# STRUCTURAL AND STRATIGRAPHIC FRAMEWORK FOR THE COASTAL PLAIN OF NORTH CAROLINA

Duncan Heron

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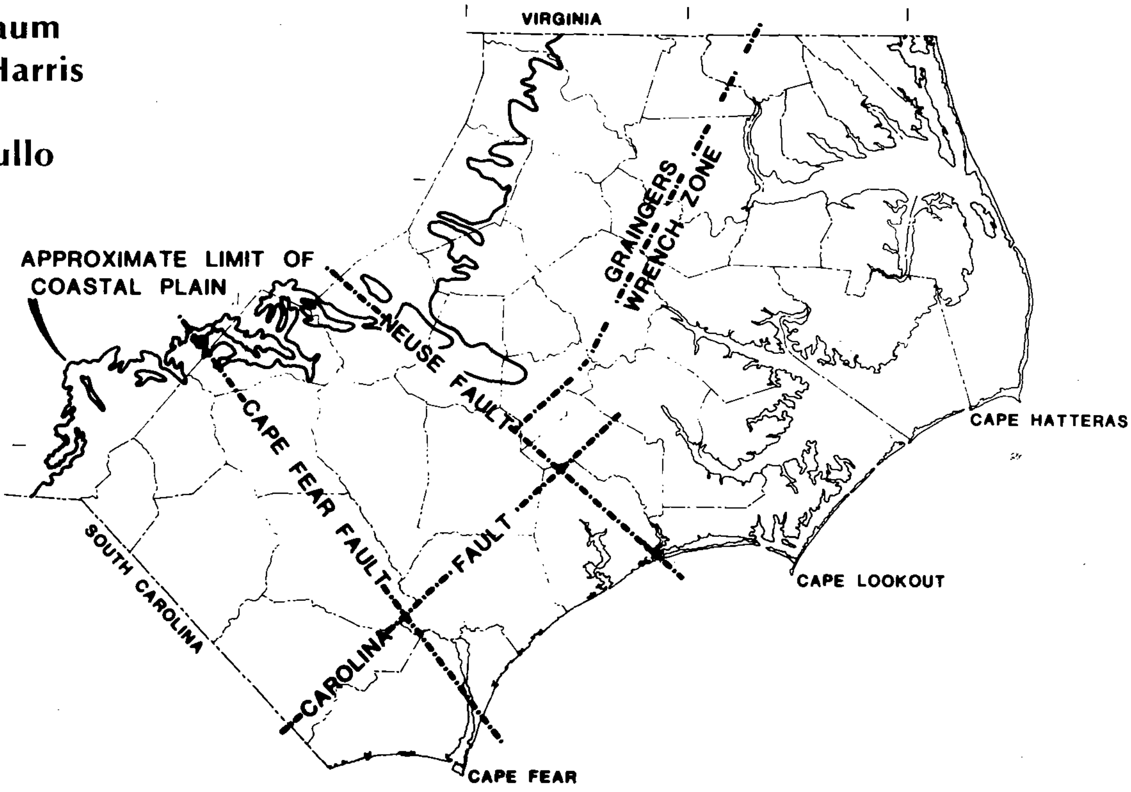

Carolina Geological Society
And
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Cover illustration: Major structural features of the North Carolina Coastal Plain.
(Figure 1 from Harris, Zullo and Baum)

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# CAROLINA GEOLOGICAL SOCIETY
# AND
# ATLANTIC COASTAL PLAIN GEOLOGICAL ASSOCIATION

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Everything should be made as
simple as possible, but not simpler.

A. Einstein

# CONTENTS

The North Carolina Geological Survey has for many years published the guidebook for the Carolina Geological Society's Annual Field Trip. This is done as a service to that group of professionals who contribute so much to the public's knowledge of North Carolina's geology and mineral resources and so that the itinerary of these very interesting trips can be duplicated by other citizens of the state and also visitors to North Carolina.

This year's guidebook is somewhat unique as it contains a collection of previously unpublished papers on the stratigraphy of North Carolina's Coastal Plain province and each paper has a fairly comprehensive bibliography of additional published information on the same subject. Even a casual reading of all these reports will lead the reader to the conclusion that there is some lack of consensus among the experts on the proper subdivision and classification of the Tertiary section found in the Coastal Plain of North Carolina. Also, there is considerable detailed work underway or planned for the immediate future in this area which has not been published upon but which will undoubtedly make substantial contributions to a resolution of the problems.

Therefore, the North Carolina Geological Survey takes no official position at this time with respect to the accuracy of the opinions and conclusions contained in this guidebook and the reader should understand that survey publication here is for the primary purpose of making the rest of the geologic community aware of the ongoing work.

# PREFACE

Many individuals have suggested that the Atlantic Coastal Plain has been affected by tectonism (e.g., Hobbs, 1904; Stephenson, 1923; Cedarstrom, 1945; LeGrand, 1955; Ferenczi, 1959; Doering, 1960), but few have considered tectonics relative to stratigraphic interpretation. Recognition of tectonically controlled depositional patterns is dependent upon an understanding of superpositional relationships and areal distribution of lithic units; a goal that has been hampered by lack of exposures, repetition of lithologies, and absence or poor preservation of diagnostic fossils. The increased availability of surface and subsurface data in the past two decades, coupled with advances in litho- and biostratigraphic methodology, have resulted in refinements and revisions of the stratigraphic framework. These changes, in turn, provide evidence of tectonic controls.

Gibson (1969) and Brown et al. (1972) were the first to suggest a broad scale correlation between tectonism and sediment distribution in the Atlantic Coastal Plain. Brown et al. (1972) showed a relationship between tectonism and sediment deposition for subsurface units in the North Carolina Coastal Plain. However, the subsurface units were not correlated with previously recognized surface stratigraphy. We have attempted to relate the tectonic framework of Brown et al. (1972) to our interpretations of the exposed Tertiary sequence, and in so doing have detailed certain aspects of the framework.

No geologic investigation is ever final; interpretations change. We are presenting a model that differs from those presented in the past and hope that this approach will be considered in future studies on the Atlantic Coastal Plain.

We are indebted to many people: Eldon Allen and Edward Burt (North Carolina Department of Natural Resources and Community Development, Geological Survey Section); Warren Blow (U. S. National Museum); Philip M. Brown (U. S. Geological Survey); Laurel M. Bybell (U. S. Geological Survey); Joseph G. Carter (University of North Carolina, Chapel Hill); G. Arthur Cooper (U. S. National Museum); Janice Cooper (University of North Carolina, Wilmington); Robert Edwards (Martin-Marietta Corporation); Paul D. Fullagar (University of North Carolina, Chapel Hill); Lloyd N. Glawe (Northeast Louisiana University); S. Duncan Heron (Duke University); Roy L. Ingram (University of North Carolina, Chapel Hill); Porter M. Kier (U. S. National Museum); F. Stearns MacNeil (U. S. Geological Survey); H. Weinburg Rasmussen (Geologisk Museum, Denmark); Daniel A. Textoris (University of North Carolina, Chapel Hill). We are also indebted to the many quarry owners and operators who have provided unlimited access to their facilities.

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Sincere thanks are extended to Sandra Cromwell, College of Charleston and Cathy Morris, UNC-W, for typing, editing, and general preparation of the guidebook.

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# HISTORICAL REVIEW OF EOCENE TO EARLY MIOCENE STRATIGRAPHY, NORTH CAROLINA

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## STRATIGRAPHY

### Mesozoic-Cenozoic Boundary

Due to the confusion of Cretaceous and Eocene strata in the Wilmington-Castle Hayne area, the Mesozoic-Tertiary boundary eluded American geologists in the Coastal Plain of North Carolina. Stanton (1891) was the first to locate the Cretaceous in a "siliceous limestone bed" (sandy, pelecypod-mold biomicrosparrudite) beneath the phosphate pebble biomicrudite facies of the Eocene.

Fallaw and Wheeler (1963) and Wheeler and Curran (1974) presented paleontological data to show that Cretaceous and Eocene fossils were not mechanically mixed by a transgressing Eocene sea as proposed by Clark (1890). Their paleontological data confirmed that the upper boundary of the Cretaceous lies below the phosphate pebble biomicrudite facies of the Castle Hayne Limestone. Wheeler and Curran (1974) formally named the Cretaceous carbonate the Rocky Point Member of the Peedee Formation (Fig. 1).

Harris and Bottino (1974) dated glauconite pellets from the Rocky Point Member using Rb/Sr ratios. Their average model age of 67.6 m.y. and an isochron age of 68.1 m.y. also confirmed that the Rocky Point Member was Late Cretaceous. Harris (1975; 1978) has since mapped the subsurface distribution of the Rocky Point Member.

### Eocene To Early Miocene

Lyell (1845) first recognized Eocene strata in North Carolina at an exposure near Wilmington. However, at the time, Lyell's Tertiary subdivisions were criticized by North American geologists who found them difficult to apply to the Atlantic Coastal Plain (Emmons, 1852; Dana, 1863), a condition still prevalent.

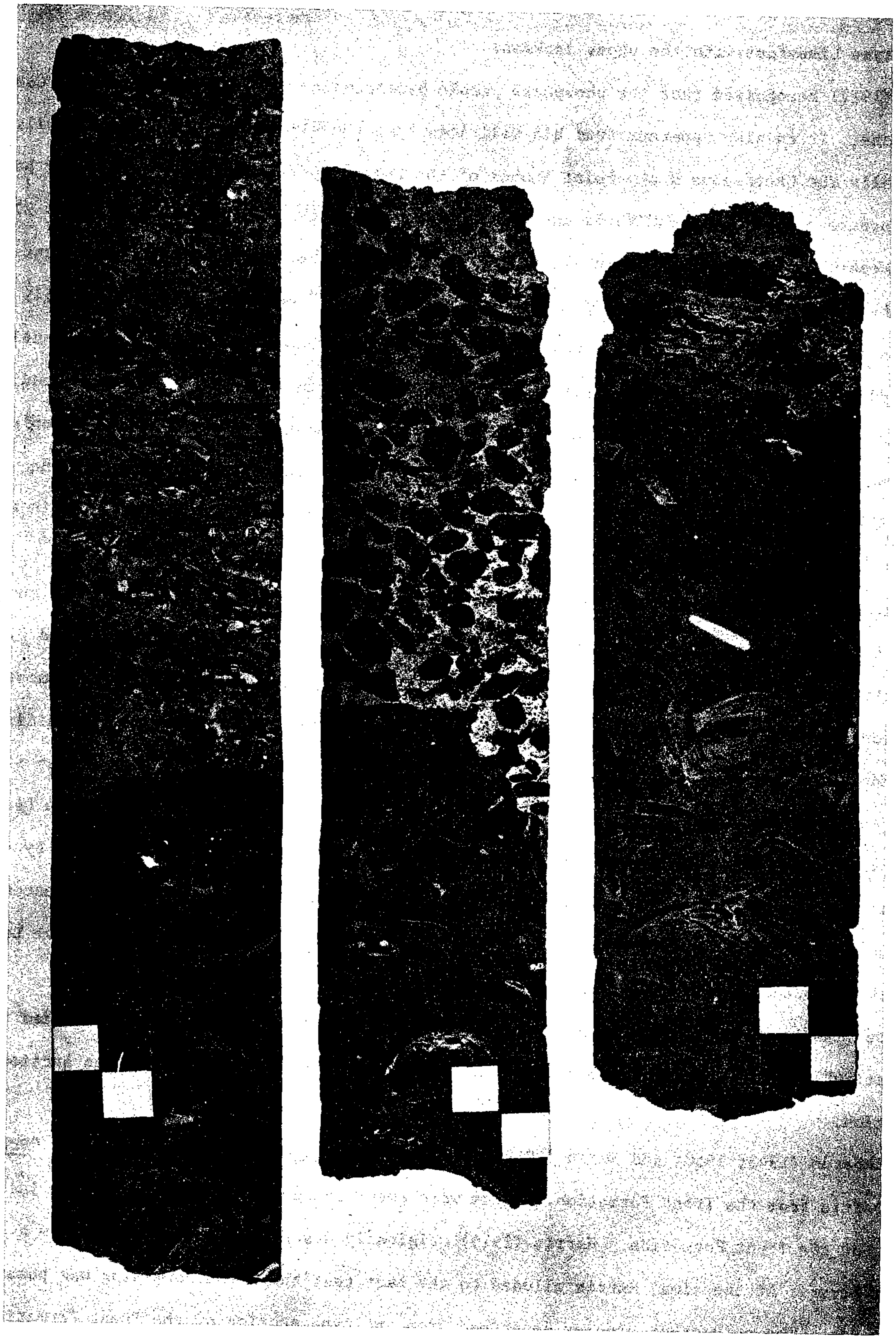
Although the stratigraphic subdivisions of the North Carolina Eocene were initially introduced by Clark (1909) and Miller (1910), Miller (1912) is usually given credit for formally dividing the Eocene into the stratigraphically lower Trent Formation and the overlying Castle Hayne Limestone (Fig. 1). The type section for the Trent Formation was designated the Trent River from New Bern to Trenton (Miller, 1912). The Castle Hayne Limestone received its name from "exposures of this formation in the vicinity of the town of Castle Hayne" (Miller, 1912, p. 185).

