the land via rivers as suggested by Millot (1962a, b) and Bushinski (1964).

The authigenic formation of attapulgite-sepiolite, and to a lesser extent the volcanic ash origin of the minerals, requires bottom conditions different from those of an open shelf. For a concentration of ions to occur a somewhat restricted basin would have to form. Such a basin would probably be silled so as to prevent an interchange of bottom waters with the more agitated near-surface waters. The Florida-

Georgia attapulgite-sepiolite has formed in a basin (Buie and Gremillion, 1964, p. 1) as have the African deposits. There is also evidence for a basin (Ridgeland Basin, p. 54) in the South Carolina section. No details are as yet available on any of these basins, but restricted conditions should be a helpful condition for the origin of the magnesium minerals as well as the phosphate.

REFERENCES

Altschuler, Z. S., Cisney, E. A., and Barlow, I. H., 1952, X-ray evidence of the nature of carbonate-apatite: Bull. Geol. Soc. America. v. 63, p. 1230-31.

Brindley, G. W., 1959, X-ray and electron diffraction data for sepiolite: Am. Mineralogist, v. 44, p. 495-500.

Brown, Philip M., 1958, The relation of phosphorite to ground water in Beaufort County, North Carolina: Economic Geology, v. 53, p. 85-101.

Buie, B. F., and Gremillion, L. R., 1963, Attapulgite in fuller's earth deposits of Georgia and Florida: Georgia Mineral Newsletter, v. 16, nos. 1-2, p. 20-25.

Buie, B. F., Gremillion, L. R., and Ritchie, F. T., 1964, Field trip to attapulgite fuller's earth localities in Georgia and Florida: Clays and Clay minerals, 12th Natl. Conf. on Clays and Clay Minerals, Pergamon Press.

Bushinski, G. I., 1964, On shallow water origin of phosphorite sediments: Deltaic and Shallow Marine Deposits, Elsevier Publishing Co., p. 62-70.

Carr, W. J., and Alverson, D. C., 1959, Stratigraphy of Middle Tertiary rocks in part of west-central Florida: U. S. Geol. Survey Bull. 1092, 111 p.

Cooke, C. W., 1936, Geology of the Coastal Plain of South Carolina: U. S. Geological Survey Bull. 867.

Cooke, C. Wythe, and MacNeil, F. S., 1952, Tertiary stratigraphy of South Carolina: U. S. Geol. Survey Prof. Paper 243-B, 29 p.

Dall, W. H., and Harris, G. D., 1892, Correlation papers, Neocene: U. S. Geol. Survey Bull. 84.

Espenshade, Gilbert H., and Spencer, C. W., 1963, Geology of phosphate deposits of northern Peninsular Florida: U. S. Geol. Survey Bull. 1118, 115 p.

Grim, R. E., 1933, Petrography of the fuller's earth deposits, Olmstead, Illinois, with a brief study of some non-Illinois earths: Econ. Geology, v. 28, p. 344-363.

Hathaway, John C., and Sachs, Peter L., 1965, Sepiolite and clinoptilolite from the Mid-Atlantic Ridge: Am. Mineralogist: v. 50, p. 852-867.

Heron, S. Duncan, Jr., Robinson, Gilbert C., and Johnson, Henry S. Jr., 1965, Clays and opal-bearing claystones of the South Carolina Coastal Plain: S. C. State Development Board, Div. of Geology, Bull. 31, 66 p.

Malde, Harold E., 1959, Geology of the Charleston phosphate area, South Carolina: U. S. Geol. Survey Bull. 1079, 105 p.

Millot, G., 1962a, Some geochemical aspects of weathering and sedimentation: Physical Sciences, Some Recent Advances in France and the U. S., New York University Press, p. 159-169.

__________, 1962b, Crystalline neoformations of clays and silica: Physical Sciences, Some Recent Advances in France and the U. S., New York University Press, p. 180-191.

Mumpton, F. A., 1960, Clinoptilolite redefined: Am. Mineralogist, v. 45, p. 351-369.

Mumpton, Fred A., and Roy, Rustum, 1958, New data on sepiolite and attapulgite: Clays and Clay Minerals, 5th Natl. Conf. on Clays and Clay Minerals, Natl. Acad. Sci.-Natl. Res. Counc. Pub. 566, p. 136-143.

Rogers, Lillian E., Martin A. E., and Norrish, K., 1954, The occurrence of palygorskite, near Ipswich, Queensland: The Mineralogical Magazine, v. 30, p. 534-540.

Rooney, Thomas P., and Kerr, Paul F., 1964, Mineralogy of North Carolina phosphorite: Geol. Soc. Am. Program, 1964 Annual Meeting, p. 165-166.

Siffert, B., and Wey, R., 1962, Synthése d'une sepiolite à temperature ordinaire: Comptes Rendus Hebdomadaires des Séances de l'Académie de Sciences, Paris, p. 1460-1462.

SEDIMENTS OF THE CHOPTANK RIVER, MARYLAND

by

John W. Kofoed
Coast and Geodetic Survey
Environmental Science Services Administration

and

Donn S. Gorsline
University of Southern California

ABSTRACT

The Choptank River on Maryland's Eastern Shore is a tributary of the Chesapeake Bay and part of one of the largest estuarine complexes in the world. Over the last century topographic and hydrographic mapping show major changes of the shorelines and sea floor which are the result of erosion, reworking, and deposition. The shorelines, by nature of the composing sediments, are quite vulnerable to erosion. The sea floor sediments are all reworked detrital and organic material and reflect selective sedimentological processes. The shallower submerged terrace sediments are generally sandy and the deeper channel sediments are more silty. Apparently, little new material is being contributed to the environment from the upper reaches of the river. The major source of detrital material will continue to be from the receding shorelines and other reworked sediments carried into the area.

INTRODUCTION

General

The Choptank River on Maryland's Eastern Shore is a tributary of the Chesapeake Bay and part of one of the largest estuarine complexes in the world. The densely populated and thriving hinterland of this complex was favored in no small way by the development of a system of navigable waterways and a productive shellfish industry. Perhaps no other comparable area supplies more seafood than does the Chesapeake Bay (Radoff, 1952). Consequently, the rapid accumulation of sediments in navigable channels and in areas of commercial shellfish beds has been a problem peculiar to the region's economic well being. Erosion too has been a problem, particularly along the Eastern Shore in the vicinity of the Choptank River where hundreds of acres of land have been lost and the floor of the bay has been modified by the action of waves and currents. In 1961, Jordan made a quantitative study of topographic and hydrographic changes of the shoreline and estuary floor in the eastern Chesapeake Bay and lower reaches of the Choptank River. His study was based on hydrographic surveys spanning a period of approximately 100 years (Jordan, 1961). Changing shorelines and depths of water were treated in detail. During the fall of 1963, bottom samples were obtained in the lower and upper reaches of the Choptank River system by means of a Phleger corer. This work was accomplished by the USC&GS Ship Marmer. The present paper is based on results of the bottom-sample analyses and considers pertinent aspects of sedimentology near the mouth of the Choptank River.

Previous Investigations

The Choptank Folio (Miller, 1912) was the first detailed geologic work in the area. This work was followed by that of Miller and Little (1916) and Miller (1926, 1926a). Stephenson, Cooke, and Mansfield (1932) discussed the area in a guidebook for the XVI International Geological Congress. Hunter (1914) and Singewald and Slaughter (1949) reported on erosion and sedimentation in Chesapeake Bay off the mouth of the Choptank River and in Tidewater Maryland, respectively. Shattuck (1906), Cooke (1930, 1931), and Breitenbach and Carter (1952) studied the Pleistocene and recent sediments and terraces. Dryden (1931) described the Miocene formations, some of which are found in the Choptank area. Other geologic work in the area of this study includes that of Clark (1918), and Wood (1926).

The history of geographical research in the bay area and parts of Delmarva Peninsula have been summarized by Miller (1926). Tides, currents, and sea level changes have been reported by Haight and others (1930) and Disney (1955). Rasmussen and Slaughter (1951, 1957) reported on the ground-water resources of the Cambridge area.

The most recent sediment studies in the immediate area include Jordan's (1961) descriptive and quantitative investigation on the bathymetry and Ryan's (1953) sedimentological study of Chesapeake Bay. The latter study dealt with all parts of the Bay except the Choptank Estuary. Also, in 1963, Biggs reported on geochemical analyses of the sulfides and related organics for a small part of the main Chesapeake Bay area.

