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Abstract

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J. R. Butler

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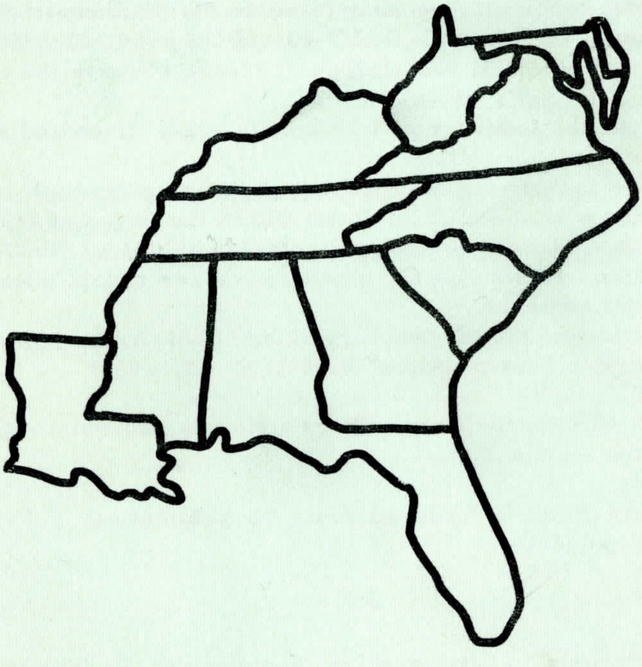

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SOUTHEASTERN GEOLOGY

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Vol. 4, No. 3

1963

PALEOCOLOGY OF THE PAMLICO FORMATION (LATE PLEISTOCENE); NIXONVILLE QUADRANGLE, HORRY COUNTY, SOUTH CAROLINA

by

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and

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ABSTRACT

The Pamlico Formation was deposited near to shore under non-marine, restricted marine, and shallow, open ocean conditions where slight fluctuations of sea level and other factors such as shifting currents, migration of barriers, etc. produced very sharp vertical and lateral facies changes.

From the observed distribution of macrofauna and microfauna, four marine environments are recognized: (1) inside intertidal, (2) shallow shelf, (3) lower bay (inlet influenced), and (4) upper bay (semirestricted).

Paleoecologic, stratigraphic, lithologic, and paleogeographic observations provide evidence that the Pamlico deposits are related to a low stand of the sea, higher than 10 feet and less than 40 feet above present sea level. Thus, it is suggested that the Pamlico Formation be correlated with the making of the Pamlico Shoreline (25-30 feet above present sea level).

Paleogeographic and subsurface studies indicate that the Pamlico Bay Shoreline was never located more than 5 to 7 miles inland from the present shoreline in Horry County.

During deposition of the Pamlico Formation, water depth was probably not more than 50 feet and generally much less; temperature of the water was probably slightly higher than that in the same latitude today; the water was usually not very turbid, but well oxygenated; and the salinity was variable. Inland from the bay and lagoon shores cypress swamps developed so that today nonmarine clays and peat beds interfinger with brackish-water deposits.

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INTRODUCTION

General Statement

A paleoecological analysis of the Pamlico Formation was undertaken with the hope that by accurately depicting the depositional environments of the deposits, it would be possible to more clearly understand the stratigraphic and age relationships of this Late Pleistocene formation. The Intracoastal Waterway was selected for study because it affords the best, thickest and most continuous exposures of fossiliferous marine Pamlico strata in the southeastern Atlantic Coastal Plain.

The area investigated is located in the Nixonville Quadrangle, Horry County, South Carolina (Figure 1).

Methods of Study

Field Work. Field study was done during the summers of 1959, 1960, and 1961. Approximately 60 fresh, unweathered samples were collected from 12 surface exposures. In addition, two shallow bore holes were drilled by a mobile auger and approximately 10 samples were collected at 5 to 8 foot vertical intervals.

Preparation of Samples. Approximately 100 grams of each unwashed sample were retained for a lithologic description of the sediment. The remaining sample fraction (approximately 5,000 grams) was washed through a set of #6 (3.360 mm.), #30 (0.590 mm.), and #200 (0.074 mm.) U. S. Standard sieves. Some samples were immersed in Varsol to aid in removal of particulate material smaller than approximately 0.062 mm. in diameter.

Faunal Analyses. Macrofaunal studies, predominantly of Mollusca, were made from the sample fractions caught on the #6 (3.360 mm.) and #30 (0.590 mm.) sieves. Every identifiable fossil in each sample was identified to species, or to genus.

Foraminiferal studies were made of 12 samples taken from the most critical surface sections. Foraminifers were retrieved from the residue caught on the #200 (0.074 mm.) U. S. Standard sieve. Foraminifera were separated from a dried 1 gram sample by floating in carbon tetrachloride and decanting the concentrate on filter paper. This procedure was repeated several times to insure removal of all specimens. Every foraminifer was picked from the float and an examination of the remaining residue was made to be certain that no specimens had remained in the sediment.

Identifications were aided by reference to the works of Bandy (1956, 1954), Cole (1931), Lankford (1959), Parker (1954), Phleger (1960, 1955, 1954, and 1951).

Sedimentary Analyses. Size distribution analyses were made of 22 samples from 3 critical surface sections. The samples, each of which weighed 100 grams, were shaken through a set of U. S. Standard sieves, consisting of a #5 (4.0 mm.), #10 (2.0 mm.), # 18 (1.0 mm.), #35 (0.50 mm.), #60 (0.25 mm.), #120 (0. 125mm.), and a #230 (0.062 mm.).

A cumulative-frequency curve was constructed on semi-logarithmic paper for each sample, and the Trask sorting coefficients were calculated according to the formula:

$$S_o \sqrt{\frac{Q_3}{Q_1}}$$

S_o = sorting coefficient, Q_3 = smaller quartile (75 per cent value), and Q_1 = larger quartile (25 per cent value).

Previous Work

Pugh (1905) made a study of Pleistocene deposits of South Carolina and listed 179 molluscan species collected from Pleistocene exposures at Simmons Bluff on Younges Island, South Carolina. He concluded that the Pamlico water temperature was the same or slightly warmer than now prevails off the coast of South Carolina.

Stephenson named the Pamlico Formation and Terrace in 1912 from Pamlico Sound, Pamlico County, North Carolina (Clark, et al, 1912).

Richards (1936) and Cooke (1937) correlated the Pamlico Formation and Terrace with the last major interglacial stage (Sangamonian), thus suggesting a genetic relationship between the 25-foot shoreline and the Pamlico Formation.

Cooke (1937) attempted to infer the sequence of late Pleistocene events from the sections studied near Myrtle Beach, South Carolina. Mansfield and MacNeil (1937) published a faunal list of Pliocene and Pleistocene mollusks collected from spoil piles along the Intracoastal Waterway in South Carolina; they included lithologic descriptions of a few sections near the spoil piles.

Flint (1942, 1940) presented evidence to show that the higher terraces recognized by Cooke were of fluvial origin. Flint recognized only two definite marine shorelines, the lower of which apparently corresponds to the Pamlico.

In 1952 David G. Frey made a pollen analysis of the Late Pleistocene "Horry Clay," a facies of the Pamlico, and a seaside peat deposit near Myrtle Beach, South Carolina. Frey concluded that the Myrtle Beach peat was deposited during the Wisconsin glacial stage along the eroding edge of the Pamlico Formation and that the "Horry Clay" was deposited during an interglacial age, presumably the early

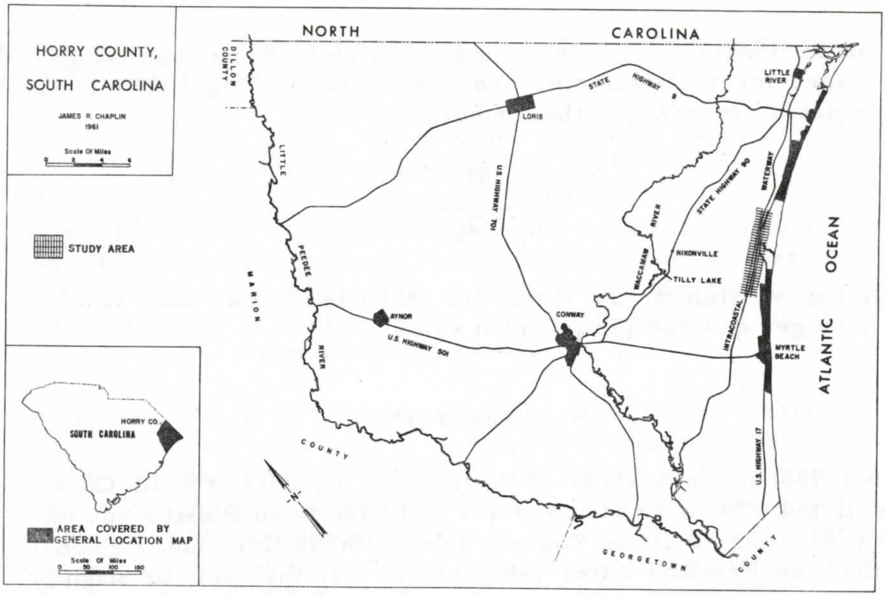

Figure 1. Horry County, South Carolina, showing area investigated for this report.

part of Sangamonian time, and followed by the deposition of the overlying marine Pamlico Formation.

Pleistocene shorelines and coastal terraces along the Atlantic Coast have been studied by several authors (Cooke, 1930, 1933, 1958; Flint, 1940, 1942; MacClintock and Richards, 1936; MacNeil, 1950; and Doering, 1960).

Richards (1959) stated that there is paleontological evidence of one shoreline (Pamlico) at an elevation of about 25 feet as well as physiographic evidence of a shoreline at about 90 feet (Wicomico) and both are regarded as Sangamonian in age. He also discussed the possibility of correlating Atlantic Coastal terraces with those of the Mediterranean.

Du Bar (1958) stated that the Fort Thompson and Anastasia formations in Florida (Wisconsinian in age) should be correlated with the formation of the 25-foot Pamlico Shoreline and are thus correlatives of the Pamlico Formation in the Carolinas.

Acknowledgments

Expenses related to the laboratory work, preparation of the manuscript, and field work were financed by the National Science Foundation in the form of a grant to J. R. Du Bar. Gratitude is expressed to James R. Solliday, University of Houston and to Hobard W. C. Furbunch who assisted with the field work. The authors are indebted to Robert Greenwood, University of Houston, for his suggestions and constructive criticisms. Special recognition is due Robert Lankford of Pan American Petroleum Corporation, Houston, Texas, who checked all foraminiferal identifications and willingly gave needed advice. John Wells, Cornell University, identified the corals and Allan Cheetham of Louisiana State University, identified the bryozoans, and both supplied ecologic data. Robert H. Parker of Scripps Institution of Oceanography, supplied valuable comments regarding the environments of some of the molluscan assemblages. Henry Johnson and LeBrun Smith of the South Carolina Development Board furnished a mobile auger and drilled the two shallow holes included in this study.

GEOLOGY OF AREA

Geomorphology

Physiographically, the area investigated is a part of the coastal terrace or "Low Country" of the South Carolina Coastal Plain. The present shoreline marks the seaward boundary of the marine coastal terraces. These terraces and their associated river valleys form the only significant topographic relief in the coastal plain region. The Pamlico Terrace, that land between the present shore and an abandoned shoreline approximately 25 feet above sea level, is the predominant physiographic feature in the study area.

The maximum elevation is approximately 50 feet above sea level, but only is characteristic of isolated Pleistocene beach ridges or dunes. Ancient beaches and swales between the beach ridges are revealed on topographic maps and aerial-photo mosaics. The area is also characterized by numerous marshes and swamps. Many of the swamps have an elliptical shape with their longer axes at right angles to the present shoreline and are known as Carolina Bays (Cooke, 1936, Prouty , 1952).

Drainage is in the youthful stage with numerous swamps in the interstream tracts and few large tributaries. The Waccamaw River is the only relatively large stream that drains this portion of the state. The Waccamaw River flows parallel to the coast in a southwestward direction and the water is generally stained brown by vegetable matter derived from the swamps through which the river flows. Evidence from the photomosaics and topographic maps suggests that the course of the Waccamaw River is controlled by the position of Pleistocene lagoons or bays that were drained when the sea level was lowered.

Regional Structure

The late Cretaceous and Eocene formations are the only deposits in the South Carolina Coastal Plain that are conspicuously deformed. These deposits constitute the southwest limb of the "Great Carolina Ridge" (Cooke, 1936), which is the dominant structural feature of the Carolina Coastal Plain. According to Cooke (1936) the "Great Carolina Ridge" or "Cape Fear Arch" as it is more commonly called, formed during the Eocene by a buckling of the earth's crust. Other authors such as Siple (1947) thought that the arch developed during the Cretaceous.

Thin patches of nearly horizontal marine Miocene formations and more extensive sheets of marine Pleistocene terrace deposits lie upon the beveled surface of the "Great Carolina Ridge."

Stratigraphy

The Peedee is the youngest Cretaceous formation of South Carolina, and the oldest formation exposed in Horry County (Figure 2). No exposures of this formation occur along the Intracoastal Waterway;

however, the Peedee has been penetrated in shallow bore holes near the Waterway, and reworked Cretaceous fossils are common in the Pamlico Formation.

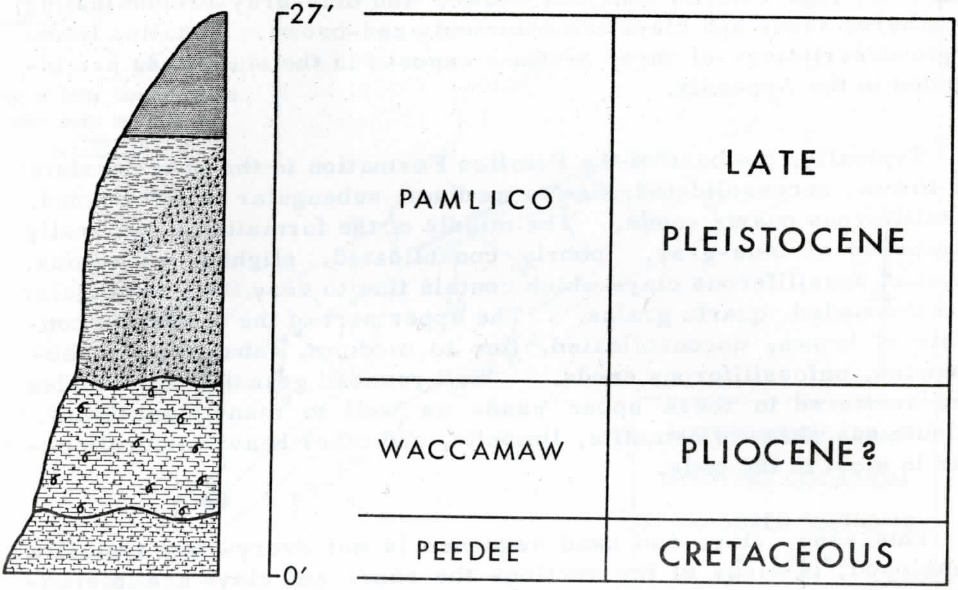

Figure 2. Generalized columnar section for Eastern Horry County, South Carolina.

The Peedee is unconformably overlain by the Waccamaw Formation, which is generally regarded as Pliocene in age. Recent studies by the senior author suggest the possibility that the Waccamaw is Pleistocene in age (Du Bar, 1959). In eastern Horry County the Waccamaw is a partially indurated, calcareous, argillaceous sand which is blue-gray where fresh, and red-brown where weathered. Generally, it contains a well preserved fauna which represents a deeper water environment than that of the overlying Pamlico.