The authors of the respective chapters of the 1912 monograph on the Coastal Plain stratigraphy of North Carolina presented confusing and often conflicting views on the stratigraphic relationship of the Trent Formation and Castle Hayne Limestone. Clark _et al_. (1912, p. 41) stated that the Eocene is "divided into the Trent and Castle Hayne formations, the relations of which are unknown from any observed contact, except in a single well boring, but they are probably unconformable." But in the same volume, Miller (1912, p. 175) stated that "there are no known exposures where the two are represented in the same section, and therefore no evidence has been obtained in this way to determine whether the Trent

| AUTHOR / SERIES | MILLER 1912 | KELLUM 1926 | BROWN 1955, 1958 | SWIFT & HERON 1969, WHEELER & CURRAN 1974 | BROWN ET AL. 1972 (# FM. NAMES NOT USED BY AUTHORS ) | BAUM ET AL. 1978 | WARD ET AL. 1978 |
|---|---|---|---|---|---|---|---|
| LOWER MIOCENE | ▨ | TRENT FORMATION | ▨ | ▨ | UNNAMED MAPPED WITH OLIGOCENE | CRASSOSTREA<br>SILVERDALE FM.<br>BELGRADE FM. | BELGRADE FM.: HAYWOOD LANDING MEM.<br>POLLOKSVILLE MEM. |
| OLIGOCENE | ▨ | ▨ | ▨ | ▨ | UNNAMED | TRENT FORMATION | RIVER BEND FORMATION |
| UPPER EOCENE | CASTLE HAYNE LIMESTONE<br>? — ?<br>CRASSOSTREA | CRASSOSTREA<br>CASTLE HAYNE LIMESTONE | CASTLE HAYNE LS. INCLUDES CRASSOSTREA: UPPER EOCENE COMPONENT | ▨ | ▨ | NEW BERN FORMATION | ▨ |
| MIDDLE EOCENE | TRENT FM. ? IN PART K CARBONATE<br>▨ | ▨ | CASTLE HAYNE LS. INCLUDES CRASSOSTREA: MIDDLE EOCENE COMPONENT | CASTLE HAYNE LIMESTONE (AGE NOT SPECIFIED) | # NEW BERN FM.<br>#CASTLE HAYNE LS.<br># ROCKY PT. MEM. | CASTLE HAYNE LIMESTONE | CASTLE HAYNE LS.: SPRING GARDEN MEM.<br>COMFORT MEM.<br>NEW HANOVER MEM. |
| UPPER CRETACEOUS | PEEDEE FORMATION | K CARBONATE<br>PEEDEE FORMATION | PEEDEE FORMATION | ROCKY POINT MEM.<br>PEEDEE FORMATION | # PEEDEE FORMATION | ROCKY PT. MEM.<br>PEEDEE FORMATION | K CARBONATE<br>PEEDEE FORMATION |

Figure 1. Chronological development of part of the formations in the Coastal Plain of North Carolina.

(facing page)
Figure 2. Split core illustrating the disconformable Mesozoic-Cenozoic boundary in the Castle Hayne area: left core, bryozoan biosparrudite facies of the Eocene Castle Hayne Limestone disconformably on the sandy, pelecypod-mold biomicrosparrudite facies of the Rocky Point Member of the Cretaceous Peedee Formation (note absence of phosphate pebble biomicrudite facies); center and right cores, phosphate pebble biomicrudite facies of the Castle Hayne Limestone on the Rocky Point Member (scale graduated in cm).



and Castle Hayne formations are conformable or not, in those regions where both are present, although evidence secured from well borings makes it probable that they are."

Clark (1909; 1912) correlated the Trent Formation with the upper Claiborne or lower Jackson, and the Castle Hayne Limestone with the upper Jackson.

Miller (1912) recognized that the phosphate pebble biomicrudite was at the base of the Castle Hayne Limestone. It is also apparent from his well logs that the "Trent Formation" in the Wilmington area is actually the Cretaceous Rocky Point Member of the Peedee Formation. The problem may have been that the phosphate pebble biomicrudite is not always present to mark the disconformity (Fig. 2). The Rocky Point Member is similar lithologically to rocks exposed at the type section of the Trent Formation along the Trent River. Thus, to Miller, the "Trent Formation" occurred stratigraphically below the Castle Hayne Limestone and therefore was older. Compounding this mistake, Miller apparently was not mapping distinct lithologies. Although he (1912, p. 173) stated that the Eocene was subdivided "on the basis of its fossils and its lithologic characters", there appears to be little or no differences in either his lithologic or faunal descriptions of the Trent Formation and Castle Hayne Limestone. Thus, the distinction between the two formations became their mutual exclusion in areal distribution (see his geologic map).

Subsequently, Kellum (1925; 1926) investigated the fauna of the Castle Hayne Limestone and Trent Formation. Like Stanton in 1891, and Stephenson in 1923, Kellum (1926, localities 10615 and 779) recognized that the sandy, pelecypod-mold biomicrosparrudite underlying the Castle Hayne Limestone in the Wilmington area was Cretaceous. Because the type section of the Trent Formation lacked diagnostic fossils (predominantly molds), he collected all of his diagnostic fossils from a quarry near Silverdale. This quarry contained well preserved fossils in an unlithified, sandy matrix. Although the fauna had Vicksburg (Oligocene) affinities, he concluded that the Trent Formation is early Miocene. By restricting the areal distribution of the Trent Formation to the area east of the Castle Hayne Limestone outcrops, Kellum (1926) depicted the typical belted Coastal Plain, the late Eocene Castle Hayne Limestone lying beneath and outcropping to the west of the early Miocene Trent Formation (Fig. 1).

Richards (1943) collected additional fossils from the Silverdale area and also concluded that the "Trent Formation" was early Miocene; however, no specimens were collected from the type section of the Trent Formation.

Both Richards (1943; 1950) and Smith (1959) have figured Pecten "elixatus" Conrad and "Pecten" trentensis Harris from the Trent Formation. These were never found at Silverdale, but are included in faunal lists of the Trent Formation. Harris (1919) originally described these species from a locality on the Trent River. At the time, Harris alluded to the fact that the Trent Formation was possibly Oligocene in age. The only other species described from the type section of the Trent Formation are

Callista neusensis (Harris), Mercenaria erecta (Kellum) and M. gardnerae (Kellum). These were found as complete shells at Silverdale and referred to molds found along the Trent River (Kellum, 1926). The holotypes of the last two are from Silverdale and not from the Trent River.

Berry (1947) essentially connected Kellum's (1926) localities to produce his Coastal Plain geologic map. The curious hook in the outcrop at Pollocksville was to accommodate Kellum's belief that the exposure of Crassostrea gigantissima at Pollocksville was part of the Castle Hayne Limestone.

For three decades, subsequent workers (Richards, 1942; 1943; 1945a; 1945b; Cooke et al., 1943; Spangler, 1950; Swain, 1951) followed Kellum's (1926) proposed stratigraphic position and age of the Trent Formation. However, Brown (1955) observed that in the subsurface, a sharp boundary exists between the Eocene Castle Hayne Limestone and the late Miocene Yorktown Formation. The microfauna indicates that the early Miocene is absent in North Carolina. He proposed the inclusion of the Crassostrea gigantissima (= Ostrea georgiana) facies of the Trent Formation into the Castle Hayne Limestone and the elimination of the formation name Trent (Fig. 1); however, Brown misinterpreted Miller (1912) in considering Crassostrea gigantissima diagnostic of the Trent Formation. Referring to the Crassostrea gigantissima facies, Miller (1912, p. 177) stated, "It seems, however, to have a very local distribution, so cannot be used to any great extent for purposes of correlation."

Lawrence (1976) investigated several localities of Crassostrea gigantissima, but concentrated on an exposure in the Martin Marietta quarry at Belgrade. The oysters lie within a channel cut into the carbonate strata below. Failing to recognize the disconformable relationship between the two units, he considered that the units were facies and that both the underlying carbonates and quartz arenites and the overlying oyster channel were late Oligocene.

The 1958 North Carolina state geologic map reflects Brown's proposals by combining all of the disputed carbonates into the Castle Hayne Limestone.

Subsequent subsurface work by Brown (1958, p. 6) indicated that no lithologic discontinuities exist between Claiborne and Jackson ostracod faunas of the Castle Hayne Limestone and that the Castle Hayne Limestone "was deposited during a temporal transgression from Claiborne time into Jackson time, the bulk of the deposition having occurred during Jackson time." Traditionally, the Castle Hayne Limestone has been considered Jackson in age (Clark, 1909; 1912; Canu and Bassler, 1920; Kellum, 1925; 1926; Cheetham, 1961; Copeland, 1964); however, Brown et al. (1972) now consider the Castle Hayne Limestone Claiborne in age.

In 1972, Brown et al. published a comprehensive subsurface stratigraphic report for the Atlantic Coastal Plain from New York to North Carolina. They did not recognize the Cretaceous Rocky Point Member. They either did not recognize the presence of a carbonate (wells NH-T-B, NH-T-16) or placed the Rocky Point Member in the overlying Castle Hayne Limestone (well PEN-OT-9). Thus, in the

Wilmington area, a sandy, pelecypod-mold biomicrosparrudite (the Cretaceous Rocky Point Member placed in the Castle Hayne Limestone) lay stratigraphically below the bryozoan carbonates of the Castle Hayne Limestone (see Fig. 2). This is the same mistake made by Miller (1912). A lithologically similar unit (New Bern Formation of Baum _et al._, 1978), also a dominantly sandy, pelecypod-mold biomicrosparrudite, overlies the bryozoan carbonates of the Castle Hayne Limestone in the New Bern area. Previously, Brown (1958) considered this unit an upper Eocene component of the Castle Hayne Limestone (Fig. 1). Because they did not recognize that the Rocky Point Member is Cretaceous or that the New Bern Formation is a distinct lithostratigraphic unit, their interpretation was that the sandy, pelecypod-mold biomicrosparrudite interfingered with the bryozoan carbonates of the Castle Hayne Limestone. Consequently, the sandy, pelecypod-mold biomicrosparrudite "facies" was interpretated as a downdip "reef" facies of the Castle Hayne Limestone (Brown _et al._, 1972)(Fig. 1).

Baum _et al._ (1978) proposed a revised stratigraphic framework for the Eocene to lower Miocene strata of North Carolina (Fig. 1). The Eocene Castle Hayne Limestone was restricted to include two dominant lithofacies: a lower bryozoan biosparrudite and an upper bryozoan biomicrudite. The New Bern Formation was proposed for the dominantly sandy, pelecypod-mold biomicrosparrudite that disconformably overlies the Castle Hayne Limestone (restricted). The New Bern Formation was tentatively assigned a late Eocene age. The original type section for the Trent Formation was restricted to the Trent River from New Bern to Pollocksville. The Trent Formation (restricted) was assigned to the early/middle Oligocene. The Belgrade and Silverdale formations were proposed for isolated early Miocene units exposed at quarries in Belgrade and Silverdale. The Belgrade Formation was considered to be a nearshore equivalent to the Silverdale Formation. The _Crassostrea gigantissima_ channels were considered to be younger than the Silverdale Formation.

Shortly thereafter, Ward _et al._ (1978) also proposed a similar stratigraphic framework (Fig. 1); however, they differ from Baum _et al._ (1978) in several important aspects. Unfortunately, some of their stratigraphic terminology is the same as Baum _et al._ (1978), but for different stratigraphic units. They divided the Castle Hayne Limestone into three members: the lower New Hanover Member (phosphate pebble biomicrudite facies of Baum _et al._, 1978); the middle Comfort Member (bryozoan biosparrudite and bryozoan biomicrudite facies of Baum _et al._, 1978); and the upper Spring Garden Member (New Bern Formation of Baum _et al._, 1978). Their River Bend Formation is essentially equivalent to the Trent Formation of Baum _et al._, (1978); however, they consider the units exposed at the Martin Marietta quarry at Belgrade (Belgrade Formation of Baum _et al._, 1978) to be a lateral equivalent to the River Bend Formation (Trent Formation of Baum _et al._, 1978). The River Bend Formation was assigned an early to late Oligocene age. The early Miocene Belgrade Formation of Ward _et al._ (1978) included two members: the lower Pollocksville Member (_Crassostrea gigantissima_ channels of Baum _et al._, 1978); and the upper Haywood Landing Member

(Silverdale Formation of Baum _et_ _al_., 1978).

## DISCUSSION

The validity of the New Bern Formation/Spring Garden Member rests on the contact between these units and the underlying Castle Hayne Limestone/Comfort Member, as well as their age relationships. Although Ward _et_ _al_. (1978) implied a conformable relationship, Baum _et_ _al_. (1978) presented the following criteria to establish the disconformable relationship between the underlying Castle Hayne Limestone/Comfort Member and the overlying New Bern Formation/Spring Garden Member:

- sharp lithologic boundary between the two units; the contact between the two units is marked by phosphatized crusts, rounded phosphated clasts of the Castle Hayne Limestone and a concentration of oysters; the phosphatized crusts have been subsequently bored by polad pelecypods (Fig. 3).
- rapid faunal change; bryozoans and foraminifera characteristic of the Castle Hayne Limestone are displaced by pelecypods in the New Bern Formation which suggests a lack of continuity in the depositional systems.
- intertidal, _Callianassa_ burrowed and red algae bearing (_Archaeolithothamnium_) calcareous quartz arenite between the Castle Hayne Limestone and the New Bern Formation indicates a distinct stratigraphic break.
- the facies of the New Bern Formation represent a transgressive sequence, rather than a regressive sequence; both the Castle Hayne Limestone and New Bern Formation internally have their own characteristic shallow water and deep water facies.
- lack of interfingering of the Castle Hayne Limestone and the New Bern Formation; recognition of the Cretaceous Rocky Point Member of the Peedee Formation no longer necessitates or implies interfingering.
- lack of faunal continuity; the abundant bryozoan fauna, as well as the characteristic mollusc, crinoid, brachiopod and echinoid fauna of the Castle Hayne Limestone is absent from the New Bern Formation; _Callista_, the dominant pelecypod in the New Bern Formation, as well as _Panopea_ and _Chlamys_ cf. _C_. _cawcawensis_, do not occur in the Castle Hayne Limestone; even on the generic level, there is little faunal overlap.
- lack of structural continuity; the depositional strike of the Castle Hayne Limestone appears to be northeast/southeast; whereas, the depositional strike of the New Bern Formation appears to be east/west.