Area and Method of Study

The Choptank River flows across the Delmarva Peninsula, which lies between Chesapeake Bay and Delaware Bay and includes parts of Delaware, Maryland, and Virginia (Figure 1). The river is approximately 70 miles long and drains the west central portion of the peninsula. With the exception of its headwaters, which rise in Kent County,

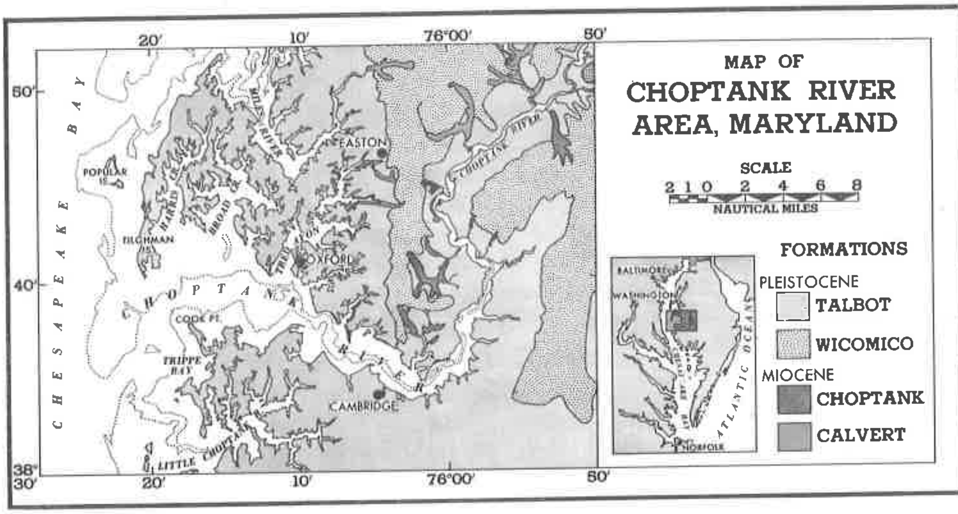

Figure 1. Map of Choptank River area. The dotted line is the 3-fathom depth contour.

Delaware, the course of the Choptank River lies entirely in Talbot, Dorchester, and Caroline Counties, Maryland. At a point approximately 45 miles southeast of Washington, D. C., and 139 miles north of Norfolk, Virginia, the river empties into Chesapeake Bay. The work reported here deals primarily with the sediments in the tidal portion of the river, its tributaries, and the adjacent portion of the Bay that receives the debouched river water and sediments.

A biased sampling pattern was used in this study, based on the changes in water depths and shorelines described by Jordan (1961). Areas of erosion, sedimentation, and those showing little or no change were sampled as well as a number of points up the river and in areas of greatest depths, or scour holes (Figure 2). Bottom samples were obtained by means of a Phleger corer. Sedimentological analyses followed and were analyzed by the standard procedures described in the following publications: Allan Hancock Staff, 1958; Allison, 1935; Bien, 1952; Krumbein and Pettijohn, 1938; and Moore and Gorsline, 1960.

GEOLOGIC AND GEOGRAPHIC SETTING

General

For the most part, poorly indurated soft rocks and semiconsolidated or unconsolidated sands, gravels, and calcareous sediments, constitute the Coastal Plain formations of Maryland. This being the case, particularly on the Eastern Shore, it is often difficult to unquestionably identify formational contacts in many locations. This problem

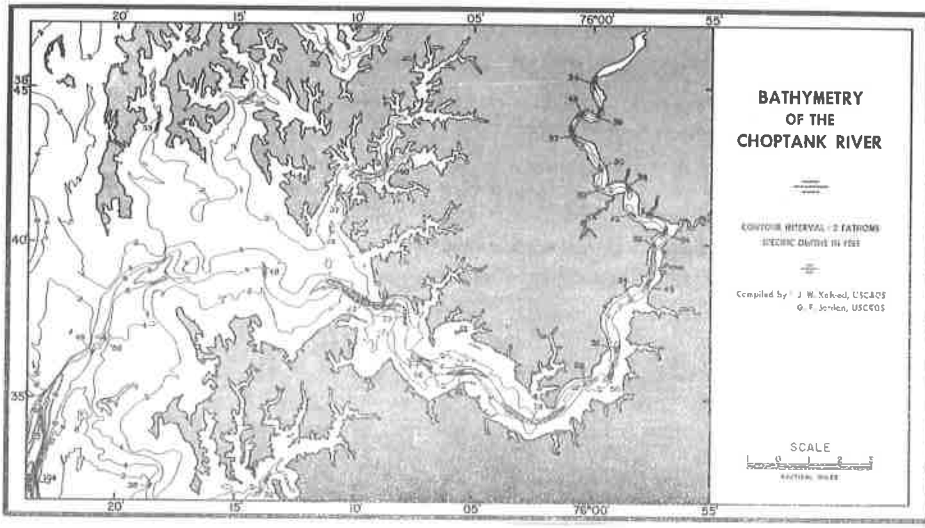

Figure 2. Bathymetry of Choptank River.

is further compounded by the lack of structural elements in the formations and by the modification and reworking of sediments during transgressions of Pleistocene seas, which has necessitated defining the Pleistocene formations on the basis of the terraces formed by the transgressing seas.

In the Choptank Watershed, surface formations range in age from Miocene to Recent but Pliocene formations are not present (Figure 1). Miocene formations underlie the entire area. However, they crop out only along the banks of some of the tributaries to the Choptank River. These formations, the Calvert and Choptank, generally strike northeast and dip gently southeast.

By far the largest portion of the Miocene surface is covered by the Pleistocene Talbot and Wicomico Formations which topographically appear as terraces. These formations are the reworked sands, gravels, and clays that may have been eroded and redeposited by a number of Pleistocene inundations. It is possible that some of these surfaces or their materials are of Pliocene age. Recent sediments are found on the floor of coastal and estuarine marshes and generally are similar in composition to the terrace sediments.

Pleistocene and Recent History

The coastal margin of the eastern United States is characterized by a number of terraces in various degrees of preservation. As a result of erosion, vegetation, and inherent low relief these terraces are often obscure and unidentifiable in many places. Consequently, not all workers in the area agree as to the number of terraces present, as discussed by Cooke (1941). Many of those who have studied the problem agree that the terraces, when present, indicate higher stands of the sea since the early Pleistocene and that the terrace features relate to the past advances and retreats of the continental ice mass. Since each successive cooling and warming is postulated to have been of lesser magnitude than the preceding cycle, the oldest terrace is concluded to be at the highest elevations and each succeeding younger, or more recently formed, terrace to be at successively lower elevations.

During the early Pleistocene, the emerged Eastern Shore of Maryland was eroded. This followed a series of Miocene and Pliocene periods of uplift, erosion, and submergence, and preceded a similar sequence of events. The number of times this occurred is not known. At the beginning of the Pleistocene the peninsula was undoubtedly much smaller and the area of the bays much larger. With time and diminishing magnitude of sea-level changes the respective dimensions of the bay and peninsula tended toward the present configuration.

With each uplift, a new drainage system must have formed on the newly exposed sediments to erode and transport the unconsolidated sediments back to the sea floor. As each successive transgression of the sea inundated the land it left its mark or scar in the form of a wave-cut scarp. These scarps became the seaward extent of the consequent terrace and the indicators of the various stands of the sea used today to relate these old surfaces.

Physiography

The physiographic expression of the western Eastern Shore of Maryland is of low relief, low elevation, and with the exception of the Pleistocene terraces, is essentially flat and featureless. This fact is attributed to the soft and readily eroded sedimentary material found throughout the area. Maximum elevations are slightly over 70 feet while approximately three-fourths of the area is below 25 feet; however, the topography of the Choptank Watershed can be characterized by the physical character of three distinct topographic features. These are the tidal marshes, and the plains of the Talbot and Wicomico terraces. The principle distinction between these features is elevation.

At the heads of the estuaries, mouths of tributary streams, along the river, and on many of the islands, tidal marshes are common. The marsh areas are underlain by sands, clays, and gravels supporting an abundant growth of marsh vegetation. Accurate charts are difficult to make for many portions of the Eastern Shore because by the nature of tidal marshes many acres are inundated by the high tide. Some of the islands are found to exist only at times of low tide as is characteristic where marshes abound.

The Talbot terrace is a flat surface of marine origin that covers the largest portion of the study area. It extends from sea level in places to elevations of 45 feet above sea level and in most areas at the lower elevations it borders the tidal marsh. Those portions of the terrace at sea level are constantly being worn away by wave action at the shorelines which in turn provides a wealth of sedimentary material to the subaqueous areas. Erosion is augmented during the winter months when the northwest winds increase the effectiveness of waves. During these times of increased wave energy the water often becomes heavily laden with suspended sediments. Stream erosion has had relatively little effect on erosion of the terraces because of the low elevations and the gentle stream gradients.

The older and higher Wicomico terrace is separated from the Talbot by a 20 to 25 foot north-south escarpment (Suffolk scarp). This escarpment is wave-cut and is particularly well defined in the vicinity of Easton (Figure 1). Since the elevations of the Wicomico terrace are greater than the Talbot it has been subjected to longer periods of erosion by streams of greater energy as evidenced by the stream and river valleys.

Hunter (1914) observed that north of the Choptank River mouth shores of the Bay were altered by erosion cutting inland in contrast to the south where large areas of marsh are apparently building. A short distance below the mouth of the river the bay widens two or three fold. Therefore, it would appear that the bay is striving for equilibrium in bay width since the aggradation is found in the widest portion and degradation dominates in the narrower northern portion of the bay.

Simply stated, the topographic history of the area is reflected in the history of the development of the terraces.