The Waccamaw occurs as isolated erosional patches so that where it is missing, the Pamlico Formation lies directly on the Peedee. Where the Waccamaw is present, the contact with the overlying Pamlico is unconformable, but in some places the contact is difficult to place due to the great abundance of reworked Waccamaw fossils in the basal Pamlico deposits. The maximum thickness of the Waccamaw in this area is probably no more than 20 feet.

The Pamlico Formation consists of sands, clays, sandy clays, argillaceous sands, and silty clays. Most of the beds are soft, unconsolidated, and moderately to abundantly fossiliferous. Some of the upper sands are, however, unfossiliferous. Fresh exposures are generally light colored with tan, brown, and blue-gray predominating; weathered sands and clays are commonly red-brown. Detailed lithologic descriptions of three sections exposed in the study area are included in the Appendix.

Typically, the base of the Pamlico Formation in the area consists of brown, unconsolidated, fine to medium, subangular to subrounded, fossiliferous quartz sands. The middle of the formation is generally composed of blue-gray, poorly consolidated, slightly micaceous, plastic, fossiliferous clays which contain fine to very fine, subangular to subrounded, quartz grains. The upper part of the formation consists of brown, unconsolidated, fine to medium, subangular to subrounded, unfossiliferous sands. Well rounded granules and pebbles are scattered in these upper sands as well as many plant fibers. Minute quantities of hematite, limonite, and other heavy minerals occur in most of the beds.

This sand, clay, and sand sequence is not everywhere typically developed; in many of the sections the sands and clays are intercalated and gradational both vertically and laterally. The clays generally contain some sand and the sands may contain enough argillaceous material to make them sticky and coherent.

The average of the sorting coefficients for 22 Pamlico samples is 1.715. The sediments grade laterally from coarse on the southwest to finer on the northeast. To the northeast, toward Little River, the sediments generally consist of sandy clays, silty clays, clays, and fine to very fine quartz sands. To the southwest, toward Myrtle Beach, the sediments are characterized by fine to medium quartz sands interbedded with some clay.

The average median diameter of sediment samples at station 20 (Figure 3) is 0.312 mm. whereas at station 52, approximately 3.8 miles to the northeast (Figure 3), the average median diameter of the sediment samples is 0.136 mm.

There is a slight decrease in the sorting coefficient to the northeast, indicating somewhat better sorting of sediment samples.

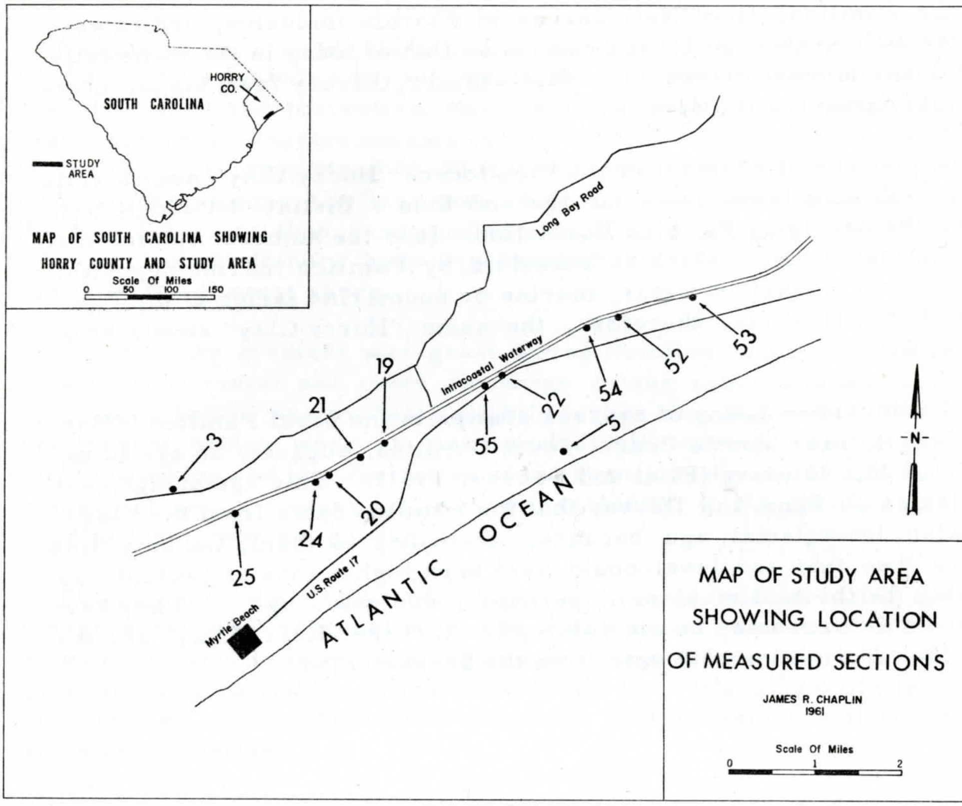

Figure 3. Location of measured sections.

The top of the Pamlico Formation nearly everywhere lies less than 50 feet above sea level. The maximum thickness of the formation, as indicated by well logs in South Carolina, is approximately 60 feet; however, in exposures, the Pamlico varies in thickness from approximately 5 to 15 feet.

The Pamlico Formation and correlatives have been mapped from Delaware to southern Florida and in all states between New Jersey and Florida, and they contain marine fossils below an elevation of 20 feet.

According to the "glacial control" hypothesis the glacial stages were times of low sea level and the interglacial stages were times of high sea level. Pleistocene marine deposits found above sea level south of the terminal moraine are most logically interpreted as interglacial provided there has been no significant movement of the land.

According to Richards (1936, p. 1644, and 1959, p. 13), the fauna of the Pamlico, from New Jersey to Florida inclusive, indicates a water temperature at least as warm as that of today in the same latitudes and in most places somewhat warmer, thereby favoring an interglacial dating for the deposit.

Cooke (1937) considered the Pleistocene "Horry Clay" near Myrtle Beach to date from a glacial age and thus a distinct lithologic unit from the overlying Pamlico Formation. It is the authors' opinion that the "Horry Clay," which is underlain by Pamlico marine deposits, represents a shallow water, marine or nonmarine facies of the Pamlico Formation and, therefore, the name "Horry Clay" should be abandoned.

Radiocarbon dating of cypress stumps in the basal Pamlico ("Horry Clay"), near Myrtle Beach, South Carolina, suggests an age in excess of 20,000 years (Flint and Deevey, 1951). This age assignment indicates to Flint and Deevey that the Pamlico dates from the Sangamonian interglacial age because, according to them, the only time since then that sea level could have been higher than at present was during the thermal maximum, perhaps 7,000 years ago. They have based this reasoning on the assumption that the "Horry Clay" and the Pamlico Formation both date from the Sangamonian.

PALEOECOLOGY

General Observations

Paleoecological interpretation has been based on faunal and sedimentary analyses. Special attention was given to the large molluscan assemblages, but other macrofossils and foraminifers were considered carefully. Excellent ecologic control is afforded because most of the Pamlico species are extant in the western Atlantic Ocean and the Gulf of Mexico. Available ecologic data related to important Pamlico molluscan species is summarized in table form (Table 1). This information has been gleaned from the authors' observations, from the literature, and from discussion with ecologists.

Particularly useful in the compilation of ecologic data were the works of Abbott (1948), Bandy (1954, 1956), Bandy and Arnal (1960), Du Bar (1958), Gardner (1948), Lankford (1959), Mansfield (1930, 1932), Olsson and Harbison (1953), F. L. Parker (1954), R.H. Parker (1956, 1959, 1960), Phleger (1954, 1955, 1960), and Phleger and Parker (1951).

Results of the present studies show that the Pamlico Formation in the area investigated was deposited near to shore under marine, brackish-water and terrestrial environments during an interglacial transgressive-regressive marine cycle. At maximum transgression the sea level probably stood 25-30 feet higher than at present and thus, water depth was generally less than 30 feet. The bay-lagoon shoreline was not more than seven miles inland from the present shore, and a series of offshore bars developed approximately at or just inland from the present shore.

The salinity gradient was great during Pamlico deposition due to the effects of runoff and river discharge during rainy seasons, and water temperature was probably slightly higher than at present. Wave and current action were at least periodically strong, resulting in much reworking and transportation of the Pamlico organisms and older assemblages. Generally, however, turbidity, in the open marine areas at least, was not great.

The complex of nearshore environments, which existed during the transgression and regression of the Pamlico Sea, is recorded as a series of intricately interfingering and overlapping facies. It is difficult, if not impossible, to trace individual beds laterally more than a few feet or yards; therefore, members in the conventional sense cannot be delineated.

Present paleoecologic analysis permits recognition in each studied section of the facies marking maximum Pamlico transgression. Assuming that transgression was due to a eustatic rise in sea level, maximum transgression would have been reached everywhere in the area at essentially the same time. Connection of the points representing maximum transgression in each section permits recognition of a valid time plane and delineation of the transgressive and the regressive units of the marine cycle.

The authors have constructed cross sections of the Intracoastal Waterway exposures showing facies relationships and the transgressive and regressive divisions (Figures 4, 5, and 6). The transgressive and regressive units are plotted with maximum transgression as the datum (Figure 6), and also with the canal water level as the datum (Figure 5). In the latter illustration four units are indicated:

(1) Upper regressive
(2) Lower regressive
(3) Upper transgressive
(4) Lower transgressive

Table 1. Ecologic Data for Some of the Typical Pamlico Molluscan Species

Species	Ecologic Notes
Pelecypoda	
Abra aequalis (Say)	North Carolina to Texas and West Indies. Low tide to 13 fms., typical of open bay and sound center assemblages of northern Gulf of Mexico. Salinity range 23 to 43 parts; temperature range 9 to 33° C. Sand, silty sand, clayey sand substrates.
Anadara brasiliana Lamarck	North Carolina to West Florida to Texas and West Texas. Pass, intertidal beach, and shallow shelf; optimum--near beach on shallow shelf.
Anadara transversa (Say)	South Cape Cod to Florida and Texas. Polyhaline bays to more than 12 fms. on shelf; optimum--shelf mud, sandy mud, shelf and sand substrates. Salinity range 23 to 42 parts; temperature range 9 to 33° C.
Anomia simplex d'Orbigny	Cape Cord to Florida, Gulf of Mexico and West Indies. Open high salinity bay and sound centers to outer shelf; optimum--shelf on hard bottoms. Salinity range 5 to 42 parts; temperature range 4 to 34° C.
Brachiodontes exustus Linné	North Carolina to West Indies, high salinity shell reef; optimum--bay and intertidal areas.
Caryocorbula contracta Say	Cape Cord to Florida and West Indies. Open high salinity bays and sound centers, and shelf to 63 fms.
Chione cancellata (Linné)	North Carolina to Florida, Texas, and West Indies. Open high salinity bays and sound margins, inlets and shallow shelf. Sand and silty sand substrates; salinity range 23 to 69 parts; temperature range 9 to 36°C.
Crassinella lunulata Conrad	North Carolina, Florida and West Indies. Restricted inlet to shelf; optimum --shelf. Depth range to 540 fms.; salinity range 30 to 40 parts; temperature range 9 to 30°C.
Crassostrea virginica (Gmelin)	Gulf of St. Lawrence to Gulf of Mexico and West Indies. Restricted bays, estuaries and lagoons where salinity ranges from 10 to 30 parts and where water temperature remains permanently above 20°C.
Cyrtopleura costata (Linné)	Massachusetts to Florida, Texas and West Indies to Brazil. Lives in high salinity bays and in shallow water just offshore; usually mud or sandy mud substrate. Minimum temperature about 35° F; salinity range 23 to 69 parts.
Dinocardium robustum (Solander)	Virginia to South Florida, Texas and Mexico. Inlet and shallow shelf to 11 fms. Sand and shell substrate; temperature range 10 to 34°C; salinity range 11 to 36 parts.
Donax variabilis Say	Virginia to South Florida and Texas. Inlet to shallow shelf; typical beach species.
Dosinia elegans (Conrad)	West Florida to Texas and South. Beach to shallow shelf; optimum--sand just below low tide.
Ensis directus Conrad	Gulf of St. Lawrence to Florida. Enclosed bays, variable low to intermediate salinity. Silty clay, sand and silt substrates; weak currents; salinity range 3 to 40 parts; temperature range 10 to 34° C.
Ervillia concentrica Gould	North Carolina to both sides of Florida and West Indies. Sand and silty sand substrates; weak currents. Salinity range 23 to 69 parts; temperature range 9 to 36° C. Open high salinity bay and sound margins and shelf.
Gemma magna Dall	Loose sands of intertidal flats.

Table 1. Ecologic Data for Some of the Typical Pamlico Molluscan Species - Contd.

Species	Ecologic Notes
Pelecypoda	
Glycymeris pectinata (Gmelin)	North Carolina, Florida and Texas. 15 to 63 fms.
Labiosa plicatella Lamarck	North Carolina to Florida, Texas and West Indies. Pass, beach and shallow shelf where chlorinity is not less than 14 pts.
Mercenaria campechiensis (Gmelin)	Chesapeake Bay to Florida, Texas, and Cuba. Bay to shallow shelf. Salinity range 15 to 69 parts; temperature range 9 to 36°C. Typical of open bay and sound margin assemblages.
Mulinia lateralis Say	Canada to Mexico. Bay to shallow shelf (0-12 fms.). Extremely euryhaline (nearly fresh to hypersaline). Substrate mud, sand, silt and shell.
Noetia ponderosa (Say)	Cape Cod, Florida and Texas. Open, high salinity bays and sound centers to outer shelf; optimum--shelf. Salinity range 23 to 40 parts; temperature to 33° C.
Nucula proxima Say	Nova Scotia to Florida and Texas. On shelf to 100 fms.; common just offshore in mud.
Phacoides amiantus (Dall)	North Carolina to both sides of Florida Sound to 640 fms.; optimum-pass to 12 fms. Temperature range 10 to 34° C. Salinity range 11 to 36 parts; sandy, shelly sand substrates.
Phacoides multilineatus (Tuomey & Holmes)	North Carolina to Florida. Bay to 120 fms.; optimum--shallow shelf to 11 fms. Most common on a sandy substrate.
Semele proficua Pulteney	North Carolina to south half of Florida and West Indies. Open high salinity bays and sound margins; moderately common in shallow water on sand and silty sand bottoms. Temperature range 9 to 36°C.
Spisula similis (Say)	Nova Scotia to South Carolina, Florida and Gulf of Mexico. Shallow continental shelf of Gulf of Mexico (0 to 12 fms.) Chlorinity above 14 or 17 parts.
Tagelus plebeius Solander	Cape Cod to South Florida, the Gulf States to Brazil. Enclosed bay in shallow water, common on the inside intertidal areas. Variable low to intermediate salinity. Found in argillaceous, sand or sandy clay substrates.
Tellina alternata Say	North Carolina, Florida and Gulf States. Inlet influence to 10 fms. On shallow shelf. Salinity range 30 to 40 parts; sand substrate.
Gastropoda	
Bittium varium Pfeiffer	Maryland to Florida, Texas and Mexico. Common in eel grass just below low tide; associated with Crassostrea virginica reefs; on open shelf to 8 ft. Found in soft mud, shell, sandy mud and sand substrates. Salinity range 0 to 36 parts.
Busycon contrarium (Conrad)	South Carolina, Florida and Gulf States. Inlets to shallow shelf (3 to 30 feet). Sand and shell substrate temperature range 9 to 30°C; salinity range 30 to 40 parts.
Cantharus tinctus Conrad	North Carolina, Florida, and West Indies. Shallow grassy, high salinity bays; sand and shelly sand substrates.
Crepidula fornicata Linné	Canada, Florida and Gulf States. Passes to shelf (10 fms.); salinity range 30 to 40 parts. Temperature range 9 to 40° C.

Table 1. Ecologic Data for Some of the Typical Pamlico Molluscan Species - Contd.