The age of the New Bern Formation remains a problem. Portions of the mega-fauna suggest a Claiborne age (_Crassatella_ cf. _C_. _alta_), whereas the presence of _Chlamys_ _cawcawensis_ suggests a Jackson age. Ward _et_ _al_. (1978) considered the New Bern Formation/Spring Garden Member to be latest

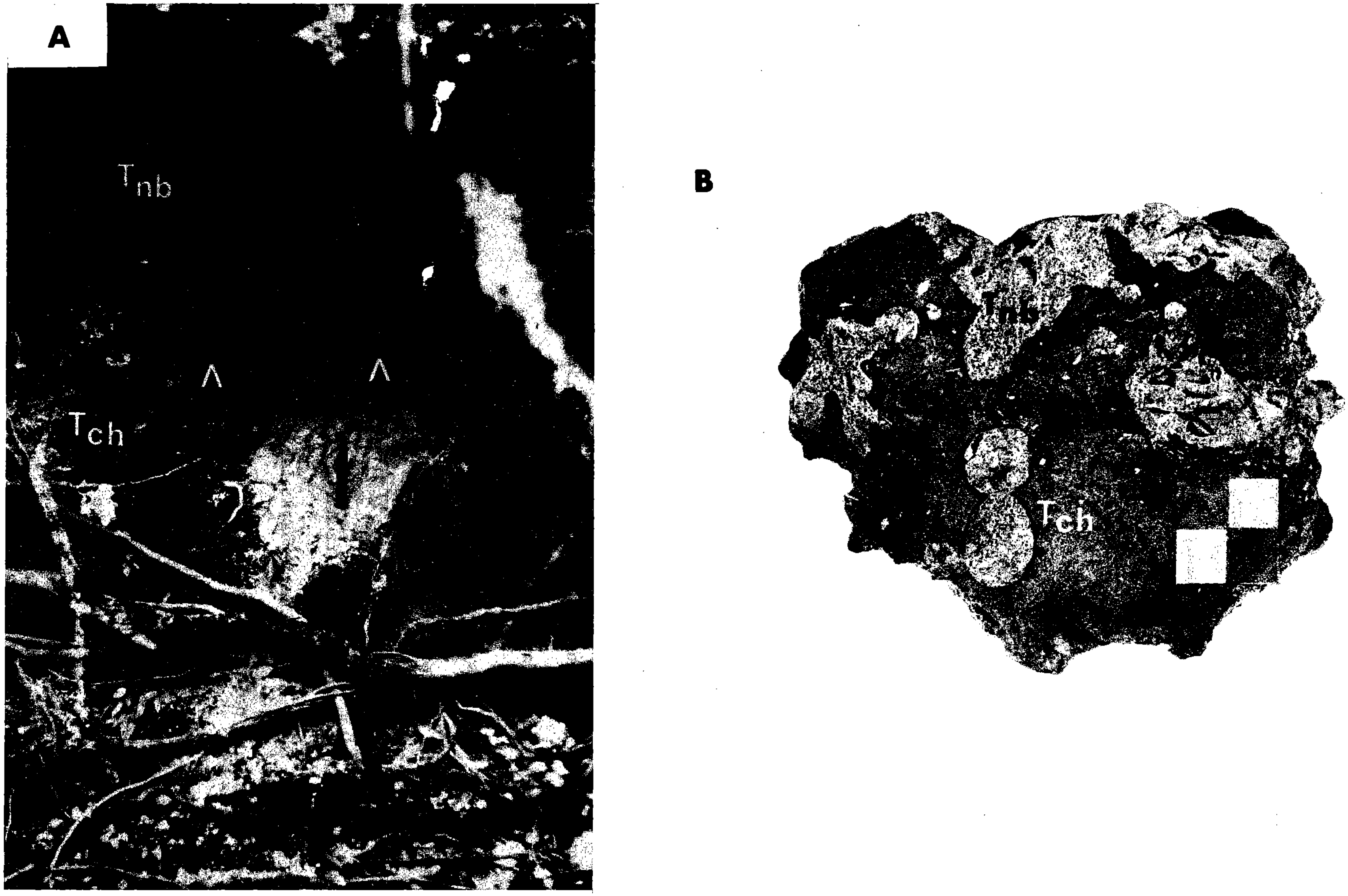


Figure 3. Disconformity between the Eocene Castle Hayne Limestone and the New Bern Formation. A) Sandy, pelecypod-mold biomicrosparrudite facies of the New Bern Formation ($T_{nb}$) disconformably on the sandy, foraminiferal biomicrite facies of the Castle Hayne Limestone ($T_{ch}$) (locality CR-8 of Baum *et al.*, 1978; hammer is scale). B) Phosphatized Castle Hayne Limestone ($T_{ch}$) bored by pholad pelecypods and susequently infilled by the overlying New Bern Formation ($T_{nb}$) (locality CR-7 of Baum *et al.*, 1978; scale graduated in cm).

Claibornian based on the presence of Macrocallista neusensis, Crassatella alta and Bathytormus protextus. Zullo and Baum (in press), Worsley and Turco (this volume) and Zullo (this volume) have suggested that the Castle Hayne Limestone (restricted) ranges from middle to late Eocene. Thus, as the New Bern Formation stratigraphically overlies the Castle Hayne Limestone (restricted), it must be latest Eocene in age.

Baum et al. (1978) suggested that the Trent Formation was early to middle Oligocene in age based on published eustatic sea level curves (Vail, 1976; Vail et al., 1977). These curves suggest a major sea level drop in the lower Chattian, thus precluding latest Oligocene sediments from the Coastal Plain. Ward et al. (1978) considered the Trent Formation (portions of their River Bend Formation) to be late Vicksburgian based on the presence of Ficus mississippiensis, Oniscia harpula, Dentalium mississippiensis, Cardium diversum, Chione imitabilis and Pecten perplanus byramensis.

The Belgrade and Silverdale formations were deemed equivalent and lateral facies by Baum et al. (1978) based on the concurrence of barnacles belonging to the Balanus concavus stock. Although Ward et al. (1978) considered the Belgrade Formation of Baum et al. (1978) to be a lithostratigraphic equivalent of the Trent Formation, they did recognize that the Belgrade Formation was younger than and contained a distinctive fauna from the Trent Formation. Ward et al. (1978) considered the Belgrade Formation of Baum et al. (1978) to be Chickasawhayan in age based on the presence of Chlamys waynesis and Anomia taylorensis.

Although the Silverdale Formation has been confused with older units, the fauna from the type section has traditionally been considered early Miocene (Kellum, 1926; Richards, 1943; Ward et al., 1978). The problem remaining is whether the Belgrade Formation is a lithostratigraphic equivalent (although not entirely a chronostratigraphic equivalent) of the Trent Formation or of the Silverdale Formation; or whether it is a litho- and chronostratigraphic unit distinct from both the Trent and Silverdale Formations (e.g., T.O. 2.2 cycle of Vail et al., 1977).

The following evidence suggests that Belgrade Formation is a nearshore, lateral facies of the Silverdale Formation:

- concurrence of barnacles belonging to the Balanus concavus stock (Solidobalaus C zone of Zullo, this volume).
- both the Trent and Belgrade formations represent transgressive sequences; thus, it would seem more plausible that the Belgrade Formation represents the nearshore equivalent to the Silverdale Formation, rather than a lateral equivalent to the underlying Trent Formation.
- concurrence of Mercenaria gardnerae and Anomia ruffini in the Belgrade and Silverdale formations; based on published faunal lists (Ward et al., 1978), there is apparently no faunal overlap between

the Trent and Belgrade formations.

- cores drilled at the base of the Belgrade quarry reveal a phosphatized surface several meters below the quarry floor; although core recovery was poor, the Belgrade Formation appears to lie disconformably on the upper barnacle, pelecypod-mold biosparrudite facies of the Trent Formation.

The "Crassostrea gigantissima" channels have generated the greatest confusion in the Coastal Plain of the Carolinas. They represent channels that cut disconformably into the Trent, Belgrade and Silverdale formations. They have traditionally been considered Eocene (Miller, 1912; Kellum, 1926); however Lawrence (1976) considered them latest Oligocene based on his interpretation of the contact between the oysters and the underlying units (Belgrade Formation). Ward et al. (1978) now consider them earliest Miocene in age. Solidobalanids occurring with the the oysters are conspecific with those found at Belgrade (see Zullo this volume). The stratigraphic importance of these oysters has been highly inflated, considering that they are a minor, discontinuous component of the Coastal Plain of the Carolinas.

## CONCLUSION

Although considerable biostratigraphic refinement needs to be accomplished, Fig. 4 is proposed as a lithostratigraphic framework for North Carolina. The problem will remain that units in which more detailed biostratigraphic information is needed (New Bern, Trent and Belgrade formations) now consist of consolidated and leached molluscan mold limestones. If published eustatic sea level curves (Vail, 1976; Vail et al., 1977) are valid, than perhaps the sequence concept for shallow marine units with endemic faunas will provide a useful tool to help unravel and order the complex stratigraphy of the Coastal Plain Province (see Baum et al., this paper). Thus, the Trent Formation "sequence", both outcrops and downdip subsurface equivalents should represent both the Rupelian and earliest Chattian. The exact age being a function of location and recognition that the maximum extent of the Oligocene sea was during the earliest Chattian. Additionally, it will be necessary to recognize the effects of local tectonic events (Harris et al., this volume; Zullo and Harris, this volume).

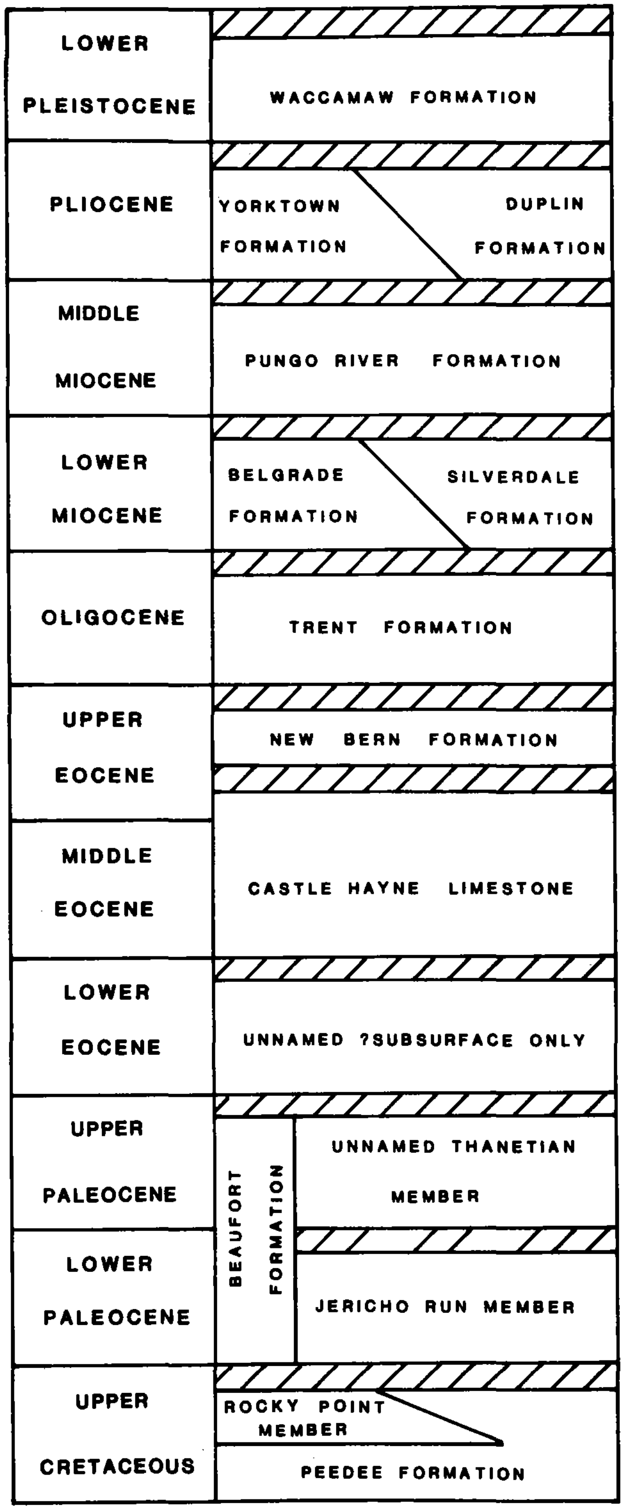


Figure 4. Stratigraphic framework for the upper Cretaceous to lower Pleistocene strata of the Coastal Plain of North Carolina.

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# TECTONIC EFFECTS ON CRETACEOUS, PALEOGENE, AND EARLY NEOGENE SEDIMENTATION, NORTH CAROLINA

by

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## INTRODUCTION

The Atlantic Coastal Plain Province is an oceanward thickening wedge of SE dipping Mesozoic-Cenozoic sediments and sedimentary rocks that unconformably overlie an oceanward dipping pre-Cretaceous basement. Three major structural features modify the general oceanward slope of the basement: Cape Fear fault in North Carolina, Ft. Monroe uplift (Norfolk arch) in Virginia, and Normandy arch in New Jersey.

Traditionally, the Atlantic Coastal Plain has been considered the stable western limb of an offshore geosyncline that has experienced little or no fault activity, only gravity induced subsidence and concomittant uplift (Murray, 1961). Consequently, most geologic interpretations of Coastal Plain geology have been governed by this tradition, with most workers not considering that tectonic activity may have affected Mesozoic-Cenozoic sediment deposition. Therefore, in many cases, the lack of recognition and consideration of the effects of tectonic activity have lead to a general misunderstanding and misinterpretation of Coastal Plain geology.