The drainage system is dendritic and relatively simple because of the lack of structural control. Generally, the land is naturally drained both by runoff and percolation to the ground water system. Many of the streams are brackish and lack currents except for a small tidal influence. The Choptank River rises in Kent County, Delaware, at an elevation of 60 feet. The tidal range is approximately two feet and extends beyond the "Y" formed by the tributary Tuckahoe Creek and the Choptank River.

Bathymetry

Because the present investigation is meant to complement Jordan's (1961) study, this discussion of the bathymetry is based upon his work. The bathymetric characteristics of the Choptank River are shown in Figure 2.

Choptank River Channel. Changes in configuration of the main channel of the Choptank River result from the nature of the containing land area and from the estuarine conditions of the river. At the mouth and in the lower reaches a broad expanse of water provides a fetch for wave generation that exposes the shoreline of the river and its tributaries to the same erosional forces found in the open bay. Redistribution and erosion of an abundant supply of sediments by waves and currents is augmented by the tides which extend upstream to the Tuckahoe Creek area.

For over 100 years sedimentation has exceeded erosion in the main channel and this net addition amounts to approximately 30 feet at the entrance. Along the course of the river scour holes are common and are maintaining their depths. Several holes are maintained in a 50 to 60 foot depth range and in some cases appear to be slowly migrating down stream.

Jordan (1961) has shown by profiles locations where one side of the channel has been eroded and a compensating amount of deposition on the opposite of the channel has occurred indicating a meander-like movement of the main channel.

Subaqueous Terraces. No attempt is made to correlate or equate the subaqueous terraces in the area. However, the existence of these features should be noted as they provide an indication of limiting depths of erosion and sedimentation. As mentioned in another section of this report the greatest shoreline erosion is along the main shores of the bay; nevertheless, erosional forces are effective elsewhere, as for example in the scour zones in channels and inlets.

Broad terraces at depths of 3 feet are present in both the Choptank and Little Choptank Rivers. These terraces are found on resistant bars, spits, and broad areas of deposition. At a slightly greater depth, generally 5 to 7 feet, what appear to be broad erosional terraces have formed. The limiting depth appears related to the degree of exposure to storms and to the stronger currents. Throughout the area of the river mouth and adjacent bay, terraces apparently formed by erosional agents can be found in depths ranging from 2 to 15 feet.

Shoreline Changes. At Cook Point on the southern side of the river entrance, the shoreline has receded approximately one-quarter of a mile. Across the river to the north, in the vicinity of Broad Creek, erosion of the shoreline has progressed three-quarters of a mile in places (Figure 1). Throughout the area Jordan (1961) has mapped shoreline changes. With the exception of a few scattered localities all changes are erosional and are not restricted solely to headlands, spits, and similar protruding features although all of these prominences have been altered.

It is evident from the map of Figures 1 and 2 that the shoreline is vulnerable and susceptible to even low magnitude erosional processes.

Changes in Sea Level. The tidal ranges for the Chesapeake Bay and its tributaries are given as yearly averages and appear as small values. However, even though extremes are infrequent it is significant to note the highest sea level recorded at Baltimore between 1902 and 1953 was 12.8 feet. The normal tidal range here is only 1.1 feet and the average yearly lowest tide over 50 years has been 2.9 feet below the mean of low waters (Jordan, 1961; Disney, 1955).

Under Johnson's (1919) classification of shorelines the present shoreline is submergent representing a rise in sea level since the last glacial period. It is logical to assume that either the subaqueous terraces have been drowned as a result of this recent increase in sea level or are very recent erosional features. However, the secular changes measured in the area by Jordan (1961) show the terraces to be erosional and depositional features altered during the past 100 years.

Tide-level observations over the past 40 years show an 0.011 foot rise per year relative to land which infers 1 foot rise in sea level since the 1840's. This change in sea level is not apparent from the comparison of soundings. If this is true it may be assumed that the Choptank River region will continue to be a submergent coastal area.

SEDIMENTOLOGY

Cores and Their Analysis

The locations of core-sample stations are shown in Figure 3. As noted earlier, the sampling sites were based on the bathymetric study of the area by Jordan (1961). An attempt was made to obtain samples from areas of deposition, erosion, and zero net change, as well as from the major features of the physical environment -- the channels, slopes, and marginal terraces. The limited period during which the ship was available restricted the total number of stations to 36, of which 34 were successfully sampled. Twenty-two of these were full-length cores of about 70 centimeters. The Phleger coring device that was used to obtain the samples penetrates to a maximum depth of approximately one meter, but thinning of the sediments ahead of the penetrating core barrel tends to shorten the core sample. Sands are very difficult to penetrate and the shorter samples, of 5 to 40 centimeters in length, were invariably sandy. All but two of the longer cores were essentially uniform in appearance. Hence, subsamples were taken only from the top and bottom 10 centimeters. The other two long cores and the remaining cores of sufficient length to permit multiple subsampling were variable in lithology. All lithologic types were sampled; channels and areas of net deposition were best represented by approximately half of the samples. Areas of erosion and upper-river channel samples were represented by only three cores. The remaining cores were collected in areas of no net change.

Representative fractions of each core subsample were dried and powdered for later chemical analysis. The remaining and larger portion of the sample was analyzed mechanically in order to determine the textural character of the sediment. The methods used in this analysis follow those described by Moore and Gorsline (1961). Computations of textural parameters were programmed for computer calculation, based on moment measures of the size distributions (see Krumbein and Pettijohn, 1938). Phi notation was used in the textural computations but

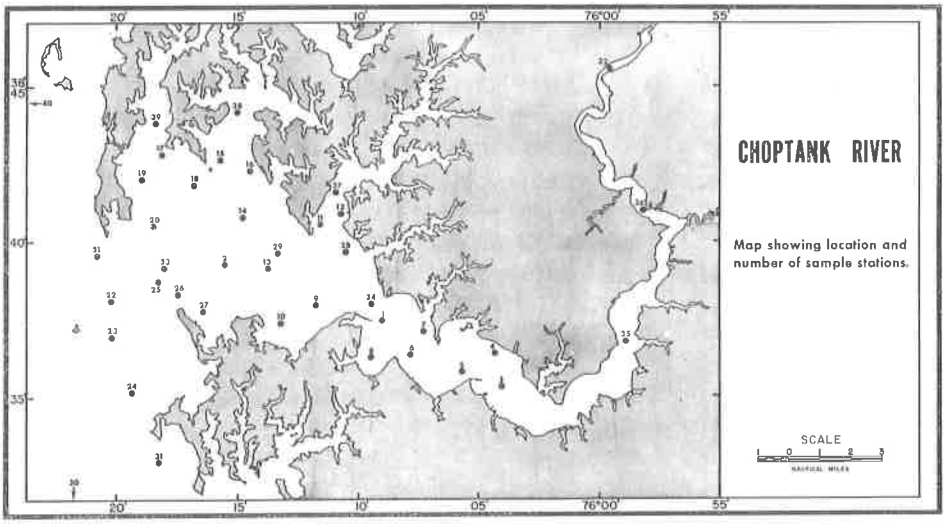

Figure 3. Locations of core-sampling stations.

diameters are noted in equivalent millimeter values for the various tabulation and plates. Coarse fractions were examined after the general method of Shepard and Moore (1954).

The analytical data are filed at the Office of Research and Development, Coast and Geodetic Survey, Environmental Science Services Administration of the U. S. Department of Commerce and at the Department of Geology, University of Southern California. Data summaries have been prepared in punch card form and data printouts may be obtained on request.

Textural Properties

The ranges in textural properties are illustrated by the plot of mean diameter versus skewness and mean diameter versus standard deviation in Figure 4. Based on this plot, the sediments fall into two major groups: a sand series designated Group I and a fine silt or silt-clay series designated Group II. A few fine-grained samples were found to lie outside the main range of the fine series and were specifically examined. Most of these points were found to result from errors in analysis, or were mixtures of fine silt and silt-clay with whole shells of biological origin. Correction of these data eliminated the extraneous points.

The grain-size distributions of the Group I sediment samples are shown in histogram form in Figure 5. The samples in this group for the most part are from the axis of the channel (see station locations in Figure 3). The grain-size distributions of the Group II samples are shown by histograms in Figure 6. Most of the latter group of samples

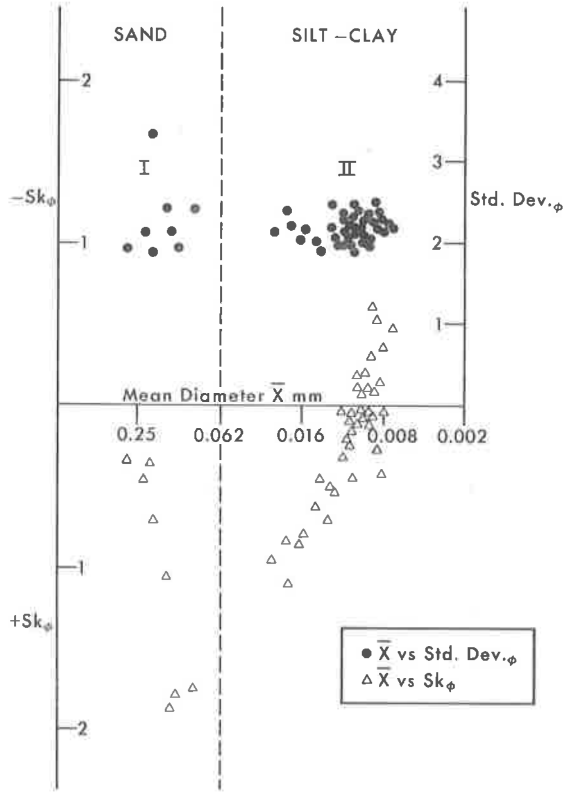

Figure 4. Ranges of grain size in sediment samples--mean diameter versus standard deviation and mean diameter versus skewness plots.

also are from the axis of the channel. In Figure 7, the Group II grain sizes are plotted as cumulative frequency curves on probability coordinates.