Species	Ecologic Notes
Gastropoda	
Crepidula plana Say	Canada to Florida and Gulf States. Bay to shallow shelf (0-12 fms.); optimum--shallow shelf. Occurs on mud, shell, sand and muddy sand substrates.
Mitrella lunata Say	Cape Fear, North Carolina to Florida; Bay to pass on all types of substrates. Typical of high salinity oyster reefs near inlets.
Nassarius obsoletus Say	Gulf of St. Lawrence to Florida and Texas. Common on intertidal mud flats.
Nassarius vibex Say	Cape Cod to Florida, Gulf States and West Indies. Typical of open sound or lagoon margins, but lives on shelf to 8 fms. Mud and sand substrates.
Odostomia impressa Say	Massachusetts to Mexico. High salinity, shell reef; common in shallow water.
Odostomia seminuda C. B. Adams	Nova Scotia to Gulf of Mexico. Beach to 12 fms. Optimum--shallow shelf.
Oliva sayana Ravenel	North Carolina to Florida, and Gulf States. Sand and muddy sand substrates; chlorinity above 17 parts. Passes to shallow shelf; common in surf zone.
Olivella mutica (Say)	North Carolina to Florida, Texas and West Indies. Sandy, silty clay, shell substrates. Bay to 10 fms; optimum--passes.
Polinices duplicatus Say	Cape Cod to Florida and Gulf States. Bay to 15 fms.; optimum--pass to shelf. Temperature range 9 to 30°C; sand substrate. Burrows into sand.
Retusa canaliculata Say	Nova Scotia to Florida and West Indies. Enclosed bays and shelf. Salinity range 20 to 39 parts; temperature range 8 to 36°C.
Seila adamsi H. C. Lea	Massachusetts to Florida, Texas and West Indies. Bay to shallow shelf (4 fms.). Occurs associated with Crassostrea virginica reefs in Texas bays. Temperature range 4 to 34°C; salinity range 5 to 41 parts.
Tectonatica pusilla (Say)	Cape Cod to Florida, Gulf States and West Indies, Pass to 18 fms.; Optimum--pass to 11 fms. on shallow shelf.
Terebra dislocata Say	Virginia to Florida, Texas and West Indies. Inlet to near beach.
Turbonilla interrupta Totten	Casco Bay, Maine to West Indies. Inlet influence to 110 fms.; sandy substrate.
Urosalpinx cinerea Say	Nova Scotia to South Florida. Intertidal to 4 fathoms.

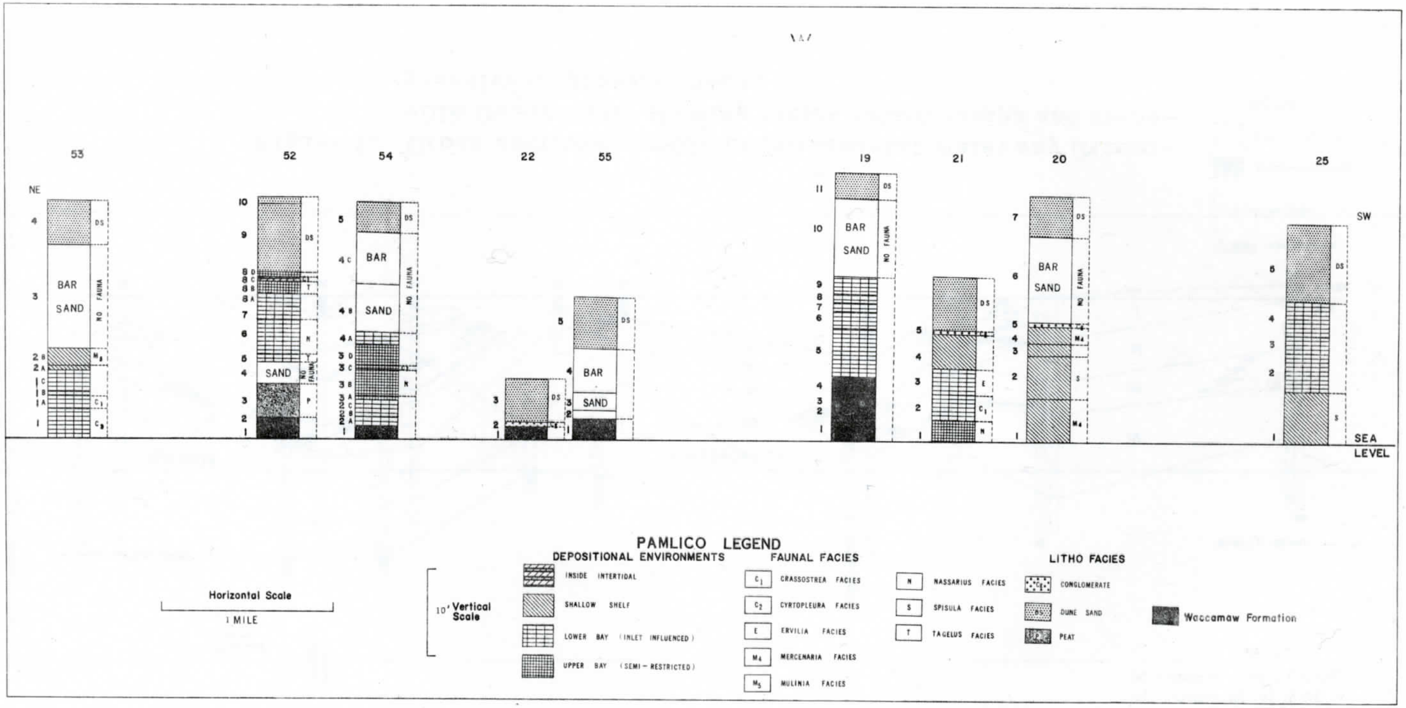

Figure 4. Measured sections along the Intracoastal Waterway (Nixonville Quadrangle) showing Pamlico depositional environments and facies.

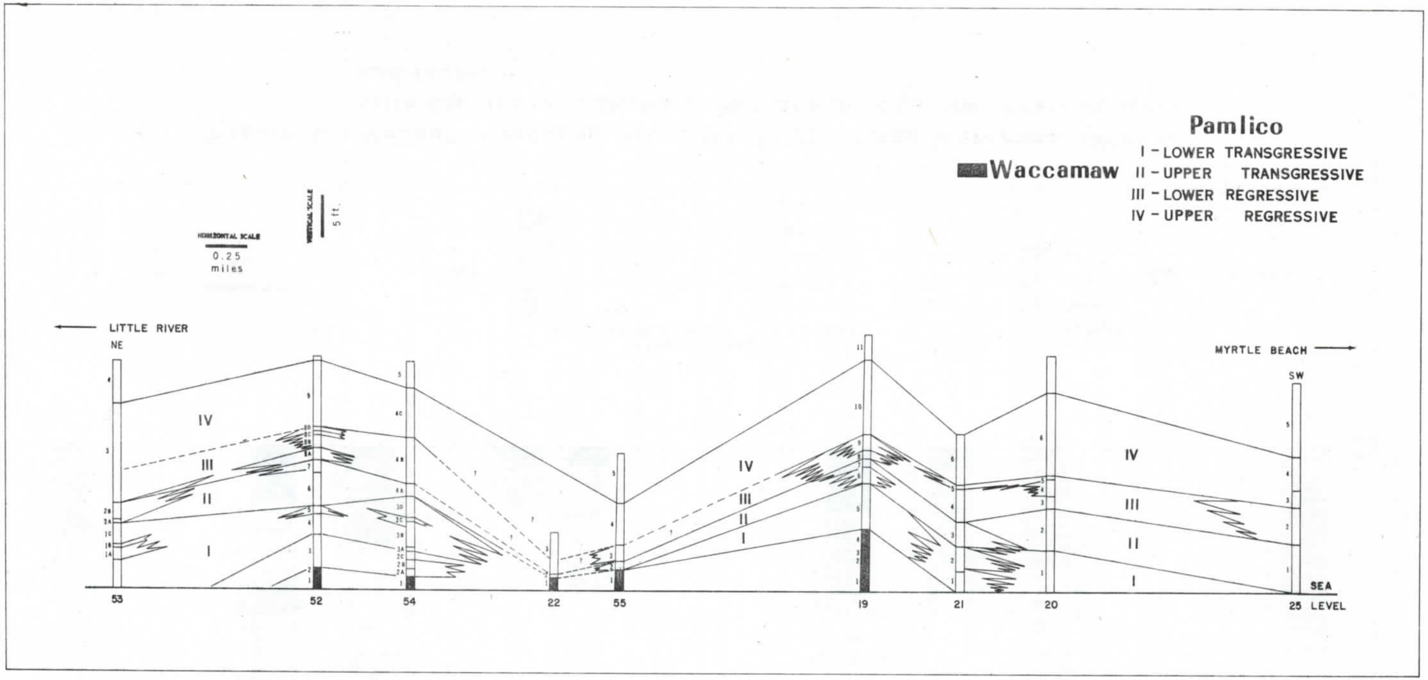

Figure 5. Cross sectional profile of Intracoastal Waterway (Nixonville Quadrangle) showing facies relationships and transgressive-regressive units.

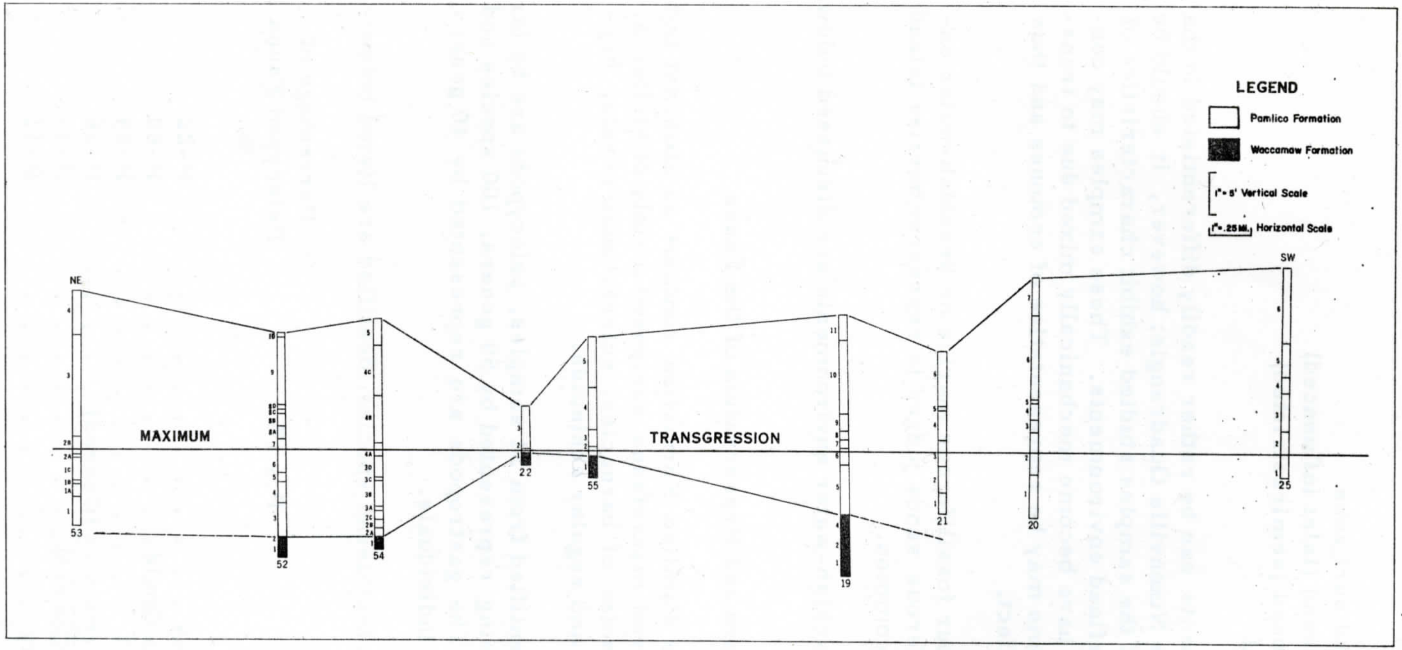

Figure 6. Cross section along Intracoastal Waterway (Nixon-ville Quadrangle) drawn with maximum Pamlico transgression as a datum plane.

A relatively simple fourfold classification of Pamlico marine environments is proposed:

(1) Shallow shelf and surf zone
(2) Lower bay or sound (inlet influenced)
(3) Upper bay or sound (semirestricted)
(4) Inside intertidal

The four environments can be rather readily differentiated in the Pamlico deposits of the Nixonville Quadrangle; however, it should be mentioned that some of the samples studied exhibit characteristics of more than one of the defined environments. These samples may contain assemblages that have become mechanically mixed due to transportation; however, some may be representative of ecotones and thus record an edge zone effect.

In addition to the four fossiliferous marine or brackish-water environments, unfossiliferous sands judged to represent barrier island and dune deposits are common.

The marine and brackish-water environments are discussed below.

Nature and Preservation of the Fauna

Macrofauna. The Pamlico Formation contains an abundant and generally well preserved macrofauna composed mainly of Mollusca, but includes some species of barnacles, scleractinian corals, bryozoans, and irregular and regular echinoids.

Of the mollusks identified from 31 samples, pelecypods are by far the most abundant, being represented by 59 genera, 100 species and 43,794 individuals. The gastropods are represented by 40 genera, 74 species and 13,883 individuals.

The most abundant molluscan species identified are listed below:

Pelecypoda	P = 1%	Percentage of Pelecypod Fauna %
Donax variabilis Say		P-22
Ervilia concentrica Gould.		P-80
Gemma magna Dall		P-89
Mercenaria campechiensis (Conrad)		P-36
Mulinia lateralis (Conrad).		P-97
Nucula proxima Say		P-11

TABLE 3. CHECK LIST OF MACROFAUNA

PHYLUM MOLLUSCA
CLASS PELECYPODA

Abra aequalis Say
Anadara brasiliana (Lamarck)
Anadara ovalis (Bruguière)
Anadara transversa (Say)
Anisodonta americana Dall
Anomia simplex d'Orbigny
Arca umbonata Lamarck
Astarte sp.
Brachiodontes exustus Linné
Brachiodontes sp.
Callocardia (Agriopoma) sp.
Cardita (Carditamera) arata (Conrad)
Cardita granulata Say
Cardita perplana Conrad
Cardita tridentata Say
Caryocorbula sp. cf. C. barrattiana (Mansfield)
Caryocorbula contracta (Say)
Chama sp. cf. C. congregata Conrad
Chama gardnerae Olsson and Harbison
Chama sp.
Chione cancellata Linné
Chione grus Holmes
Chione latilirata (Conrad)
Chione sp.
Chlamys (Plagioctenium) solarioides (Heilprin)
Chlamys sp.
Corbicula densata (Conrad)
Crassinella dupliniana Dall
Crassinella lunulata (Conrad)
Crassinella nansemondensis Gardner?
Crassostrea virginica (Gmelin)
Crenella sp.
Cumingia tellinoides Conrad
Cyrtopleura (Scobinopholas) costata (Linné)
Dinocardium robustum (Solander)
Diplodonta caloosaensis Dall
Divaricella quadrisulcata (d'Orbigny)
Divaricella sp. cf. D. waltonia Gardner
Donax variabilis Say
Donax sp.
Dosinia elegans Conrad
Echinochama sp.
Ensis directus Conrad
Ervillia concentrica Gould
Erycina carolinensis Dall
Erycina sp.
Fossularca adamsi (Dall)
Gemma magna Dall
Glycymeris americanus (DeFrance)
Glycymeris pectinatus Gmelin
Gouldia metastriatum (Conrad)
Labiosa plicatella Lamarck
Laevicardium mortoni Conrad
Lucina punctulata Lea
Macoma carolinensis Gardner and Aldrich?
Macoma sp.
Macrocallista maculata Linné
Macrocallista (Paradione) reposta (Conrad)?
Macrocallista sp.
Mactra sp.
Mercenaria campechiensis (Conrad)
Mercenaria campechiensis carolinensis (Conrad)
Mercenaria rileyi (Conrad)?
Mercenaria sp.
Mulinia lateralis (Conrad)
Mysella bladenensis Gardner
Mysella velaini Gardner
Mysella sp.
Noetia limula (Conrad)
Noetia ponderosa (Say)
Nucula proxima Say
Nuculana (Saccella) acuta (Conrad)
Nuculana sp.
Ostrea sculpturara Conrad
Ostrea sp.
Pandora trilineata Say
Panope sp. cf. P. bitruncata (Conrad)
Parastarte triquetra (Conrad)
Periploma inequale C. B. Adams
Phacoides amiantus (Dall)
Phacoides multilineatus (Tuomey and Holmes)
Phacoides waccamawensis Dall
Phacoides sp.
Pitar sp.
Plicatula marginata Say
Semele proficua Pulteney
Semele sp. cf. S. proficua Pulteney
Spisula (Hemimactra) modicella (Conrad)
Spisula (Hemimactra) solidissima Dillwyn
Spisula sp.
Sportella sp.
Tagelus plebeius Solander
Tellina alternata Say
Tellina (Morella) macilenta Dall
Tellina (Acorylus) suberis Dall
Tellina sp.
Trachycardium isocardia (Linné)
Transenella carolinensis Dall
Verticordia (Trigonulina) emmonsii Conrad