Hobbs (1904) recognized major lineaments along the Atlantic border region and suggested that the lineaments were the result of a crustal fracture field. Brown et al. (1972) in a study based on subsurface data established a regional tectonic framework for the Atlantic Coastal Plain and found that many of their structural axes coincided with those of Hobbs. Recently other workers have suggested Cretaceous and/or Tertiary deformation in the Coastal Plain of Maryland (Jacobeen, 1972), Virginia (Mixon and Newell, 1977; Dischinger, 1979), North Carolina (Brown et al., 1977; Baum et al., 1978); South Carolina (Inden and Zupan, 1975; Zupan and Abbott, 1975; Higgins et al., 1978; Rankin et al., 1978; Zoback et al., 1978; Baum and Powell, 1979), and Georgia (Prowell et al., 1975; Cramer and Arden, 1978; Cramer, 1979).

The main purpose of this study is to refine and detail the basement-rooted tectonic framework introduced by Brown et al. (1972) for the Atlantic Coastal Plain and to show its sequential effect on Cretaceous, Paleogene, and early Neogene sedimentation in North Carolina. Tectonic activity also has affected Plio-Pleistocene sedimentation, drainage and geomorphology, and is discussed by Zullo and Harris in the following paper.

## GEOLOGIC SETTING

The emerged North Carolina Coastal Plain is underlain by Lower Cretaceous to Quaternary sediments and sedimentary rocks that extend from a feather-edge along the Fall Line to a maximum thickness greater than 3 km at Cape Hatteras. The area represents a typical belted Coastal Plain with younger beds progressively cropping out closer to the coast. Structurally, four major features rooted in the pre-Coastal Plain basement have periodically affected Mesozoic-Cenozoic sedimentation: Cape Fear fault, Neuse fault, Carolina fault, and Graingers wrench zone (Fig. 1). Interpretations of the times of tectonic activity are discussed later in this paper.

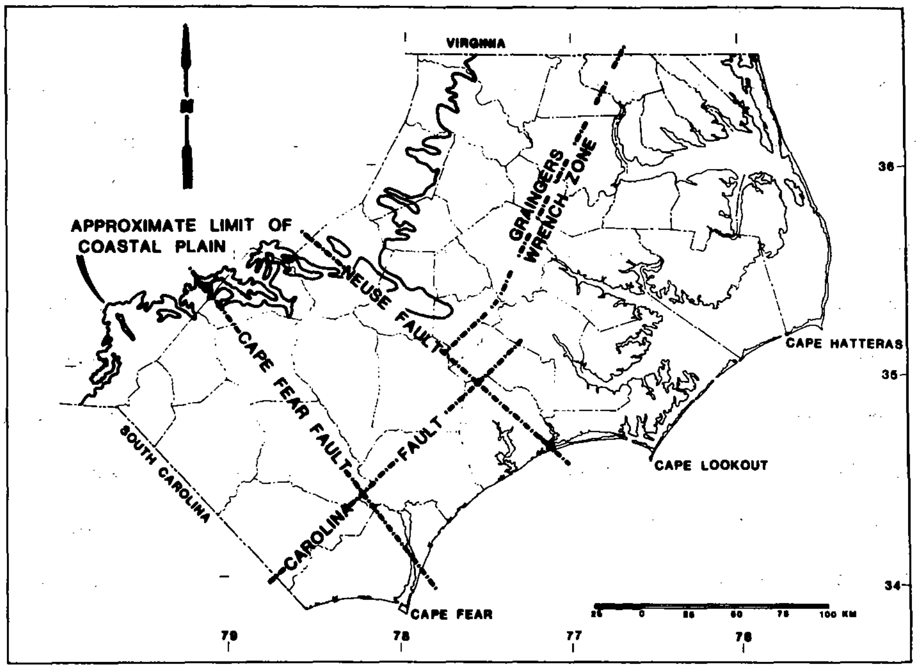

Figure 1. Major structural features of the North Carolina Coastal Plain.

## Cape Fear Fault

Dall and Harris (1892) originally recognized a major positive feature (Cape Fear arch) along the Cape Fear River; however, Stephenson (1923) is usually given credit for first delineating the structure. Since then many workers have documented the presence of a structure along the Cape Fear River that has undergone periodic movement (MacCarthy, 1936; Mansfield, 1937; Richards, 1945; Straley and Richards, 1950; Baum et al., 1977; Harris et al., 1977). Harris et al. (1979) suggested that the Cape Fear arch represents a basement fault that has experienced episodic and differential movement from Lower Cretaceous through the Quaternary.

Cape Fear fault trends NW-SE and can be traced from about Fayetteville, Cumberland County, to Carolina Beach, New Hanover County. The approximate location of the fault is NE of the line separating the Peedee drainage basin from the Cape Fear drainage basin. The direction of relative movements along Cape Fear fault has periodically reversed.

## Neuse Fault

Ferenczi (1959) postulated that a fault occurred along the Neuse River and called the feature the Cape Lookout-Neuse River fault zone. Baum et al. (1978) also recognized the feature and shortened the name to the Neuse fault. Subsequently, Harris et al. (1979) changed the trend of Neuse fault. Neuse fault trends NW-SE parallel to Cape Fear fault and can be traced from about Smithfield, Johnston County, to Bogue Inlet at the mouth of the White Oak River, Onslow-Carteret County line. The fault is probably part of a series of basement faults that occur between the Neuse and New Rivers that have a sense of relative movement with the north side down. Movement along Neuse fault has occurred periodically from Lower Cretaceous through the Quaternary.

### Carolina Fault

LeGrand (1955) and Ferenczi (1959) postulated a fault zone trending NE-SW, parallel to the coast, that could be traced through the vicinity of Kinston, Lenoir County. The unnamed fault was suggested by the occurrence of saltwater incursion near the confluence of the Cape Fear and Black Rivers. Baum et al. (1978) named the feature Carolina fault and showed that the fault can be traced from the confluence of the Cape Fear and Black Rivers, Pender County, to Kinston, Lenoir County. Recent work suggests that the trace of the fault passes through Cove City, Craven County.

### Graingers Wrench Zone

Graingers wrench zone was proposed by Brown et al. (1977) to explain surface topography and anomalous exposures of the Paleocene Beaufort Formation in the Kinston area, Lenoir County. The wrench zone trends NE-SW (parallel to the Carolina fault) and can be traced through the town of Graingers, Lenoir County. Because the projected trace of Graingers wrench zone corresponds to gravity anomalies identified by Johnson (1975), and to geomorphic and stratigraphic features in southeast Virginia, Graingers wrench zone may extend for 250 km. Brown et al. (1977) interpret that the most recent movement along the fault zone has resulted from wrenching along a pre-Coastal Plain basement fault.

Graingers wrench zone consists of a series of en echelon faults that extend north from Neuse fault. Although the sense of relative movement on each individual fault varies within the zone, there is an overall sense of downward movement progressively toward the east. Won et al. (1979) suggest that the Graingers wrench zone coincides with a Triassic Basin border fault and have identified the width and length of the basin from gravity data. The 20 km wide basin occupies the areas bounded by the Graingers wrench zone and Carolina fault. The Graingers fault was active as early as the Triassic (pre-Coastal Plain sedimentation), but wrench movement probably occurred during the Paleocene and maybe as recently as the Quaternary.

## DISCUSSION

### Cretaceous

Clastic sediments of the Fredericksburg and Washita Stages (Cretaceous Unit F of Brown et al., 1972) represent the earliest widespread deposition of Mesozoic sediments in North Carolina. Unit F only crops out south of the Neuse fault, along the Fall Line, but is widespread throughout the Coastal Plain (Fig. 2). The distribution, thickness, and attitude of Cretaceous Unit F suggests that syn-depositional tectonic activity affected Fredericksburg and Washita deposition.

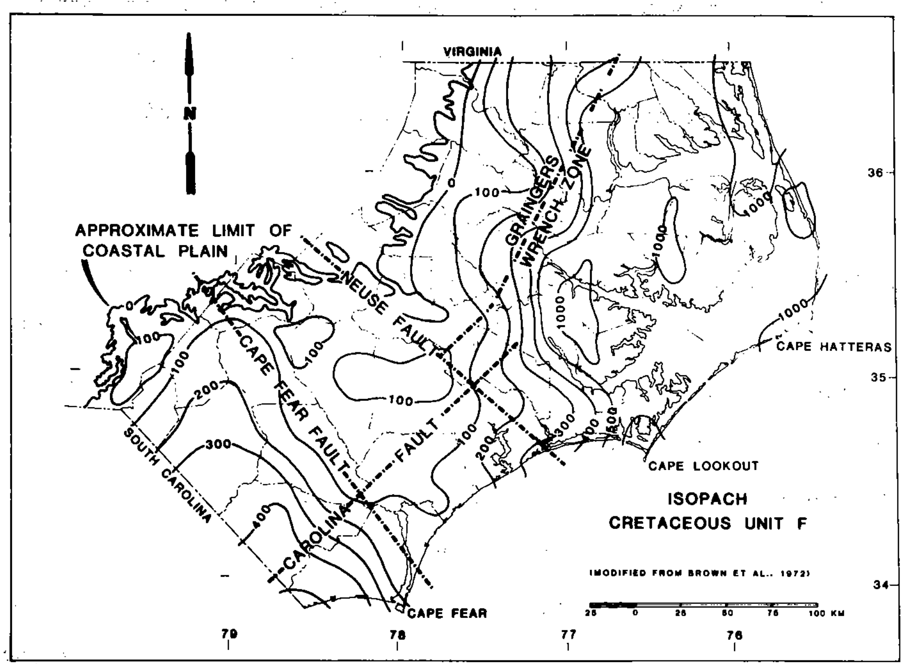

Figure 2. Isopachous map of Cretaceous Unit F (modified from Brown et al., 1972).

Isopachous mapping of Cretaceous Unit F (Fig. 2) reveals that the unit attains a thickness of about 100' (30 m) between the traces of Cape Fear and Neuse faults. South and north of the faults, respectively, Cretaceous Unit F obtains a thickness of about 500' (150 m). Because isopachous relationships are related to basin configurations, as well as tectonism, three possible interpretations can explain the isopach map of Cretaceous Unit F:

1) pre-depositional subsidence north of Neuse fault and south of Cape Fear fault,
2) syn-depositional subsidence north of Neuse fault and south of Cape Fear fault, with sediment deposition equaling subsidence,
3) post-depositional uplift of the area between Neuse and Cape Fear faults.

Comparison of structure contours on top of Cretaceous Unit F (see Brown et al., 1972, Plate 9) with the isopach map of the unit favors interpretation 2.

If pre-depositional uplift elevated the block between Cape Fear and Neuse faults, consequently controlling sedimentation, structure contours on top of Cretaceous Unit F should indicate a structural nose or positive area between the faults that mimics the thinning of the unit illustrated by the isopachous map. Because no high or structural positive is present, pre-depositional uplift probably was not important.

By the same line of reasoning, if post-depositional uplift elevated the block between Cape Fear and Neuse faults, structure contours on top of Cretaceous Unit F should also indicate a positive area between the faults. In addition, if the assumption is made that post-depositional uplift occurred prior to deposition of overlying Cretaceous Unit E, then an isopach of Unit E should mimic the isopach of Unit F by indicating thick areas north and south of Neuse and Cape Fear faults, respectively. Also, lithofacies distributions of Cretaceous Unit E would indicate that the uplifted area had served as a source area during deposition. Because the isopachs of Cretaceous Unit E and Unit F are dissimilar in pattern and because available evidence suggests that Unit E did not serve as a source area, post-depositional uplift of the area between Cape Fear and Neuse faults probably is not responsible for the distribution and thickness of Cretaceous Unit F.

We suggest then that isopachous mapping and structure contours on top of Cretaceous Unit F support syn-depositional subsidence south and north of basement-rooted Cape Fear and Neuse faults, respectively, with sediment deposition balancing subsidence. Regardless of whether syn-depositional subsidence occurred independent of pre- or post-depositional uplift, isopachous mapping of Cretaceous Unit F documents that faulting was active in controlling deposition of the unit. Differences in the amount of dip on Cretaceous Unit F north and south of Neuse fault and the position and outcrop pattern of the unit along the Fall Line suggests some post-depositional shifting or readjustment of the block north of Neuse fault. Available data suggests that Carolina and Graingers faults were not active during the Lower Cretaceous.

There is no evidence of movement along Cape Fear and Neuse faults and Graingers and Carolina faults during the Upper Cretaceous.

## Paleogene

Paleocene. The Paleocene Beaufort Formation crops out in Lenoir and Craven Counties and contains Danian (Brown et al., 1977) and Thanetian equivalents (Harris and Baum, 1977). Danian beds are referred to as the Jericho Run Member and are locally present as a silicified mudstone assigned to the P1 planktic foraminifera zone (Brown et al., 1977). Thanetian beds are unnamed and disconformably overlie the Jericho Run Member of the Cretaceous Peedee Formation. These beds consist of consolidated sandy, glauconitic foraminiferal biomicrosparite and unconsolidated sandy, foraminiferal biomicrite. They correlate with the P4 planktic foraminiferal zone of Berggren (1971). Authigenic glauconites from the Thanetian beds have been dated by Harris and Baum (1977) at 55.7 and 57.8 m.y.

