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THE MODERN SEDIMENTS OF PAMLICO SOUND, NORTH CAROLINA

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ABSTRACT

The following eleven environments of deposition in Pamlico Sound are recognized by characteristic lithology: (1) barrier island--medium, clean, quartz sand containing a relatively high percentage of heavy mineral grains; (2) central basin--dark gray, organic-rich, slightly sandy, shelly mud; (3) cross lagoon shoal--very similar to barrier island lithology but with slightly smaller average grain size and slightly less heavy minerals; (4) finger shoal--clean, fine, very well sorted quartz sand; (5) inlet--clean, medium, very shelly quartz sand, echinoid spines more abundant than in other environments; (6) lagoonal beach--poorly sorted, clean, coarse, quartz sand that is more poorly sorted than any other non-muddy sediment in the sound, shell fragment and heavy mineral percentages low; (7) lagoon near narrows--poorly sorted, slightly muddy sand that is the most poorly sorted muddy sediment in the sound, small pebbles occasionally present; (8) lagoon near river mouth--slightly sandy, dark, shelly, micaceous organic-rich mud that has the greatest percentage of mud of any sediment in the sound; (9) mainland marsh--muddy, very fine sand containing a very high percentage of peaty material; (10) marginal lagoon--variable lithology; on the barrier island side it is a well sorted, clean, fine sand similar to barrier island sand but slightly finer-grained, on the mainland side it is a silty, fine sand containing mica and a moderate amount of shell fragments; (11) protected mainland embayment--organic-rich, muddy, very fine sand containing a variable percentage of shell fragments and a high percentage of wood fragments.

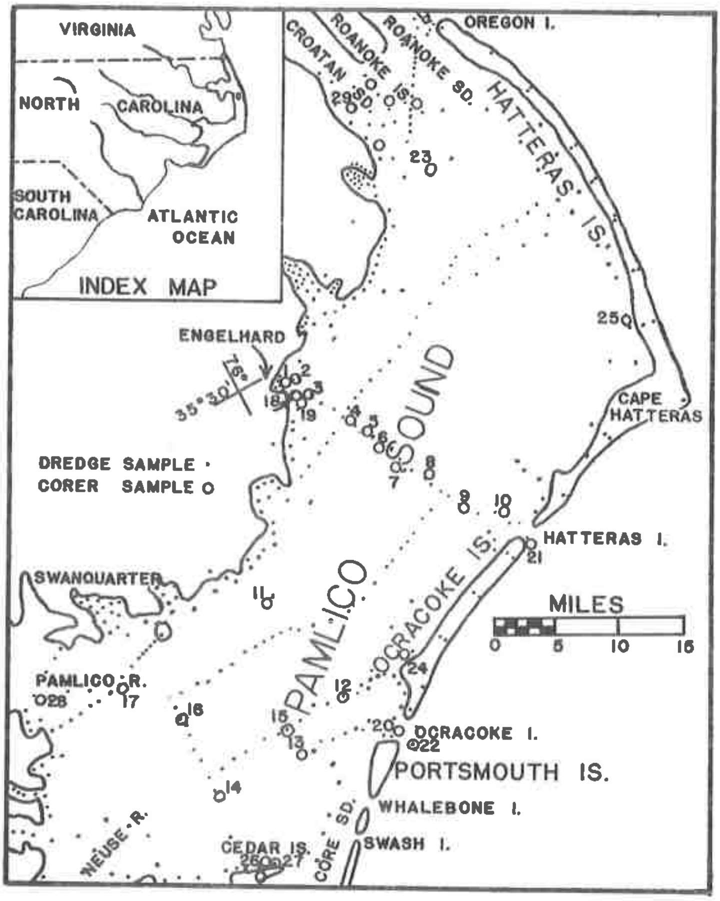

Figure 1. Distribution of samples in Pamlico Sound.

INTRODUCTION

Over 500 grab samples and cores (Figure 1) were taken in order to describe the modern sediments of Pamlico Sound and to investigate the relationships between the properties of these sediments and their environments of deposition.

Sediments of estuaries, sounds, and beaches adjacent to Pamlico Sound have been studied at the University of North Carolina. Griffin and Ingram (1955) studied the clay minerals of the Neuse River estuary, which empties into Pamlico Sound. Skean (1959) studied the distribution of sediments in northern Core Sound, which is confluent with southern Pamlico Sound. Fisher (1962) studied the recent history of inlets on the Outer Banks and the geomorphic expression of former inlets. Fisher (1967) studied beach ridges along the North Carolina coast. Allen (1964) studied the clay minerals of the Pamlico River.

Guy (1964) studied the distribution of heavy minerals along North Carolina beaches. Benson (1965) worked on the clay minerals of marsh and adjacent non-marsh environments along the North Carolina coast.

Smith and Dolan (1961) studied the geology of the Outer Banks of North Carolina. They presented evidence that the Outer Banks are actually a complex of relict shore lines.

Several workers from the University of Kansas have examined sediments in the western Pamlico Sound area. Duane (1962, 1964) studied the sediment of western Pamlico Sound. He was able to use sediment skewness as an environmental indicator. Rochna (1961) studied the sediment and physiography of the Outer Banks between Cape Lookout and Ocracoke Inlet. The ecology of the Rhizopodea and Ostracoda of southern Pamlico Sound was investigated by Grossman and Benson (1967). Pierce (1964) studied the recent stratigraphy and geologic history of the Core Banks region.

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The authors appreciate the helpful suggestions of W. H. Wheeler and W. A. White, Geology Department, University of North Carolina; and R. R. Jordan, Geology Department, University of Delaware.

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Methods

A Peterson dredge and a Phleger corer were used to obtain samples. Where the sand was too hard to be penetrated by the corer, a Scuba diver pounded in a plastic core liner, dug it out, and handed it in a vertical position to someone in the boat.

Analysis of the coarse fractions under a binocular microscope provided data for the construction of the following maps using the procedure of Ingram (1965) (Figures 2-5). These maps are useful in that the same generalized natural sedimentary environments of the Sound are shown by mapping the distribution of different sedimentary parameters. Figure 2 shows the distribution of the dominant size classes present. The distribution of modal, maximum, and minimum Wentworth size classes (Figures 3, 4, 5) indicate similar environmental patterns.

GEOLOGIC AND GEOGRAPHIC SETTING

Pamlico Sound is a lagoon created by the formation of a barrier island--the Outer Banks. The mainland shore of the sound is composed of Quaternary sediments of the Atlantic Coastal Plain. This mainland shore has undergone some submergence, resulting in an estuaried coast.

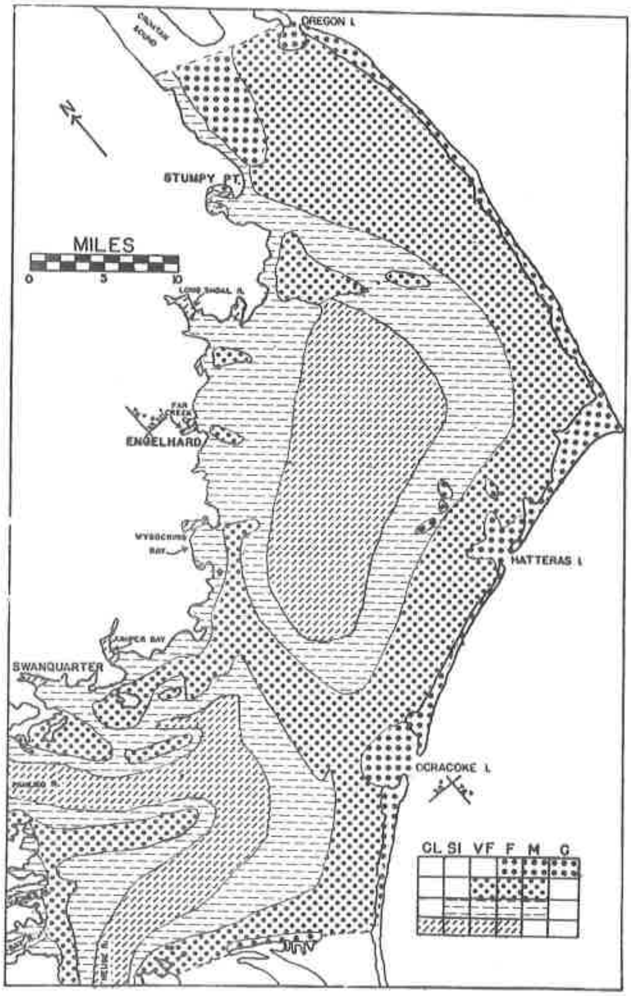

Figure 2. Map of distribution of dominant Wentworth size classes present.

Roelofs and Bumpus (1953) described currents in Pamlico Sound as very weak, depending mainly upon the direction and velocity of the wind and not upon tidal oscillation. Wind friction currents may reach 69 cm/sec in a squall, but 10 to 26 cm/sec is an average current velocity (Roelofs and Bumpus, 1953). Currents resulting from runoff from the rivers are calculated by Roelofs and Bumpus to be only about 0.5 cm/sec. Near the inlets spring tidal currents have velocities from 1.6 to 2.6 knots (Taylor, 1951).

Roelofs and Bumpus (1953) reported that water temperature in Pamlico Sound showed a seasonal cycle closely related to air temperature.

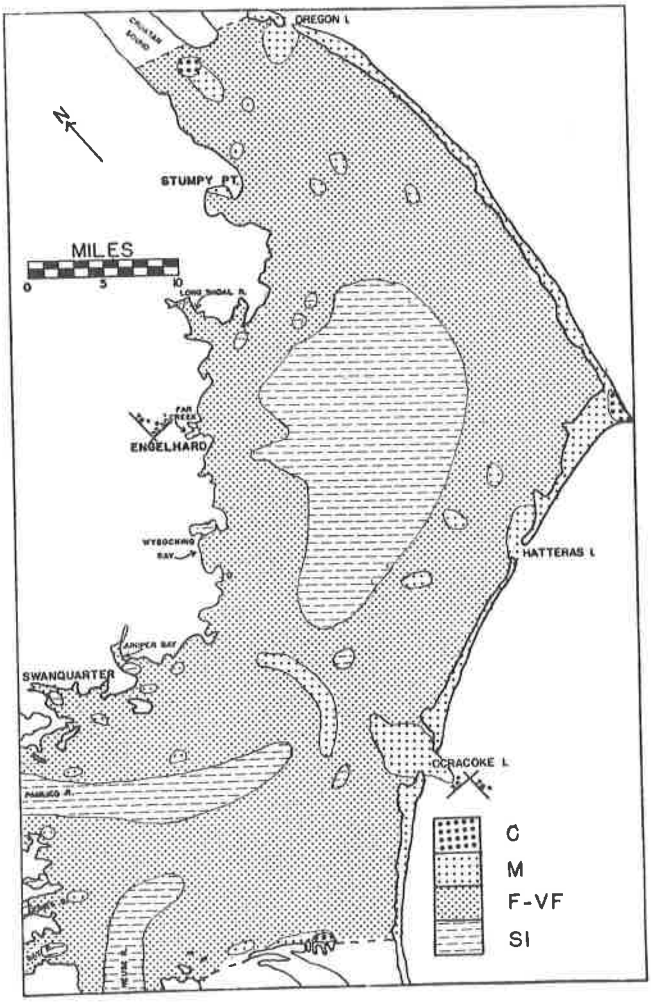

Figure 3. Map of distribution of modal Wentworth class.

Constant wind agitation of the water prevents any appreciable thermal stratification in the sound (Roelofs and Bumpus, 1953).

The horizontal distribution of salinity in Pamlico Sound (Figure 6) is influenced by wind and long-term runoff (Roelofs and Bumpus, 1953). Salinity is normally highest near the inlets (particularly Ocracoke Inlet) and lowest near the rivers and the northern part of the sound. Figure 6 shows the bottom salinity pattern during July 1927 (Taylor, 1951).

The land surrounding Pamlico Sound is extremely flat and swampy. No large bluffs are seen on the shoreline, with the exceptions of several small ones back of Cape Hatteras.

The bottom of Pamlico Sound is generally flat (Figure 7). The

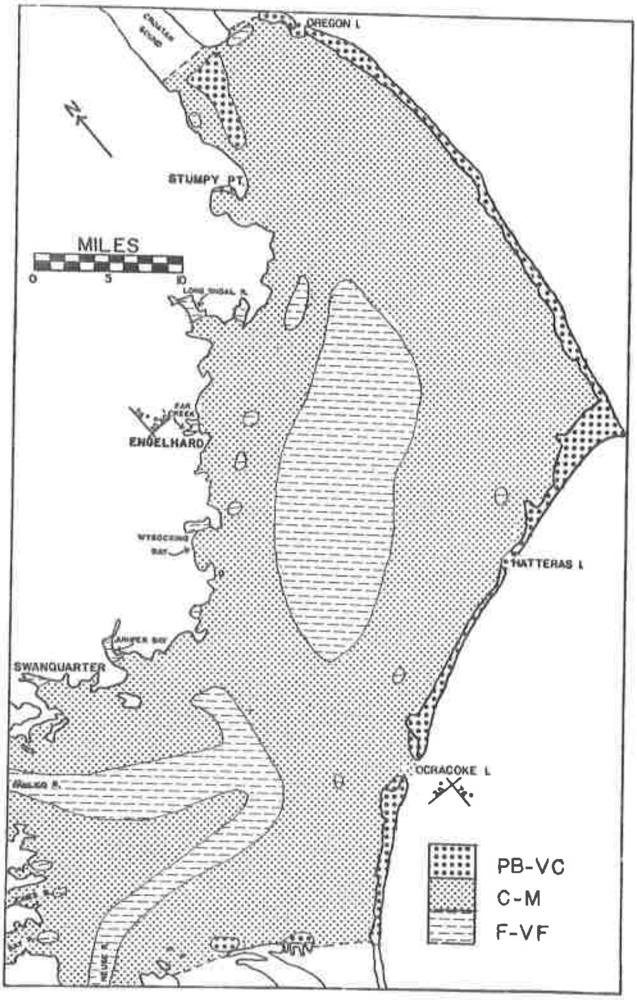

Figure 4. Map of distribution of maximum Wentworth class.

sound is divided into two wide, central basins separated by finger-shaped sand shoals. The floors of the central parts of these basins are uniformly 18-24 feet deep. The finger shoals have only 3 to about 12 feet of water over them, depending on the proximity to land. Several smaller versions of these finger shoals jut out from headlands and are much the same as the larger ones. Bluff Shoal is very much like a typical finger shoal but extends completely across the sound and merges with the deltaic shoals of Ocracoke Inlet.

SEDIMENTARY ENVIRONMENTS

Shepard and Moore (1955) defined a sedimentary environment

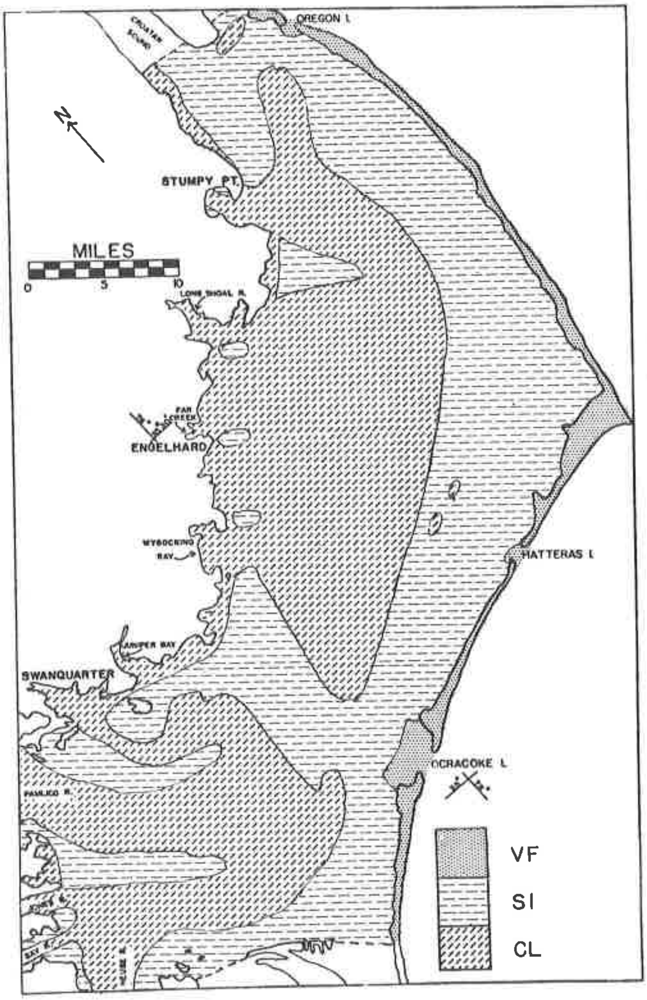

Figure 5. Map of distribution of minimum Wentworth class.

as "a spatial unit in which external physical, chemical, and biologic conditions and influences affecting the development of a sediment are sufficiently constant to form a characteristic deposit."

In Pamlico Sound the main physical conditions and influences affecting sedimentation are water depth and wave and current action. The chemical and biologic conditions and influences were not investigated in any detail for this study.

In general, sediment in deep water is finer-grained than sediment in shallow water because water movement is usually at a minimum in deep water, and the fines can settle out. Also, deep water is usually distant from the source of the sediment, and only fine-grained material has been transported that far.

Figure 6. Bottom salinity map of Pamlico Sound for July, 1927 (from Taylor, 1951). Salinity in parts per thousand.

Wave and current action distributes the sediment and winnows out fine-grained material. The northeast-southwest orientation of Pamlico Sound coincides with the dominant wind directions. This is the main reason for the dominance of wind-generated waves and currents over river or tidal currents. Another reason for the weakness of tidal and river currents may be the great disparity of the area of the sound and the discharge of rivers and inlet tidal rips. The degree of protection offered by the configuration of the shoreline affects the strength of wave and current action.

On the basis of Shepard and Moore's definition of a sedimentary environment (1955), the following 11 sedimentary environments in

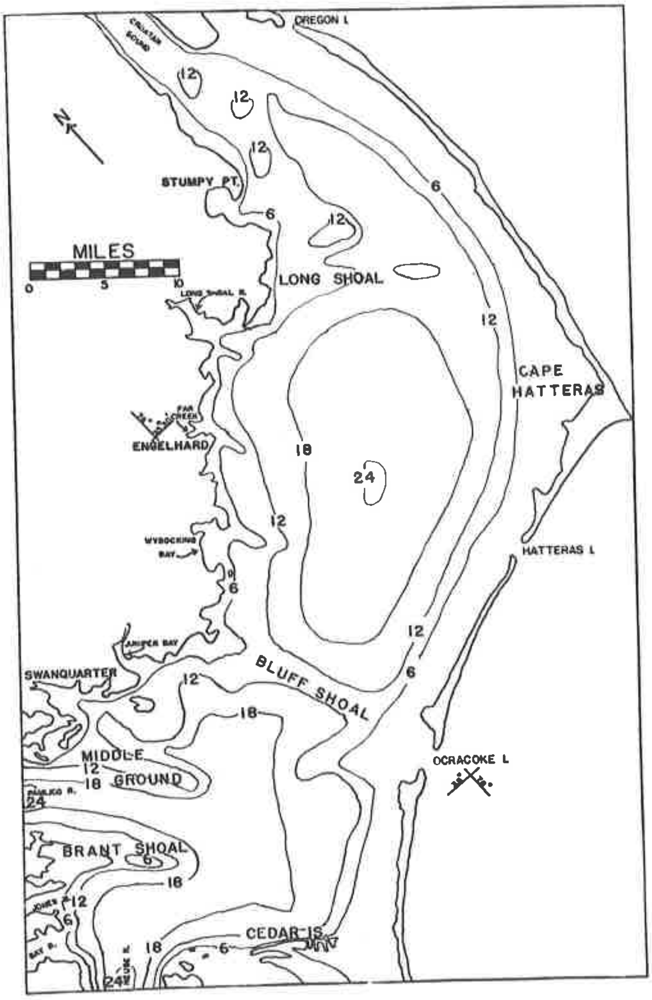

Figure 7. Bathymetric map of Pamlico Sound (in feet).

Pamlico Sound can be described (Figure 8): (1) barrier island (BI), (2) cross lagoon shoal (CLS), (3) central basin (CB), (4) finger shoal (FS), (5) inlet (I), (6) lagoonal beach (LB), (7) lagoon near narrows (LNN), (8) lagoon near river mouth (LNR), (9) mainland marsh (MM), (10) marginal lagoon (ML), and (11) protected mainland embayment (PME).

Barrier Island

Included in the barrier island environment are the off-shore islands: Bodie, Hatteras, Ocracoke and Portsmouth.