No attempt has been made to chart the areal distribution of sediment textural parameters since the channel, central slope, and bay-floor samples are all of about the same grain size, whereas the shallow terrace samples are highly variable gravels and sands and are represented by relatively few sample localities. A schematic view of the areal distribution of sediment textures would show fine sediment covering much of the bottom at depths greater than 20 to 25 feet and sandy bottom at lesser depths.

The various diagrams indicate several environmental controls in the observed characteristics. In the Group II samples the main trend is towards negative skewness with decreasing mean size. This reflects the effect of artificial deflocculation of naturally flocculated aggregates

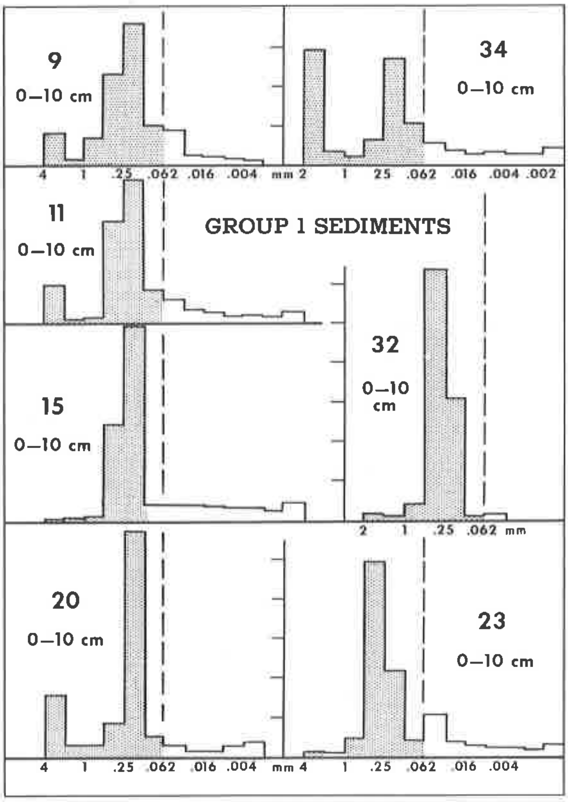

Figure 5. Histograms showing grain-size distribution in Group I sediments of Figure 4. Labels indicate core-sampling station, length of core sample, and mean diameter in millimeters.

which probably behave hydraulically as silts in nature. Channel samples are generally distributed around an average skewness of zero and range from about -0.5 to +0.5, although there is considerable overlap. Central bay-floor samples outside the channels but in areas of fine sediment mainly are skewed positively and reflect either a coarse sand or a shell fragment admixture with the uniform silt-clay type. The majority of these samples of Group II character are in the areas of net deposition and thus probably represent a single sediment sequence laid down by tidal currents in the deeper and low-turbulence zones of the system.

The Group I samples are sands with modal sizes in the medium and fine grades with variable additions of shell fragments at the coarse end of the distribution and silt-clay matrix at the fine end. This variation in minor components causes the spread in values shown in Figure

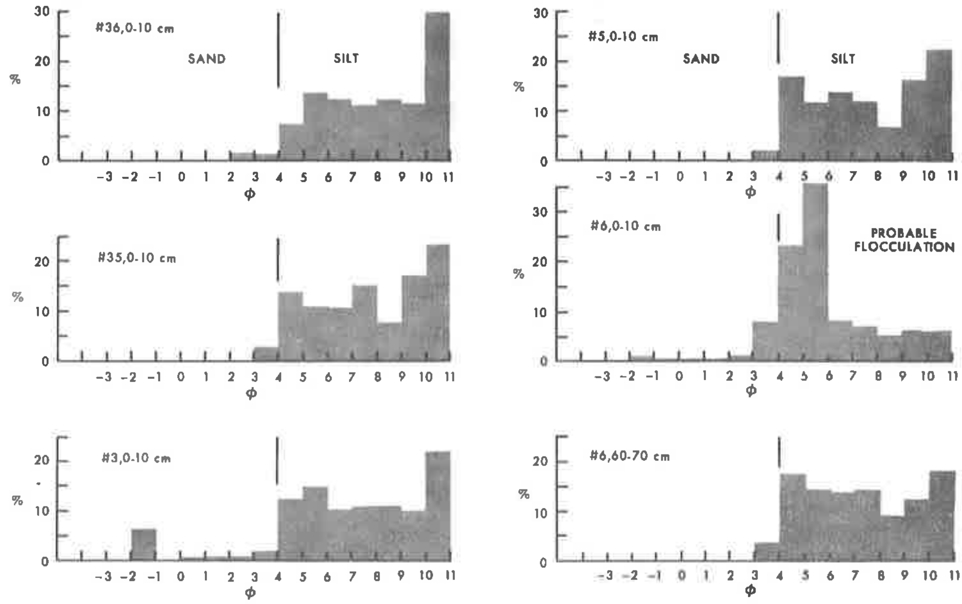

Figure 6. Histograms showing grain-size distribution in Group II samples of Figure 4. Labels indicate core-sampling station, length of core sample, and mean diameter in phi units.

4. All of the sands are within the depth range of the shallow terrace being swept by waves.

Kurtosis has not been interpreted in detail inasmuch as it is a reflection of sorting (or standard deviation) and is much influenced by the tails of the size distribution plots; the parts which are also subject to the largest errors.

Calcium Carbonate Contents

Calcium carbonate contents were determined from gasometric analyses (Bien, 1952). With the exception of two or three samples containing shells or shell fragments, carbonate contents are less than 5 percent and the great majority are one percent or less by weight. This may be due in part to the presence of reduced conditions in the channel sediment and other areas of fine sediment deposition. Pollution too may be a factor; numerous small towns and two small cities dump much of their wastes into the river. In the shallow terrace sediments shells and shell fragments are much more common and almost all of the high carbonate sediments are Group I sands.

Carbonate is predominantly shell fragments, with lesser amounts of foraminifera. No detrital carbonate was noted. Rates of sedimentation may be an important factor in limiting the amount of carbonate, and leaching may occur in the reduced fine sediments.

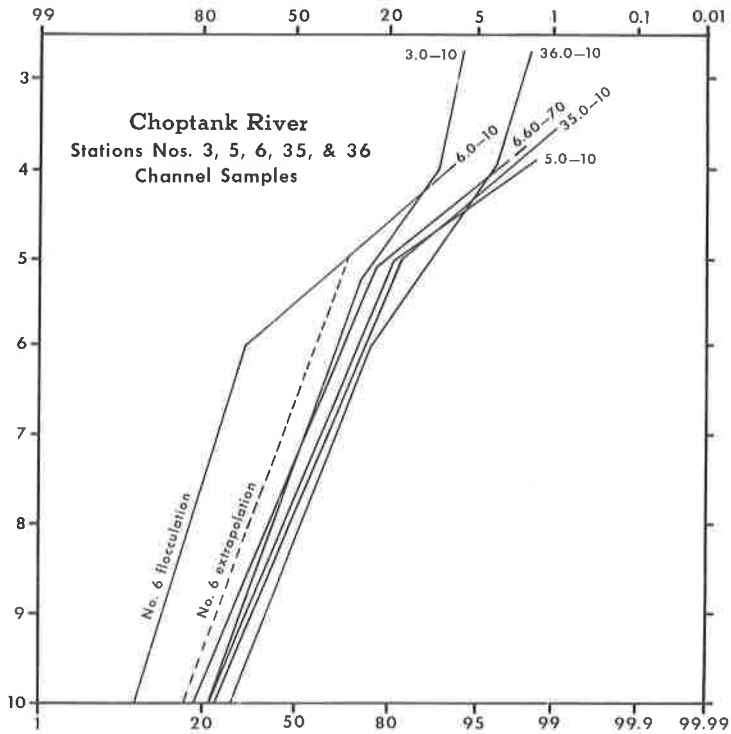

Figure 7. Group II samples of Figure 6 plotted as cumulative frequency curves along probability coordinates.

Organic Contents

The organic carbon and nitrogen contents of surface sediment have been plotted in Figure 8. The graphical plot of these points shows the majority of values to fall along a trend with an approximate slope of about 9 or close to the average carbon-nitrogen ratio of the surface sediments.