Outcrops of the Beaufort Formation occur near the intersection of Neuse fault and Graingers wrench zone and are related to a structural mosaic of horst, graben, and half grabens with the faults trending NE-SW (Brown et al., 1977) (Fig. 3). These en echelon faults overlie a buried Triassic Basin (Won et al., 1979). Variations in thickness and sudden lateral terminations of the Jericho Run Member and Thanetian

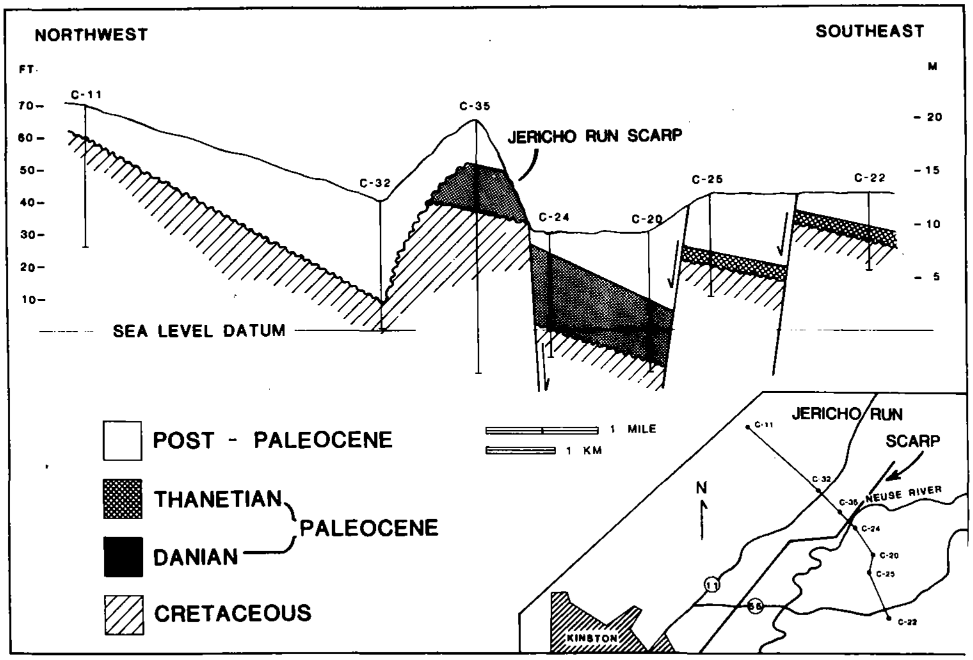

Figure 3. Northwest-southwest section across Graingers Wrench Zone.

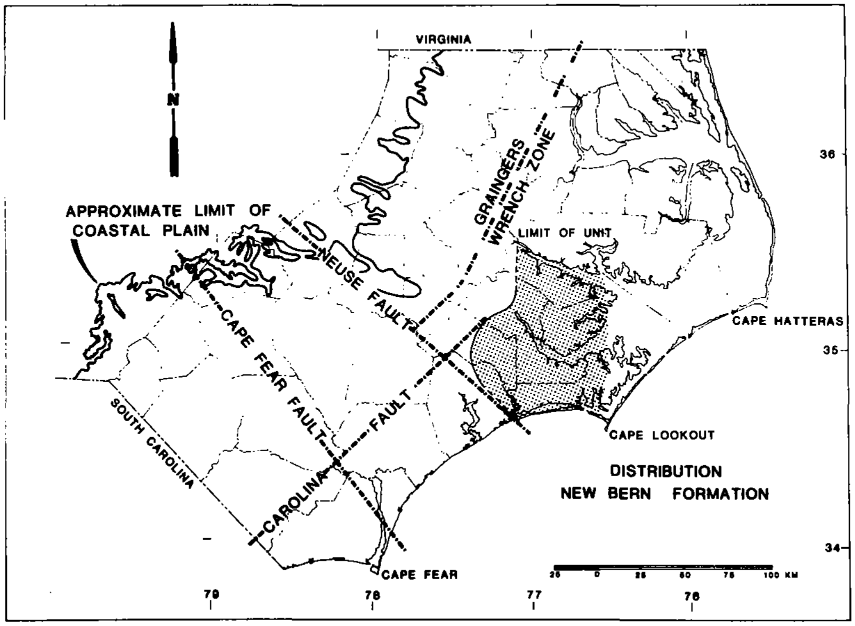

Figure 4. Distribution of the upper Eocene New Bern Formation.

sediments (Fig. 3), suggest that these faults experienced episodic movement during the Paleocene(?) and the post-Paleocene. Except for a minor reentrant of Paleocene beds along the Pender-Onslow County line (see Brown et al., 1972, Plate 15), the Beaufort Formation is restricted to the area north of Neuse fault. The lack of a regionally recognizable marker horizon overlying the Beaufort Formation circumvents establishing the time of post-Paleocene movement. However, offset of the Eocene Castle Hayne Limestone suggests post-Eocene deformation. Brown et al. (1978) recognize the following features that are associated with a NE-SW trending scarp that borders Jericho Run: 1) an uplifted stratigraphic marker horizon, 2) triangular faceting of the scarp, 3) extensive parallel ravinement normal to the scarp, and 4) the presence of breccias along the toe of the scarp. The excellent preservation of these features in a humid environment suggests some Quaternary movement along the Graingers wrench zone.

Eocene. One of the most extensive transgressions of the Cenozoic in North Carolina occurred during the middle to upper Eocene. Eocene seas transgressed most of the Coastal Plain reaching the Fall Line, depositing tropical marine carbonates atypical of other Cenozoic sedimentary units in North Carolina.

The middle to upper Eocene Castle Hayne Limestone consists of three prominent facies: lower phosphate-pebble conglomerate, middle bryozoan biosparrudite, and upper bryozoan-sponge biomicrudite. Bryozoan biosparrudite and bryozoan biomicrudite are the two dominant facies of the Castle Hayne Limestone. Numerous diastems and Dorag dolomitization in the bryozoan biomicrudite in the lower Cape Fear area (Brunswick and New Hanover Counties), suggests movement of Cape Fear fault during middle and upper Eocene.

The upper Eocene New Bern Formation consists of sandy, pelecypod-mold biomicrosparrudite and represents the youngest outcropping Eocene strata in North Carolina (see Baum et al., this volume). "Outcrops of the New Bern Formation are confined to an area lying between the Neuse and Trent Rivers..." (Baum et al., 1978). The New Bern Formation is restricted to the area north of the Neuse fault and east of Carolina fault (Fig. 4). Because of this restriction, and because the New Bern Formation represents a major lithologic change from a carbonate dominated regime (Castle Hayne Limestone) to a clastic dominated regime (New Bern Formation), the area north of Neuse fault was downdropped during latest Eocene. Movement on Neuse fault appears to coincide with movement along "Santee" fault, in the Charleston area of South Carolina (Harris et al., 1979; Baum and Powell, 1979; Baum et al., this volume).

Oligocene. The Oligocene Trent Formation is restricted to the area north of New River, Onslow County, east of Carolina fault. However, the distribution, thickness, and lithofacies of the Trent Formation do not suggest Oligocene movement of Neuse and Carolina faults.

### Neogene

Miocene. The lower Miocene Belgrade and Silverdale Formations (and the Crassostrea beds) are restricted to the area east of the Trent Formation and do not appear to be related to tectonic activity. Depositional strike of these units is N-S; consequently, because of the orientation of the North Carolina coast, they do not crop out south of New River. Fossils assignable to the lower Miocene have been found on Onslow and Topsail beaches, suggesting that these units are exposed on the continental shelf south of New River.

The middle Miocene Pungo River Formation is restricted to the area north of Neuse fault and east(?) of Graingers and Carolina faults (Fig. 5). Miller (1971) suggested that deposition of this unit was controlled by NE-SW trending faults. Deep-water deposits (100-200 m) of phosphate, diatomite, and carbonate suggest that the rate of subsidence exceeded the slow supply of terrigenous sediments (Gibson, 1967).

## SUMMARY

1. Mesozoic and Cenozoic deposition in the North Carolina Coastal Plain was affected by four basement-rooted structural elements: Cape Fear fault, Neuse fault, Carolina fault, and Graingers wrench zone.
2. During the lower Cretaceous (Fredericksburg and Washita stages), syn-depositional tectonism along Cape Fear and Neuse faults resulted in elevation of the area between the faults. Consequently, isopachous mapping of Fredericksburg and Washita sediments reflect thick areas south and north of Cape Fear and Neuse faults, respectively, with an intervening thin area. Structure contours on top of Fredericksburg and Washita sediments do not reflect this uplift, therefore, sediment supply and deposition kept pace with the rate of uplift.
3. The Paleocene Beaufort Formation is restricted to the area north of Neuse fault, and appears to be related to reactivated Triassic faults. Graingers wrench zone and Carolina fault bound and limit Paleocene deposits and reflect movement during the Paleocene. The distribution, thickness and lithofacies of Danian and Thanetian beds support Paleocene movement. The excellent surface preservation of a surface scarp coincident with Graingers wrench zone suggests Quaternary movement.
4. Middle to upper Eocene sediments (Castle Hayne Limestone) support Eocene tectonism in the Coastal Plain. Numerous diastems and Dorag dolomitization in the upper biomicrudite in the lower Cape Fear region suggests late Eocene movement along Cape Fear fault. The restricted occurrence of the upper Eocene New Bern Formation to the east of Carolina fault and north of Neuse fault suggests latest Eocene activity along Carolina and Neuse faults.
5. The distribution, thickness, and lithofacies of Oligocene sediments (Trent Formation) suggests no tectonic activity during that epoch.
6. The distribution of Belgrade and Silverdale Formations and the *Crassostrea* beds do not suggest tectonism during the lower Miocene. The restriction of the middle Miocene Pungo River Formation to the area north of Neuse fault suggests that Neuse fault was active with the north side down.

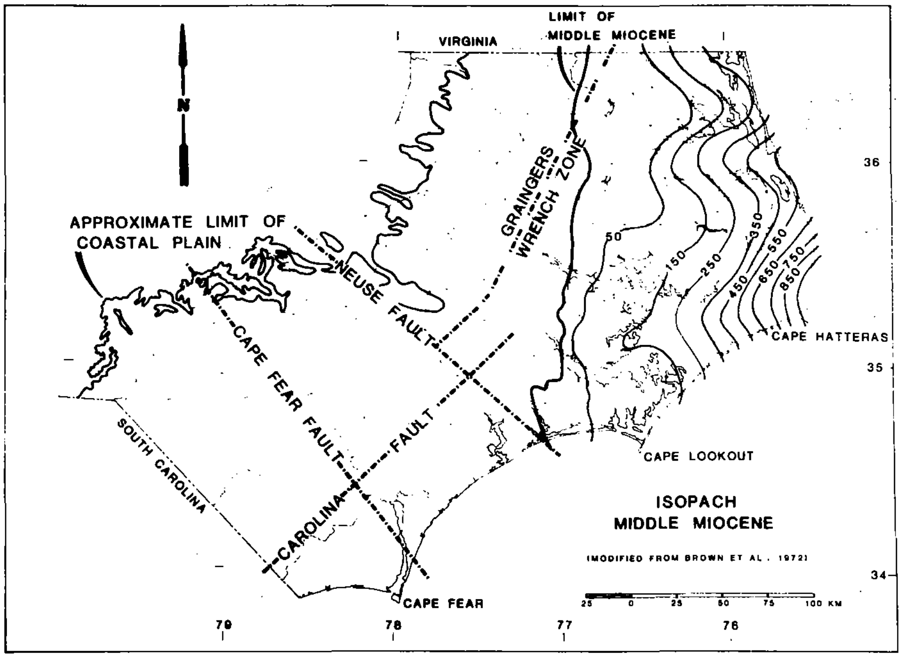

Figure 5. Distribution and thickness of the middle Miocene Pungo River Formation (modified from Brown et al., 1972).

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# PLIO-PLEISTOCENE CRUSTAL WARPING IN THE OUTER COASTAL PLAIN OF NORTH CAROLINA

by

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# INTRODUCTION

Many landforms and associated sedimentary deposits in the southeastern Atlantic Coastal Plain preserve a record of repeated inundations and withdrawals of the sea during the Pliocene and Pleistocene. Traditional interpretations of the origins of these features presume that the Coastal Plain was a stable crustal region during and after their formation. Periodic glacio-eustatic transgressions and regressions of the sea are correlated with interglacial and glacial stages, respectively, of the Pleistocene (e.g., Oaks and DuBar, 1974), or with earlier displacements of ocean basin waters onto the land during episodes of increased sea floor spreading (Le Pichon, 1968).

Reliance on a stable crust model for the explanation of Plio-Pleistocene events is in marked contrast to the conclusions derived from studies of older Tertiary and Cretaceous Coastal Plain sediments, whose distribution and character are known to have been influenced by episodic activity along major structural features (e.g., Baum et al., 1978; Brown et al., 1972, 1977; Ferenczi, 1959; Harris et al., 1979; Richards, 1950). Few studies have suggested that tectonic activity in the Coastal Plain might have played a role in modifying the effects of eustatic sea level change during the Pliocene and Pleistocene. Doering (1960) concluded that upwarping of the Cape Fear arch (fault) in southeastern North Carolina, together with regional uplift of the Appalachian Highlands and inner Piedmont, preceded Pleistocene glacio-eustatic oscillations. Winker and Howard (1977), based on a re-interpretation of relict shoreline sequences in the Atlantic Coastal Plain south of the Cape Fear River, North Carolina, arrived at similar conclusions, and provided tentative evidence for Pleistocene uplift along the Cape Fear fault.

Direct evidence of Pleistocene tectonic activity in the Coastal Plain is difficult to obtain. Faulting of units in subsurface is obscured because of the minor amounts of displacement involved, and because of the thinness, lithologic similarity, and discontinuity of Pleistocene sediments. Surface fault scarps are rapidly obliterated by fluvial erosion of the unconsolidated surficial sediments. Instead, reliance must be placed upon recognition of the secondary effects of tectonic activity on regional geology and geomorphology.