The subaerial barrier island is included as a sedimentary environment of Pamlico Sound in order to better understand the sediments

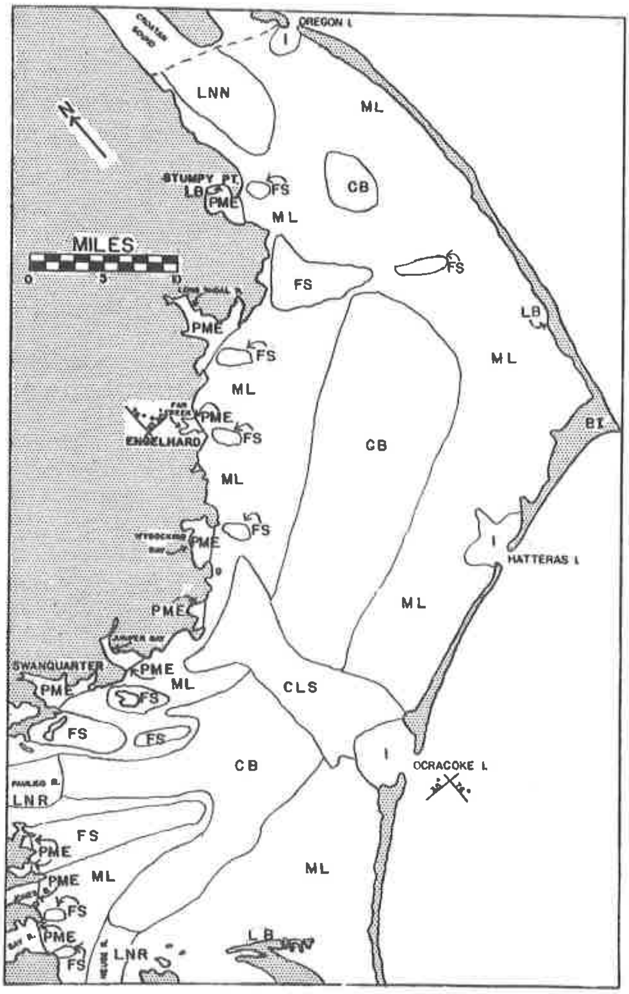

Figure 8. Sedimentary environments in Pamlico Sound.

in the sound. (The barrier island is the probable source of much lagoonal sand because much barrier island sand is probably washed or blown into Pamlico Sound). The texture of barrier island sand is similar to texture of sand from the barrier island side of Pamlico Sound. Fisher (1962) concluded that much of the shoal areas back of the barrier island are relict inlet deltas containing sediment washed in when the inlet broke through the barrier island.

The modal size class of barrier island sediment is medium sand. The dominant size range of the grains is very fine to coarse sand. However, a minor amount of very coarse sand is present, and small pebbles are sometimes seen in the surf zone of the ocean beach.

Barrier island samples were collected at the top of the berm on the ocean side, in the midst of the dunes, and on the sound beach of the barrier island. All of these samples have essentially the same texture except that the ocean beach samples are usually slightly coarser than the dune samples and very slightly coarser than the sound beach samples. The dune samples appear to be more rounded and have less shell fragments than sound or ocean beach samples.

The sound side of the barrier island is often swampy and peaty, and much of it is covered by coarse dune and beach sand that has washed or blown over the marsh in a storm. Evidence of this washover is seen after almost every large storm. Sand drifts extend fan-like across the highway and spread out into the marshy areas and adjacent lagoon. When the temporary inlet at Buxton--formed during the March 1962 storm--was examined, thick sand deposits over peaty material were seen near the sound side of the inlet in the trench which was dug across the barrier island by the new inlet.

Cross Lagoon Shoal

Bluff Shoal, located between Ocracoke Inlet and the mainland shore north of the inlet, is an example of a cross lagoon shoal (Figure 7).

This environment is based on several influencing conditions. The cross lagoon shoal is defined by the 15 foot contour line, and much of this shoal is only 10 feet deep or less. The cross lagoon shoal is exposed to northeast and southwest wind-generated waves and currents which because the environment is so shallow, can winnow out fines and produce a well sorted sediment. This shoal is adjacent to Ocracoke Inlet, and sediments from the two areas are similar. Therefore, apparently, sediment from the ocean or sediment eroded from the barrier island is transported through Ocracoke Inlet by tidal currents and distributed on the cross lagoon shoal by inlet tidal and wind-generated lagoonal currents. Meade (1969) agrees by stating that decreasing landward percentages of garnet and yellow quartz indicate an offshore barrier beach source of Pamlico Sound sediments.

Salinity and pH approach those of an inlet and the open nearshore ocean (Figure 6, and Duane, 1962).

Sediment is dominantly a clean quartz sand. The modal size class is medium sand. On the edges of the shoal fine sand is the modal class. Size classes range from minor amounts of silt to coarse sand. In general, sediment is similar to barrier island sand.

Central Basin

There are two good examples of the central basin environment in central and southwestern Pamlico Sound. A third, northern basin is much smaller and has been mostly filled-in with coarse sediment from nearby Oregon Inlet and the barrier island.

The central basin in the central part of Pamlico Sound is an elongate basin between Bluff and Long Shoals (Figure 7). The edge of this basin follows the 18 foot contour line, and the middle is about 24 feet deep. There are few topographic irregularities other than several tidal deltas from Hatteras Inlet that overlap into this environment.

The central basin in the southwestern part of Pamlico Sound is located between Bluff Shoal and the southwestern end of Pamlico Sound and is confluent with the Neuse and Pamlico river mouths (Figure 7). This basin is also fairly uniform topographically with the exception of two large finger shoals, Middle Ground and Brant Shoal that project into the middle of the basin.

The much smaller and shallower basin north of Long Shoal (Figure 7) is atypical because coarse sediment from Oregon Inlet and the barrier island have partially filled it; thus, this environment is not affected by the same conditions that affect the other two basins. The only physical characteristic that the northern basin has in common with the two other basins is a central location in the sound. The maximum depth of the northern basin is only about 16 feet, in a very small area near the center, compared with 24 feet for the other two basins.

The central basin environment is based on several influencing conditions. The 18 foot contour line defines the edge of the basin. The uniform deeper water prevents much water movement at the bottom; this lack of water movement causes fines to settle out and prevents much stirring up of the bottom sediments once they are deposited. The primary source of this sediment is probably the mainland because estuaries emptying into the sound are muddy, and lagoonal water is muddier and more organic colored near the mainland shore than it is near the barrier island. Oxygen available for oxidizing organic material is probably scarce because currents and waves do not mix oxygen into the deep parts of the sound. On a choppy day a Scuba diver reported little water movement below 8 or 10 feet. Salinity is intermediate between that of an estuary and that of the open ocean (Figure 6).

Sediment is dominantly silt and clay with only slight amounts of sand. This mud contains layers of shell fragments. The modal class is silt. The dominant maximum size class is very fine sand; however, some fine sand is present. Fine sand is more common in the southwest basin than in the central one. Near the margins of the central basin, adjacent to the marginal lagoon, minor amounts of medium sand are present. The modal size is a little coarser in the southwestern basin than in the central one. The modal size class in the southwestern basin is dominantly silt, but almost as many samples have very fine sand for the modal size class. The dominant maximum size class in the southwestern basin is fine sand. There is more sand in the portions of the central basin nearest a finger shoal, inlet, or the barrier island; and there is less sand in the portions near river mouths.

Finger Shoal

On the mainland side of Pamlico Sound there are at least ten finger-shaped shoals that trend perpendicular to the mainland. In every case, the shoal juts out from the mainland from the margin of an estuary, a deeply indented bay or a tidal creek. Thus, they all appear to be genetically related, and may be relict river mouth shoals left from a time of lower sea level.

Brant Shoal and Middle Ground are the two largest finger shoals (Figure 7). They extend about ten miles southeast from either side of the mouth of the Pamlico River. Long Shoal, which is adjacent to Long Shoal River extends, interrupted by erosion, almost all the way across the sound (Figure 7). Minor finger shoals are located adjacent to the mouth of Stumpy Point Bay, south of the mouth of Long Shoal River (Pingleton Shoal), south of the mouth of Par Creek at Engelhard (Gibbs Shoal), adjacent to the mouth of Wysocking Bay (Gull Shoal), adjacent to the east shore of Swanquarter Bay and one extending out from each side of Bay River (Figure 8). Bluff Shoal is finger-like but is discussed under a separate heading because: Bluff Shoal sediment is different from finger shoal sediment; Bluff Shoal is not located adjacent to an estuary, bay or tidal creek mouth and the finger shoals are; Bluff Shoal extends all the way across the sound and merges with the inlet environment. Therefore, Bluff Shoal is probably genetically different than the finger shoals.

The conditions affecting finger shoals are dominantly physical. Finger shoals are delineated by a depth anomaly and a sediment anomaly. The margins of the largest finger shoals, Middle Ground and Brant Shoal, are defined, generally, by the 14 foot contour line and by the edge of the clean, well sorted finger shoal sand. Edges of the smaller finger shoals are defined, generally, by the 10 foot contour line and the edge of the clean, well sorted finger shoal sand. Water is shallow, therefore, wind-generated currents and waves affect the sediment and winnow out fines. The dominant source of the sediment is probably the mainland because the shoals project from the mainland.

Salinity is less in the finger shoal environment than in the cross lagoon shoal environment. The reduced salinity provides a desirable environment for oysters, which are found adjacent to finger shoals. These oysters probably trap slight amounts of sediment, thus decreasing the depth of water over the shoals.

Water over the finger shoals is oxygenated so that little unoxidized organic material is found in finger shoal sediment. Currents also would carry organic material away.

Sediment type is more consistent for the finger shoals than for any other environment in the sound. Because of the shallowness, sediment on the finger shoals is constantly affected by currents that winnow out fines and leave a well sorted sand. The modal class of sediment on the finger shoals is fine sand. The dominant maximum size class is medium sand, and the minimum size class is silt for almost every finger shoal sample collected. Silt is minor in most samples, however.

Inlet

There are three areas of inlet environment in Pamlico Sound: Ocracoke, Hatteras, and Oregon Inlets. These areas contain sand deposited in tidal deltas and corresponding channels extending out into the sound. The shape and distribution of the sand bodies are changing almost continually. The tidal delta is best developed at Ocracoke Inlet. This is understandable because salinity data shows that there is considerable communication between ocean and sound water here. Thus, there are currents capable of moving much sand into the sound.

The boundaries of the inlets are defined by the boundaries of the tidal delta--the area affected by inlet tidal currents. This area is generally less than 10 feet deep except for tidal inlet channels that may be 40 feet deep or more. Tidal currents in the inlet are the strongest type of current in the entire sound. Taylor (1951) reported average inlet current velocities of 1.4 knots at Ocracoke Inlet and 2.0 knots at Hatteras Inlet. Therefore, fine-grained sediment is winnowed out.

Sediments of the three inlets in the Pamlico Sound area are all very similar. They are characterized by coarseness, lack of good sorting, presence of broken shell material and lack of fines. The dominant modal size class of sediment for the three inlets is medium sand. The maximum sediment size class is coarse to very coarse sand. The dominant minimum size class is very fine sand. Clay and silt are usually winnowed out by strong tidal inlet currents, but silt may be found in minute quantities possibly from the breaking-off of silt-sized particles of quartz from bigger ones by abrasion. As a rule, the maximum, minimum and modal size classes are smaller in inlet samples soundward from the ocean-sound contact, suggesting that the ocean and barrier island beach are the dominant sediment sources. Sediments of inlet, barrier island and near-shore ocean environments are all very similar.

Lagoonal Beach

There are very few beaches on the mainland side of Pamlico Sound (the beach at Stumpy Point is an exception), but small beaches are found along the sound side of the barrier island. The lagoonal beach is especially well-developed at Cedar Island in southern Pamlico Sound (Figure 7).

Lagoonal beaches are defined as sandy beaches on the shores of Pamlico Sound. This includes the area from just below the low tide mark to the barrier dunes. The most important physical condition influencing sedimentation on the lagoonal beach is wave action. Wave action may be vigorous, much the same as on an open-ocean beach. At Cedar Island, waves breaking on shore are sometimes large because strong northeast winds which cause them can travel up to about 50 miles over open water. The shore is directly exposed to these strong winds. Wave action on the beach at Stumpy Point is slight because of the protected location.

The source of sediment affects sedimentation in lagoonal beaches. Most sediment at Cedar Island is probably derived from the barrier island or the inlets because textures of sediment from these areas are all similar, and because northeast wind-generated currents could transport sand down to Cedar Island. However, some of the coarse-grained sand on Cedar Island beach is probably reworked Pleistocene sand from old beach ridges on Cedar Island.

The salinity of the water at most lagoonal beaches is much less than that of the open ocean.

Sediment is otherwise much like sediment from an ocean beach. It is poorly sorted and coarse. Most fines have been winnowed out. The modal size class is variable because most size classes are present in almost equal quantities. The modal size class ranges from very fine to coarse sand. Medium sand is the dominant modal size class. Very coarse sand is the dominant maximum grain size; however, some small pebbles are present. Silt is the minimum grain size in all samples, but this may be mostly broken pieces of larger grains formed by abrasion in the surf.

In general, lagoonal beach sediment is more poorly sorted than cross lagoon shoal, finger shoal or marginal lagoon sediment.

Lagoon Near Narrows

The northwestern portion of Pamlico Sound, just south of Croatan Sound, is an example of the lagoon near narrows (Figure 7). The boundaries of the lagoon near narrows are defined by the extent of the 10 to 12 foot channel here and by the extent of the coarse sand that is presumably the extent of the moderately swift lagoon near narrows currents.

The most important factor influencing sedimentation in the lagoon near narrows is the constrictive channel extending from Croatan Sound into northwestern Pamlico Sound. The constriction may increase the southward flowing current so that coarse sediment from Roanoke Island and Croatan Sound is transported southward into Pamlico Sound. Probably so much mud is being washed down from Roanoke Island marshes that the currents in the lagoon near narrows, although moderately strong, cannot winnow it all out. Venturi action may pull some coarse sediment in from nearby Oregon Inlet. Some of the coarse sediment may be relict sand bodies.

There are some oysters present which probably affect sedimentation by creating shoal conditions by the trapping of sediment and by sheer mass of number.

Samples collected within three miles south of Croatan Sound are the coarsest samples in the lagoon near narrows. The maximum grain size decreases southward in the lagoon near narrows environment. This is further evidence that the sediment is mostly derived from Roanoke Island and Croatan Sound. The modal size classes of the coarsest samples in the northern part of the environment are medium and fine sand. The dominant maximum grain size is coarse sand, but some small pebbles are present. Silt is the dominant minimum grain size; however, a few samples near the mainland contain clay. In the southern part of the environment the modal size class is fine sand. There, medium sand is the dominant maximum grain size. Clay sized sediment is more abundant in the southern part of the environment than in the northern part.

Lagoon Near River Mouth

Examples of this environment are the mouths of the Pamlico and Neuse Rivers. There are also numerous small rivers or tidal creeks emptying into Pamlico Sound, but they have their headwaters only a short distance from Pamlico Sound in the marginal swamplands. Their sediment contribution to Pamlico Sound is negligible.

The lagoon near river mouth environment is a deep, elongate channel whose lateral boundaries are defined by the 18 foot contour line. The environment extends from the narrowest part of the mouth of the estuary 4 miles toward the center of the sound. This arbitrary distance was chosen as the approximate extent of the river mouth channel and, thus, the extent of most estuarine current influence on sedimentation.

The depth of the water and the corresponding lack of much water movement along the bottom are the dominant conditions affecting sedimentation in the lagoon near river mouth. Water in the lagoon near river mouth is from 18 to 24 feet deep. Sediment on the bottom is protected from most wind-generated currents and waves, and river currents are very slow. Thus, fine grained material is deposited and is rarely stirred up once it is deposited.

The mainland source of these sediments is frequently muddy. This also affects the nature of lagoon near river mouth sediment.

Salinity and pH are estuarine-like. Salinity is about 19 parts per thousand (Figure 6), and the water is weakly acidic (Duane, 1962).

Sediment is dominantly a clayey silt. Lagoon near river mouth sediment contains more clay than any other sediment in the sound. Clay or silt is the modal sediment class. Minor amounts of very fine sand are present in the deeper samples; slightly more very fine sand is present in shallower samples. However, one sample from a depth of 25 feet in the mouth of the Pamlico River contains clay as a modal size class with very minor amounts of coarser sediment up to, and including, medium sand. This probably represents mixing from the adjacent coarser-grained finger shoal.

Sediment from the lagoon near river mouth is similar to central basin sediment but generally contains more clay and may contain very minor amounts of sediment coarser than that usually found in the central basin. Central basin sediment usually contains less shell fragments than does the lagoon near river mouth sediment.

Mainland Marsh

The western, or mainland, shore of Pamlico Sound consists of low marshlands that are an example of the mainland marsh environment. The mainland marsh is adjacent to the western side of the lagoon and is probably a main source of sediment for the sound. Much of the organic debris present in Pamlico Sound probably originated in the mainland marsh because as the mainland coast is approached the water becomes murkier owing to organic debris and mud.

The mainland marsh sediment is essentially a peaty, silty, very fine sand. The modal size class is either silt of very fine sand. Much clay is present. The dominant maximum size class is fine sand, but minor amounts of medium sand are present.

Marginal Lagoon

The marginal lagoon environment is the shallow periphery of Pamlico Sound. This environment extends from the shores of Pamlico Sound to the 18 foot contour line (edge of the central basin). Much of the area is 10 or less feet deep. Excluded are embayments and specialized marginal shoals such as finger shoals, cross lagoon shoals, inlets and lagoonal beaches. Mainland embayments are peripheral but comprise another environment because of their protected nature.

The marginal lagoon environment covers a large area. Sediment from the barrier island side of the marginal lagoon is different from the sediment from the mainland side of the marginal lagoon. However, the marginal lagoon environment is based on water depth (less than 18 feet) and wave and current energy (moderate), not sediments. Water depth and wave and current energy are about the same on both sides and sediment would probably be also similar if the sources of sediment for both sides were the same.

The source of marginal lagoon sediment on the barrier island side of the lagoon is dominantly the clean barrier island sands that are washed and blown into eastern Pamlico Sound. Also, much eastern marginal lagoon sediment may be that of relict inlet tidal deltas that Fisher (1962) presumed to be extant in large numbers.

Sediments derived from the erosion of the muddy mainland marsh and river sediments are probably the main sources of marginal lagoon sediment on the mainland side of the lagoon because these sources of muddy sediment are adjacent to the marginal lagoon, the rivers contain much fine sediment in suspension and the water near the marginal mainland marsh shore is murkier than water in other parts of Pamlico Sound.

Specialized shoals, such as finger shoals, cross lagoon shoals, inlets and lagoonal beaches, have stronger current action affecting sedimentation and are often shallower than the marginal lagoon; thus, their sediment is a cleaner sand.

Chemical influences affecting sedimentation in the marginal lagoon are variable. Sedimentation on the mainland side of the marginal lagoon is influenced by the salinity and pH, which are estuarine. Salinity is low (Figure 6) and the water is slightly acidic (Duane, 1962). Chemical influences affecting sedimentation in the barrier island side of the marginal lagoon are more near-shore ocean-like (higher salinity and nearly neutral pH).

Biologic conditions affecting sedimentation, such as sediment-trapping oyster beds and burrowing organisms, which produce mottling, are more pronounced on the mainland side of the marginal lagoon than on the barrier island side.

Sediment on the barrier island side of the marginal lagoon is very similar to barrier island sediment, the major source. The modal size class is fine sand. The minimum size class is silt, which is present in very minor quantities. The dominant maximum size class is medium sand, although there are a few samples containing minor amounts of coarse sand (these may be near relict inlets). The barrier island side of the marginal lagoon is somewhat protected by the barrier island from strong current action capable of transporting much coarse material; thus, the modal size class of sediment from the barrier island side of the marginal lagoon is finer-grained than the modal size class of the barrier island sediment.

Sediment from the mainland side of the marginal lagoon is a silty fine sand, which reflects the muddy mainland marsh source. The modal size class is fine sand. The dominant maximum size class is medium sand; however, some coarse sand is present. Clay is the minimum size class, although it is present only in minor quantities in areas exposed to wave and current action.

Protected Mainland Embayment

The small bays and estuaried tidal creeks along the mainland side of Pamlico Sound are examples of the protected mainland embayment environment. The tidal creek estuaries may be considered essentially the same as embayments because the small creeks emptying into the heads of the estuaried parts of the creeks are very small and almost insignificant. Bays and tidal creeks included in this environment are: Stumpy Point Bay, Long Shoal River, Pains Bay, Far Creek (Engelhard), Wysocking Bay, East Bluff Bay, West Bluff Bay, Juniper Bay, Coffee Bay, Swanquarter Bay, Mouse Harbor, Big Porpoise Bay, Middle Bay, Jones Bay and West Bay (Figure 8).