Another form of interpretation is by analysis of the ranges and modes of organic values in different environmental groups. Figure 9 shows the higher concentrations of nitrogen and carbon occur in the fine-grained sediments of textural Group II and that the organic content of the sediments in general is relatively high. The larger coarser grain sizes also appear to exert a significant influence. The relatively low organic values occur in the coarse or sand-sized samples of Group I. Since the areas of deposition consist mainly of fine sediment, the organic contents in these areas are essentially the same as shown for the fine-grained sediments of Group II. A definite correlation also appears to exist between the organic content and areas of coarser

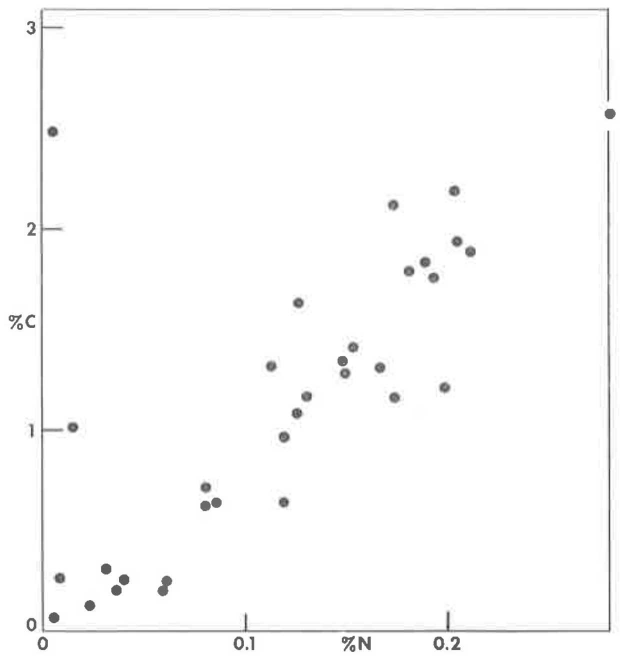

Figure 8. Carbon-nitrogen ratios of Choptank River surface sediments, given as percent of total weight of sample.

grain sizes. Relatively low organic contents are noted in the coarse or sand-sized samples of Group II. The areas of deposition consist mainly of fine sediments and show marked increases in organic contents similar to the fine-grained sediments of Group II.

The carbon-nitrogen ratios in the surface sediments are quite uniform. The average values of these samples were in the normal range for open-ocean shelf environments (Emery, 1960). These values are, however, quite different from observed ratios in bays and estuaries known to the authors (and reported by Kofoed and Gorsline, 1962; Stewart and Gorsline, 1962, and Gorsline and Stewart, 1962) in which the ratios average as high as 20.

CONCLUSIONS

Origin of Sediments

It appears that the major contribution of fine-grained sediments to the channel and other areas of silt and clay deposition is from outside the river system, most probably from the waters of the open bay. Since fine silt and clay particles usually travel along a similar path as

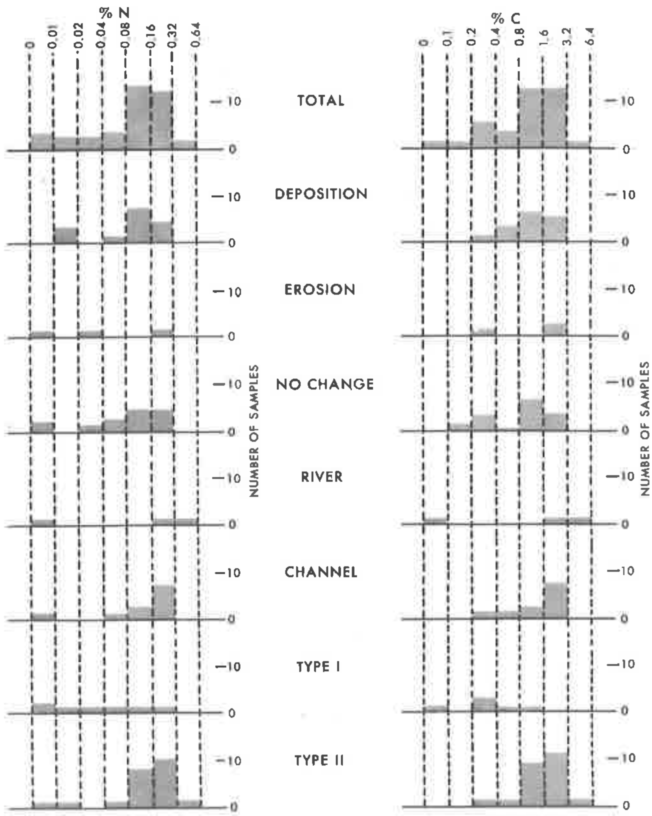

Figure 9. Histograms showing organic carbon and nitrogen contents of Choptank River sediments by different environmental groups.

that of the organic matter -- owing to similar settling velocities, to the probable absorption of organics by the clays or the incorporation of organic material with clay and silt in the production of fecal pellets by many organisms -- it follows that much of the clay-silt must be brought into the river from the bay by tidal circulation. The salinity wedge in the bay system channels also suggests that this is a dominant mechanism inasmuch as the estuarine circulation systems tend to have a net inshore (upstream) motion in the bottom waters. Further, the larger expanse of open water in the bay is conducive to erosion of the unconsolidated and generally fine-grained sediments of the eastern shore. This was shown graphically and vividly by Jordan (1961). However, some silt sediments are delivered to the river by runoff and are transported to the bay without interruption.

The most likely source of the organic content is planktonic protein or marine microbiological reworking of similar material.

Sand-sized sediments are found within the depth range of the shallow terrace. Inasmuch as sand is not being supplied to these areas, the sands must be reworked sediments of older Pleistocene deposits. The sand-sized sediments occur in a shallow depth range where waves and currents readily winnow the silts and clays. Hence, these areas are essentially nondepositional areas where sand-sized materials tend to concentrate.

Relation of Sediments to Areas of Cut and Fill

The areas of cut and fill described by Jordan (1961) can grossly be described as areas of sand and silt-clay sediments respectively. The sands (sediments of larger mean grain size) are lag deposits resulting from winnowing by waves and currents and are essentially limited to the shallow terraces along the shorelines. The silt-clay sediments are generally in the deeper areas of the estuary and appear to be "streamed" or transported along the axis of flow.

Areas such as Tilghman Island, Cook Point, and Sharps Island have been subject to the greatest amount of erosion over the years. There is no reason to believe this condition will change in the near future without engineering works. The peninsula of Tilghman Island and Cook Point could continue to be eroded to the wave base. This would result in loss of more than half of the present land area in the next 100 years. As mentioned previously, the present shoreline is a submergent feature and this further complicates the problem.

REFERENCES CITED

Allan Hancock Foundation Staff, 1958, A field and laboratory manual of oceanographic procedures (preliminary report), Allan Hancock Foundation mimeo. rept., Univ. of Southern California, 128 p.

Allison, L. E., 1935, Organic soil carbon by reduction of chronic acid: Soil Sci., v. 40, 311 p.

Bien, George S., 1952, Chemical analysis methods: Scripps Inst. of Oceano., Ref. 52-58.

Biggs, Robt. B., 1963, Deposition and early diagenesis of modern Chesapeake Bay muds: Mar. Sci. Center, Lehigh University, 119 p.

Breitenbach, R. E., and Carter, G. F., 1952, Report on a preliminary study of the twenty-five foot terrace in Maryland: John Hopkins Univ. mimeo. rept., no. 4, 5 p.

Clark, W. B., 1918, The geography of Maryland: Maryland Geol. Survey, v. 10, pt. 1, 127 p.

Cooke, C. W., 1930, Correlation of coastal terraces: Jour. Geol., v. 38, p. 577-589.

__________, 1931, Seven coastal terraces in the Southeastern states: Wash. Acad., Sci. Jour., v. 21, p. 503-513.

_____________, 1941, Two shorelines or seven?: Amer. Jour. Sci., v. 11, p. 171-192.

Disney, L. P., 1955, Tide heights along the coasts of the United States: Proc. Amer. Soc. Civil Engineers, v. 81, sep. 666.

Dryden, A. L., Jr., 1931, Calvert (Miocene) tilting of the Maryland Coastal Plain: Wash. Acad. Sci. Jour., v. 21, p. 131-134.

Gorsline, Donn S., and Stewart, Richard A., 1962, Benthic marine exploration of Bahia de San Quintin, Baja, California, 1960-61 marine and Quaternary geology: Pacific Naturalist, v. 3, no. 8, p. 282-318.

Haight, F. J., Finnegan, H. E., and Anderson, G. L., 1930, Tides and currents in Chesapeake Bay and tributaries: U. S. Dept. Comm., Coast and Geodetic Survey, Spec. Pub. 162.

Hunter, J. F., 1914, Erosion and sedimentation in the Chesapeake Bay around the mouth of the Choptank River: U. S. Geol. Survey, Prof. Paper 90-B.

Johnson, D. W., 1919, Shore processes and shoreline development: New York, John Wiley and Sons, 584 p.