## CAPE-FEAR - NEW RIVER COASTAL PLAIN, NORTH CAROLINA

The geology of Plio-Pleistocene deposits in the outer Coastal Plain between the Cape Fear and New Rivers, North Carolina (Fig. 1) has not been studied in detail. The region is a structural and geomorphic entity bounded to the southwest by the Cape Fear fault, and to the northeast by the Neuse fault. The Cape Fear fault, whose axis is approximated by the course of the Cape Fear River, has been active periodically since Aptian-Albian time and has had a profound influence on the distribution and thickness of Cretaceous and Tertiary units on either side of its axis. Initial movement along the Neuse fault, which can be traced from the vicinity of Smithfield, North Carolina southeast to the coast between New and Neuse Rivers, also occurred during Aptian-Albian time. Changes in structural and depositional strike and thickness of

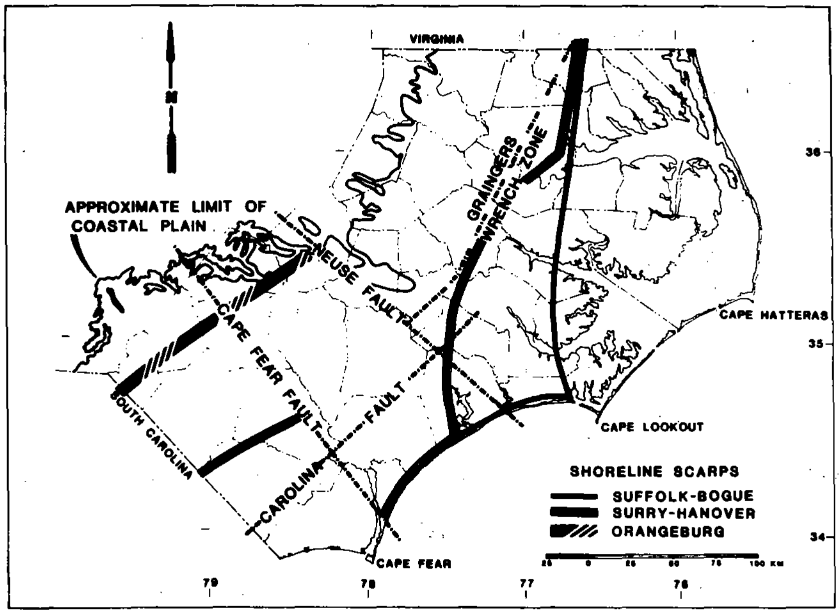
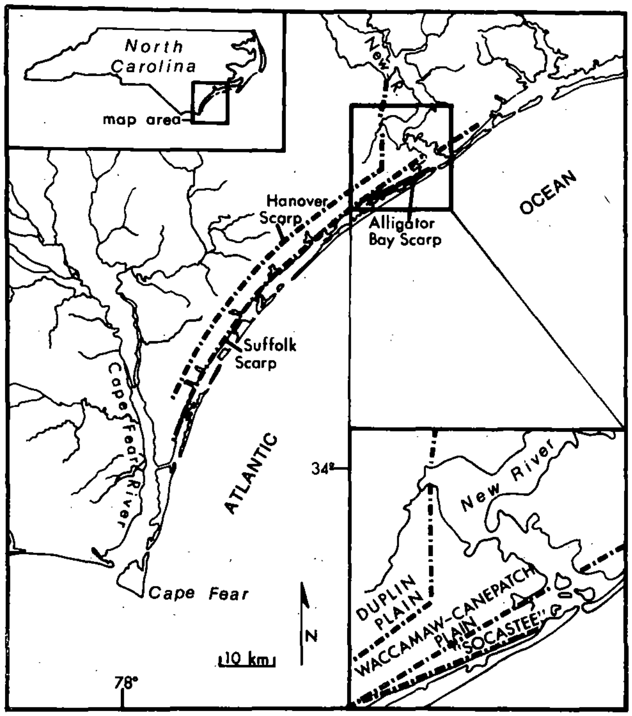
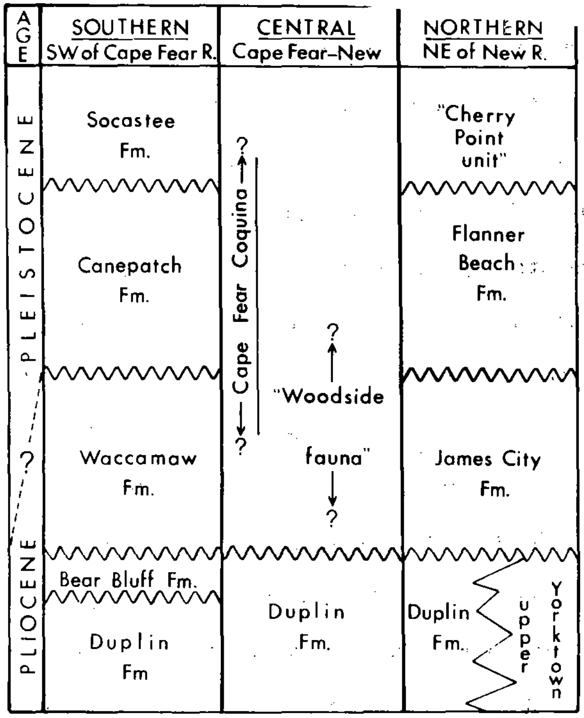


Figure 1. Relation of scarps to major structural Features, North Carolina Coastal Plain.





| AGE | SOUTHERN SW of Cape Fear R. | CENTRAL Cape Fear–New | NORTHERN NE of New R. |
|---|---|---|---|
| PLEISTOCENE | Socastee Fm. | ? ← Cape Fear Coquina → ? | "Cherry Point unit" |
| | Canepatch Fm. | | Flanner Beach Fm. |
| ? | Waccamaw Fm. | ? ↑ "Woodside fauna" ↓ ? | James City Fm. |
| PLIOCENE | Bear Bluff Fm. | Duplin Fm. | Duplin Fm. / upper Yorktown |
| | Duplin Fm | | |

(left)
Figure 2. Location of scarps and plains, outer Coastal Plain, North Carolina.

(right)
Figure 3. Stratigraphic relationships of upper Cenozoic units, Carolina Coastal Plain.

Tertiary units crossing the fault indicate periodic movement in the Paleogene and early Neogene (see Harris et al., this volume).

Unlike adjacent sections, this part of the Coastal Plain is characterized by a dearth of either large scale relict shoreline features or Pleistocene marine deposits. In addition, drainage development and direction of flow differ markedly from those seen in adjacent Coastal Plain sections. Detailed geomorphic analysis, utilizing recently completed 7.5' topographic quadrangles with 5-foot (1.5 m) contours, coupled with field mapping and analysis of subsurface data have been used to delimit relict shorelines and associated marine deposits in the region. The data obtained from these varying lines of evidence indicate that the unusual geologic and geomorphic features of the Cape Fear-New River region are the result of episodic tectonic activity during the Pliocene and Pleistocene.

## SHORELINE SCARPS AND ASSOCIATED MARINE DEPOSITS

An erosional scarp, here designated Hanover Scarp, with an average relief of 5 m can be traced from central New Hanover County northeastward to the west side of New River, Onslow County (Fig. 2). At this point, Hanover Scarp turns abruptly north and is traced for 20 km along the west side of New River. A second scarp, located seaward of Hanover Scarp and essentially delimiting the modern mainland coastline, parallels Hanover Scarp between central New Hanover County and New River. This scarp, as predicted by Mixon and Pilkey (1976), is the southwesterly continuation of their Bogue Scarp. Bogue Scarp as mapped by Mixon and Pilkey (1976) continues northeastward past New River and parallels the shoreline into central Carteret County where it connects with elements of the north-trending Suffolk Scarp of southeastern Virginia (Mixon and Pilkey, 1976; Oaks and DuBar, 1974). A third scarp, here designated Alligator Bay Scarp, occurs seaward of Suffolk Scarp between Spicer and Alligator Bays west of New River. This minor scarp is submerged southwest of Spicer Bay, and has not been mapped northeast of New River, although Mixon and Pilkey (1976) indicate the presence of what is presumed to be this scarp along part of the Bogue Sound shoreline.

These three scarps form the seaward borders of tilted plains. These plains are immediately underlain by a veneer of nonmarine deposits that overlie fossiliferous marine sediments, and are regarded as subaerially modified sea floors of former marine transgressions. The surface landward of Hanover Scarp is an extensive, moderately dissected, west to northwest sloping plain. This plain is continuous inland to the seaward edge of the inner Coastal Plain (Orangeburg Scarp), and is characterized by the development of Carolina Bays. In the Early Pliocene the outer and middle southeastern Atlantic Coastal Plain was inundated by the Duplin sea to Orangeburg Scarp. The youngest fossiliferous marine deposits underlying the plain between Orangeburg and Hanover Scarps are outliers of the Duplin Formation (Figs. 3 and 4).

The dissected plain between Hanover and Suffolk Scarps is underlain by younger marine deposits including equivalents of the Waccamaw and overlying Canepatch formations of South Carolina (Figs. 3 and 4).

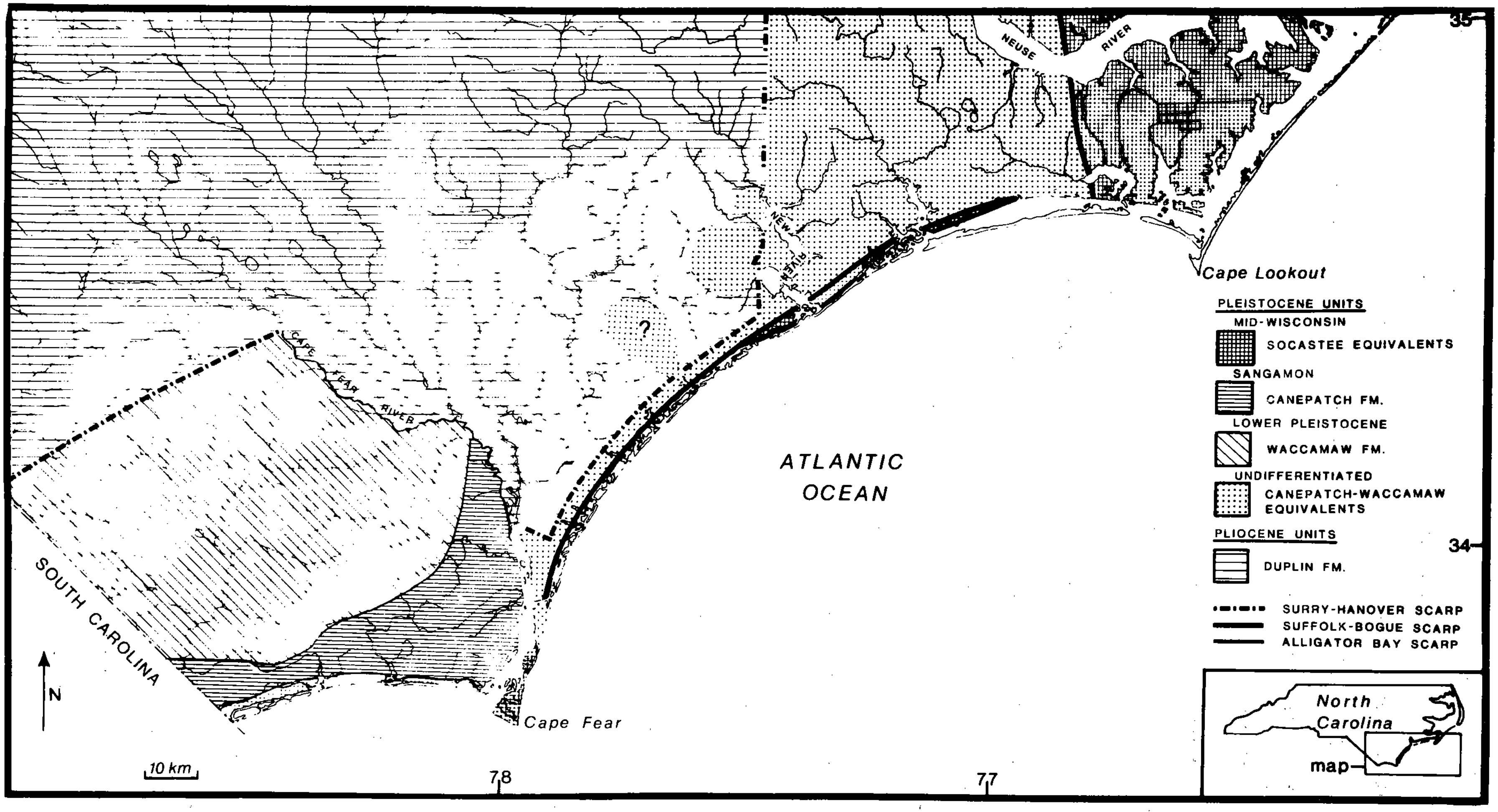


Figure 4. Geology of Plio-pleistocene deposits, outer Coastal Plain, North Carolina (modified from DuBar _et al._, 1974; Mixon and Pilkey, 1976).

The age of these units is not established conclusively, but the marine transgressions responsible for their deposition appear to have occurred between the beginning of the Pleistocene (Calabrian) and the end of the Sangamon Interglacial (Campbell et al., 1975; DuBar et al., 1974).

Subsurface stratigraphy of the plain between Alligator Bay and Suffolk Scarps is not known. Richards (1950) reports fossils from this area that may be related to the Socastee fauna. The Socastee Formation overlies the Canepatch Formation in South Carolina and is considered to represent a minor transgression during the mid-Wisconsin Interstadial (Figs. 3 and 4). Socastee equivalents are known east of Suffolk Scarp farther to the north in the Neuse River region, North Carolina (Mixon and Pilkey, 1976; Oaks and Dubar, 1974).

## DISCUSSION

Assuming that the Duplin plain, the Waccamaw-Canepatch plain, and the "Socastee" plain were formed as nearly horizontal surfaces, the presently observable slopes and slope directions on the plains indicate that episodic and differential uplift have occurred in the region (Fig. 5C). The Duplin plain is at an elevation of 12.2 m in central New Hanover County, but to the northeast, over a distance of 60 km, its elevation gradually increases by nearly 9 m to 21 m on the west side of New River. The Waccamaw-Canepatch plain rises less than 2 m between central New Hanover County and New River, and the "Socastee" plain, although only traceable for about 12 km southwest of New River, rises from sea level to 4.6 m at New River. Although all three plains presently dip west or southwest from an axis along New River, the observed differences in slopes of these plains are indicative of at least three periods of tectonic activity between the time of withdrawal of the Duplin sea and the present.