The dominant physical influences affecting sedimentation in protected mainland embayments are the source of the sediment and the protection against waves and currents. The chief source of sediment is probably the muddy mainland marsh because it is adjacent to the protected mainland embayments and because the sediment in the embayments contains much organic material similar to the mainland marsh. In spite of the shallowness of the environment, very little coarse sediment is present because the configuration of the coastline protects embayments from current and wave action.

Salinity (Figure 6) and pH are estuarine-like. The water is probably the most acidic of any environment in the sound because it contains much organic material derived from the adjacent mainland marsh. Many organisms are present, burrowing into sediment and mixing it, producing mottles.

Sediment is an organic-rich, muddy sand. The modal size class varies from fine sand near the more unprotected mouth of embayments to silt at the extreme heads of bays. Minimum size class is clay. The dominant maximum size class is fine sand. Medium sand is present near the mouths of the protected mainland embayments. The margins are slightly sandier, particularly at Stumpy Point Bay.

SEDIMENTARY PARAMETERS

Three Inman (1952) parameters were calculated for representative samples from each environment (Table 1). These are:

phi median diameter-- $Md\Phi = \Phi 50$
phi deviation measure-- $\sigma\Phi = 1/2(\Phi 84 - \Phi 16)$
phi skewness measure-- $\alpha\Phi = \dfrac{1/2(\Phi 16 + \Phi 84) - Md\Phi}{\sigma\Phi}$

where Φ 16, Φ 50, and Φ 84 refer to the values in phi units at the 16th, 50th and 84th percentiles in the graph of size classes in phi units plotted against weight percentages of the size classes.

A clear separation of Pamlico Sound into the 11 environments described is not shown from the Inman parameters, but trends suggest these environments.

The Inman median diameter data show that the median diameter of sediment samples decreases toward the lagoon near river mouth, the central basin and also toward the shallow protected mainland embayment. Water is quiet in these environments, and fine sediment is deposited.

The median diameter increases toward the shoals (Figure 9). The order of increasing median diameter is: lagoon near river mouth, central basin, mainland marsh, protected mainland embayment,

Table 1. Inman Phi Parameters for Representative Samples

Environment	MdΦ	σΦ	αΦ
Barrier Island	1.85	.68	.06
C. L. S.	2.35	.68	-.31
C. L. S.	2.20	.63	-.10
C. B.	4.60	.44	.28
C. B.	4.49	.34	.21
Finger Shoal	2.61	.34	-.09
Finger Shoal	2.44	.36	.06
Finger Shoal	2.28	.38	.26
Finger Shoal	2.52	.34	-.12
Finger Shoal	2.36	.34	.23
Finger Shoal	2.56	.34	-.06
Inlet	2.08	.60	.03
Inlet	2.45	.63	-.36
Lagoonal Beach	1.50	.88	-.09
L. N. N.	1.14	.74	-.24
L. N. N.	2.36	.85	-.13
L. N. R.	4.72	.58	.17
L. N. R.	4.60	.30	o
Mainland Marsh	4.43	.34	.15
M. L.	2.90	.96	.45
M. L.	2.56	.24	.20
M. L.	2.54	.50	-.08
M. L.	2.02	.65	.03
M. L.	2.73	.39	-.18
M. L.	2.76	.34	-.06
M. L.	2.64	.34	-.59
P. M. E.	4.50	.41	-.02
P. M. E.	2.80	.64	.08
P. M. E.	2.53	.48	-.04
P. M. E.	4.19	.95	-.46

marginal lagoon, finger shoal, cross lagoon shoal, inlet, barrier island, lagoonal beach and lagoon near narrows. The coarsest environments are relatively shallow and exposed to wind-generated waves and currents that can bring in coarse material and winnow out fines.

The Inman phi deviation measure may be expressed by use of this arbitrary scale: 0.5 well sorted, 0.5-1.0 sorted, 1.0-2.0 poorly sorted and 2.0 very poorly sorted. On this basis the representative samples show that 5 environments are well sorted and 6 sorted. Thus, good sorting is a typical property of Pamlico Sound sediments. The sound sediment is sorted so well because the sound is oriented northeast southwest coinciding with the direction of the dominant winds pro-

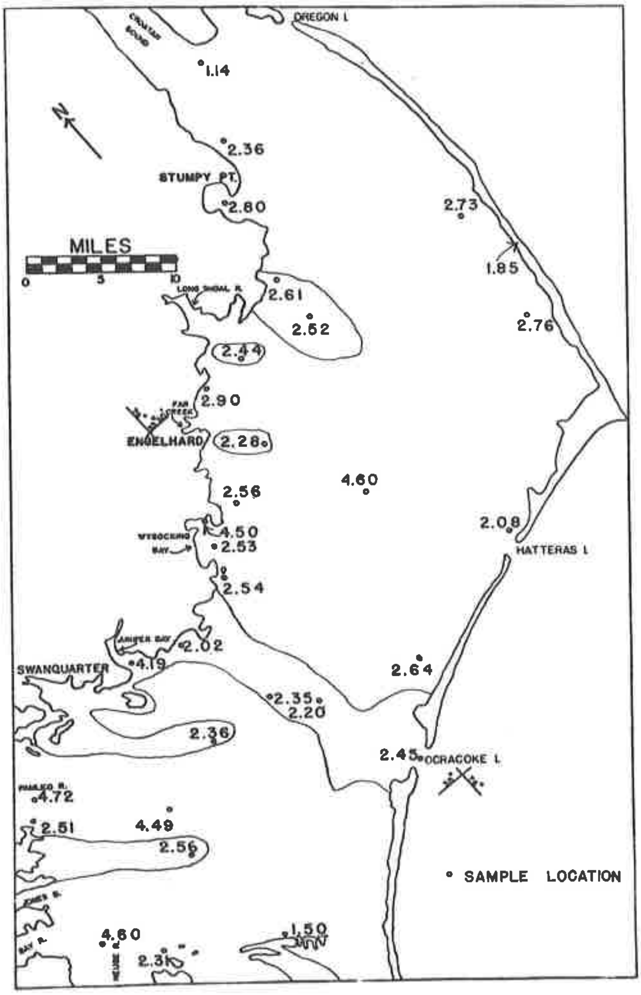

Figure 9. Map of distribution of Inman phi median diameter. Coast-perpendicular shoals outlined.

ducing currents capable of sorting.

The environments whose sediments are "well sorted" are: the mainland marsh, finger shoals, marginal lagoon, central basin and lagoon near river mouth, in order of increasingly poorer sorting. The shoals and marginal areas are generally best sorted because they are exposed to the constant winnowing action of waves in shallow water. The sorting of finger shoal sediment, especially, is very constant from sample to sample. The central basin and lagoon near river mouth environments are almost as well sorted because they are quiet water environments in which only fine-grained sediment is deposited. Also, most coarser sediment has been deposited before being transported this far.

Sediment from the lagoonal beach and lagoon near narrows is more poorly sorted than the sediment from any other environment in Pamlico Sound but still is classified as "sorted". The washing in and out of waves on lagoonal beaches mixes up a size range of mostly coarse sediment and actually removes only the finest grains. Sediment from the lagoon near narrows in Pamlico Sound is probably derived mainly from a very close source--Roanoke Island. Thus, much coarse material is present as well as finer sediment. Also, Roanoke Island protects the area from sorting by northeast wind-generated currents.

Sediments in the other environments of Pamlico Sound are approximately equally sorted. It is interesting that sediment from cross lagoon shoal (Bluff Shoal) is noticeably poorer sorted than the finger shoals which it morphologically resembles. This lends support to the classificiation of Bluff Shoal as a separate environment.

Sediments from the marginal lagoon have the most variation in sorting. Phi deviation measure values range from 0.24 to 0.96. This is understandable because different sections of the marginal lagoon are influenced by different physical, chemical and biological conditions.

A sediment size distribution skewed to the left (coarser sediment) is negatively skewed. A sediment size distribution skewed to the right (finer sediment) is positively skewed. On this basis the following environments in Pamlico Sound are dominantly positively skewed; lagoon near river mouth, central basin, mainland marsh. This abundance of finer sediments relative to coarse sediments reflects weak winnowing action owing to weak currents and/or protection from currents by water depth and/or configuration of the shoreline. Environments whose sediment distributions are dominantly negatively skewed are: cross lagoon shoal, inlet, lagoonal beach and lagoon near narrows. These environments contain mostly coarse sediment. Many of the samples are only very slightly skewed either way.

Edwards (1961) found that sediment in shoal and channel environments in the North River estuary is dominantly positively skewed. This is partially true in Pamlico Sound. Lagoon near river mouth samples and most finger shoal samples are positively skewed, but sediments from most other shoal environments such as cross lagoon shoal and inlet are negatively skewed.

Duane (1964) showed that the sign of skewness is environmentally sensitive in western Pamlico Sound sediments. He explained negative skewness by winnowing action. Sediment from beaches, littoral zone and tidal inlets is negatively skewed. Sediment from a sheltered lagoon filling with sediment is dominantly positively skewed. In areas where winnowing action is operative intermittently (shifting, intermittent wind) sediment is characterized by local differences in the sign of skewness. These areas of intermittent winnowing are on the mainland

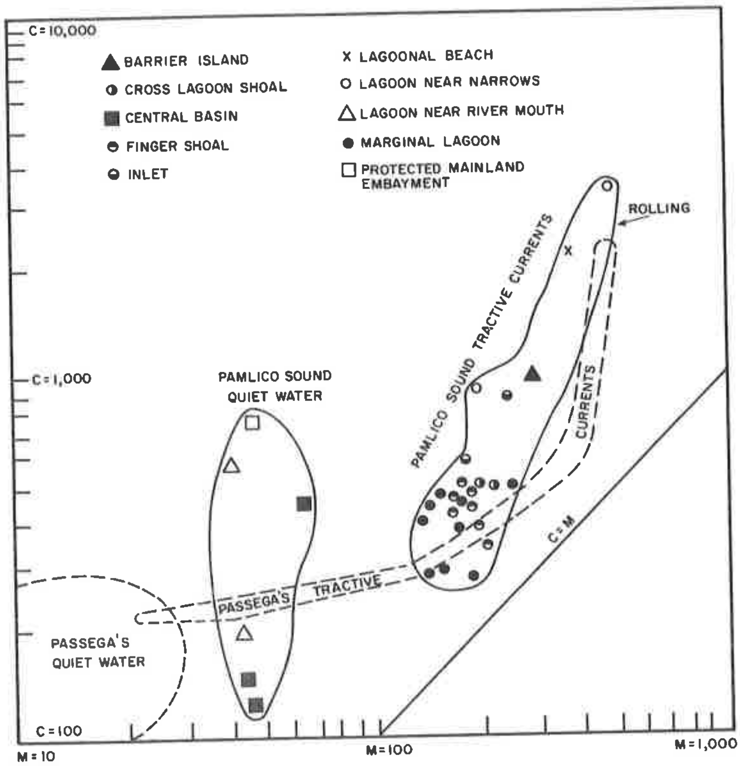

Figure 10. CM pattern.

side of the sound near the estuaries.

Skewness data from the present study (Table 1) are generally in agreement with Duane's (1964) data. One exception is the sign of skewness of finger shoal sediment samples that is negative or positive but mostly positive. Most shoal sediment, according to Duane, should be negatively skewed. Perhaps the winnowing action on these shoals is interrupted by an occasional influx of muddy sediment from the mainland that is deposited on the finger shoal and overwhelms the winnowing action.

The CM pattern of Passega (1957) was plotted (Figure 10). This is a scatter diagram of C, the first percentile, plotted against M, the median diameter, on logarithmic paper. The first percentile is essentially the diameter of the coarsest sediment present (only 1 percent is coarser). Both C and M are expressed in microns. The CM pattern is useful because the coarse fraction of a sediment is usually more representative of the depositional agent than is the fine fraction (Passega, 1957).

The CM pattern for representative Pamlico Sound samples shows a clear separation of deep quiet water and tractive current or shoal deposits (Figure 10). The quiet water environments (central basin, lagoon near river mouth and protected mainland embayment) are found in the lower left part of the CM pattern (Figure 10) very close to the quiet water environment delineated by Passega (1957). Most of the shoaly environment samples are close together near the C-M limit. This is the area of Passega's diagram whose sediments are transported by tractive currents. Very coarse shoal environments, such as lagoonal beach and lagoon near narrows, are separated from the other tractive current environments and are located in the upper right portion of the CM pattern.

The finger shoal samples are closely grouped together in the CM pattern. They are well sorted. They are also distinct from cross lagoon shoal samples, which is further evidence supporting the designation of cross lagoon shoal as a separate environment.

Several of the environmental patterns are elongate in a vertical direction along the C axis. The occurrence of coarser sand in some samples than in others probably explains this vertical distribution of different samples from lagoon near river mouth, inlet and central basin environments. Samples from the lagoon near narrows are riverlike with poor sorting, occasional pebbles and shell fragments; thus, they form an elongate vertical pattern on the CM pattern.

The shapes of the quiet water and tractive current divisions of the Pamlico Sound CM pattern are very similar to the shapes of the quiet water and tractive current divisions of the northern Core Sound CM pattern (Skean, 1959). The quiet water divisions are in much the same position. Skean found that most northern Core Sound tractive current samples fall into the lower part of the tractive current division of the CM pattern, and beach samples are located in the upper part of the tractive current division. This is also true of the Pamlico Sound CM pattern.

In summary, these trends are shown with the use of sedimentary parameters in Pamlico Sound: (1) Median diameter decreases away from cross lagoon and finger shoals toward the center of the sound and also toward other quiet water environments such as lagoon near river mouth and protected mainland embayment. (2) Most sediment in Pamlico Sound is "sorted" or "well sorted" due to the coincidence of the northeast-southwest sound orientation with the dominant wind directions. Shoals, particularly finger shoals, are best sorted because they are in shallow water affected by wind-generated currents. (3) The sign of skewness (caused by winnowing) is characteristic of environments affected by current and wave action (inlet, lagoon near narrows, lagoonal beach, eastern marginal lagoon and cross lagoon shoal). Positive skewness is typical of environments in which winnowing is not a constant force (environments of active deposition such as: central basin, lagoon near river mouth and parts of the mainland side of the marginal lagoon). (4) When samples were plotted on the CM diagram they fell into characteristic positions corresponding to Passega's (1957) quiet water deposited or tractive current deposited sediment.

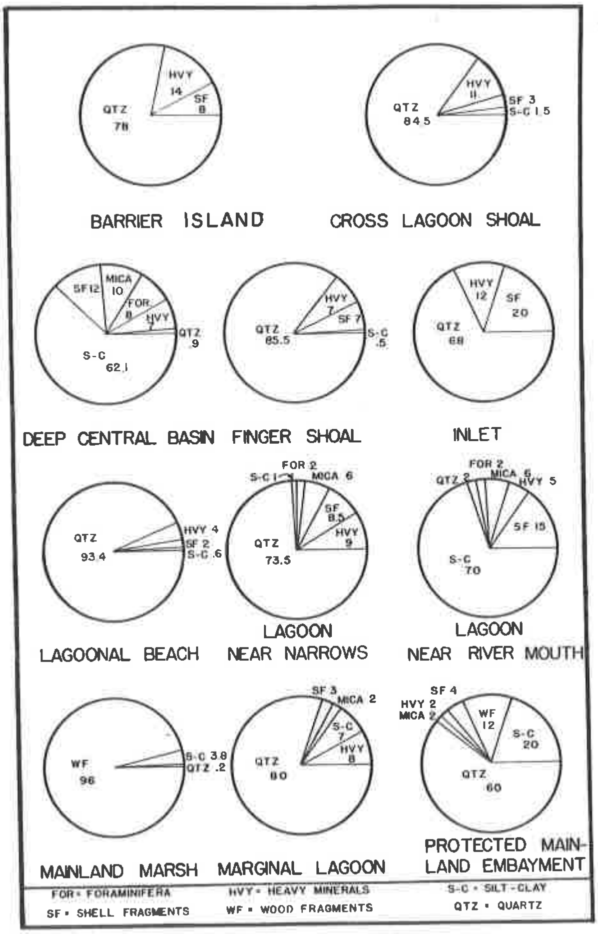

Figure 11. Average composition of sediment samples.

COARSE FRACTION STUDIES

A study of the coarse fraction of samples from the eleven environments in Pamlico Sound was made (Figure 11) using the methods of Shepard and Moore (1954). The following types of particles and physical properties are significant in the samples studied under a binocular microscope: (1) terrigenous grains (principally quartz, heavy minerals, mica and some feldspar), (2) shell fragments (Figure 12) (mostly oysters, with some other mollusks and echinoid fragments), (3) wood fragments and (4) micro-organisms (foraminifera and ostracoda).

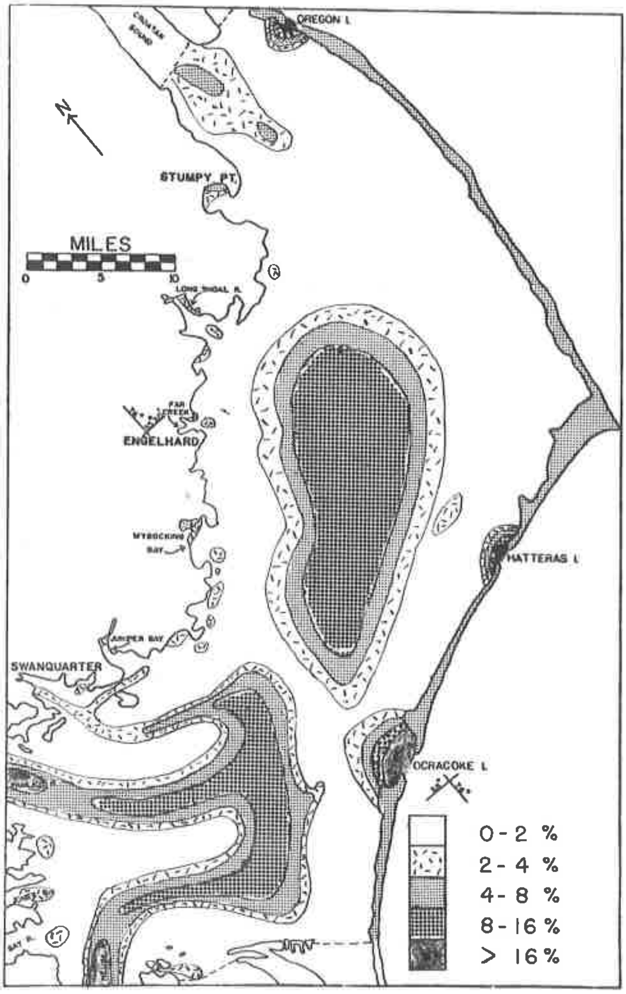

Figure 12. Map of percent distribution of shell fragments.

SEDIMENTARY STRUCTURES

Pamlico Sound can be divided into 3 environments on a basis of minor sedimentary structures. These structural environments are based on: mottled cores, homogeneous cores and banded cores (Figure 13).

Mottled cores are characteristic of muddy environments near the mainland. This includes: protected mainland embayments, mainland side of the marginal lagoon and parts of the lagoon near narrows near the mainland. Most of the mottles are muddy, organic-rich sediment that has probably been mixed by burrowing organisms, such as

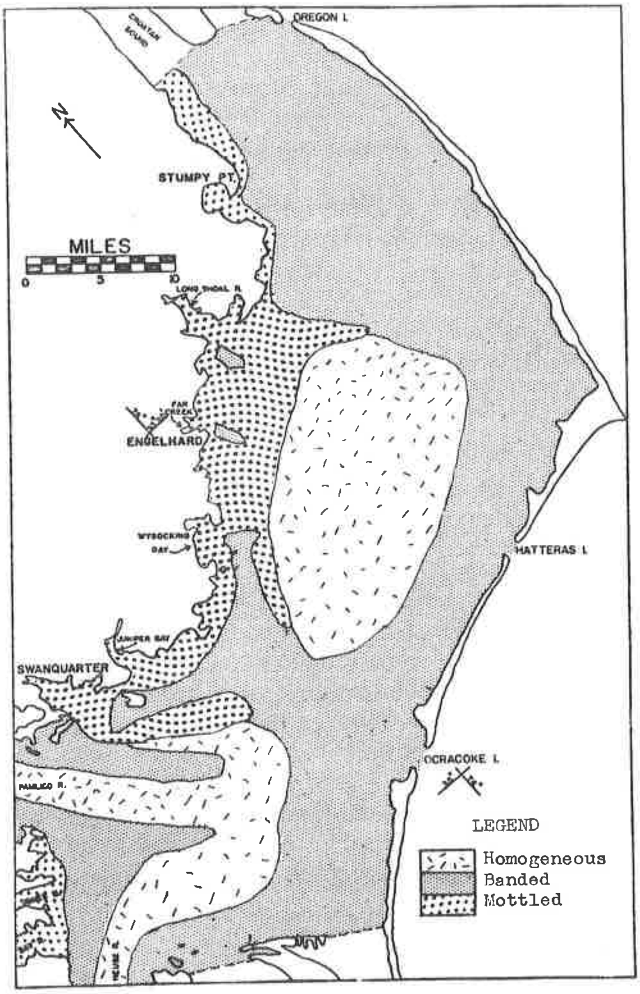

Figure 13. Distribution of sedimentary structures.

pelecypods and worms. The mottles may have been layers or bands similar to those in other parts of the lagoon before being mixed by burrowing organisms that apparently are more prolific in the muddy, organic-rich sediments on the mainland side of the sound than in the clean sands of the barrier island side. Further mixing of the mottles by organisms might produce homogeneous sediment. Most of the dark mottles become less distinct after the tube is cut because the organic material present oxidizes in the air.