Jordan, G. F., 1961, Erosion and sedimentation eastern Chesapeake Bay at the Choptank River: U. S. Dept. Comm., Coast and Geodetic Survey Tech. Bull., no. 16, 8 p.

Kofoed, John W., and Gorsline, D. S., 1962, Sedimentary environments in Apalachicola Bay and vicinity, Florida: Jour. Sed. Petrology, v. 33, no. 1, p. 205-223.

Krumbein, W. C., and Pettijohn, F. J., 1938, Manual of sedimentary petrography: New York, Appleton Century Crafts, Inc., 549 p.

Miller, Benjamin L., 1912, U. S. Geol. Survey Geol. Atlas, Choptank folio, no. 182.

_____________, 1926, The physiography of Talbot County: in Miller, and others, The Physical Features of Talbot County, Maryland, Geol. Survey Rept., p. 41-52.

_____________, 1926a, The geology of Talbot County: in Miller, and others, The Physical Features of Talbot County, Maryland Geol. Survey Rept., p. 55-81.

Miller, Benjamin L., and Little, H. L., 1916, Map of Talbot County (Maryland) showing the geological formations: in Talbot County, Md. Geol. Survey map.

Moore, J. E., and Gorsline, Donn S., 1960, Physical and chemical data from bottom sediments, South Atlantic coast of the U. S., U. S. Fish and Wildlife Serv., Spec. Sci. Rept., no. 366, 84 p.

Radoff, Morris L., 1952, Maryland Manual: Hall of Records Comm. of the State of Maryland.

Rasmussen, W. C. and Slaughter, Turbit H., 1951, Notes on the geology and groundwater resources of the Cambridge area, Maryland: U. S. Geol. Survey, Rept. Open File, no. 115, 49 p.

_____________, 1957, Groundwater resources: in The water resources of Caroline, Dorchester, and Talbot Counties, Bull. Md. Dept. Geol., Mines and Water Resources, no. 18, 246 p.

Ryan, J. Donald, 1953, The sediments of Chesapeake Bay: Bull. Md. Dept. Geol., Mines and Water Resources, no. 12, 115 p.

Schultz, L. G., 1964, Quantitative interpretation of mineralogical composition from X-ray and chemical data for Pierre shale: U. S. G. S. Prof. Paper 319-C, 31 p.

Shattuck. G. B., 1906, The Pliocene and Pleistocene deposits of Maryland: Md. Geol. Survey, Pliocene and Pleistocene, p. 23-237.

Shepard, F. P., and Moore, D. G., 1954, Sedimentary environments differentiated by coarse-fraction studies: Bull. Amer. Assoc. Petrol. Geol., v. 43, no. 9, p. 2051-67.

Singewald, J. T., Jr., and Slaughter, T. H., 1949, Shore erosion in Tidewater Maryland: Bull. Md. Dept. Geol., Mines and Water Resources, no. 6.

Stephenson, Lloyd W., Cooke, C. W., and Mansfield, Wendell C., 1932, Chesapeake Bay region: Inter. Geol. Congress, Guidebook 5, 49 p.

Stewart, Richard A., and Gorsline, Donn S., 1962, Recent sedimentary history of the St. Joseph Bay, Florida: Sedimentology, v. 1, no. 4, p. 256-286.

Wood, B. D., 1926, The hydrography of Talbot County: Md. Geol. Survey Rept., p. 155-158.

STRATIGRAPHY OF THE JACKSON GROUP (EOCENE) IN CENTRAL GEORGIA

by

Robert E. Carver
The University of Georgia

ABSTRACT

In central Georgia two distinct facies of the Jackson Group are present. The dominantly calcareous Ocala facies lies to the south and southeast and the dominantly clastic Barnwell facies to the north and east. The Barnwell facies, composed of the Twiggs Clay, Irwinton Sand, and Upper Sand Members of the Barnwell Formation, is a regressive sequence entirely equivalent to the Ocala Limestone of the coastal area. The Ocala facies consists of the Ocala Limestone and Cooper Marl. The Cooper Marl is equivalent to upper parts of the Ocala Limestone and occupies a geographic position between the Barnwell facies and the fully developed Ocala Limestone.

INTRODUCTION

A recent geological reconnaissance in the vicinity of Hawkinsville, central Georgia (Carver, 1964) produced field data which clarify facies relationships in the Jackson Group of central and east Georgia. The area studied included Pulaski County (Figure 1) and parts of Houston Bleckley, Dodge, and Dooly Counties. The northern part of Pulaski County occupies a critical position with respect to the Jackson Group. It lies near the center of a region of rapid facies change, with the Ocala Limestone fully developed to the south and southeast and the Barnwell Formation well developed to the north and east. Outcrop sections in this area form a link between the two major facies and provide a means of developing accurate correlations among the several lithologic units of the Jackson Group.

ACKNOWLEDGEMENTS

The field work was supported by the Office of Water Resources Research, the Pulaski County Area Development Corporation, and the University of Georgia. I am indebted to S. M. Herrick, R. C. Vorhis, and S. M. Pickering Jr. all of whom freely contributed their personal observations, critically read the orginal draft of the manuscript, and stimulated the research in many ways, but are in no way responsible

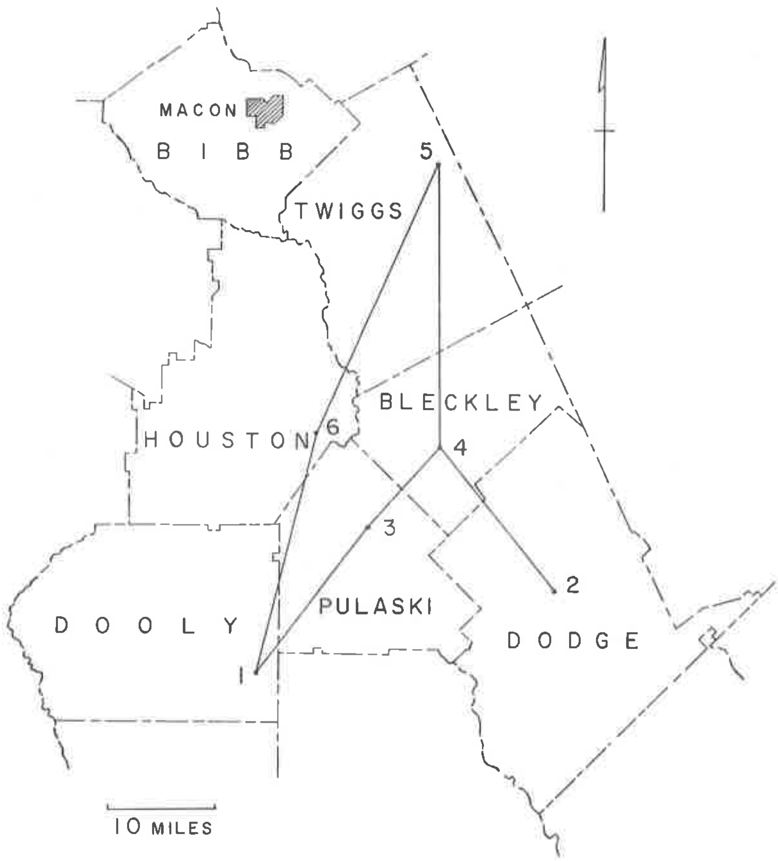

Figure 1. County outline map of central Georgia, showing the counties discussed in this report and their relation to Bibb County and the City of Macon. Numbers indicate the locations of wells and sections presented in the panel diagram, Figure 6.

for the geologic interpretations presented. P. E. LaMoreaux, State Geologist of Alabama, read the manuscript and offered valid criticism and many helpful suggestions for which I am especially grateful.

Note on the Lithology of Marls

The term "marl", never a satisfactory rock name, has been badly misused in the Atlantic Coastal Plain area. The name should be used in reference to calcareous sediments containing abundant clay, but in the Coastal Plain it has been used to describe any soft calcareous rock (Heron, 1962). Malde (1959) has pointed out that the Cooper Marl is not a marl at all; it is best described as an arenaceous, slightly argillaceous calcilutite in the Charleston area of South Carolina, and as a poorly indurated biomicrite in the central Georgia area. Use of the term "marl" in relation to the Cooper Marl in this paper is justified only because it is so common in the literature cited and because a change in terminology on the basis of the study reported would be confusing and, possibly, inaccurate.