PHYLUM MOLLUSCA
CLASS GASTROPODA

Anachis avara translirata Ravenel
Bittium sp. cf. B. varium Pfeiffer
Brachycythara sp. cf. B. galae Fargo
Busycon carica Gmelin
Busycon contrarium Conrad
Busycon sp.
Caecum flemingi Gardner and Aldrich
Caecum floridanum Stimpson
Caecum sp. cf. C. imbricatum Carpenter
Caecum regulare Carpenter
Caecum sp.
Cancellaria reticulata Linné
Cantharus tinctus Conrad
Cantharus sp.
Cerithiopsis greeni C. B. Adams
"Circulus" (supra-nitidus Wood subsp.)
Conus sp. d'Orbignyi (Fischer)
Crepidula aculeata Gmelin
Crepidula fornicata Linné
Crepidula plana Say
Crucibulum auriculum Gmelin
Crucibulum sp.
"Drillia" eburnea Conrad
"Drillia" sp.
Epitonium angulatum Say
Epitonium antillarum (deBoury)
Epitonium humphreysi Kiener
Epitonium rupicola Kurtz
Epitonium sp.
Eupleura caudata (Say)
Goniobasis sp.
Liotia (Arene) gemma (Tuomey and Holmes)
Littorina irrorata Say
Lunatia heros (Say)
Marginella (Bullata) antigua Redfield
Marginella apicina Menke
Marginella aureocincta Stearns
Marginella contracta Conrad
Marginella sp.
Melanella conoidea (Kurtz and Stimpson)
Melanella sp.
Mitrella lunata Say
Nassarius acutus Say
Nassarius arata (Say)
Nassarius consensus Ravenel
Nassarius irrorata (Conrad)
Nassarius obsoletus Say
Nassarius vibex Say
Odostomia (Menestho) impressa Say
Odostomia (Chrysallida) seminuda C. B. Adams
Odostomia (Menestho) trifida Tötten
Odostomia sp.
Oliva sayana Ravenel
Olivella mutica Say
Polinices duplicatus Say
Pyramidella (Longchaeus) adamsi Carpenter
Pyramidella (Syrnola) fusca C. B. Adams
Retusa canaliculata Say
Seila adamsi Lea
Strombiformis biconica Gardner
Tectonatica pusilla (Say)
Teinostoma smikron Gardner
Terebra concava Say
Terebra dislocata Say
Triphora pulchella C. B. Adams
Turbonilla (Pyrgiscus) interrupta Totten
Turbonilla sp. A
Turbonilla sp. B
Turritella subannulata Heilprin
Turritella sp.
Urosalpinx cinerea Say
Urosalpinx perrugata Conrad
Vermicularia sp.
Vexillum sp.

PHYLUM BRYOZOA

Crisia sp.
Discoporella denticulata (Conrad)
Parasmittina trispinosa (Johnston)
Schizoporella unicornis (Johnston)

PHYLUM COELENTERATA
CLASS ANTHOZOA

Astrangia astreiformis (Tuomey and Holmes)
Septastraea crassa (Holmes)

PHYLUM ECHINODERMATA
CLASS ECHINOIDEA

Encope emarginata (Leske)
Echinoid spines

PHYLUM ARTHROPODA
CLASS CIRRIPEDIA

Balanus sp.

Pelecypoda	P = 1%	Percentage of Pelecypod Fauna %
Phacoides multilineatus (Tuomey and Holmes)		P-35
Tellina alternata Say		P-27

Gastropoda	Percentage of Gastropod Fauna %
Anachis avara translirata Ravenel	P-33
Mitrella lunata Say.	P-60
Nassarius obsoletus Say	P-100
Polinices duplicatus Say	P-15
Retusa canaliculata Say.	P-94
Turbonilla interrupta Totten	P-35

Many of the pelecypod species reflect a lateral gradient in their relative abundances. Cardita granulata Say, Donax variabilis Say, Ervilia concentrica Gould, and Spisula solidissima Dillwyn are most abundant in samples from stations to the southwest toward Myrtle Beach (Figure 2), and are very scarce or absent to the northeast toward Little River. The following pelecypod species were found to be predominant at stations to the northeast; Chione cancellata Linné, Mercenaria campechiensis (Conrad), and Tellina alternata Say. The most common and uniformly distributed pelecypod species is Mulinia lateralis (Conrad) which is present at almost every locality and constitutes a fairly high percentage of the total pelecypod fauna in most samples.

A lateral change was also noted in the gastropod fauna with the following species predominant at stations to the southwest: Crepidula fornicata Linné, Mitrella lunata Say, Olivella mutica Say, and Turbonilla interrupta Totten. The predominant gastropod species found at localities to the northeast were Nassarius obsoletus Say and Urosalpinx cinerea Say. The most uniformly distributed gastropod is Retusa canaliculata Say. . Turbonilla interrupta Totten and Anachis avara translirata Ravenel are also common in nearly all samples studied.

Macrofossils other than mollusks generally occur sprasely throughout the Pamlico Formation in the area studied.

Bryozoans, particularly Discoporella denticulate (Conrad), are abundant at localities to the southwest and relatively rare or absent toward the northeast. The large colonial coral Septastraea crassa Holmes is sparsely distributed, but occurs most commonly to the southwest. Broken echinoid spines are common only in samples from localities to the southwest and Encope emarginata (Leske), common today in the Florida Keys area, was identified from the basal unit at station 25 and from unit 2 at station 20. Only one small specimen of Mellita quinquesperforata has been identified from the Pamlico in Horry County. Barnacle fragments (Balanus sp.) were sparsely distributed in a few of the samples studied.

Microfauna. The Pamlico Formation contains a fairly abundant, well preserved foraminiferal fauna which constitutes 12 percent of the total fauna studied. A total of 59 species and 30 genera were identified of which 95-99 percent are calcareous benthonic forms.

The characteristic benthonic genera are Elphidium, Hanzawaia, Quinqueloculina, and "Rotalia." The fauna is dominated by the extant species Elphidium delicatulum Bermudez and "Rotalia" beccarii (Linné). The most apparent lateral change noted is the dominance of the species Elphidium delicatulum Bermudez at localities to the southwest and the relative absence of other Elphidium species. However, to the northeast the fauna is characterized by the presence of Elphidium delicatulum Bermudez, Elphidium poeyanum (d'Orbigny), and Elphidium matagordanum (Kornfeld). Buliminella elegantissima (d'Orbigny) becomes more abundant to the northeast whereas the genus Quinqueloculina is nearly absent in the northeast but relatively common at stations to the southwest. Vertically, Elphidium delicatulum Bermudez becomes increasingly more abundant from the basal unit to the upper unit at station 20. At station 25 this relationship also occurs except for the uppermost bed in which Elphidium incertum (Williamson) dominates.

Ostracodes are common in the Pamlico Formationand were picked from the micro samples studied; however, no species were identified.

Evidence of Reworking. In general, the Pamlico specimens are relatively fresh and unworn; however, some assemblages contain many fragmented and abraded specimens. Surf forms such as Donax variabilis and Olivella mutica are represented by both worn and unworn specimens; however, the degree of abrasion is not a completely trustworthy guide to the distance a species might have been carried before burial (Ladd, 1957, p. 49). Constant wave action upon the beach forms prior to burial gives a false indication of distance of transportation. In addition, Kuenen (1950) pointed out that larger fragments are abraded more quickly by current and wave action than smaller ones.

TABLE 2. DISTRIBUTION OF TOTAL FORAMINIFERA
IN PERCENT OF TOTAL NUMBER OF SPECIMENS
PER GRAM OF SAMPLE

STATION	WA 19	WA 20					WA 25				WA 52	WA 53
SAMPLE	5	1	2	3	4	5	1	2	3	4	6	10
TOTAL NUMBER OF FORAMINIFERA PER GRAM OF SAMPLE P = 1%	237	111	10	119	1856	132	35	988	122	71	3388	1225
FORAMINIFERA												
Angulogerina occidentalis (Cushman)	2	-	-	2	P	-	-	P	-	-	-	P
Anomalina sp.	-	-	-	-	-	-	-	P	-	-	-	-
Bolivina lowmani Phleger and Parker	-	P	-	-	P	-	-	1	-	-	1	P
Bolivina pseudoplicata Heron-Allen and Earland	-	P	-	-	P	-	-	P	-	-	-	-
Bolivina sp.	-	-	-	-	P	-	2	P	1	-	P	1
Buccella frigida (Cushman)	P	-	-	P	-	P	-	P	-	-	-	-
Buccella sp. cf. B. frigida (Cushman)	-	-	-	-	-	-	5	-	-	-	-	-
Bulimina sp.	-	-	-	P	-	-	-	P	-	-	-	-
Buliminella elegantissima (d'Orbigny)	-	1	-	-	P	-	-	2	-	-	8	9
Cassidulina laevigata d'Orbigny	P	-	-	-	-	-	-	-	-	-	-	-
Cassidulina subglobosa H. B. Brady	-	-	-	-	-	-	-	P	-	-	-	-
Cassidulina sp. cf. C. subglobosa H. B. Brady	P	-	-	-	-	-	-	-	-	-	-	-
Cibicides sp.	14	P	-	7	P	-	-	P	-	-	P	-
Cornuspira involvens (Reuss)	P	-	-	-	-	-	-	-	-	-	-	-
Dentalina sp.	-	-	-	-	-	-	-	-	-	-	P	-
Discorbis columbiensis Cushman	-	11	-	P	-	-	-	3	P	-	-	1
Discorbis sp. cf. D. columbiensis Cushman	-	-	-	-	P	-	-	-	-	-	-	-
Discorbis consobrina (d'Orbigny)	-	-	-	-	-	-	-	P	-	-	-	-
Discorbis sp. cf. D. consobrina (d'Orbigny)	-	-	-	-	P	-	-	-	-	4	P	P
Discorbis floridana Cushman	-	-	-	-	-	-	-	P	-	-	P	-
Discorbis floridensis Cushman	P	4	-	-	P	-	-	-	-	-	-	-
Elphidium advenus (Cushman)	1	-	-	-	-	-	-	-	-	1	-	-
Elphidium delicatulum Bermudez	-	56	30	35	86	98	34	76	63	-	41	51
Elphidium discoidale (d'Orbigny)	-	-	-	-	-	-	-	-	-	1	-	-
Elphidium sp. cf. E. discoidale (d'Orbigny)	-	-	-	-	P	-	-	-	-	-	-	-
Elphidium fimbriatulum (Cushman)	-	-	-	-	P	-	-	-	-	-	-	-
Elphidium gunteri Cole	2	1	-	1	-	-	-	-	-	12	-	-
Elphidium sp. cf. E. gunteri Cole	-	-	-	-	-	-	-	-	-	-	-	-
Elphidium incertum (Williamson)	-	-	-	-	5	-	-	-	-	57	-	-
Elphidium incertum mexicanum Kornfeld	8	-	-	-	-	-	-	-	-	-	-	-
Elphidium sp. cf. E. incertum mexicanum Kornfeld	-	-	-	-	-	-	-	P	12	-	-	-
Elphidium matagordanum (Kornfeld)	-	-	-	-	-	-	-	-	-	-	27	4
Elphidium poeyanum (d'Orbigny)	-	-	-	-	-	-	-	-	-	-	8	4
Eponides repandus (Fichtel and Moll)	-	-	-	3	-	-	-	P	P	-	-	-
Globigerina eggeri Rhumbler	P	-	-	-	-	-	-	-	-	-	-	-
Globigerina sp.	-	-	-	-	P	-	-	-	-	-	P	P
Globigerinella aspera (Ehrenberg)	-	-	-	-	-	-	-	-	-	-	P	1
Globigerinoides ruber (d'Orbigny)	2	-	-	-	-	-	-	-	-	-	-	-
Globulina sp.	-	-	-	-	-	-	-	-	-	-	P	P
Gumbelina sp.	-	-	-	-	P	-	-	-	-	1	2	5
Gyroidina sp.	-	-	-	-	-	-	-	-	-	-	-	P
Hanzawaia concentrica Cushman	12	1	-	8	P	-	-	P	3	8	-	P
Nonion sp.	-	-	-	-	P	-	-	P	-	-	-	-
Nonionella atlantica Cushman	-	-	-	-	P	-	-	P	P	-	-	-
Planulina exorna Phleger and Parker	29	-	-	5	P	-	-	-	1	-	-	-
Pyrgo sp.	-	-	-	P	-	-	-	-	-	-	-	-
Quinqueloculina compta Cushman	-	-	-	2	-	-	5	-	1	-	-	-
Quinqueloculina sp. cf. Q. compta Cushman	P	-	-	-	-	-	-	-	-	-	-	-
Quinqueloculina funafutiensis (Chapman)	-	-	30	3	-	-	5	P	-	-	-	1
Quinqueloculina sp. cf. Q. funafutiensis (Chapman)	1	-	-	-	-	-	-	-	-	-	-	P
Quinqueloculina lamarckiana d'Orbigny	3	-	40	3	-	-	11	1	2	-	-	-
Quinqueloculina sabulosa Cushman	-	-	-	P	-	-	-	-	-	-	-	-
Quinqueloculina sp.	-	2	-	8	P	-	-	P	4	-	-	-
Robulus americanus (Cushman)	-	-	-	1	-	-	-	-	-	-	-	-
Rotalia beccarii (Linné)	16	16	-	3	2	P	2	8	4	12	8	15
Spirillina decorata Brady	-	-	-	-	P	-	-	-	-	-	-	-
Spirillina sp. cf. S. decorata Brady	P	-	-	-	-	-	-	-	-	-	-	-
Textularia sp.	P	-	-	9	P	-	5	P	2	-	-	-
Triloculina sp.	-	-	-	-	-	-	-	P	-	-	-	-

Most of the reworked Waccamaw specimens are easily recognized on the basis of the preservation. The Waccamaw forms are characteristically gray in color with a dull, chalky appearance, whereas the younger Pamlico (Late Pleistocene) forms are generally fresher in appearance (with the exception of the species mentioned in the previous paragraph).

Cretaceous species reworked into the Pamlico can be readily differentiated on the basis of preservation and because none of the species are known to have survived into the Cenozoic.