Homogeneous cores are characteristic of the central basin and lagoon near river mouth. Here, either there has been a complete mixing of contrasting sediments in mottles or bands to form a homogeneous sediment; or there were no contrasting sediments present originally, and the homogeneity is primary--not caused by organisms. Probably the latter is true because the sediment that is well sorted, and there is no evidence of much contrasting sediment that has been mixed in. Thin shell fragment layers are characteristic of homogeneous central basin cores. They may be concentrations that were washed-in from shell-rich environments, such as inlets or nearby oyster bars, during storms.

Banded cores are characteristic of sandy environments and are found dominantly near the barrier island side of the lagoon, but also elsewhere if the sediment is mostly sand. These environments are: marginal lagoon (barrier island side), inlet, lagoonal beach, finger shoals and cross lagoon shoal. The bands are often indistinct and sometimes are thin, irregular and stringer-like. These alternating bands of mud and sand probably represent alternating periods of quiet and rough water. Black, organic mottles are small or non-existent because there is not much organic material available, and the sand is so permeable to oxygen that most of the organic material that is present is oxidized. There is a lack of many burrowing organisms in the sandy areas, thus the bands are relatively undisturbed. The banding in inlet cores is usually not as pronounced as banding in other sand environments. This may be due to swift currents in inlets that would winnow out most fines and also stir up and destroy much banding.

COMPARISON WITH OTHER LAGOONS

Sedimentation in Pamlico Sound can be compared with sedimentation in lagoons in the central Texas coast. The Texas coast is similar to the North Carolina coast because it also is embayed and protected from the ocean by a barrier island system.

Shepard and Moore (1955) found that salinity, waves, currents, source, and depth of water are the primary controls of sedimentation in the central Texas coast. These factors are also the primary controls of sedimentation in Pamlico Sound. Also, it should be noted that the configuration of the shoreline controls the effect of waves and currents.

The central, deep parts of bays in the central Texas coast area are characterized by the lack of stratification and by high clay content (Shepard and Moore, 1955). The same is true of the analogous central basin environment of Pamlico Sound. Another similarity that characterizes this environment in the two areas is the presence of layers of oyster shell fragments.

Living oyster reefs are found in bays in the central Texas coast (Shepard and Moore, 1955). They occur similarly in Pamlico Sound, mostly on the mainland side.

In the central Texas coast area the lower bays near inlets are characterized by a dominance of sand (Shepard and Moore, 1955). Also characteristic of the lower bays near inlets (particularly characteristic of inlets) is the presence of echinoid spines. In Pamlico Sound the barrier island side of the marginal lagoon and the inlets are analogous to Shepard and Moore's lower bays and inlets. These areas in Pamlico Sound are characterized by the dominance of sand, particularly near the inlets. Echinoid spines were also seen in Pamlico Sound samples, particularly near the inlets. Duane (1962), also reported that echinoid spines are characteristic of inlet environments in Pamlico Sound.

Shepard and Moore (1955) found that wood fragments are characteristic of bay near river mouth sediment in Texas bays. Wood fragments were not found in the samples studied from the lagoon near river mouth in Pamlico Sound, but they were found in the nearby protected mainland embayments and mainland side of the marginal lagoon.

Thus, it is apparent that coarse fraction studies are useful in characterizing sedimentary environments in Pamlico Sound, just as they are useful in characterizing environments in central Texas coast bays.

Lithologic and structural characteristics of Pamlico Sound are much like those of "normal brackish or salt water lagoons" studied by Van Straaten (1959). His examples are the Zuiderzee (Netherlands), Rhone delta lagoons, Barataria Bay, and Texas bays. Sediments in these areas are sands, clayey sands, sandy clays, and clays with small or moderate content of silt. Pamlico Sound sediment is mostly very fine to fine sand which is frequently silty or clayey.

Ryan (1953) reported some banding in cores from Chesapeake Bay. This is similar to the situation in Pamlico Sound. He also found that channels contain fine sediments. This is also true of lagoon near river mouth channels in Pamlico Sound.

Some of the cores from Pamlico Sound, especially those near mainland bays, are similar to sections in Cretaceous Black Creek Formation beds studied by Swift (1964) in the Carolinas. Swift assigns these beds to a lagoonal facies. He describes typical lagoonal sediments as: "lenticular, thinly bedded to varieties whose bedding is subdued and largely obscured by flamboyant mottles." He further describes structures as: "sub-horizontal wisps, pockets, irregular masses. Mottles are clean grayish white sand, in a matrix of dark gray clayey sand." Most sandy zones in Pamlico Sound cores are "sub-horizontal wisps, pockets, or irregular masses." Therefore, the study of structures in the modern sediments of Pamlico Sound helps substantiate Swift's designation of lagoonal facies to certain beds in the Cretaceous Black Creek Formation.

CONCLUSIONS

It is apparent that there are reproducible relationships between the physical properties of sediments and their environments of deposition in Pamlico Sound. These relationships are shown best by preparing facies maps from data derived from the megascopic examination of sediment samples and from the study of structures in shallow cores. The sedimentary relationships delineated in Pamlico Sound should be at least partially applicable to similar ancient sediments.

Pamlico Sound can be divided into eleven environments of deposition, each recognized by characteristic lithology: barrier island, central basin, cross lagoon shoal, finger shoal, inlet, lagoonal beach, lagoon near narrows, lagoon near river mouth, mainland marsh, marginal lagoon, protected mainland embayment.

Water depth, sediment source and wave and current action are the dominant factors controlling sediment distribution in Pamlico Sound.

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STRUCTURE OF THE DUMPLIN VALLEY FAULT ZONE IN EAST TENNESSEE

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ABSTRACT

The Dumplin Valley fault zone extends from Morristown to Etowah, Tennessee, a distance of about 90 miles. Involved in faulting are some 10,000 feet of sedimentary rocks that range in age from Early Cambrian to Middle Ordovician. The Rome Formation, Conasauga Group, Knox Group, and part of the Chickamauga Group are represented.

Two large thrusts and their branches are traceable through most of the mapped area. They are interconnected only at one place. Toward the southwest the southeasternmost fault overrides the northwest fault. At the northeast end of the structure stratigraphic displacement on the faults diminishes and two large, open anticlinal folds are the most prominent structural features. At the southwest end of the mapped area faulting also diminishes and branches from the remaining major fault terminate in tight folds. The structure of the footwall is synclinal with rocks of the Chickamauga-Knox groups exposed over a wide area.

The Dumplin Valley fault zone is a complex of branching splay thrusts that developed in a superficial hanging wall anticline where the underlying major sole in the area changes level. The thrust presumably changes level from shales of the Rome Formation, across the competent carbonates of the Knox, into shaly limestones of the Chickamauga Group. Erosion has cut down to the ramp zone where the structure is buttressed against the Knox Group in the footwall, so that the dips of the faults at the present surface are moderate.

INTRODUCTION

At least ten major thrust faults exist in the Valley and Ridge Province of East Tennessee at the latitude of Knoxville. The present study is concerned with a portion of one of these thrust systems. The surface extent of the Dumplin Valley fault zone is from Morristown to Etowah, Tennessee, a distance of some 90 miles. About 52 miles of

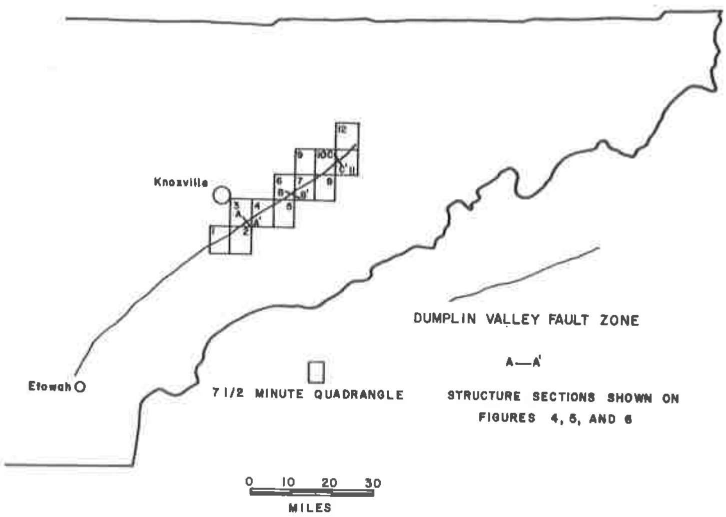

Figure 1. Location, extent, and index to mapping of the Dumplin Valley fault zone. 1. Maryville Quadrangle. Mapped by J. M. Cattermole, U. S. G. S. GQ-163. 2. Wildwood Quadrangle. Mapped by R. B. Neuman, U. S. G. S. GQ-130. 3. Shooks Gap Quadrangle. Mapped by J. M. Cattermole, U. S. G. S. GQ-76. Reconnaissance mapping by R. D. Hatcher, Jr. 4. Boyds Creek Quadrangle. Mapped by D. D. Harper, University of Tennessee Master's thesis. 5. Douglas Dam Quadrangle. Mapped by B. C. Stewart and R. D. Hatcher, Jr. 6. New Market Quadrangle. Mapped by R. D. Hatcher, Jr. 7. Jefferson City Quadrangle. Mapped by R. D. Hatcher, Jr. 8. White Pine Quadrangle. Mapped by R. D. Hatcher, Jr. 9. Talbott Quadrangle. Mapped by C. P. Finlayson, C. R. L. Oder and A. E. Coker, Tenn. Division of Geology G. M. -163NW. 10. Morristown Quadrangle. Mapped by C. R. L. Oder and R. C. Milici, Tenn. Division of Geology G. M. -163NE. 11. Springvale Quadrangle. Detailed and reconnaissance mapping by R. D. Hatcher, Jr. 12. Russellville Quadrangle. Reconnaissance mapping by R. D. Hatcher, Jr.

the northeastern portion have been mapped in detail by the writer and others and available data were compiled by the writer for this study (Figure 1).

Acknowledgments

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PREVIOUS INVESTIGATIONS

Keith (1895, 1896a, 1896b, 1901) recognized, and mapped in part, the complex faulting that occurs in the Dumplin Valley structure. His maps are more detailed than earlier maps of this area (Safford, 1869) and show some subdivisions of the Conasauga Group.

Bridge (1945) mapped to the edge of the fault zone in his study of the Mascot-Jefferson City zinc district. Rodgers (1953a) compiled the geology of East Tennessee and made a regional interpretation of the faulting in this portion of the Valley and Ridge. The data from the quadrangles, shown in Figure 1 with some modification, has been incorporated into the present analysis.

STRATIGRAPHY

Some 10,000 feet of Early Cambrian to Middle Ordovician sedimentary rocks are involved in the Dumplin Valley structure (Figure 2). The oldest unit in the structure is the Lower Cambrian Rome Formation exposed in the hanging wall. Overlying the Rome are the six formations of the Middle and Upper Cambrian Conasauga Group. The Conasauga Group is overlain by the siliceous carbonates of the Upper Cambrian and Lower Ordovician Knox Group. The five formations composing the Knox Group occur principally on the southeast flank of the structure. At the present level of erosion the Middle Ordovician Lenior Limestone, Holston-Tellico Formation, and Ottosee shale of the Chickamauga Group make up the major portion of the footwall sequence and the Knox is exposed extensively along the faults in the footwall. Detailed descriptions of all the formations may be found in reports of Hatcher (1965), Bridge (1956), and Rodgers (1953a).

DESCRIPTIVE STRUCTURE

Two major thrust faults are the most prominent tectonic features in the northeastern portion of the Dumplin Valley fault zone (Hardeman, 1966). Both are traceable throughout most of this portion

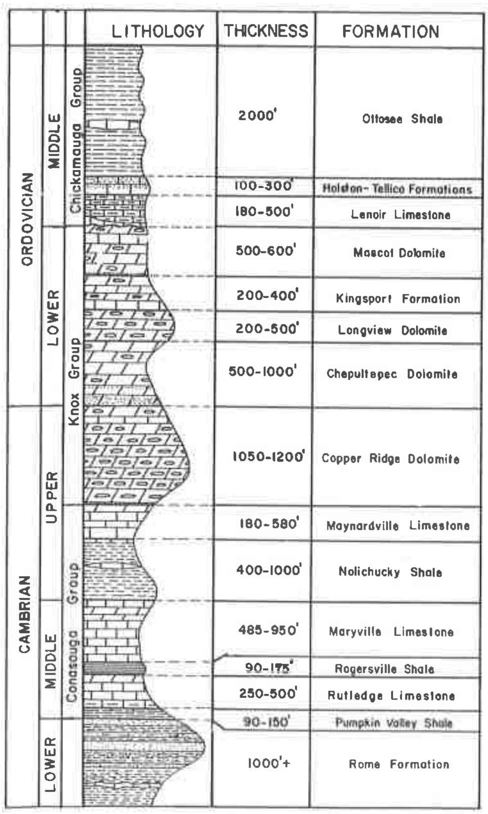

Figure 2. Stratigraphic section.

of the structure. However, to the southwest the southeasternmost fault has overridden the northwest fault producing an abnormally wide outcrop belt of the Rome Formation (Figure 3). Along the traces of both faults there are many slices of diverse sizes as well as numerous branch faults and parasitic folds (Figure 4). Faults are generally localized in incompetent zones in the Conasauga Group and Rome Formation.

The hanging wall structure of the Dumplin Valley fault zone consists of a number of minor thrusts and folds of diverse sizes. Toward the northeastern end of the structure two large northeast-plunging anticlines dominate the hanging wall structure (Figure 5). At the southwest end of the study area faulting in the hanging wall diminishes in frequency and in the Maryville quadrangle is replaced by a series of parallel trending tight folds which plunge southwesterly and diverge some 10 to 15 degrees from the strike of the structure (N35-40°E versus N50°E for the structure).

The footwall structure is synclinal. Rocks of the Chickamauga

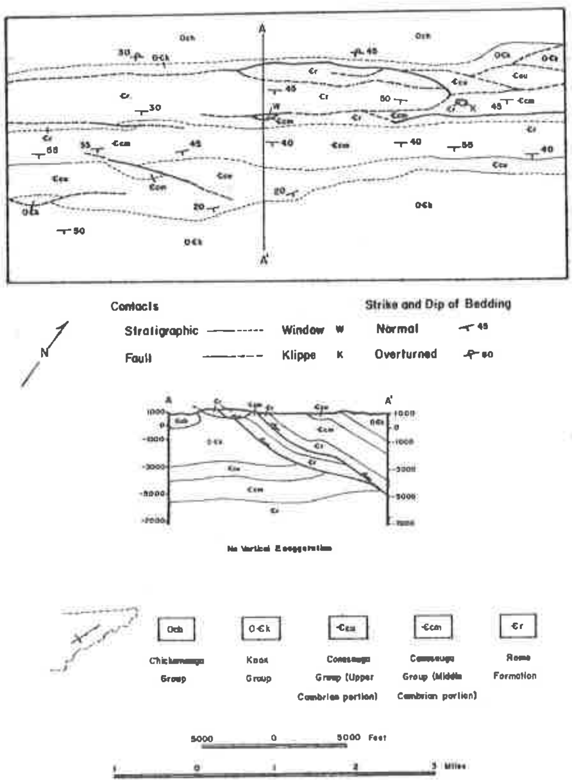

Figure 3. Geologic map and structure section of a portion of the Dumplin Valley fault zone.

Group dominate, but the Knox Group is exposed over a wide area as well. Minor faults extend from the main faults and cut footwall rocks in several places.

DEVELOPMENT OF THE MAJOR STRUCTURE

Two opposing schools of thought have evolved through the years regarding the structure of the Central and Southern Appalachians: the "thin-skinned" theory and the "thick-skinned" theory (Rodgers, 1949). The "thin-skinned", or no basement, hypothesis states that the Valley and Ridge structures are features marginal to the main area of deformation and were produced by tangential stresses that produced bedding thrusts of considerable magnitude, some having several miles of displacement in the sedimentary prism without involvement of the basement rocks (Rodgers, 1953b). Stresses were probably also applied to

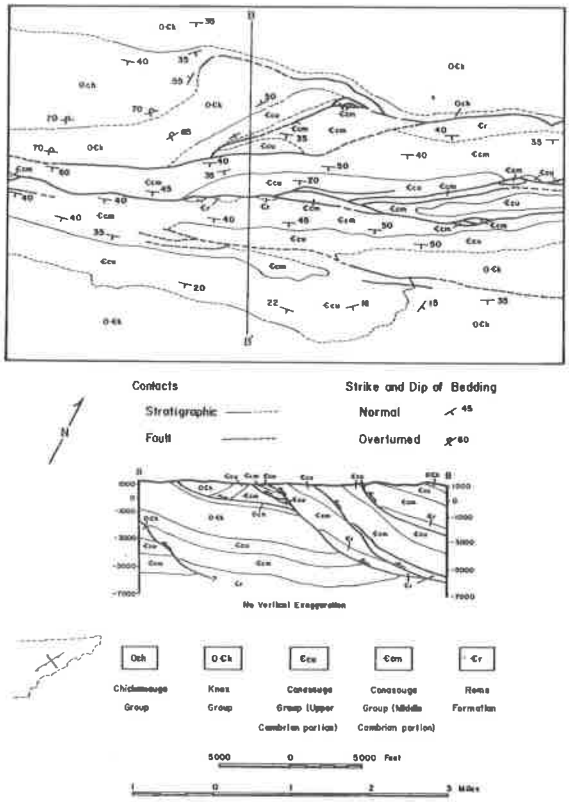

Figure 4. Geologic map and structure section of a portion of the Dumplin Valley fault zone from the New Market and Jefferson City quadrangles.

the basement rocks but their rupture strength was not exceeded. Movement of these great thrust sheets to the northwest and upward deflection of faults across competent strata produced rootless folds and associated splay thrusts in some areas. Some faults apparently originated as bedding thrusts in a particular stratigraphic interval and broke upward across competent strata from one shaly stratigraphic position to another. Thus a given fault need not everywhere have a low angle of dip, but high angle segments may exist within a given fault system. Gravity and magnetic surveys from the Valley and Ridge of Tennessee support the no basement hypothesis (Watkins, 1962).

The "thick-skinned" theory requires that the sedimentary cover adjust passively to extensive deformation in the basement. Thus, the basement is involved in faulting and the faults are assumed to have a high angle of dip (Ulrich, 1911; Cooper, 1961, 1964).

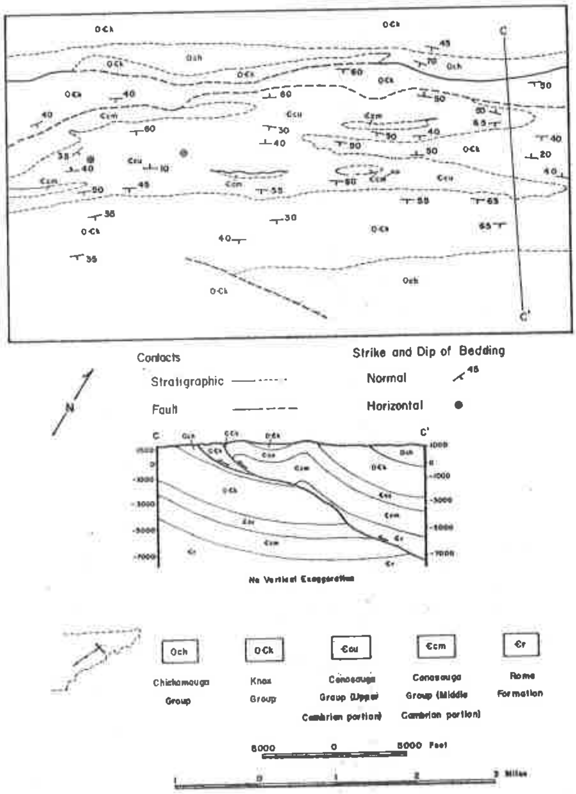

Figure 5. Geologic map and structure section from a portion of the Dumplin Valley fault zone near the northeast end.

More features of the Dumplin Valley structure seem compatible with the "thin-skinned" theory than with the "thick-skinned" theory. Faults follow zones of weakness and are parallel or subparallel to bedding, but at the same time generally have moderate to steep attitudes, at least at the present surface.