PREVIOUS WORK

Veatch and Stephenson (1911) prepared the first report covering the geology of the Coastal Plain of Georgia as a whole, and were the first to describe the upper Eocene outcrops at Taylor's Bluff, on the Ocmulgee River three miles north of Hawkinsville. They assigned the lower part of the outcrop (now referred to the Jackson Group) to their Jackson Formation and considered the upper marls to be Oligocene in age (these upper marls are now regarded as part of the Cooper Marl of the Jackson Group). Outcrops of the Twiggs Clay in Houston County were identified by Veatch and Stephenson as the (Claiborne age) Congaree Clay Member of the McBean Formation. Brantley (1916), on the basis of new paleontological evidence and at the suggestion of T. W. Vaughn, used the name Jackson Group in place of Jackson Formation and assigned the (then unnamed) Twiggs Clay to the Jackson Group. In 1919 Cooke and Shearer published a definitive paper in which they established the broad outlines of the stratigraphic nomenclature currently used, and described the facies relationships of the upper Eocene of Georgia essentially as they are understood today. Cooke and Shearer named the Tivola Tongue of the Ocala Limestone, the Twiggs Clay Member of the Barnwell Formation and recognized the presence of the Cooper Marl in the eastern part of the state. Their description of the Cooper Marl in eastern Georgia is as follows (p. 54):

> "At the base of the Barnwell formation along Savannah River is a bed of impure limestone or marl that contains large numbers of shells of Ostrea georgiana Conrad, a huge oyster, some specimens of which attained a length of nearly 2 feet. This species appears in eastern Georgia to be restricted to the lower part of the Barnwell Formation. The Ostrea georgiana zone has been traced for miles into South Carolina, and it seems probable that this zone represents a tongue of the Cooper marl of South Carolina and that it is continuous beneath the cover of younger deposits in southeastern Georgia with the Ocala limestone of Georgia and Florida. Local oyster beds that appear to occupy the same stratigraphic position as the bed on Savannah River have been seen as far west as Danville."

The facies relationships outlined by Cooke and Shearer are presented in Figure 2. This work was extended and confirmed in a later (1943) paper by Cooke. In this later instance the Taylor's Bluff exposures were assigned to the Ocala and Cooper Marl Formations. Cooke expressed the opinion that the Cooper Marl in central Georgia was younger than any part of the Barnwell, and it is so listed in the correlation chart by Cooke, Gardner, and Woodring (1943), but in the next sentence said (1943, p. 75) "However, it would not be surprising if the littoral facies of the Cooper resembled the littoral facies of the Ocala, and both may be represented in the Barnwell." Cooke and MacNeil (1952) considered the Cooper Marl of South Carolina to be of possible early Oligocene age and Pickering (1961) lists the Cooper Marl of central Georgia as questionable early Oligocene. The paleontological evidence for these correlations, however, is not nearly as strong as the evidence for the Jackson age of the Barnwell in South Carolina developed by Cooke and MacNeil (1952). In summary, if the Cooper Marl is entirely equivalent to the Barnwell Formation, it is probably entirely Jackson in age; but if the Cooper Marl is in part, or in whole younger than the Barnwell Formation is it probably early Oligocene in age, at least in part. It should be noted that this paper deals with the Jackson Group, not the Jackson Stage, and that the precise age of the Cooper Marl is not germane to the problem at hand.

LaMoreaux (1946), working in the Coastal Plain of east-central Georgia, was able to divide the Barnwell into three members; an upper sand member containing well rounded quartz pebbles, the Irwinton Sand Member with a mottled green clay at the top, and the Twiggs Clay Member of Cooke and Shearer. Herrick (1961) restored the use of Jackson Group for upper Eocene formations of the Coastal Plain of Georgia. In the same year (1961) Murray in Geology of the Atlantic and Gulf Coastal Province of North America recommended the use of Ocala Group for the calcareous facies of the upper Eocene rocks of the southeastern United States. LeGrand (1962) used the term Jackson Group in description of the upper Eocene of the Macon area, but mapped the units as Ocala and Barnwell formations undifferentiated, making no attempt to distinguish the Cooper Marl from the Ocala Limestone. In 1965 R. C. Vorhis noted that units in Pulaski County previously mapped as Ocala Limestone (Cooke, 1939) should be assigned to the Cooper Marl. Vorhis also proposed the name Clinchfield Sand for a sand which occurs at the base of the Jackson Group or just below the Jackson Group and has been called Gosport Sand of the Claiborne Group by others (Herrick, 1961, p. 28; LeGrand, 1962).

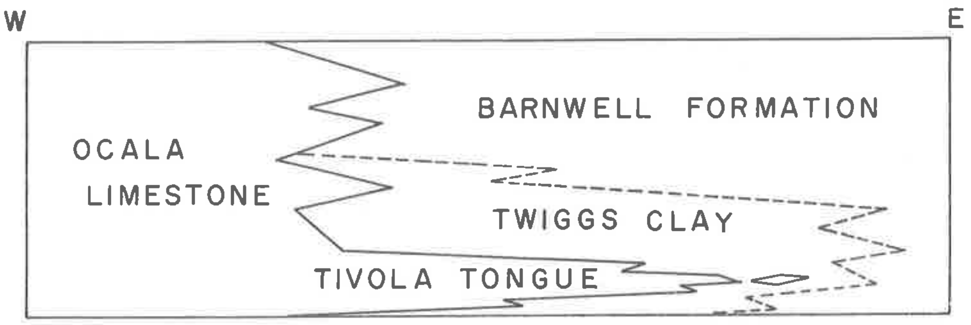

Figure 2. Facies relationships of the Jackson Group as presented by Cooke and Shearer (1918).

STRATIGRAPHY

Nomenclature

There are two groups of Jackson age sediments in Georgia, according to current usage; the Ocala Group (Murray, 1961) consisting of undifferentiated limestones in Georgia and the Inglis, Williston, and Crystal River Formations in Florida; and the Jackson Group consisting of the Barnwell Formation, Cooper Marl (Herrick, 1961), and possibly the Clinchfield sand (Vorhis, 1965). The term "Ocala Group" is not entirely satisfactory because it involves raising a well established formation name to group status on the basis of studies in a limited area, leaving the undifferentiated Ocala Formation outside the Florida area in a nomenclatural limbo. It is preferable to follow Herrick's (1961) usage and refer the Ocala Formation to the Jackson Group. The facies may then be distinguished by reference to the Ocala (calcareous) facies and Barnwell (clastic) facies of the Jackson Group.

A sand which occurs at the base of the Jackson Group in central Georgia has been called the Gosport Sand by Herrick (1961) in some cases and in some cases included in one or the other of the Jackson Group formations. Vorhis (1965) suggests the name Clinchfield Sand for this unit and, as I understood his presentation, would include it in the Jackson Group. The "Clinchfield" name has been presented only in abstract and has no formal status. It is used in an entirely informal sense in this report. The age of the Clinchfield sand is not known with any certainty, but its inclusion in the Jackson Group seems reasonable and proper on the basis of present knowledge and I have followed that procedure. A summary of the stratigraphic nomenclature employed in this report is presented in Table 1.

Table 1. Summary of stratigraphic nomenclature.

Upper Oligocene
- undifferentiated

Upper Eocene (Jackson Stage in whole or in part)
- Jackson Group
  - Barnwell Formation
    - Upper Sand Member
    - Irwinton Sand Member
    - Twiggs Clay Member
  - Cooper Marl
  - Ocala Limestone
  - Clinchfield Sand

Description of Sections

Figure 3 is a panel diagram consisting of six sections in the central Georgia area. Section 1 is located in Dooly County, 10 miles east of Vienna, Georgia; a subsurface section described by S. M. Herrick (1961, p. 165, Well No. GGS 258). Herrick reports 110 feet of fossiliferous, glauconitic Ocala Limestone with 10 feet of sand at the base. The well bottoms in the sand, here referred to the Clinchfield sand of Vorhis (1965), and the sand may be somewhat thicker than shown. Section 2 is located in Dodge County near Eastman, Georgia (Herrick, 1961, p. 156, Well No. GGS 222). The well bottoms in 75 feet of limestone identified by Herrick as Ocala Limestone.

Section 3 is Well No. GGS 339 in Hawkinsville, Pulaski County, Georgia (Herrick, 1961, p. 328). Herrick describes the upper part of the Jackson Group in this well as consisting of 5 feet of glauconitic sand overlying 15 feet of either very arenaceous limestone or indurated sand. These units are combined as sand for the purpose of presentation in the panel diagram and assigned to a more appropriate lithologic unit, the Irwinton Sand. The sands at the top of the Jackson Group in the well are underlain by 56 feet of marl, 39 feet of limestone, and 10 feet of sand, all grouped as Barnwell Formation by Herrick. The Cooper Marl, Ocala Limestone, and Clinchfield sand are lithologic units of formation rank and, on the basis of the lithology of the lower part of the Jackson Group in this well, the marl is plotted in Figure 3 as Cooper Marl, the limestone as Ocala Limestone, and the sand as Clinchfield sand. Section 4, a well at Cochran, Bleckley County, Georgia (Herrick, 1961, p. 27, Well No. GGS 195) consists of 26 feet of sand underlain by 125 feet of interbedded marl and limestone with 10 feet of sand at the base. Herrick has assigned the sand at the top of the Jackson Group here to the Cooper Marl; the marls to the Twiggs Clay Member of the Barnwell Formation; the limestones, with the exception of a thin limestone in a thick marl unit in the upper part of the section,