The divergence of slopes of the Duplin and Waccamaw-Canepatch plains towards New River indicates uplift along the Neuse fault after withdrawal of the Duplin sea and prior to Canepatch transgression (between three million and 75,000 years ago). The divergence of slopes of the Waccamaw-Canepatch and "Socastee" plains toward the Cape Fear fault indicates uplift of the fault after Canepatch sea withdrawal and prior to transgression of the Socastee sea (between 75,000 and 32,000 years ago). The divergence of slopes of the "Socastee" plain and the modern sea level plain towards New River indicates uplift along the Neuse fault in the past 30,000 years that resulted in the present attitude of the plains (Figs. 5A-C).

Post-Waccamaw-Canepatch uplift along the Cape Fear fault also is recorded by regional anomalies in distribution and elevations of these formations. The Cape Fear River, whose course approximates the trend of the Cape Fear fault, forms the boundary between two distinct geologic regions. Northeast of the river the Waccamaw and Canepatch formations are restricted to the narrow coastal strip seaward of Hanover Scarp, and are not found above +5 m elevation. Southwest of the river the Waccamaw Formation extends about 80 km inland to the seaward edge of the middle Coastal Plain (Surry Scarp), and its base is found at elevations up to +28 m (DuBar et al., 1974; Howard, 1974). The Canepatch Formation extends about 20 km inland, and its base occurs at elevations up to +13.7 m (DuBar et al., 1974).

The widespread distribution and higher elevations of Pleistocene formations southwest of the Cape Fear River indicate that: (1) prior to Waccamaw-Canepatch deposition the region southwest of the river was lower than the region to the northeast; and (2) after Waccamaw-Canepatch deposition the southwestern region was uplifted with respect to the northeastern region. This uplift is tentatively correlated with the initial "reverse" tilting of the Waccamaw-Canepatch plain between Cape Fear and New Rivers.

Late Pleistocene uplift along the Cape Fear fault is further suggested by modern drainage patterns (Fig. 1). The Cape Fear drainage basin is narrow and exhibits a parallel pattern with dominant southeasterly flow. Inland the Cape Fear River flows at the base of a high, northeastward-facing bluff that forms an extremely narrow divide with the Lumber-Big Swamp drainage basin to the southwest. This bluff, actually a receding fault line scarp, loses elevation seaward, and is not distinguishable in the outermost Coastal Plain. Here the divide between the Cape Fear and Waccamaw drainage basins is broad and low, and no abrupt change in elevation marks the divide. Drainage patterns in the Lumber-Big Swamp and Waccamaw basins are dendritic, and flow predominantly to the southwest. The Lumber-Big Swamp and Waccamaw drainage systems are characterized by underfit, poorly integrated, complexly meandering streams occupying very large floodplains, whereas the Cape Fear drainage system is well integrated and composed of streams in accord with their floodplains.

We propose that the Cape Fear system is younger than drainage systems to the southwest, and developed as a result of uplift of the Coastal Plain southwest of the Cape Fear fault. Prior to uplift, runoff from the inner Coastal Plain and Piedmont flowed southwesterly across what is now the Cape Fear drainage basin, and deposited the sequence of prograded fluviodeltaic sediments described by DuBar _et al_. (1974) as overlying marine Plio-Pleistocene deposits southwest of the Cape Fear River. Uplift resulted in the beheading of these major drainage systems, causing the formation of underfit streams downstream, and in the deflection of upstream runoff to the southeast, forming the Cape Fear drainage system.

On the basis of the data presented, we propose the following sequence of geologic events:

(1) In the early Pliocene the Duplin sea transgressed over the outer and middle Coastal Plain, cutting and occupying Orangeburg Scarp.

(2) Uplift along the Neuse fault parallel to the modern course of New River occurred after withdrawal of the Duplin sea from the Coastal Plain (circa three million years ago), and resulted in warping of the Duplin plain and a general westward dip to the surface between Cape Fear and New Rivers (Fig. 5A).

(3) In the (?early) Pleistocene, the Waccamaw sea transgressed over unelevated regions of the Coastal Plain southwest of Cape Fear River and northeast of New River, cutting and occupying Surry Scarp. The Waccamaw transgression was insufficient to inundate the uplifted region between Cape Fear and New Rivers, and was limited to the cutting and occupation of Hanover Scarp.

(4) Withdrawal of the Waccamaw sea from the Coastal Plain was followed by the less extensive Cane-

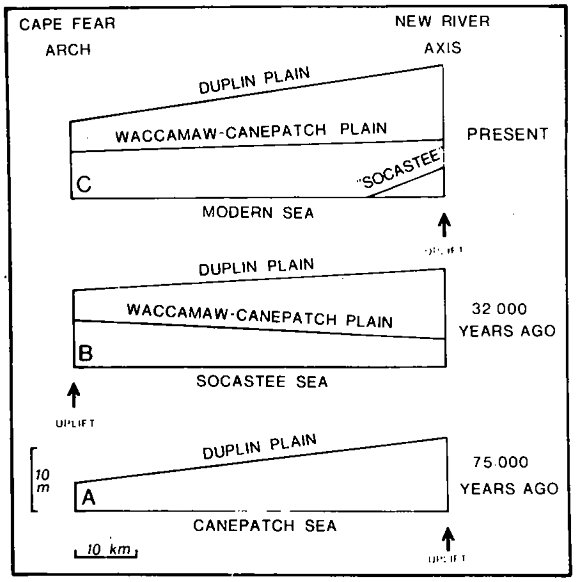


Figure 5. Diagrammatic SW-NE profiles of plains between Cape Fear and New Rivers. (A) Slope of Duplin plain during occupation of Hanover Scarp by Canepatch sea. (B) Slope of Duplin and Waccamaw-Canepatch plains during occupation of Suffolk Scarp by Socastee sea. (C) Present slopes of Duplin, Waccamaw-Canepatch, and "Socastee" plains during modern (Holocene) transgression. Arrows below profiles indicate area of preceding tectonic activity.

patch transgression that re-occupied part of the unelevated outer Coastal Plain and Hanover Scarp during the Sangamon Interglacial.

(5) Withdrawal of the Canepatch sea, presumably at the end of the Sangamon (circa 75,000 years ago) was accompanied by uplift along the Cape Fear fault that resulted in elevation of the region southwest of the Cape Fear River, the development of the Cape Fear drainage system, reduction in the general westward slope of the Duplin plain, and the initial "reverse" or eastward slope of the newly formed Waccamaw-Canepatch plain (Fig. 5B).

(6) The Socastee transgression during the Wisconsin Interstadial (circa 32,000 years ago) occupied coastal regions on both sides of the Cape Fear River and cut and occupied Suffolk Scarp northeast of the river. Further uplift along the Neuse fault occurred after withdrawal of the Socastee sea and resulted in presently observed plain slopes and elevations in the region between Cape Fear and New Rivers (Fig. 5C).

## IMPLICATIONS

Recognition of tectonic activity during periods of eustatic sea level change significantly alters interpretations of Plio-Pleistocene history of the North Carolina Coastal Plain. Some determinations of Pleistocene sea level are based on localities now known to have undergone appreciable post-depositional uplift. Regional correlation of scarps and associated relict shoreline features requires re-examination, as it is based on overestimates of maximum sea level and on assumed crustal stability. Furthermore, documentation of Plio-Pleistocene crustal instability in one part of the Atlantic Coastal Plain suggests the possibility that other areas were similarly affected. We offer the suggestion that at least some of the problems encountered in the elucidation of Plio-Pleistocene geologic history of the Coastal Plain may best be solved through abandonment of the stable crust model.

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# SOME STRATIGRAPHIC PROBLEMS OF THE PLEISTOCENE STRATA IN THE AREA FROM NEUSE RIVER ESTUARY TO HOFMANN FOREST, NORTH CAROLINA

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This article is somewhat tangential to the main purpose of this field trip on the Paleogene and Miocene of the outer Coastal Plain. Nevertheless, a brief statement about some of the problems presented by these "Surficials", which, to the frustration of economic geologists, cover up so many of the "important rocks" seems in order.

The North Carolina Coastal Plain is veneered nearly everywhere by a few meters of unconsolidated sediments, usually sandy, which are informally called "Surficials." In the upper Coastal Plain to the west of the Orangeburg or Coats scarp these "Surficials" are generally regarded as Pliocene or, at most, upper Miocene in age. The middle Coastal Plain, between the Coats and Surry scarps has sediments of Pliocene or older Pleistocene age (Daniels et al., 1978).

The area of this field trip lies entirely within the lower Coastal Plain to the east of the Surry scarp. The "Surficials" here are of younger Pleistocene age and belong to three stratigraphic units. These outcropping units are the Wicomico morphostratigraphic unit (msu) between the Surry and Walterboro scarps; the Talbot (or Chowan) msu (or Flanner Beach Formation in part) between the Walterboro and Suffolk scarps; and the Pamlico msu (or Core Creek Formation) from the Suffolk scarp to the sea. Another unit, the lower Pleistocene Croatan Formation, underlies the surficials in the eastern part of the area of this field trip with discontinuous patches as far west as the Surry Scarp at Fountain (Snyder and Katrosh, 1978).

The presence of scarps and terraces resulting from changing sea levels has dominated geomorphic interpretations of this area. These, in turn, have influenced the stratigraphic interpretations. Oaks and DuBar (1974a) have ably summarized the earlier literature. They (p. 4) note that "the surface of the coastal plain consists of a series of broad, gently eastward sloping plains or 'terraces,' of considerable lateral extent coastwise, which are separated by linear eastward-facing scarps. Each 'terrace' was inferred to be a wave-cut surface thinly veneered with marine sediments, and to terminate landward (westward) at a wave-cut scarp.......The same name was applied to the stratigraphic unit, to the 'terrace' it was presumed to underlie and to the bounding landward scarp. Former positions of sea level were presumed to lie at the top of each scarp." Chief among these earlier workers were Shattuck (1906), Johnson (1907), Stephenson (1912), and Cooke (1931).

Starting with Moore (1956), workers have been more cognizant of the need to discriminate as to whether a terrace was erosional or depositional or both; whether the sediment now flooring the terrace was older than or penecontemporaneous with the stillstand of the sea that permitted the scarp to be cut; and to establish the facies present and the relationships of all these considerations to the geomorphology. Some of the modern workers with appropriate references are: Oaks and Coch (1973), Oaks and DuBar (1974b), Oaks et al., (1974), and Johnson (1972) in Virginia; Mixon and Pilkey (1976) and the present authors, Daniels et al. (1972, 1977a), and Daniels et al. (1978a), and DuBar et al. (1974) in

North Carolina; and Colquhoun (1969) and Colquhoun and Johnson (1968) in South Carolina.

The normal progress of stratigraphic work tends to leave behind it a wake of nomenclature. Much of this nomenclature merely reflects the increased refinement and discrimination as more knowledge accumulates. Some of the nomenclature reflects the differing viewpoints of succeeding generations or of contemporaneous competitors.

The oldest Pleistocene unit in this area is the Croatan Formation, which is not a "Surficial." It is now regarded by most workers as lower Pleistocene in age (Akers, 1972); although it was generally thought to be Pliocene until this decade (Mansfield, 1928; DuBar and Solliday, 1963).

The Croatan Formation consists of sand and sandy loam which are rich in marine fossil shells at many localities. In certain areas, there are marine zones which include one or more organic layers which may be peats or loamy sands with abundant pieces of cypress wood or may be merely organically stained sediments which are paleosols.

The Croatan Formation was really named for a collection of fossils from the type localities and was regarded as Pliocene in age. In his measured section on the south bank of the Neuse estuary about 13 miles below New Bern, Dall (1892, p. 5) noted 10 feet of "soil and ferruginous sand" at the top, underlain by "ferruginous sandy clay, 10 to 12 feet," and under that "bluish clay with fossils (Pliocene), 5 to 6 feet." He explicitly labeled the lower clay as Pliocene and noted its differing lithology. He did not explicitly place the top of the Croatan Formation at the top of the blue clay. Mansfield (1928, p. 135), however, noted that there were two faunas mixed in the collections from these localities, one Pliocene and one Pleistocene, and he proposed to restrict the name Croatan to the Pliocene part. He noted an unconformity at the top of the Croatan Formation.

DuBar and Solliday (1963) took note of the confusion in the fossils that were collected for Dall and were unable to find an unconformity at the base of the Flanner Beach Formation in the type area "11 to 15 miles" downstream from New Bern. Also, they regarded the organic layer at the base of the section at Flanner Beach as being part of the Flanner Beach Formation and noted (p. 223) in a significant comment that this layer "grades laterally into the units which Mansfield apparently restricted to the Pliocene." (It is our view that the organic layer grades laterally into typically Croatan layers, precisely because it is part of the Croatan Formation). For these reasons they renamed the unit as the James City Formation.

In our augering in the type area of the Croatan Formation, we find an abrupt change in lithology between the Flanner Beach Formation and the underlying Croatan Formation. This is true on the Cherry Point Marine Air Station at Slocum's Creek (one of Dall's localities). Also, we can see the disconformity a foot above the water line at a beach two miles west of Slocum's Creek (and two miles east of Flanner Beach) which is probably Dall's other Croatan locality. Many fossil colonial coral masses can be seen in the fine-grained Croatan sediment in just a few inches of water. Corals are very rare in the Flanner Beach Formation.

The type locality of the James City Formation of DuBar and Solliday (1963) is in James City, three miles southeast of New Bern and 9 to 11 miles upstream from the two "type" localities of the Croatan. We believe that the Croatan Formation as defined (however poorly) by Dall and redefined clearly by Mansfield (1928) is a valid name and that the name James City Formation is a junior synonym.

In the course of our work in the peninsula between the Neuse and the Pamlico rivers, just to the north of the area of this field trip, it began to be evident that the uppermost few inches of a sedimentary unit immediately underlying the Talbot or Pamlico units were usually organic and had a distinctive dark brown color. As we worked south, we encountered more organic matter. We gave this unit a provisional name of the "Small Sequence." In the area south of the Neuse River there were often more than one organic layer, up to five layers near Harlowe Creek which is northwest of Morehead City and southeast of the type area. These organic layers were intercalated with layers containing marine fossils.