The hanging wall structure is for the most part anticlinal and that of the footwall synclinal (see Figures 3 and 4). The core of the structure in the hanging wall is a complex of overriding thrusts (Figures 3 and 4). The simplest interpretation of the structure would be a faulted fold with a complexly deformed core. However, with this intimate association of faults and folds there arises the question of the respective origins of each element and of whether faulting preceeded folding or vice versa. Rich (1934), in his study of the Pine Mountain fault, concluded that the Powell Valley anticline was produced by a thrust rising from one zone of weakness to another by ramping across a competent sequence, and his conclusion has been verified by drilling. Harris (1967), in a study of data from the Bales well on the Powell Valley anticline, corroborates Rich's conclusions but suggests that ramping along with imbricate thrusting within a particular zone produced the Powell Valley anticline.

In a study of well data from the Plateau of the Central Appalachians, Gwinn (1964) also has demonstrated the principle of rootless anticlines forming above a fault ramping across a competent zone to a higher decollement. The Sequatchie anticline was likewise interpreted by Milici (1963a, 1963b) as a structure produced by ramping of the Sequatchie Valley thrust from a lower to a higher weakness zone; in the latter the Sequatchie Valley thrust becomes the Cumberland Plateau overthrust of Stearns (1954, 1955).

In all the examples cited, folds were produced in association with thrusting. The Dumplin Valley fault zone was similarly produced by ramping of a thrust, apparently from a decollement in the Rome Formation, into the incompetent rocks of the Middle Ordovician sequence. At several places in the Jefferson City Quadrangle the dip of the northwestern thrust flattens considerably. In these places the Middle Ordovician Lenior Limestone is in the footwall directly beneath the fault. Elsewhere, except in the Wildwood Quadrangle (Newman, 1960), the attitudes of both major faults are relatively steep (40 to 60 degrees), even though in places the footwall rocks are incompetent Middle Ordovician shaly limestones (Lenior) and in others they are massive dolomites and limestones of the Knox Group. Buttressing of the hanging wall against the Knox in the footwall sequence is the probable cause of the steep dips on the faults in the structure, because the portion of the structure observed at the present level of erosion is the "ramp level" while that portion that flattened into the younger incompetent zone is now largely eroded away.

The Dumplin Valley fault zone consists of a complex of branching splay thrusts as defined by Gwinn (1964, p. 890). These thrusts are thought to have developed along the zone of inflection of the superficial fold which formed in the subsurface in the area where the major decollement changes level from the Rome to the Chickamauga rocks (Figure 6).

DEVELOPMENT OF STRUCTURES WITHIN THE HANGING WALL

The splay thrusts which form the Dumplin Valley structure behave mechanically in the same manner as the larger thrusts that come to the surface farther to the west, i. e., by ramping across a competent sequence from one weakness zone to another. The folds which are present on the hanging wall of the structure formed above the splay thrusts in response to the ramping process.

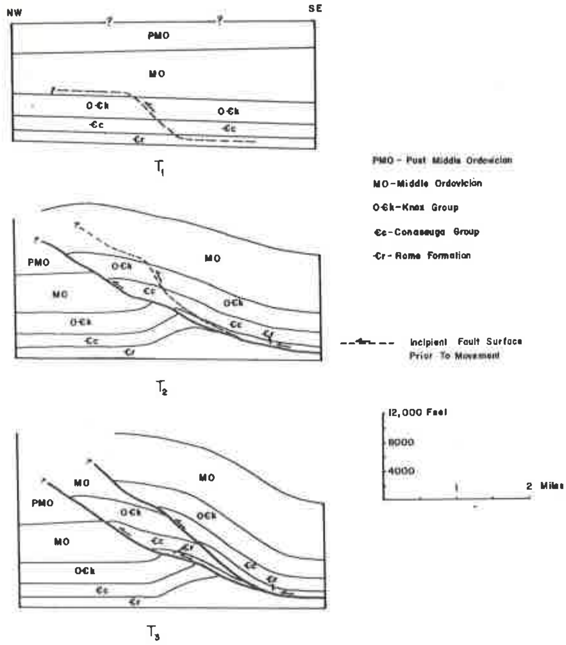

Figure 6. Interpretive sequential sections across the Dumplin Valley fault zone showing the development of the structure as interpreted by the writer. Depth to basement was estimated to be between 15,000 and 18,000 feet from the present surface by Watkins (1964).

The northwest fault and associated structures probably formed first, then the southeast fault ramped over the hanging wall of the northwest fault as a backlimb thrust (Figure 6). Toward the southwest end of the study area the northwest fault was completely overridden by the southeast fault (Figure 3).

The axes of two major anticlinal folds, which are present in the hanging wall assemblage at the northeast end of the structure, have been cut off by the southeast fault (Figure 5). These folds probably originated in association with the northwest fault and were then truncated as the southeast fault ramped up over the hanging wall of the other major fault.

The style of folding at either end of the structure appears to be somewhat controlled by differences in the stratigraphy of the Conasauga Group. At the northeast end there is a significantly lower shale-carbonate ratio (0.467), caused by relative thickening of the Maryville

Limestone and thinning of the Nolichucky Shale. This gave rise to more competent folding. The tight folds at the southwest end, which are caused by a higher shale-carbonate ratio (0.825), probably also are attributed to relative thicknesses in the same two units, but in the reverse of the former case.

CONCLUSIONS

1. The Dumplin Valley fault zone yields readily to a "thin-skinned" interpretation. Although low angle faulting is present in the structure, erosion has reduced the structure to the ramp zone where high angle thrusting predominates.

2. The Dumplin Valley fault zone is a complex of branching splay thrusts in a superficial drag fold which formed where the major sole in the area changes level. Major faults in the structure have refracted across a competent sequence (the Knox Group) from the Rome shales to the shaly limestones of the Chickamauga Group.

3. Folds in the hanging wall at either end of the study area have formed as parasitic folds resulting from subsidiary faulting. The stratigraphy of the Conasauga Group played a role in determining the style of folding at either end of the structure.

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EOLIAN SANDS ASSOCIATED WITH COASTAL PLAIN RIVER VALLEYS -- SOME PROBLEMS IN THEIR AGE AND SOURCE[1]

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ABSTRACT

Eolian sands on the east sides of river valleys in the Neuse drainage basin have two major source areas. One source is the adjacent flood plain during major periods of deposition of beaches, spits and bars of adjacent estuaries. The second source is the outcrop of coarse sandy sediments on west-facing valley slopes. Eolian sands associated with valley slope source areas can range in age from Pliocent to Recent although one radiocarbon date suggests that some are Recent.

INTRODUCTION

Isolated sand bodies with a gently undulating topography are found along the east sides of many north-south trending streams or reaches in the Coastal Plain of North Carolina. These sand bodies have Turkeyfoot Oak, (Quercus falcutes), cacti (Cactaceae spp.) and other plants that are common in the sandhill region of North and South Carolina. Similar areas occur on the east side of the Great Pee Dee

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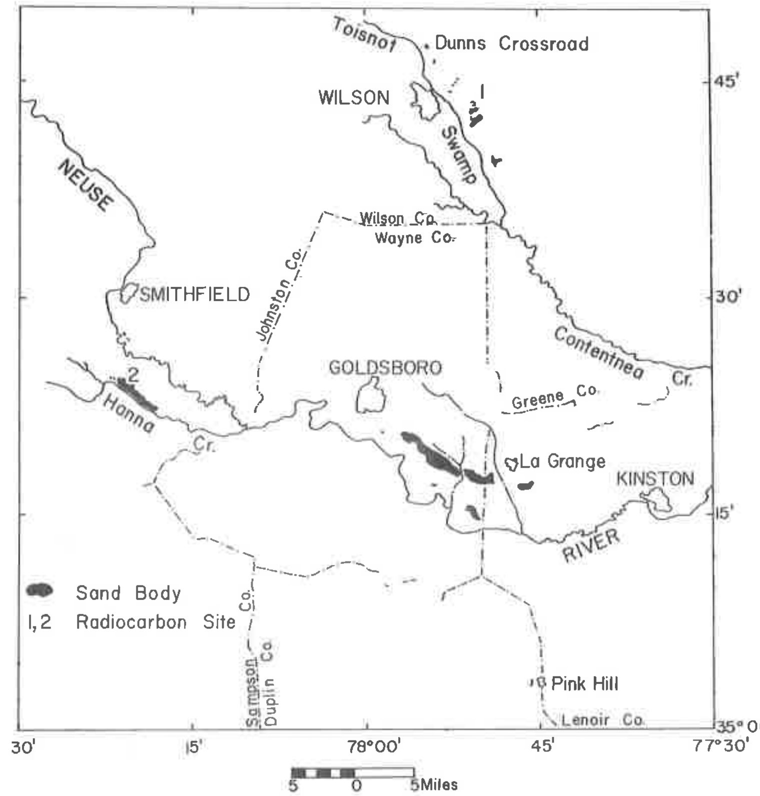

Figure 1. Location of major sand bodies associated with river valleys in the Neuse drainage, middle Coastal Plain.

River near Bennettsville, South Carolina, and on the east side of the Cape Fear River and Black River in Bladen and Pender Counties, North Carolina. These isolated sand bodies are less than 1 mile wide although they may be up to 5 miles long on the east sides of river valleys. They appear to be related to very local conditions and commonly are unrelated to marine transgression or regression. For these reasons we believe that these sand bodies are not the same as those mapped extensively by Colquhoun (1966, 1969), but they are similar to the dunes mentioned by Gagliano and Thom (1967). In this report we will describe the areal distribution of these sand bodies, their relation to other deposits and textural features and interpret their age and genesis.

AREAL DISTRIBUTION AND PROPERTIES

Isolated sand bodies have been mapped along the east side of

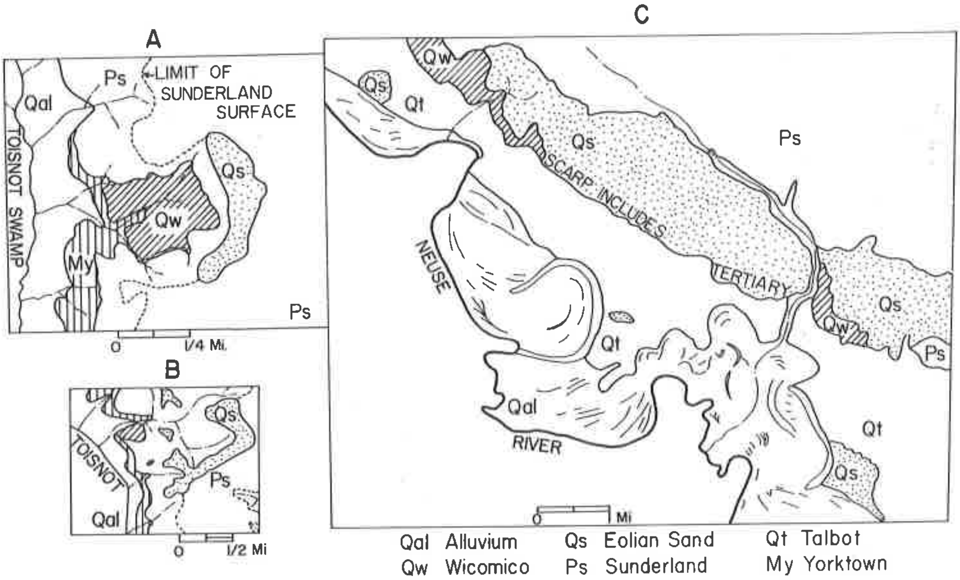

Figure 2. Detail of relations among sand bodies and surficial sediments. A. Toisnot swamp valley 1/2 mile south junction 1327 and 1330, Wilson County. B. Toisnot swamp valley 1/2 mile north junction 1503 and US 264, Wilson County. C. Neuse valley southeast from Goldsboro, Wayne County.

Toisnot Swamp from Wilson to a point near its junction with Contentnea Creek, along the east side of Hanna Creek in the Neuse Valley below Smithfield, and along the Neuse Valley east and south of Goldsboro (Figure 1). There are also local occurrences of similar bodies in the Neuse drainage above the Surry scarp. Each sand body is always associated with a north-south stream or a large north-south reach such as the one in the Neuse River near Goldsboro. The sand bodies along the Neuse River are oriented with their long axes parallel to the long axis of the stream except near Toisnot Swamp where many are oriented normal to the stream (Figures 1, 2). The stream-facing side of the body usually is sharply limited by a valley slope or a valley-facing scarp, but the sands drape down some valley-facing scarps (Figure 3). The side away from the stream (east) is sharply separated from the flat Coastal Plain surface by a short slope of 5 to 10 percent. The vertical height of the sand body is best seen from the east side where in comparison to the flat or gently undulating Coastal Plain surface it appears as a hill 5 to 15 feet high.

The sand bodies have a characteristic topography that if different from that of the surrounding surface. Numerous roughly circular depressions occur that are separated by swells 2 to 10 feet high. Maximum relief on a sand body near Goldsboro measured along randomly

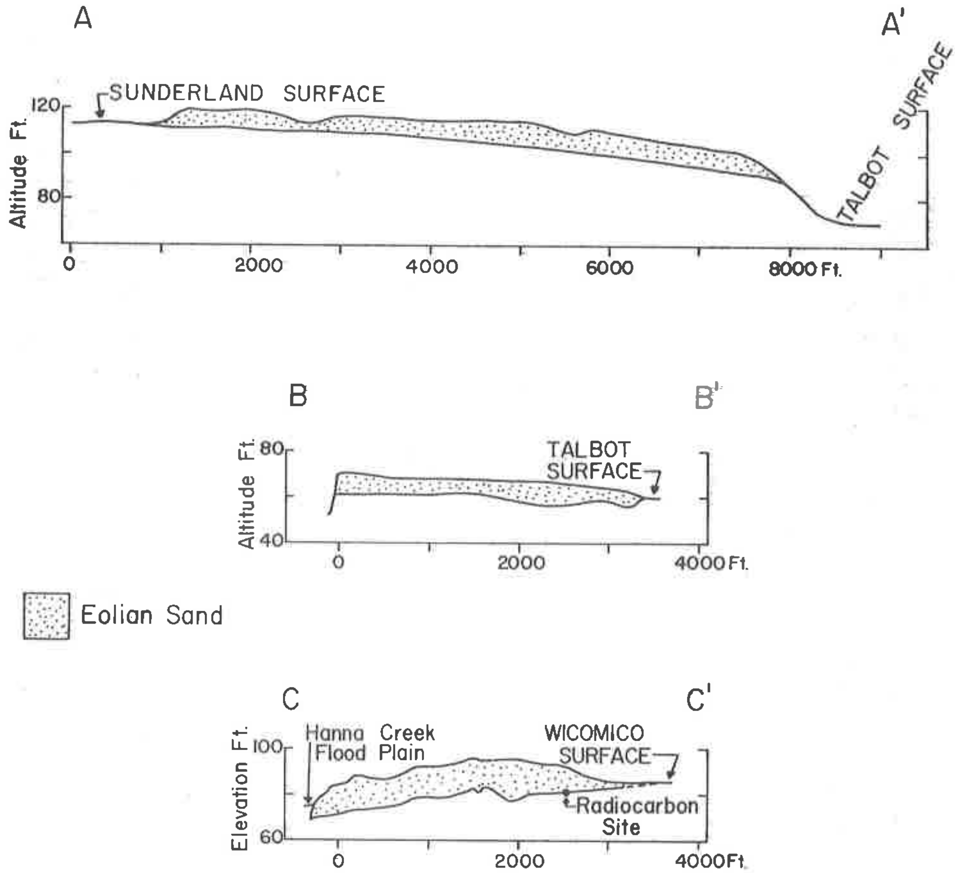

Figure 3. Cross sections across sand bodies near Goldsboro and east of Hanna Creek, Neuse drainage.

oriented 600 foot transects (Daniels, et al. In press) is 4.9 ± 2.6 feet. The same type of measurements on the adjacent Sunderland surface is 0.8 ± 0.6 feet.

These sand bodies abruptly overlie sediments with clay to loamy sand texture of the Sunderland, Wicomico, and Talbot surfaces in the Neuse drainage (Figure 2). A buried soil usually is found directly below the contact. In sites where the soil is well drained, the contact between the sand and the A2 horizon of the buried soil is difficult to see, but usually can be located by differences in sand sizes. The contact is sharp in poorly drained sites on the buried surface because the dark, organic-rich, usually fine textured A1 horizon of the buried soil contrasts to the overlying loamy sand. In some areas the buried soils have a morphology similar to present soils on the adjacent Coastal Plain surfaces (Nettleton, 1966), but in others the buried soils are less well developed.

The sand bodies have no sedimentary structure where exposed in road cuts. The sands are loose and single grained. They contain

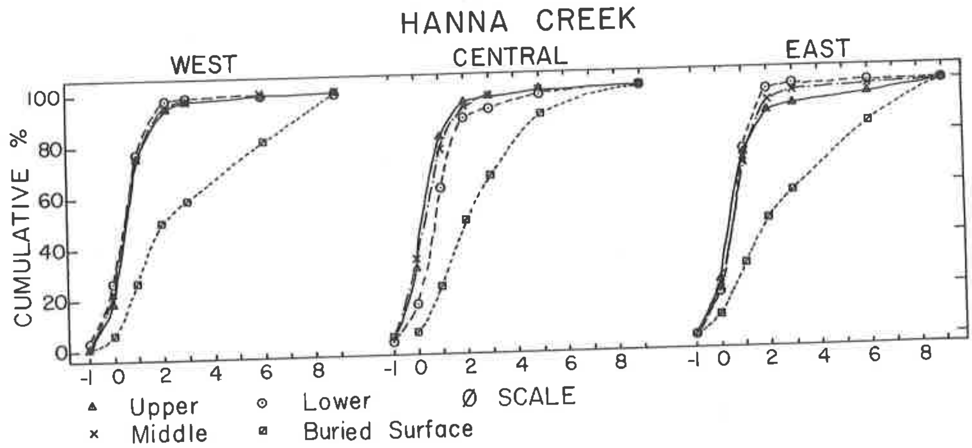

Figure 4. Cumulative curves for sand body east of Hanna Creek, Neuse River Valley.

only 1- to 4- percent clay (Figure 4) and silt contents are uniformly low. There is little vertical variation in sand size above the buried surface. Particle-size information on one traverse across a sand body (Figure 4), demonstrates the lack of horizontal variation in sand sizes. The sands are dominated by the 1 phi sizes (0.5 - 0.25mm) but there is some finer sand (.05 - .5mm) and a very small amount of fine gravel (2 - 10mm). The grain size contrast between the sand body and the underlying material is large. Feldspar contents of the sand varies widely (Figure 5) and there appears to be no relation between feldspar content and the age of the surface the sands overlie.

A description of a typical vertical section in a depressional area in a sand body follows. This description is from a bore hole located east of Hanna Creek in Johnston County, North Carolina (Figure 1).

Horizon	Description	Thickness (feet)
A1 & B	Modern soil; grayish brown (10YR 5/2) medium sand grading to yellowish brown to light yellowish brown (10YR 5/8 - 6/4) medium sand; abrupt lower boundary to	4.0
Bh1	Dark reddish brown (5YR 2/2) medium sand; clear lower boundary to	0.2
Bh2	Reddish gray (5YR 5/2) medium sand; clear lower boundary to	1.8
Bh3	Dark reddish brown (5YR 2/2) medium sand; gradual lower boundary to	1.0

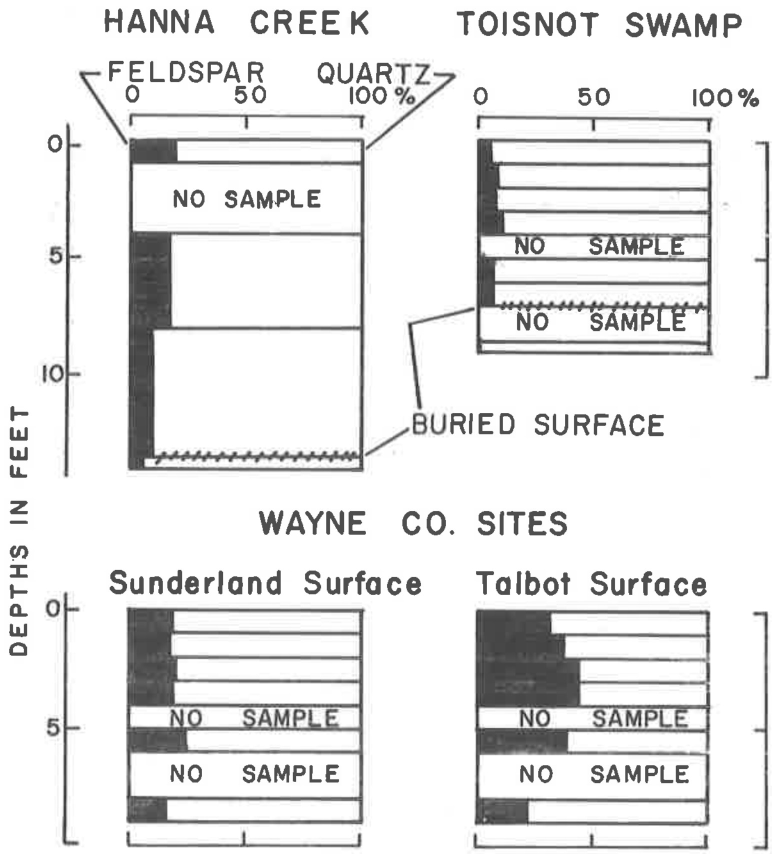

Figure 5. Feldspar and quartz contents from sand bodies and underlying sediments.