The Pamlico shells are generally very fragmental and sharp, suggesting that they have not been transported a great distance. Fragmentation of the shells is due largely to compaction of sediments rather than current action. The occurrence of paired valves of mollusks further suggests a lack of extensive transportation. Many of the shells show evidence of current orientation, whereas at some stations evidence of turbulent water is indicated where the axes of the bivalves are oriented in various directions and planes.

Generally, transportation has resulted in mingling of Pamlico assemblages representing two or more nearby and commonly closely related environments. As a result, it is not feasible to attempt such a detailed breakdown of marine environments as proposed by Parker (1956) in his study of the northwest Gulf of Mexico.

Depositional Environment

Shallow Shelf and Surf Zone. Assemblages interpreted to have lived on the shallow shelf and in the surf zone were collected from the following sections (Figure 4):

Section	Units
53	2A, 2B
20	1, 2, 3, 4
25	1

The shallow shelf, according to Parker (1960), extends in the Gulf of Mexico to approximately 13 fathoms. The inner portion of the shelf near to the beach where the breakers form can be considered the surf zone. The deepest water of the shelf environment represented by the Pamlico Formation in Horry County is probably not more than 6 fathoms. Distance from the offshore bars was probably not more than a mile, and to the bay-lagoon shoreline not more than 7 miles.

The inner shallow shelf is a high energy level environment which is at least partially above wave base at all times and is often swept by strong longshore currents. The bottom is commonly sandy and is characterized by heavy shelled epifaunal species and numerous burrowing forms. The species are of necessity euryhaline and eurythermal as the seasonal salinity and temperature gradients are generally great.

Typically the Pamlico units representing this environment are comprised of 75-90% sand and shells. The sand is nearly completely quartz with a size range from fine to coarse (Figure 7). The presence of many large quartz grains and the angularity of the grains indicate that the sediments were deposited near to shore in a shallow turbulent water. The average Trask sorting coefficient for section 20 (Figure 4) is 1.89 which is well within the range to be expected in a shallow shelf, nearshore environment.

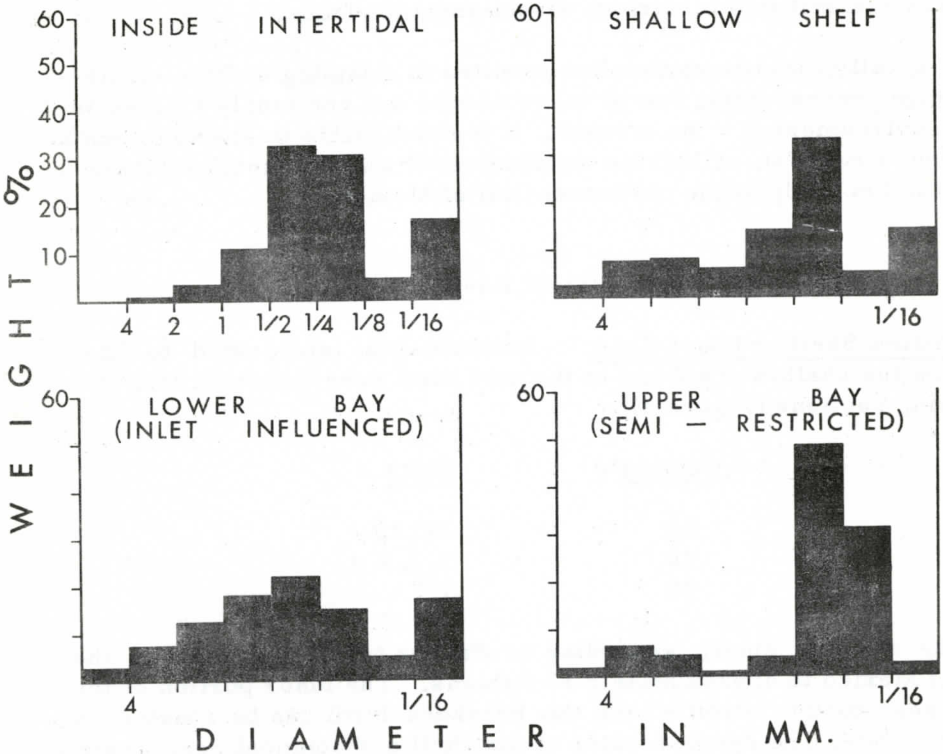

Figure 7. Examples of grain size distribution in the four marine and brackish-water environments of the Pamlico Formation.

The most common mollusks and foraminifer species of the Pamlico shallow shelf environment are listed below:

Most Common Molluscan Species in Shallow Shelf and Surf Zone Assemblages

Species	Percentage
Pelecypoda	
Anadara transversa	0.0 - 3.0%
Cardita granulata	0.0 - 7.0
Donax variabilis	2.0 - 22.0
Ervillia concentrica	0.0 - 66.0
Mulinia lateralis	9.0 - 84.0
Gastropoda	
Anachis avara translirata	0.0 - 18.0%
Crepidula fornicata	0.0 - 12.0
Mitrella lunata	0.0 - 35.0
Olivella mutica	6.0 - 50.0
Retusa canaliculata	P - 36.0
Turbonilla interrupta	0.0 - 23.0
Urosalpinx cinerea	0.0 - 18.0

Most Common Foraminifer Species in Shallow Shelf and Surf Zone

Species	Percentage
Elphidium delicatulum	30.0 - 86.0%
Hanzawaia concentrica	0.0 - 8.0
Planulina exorna	0.0 - 5.0
Quinqueloculina compta	0.0 - 5.0
Quinqueloculina funafutiensis	0.0 - 30.0
Quinqueloculina lamarckiana	0.0 - 40.0
"Rotalia" beccarii	0.0 - 16.0
Textularia sp.	0.0 - 9.0

Among the Pamlico macrospecies seemingly most diagnostic of this environment are those listed below:

Pelecypoda

Anadara brasiliana
Anadara ovalis
Arca umbonata
Chama sp. cf. C. congregata
Dinocardium robustum
Donax variabilis
Ensis directus
Gouldia metastriatum
Noetia ponderosa
Spisula solidissima
Tellina alternata
Trachycardium isocardia

Gastropoda

Busycon sp.	Melanella conoidea
Caecum spp.	Oliva sayana
Crepidula fornicata	Olivella mutica

Bryozoa	Coelenterata
Discoporella denticulata	Septastraea crassa
Parasmittina trispinosa	Echinoidea
Schizoporella unicornis	Encope emarginata

The small discoidal bryozoan, Discoporella denticulata (Conrad) is common, and today is restricted to the Atlantic, from the Straits of Florida to Beaufort, North Carolina, on the American coast and from Madeira to the Mediterranean. It has been recorded from depths of 3-63 fathoms and requires a loose, granular substrate and open marine water.

Two species of encrusting bryozoans were represented in these beds; Schizoporella unicornis (Johnston), the most common, and Parasmittina trispinosa (Johnston). These two species have a nearly world-wide distribution at present, with Schizoporella unicornis most common in coastal and estuarine waters at depths to 30 fathoms, and Parasmittina trispinosa most common in open marine water from the shore to 150 fathoms.

Encope emarginata (Leske) today lives in the shallow open ocean in more southern latitudes. Its presence in considerable abundance in the Pamlico of South Carolina suggests that the water temperature may have been somewhat warmer than at present.

Large colonial masses of the coral Septastraea crassa (Holmes) occur side by side with the bryozoans, Encope and large communities of Mercenaria campechiensis.

Septastraea crassa (Holmes) is reputedly extinct, but is similar to living species characteristic of the shallow shelf.

Typical intermediate shelf molluscan species are absent from these assemblages with the exception of Cardita granulata Say and Gouldia metastriatum (Conrad); however, possibly these are introduced forms. Species such as Olivella mutica and Donax variabilis strongly indicate that these deposits were formed close to the beach, probably just outside the surf zone.

Brackish water species are generally not common except where locally they were washed through inlets into the open sea. Reworked Waccamaw and Cretaceous fossils associated with the shelf assemblages probably also were washed to sea through inlets or reworked from the ocean floor by waves and currents. Evidence of strong current action can be seen in the upper part of section 20 (Figure 4) where most of the shells lay with the convex side up and the long axes of the shells oriented parallel to one another.

Foraminifers are sparse in the shallow shelf Pamlico deposits. The extant species *Elphidium delicatulum* is the most abundant, comprising up to 86% of the fauna. *Quinqueloculina* spp. and "*Rotalia*" *beccarii* are also relatively abundant. *Elphidium delicatulum* has been recorded by Parker, Phleger, and Pierson (1953) living in San Antonio Bay at water depth to one fathom, temperatures of 13-31°C, and at salinities ranging from 2.9-42 0/00. Phleger (1954) recorded this species living in the open gulf just inside Mississippi Sound at a water depth ranging from 0-10 fathoms. Phleger (1955) also recorded the same species from the southeastern Mississippi Delta area at water depths of 0-10 fathoms, temperatures of 10-31.5°C, and at salinities ranging from 14-20 0/00. Walton (1960) recorded *Elphidium delicatulum* living around the vicinity of Horn Island, Mississippi, in brackish water at depths of 0-4 feet.

The relatively small number of species and the high percentage of calcareous forms (95-99 per cent) is indicative of a nearshore environment. According to Bandy and Arnal (1960, p. 1922) species increase in number with increasing depth of water and greater distance from shore. Bandy and Arnal (1960, p. 1923) further stated that the percentage of Foraminifera in sediments of modern seas increase away from shore toward the edge of the continental shelf. Section 20 contains several species of *Quinqueloculina*, particularly in unit 3. According to Bandy and Arnal (op. cit.) diverse porcelaneous species of Foraminifera, particularly the Miliolidae, are characteristic of the intertidal zone and the inner part of the continental shelf of modern oceans and are thus excellent indices of nearshore conditions.

The presence of the planktonic form, *Globigerina* sp. and the following open-ocean benthonic species of *Bolivina lowmani*, *Bolivina pseudoplicata*, *Buccella frigida*, *Elphidium incertum*, *Buliminella elegantissima* and *Hanzawaia concentrica* indicate an open-ocean marine influence. Common beach forms present include *Elphidium incertum mexicanum*, *Quinqueloculina compta*, and "*Rotalia*" *beccarii*. Those species which are able to adapt themselves to variable conditions and occur in appreciable frequencies in both open-ocean and bay assemblages are *Buccella frigida*, *Elphidium gunteri*, *Elphidium* poeyanum, and "Rotalia" beccarii vars.

Lower Bay or Sound (inlet influenced). Assemblages interpreted to represent a lower bay or sound environment close to or including inlets were collected from the following sections (Figure 4):

Section	Unit
54	2A, 2B, 2C
53	1, 1A, 1B, 1C
52	5, 6, 7
25	2, 3, 4
21	2, 3
19	5, 6, 7, 8, 9

This environment is characterized by a mixture of shallow shelf, inlet and indigenous species; by relatively strong currents, especially near inlets; a salinity gradient slightly greater than that for the shallow shelf; and by an argillaceous sand or fine sand substrate (Figure 7).

The environment is most typically developed in that part of bays, sounds or lagoons that has direct access to the open ocean through tidal inlets formed between barrier islands. The most important factor in this environment is the tide and related diurnal exchanges of brackish and marine water masses. The water depth probably ranged from 5 to 15 feet in the bay centers, to as much as 45 feet in the inlets.

The mixture of ecologic types in the fauna of this environment is partially the result of mechanical transportation by the strong tidal currents of the inlets; however, some species are indigenous, whereas others, most typical of the shallow shelf, may have become established in the bays during periods of sustained high salinity; during long periods of low salinity upper bay or brackish water species could migrate into the areas near inlets.

The Trask coefficient of sorting for four samples representing a lower bay environment range from 1.40 to 2.50.

The most common molluscan and foraminiferal species in this environment are listed below:

Most Common Molluscan Species in the Lower Bay or Sound (Inlet Influenced) Assemblages

Species	Percentage
Pelecypoda	
Abra aequalis	0.0 - 10.0%
Anadara transversa	0.0 - 8.0
Brachiodontes exustus	0.0 - 20.0
Cardita granulata	0.0 - 11.0
Caryocorbula contracta	0.0 - 17.0
Chione cancellata	0.0 - 8.0
Crassinella lunulata	0.0 - 8.0
Ervillia concentrica	0.0 - 80.0
Mercenaria campechiensis	0.0 - 10.0
Mulinia lateralis	0.0 - 97.0
Phacoides multilineatus	0.0 - 11.0
Tellina alternata	0.0 - 13.0
Gastropoda	
Anachis avara translirata	0.0 - 21.0
Crepidula fornicata	0.0 - 20.0
Mitrella lunata	0.0 - 60.0
Olivella mutica	0.0 - 29.0
Retusa canaliculata	0.0 - 94.0
Teinostoma smikron	0.0 - 14.0
Turbonilla interrupta	0.0 - 33.0

Most Common Foraminifera Species in the Lower Bay or Sound (Inlet Influenced) Assemblages

Species	Percentage
Buliminella elegantissima	0.0 - 8.0%
Cibicides sp.	0.0 - 14.0
Elphidium delicatulum	0.0 - 98.0
Elphidium matagordanum	0.0 - 27.0
Hanzawaia concentrica	0.0 - 12.0
Planulina exorna	0.0 - 29.0
Quinqueloculina lamarckiana	0.0 - 3.0
"Rotalia" beccarii	P - 16.0

The Pamlico macrospecies seemingly most diagnostic of the lower bay environment are listed below:

Pelecypoda

Anomia simplex
Chione cancellata
Crassinella lunulata
Cyrtopleura costata
Ervillia concentrica
Mercenaria campechiensis
Nuculana acuta
Phacoides amiantus

Gastropoda

Anachis avara translirata
Busycon contrarium
Mitrella lunata
Nassarius irrorata
Odostomia spp.
Polinices duplicatus
Pyramidella fusca
Seila adamsi
Strombiformis biconica
Teinostoma smikron
Turbonilla interrupta

Upper Bay or Sound (semirestricted). Assemblages interpreted to represent an upper bay or sound (semirestricted) environment were collected from the following sections (Figure 4):

Section	Unit
52	8A, 8B
54	3A, 3B, 3C, 3D
21	1

As presently conceived, the upper bay or sound environment was developed in those areas of enclosed water bodies generally located behind barrier islands which show little or no open ocean influence and which are continuously inundated. Most typically such an environment would be found in centers or landward portions of bays, sounds or lagoons, but could develop throughout such bodies of water if they were enclosed on the seaward side by continuous barrier islands. Where barriers are not continuous, physio-chemical and biological gradients would exist between the upper and lower bay environments and no clear-cut division between the two could be made. Where the restricted body of water is entered by a stream, river influenced, low salinity conditions would prevail (Parker, 1960, p. 309); however, this type of environment has not been recognized in the Pamlico of the Nixonville Quadrangle.

Except near stream mouths, salinity was probably more constant in the upper bay environment than in the lower bay environment, with a normal range of 10 0/00 to 20 0/00 punctuated by occasional reductions to as low as 5 0/00. Weak currents generally prevailed and subsequently current orientation of fossils is rare. The substrate was generally silty or argillaceous fine sand (Figure 7). The Trask coefficient of sorting for sample 52-8B is 1.33.

The molluscan assemblages include burrowing species, sessile forms such as Brachiodontes exustus and numerous small forms adapted to quiet water and a soft substrate.

The foraminiferal assemblages were not examined for units definitely assigned to an upper bay environment; however, the relative abundance of the low salinity species Elphidium poeyanum in unit 52-6 suggests at least periodically restricted water and low salinity conditions during deposition of the unit.