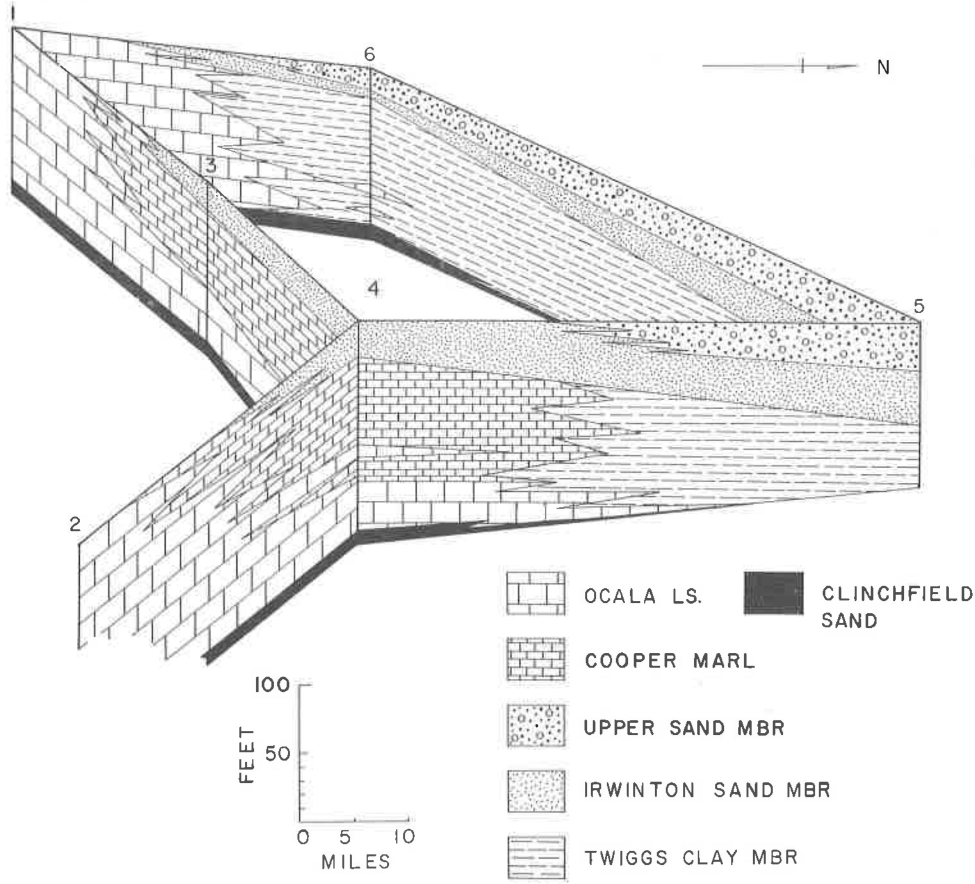

Figure 3. Panel diagram of the Jackson Group in central Georgia. Sections, numbered 1 through 6, are described in the text, and locations are shown in Figure 1. Section points are plotted planimetrically in proper geographic relationship and the sections (or well logs as the case may be) are hung from the plotted points, no perspective or dip relationships are implied. No significance should be attached to the order in which the various stratigraphic units are listed at the bottom of the figure.

to the Ocala Limestone; and the basal sand to the Gosport Sand of the Claiborne Group. Herrick's Ocala Limestone units have been retained in Figure 3 and the other units reassigned on the lithologic basis used in Section 3. It should be noted that Herrick cites no paleontologic evidence for the age of the lower sand and reclassification of the sand as a Jackson Group sand is consistent with Herrick's usage in this area.

Section 5 is an outcrop section located in central Twiggs County on Ugly Creek and described by LaMoreaux (1946, p. 97) as typical of that area. The section consists of 35 feet of coarse sand with quartz pebbles at the base, the Upper Sand Member of the Barnwell Formation; overlying 39 feet of fine-grained, cross-bedded sand with 4 feet of waxy, sandy clay at the top, the Irwinton Sand Member; and 45 feet of pale green clay with fine white sand streaks near the base, the Twiggs Clay member. The sand streaks at the base of the Twiggs Clay probably represent the feather edge of the Clinchfield Sand.

On Georgia Highway 247, 2.4 miles northwest of the Houston-Pulaski County line and at the crest of the divide between Dry Creek and Big Indian Creek, sand of the Barnwell Formation is exposed in a road cut, large borrow pit, and a drainage ditch joining the borrow pit and road cut. The section at this locality is section 6 of Figure 3. The Clinchfield Sand is exposed along the banks of Big Indian Creek and the Twiggs Clay is exposed at several places on both sides of the divide and in the road cut.

Big Indian Creek Section

	Approximate Thickness, Feet
Residuum (upper Oligocene)	
6. Scattered boulders and cobbles of chert on undissected top of divide.	
5. Uniform, featureless, dark red, sandy, silty clay.	12
Eocene (upper Eocene)	
Barnwell Formation	
Upper Sand Member	
4. Sand, poorly-sorted, lenses and irregular streaks of sub-angular to well-rounded quartzose pebbles, variegated white, yellow orange, and red. Contact with unit above dips gently to southeast and is defined by abundant well-rounded quartzose pebbles. Contact with unit below irregular.	16
Irwinton Sand Member	
3. Sand, fine-grained, cross-bedded, variegated like unit 4. Contact with unit below smooth and regular.	5
Twiggs Clay Member	
2. Clay shale, plastic, sticky when wet, blocky and crumbly when dry, gray-green weathering white. Many ground water seeps at contact with unit above. Commonly slumps in highway cuts. Two lenses of dense, fossiliferous, cream to white	

limestone in lower part, 2 feet and 4 feet thick respectively. 90

Clinchfield sand

1. Sand, fine-grained, structureless, white to cream. 10

Pickering (1961) described the Twiggs Clay and one of the limestones at this locality. LeGrand (1962) mapped the sand at Big Indian Creek (unit 1) as Gosport Sand and the material above as Ocala-Barnwell undifferentiated. Pickering also states that a thin marl or zone of lime nodules occurs at the top of the Twiggs Clay at this locality (oral communication, April 8, 1965); it is probably discontinuous because it was not observed in several trenches across the contact near the drainage ditch.

The six sections described above complete Figure 3. The Clinchfield sand is overlain by Ocala Limestone or its lateral equivalents the Cooper Marl and Barnwell Formation. One facet of the facies relationships which does not stand out in Figure 3 is that tongues of the Cooper Marl overlie the Twiggs Clay in many places, as at Pickering's Anderson Gift Church locality (1961, p. 85) approximately half way between sections 3 and 6 of Figure 3. But, in a general way, the Cooper Marl geographically lies between the Ocala Limestone and the Twiggs Clay Member of the Barnwell Formation. The coarse clastic facies of the Barnwell Formation, probably littoral to continental in origin, overrode the marine sediments in regressive sequence.

REFERENCES

Brantley, J. E., 1916, Limestones and marls of the coastal plain of Georgia: Georgia Geol. Survey Bull. 21.

Carver, R. E., 1964, Reconnaissance geology of Pulaski County, Georgia: Report to the Pulaski County Area Development Corporation, in open file at the University of Georgia Library, Athens.

Cooke, C. W., 1939, Geologic map of the Coastal Plain of Georgia: in Geologic Map of Georgia, Georgia Division of Mines, Mining, and Geology, Atlanta.

__________, 1943, Geology of the Coastal Plain of Georgia: U. S. Geol. Survey Bull. 941.

Cooke, C. W., Gardner, Julia, and Woodring, W. P., 1943, Correlation of the Cenozoic formations of the Atlantic and Gulf Coastal Plain and the Caribbean region: Bull. Geol. Soc. Amer., v. 54, p. 1713-1723.

Cooke, C. W., and MacNeil, F. S., 1952, Tertiary stratigraphy of South Carolina: U. S. Geol. Survey Prof. Paper 243-B.

Cooke, C. W., and Shearer, H. K., 1919, Deposits of Claiborne and Jackson age in Georgia: U. S. Geol. Survey Prof. Paper 120.

Heron, S. D., Jr., 1962, Limestones of the Coastal Plain of South Carolina: S. C. State Development Board, Div. of Geology, Bull. 28, 128 p.

Herrick, S. M., 1961, Well logs of the Coastal Plain of Georgia: Georgia Geol. Survey Bull. 70.

LaMoreaux, P. E., 1946, Geology and ground-water resources of the Coastal Plain of east-central Georgia: Georgia Geol. Survey Bull. 52.

LeGrand, H. E., 1962, Geology and ground-water resources of the Macon area, Georgia: Georgia Geol. Survey Bull. 72.

Malde, H. E., 1959, Geology of the Charleston Phosphate Area: U. S. Geol. Surv. Bull. 1079.

Murray, G. E., 1961, Geology of the Atlantic and Gulf Coastal Province of North America: Harper & Bros., New York, 692 p.

Pickering, S. M., Jr., 1961, Geology of iron ore deposits of the Perry Quadrangle, Georgia: Georgia Mineral Newsletter, Georgia Geological Survey, Atlanta, v. 14, p. 83-90.

Veatch, Otto, and Stephenson, L. W., 1911, Geology of the Coastal Plain of Georgia: Georgia Geol. Survey Bull. 26.

Vorhis, R. C., 1965, Notes on the stratigraphy of Pulaski County, Georgia: oral presentation and abstract, Geol. Soc. Amer., Southeastern Section, annual meeting, 1965, Nashville, Tenn.