Horizon	Description	Thickness (feet)
Bh4	Dark reddish brown (5YR 3/4 to 3/2) medium sand; gradual lower boundary to	2.0
Bh5	Dark brown to brown (7 5YR 4/2) medium sand; base of sand body; abrupt lower boundary to	5.0
II Alb & Bb	Very dark grayish brown (10YR 3/2) loam; buried soil in Wicomico sediments; base of observation at 19 feet.	4.0

The upper part of the section with light yellowish brown color is thicker close to the valley slope and on the crests of swells. The dark reddish-brown organic stained Bh horizon is common in all areas except near the valley slope where water tables are deep. These dark lower sections are interpreted as Bh horizons - accumulations of organic matter by translocation from the surface - rather than buried A horizons. Most Bh horizons have a hue to the 5 YR (Munsell) whereas most buried A1 horizons have a hue of 10YR (Malcom, 1964). Similar horizons in sandy materials near Pink Hill, North Carolina have no pollen but buried A1 horizons with 10YR hues have abundant pollen. These dark organic stained horizons in the sands are similar to the humate described by Swanson and Palacas (1965) in Florida. We interpret these humic horizons as post-depositional modification of the sands by translocation of organic matter from the surface.

The organic-stained sand is composed of several discontinuous lenses or layers that vary vertically and horizontally in color. The body of organic-stained sand is easily identified and traced but the individual lenses or layers are not.

The thickness of the sand body has a direct influence on the vegetation. In thick sand bodies, about 10 to 15 feet, the crests of swells have a mixed pine and Turkeyfoot Oak vegetation; where the sands are 15 feet or more thick, Turkeyfoot Oak and associated vegetation seem to predominate. In sand bodies less than 10 feet thick, pines are dominant and in many areas the vegetation is grossly similar to the adjacent clayey areas. Because a seasonal water table occurs above the less permeable buried surface, the relation between sand thickness and vegetation probably is related to the depth of the water table.

Origin

Any mechanism of deposition for these sand bodies must account for several facts. These bodies are dominated by sand, indicating a very selective process that separates the coarse and fine particles because most upper and middle Coastal Plain sediments in this area are mixtures of sand, clay, and silt. The sands are deposited in narrow bands along the east side of generally north-south trending reaches and stand 10 to 15 feet above the surrounding surface (Figure 3). The sand bodies are oriented either parallel to the valley trend or normal to the trend. These bodies occur on the highest parts of the landscape as well as only slightly above the flood plain. There is an abrupt vertical and horizontal contact between the sand body and adjacent materials, and the buried soil at the top of the underlying sediment is neither channeled nor truncated. The sands are structureless. In places, the sand body draped over scarps associated with river valleys and in others it is truncated by these scarps. These sands are not giant A2 horizons because there is no associated argillic horizon.

Fluvial processes would channel and erode the buried soils and would be effective only on the lower, not the highest parts of the landscape. Slope wash is not responsible because these sand bodies are 10 to 15 feet above the highest part of the local landscape. Their spotty distribution along river valleys and the lack of definite associated shore lines tends to discount deposition of these sands in a body of water. There is no single feature of these sand bodies that precludes their deposition by wind. The features that argue most strongly for wind deposition are their clean sands and location on the east sides of stream valleys.

Age

The buried soils below the sand bodies show that there was a significant interval of weathering before their deposition. South of Dunn's crossroads (Figure 1, 2A) and southeast of Goldsboro eolian sands overlie the Sunderland surface or Sunderland materials (Figures 2C, 3-A-A'). These sand bodies do not overlie the adjacent Wicomico sediments although they drape down the slope separating the Sunderland and Wicomico sediments (Figures 2A, 3A-A'). South of Goldsboro the large sand body is truncated by the river-facing scarp that merges with the Talbot surface (Figure 3A-A'). The sand bodies near Dunn's crossroads and the large body near Goldsboro are post Sunderland surface. If the Wicomico surface was the source for these sands there should be a few areas with a sand cover. None has been found during the mapping of the entire Toisnot Swamp valley or the Neuse valley between Kinston and Goldsboro. We suggest that the source was basal coarse Wicomico sediments, which indicates that these sand bodies are pre-Wicomico surface.

Similar relations on a younger surface are found east of Hanna Creek where the sands overlie the Wicomico surface. The sands drape down a post Wicomico slope and are buried by the sediments in the flood plain (Figure 3 C-C'). They could be related to sedimentation during any time later than Wicomico.

Sands overlying Talbot sediments in the Neuse Valley near Goldsboro (Figure 2C) are truncated by the meander scar topography next to the Neuse River. The sand body in Figure 3, B-B', is older than the abandoned channel that truncates it but younger than the Talbot surface because it buries soils on this surface. Sands overlying the Talbot sediments are related to the development of the meander scar topography. The limited distribution of these sands indicates that the meander scar area has not been a favorable source.

North of Wilson, near Goldsboro and near Hanna Creek the eolian sands appear to be related to sedimentation or erosion and sedimentation on adjacent flood plains. The sands along Toisnot Swamp and Contentnea Creek south of highway 42 may have a different source. Figure 2B shows the typical relations between these eolian sands, topography, and surficial sediments. The sand bodies are linear, but they have 2 axes, one parallel to the trend of the valley wall and another normal to the wall. There is no apparent spatial relation between these sands and the Wicomico sediments or the lower terrace or flood plain in the Toisnot Valley. The sand body overlies the eroded edge of the Sunderland geomorphic surface as it does south of Dunn's crossroads (Figure 2A, B), but the adjacent slope grades to an ephemeral stream or drainageway rather than to a flat depositional surface such as the Wicomico or Talbot. The sands do not drape down this slope to a flat depositional surface. This indicates that the adjacent slope and possibly the narrow flood plain of the drain are the source of the sand. A small area of eolian sand about 1 mile west of Pink Hill, (Figure 1) has similar relations to drainages. Eolian sands associated with valley slopes near Dunn's crossroad can range in age from Pliocene to Recent and are not necessarily related to the major depositional periods.

Radiocarbon dates from organic materials at and below the contact of the eolian sands help but do not solve the age problem of these sands. A sample of buried peat and A1 horizon 11 feet below the surface of the Hanna Creek sands was dated at 29,300 + 1,400 - 1,000 years. The A1 horizon of a poorly drained soil 7 feet under the Toisnot Swamp sands was dated at 10,790 ± 240 years.[2] The Hanna Creek sands bury a weakly developed soil at the top of the Wicomico sediments. The soil under the Toisnot Swamp sands is strongly horizonated and is comparable to modern soils on the Sunderland surface (Nettleton, 1966). Before these radiocarbon dates can be accepted as giving a maximum age for the overlying sands it must be established that contamination with modern carbon has not altered, or made younger, the apparent age. These samples were not pretreated to remove contaminating material.

Olson and Brocker (1958) claim that a sample older than 100,000 years would have an apparent age of 37,000 years if contaminated by only 1 percent modern carbon. Possible sources of contamination for the Hanna Creek site are tree roots and soluble organic matter from the surface and the overlying Bh horizon. Tree roots were not seen in the sample but cannot be precluded because pine roots extend below 11 feet. Probably a more important source of possible contamination is the soluble organic matter from the surface and overlying Bh horizons.[3] The peat and A1 sample just below the eolian sand would be constantly bathed in this water-soluble organic matter. It is doubtful whether the organic matter from above could replace carbon in the structure of the peaty material, but it can be trapped in it and intermixed to some degree with the highly decomposed organic matter of the A1. Because a "dead" sample contaminated with 1- or 2- percent modern carbon could

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2 Dated by Isotopes, Incorporated.

3 Organic matter in the Bh horizon is slightly water soluble because wells in these Bh horizons are always "tea colored" regardless how long they are pumped (See Swanson and Palacas, 1965).

give a reading of 29,300 years, the Hanna Creek date must be considered as being influenced by contamination. The opportunity for contamination is there and is difficult to exclude unless wood samples give the same date. Even with wood samples it must be proven that they are buried aerial parts of a tree and not the tap roots of a contempory tree.

The Toisnot Swamp radiocarbon sample has a slightly different setting from the Hanna Creek sample. At Toisnot Swamp the buried A1 horizon is only 7 feet below the surface and root contamination of the sample is possible. There is no Bh horizon above the buried A1 and significant contamination from soluble organic matter should be slight. Roots were not seen in the Toisnot Swamp sample. But more important than some root contamination is that a sample with a true age of 40,000 years would require approximately 30 percent contamination by contemporary carbon to give an age of 10,000 years (Olson & Brocker, 1958). Olson and Brocker also claim that radiocarbon ages younger than 20,000 years are more likely to be correct than in error even without pretreatment. The Toisnot Swamp sample probably is very close to 10,700 years and it must be assumed that the overlying sand is that age or younger.

From the radiocarbon dates and stratigraphic and geomorphic relations, eolian sands seem to have two distinct places in the history of the Coastal Plain. Sands such as those near Dunn's crossroads, the large body southeast from Goldsboro (Figure 2A, C), and those at the Hanna Creek site probably are related to aggradation of the adjacent flood plain sometime during one of the major depositional periods. Other sand bodies such as those south of route 42 on the east side of Toisnot Swamp probably are related to very local conditions and deposition could have occurred at any time.

DEPOSITIONAL ENVIRONMENT

The abrupt thinning of sand bodies at their eastern edge and their lack of internal structure suggests that they were blown into standing vegetation. This is similar to the precipitation ridge described by Cooper (1958). This seems to negate the requirement of a drastic climatic change to have these sands deposited. Under current climatic conditions, sands blow readily each spring from flat areas and west-facing slopes that have been recently cultivated and left bare. Very little movement occurs where even a small amount of vegetation, soybean stubble for example, remains. Vegetation is one of the best methods of preventing soil erosion by wind (Chepil, 1945; Chepil and Woodruff, 1963) so it is safe to assume that eolian sands were blown from a bare or nearly bare source area.

Eolian sands associated with major depositional cycles, such as those on the Sunderland surface near Goldsboro, could easily have a bare source during aggradation of the adjacent flood plain (Figure 6A).

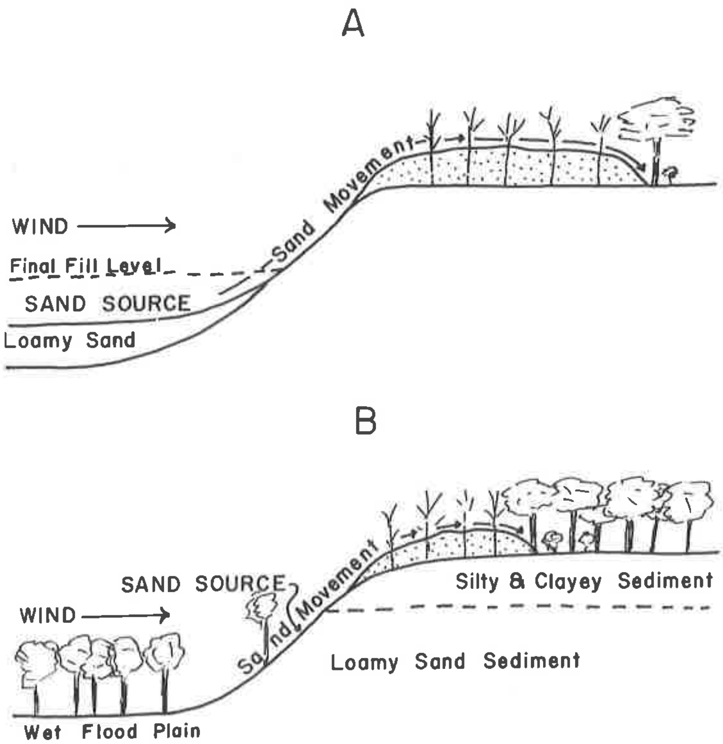

Figure 6. Eolian sands derived from: A. Source area adjacent flood plain during aggradation. B. Source area adjacent valley slope.

If the source area were limited as near Dunn's cross-roads (Figure 2A) the sands should form a narrow band oriented parallel to the source. The dominant wind direction could be from the west but growing vegetation and a limited supply would prevent movement very far from the source. At Goldsboro, the east-west extent of the Wicomico sediments during their deposition in the Neuse Valley was 10 to 15 miles. Westerly winds would have a large source area if the area was a flood plain. Sea level was about 95 feet when the Surry Scarp was cut (Daniels, et al., 1966) and the altitude of the Wicomico surface near Goldsboro is 95 feet or less. An estuary rather than a flood plain may have existed near Goldsboro during Wicomico time. This suggests that the source for the large sand body in this area could be bars or spits or a beach that furnished a large supply of sand. These bars and spits would almost be a point source. Either a large source area or supply would allow the sand to penetrate far into vegetation because once a critical depth is reached the vegetation would no longer inhibit sand movement.[4] It is possible that the large sand body near Goldsboro (Figure 2C) grew downwind by overwhelming vegetation and transporting sand across a thick bed of eolian sand. (See Cooper, 1967, plate 10). This suggests that the initial area of deposition was almost a point and that very little of the Neuse Valley was positioned correctly or in a condition to serve either as a source or a depositional area.

The Hanna Creek area is a different situation. The sands east of Hanna Creek are 0.1 to 0.5 mile east of the west valley wall that rises 80 feet above their base. This suggests that southwest winds would be less effective sand movers than west-northwest winds that have a sweep of two miles or more (See Four Oaks Quadrangle). For northwest winds to deposit the Hanna Creek sands, the source had to be a bar of Hanna Creek because northwest winds sweep largely the silty Wicomico surface and the sands overlie this surface (Figure 3, C-C'). Again we have the suggestion of a point source for the sands unless the winds were sweeping sands off bars on the east side of the creek and moving them downwind in only a slightly more easterly direction than this reach of Hanna Creek. The sand body truncated by the meander scar topography of the Neuse near Goldsboro (Figures 1, 2, 2, B-B) also suggests a northwest wind direction; one nearly parallel to the larger body to the north.

The small eolian sand bodies that are related to valley sides probably have a source area different from bodies associated with major depositional periods. An aggrading flood plain that was nearly free of vegetation could be a source but this seems unlikely because these sands are 1/2 mile or more from the flood plain, do not drape down onto the flood plain, and are aligned along drainageways (ephemeral streams). If the sands were related to an aggrading flood plain they should drape down the valley slope much as they do at the Hanna Creek site (Figure 3). About the only source area that is compatable with the areal distribution of these small sand bodies is the adjacent valley slope. The upper silty and clayey sediments of the surficial formations (Figure 6B) are difficult to erode by wind under most conditions (Chepil and Woodruff, 1963). If the flood plain is excluded as a source, the only remaining source for these sands is the coarse textured sediments in the lower part of the surficial formation. These sediments crop out in the middle or lower part of the slope and are the driest part of the landscape. The outcrop of coarse textured sediments on west-facing slopes would have the most xeric conditions in the area; wind exposure would be a maximum; they would have the highest temperatures with

4. Pines and other trees can have roots buried 4 to 5 feet providing oxygen is not shut off or limited and pressure from the surrounding material does not injure the cambium layer. Burial much greater than 5 or 10 feet usually results in death of the tree (oral communication, C. B. Davey, N. C. S. U., Raleigh, 1969).

the resultant great moisture stress on vegetation; and soils in the coarse basal sediments would have the lowest moisture-holding capacity and this would limit plant growth. Vegetation weakened by drought and probably fire could not prevent some sand movement because the west-facing slopes would be subject to the greatest wind drag. Once erosion began it would continue and extend to adjacent areas (Chepil, 1945) until vegetation was reestablished.

Sand bodies that have the basal coarse part of the surficial outcrop on valley slopes as a possible source area are narrow and discontinuous. This is reasonable because this source probably would not furnish large quantities of sand. Dry times or periods of climatic fluctuation would be the most likely time for valley sides to be source areas for eolian sands. But conditions can vary widely and it is unlikely that all such eolian sands were deposited at the same time. There is even little reason not to expect multiple deposition in places although we have no evidence of this in our area.

SUMMARY AND CONCLUSIONS

Eolian sands along the east sides of rivers or the east sides north-south reaches appear to have two major source areas. One source is the adjacent flood plain during periods of major sedimentation and another is bars, spits, or beaches of an estuary. Large bare sources areas are almost ruled out by the very limited distribution of the eolian sand. Limited distribution of the sands also argues that many conditions must be met before eolian sands are produced here.

The other source probably is the outcrop area of the coarse basal sediments of thé surficial formations on west-facing valley slopes. These areas would be subjected to the greatest wind drag and have the most xeric conditions on the local landscape. Drought, fire, climatic change, or any accident that weakens vegetation and bares the surface probably would initiate a period of sand deposition. Sands derived dominantly from valley sides can have a wide range in age depending primarily upon local rather than regional conditions. Because these sands overlie surfaces as old as Pliocene, it is possible for them to range in age from Pliocene to Recent.

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MIDDLE ORDOVICIAN STRATIGRAPHY IN CENTRAL SEQUATCHIE VALLEY, TENNESSEE

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ABSTRACT

Middle Ordovician strata of central Sequatchie Valley, Tennessee consist of the Pond Spring Formation, Murfreesboro Limestone, Ridley Limestone, Lebanon Limestone and Carters Limestone of the Stones River Group; and the Hermitage Formation, Cannon Limestone and Catheys Formation of the Nashville Group. The 1,350 foot thick sequence is predominately carbonate and is correlative to the Chickamauga Supergroup at Chickamauga, Georgia.

INTRODUCTION

Sequatchie Valley is in a key position between the well known stratigraphy of Central Tennessee and the undeciphered mixture of Valley and Ridge rocks. Middle Ordovician strata in Sequatchie Valley, Tennessee, are shelf carbonates containing only small amounts of terrigenous clastics and the rock sequence is divided into eight formations, which are correlated with strata in the Central Basin of Tennessee primarily upon lithologic characteristics.

Middle Ordovician strata in Sequatchie Valley have been studied by Butts (unpublished map) and correlated with strata in Central Tennessee by Bassler (1932) and Wilson (1949). The writer and James W. Smith have correlated Middle Ordovician strata at Chickamauga, Georgia, with those in Sequatchie Valley and Central Tennessee and have defined and described the Chickamauga Supergroup in its type area (Milici and Smith, 1969). Table 1 illustrates the development of Middle Ordovician stratigraphic nomenclature in Sequatchie Valley.

The purpose of this paper is to provide detailed lithostratigraphy in the Sequatchie Valley region in order to more precisely demonstrate regional correlations of Middle Ordovician strata between the Central Basin of Tennessee and the Valley and Ridge at Chickamauga, Georgia.

Table 1. Middle Ordovician Stratigraphic Nomenclature in Sequatchie Valley, Tennessee.

Butts (unpublished map)		Bassler (1932, p. 41-42)		Wilson (1949, p. 321)			This report
Catheys limestone		Catheys formation	Nashville Group	Catheys formation	Chickamauga Supergroup	Nashville Group	Catheys Formation
Flannagan Ch.		Cannon limestone		Cannon facies of the Bigby-Cannon limestone			Cannon Limestone
Curdsville limestone		Hermitage and Curdsville formations		Hermitage formation (including the Curdsville member)			Hermitage Formation
Lowville limestone		Lowville limestone	Stones River Group	Carters limestone		Stones River	Carters Limestone
Lebanon limestone	Stones River Group	Lebanon limestone		Lebanon limestone			Lebanon Limestone
Ridley limestone		Ridley limestone		Ridley limestone			Ridley Limestone
				Pierce limestone			
Mosheim limestone		Murfreesboro limestone		Murfreesboro limestone			Murfreesboro Limestone
							Pond Spring Formation

Acknowledgments

The writer is indebted to L. D. Harris and R. A. Laurence of the U. S. Geological Survey and E. T. Luther and S. W. Maher of the Tennessee Division of Geology for a critical review of the manuscript. C. W. Wilson, Jr. of Vanderbilt University, has at different times visited with the writer in the field and has discussed problems of Middle Ordovician stratigraphy with him.