The most common molluscan species in the upper bay environment are listed below:

Most Common Molluscan Species in the Upper Bay or Sound (Semirestricted) Assemblages

Species	Percentage
Pelecypoda	
Chione cancellata	0.0 - 14.0
Gemma magna	0.0 - 89.0
Mercenaria campechiensis	0.0 - 36.0
Mulinia lateralis	0.0 - 27.0
Semele proficua	0.0 - 9.0
Gastropoda	
Nassarius obsoletus	2.0 - 99.0
Retusa canaliculata	0.0 - 84.0

The Pamlico macrospecies seemingly most diagnostic of the upper bay environment are listed below:

Pelecypoda
- Brachiodontes exustus
- Gemma magna
- Semele proficua

Gastropoda
- Bittium sp. cf. B. varium
- Terebra dislocata

Inside Intertidal. All intertidal environments of the enclosed area behind barrier islands are included in this category; bay, beaches, marshes, tidal flats, and low salinity oyster reefs.

Clear-cut examples of intertidal environments are rare in the Pamlico of the Nixonville Quadrangle; however, they appear to be common in the Wampee Quadrangle to the north.

Only one sample, 52-8C, studied by the authors appears to contain a possible intertidal fauna. The only macrospecies in this sample are Crassostrea virginica and Nassarius obsoletus. Both of these species are common in tidal mud flats today. The argillaceous sandy character of this sample seems fairly typical of modern tidal flats (Figure 7) examined by the authors.

SUMMARY AND CONCLUSIONS

The faunal, stratigraphical, sedimentological, and paleogeographical evidence leads the authors to the following conclusions concerning the depositional environment of the Pamlico Formation.

1. All of the beds were deposited near to shore in the vicinity of discontinuous barrier islands.

2. Deposition of beds occurred during a major transgression-regression cycle.

3. At maximum transgression the water was probably not more than 45 feet deep in the area studied.

4. At maximum transgression the Pamlico bay shoreline probably was not more than 5-7 miles inland from the present shoreline along the South Carolina Coast.

5. During deposition of many beds, the water salinity was 33-36 0/00 with some beds indicating periodic salinity reductions to possibly as low as 5-15 0/00.

6. The water was never very turbid in this area during Pamlico time.

7. A warm temperate climate prevailed with ocean water temperatures probably slightly higher than today along the South Carolina Coast.

8. During the deposition of the Pamlico Formation several nearshore environments of deposition occurred in close proximity, resulting in the development of very sharp lateral and vertical facies changes.

9. In general, deposits to the northeast represent more restricted conditions as compared to relatively open marine conditions indicated by the deposits to the southwest.

10. Sediments to the northeast consist of clays, silty clays, and sandy clays whereas to the southwest the chief sediments are sand, argillaceous sand, and shelly sand.

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APPENDIX

Stratigraphic Sections

Section 19. Along right bank of Intracoastal Waterway, Nixonville Quadrangle, Horry County, South Carolina, about 1.4 miles downstream from point where U. S. Highway 17 comes closest to canal (See Figure 3).

Description	Thickness in feet
Recent	
11. Sand, white to cream colored, unfossiliferous	2.5
Pleistocene Series	
Pamlico Formation	
10. Sand, yellowish brown, 10YR 6/2, unconsolidated, slightly argillaceous, fine to medium subangular to subrounded quartz grains, some granule size, rounded, quartz grains, slightly limonitic; unfossiliferous. Sharp contact with Bed 9	9.0
9. Sand, yellowish brown, 10YR 6/2, unconsolidated, fine, angular to subangular quartz grains; shell fragments very abundant, worn, and oriented horizontally.	2.0
8. Sand, dark yellowish orange, 10 YR 6/6, unconsolidated, fine angular to subangular quartz grains, contains some well rounded granules and pebbles; large mollusk shells abundant and well preserved. Sharply gradational with Bed 7 below.	1.8

Description	Thickness in feet
7. Sand, light olive gray, 5Y 5/2 unconsolidated, containing fine to very fine subangular to subrounded quartz grains; limonite abundant, mollusk shells abundant and current sorted.	0.8
6. Shelly sand, light bluish gray, 5B 7/1, mottled red-brown in upper 1.0 foot where weathered, unconsolidated, argillaceous, slightly micaceous, and containing fine to medium subangular to subrounded quartz grains, some containing hematite stains; large mollusk shells abundant and appear current oriented. Sharp contact with Bed 5	2.0
5. Sand, light gray, N6, red-brown when weathered, poorly consolidated, argillaceous, slightly micaceous, containing fine to medium subangular to subrounded quartz grains, small amounts of limonite and hematite present; shells of <u>Mulinia</u> and other species fragmental. Unconformable contact with Bed 4 below.	5.5
Unconformity	
Pliocene?	
Waccamaw Formation	
4. Sandy clay, light bluish gray, 5 B, 7/1 to N6, red-brown where weathered, composed of poorly consolidated, argillaceous, fine to medium subangular to subrounded quartz grains, slightly limonitic; fossils abundant with valves paired as oriented in life	2.5
3. Coral bed, coral masses lying flattened to underlying Waccamaw surface. Corals attached to <u>Chlamys</u> and <u>Ostrea</u> valves. Coral bed represents the boundary between Bed 2 below and Bed 4 above and contains a mixture of sediments from both underlying and overlying beds	0.3
2. Marl, light to medium gray, N5 to N6, brown where weathered, composed of sand, well consolidated calcareous material with argillaceous matrix; shells abundant with <u>Chlamys</u> and <u>Ostrea</u> most abundant near top.	1.5
1. Marl, bluish gray to light gray, 5B 7/1 to N6 where fresh, red-brown on weathered surface, consists of hard, indurated, calcareous material with argillaceous matrix; shells common but poorly preserved, mostly casts and molds	3.0
Total section exposed	31.9

Section 20. Along right bank of Intracoastal Waterway, Nixonville Quadrangle, Horry County, South Carolina, about 0.7 miles downstream from section 19 (See Figure 3).

Description	Thickness in feet
Recent	
7. Sand, white, unfossiliferous	4.5
Pleistocene Series	
Pamlico Formation	
6. Sand, moderate brown, 5YR 3/4, composed of unconsolidated, fine to medium subangular to subrounded, slightly frosted quartz grains. Scattered pebbles in lower 2 feet, upper part lacks pebbles, laminated beds 4 inches to 12 inches in thickness. Limonite and hematite present; plant fragments common.	10.0

Description	Thickness in feet
5. Conglomerate, yellowish brown to reddish brown, 10 YR 2/2 to 10R 3/4, hard, hematitic, well rounded quartz pebbles 1/8 inch to 1/4 inch on average. Lower 2 inches of conglomerate grades upward to a red-brown coarse pebbly sand, 4 inches in thickness; unfossiliferous	0.5
4. Sand, dusky yellow, 5Y 6/4, composed of poorly consolidated, argillaceous, very fine to medium subangular to rounded quartz grains, sand and clay intercalated with gray clay bands 1 to 2 inches in thickness and unfossiliferous, sand layers become increasingly argillaceous upward, thickest sand unit at base contains large laterally oriented shells; minute quantities of mica, limonite, and hematite present. <u>Mercenaria</u> common. Contact slightly gradational to Bed 3	2.0
3. Sand grayish olive, 10Y 4/2, slightly consolidated, fine to coarse, subrounded to rounded, quartz grains. Contains highly rounded, polished pebbles, limonite stains on some quartz grains. Shells abundant and oriented laterally with convex sides up; bryozoans common. Sharp contact with Bed 2 below	1.5
2. Sand, yellowish gray, 5Y 7/2, unconsolidated, medium to coarse subangular to subrounded, frosted quartz grains, shells abundant, well preserved; <u>Spisula</u> common, <u>Encope</u> present in upper 1 foot	5.0
1. Sand, moderate olive brown, 5Y 4/4, unconsolidated, fine to medium, subrounded to rounded, frosted quartz grains; very fossiliferous, <u>Mercenaria</u> oriented in life position, paired, and some valves bored by <u>Clione</u>, bryozoans abundant.	5.0
Total section exposed	28.5

Section 52. Along right bank of Intracoastal Waterway, Nixonville Quadrangle, Horry County, South Carolina, about 3.0 miles upstream from section 19 (See Figure 2).

Description	Thickness in feet
Recent	
10. Sand, tan or cream; unfossiliferous	0.5
Pleistocene Series	
Pamlico formation	
9. Sand, dusky yellowish brown, 10 YR 2/2, unconsolidated, fine, angular to rounded, quartz grains, gray to brown in lower 3 feet, middle 1.5 feet brown and tan, laminated, and finely cross-bedded; upper 3.5 feet dark brown to tan with darkest at top 1.0 foot; plant fragments common	8.0
8D. Sandy clay, olive gray, 5Y 4/1, plastic, semiconsolidated, argillaceous, micaceous, containing fine to very fine, subangular to subrounded quartz grains, some well rounded coarse quartz grains; unfossiliferous. Gradational to Bed 8C below and Bed 9 above.	0.5
8C. Clay, light gray, N6, plastic, poorly consolidated, slightly micaceous, containing some fine to very fine, subangular to subrounded quartz grains, limonite and gypsum present; shell fragments abundant with <u>Crassostrea</u> fragments extremely abundant.	0.5
8B. Sand, olive gray 5Y 3/2, composed of consolidated fine to very fine, subangular to subrounded quartz grains, slightly argillaceous and micaceous with minor amounts of limonite; contains life-oriented <u>Tagelus</u>. Gradational to Bed 8A and 8C.	1.5
8A. Sand, moderate olive brown, 5Y 4/4, unconsolidated, slightly micaceous, containing fine to very fine, subangular to subrounded, quartz grains. Limonite present; fossiliferous	1.5
7. Sand, light olive gray, 5Y 5/2, unconsolidated, argillaceous, micaceous, containing fine to very fine, angular to subangular, quartz grains. Shell beds at base grade sharply to sand above	1.5

Description	Thickness in feet
6. Clay, medium gray, N5, moderately indurated, massive, plastic with some fine to very fine, subangular to subrounded quartz grains. Slightly micaceous and traces of pyrite observed; Nassarius common. Contact gradational to Bed 7	5.0
5. Sand, medium dark gray, N4, unconsolidated, fine to medium, subrounded to well rounded, quartz grains with argillaceous matrix. Some coarse quartz grains well rounded, limonite and hematite present with traces of mica; Tagelus oriented as in life. Gradational to Bed 6 above.	1.0
4. Sand, pale reddish brown to moderate brown, 10R/5/4 to 5YR 3/4, unconsolidated and unfossiliferous	2.5
3. Sand, grayish black, N2, nonmarine sand, composed of fine to medium subangular to subrounded quartz grains, quartz grains well rounded; carbonaceous material including wood fibers extremely abundant. Sharp contact with Bed 2 above.	4.0
Pliocene?	
Waccamaw formation	
2. Shell bed, sandy, in 6-8 inch lenses, composed of unconsolidated, olive gray, 5Y 3/2, coarse quartz sand, weathered in upper 2-3 inches to a blue-gray where in contact with Bed 3. Contains reworked Waccamaw shells. Sharp contact with Bed 3 and Bed 1	0.7
1. Oyster bed, containing a matrix of small shells and unconsolidated, light olive gray, 5Y 5/2, coarse sand; shells appear slightly current sorted, Crassostrea most abundant, other shells include Chione, Chlamys, Ostrea, and Septastrea crassa	2.0
Total section exposed	28.2

ROCKS OF THE CAROLINA SLATE BELT IN ORANGE COUNTY, NORTH CAROLINA

by

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University of North Carolina

ABSTRACT

Volcanic and sedimentary rocks of the Carolina Slate Belt in Orange County, North Carolina are being studied to determine the stratigraphy, structure, metamorphic history, and origin of rock units. Mapping thus far has been concentrated in the central and southwestern parts of the county, where there are relatively few intrusive rocks. The major rock units include argillite, slate, phyllite, greenstone, metamorphosed lithic-crystal tuff, devitrified glassy rocks, breccia, and volcanic conglomerate. Most of the rocks have a pronounced cleavage that strikes approximately northeast and is vertical or nearly so. The cleavage is not as well developed in the greenstone, breccia, volcanic conglomerate, and devitrified glassy rocks, but it is evident in nearly every outcrop. Bedding is rarely observed; however, the cleavage appears to be parallel to axial planes of major folds.

Low-rank regional metamorphism has formed mineral assemblages typical of the chlorite zone. The most common assemblage in the greenstone is epidote-chlorite-quartz-actinolite-albite. Minerals of the phyllite are sericite-chlorite-quartz, locally with chloritoid. Epidote, chlorite, quartz, and plagioclase are nearly ubiquitous in the rock units, and calcite is very common.

Field relationships, local amygdaloidal structure, and chemical composition indicate that the greenstones are metamorphosed andesite flows. The devitrified tuffs or flows are dense, dark gray, flinty rocks which have as much as 25 percent feldspar crystals in a groundmass that probably was mostly glass. Some of the devitrified glass has lenticular structures, outlines of shards, compaction features, and spherulites which are similar to those described from welded tuffs and other glassy rocks.

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ILLUSTRATIONS

INTRODUCTION

Carolina Slate Belt

Volcanic and sedimentary rocks of the Carolina Slate Belt crop out in a zone about 50 miles wide trending northeast-southwest across the Piedmont of central North Carolina and into adjacent states (Figure 1). The total length of the belt from Virginia to Georgia is about 400 miles (King, 1955, p. 343). It is commonly called the Carolina Slate Belt, although slate is not the major rock type in all parts of the zone and it is not a single continuous belt. The name is retained here because it is in general use among geologists of the Southeast and because application of a name such as series, system, or group to rocks of the entire belt implies correlation and classification that are not yet warranted.

Rocks in the Carolina Slate Belt include argillites, slates, phyllites, tuffs, breccias, volcanic conglomerates, and flows. The rocks generally show the effects of low-grade metamorphism, and their mineral assemblages are typical of the chlorite zone of regional metamorphism. Rocks of higher metamorphic grade are present on both sides of the main belt. Conley (1962), Stuckey and Conrad (1958) and King (1955) have reviewed the geology of the Slate Belt.

General Geology of Orange County

Orange County is situated in north-central North Carolina (Figure 1). Triassic sedimentary rocks of the Durham basin occur in the extreme southeastern part, but most of the county lies in the Carolina Slate Belt (Figure 2). A number of dolerite dikes of probable Triassic age are present in the Durham basin and also intrude the Slate Belt rocks near the edge of the basin. Intrusive igneous rocks of Paleozoic (?) age occur mainly in several stocks near Chapel Hill and a large batholithic mass underlies the northwestern part of the county. Rock types of these intrusions include diorite, tonalite, granodiorite, and quartz monzonite.

On the Geologic Map of North Carolina (Figure 2), the metamorphosed volcanic and sedimentary rocks have been grouped into two general divisions: felsic volcanic slates and mafic volcanic slates. The felsic volcanic slates are mainly light-colored argillites, seri-

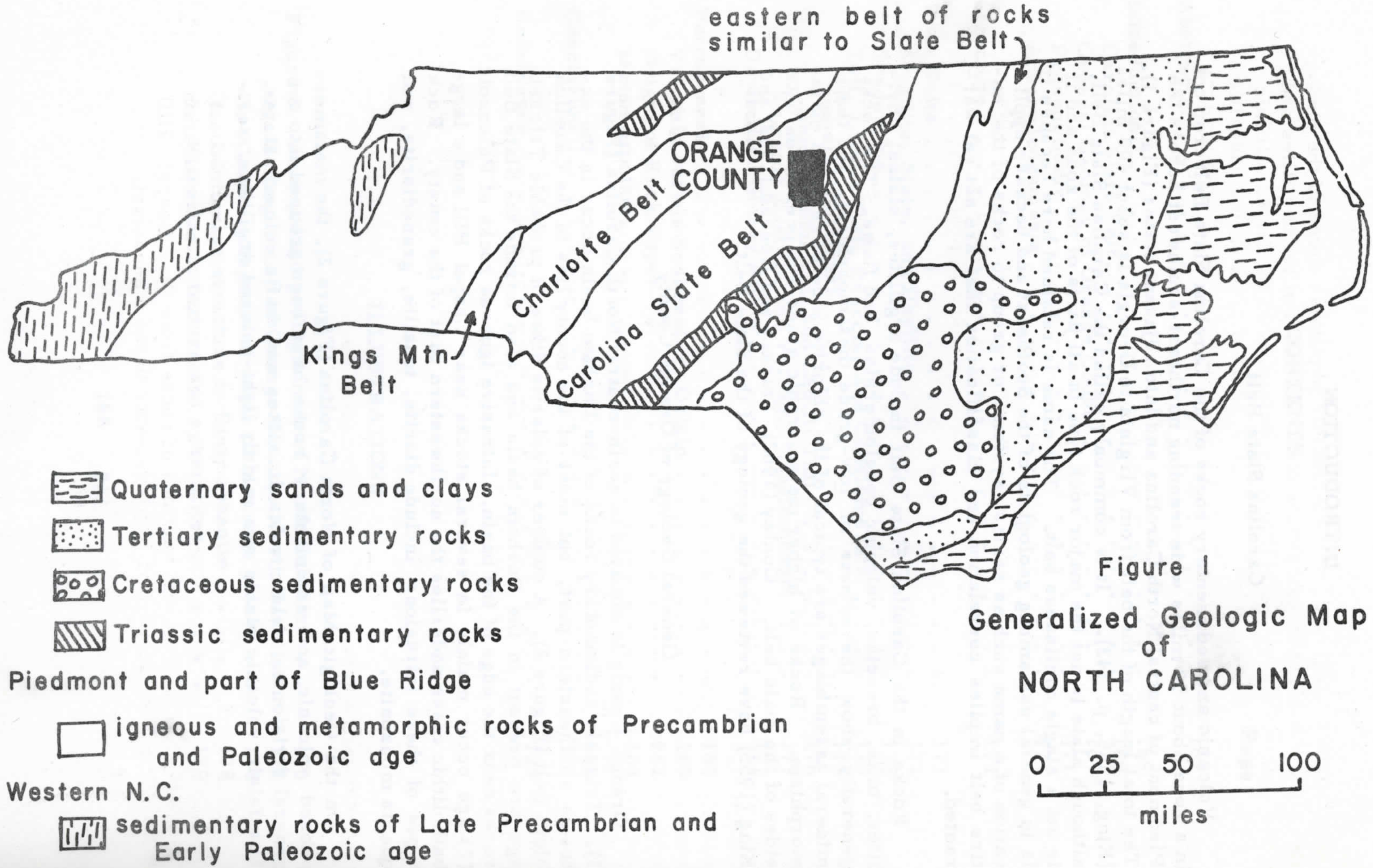


Figure 1

Generalized Geologic Map of NORTH CAROLINA cite-chlorite slates, and sericite-chlorite phyllites. Some of the phyllites are probably metamorphosed tuffs, but most of the argillites and slates appear to be of sedimentary origin. In the felsic volcanic slates, relatively thin layers of darker-colored greenstone, andesitic tuff, devitrified vitric tuff, and volcanic breccia or conglomerate are common. The darker-colored rock types predominate in the mafic volcanic slates, but there are interlayered zones of argillite, slate, and phyllite. Therefore, the two subdivisions merely indicate whether light-colored or dark-colored rocks are dominant in a given area.

No detailed report has been published on the geology of Orange County. Graduate students under the direction of V. I. Mann (D. K. Kirstein, 1956; T. G. Clark, 1957; L. D. Hayes, 1962; unpublished Masters theses, University of North Carolina) have studied rocks of the Chapel Hill quadrangle and a summary report is in preparation.

Present Study

In the spring of 1962, the writer started a project to determine the stratigraphy, structure, metamorphic history, and origin of volcanic and sedimentary rocks of the Carolina Slate Belt in Orange County. Field work has been concentrated in the central and southwestern parts of the county, where there are relatively few intrusive rocks. This was done in order to avoid the contact zones around some of the intrusions, where there has been contact metamorphism, metasomatism, and assimilation that make it more difficult to interpret the pre-intrusion history. Geologic reconnaissance has been made in other parts of the county.

Several weeks have been spent in the field. A total of 53 thin sections have been made for this project, and 37 thin sections were studied from other collections at the University of North Carolina.

The purpose of this report is to present preliminary results and to discuss some of the problems concerning origin of the various rock types. A more complete report is in preparation and will include geologic maps of critical areas, chemical analyses, quantitative petrographic data, and x-ray analyses of aphanitic rocks.

Acknowledgements

This project was supported by a grant from the Research Council of the University of North Carolina. V. I. Mann aided in preparation of the report by lending thin sections of rocks from the Chapel Hill quadrangle and by suggesting improvements in the manuscript.

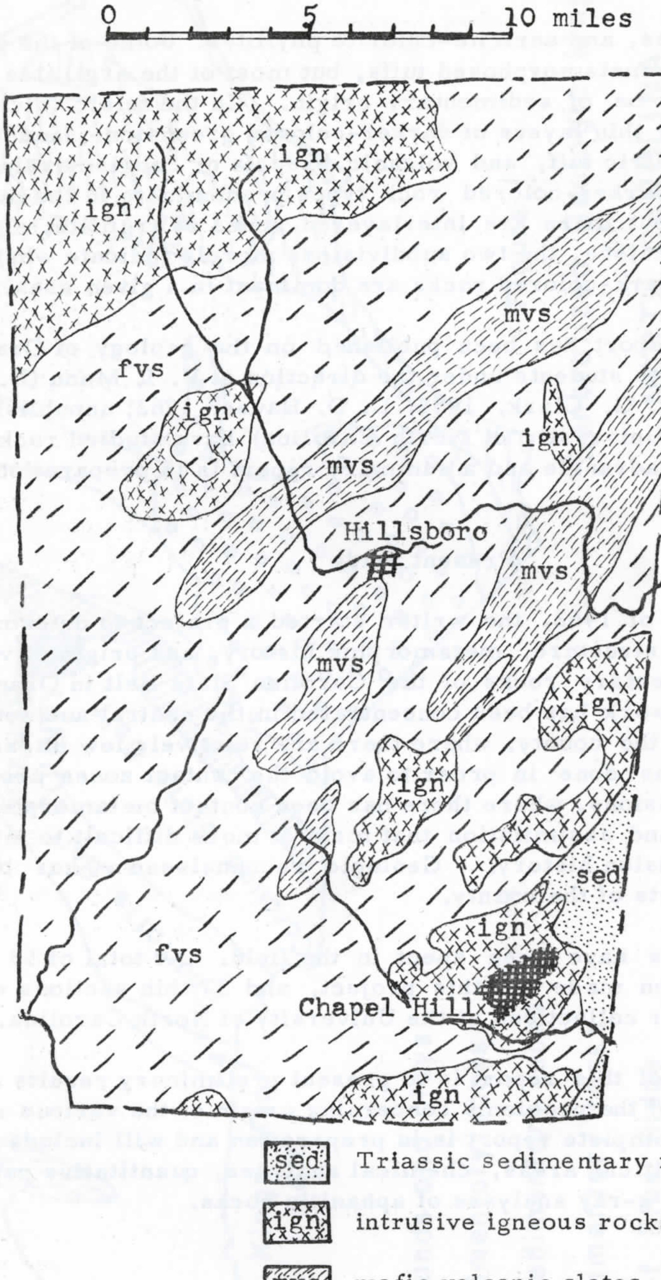


Figure 2. Geologic Map of Orange County, North Carolina. After Geologic Map of North Carolina, 1958.

STRUCTURE

A prominent, nearly vertical cleavage is present in almost every outcrop of Slate Belt rocks. In the slates and phyllites, it is commonly developed to the extent that the rock will split into paper-thin laminae. In these rocks, it is a true slaty cleavage caused by parallel arrangement of the platy minerals, mainly sericite and chlorite. In the breccias, volcanic conglomerates, greenstones, and vitric tuffs, the cleavage may be absent or may appear as widely-spaced fractures with no visible alignment of minerals. All gradations may be found between the two extremes of development of cleavage.

Figure 3 is a contour diagram of poles of cleavage planes, plotted on a stereographic net (lower hemisphere). The readings were taken mainly from slates and phyllites in the southwestern part of the county and all readings are from the southern half of the county, south of U. S. 70. The diagram shows that strikes of cleavage planes range from about N 30 E to E-W, and dips are high, generally near vertical. The maximum concentration of points, which is the approximate mean attitude of cleavage planes, is at N 52 E, 81 NW.

Stratification is rarely observed in the field, and the scarcity of outcrops hinders geologic mapping. Judging from the preliminary mapping, the few stratification readings yet available, elongation of ridges on aerial photographs, and general pattern on the geologic map (Figure 2), there is a series of open folds with nearly vertical axial planes striking approximately northeast. The slaty cleavage apparently parallels the axial planes and is generally not parallel to stratification.

ROCK UNITS

Agrillite, slate, and phyllite

The dominant rock types in the areas mapped as felsic volcanic slates in Figure 2 are argillite, slate, and phyllite, The rocks are fine grained and light colored. Colors range from very light gray to yellowish gray (5 Y 8/1) or light greenish gray (5 G 8/1) on fresh surfaces. The most common minerals are sericite, quartz, and chlorite. The following mineral assemblages were noted:

sericite-quartz-opaque minerals
sericite-quartz-chlorite-opaque minerals
sericite-quartz-chlorite-plagioclase-opaque minerals
sericite-quartz-calcite-opaque minerals
sericite-quartz-chloritoid-chlorite-opaque minerals

Opaque minerals include hematite, magnetite, pyrite, and leucoxene. Chloritoid has been observed only in phyllite with well-developed slaty cleavage, which possibly indicates some relationship between nature of deformation and formation of chloritoid.

Contours: 2-5-10-15-20-25%

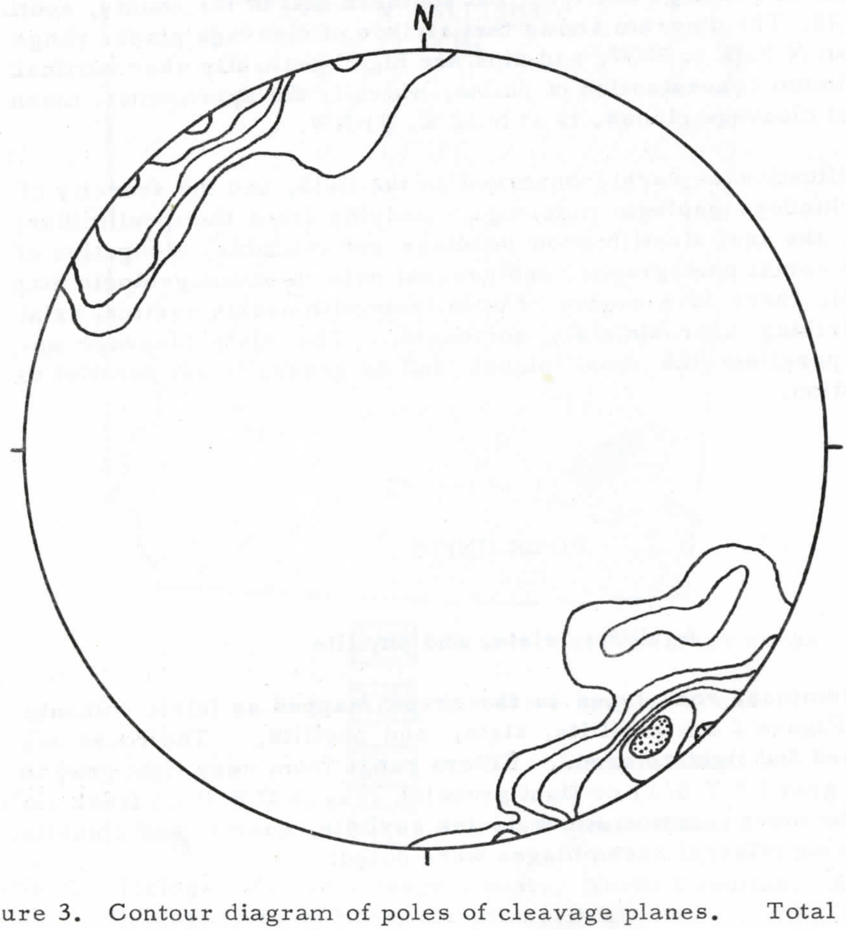


Figure 3. Contour diagram of poles of cleavage planes. Total of 37 readings from south of U. S. highway 70.

Generally the only structure visible in outcrop is slaty cleavage. In some cases, however, the argillite has alternating light and dark laminae less than one millimeter to several millimeters thick.

Greenstone

The greenstone is a fine-grained rock that is grayish green (10 GY 5/2) to pale green (10 G 6/2) on fresh surfaces. Cleavage is poorly developed or absent. Locally, the greenstone contains spherical or ellipsoidal aggregates of quartz, chlorite, and epidote. Quartz ellipsoids are most common and stand out conspicuously on weathered surfaces. They range in diameter from a fraction of an inch to slightly more than one inch. The structures are interpreted to be amygdules formed by mineral deposition in vesicles of a lava flow.

The major minerals of the greenstone are epidote, quartz, chlorite, and plagioclase. The most common mineral assemblages are:

epidote-chlorite-quartz-plagioclase-(sericite)
epidote-chlorite-quartz-actinolite-(sericite)
epidote-chlorite-quartz-actinolite-plagioclase-(sericite)
epidote-chlorite-quartz-plagioclase-calcite
epidote-chlorite-quartz-(sericite)

The composition of plagioclase is difficult to determine because grains are small and riddled with inclusions. However, several determinations indicate that the plagioclase is albite.

Tuff, Lapilli Tuff, Breccia, and Volcanic Conglomerate

General Statement

Rocks described in this report, as tuff, breccia, and volcanic conglomerate represent accumulations of lithic, crystal, and vitric clasts in various proportions. There is a range in grain size from silt or fine ash to clasts one foot or more in diameter, and a range in grain shape from angular to rounded. Probably all gradations are present between deposits of purely volcanic origin and thoroughly reworked, well-sorted sediments. However, nearly all the lithic clasts are volcanic and possibly sedimentary rocks similar to the interlayered flows, tuffs, and argillites. Clasts of schist, gneiss, granite, and other phaneritic crystalline rocks are very rare. Therefore, the clastic rocks discussed here probably originated by direct accumulation of volcanic debris and by sedimentary reworking of penecontemporaneous materials.

All of the rocks have been affected by low-rank regional metamorphism, which in many cases makes it very difficult to determine the pre-metamorphic nature of the rock. The original mafic minerals have been completely destroyed; there are no relict crystals of biotite, hornblende, and pyroxene, even though these minerals were probably present before metamorphism. Some of the plagioclase crystals may be relicts, as they show strong normal zoning and centers of andesine composition. Since the Carolina Slate Belt rocks are of Paleozoic age or older, the volcanic glass has devitrified and its former existence must be verified by indirect evidence.

In rocks which have well-developed cleavage, the original texture has been completely destroyed. The lava flows (greenstone), coarse clastic (breccia and volcanic conglomerate), and dense vitric tuff were apparently more resistant to the deformation and retain original texture. Some of the phyllite is definitely derived from tuff, as evidenced by remnants of flattened and sheared clasts deformed by slip or flow in the plane of cleavage.

An attempt has been made in this report to use geologic terms in accordance with definitions given in the A.G.I. Glossary. Volcanic ash is uncemented pyroclastic material consisting of fragments under 4 mm in diameter and tuff is indurated volcanic ash. The equivalent terms for particles 4 to 32 mm in diameter are lapilli and lapilli tuff. Volcanic breccia is here used without genetic connotation for clastic rocks containing angular fragments greater than 32 mm in diameter, in which the clasts are predominantly volcanic rocks. Volcanic conglomerate is the analogous term for rocks in which the fragments are rounded. The terms are used without connotation of mode of origin--whether the rocks were formed by volcanic processes or sedimentary reworking.