STRATIGRAPHY

Middle Ordovician strata are exposed in gently rolling farm lands and woods in eastern Sequatchie Valley and there dip moderately to the southeast (15-25 degrees). In central Sequatchie Valley the sequence is 1,350 feet thick and is best exposed along both sides of Henson Creek, in immediately adjacent areas of the Henson Gap and Mount Airy quadrangles (Figures 1, 3) and in fields generally 1,000-3,000 feet northwest of Howard Cemetery (Figure 4).

Sequatchie Valley Middle Ordovician formations are divided into the Stones River and Nashville Groups (Wilson, 1949) and the Stones River and Nashville Groups were combined into the Chickamauga Supergroup at Chickamauga, Georgia (Milici and Smith, 1969). The

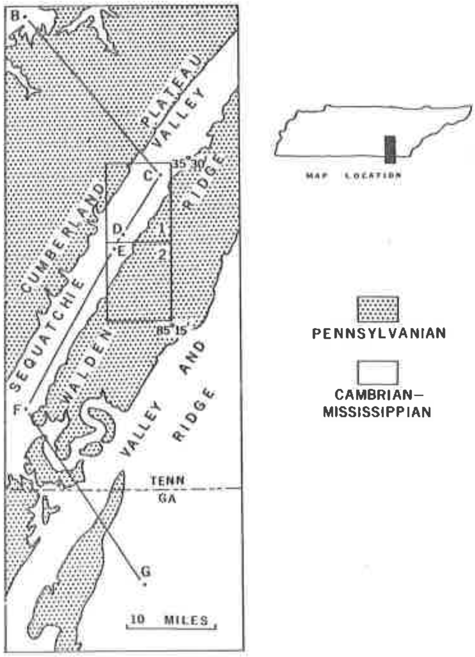

Figure 1. Location of Middle Ordovician sections in Sequatchie Valley and adjacent regions. Mount Airy quadrangle--1; Henson Gap quadrangle--2. Letters refer to sections in Figure 2.

Supergroup overlies the Knox Group (Cambrian and Ordovician) unconformably and in Sequatchie Valley is overlain by the Inman Formation (Upper Ordovician).

The Stones River Group consists of Pond Spring Formation (Milici and Smith, 1969), Murfreesboro Limestone, Ridley Limestone, Lebanon Limestone and Carters Limestone. The Nashville Group consists of the Hermitage Formation, Cannon Limestone and Catheys Formation. Stratigraphic nomenclature and history of usage have been described in earlier reports and need not be duplicated in detail here (Table 1). The reader is referred to the work of Wilson (1949) for the most comprehensive discussion of Middle Ordovician nomenclature, and to Milici and Smith (1969) for definition of the Pond Spring Formation.

Pond Spring Formation

The Pond Spring Formation (Wells Creek Dolomite of earlier Central Tennessee reports; lower member of the Murfreesboro Limestone of earlier Sequatchie Valley maps) is the basal deposit on the post-Knox unconformity in Sequatchie Valley. In Sequatchie Valley the Pond

Spring ranges from a few thin beds up to 150 feet thick. The wide range of thickness of the formation probably reflects relief on the post-Knox unconformity. Where observed in the Henson Gap and Mount Airy quadrangles the Pond Spring Formation is 15 feet thick or less; a basal unit is composed of fine-grained, yellowish gray weathering dolomite or calcarenite with angular pebbles or cobbles of chert and carbonate. The lower limestones and dolomites extend upward for 8 or 10 feet and grade into medium light-gray calcilutites which in places contain angular chert fragments. The lithology and thickness of the Pond Spring varies along strike and in some places in central Sequatchie Valley the Pond Spring contains grayish-red calcareous shales and mottled greenish-gray and grayish-red argillaceous limestones.

One of the best exposures of the post-Knox unconformity is found along the southeast bluff of the Sequatchie River about 1,000 feet northwest of Hall Church, Henson Gap quadrangle (Milici and Wedow, 1964). There local relief of about 15 feet and sedimentary features along the post-Knox karst terrain may be seen. At the Hall Church exposure basal Pond Spring beds are dolarenties that were apparently derived from weathering and reworking of upper Knox beds. The dolarenites grade laterally into pebble and cobble-bearing strata and upward into thick-bedded gray Murfreesboro calcilutite. The upper surface of the Knox is very irregular and in one place a pinnacle 10 feet high extends through the Pond Spring into the Murfreesboro.

Murfreesboro Limestone

The Murfreesboro Limestone consists of 450 feet of limestone and argillaceous limestone in central Sequatchie Valley. The exposure along Henson Creek is the most continuous exposure of the Murfreesboro in central and southern Sequatchie Valley, Tennessee, and there only about two-thirds of the formation can be seen.

The Murfreesboro Limestone is divided into four members in the Henson Creek section (Figures 2D, 2E, 3). The lower 73 feet is medium-light gray, generally thick-bedded calcilutite or calcisiltite (lower calcilutite member). The limestone appears to have little or no clastic material and is lithologically similar to the Mosheim Limestone of eastern Tennessee.

The lower calcilutite is overlain by 50 feet of generally thin-bedded light olive-gray argillaceous calcilutites (argillaceous member).

Overlying the argillaceous member are 225 to 230 feet of generally even-bedded, medium-light gray to medium-gray, thin to medium-bedded calcilutite and small amounts of argillaceous limestones (middle calcilutite member). The contact of the middle calcilutite member with the upper member of the formation is picked where generally even-bedded, relatively pure limestones are succeeded by fucoidal or splotchy limestone (for a discussion of fucoids see Wilson, 1949, p. 27-29, 36).

The upper member of the Murfreesboro consists of about 100 feet of medium-gray to medium-dark gray, commonly fucoidal calcilutite or calcisiltite with bedding 6-inches to 2-feet thick. The upper half of the member contains beds or lenses of medium-dark gray chert up to 3-inches thick (cherty fucoidal member).

In the Henson Creek section the contact between the Murfreesboro and Ridley is picked where fucoidal, cherty limestones are succeeded by very argillaceous, shaly-weathering limestones. The upper 100 feet of the Murfreesboro is more similar lithologically to overlying limestone of the Ridley than to limestones lower in the Murfreesboro. However, the prominent development of chert in the upper 50 feet of the Murfreesboro at Henson Creek is in the same stratigraphic position as cherts that mark the top of the Murfreesboro in Central Tennessee and in northwestern Georgia (Wilson, 1949; Bentall and Collins, 1945; Milici and Smith, 1969). Except for its upper member the Murfreesboro is characterized by even-bedded and even-textured limestones; in contrast Ridley limestones are poorly bedded, fucoidal or splotchy and to the writer's knowledge the Ridley contains no even-textured limestone.

Ridley Limestone

The Ridley Limestone in central Sequatchie Valley consists of 200 to 280 feet of limestone, argillaceous limestone and calcareous shale. The formation is readily divisible into three members: a lower limestone and argillaceous shaly limestone member, a middle argillaceous limestone member (Pierce Member) and an upper limestone member (Figures 2, 3, 4); the members persist throughout Sequatchie Valley and into northwestern Georgia (Milici and Smith, 1969).

The lower member of the Ridley is composed of 47 to 50 feet of very argillaceous, shaly-weathering, light olive-gray calcilutute to calcisiltite overlain by 23 to 40 feet of medium- to medium-dark gray or brownish-gray limestone. The total thickness of the member ranges between 70 and 90 feet, where measured.

The middle member of the Ridley at Henson Creek contains 26 to 36 feet of fossiliferous, argillaceous calcisiltite. Correlation of the middle member of the Ridley Limestone in this area with the Pierce Limestone of Central Tennessee has not been effected with certainty and will require detailed paleontologic studies. The tentative correlation of these beds in Sequatchie Valley with the Pierce is based on position in sequence and on correlations that Cooper (1956) made with similar beds at Chickamauga, Georgia.

The upper member of the Ridley Limestone consists of 91 to 150 feet of medium-light to medium-dark gray limestone. The beds are commonly fucoidal and are generally 6-inches to two-feet thick. Some thin beds (1- to 2-inches) are exposed in the Howard Cemetery section, and about 10 feet of light olive-gray, argillaceous, shaly-weathering

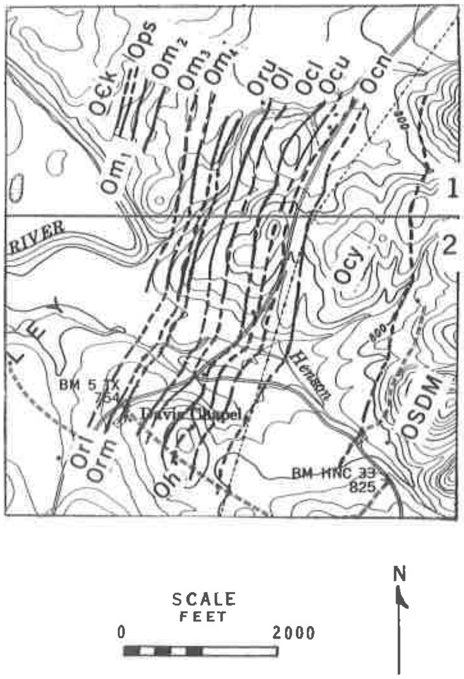

Figure 3. Geologic map of the Henson Creek section, Mount Airy and Henson Gap quadrangles. OЄk- Knox Group, Ops- Pond Spring Formation; Om_1- Murfreesboro Limestone, lower calcilutite; Om_2- Murfreesboro Limestone, argillaceous member; Om_3- Murfreesboro Limestone, middle calcilutite; Om_4- Murfreesboro Limestone, cherty fucoidal member; Orl- Ridley Limestone, lower member; Orm-Ridley Limestone, middle (Pierce) member; Oru- Ridley Limestone, upper member; Ol- Lebanon Limestone; Ocl- Carters Limestone, lower member; Ocu- Carters Limestone, upper member; Oh- Hermitage Formation; Ocn- Cannon Limestone facies of the Bigby-Cannon Limestone; Ocy- Catheys Limestone; OSDM- Upper Ordovician, Silurian, Devonian, and Mississippian strata.

calcilutites are found near the top of the formation near Davis Chapel (East Valley Baptist Church). The upper Ridley contains some fossiliferous beds, although fossils are generally sparse within the member.

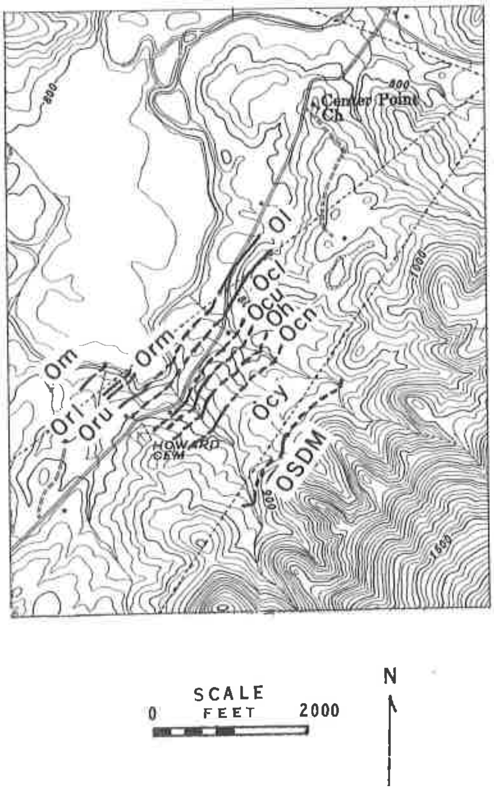

Figure 4. Geologic map of the Howard Cemetery section, Mount Airy quadrangle. Om- Murfreesboro Limestone; Orl- Ridley Limestone, lower member; Orm- Ridley Limestone, middle (Pierce) member; Oru- Ridley Limestone, upper member; Ol- Lebanon Limestone; Ocl- Carters Limestone, lower member; Ocu- Carters Limestone, upper member; Oh- Hermitage Formation Ocn- Cannon Limestone facies of the Bigby-Cannon Limestone; Ocy- Catheys Limestone; OSDM- Upper Ordovician, Silurian, Devonian, and Mississippian strata.

Lebanon Limestone

The Lebanon Limestone consists of 38 to 90 feet of thin-bedded fossiliferous limestones (Figures 2-4). Sowerbyella Jones and small branching bryozoans are common in the formation. The Lebanon is distinguished from the underlying Ridley and overlying Carters limestones chiefly by its bedding thickness (generally 1/4- to 2-inches) and by the irregular nature of Lebanon bedding surfaces.

The Lebanon is fucoidal, as are most other Stones River limestones (Wilson, 1949). Some beds are argillaceous and weather yellowish-gray. Shell hashes and intraclasts are common and the formation contains a higher proportion of calcarenite than the Ridley.

Carters Limestone

In Central Tennessee, Sequatchie Valley and at Chickamauga, Georgia, the Carters Limestone is divided into lower and upper members (Figures 2-4) separated by the T-3 bentonite (Wilson, 1949) and its underlying tabular chert. In central Sequatchie Valley the lower member is composed of 70 to 140 feet of fucoidal, medium light- to medium-gray limestone generally in beds 1- to 2-feet thick. Partings or thin beds of argillaceous limestone are common and some beds contain dark-gray chert in irregular layers 2 or 3-inches thick. Weathered limestone is medium-light to light gray and cherts weather yellowish brown.

The upper member of the Carters Limestone is composed of medium-gray argillaceous calcilutite or calcisiltite, generally in beds 1- to 6-inches thick. The light olive-gray or yellowish-gray color is characteristic of the weathered limestones. The member is generally unfossiliferous, although fossils are common in the chert below the T-3 bentonite. Some beds are shaly, some laminated, some mudcracked and some contain thin beds of intraclasts.

Bentonite T-4 and its underlying chert occur 9 to 13 feet from the top of the formation (measured from the chert bed). The T-4 chert is generally thinner than T-3 chert, presumably because the T-4 bentonite is not as thick as the T-3 clay. Although the bentonites are only poorly exposed, thicknesses of about 3 feet and 2 feet were inferred for T-3 and T-4 clays, respectively from the extent of covered intervals.

Hermitage Formation

The Hermitage Formation, the lowest formation of the Nashville Group, is composed of 60 to 70 feet of argillaceous medium-gray to medium dark gray or light olive gray calcilutites to calcarenites (Figures 2-4). The beds are 6-inches to 2-feet thick and commonly weather to a rubble of irregular limestone nodules. Silicified brachiopods, cup corals and gastropods are common. Hermitage limestones contrast markedly with the upper member of the Carters Limestone and the base of the Hermitage is picked at the first appearance of rubbly-weathering medium-gray limestone.

Because of its argillaceous nature, the Hermitage is generally poorly exposed. However, the formation is almost completely exposed in the Howard Cemetery section and its lower three-quarters is moderately well exposed near Henson Creek.

Cannon Limestone

The Cannon Limestone facies of the Bigby-Cannon Limestone (Wilson, 1949) consists of about 85 to 115 feet of medium-light gray to medium-dark gray calcilutite to calcarenite (Figures 2-4). Upper beds are slightly argillaceous and weathered surfaces have thin yellowish-gray layers or irregular splotches. Medium-dark gray to dark-gray chert occurs parallel to bedding as irregular masses up to 1-foot long and 6-inches thick near the top of the formation and in 1-inch balls and lenses in some limestones in the lower half of the formation. The formation is mostly well-bedded and in general beds range from 6-inches to 1-foot thick. Freshly broken rock commonly has a petroliferous odor.

A high-spired gastropod (cf. Hormotoma Salter) and a large pelecypod (cf. Cyrtodonta Billings) are diagnostic, although orthoconic cephalopods, brachiopods, bryozoans and corals are also present.

The Hermitage-Cannon contact is gradational and mapped where argillaceous nodular-weathering limestones give way to relatively pure limestones.

Catheys Formation

In central Sequatchie Valley the Catheys Formation is readily divisible into three members: a lower laminated argillaceous limestone member (laminated siltstone facies of Wilson, 1949); a middle fossiliferous limestone member; and an upper argillaceous limestone member. The formation is about 300 feet thick (Figures 2E & F, 3, 4).

The laminated siltstone member is 70 to 89 feet thick where measured in central Sequatchie Valley. The member is composed of argillaceous calcilutites and calcisiltites, with minor amounts of fine-grained calcarenites. The characteristic rock is laminated, with yellowish-gray-weathering argillaceous laminae and thin layers alternating with medium-gray beds (contour rock). Thin or medium beds are common. Some beds contain appreciable amounts of a green mineral (glauconite?), some are mudcracked, some exhibit ripple marks and some have medium-gray chert in irregular nodules up to 6-inches long and 2-inches across. Interbeds of medium-gray, fossiliferous limestones are similar lithologically to limestones of the middle member.

The middle fossiliferous limestone member is about 190 feet thick. The member is moderately well exposed along Henson Creek and the lower third of the member is exposed in the Howard Cemetery section. The member is composed of medium-light gray to medium-gray calcilutite to coarse-grained calcarenite in irregular beds generally 1- to 4-inches thick, with beds of medium-gray calcareous shale 1- to 2-inches thick.

The upper argillaceous limestone member is about 40 feet thick in the Henson Creek section and is 54 feet thick at Inman, Sequatchie quadrangle. The upper member is composed of medium-gray or greenish-gray, olive-gray weathering silty or argillaceous limestone. Beds are 2-inches to 1-foot thick and fossils are abundant.

The contact of the Catheys Formation with the Cannon Limestone in central Sequatchie Valley is drawn above the slightly argillaceous medium to thick beds of the upper Cannon and just beneath very thin or laminated beds of the Catheys. The Catheys-Inman contact is drawn above 1-inch to 1-foot beds with irregular surfaces and below very thin beds with smooth surfaces. The only known exposure of the Catheys-Inman contact is at the Inman section.

CONCLUSION

Middle Ordovician carbonate strata in central Sequatchie Valley, Tennessee, may be divided into units recognized in the Central Basin of Tennessee and at Chickamauga, Georgia. Total thickness of the strata varies little across the region and the sequence contains only a little more shale at Chickamauga, Georgia than in Central Tennessee and in Sequatchie Valley, Tennessee.

Stratigraphic boundaries or units most appropriate for long range correlation are: the Knox-Stones River contact; the upper cherty member of the Murfreesboro Limestone; the upper member of the Carters Limestone, with bentonites T-3 and T-4; and the Catheys Upper Ordovician contact.

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APPENDIX

Sections were hand-leveled with a clinometer, and measurements are considered accurate to within ± 10 to 15 percent of the thickness. Accuracy of thickness measurements is dependent upon the accuracy of the dip measurement and the care taken in leveling process. In general, measurements of thinner and better exposed formations are more accurate than measurements of thicker and less well exposed formations.

INMAN SECTION, SEQUATCHIE QUADRANGLE

Thickness (feet)	Description
	CATHEYS FORMATION, measured in road cuts on east side of East Valley Road at Inman bridge.
	Argillaceous limestone member.
54	CALCILUTITE to CALCARENITE, fine-grained, medium light- to medium-gray, some argillaceous and weathers greenish gray; beds generally 1- to 4-inches, even, irregular; very fossiliferous with abundant bryozoans and brachiopods; some beds with a green mineral (glauconite?).
	Middle member.
110	CALCILUTITE to CALCARENITE, fine-grained, medium gray, beds 1- to 4-inches, with partings and beds up to 2-inches of medium gray argillaceous limestone; with abundant bryozoan and brachiopod fossils.
27	INTERBEDDED, LIMESTONE as in 110 feet above, and CALCILUTITE to CALCISILTITE, greenish gray, in partings or beds up to 4-inches, even, irregular; weathers to light olive gray shaly limestone.