<u>Lithic-crystal tuff and lapilli tuff</u>

The tuff and lapilli tuff are mostly light gray (N 7), medium gray (N 5), medium bluish gray (5 B 5/1), and dark greenish gray (5 G 4/1). Commonly the rock has a speckled appearance caused by white feldspar crystal clasts and lithic clasts that are darker than the matrix.

Clastic texture is generally obvious in hand specimen, but in some cases has been destroyed by metamorphic recrystallization and deformation. Even in the same rock type, cleavage is not equally developed in all parts of the county.

Lithic clasts are generally subangular to subrounded fragments of dacitic or andesitic volcanic rocks. The clasts were derived from fine-grained, cryptocrystalline, and probably glassy rocks. The crystal clasts are angular to subangular grains of plagioclase and quartz, with plagioclase being much more common. If any other types of crystals were present, they have been altered beyond recognition. Most of the plagioclase is extensively sericitized or replaced by epidote, sericite, chlorite, and calcite. However, some plagioclase clasts appear to be relict crystals that show normal zoning and preferential sericitization in the centers of the crystals. The relict plagioclase is oligoclase and andesine in composition.

The tuffs are mixtures of lithic and crystal clasts in various proportions. At least a small amount of vitric material must have originally been present, because spherulites and vitroclastic texture have been observed in several thin sections.

Plagioclase, epidote, chlorite, quartz, and sericite are the major mineral constituents. Calcite is present in most of the thin sections, but is never a major constituent.

Volcanic breccia and volcanic conglomerate

The volcanic breccia and volcanic conglomerate are similar to the tuff and lapilli tuff in color, texture, and mineral composition. Larger clasts are lithic, but crystal clasts make up a significant proportion of the matrix. As in the tuffs, the lithic clasts are mainly volcanic rocks of dacitic and andesitic composition. Volcanic breccia is more common than volcanic conglomerate in areas mapped thus far. Largest clasts observed are one foot in diameter.

Devitrified glassy rocks

Dense, dark-colored aphanitic rocks that are probably devitrified glassy rocks form a relatively minor part of the volcanic-sedimentary sequence, but are of special petrologic interest. They are very hard, have a flinty appearance, and ring under the hammer. The color is dark gray (N 3) to medium gray (N 5) or medium bluish gray (5 B 5/1). Light-colored crystals of feldspar can be seen in almost every hand

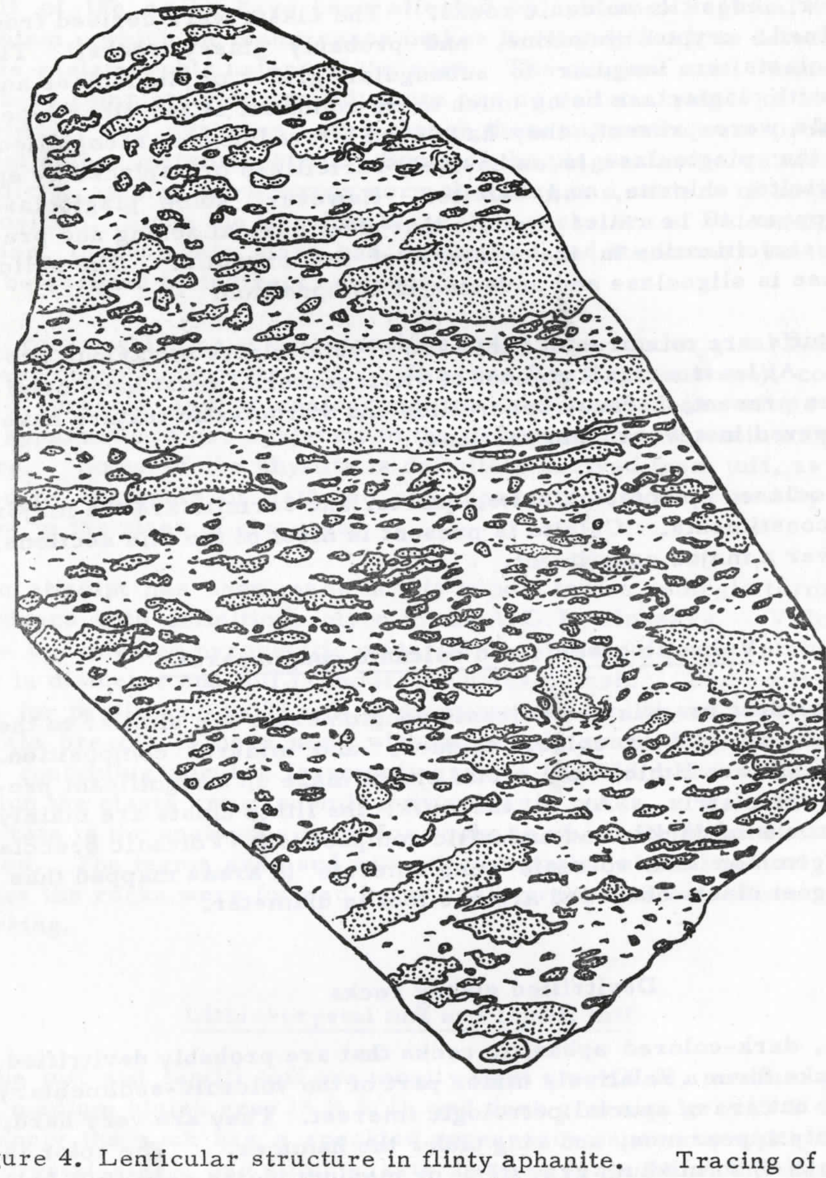


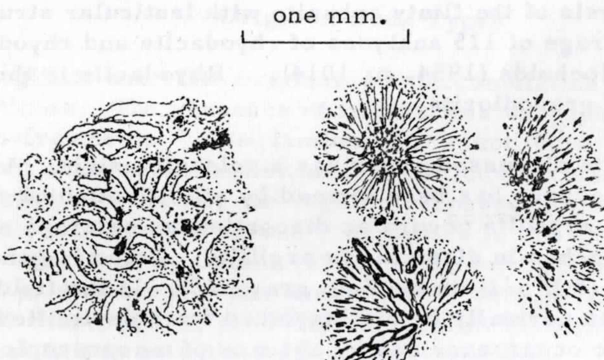
Figure 4. Lenticular structure in flinty aphanite. Tracing of sawed surface, actual size. Lenticles or dark gray groundmass is medium bluish gray.

specimen. Percentage of feldspar crystals ranges from less than one to twenty-five.

Flinty aphanite is the non-genetic, descriptive name applied to these rocks in the field. Aphanite is a general term applied to dense, homogeneous rocks whose constituents are too small to be distinguished by the unaided eye (A.G.I. Glossary). The adjective flinty describes the dense cryptocrystalline appearance and the property of breaking with sub-conchoidal fracture and sharp edges.

Most of the flinty aphanite is massive and has no visible structure or texture other than scattered feldspar crystals one to four mm long. In one outcrop, the rock has a distinctive fragmentary structure (Figure 4). The fragments are roughly lenticular in shape, with ragged edges. Maximum thickness of lenticles is about one inch, and they are essentially parallel over the entire outcrop. The lenticles are dark gray (N 3) and the groundmass is medium gray (N 5) to medium bluish gray (5 B 5/1). Plagioclase crystals occur in both lenticles and groundmass.

In thin section, the lenticular structures are slightly different in texture and mineral composition from the groundmass. The ground-



A. Vitroclastic Texture. B. Spherulites.

Figure 5. Vitroclastic texture and spherulites.

mass has a mean grain size that is very small, probably less than 0.01 mm, and grain size of the lenticles is slightly larger. Many of the minerals other than the large clasts or phenocrysts of plagioclase cannot be definitely identified by microscopic means, but the groundmass apparently is richer in sericite than the lenticles. The groundmass has a banded appearance, and the bands diverge and converge around the discontinuous lenticles.

Vitroclastic texture (Figure 5A) was observed in several thin sections from localities other than the one showing lenticular structure. In this texture, the outlines of compacted glass shards are preserved. It was observed in various degrees of preservation. Most of the flinty aphanite may be vitric-crystal tuff in which the vitroclastic texture was destroyed by subsequent metamorphism.

Spherulites provide further evidence for the presence of glass that was later devitrified. They occur in flinty aphanite from several localities. The spherulites are small spherical to sub-spherical mineral aggregates with a radial arrangement (Figure 5B). The radial minerals appear to be feldspar and quartz, but grains are too small for positive identification by microscope. The spherulites are generally one-half to one millimeter in diameter.

Constituent minerals of the flinty aphanite are plagioclase, sericite, epidote, chlorite, quartz, calcite, and opaque minerals. The strongly altered clasts or phenocrysts of plagioclase are oligoclase and sodic andesine. Plagioclase crystals in the matrix are too small for determination of composition by microscope.

A chemical analysis of the flinty aphanite with lenticular structure is similar to the average of 115 analyses of rhyodacite and rhyodacite-obsidian given by Nockolds (1954, p. 1014). Rhyodacite is the extrusive equivalent of granodiorite.

The flinty aphanite discussed above has a volcanic origin. A rock of very similar appearance has been formed by silicification of argillite. The silicified argillite occurs as discontinuous outcrops and as concretions up to 8 inches in diameter in argillite. Color is generally medium bluish gray (5 B 5/1) or medium gray (N 5). In the field, the silicified argillite can normally be distinguished from devitrified glassy rocks by geologic occurrence and by absence of macroscopic feldspar crystals. Mean grain size is less than 0.01 mm, therefore the minerals could not be definitely identified by microscope. Minerals tentatively identified include quartz, feldspar, epidote, and chlorite.

PETROGENESIS

Volcanic versus Sedimentary Origin

There is good evidence for volcanic origin of rocks such as the amygdaloidal greenstone and devitrified vitric-crystal tuff, and equally good evidence for sedimentary origin of the laminated argillites. For many of the rocks, such a distinction is impossible. Some of the lithic-crystal tuff could equally as well be called volcanic greywacke. Bedding is perhaps the best criterion for sedimentary origin, but it is rarely observed. Rounding and sorting are not always reliable criteria for sedimentary origin. For example, Pitcher and Read (1952, p. 330) described an "intrusion-breccia" with subrounded or well-rounded quartzite fragments. Volcanic ash is well sorted in some cases (Henson, 1952, p. 294).

Sedimentary reworking of volcanic materials is to be expected, especially in parts of a volcanic field away from the vent areas. In the Absaroka volcanic field of northwestern Wyoming, Parsons (1960, p. 142) found that coarse, angular to subangular volcanic breccias near the vent areas grade laterally into well-bedded volcanic sandstones and conglomerates at distances of 5 to 15 miles from the source. Rouse (1937, p. 1281) concluded that water-laid deposits prevail throughout the Absaroka volcanic field. Relative importance of volcanic and sedimentary rocks in any part of a volcanic field will depend upon several factors, including distance from volcanic source, type of volcanic activity, and length of periods between outbursts.

Origin of Rock Types

The argillite and slate originated by accumulation of clay-and silt-sized particles. The presence of laminations suggests a lacustrine or marine environment. The laminations must have been formed by intermittent changes in depositional conditions such as seasonal variation, periodic currents, or regularly-spaced eruptions of volcanic ash. Thinly laminated ("varved") argillites in the Carolina Slate Belt have been described by Conley (1962, p. 6) and by Stromquist and Conley (1959, p. 4-5) from areas southwest of Orange County. Theismeyer and Storm (1938, p. 1964) considered the laminated argillites near Chapel Hill to be varved glacial lake deposits.

Original features of the phyllite have been obscured by deformation and recrystallization, but the rock apparently was derived from both argillites and tuffs.

The greenstones probably are metamorphosed andesite lava flows, as indicated by outcrop patterns, mineralogy, chemical composition, and amygdaloidal structure. No pillow structures have been found; possibly they are absent because subaerial, rather than submarine, conditions previlaed.

Tuff, breccia, and volcanic conglomerate probably were formed by several of the following processes: ash fall, glowing avalanche, block-and-ash flow, volcanic mudflow, brecciation in lava flows, and sedimentary reworking of volcanic material. A combination of modes of emplacement is typical of volcanic fields.

Most of the flinty aphanites are devitrified glassy rocks. They retain several features which are similar to those described from younger volcanic glass: (1) vitroclastic texture, (2) spherulites, and (3) lenticular structure. Vitroclastic texture is very distinctive and is diagnostic of vitric ash. Only a few thin sections showed vitroclastic texture, but it originally may have been present in most of the flinty aphanite and was later destroyed by devitrification and metamorphism. Vitroclastic texture preserved in the flinty aphanite is similar in appearance to texture of welded tuffs described by Ross and Smith (1961).

Spherulites occur in devitrified obsidian flows and welded tuffs (Bascom, 1896; Enlows, 1955; Ross and Smith, 1961). Lenticular structure has been observed in glassy rocks from several localities (Martin, 1959; Ross and Smith, 1961; Molloy and Kerr, 1962). The lenticles occur in welded tuffs and have been interpreted to be collapsed pumice fragments (Martin, 1959, p. 405; Ross and Smith, 1961, p. 29) or local pockets of crystallization (Martin, 1959, p. 406). Molloy and Kerr (1962) have described structures of similar appearance, which they called autoliths, in the Mount Belknap volcanic group of south-central Utah. One rhyolite unit in the Mount Belknap volcanics appeared to be arranged in three concentric zones around the vents. Rhyolite with flow structure comprised the inner zone; the middle zone was rhyolite formed by compaction of glassy fragments and did not have flow structure; and the outer zone was a compaction tuff with fragment size increasing inward (p. 217). The postulated mode of emplacement is air-fall aggregation and gravity flow. Near the source, the temperatures were sufficiently high so that the material fused together and flowed as a plastic mass toward lower elevations (p. 226-228). The rhyolite unit cannot be considered a lava flow or a welded tuff (since the term welded tuff generally implies emplacement by nuée ardente), even though it has structures similar to both types of rock units.

The above example illustrates that considerable evidence is needed before the mode of emplacement can be accurately interpreted. Emplacement of volcanic rocks, especially glassy and clastic rocks, is still poorly understood. Although the flinty aphanites have structures similar to those described in welded tuffs, the writer believes that it is premature to assign the aphanites a name implying mode of emplacement.

Metamorphism

The most abundant minerals are chlorite, epidote, quartz, sericite, and plagioclase. Chloritoid occurs in the phyllite and actinolite in the greenstone. The assemblage epidote-chlorite-quartz-actinolite-albite (?) is common in the greenstone. Brown biotite, almandine, kyanite, and other minerals indicative of medium or high grades of metamorphism were not observed in the area. The mineral assemblages are typical of the chlorite zone of regional metamorphism or the quartz-albite-muscovite-chlorite subfacies of the green schist facies (Turner and Verhoogen, 1960, p. 533-537).

CONCLUSION

Rocks of the Carolina Slate Belt in Orange County are mainly clastic rocks of both volcanic and sedimentary origin, with relatively thin intercalated lava flows. Devitrified glassy rocks form a significant part of the volcanic-sedimentary sequence, but their mode of emplacement is not known. Most of the units have the composition of andesite or dacite, but some of the devitrified glass is similar to rhyodacite in composition.

The rock types are generally similar to those previously described in other areas of the Carolina Slate Belt. The presence of devitrified glass was suspected at least as early as 1894 (Williams, 1894).

Many of the rock types are not amenable to microscopic study because of extremely small grain size. Further study is being conducted by x-ray methods. A digital computer is used to aid in identification of minerals from the x-ray record (Snipes and Butler, 1962).

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