HENSON CREEK SECTION, HENSON GAP QUADRANGLE, FIGURE 3

Thickness (feet)	Description
	CATHEYS FORMATION, upper argillaceous member. Intermittently exposed in Henson Creek about 800 feet northwest of BM HNC 33 825.
40	CALCISILTITE, medium gray, weathers olive gray, silty or argillaceous, beds 2-inches to 1-foot, even, irregular.
	Middle member. Intermittently exposed in Henson Creek and adjacent fields up to 2000 feet northwest of BM HNC 33 825.
190	CALCISILTITE to CALCARENITE, coarse grained; medium

Thickness (feet)	Description
	gray, beds 1-inch to 1-foot, even, irregular, some argillaceous, some very fossiliferous, with abundant bryozoans and brachiopods.
	Laminated siltstone member; measured in Henson Creek and adjacent fields generally 2000 to 2300 feet northwest of BM HNC 33 825.
27	COVERED
43	CALCISILTITE to CALCARENITE, fine-grained, argillaceous, medium gray, weathers yellowish gray, beds 1- to 8-inches, even, irregular, some laminated; fossiliferous, with brachiopods, cephalopods; with some medium gray chert in irregular nodules up to 2-inches across and 6-inches long.
	CANNON LIMESTONE, measured in Henson Creek and adjacent fields 2000 to 2500 feet northeast of Davis Chapel.
79	CALCILUTITE to CALCARENITE, fine grained; medium- to medium dark-gray, beds 6-inches to 1-foot, even, irregular, with pelecypod (cf. Cyrtodonta) abundant near upper part of lower half together with cephalopods and gastropods (cf. Hormotoma). Upper 15 feet is slightly argillaceous and contains bryozoans, brachiopods, and medium gray chert in irregular nodules up to 2-inches across and 6 inches long.
40 est.	COVERED
	HERMITAGE FORMATION, measured in hollow 1300 feet east-northeast of Davis Chapel.
38	CALCILUTITE to CALCISILTITE, medium gray, generally argillaceous, beds 2-inches to 1-foot, even, irregular; weathers to rubbly outcrop; some beds contain small amounts of calcarenite, medium grained, medium light- to medium-gray; fossil cup corals are common in lower beds.
	CARTERS LIMESTONE, upper member, measured in fields about 1000 feet east of Davis Chapel.
32	CALCILUTITE to CALCISILTITE, medium gray, weathers yellowish gray, poorly exposed, beds 1- to 6-inches, even, irregular, some laminated, some with intraclasts; T-3 chert at base of member contains fossils; T-4 chert is about 9 feet from the top of the formation.
	Lower member, measured in fields generally 500 to 900 feet east-northeast of Davis Chapel.
70	CALCILUTITE to CALCARENITE, medium grained; medium light- to medium gray, beds generally 6-inches to 2-feet, even,

Thickness (feet)	Description
	irregular, fucoidal, with dolomitic or argillaceous splotches; some beds fossiliferous, with brachiopods and corals; some beds with irregular layers of medium-gray chert up to 1-inch thick.
	LEBANON LIMESTONE, measured in fields generally 300 to 500 feet east-northeast of Davis Chapel.
38	CALCISILTITE to CALCARENITE, coarse-grained; light- to medium-gray, fucoidal, bedding 1/4- to 4-inches; even, irregular, very fossiliferous with abundant brachiopods including Sowerbyella, and with a coquina bed at base.
	RIDLEY LIMESTONE, upper member, measured in fields 200 to 300 feet northeast of Davis Chapel.
3	CALCILUTITE to CALCARENITE, medium grained; light-to medium gray, poorly exposed, but thicker bedded than overlying Lebanon.
10	CALCILUTITE, very argillaceous, light olive gray, weathers to shale, yellowish gray, poorly exposed.
150	CALCILUTITE to CALCARENITE, medium grained; medium light- to medium-gray, some beds light olive gray, beds 1- to 2-feet, even, irregular, in part argillaceous with yellowish gray splotches, in part rubbly weathering.
	Middle member (Pierce), measured in cut on east side of East Valley Road, adjacent to west side of Davis Chapel.
26	CALCISILTITE, very argillaceous, medium gray or light olive gray, weathers to shale, yellowish gray beds generally 1-4- to 1/2-inch some up to 2-inches, even, irregular; fossiliferous with brachiopods (Sowerbyella ?).
	Lower member, measured along east cut of East Valley Road, generally 200 to 400 feet west and south of Davis Chapel.
40	CALCILUTITE to CALCARENITE, medium grained; medium dark gray or brownish gray, beds generally 1-inch to 1-foot, even, irregular, some argillaceous in lower part and weathers yellowish gray or olive gray.
50	CALCILUTITE to CALCISILTITE, very argillaceous, light olive gray, some medium gray, weathers to shale, yellowish gray, beds 1/2- to 2-inches, even, irregular, some with a few fossil brachiopods and bryozoans.
	MURFREESBORO LIMESTONE, cherty fucoidal member; pieced from exposures along East Valley Road 500 feet west-southwest of Davis Chapel and in fields near Sequatchie River about 2000 feet north-northeast of Davis Chapel.

Thickness (feet)	Description
100	CALCILUTITE to CALCISILTITE, medium- to medium dark gray, fucoidal, beds 1-inch to 2-feet, even, irregular, with medium dark gray chert lenses and nodules up to 3-inches across in upper half.
	Middle member.
2	CALCILUTITE to CALCISILTITE, medium dark gray, beds 2-inches to 1-foot, even, irregular, with abundant Maclurites?, silicified brachiopods and cephalopods.

HENSON CREEK SECTION, MOUNT AIRY QUADRANGLE, FIGURE 3

Measured from East Valley Road west to the Sequatchie River in woods and fields 1000 to 1500 feet north of south edge of quadrangle.

Thickness (feet)	Description
	HERMITAGE FORMATION
57	CALCILUTITE to CALCARENITE, medium grained; medium- to medium dark-gray, argillaceous, beds 6-inches to 1-foot, even, irregular, rubbly weathering, some beds with silicified brachiopods.
	CARTERS LIMESTONE, upper member.
39	CALCILUTITE to CALCISILTITE, medium gray; weathers light olive gray, beds 1/4- to 2-inches, even, irregular; some mud-cracked, some laminated, some with intraclasts. T-4 is about 10 feet from the top of the formation (measured to T-4 chert), and T-3 is at the base of member. T-3 chert contains silicified fossils.
	Lower member.
62	CALCILUTITE to CALCISILTITE, medium light gray, beds 1-inch to 1-foot, even, irregular, fucoidal.
68	COVERED
	LEBANON LIMESTONE
90	CALCILUTITE to CALCARENITE, medium grained; light- to medium-gray, beds generally 1/2- to 2-inches, some beds up to 4-inches thick; generally fucoidal, some fossiliferous, some with intraclasts.
	RIDLEY LIMESTONE, upper member.

Thickness (feet)	Description
91	CALCILUTITE to CALCISILTITE, medium- to medium dark-gray, with some calcarenite, light- to medium-gray, beds 1- to 6-inches, even, irregular, fucoidal, some fossiliferous.
	Middle member (Pierce).
36	CALCILUTITE to CALCISILTITE, argillaceous, medium gray, yellowish gray, light olive gray, poorly exposed, very fossiliferous with numerous brachiopods.
	Lower member.
23	CALCILUTITE to CALCARENITE, medium grained; medium dark gray, some argillaceous, light olive gray, beds 4-inches to 2-feet, even, irregular, with 1- to 2-inch beds near base.
47	CALCILUTITE to CALCISILTITE, medium gray, very argillaceous, weathers to shale, yellowish gray, light olive gray; some beds fossiliferous with bryozoans, brachiopods, low-spired gastropods.
	MURFREESBORO LIMESTONE, cherty fucoidal member.
33	CALCILUTITE, medium- to medium dark-gray, beds 6-inches to 2-feet, even, irregular, fucoidal; with medium dark gray chert in balls or irregular lenses up to 3-inches across.
100	COVERED
	Middle calcilutite.
166	CALCILUTITE, medium light-to medium-gray, beds 1-inch to 1-foot, even, irregular, intermittently exposed in woods.
	Argillaceous member.
50	CALCILUTITE, argillaceous, light olive gray beds 1- to 4-inches, even, irregular, intermittently exposed in woods.
	Lower calcilutite.
73	CALCILUTITE to CALCISILTITE, medium light gray, beds 6-inches to 2-feet, even, irregular.
	POND SPRING FORMATION
8	CALCISILTITE to CALCARENITE, some dolomitic, medium gray, weathers yellowish gray, beds 1-inch to 1-foot, with angular medium gray chert fragments up to 3-inches across.
	KNOX GROUP
10	DOLARENITE, fine-grained, medium light-gray, cherty, poorly exposed.

HOWARD CEMETERY SECTION, MOUNT AIRY QUADRANGLE, FIGURE 4

Thickness (feet)	Description
	CATHEYS FORMATION, middle member. Intermittently exposed along northeast side of branch, 1000-1500 feet east of Howard Cemetery.
63	CALCILUTITE to CALCARENITE, medium grained; medium light- to medium-gray, beds generally 1- to 4-inches; even, irregular, rubbly weathering; with interbeds of medium gray calcareous shale; very fossiliferous, with numerous bryozoans and brachiopods.
	Laminated siltstone member.
89	CALCILUTITE to CALCISILTITE, light gray, light olive gray, weathers yellowish gray, medium gray, some argillaceous, laminated (contour rock). Some beds with green mineral (glauconite?); some mudcracked, some ripple marked, some with intraclasts; with some zones of fossiliferous limestones as in 63 feet above; beds in laminae to 8-inches thick, even, irregular.
	CANNON LIMESTONE. Measured along northeast side of branch about 800 feet northeast of Howard Cemetery.
115	CALCILUTITE to CALCARENITE, coarse grained; medium light- to medium dark-gray, beds generally 6-inches to 1-foot, even, irregular; upper beds contain some yellowish gray splotches; some bedding surfaces contain gastropods and cephalopods. Medium dark- to dark-gray chert occurs in irregular masses up to 1- foot long and 6-inches across near top and in balls and lenses about 1-inch across about 70 feet below top of formation. Freshly broken rock emits a petroliferous odor. Some beds contain large ovoid clams (cf. Cyrtodonta).
	HERMITAGE FORMATION, measured along northeast side of branch about 700 feet northeast of Howard Cemetery.
66	CALCILUTITE to CALCARENITE, fine-grained, argillaceous, medium gray, weathers light olive gray, nodular weathering, beds 8-inches to 2-feet, even, irregular. Some beds have irregular lenses of recrystallized limestone. Silicified brachiopods occur 20 to 25 feet from the top, and cup corals and gastropods are near the base.
	CARTERS LIMESTONE, upper member measured along northeast side of branch about 650 feet northeast of Howard Cemetery.
39	CALCILUTITE to CALCISILTITE, medium gray, weathers light olive gray or yellowish gray, beds generally 1/4- to 6-inches, even, irregular; some laminated, some mudcracked, some with intraclasts, T-3 chert with silicified fossils. T-3 bentonite is at the base of the member, and T-4 bentonite is 13 feet below the top of the formation (measured to the chert).

Thickness (feet)	Description
	Lower member; measured in quarry on east side of road, 1000 feet northeast of Howard Cemetery and on northeast side of branch 1700 feet northeast of Howard Cemetery.
110	CALCILUTITE to CALCARENITE, fine-grained; medium gray, weathers medium light gray with yellowish gray dolomitic and argillaceous splotches and fucoids. Bedding is generally 1- to 2-feet, even, irregular; partings and thin beds up to 4-inches thick of argillaceous, shaly weathering limestone are common. Some beds contain dark gray chert in irregular layers 2- to 3-inches thick. A prominent zone of irregularly bedded chert is about 63 feet from the top of the member.
15	CALCILUTITE to CALCARENITE, fine-grained; medium gray, poorly exposed, beds generally 1- to 2-inches, fossiliferous; some are slightly argillaceous and weather yellowish gray.
15	CALCILUTITE to CALCARENITE, coarse-grained; medium gray, beds 1/2- to 4-inches, even, irregular.
	LEBANON LIMESTONE. Measured along east side of road 2500 to 2000 feet northeast of Howard Cemetery.
14	CALCILUTITE, light olive gray, slightly argillaceous, weathers yellowish gray, beds 1/4- to 2-inches, poorly exposed.
66	CALCILUTITE to CALCARENITE, coarse grained, medium light- to medium-gray, beds 1/4- to 6-inches, even, irregular, fucoidal, fossiliferous, with bryozoans, brachiopods, cystoid stems; some beds slightly argillaceous, weather yellowish gray.
	RIDLEY LIMESTONE, upper member. Measured in fields along south bank of Sequatchie River 800 to 200 feet northwest of Howard Cemetery.
96	CALCILUTITE to CALCARENITE, fine-grained, medium gray, generally fucoidal, beds 6-inches to 2-feet but with two 5-foot zones of 1- to 2-inch beds 25 and 35 feet below the top of the formation.
10	COVERED
15	CALCILUTITE to CALCISILTITE, medium gray, fucoidal, beds 1- to 6-inches, even, irregular.
	Middle member.
19	COVERED, but with float of slightly argillaceous light-olive gray fossiliferous limestone.
	Lower member.
10	CALCILUTITE to CALCISILTITE, medium gray, fucoidal, beds 6-inches to 1-foot, poorly exposed.
	COVERED.

MORPHOLOGY OF THE CONTINENTAL MARGIN OFF SOUTHEASTERN FLORIDA

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ABSTRACT

The morphology of the continental margin off southeastern Florida reflects the influence of four separate shaping processes; reef building during the Tertiary, deposition on the shelf in the then littoral zones of the Pleistocene, erosion by the Gulf Stream, and deposition and shaping by bottom currents.

INTRODUCTION

Bathymetric charts when used in conjunction with bottom samples and other geologic data can yield considerable information as to the origin of the morphology of the sea floor. The kind of bathymetric information available off the east coast of the United States is well illustrated by the chart of a segment of the continental margin off southeastern Florida shown in Figure 1. This chart was compiled by the writer from soundings from U. S. Coast and Geodetic Survey hydrographic surveys. A 4 meter interval was used on the shelf to a depth of 100 meters, and a 20 meter interval beyond that depth. Five physiographic provinces can be distinguished on the chart. They include the continental shelf, Florida-Hatteras Slope, Straits of Florida, Blake Plateau and the Bahama Banks (Little and Great Bahama Banks) (Figures 1 and 2).

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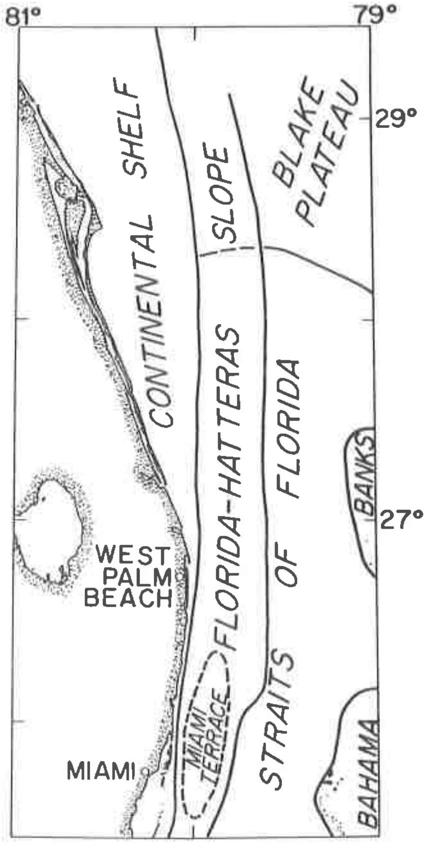

Figure 2. Physiographic provinces included within the bathymetric chart in Figure 1.

PHYSIOGRAPHIC PROVINCES

The continental shelf has its greatest development north of Cape Kennedy where it reaches a width of over 70 km. Off Miami where the Gulf Stream axis is located immediately offshore, the shelf is only 5 km wide. Morphologically the shelf can be divided into several zones; an inner smooth zone extending to a depth of about 16 meters, a ridge zone ranging from 16 to 40 meters, a smooth zone 40 to 60 meters deep, and a ridge zone between the 60 and 80 meter contours. The ridges, 16 to 40 meters deep, occur in a zone of the shelf blanketed by relict terrigenous sands containing appreciable quantities of shell debris. Similar features have also been reported from other segments of the continental shelf off the east coast of the United States by Uchupi (1968). He has suggested that most of the ridges represent offshore bars formed during lower stands of sea level during the Pleistocene. Uchupi (1968) has further suggested that some of the ridges may still be active at the present particularly during intense storms such as hurricanes.

The most striking topographic feature atop the shelf is a ridge or series of ridges located along the shelf's edge. These topographic features have been traced from Miami to as far north as Cape Hatteras, North Carolina (Zarudzki and Uchupi, 1968). In some areas the ridge or ridges are bordered on the landward or seaward side or both by depressions less than 5 meters deep. In places narrow channels several hundred meters wide and about 4 meters deep cut across the ridge complex. Pinnacles along the crest of the ridge rise as much as 10 meters above their surroundings. Off Cape Kennedy the ridge complex appears to consist of oolitic and pelletal limestone capped with coral debris (Macintyre and Milliman, 1968). South of West Palm Beach the ridges appear to contain more coral debris. All the segments of the ridge complex along the shelf's edge examined to date are inactive and are believed to be related to former lower stands of sea level during the Pleistocene (Macintyre and Milliman, 1968).

Beyond the shelf's edge is a smooth slope, 600-800 meters high with a gradient of less than one degree known as the Florida-Hatteras Slope. This topographic feature was apparently formed by sediments prograding in the direction of the Blake Plateau. Seismic profiles taken in the area reveal that progradation has exceeded 30 km in some places (Uchupi and Emery, 1967). Off Miami the Florida-Hatteras Slope is broken by the Miami Terrace. The ridge along the seaward edge of this terrace at a depth of about 400 meters is a coral reef active during the Miocene (Uchupi and Emery, 1967), with the terrace landward of the ridge being a depositional feature formed by sediment ponding behind the reef. The narrow shelf west of the terrace was formed later by sediment progradation over the lagoonal sediments in the direction of the reef.

Seaward of Miami Terrace is a narrow depression 800 meters deep running parallel to the slope and flanked on the seaward side by a broad ridge. Uchupi (1966) and Malloy and Hurley (1968) believe that this depression is a non-depositional feature and the ridge a depositional rise formed by bottom currents. Off Miami, in the center of the Straits of Florida, is a smooth plain dipping southward with a gradient of less than 1 minute (less than 1:1000). North of this plain a narrow trough less than 15 km wide can be traced northward to Lat. 28° 30'N (Figure 1). Along the center of this trough, beneath the axis of the Gulf Stream, a line of depressions 780 to 800 meters deep occurs. These hollows may have been formed by erosion by the Gulf Stream (Pratt, 1966). Sapping by submarine fresh water springs may also have played some role in the formation of these depressions (Manheim, 1967). Extending across some of the hollows, at right angles to the Gulf Stream axis, are ridges about 20 meters high. These ridges appear to represent sand waves formed under the influence of the Gulf Stream. Apparently these sand waves have partially filled some of the depressions suggesting that the hollows are not now being carved by the Gulf Stream, but were formed in the past. Uchupi (1967) has suggested that the depressions were carved during the Pleistocene when sea level may have been 200 meters lower than it is now.

The minor segment of the Blake Plateau shown in Figure 1 has an extremely irregular floor. Topographic irregularities are due to sand waves trending east-west superimposed on north-south depressions.

The easternmost province within Figure 1 is the Bahama Banks --Great and Little Bahama Banks. The tops of these topographic highs are less than 20 meters deep and topographically are very irregular with numerous islands or cays, sand ridges and small coral mounds rising above their general surroundings. The side slopes of the banks can be divided into two segments, a steep upper segment about 200 meters high that Newell (1959) believes was formed by coral reefs active during the Tertiary, and a lower, smoother, convex segment about 500-600 meters high that represents a depositional slope molded by bottom currents. Off Little Bahama Bank this lower slope is cut by numerous small ridges that may represent channel divides and/or sand waves. Some of the ridges can be traced to a depth of 200 meters.

ROLE OF FAULTING IN THE FORMATION OF THE MARGIN

Over the years numerous writers have suggested that the side slopes of the Straits of Florida, the channels indenting the Bahama Platform, and the Florida-Hatteras Slope are fault controlled (Jordan, Malloy and Kofoed, 1964; Kofoed and Malloy, 1965; Maher, 1965; Pressler, 1947; Talwani, Worzel and Ewing, 1960). Talwani, Worzel and Ewing (1960), for example, believe that the gravity anomaly pattern in the Bahamas (negative in the troughs and positive in the banks) stems from a combination of down faulting of relatively light material and the filling of the structural lows with light material. Hess (1960), on the other hand, has suggested that the present morphology of the Bahamas is due to: (1) formation of a trellis drainage system on gently folded sedimentary rocks, (2) brief rapid submergence that drowned the river valleys, (3) followed by slow submergence and upgrowth of reefs along the valley sides and the formation of lagoonal conditions behind the reefs. Seismic reflection (Uchupi, 1966, 1967; Emery and Uchupi, 1967) and seismic refraction studies (Sheridan, Drake, Nafe and Hennion, 1966, p. 1987) clearly demonstrate that the present relief of the Straits of Florida and the Blake Plateau has resulted from non-deposition and not faulting. Only south of the Florida Keys did Uchupi (1966) encounter any evidence of faulting. Geological studies also indicate that the northern coast of Cuba in part and probably some of the immediate offshore area north of Cuba are also fault controlled (Pressler, 1947). Possibly the rest of the side slopes of the Straits of Florida and the Florida-Hatteras Slope are also in some way related to structures that are too deep-seated to be observed by the seismic profiler. Data available to date, however, suggests that morphology of the continental margin off southeastern Florida as a whole can best be explained by sedimentary processes rather than faulting.

SUMMARY

A topographic chart of the continental margin off southeastern Florida displays in considerable detail the surface morphology of the margin. Topographic features on the chart are believed to be due to reef build up during the Tertiary, deposition on the shelf along former strand lines during the Pleistocene when sea level was lower than now, erosion by the Gulf Stream and deposition and shaping by bottom currents.

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