It is exactly in this Harlowe Creek area that Mixon and Pilkey (1976) have placed their "Neuse River paleochannel." It is our belief that this material is a part of the Croatan Formation and that a later Pleistocene paleochannel is not needed in order to explain the presence of much woody organic material.

On the peninsula between the Neuse and Pamlico rivers, the Croatan Formation rests unconformable on the Yorktown Formation. The top few inches of the Yorktown in most of our auger holes are either a whitish calcareous fine sediment that is much lighter in color than most of the formation, or is so calcareous as to impede the augering. This surely represents a zone of calcium carbonate deposition due to subaerial weathering on an old erosion surface subsequently buried by the mostly marine sands of the Croatan Formation. The contrast between the Yorktown and Croatan formations can be clearly seen in some of the walls of the Texasgulf phosphate pit, also called the Lee Creek mine, at Aurora. The faunas are also quite different. For instance, the Yorktown Formation contains abundant Ecphora; the Croatan Formation does not.

We disagree with the statement of Mixon and Pilkey (1976, p. 7) that "until detailed field mapping and regional biostratigraphic studies determine that these strata form a mappable lithic unit separable from the Yorktown beds in nearby areas, both in the subsurface and exposed at the surface (for example, Lee Creek phosphate mine in Beaufort County), it appears more logical to include them in the Yorktown Formation."

We hope that the many auger holes we have put down in this region constitute sufficient detail to confirm our conclusions (see Daniels et al., 1972, Fig. 4). In addition to the auger holes plotted on that map, we subsequently drilled a series of holes connecting our previous work to the section and the Texasgulf pit. These are shown in a cross-section which was appended to our 1972 guidebook. We believe that our auger data show clearly that the Croatan Formation unconformably overlies the Yorktown Formation from Aurora south to the Neuse River.

South of the Neuse River, the Yorktown Formation is commonly missing and the Croatan Formation lies directly on Eocene or Oligocene units.

Mixon and Pilkey further state (1976, p. 9) that "it would seem that the 'Small sequence' is not a valid geologic unit." With that much we agree. It is not valid because it is synonymous with the Croatan Formation, a conclusion we reached not long after the publication of our 1972 guidebook. Their full statement is that it "is not a valid geologic unit, in either lithostratigraphic or biostratigraphic sense, inasmuch as it lumps dissimilar stratigraphic units such as the marine James City Formation of DuBar and Solliday (1963) (Pliocene?), the cypress stump bed at Flanner Beach and other swamp deposits (Pleistocene), and fossiliferous marine beds in the area of the Texasgulf Sulphur phosphate mine which appear to have been assigned to the Yorktown Formation (Miocene and Pliocene) by other workers."

It is our belief that our work is sufficiently regional and sufficiently detailed to show that these various localities and lithologies do, indeed, belong to the same stratigraphic unit.

The "Surficials" underlying the Wicomico and Talbot (= Chowan) surfaces may prove to be one stratigraphic unit. We have augered sediments along and on either side of the Walterboro (45 ft.) scarp and have found only limited evidence of any inset relationship of the Talbot msu.

The Wicomico msu lies to the west of the Talbot msu between the Surry scarp at 29 m (90 ft.) and the Walterboro scarp at 14 m (45 ft.). Although there is no obvious lithologic break between the two units, the Wicomico unit as a whole is slightly coarser. There is more medium and coarse textured sand and not as much silty material so common in the Talbot msu along its eastern half. Also, the Wicomico sediments are more dissected, and the streams have cut to greater depths than on the Talbot and Pamlico surfaces. As a result, there is more water movement and a greater depth to gley colors.

An interesting exception is in the area of Hofmann Forest. The Hofmann Forest pocosin is an area of 34,000 hectares (120 sq. mi.) in Jones and Onslow counties which has histosols 0.4 to 2 m (1.3 to 6 ft.) thick. This pocosin lies at about 17 m (53 ft.) above sea level (Daniels et al., 1977b). It occupies portions of the Wicomico and Talbot plains at elevations of 20 to 12 m (65 to 40 ft.). The presence of this peatland shows that something is retaining or adding water to the interstream divides.

Most of the organic materials are highly decomposed except for local accumulations of the logs of the Atlantic white cedar. Carbon content ranges from 6 to 45%, and the mineral content is high (about 50% by weight but 10% or less by volume). The contact between the organic and underlying mineral sediments is gradual (Daniels et al., 1977b, p. 1177).

A continuous or nearly continuous organic cover is suggested by the underlying mineral soils that have little horizonation but do have gley colors (5GY 4/1 or similar) within 1.4 m of the mineral surface under all organic areas of the forest (Daniels et al., 1977b).

Gley sediments require an interpretation of water movement different from that of brown and gray sediments. The gleyed sediments are beds through which little or no water has moved. They have changed little since deposition. Sediments with gley colors usually have high amounts of ferrous iron. The flatness of the terrain and the wide spacing of natural channels inhibits natural flow through the Wicomico sediment.

The underlying Castle Hayne (Eocene) or Trent (Oligocene) formations can be good aquifers. But their properties in the subsurface of this area are such that they are virtually impervious. Peek and Nelson (1967) regard the center of the divides between the Pamlico and Neuse Rivers as recharge areas for the Castle Hayne aquifer. This is not the case in the Hofmann Forest pocosin where the presence of histosols at the surface and gley colored sediments just below show that little or no water is moving downward.

The Croatan Formation discontinuously underlies the Wicomico in the Hofmann Forest area and is of minor importance there.

The Talbot msu occurs between the toe of the Walterboro scarp, altitude 14 m (45 ft.) and the Suffolk scarp. The Talbot msu ranges in texture from sand to silt to clay. It is coarsest at the base in about half of our drill holes. However, as at Flanner Beach section, vertical and horizontal changes in texture occur over short distances. The Talbot is most fossiliferous south of the Neuse River. The fossils may form a very concentrated layer or layers such as the basal very thin Rangia zone and the immediately overlying Dinocardium zone at Flanner Beach and also at Baird Creek on the north side of the Neuse River, or they may be scattered throughout a silty or clayey matrix.

It has been shown (Gamble et al., 1970) that the weathering on the Coastal Plain of the Carolinas is such as to create A-horizons that are mistaken for separate formations. Such an A-horizon may have a rather abrupt base, so abrupt as to give the appearance of a sandier unit overlying a silty clay loam to sandy loam. It is our view that this is exactly the case at Flanner Beach. Our detailed drilling there combined with examination of the cliff has shown that, although fossils do in fact thin out above the basal part of the Flanner Beach Formation, much of the disappearance upward of calcareous shells has been due to leaching. The middle of the cliff shows small holes marking the sites of external molds. Higher up, these holes have collapsed or have been infilled. As the surface is reached the pedogenic processes have completely destroyed any vestige of the fossils. Accordingly, we would disagree with Fallaw and Wheeler (1971) when they set aside the name, Flanner Beach Formation, and proposed the name, Neuse Formation, with a type locality at Baird Creek across the Neuse estuary, on the premise that DuBar and Solliday (1963) had included two units in their Flanner Beach Formation. The present authors believe that it is one formation, the Flanner Beach Formation, which differs significantly toward the top only because of pedogenesis.

Another controversy has been the organic clay underlying the Flanner Beach Formation at the Flanner Beach locality. Richards (1950, p. 33) referred this unit to the Horry Clay, which has its type locality in northeastern South Carolina. Whitehead and Davis (1969) regarded it as an organic clay in the interglacial Flanner Beach Formation. DuBar and Solliday (1963, p. 230) placed the "peaty sandy clay with cypress logs and stumps" at the base of the Flanner Beach Formation.

We regard the presence of organic layers as very typical of the Croatan Formation throughout its extent. This layer is at the top of the Croatan Formation and is overlain by the basal layer of the Flanner Beach Formation which is very rich in small and large marine invertebrate fossils.

The Pamlico msu includes all surficial Pleistocene sediments of the mainland east of the Suffolk (or Grantsboro) scarp. The Pamlico sediments are commonly fine textured in the upper 0.9 to 1.5 m (3 to 5 ft.) and range from sand to silty clay loam at the base. Marine fossils are abundant both as a basal hash layer and as shells dispersed throughout a sandy matrix. Members of the Core Creek Formation have been named and described in detail by Mixon and Pilkey (1976).

The Suffolk scarp has a toe at about 6 m (19 ft.). It is very conspicuous from the Virginia line to the Neuse River. Mixon and Pilkey (1976) have named it the Grantsboro scarp on the Neuse-Pamlico peninsula. From the Neuse River south to Bogue Sound it is less distinct, although still discernable in many places. The scarp turns abruptly southwest and lies 1.6 or 3.2 km (1.0 or 2.0 mi.) inland and parallel to the present coastline at least as far south as Pender County.

Although the Minnesott or Arapahoe ridge lies just to the north of the field trip area, a consideration of it will show some features pertinent to the areal geology. From Minnesott Beach north to a point west of Aurora, the Suffolk (or Grantsboro) scarp rises from 6-13 m (19-40 ft.) in elevation. The scarp is accentuated here by the presence along its top of a linear sand ridge which rises slightly above 19 m (60 ft.). Large sand ridges of the Atlantic Coastal Plain are generally regarded as former offshore barriers and cross-sections show the ridge as a barrier island sand interfingering to the back side (to the west) with silty sediments of the lagoon (Daniels et al., 1977a).

But here the picture is quite different. The present soil horizon on the Talbot surface continues at about 13 m (40 ft.) eastward at the same elevation but beneath the sand ridge reaching almost, but not quite, to its eastern margin. Although not quite as clearly shown, it is probable that the Minnesott or Arapahoe ridge sand is continuous with the Core Creek Formation (Pamlico msu) to the east which underlies the 6 m Pamlico surface. In other words, this is a storm beach on a normal shoreline and not an offshore barrier. This runs contrary to previous views; however, we are in agreement with Mixon and Pilkey (1976).

The area north of the estuarine portion of the Neuse River is nearly flat and featureless with only minor variations in elevation with the exception of the very prominent Suffolk scarp and its associated

Arapahoe (or Minnesott) sand ridge. The area between the Neuse estuary and Bogue Sound is another matter. This area is well described and illustrated by Mixon and Pilkey (1976, p. 10-11). They note that "the sand ridges and the underlying well-sorted sand deposits of the Newport area are comparable to land forms and associated sedimentary deposits of other coastal regions which have been interpreted as beach-ridge complexes and are inferred to have a similar origin." These converging beach ridges and intervening swales are beautifully shown in aerial photographs.

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# ORIGIN OF AN OUTLIER OF THE EOCENE CASTLE HAYNE LIMESTONE IN DUPLIN COUNTY, NORTH CAROLINA

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# INTRODUCTION

The major outcrop belt of the middle Eocene Castle Hayne Limestone in the Coastal Plain of North Carolina is essentially continuous and lies directly beneath Pleistocene surficials. The Castle Hayne Limestone consists of four major lithologies: (1) a discontinuous basal phosphatic conglomerate facies is overlain by (2) a relatively high energy, cross bedded, biosparite facies in the western parts of the belt, (3) a quieter and deeper water biomicrite facies to the east, and (4) an even deeper water, foraminiferal biomicrite facies on the western edge of the outcrop belt that continues eastward in the subsurface (Baum et al., 1978). Cretaceous sediments belonging to the Peedee Formation underlie the Pleistocene surficials to the west of this belt (Swift, 1964), and are overlain by outliers of the Castle Hayne Limestone. These outliers are concentrated in Duplin, Wayne, Lenoir, Pitt, and Green Counties. They consist of surprisingly thick accumulations of sediment occupying depressions in the underlying Peedee Formation, and indicate that the Castle Hayne Limestone was once more extensive in its westward distribution. Studies of these outliers are important to the overall understanding of the Castle Hayne Limestone because they provide a better idea of the original extent of the formation and its facies.

Because these outliers have little or no surface expression, it has been difficult to determine their location, size, and distribution. Some have been exposed by downcutting streams and lime sinks. Most, however, have been discovered accidentally while drilling or excavating. Many are now used for sources of ground water (Pusey, 1960), and several are being quarried. Drilling shows that many are more than 100 ft (30.5 m) thick, and some are large enough to supply water for 15 domestic wells (Pusey, 1960).

Four common geologic processes can produce a depression in which sediment may accumulate and be preserved: (1) pre-, syn-, or post-depositional faulting; (2) solution of underlying sediments to form sinks; (3) submarine erosion; and (4) fluvial erosion. Based on evidence to be presented, it is here postulated that these depressions are former stream valleys (Fig. 1).

Throughout most of its outcrop belt the Castle Hayne Limestone disconformably overlies the Paleocene Beaufort Formation, the Cretaceous Peedee Formation, or the Cretaceous Rocky Point Member of the Peedee Formation (Baum et al., 1978). This disconformity represents the eroded surface over which the middle Eocene sea transgressed. This surface is irregular, with local relief of up to 10 ft (3 m) (Upchurch, 1973). Westward this erosional surface should have been even more pronounced because of an overall rise in elevation of the land surface. Stream valleys would have become deeper, having to cut deeper to reach base level. With a rise in sea level sufficient to completely cover the lower North Carolina Coastal Plain, and eventually the upper Coastal Plain, low areas such as stream valleys with open access to the ocean, would have been the first to become drowned on the higher coastal plain. These valleys would have eventually become filled with marine sediment, resulting in a thicker sediment accumulation in the valleys than on the higher interstream divides. With retreat of the sea and subsequent erosion, these sediment filled valleys would more likely be preserved than sediment deposited on the interstream divides.

Evidence for these ideas is provided by the outlier in which the Atlantic Limestone Quarry operates, in Duplin County, on U. S. Hwy 117, 1.9 mi (3.1 km) north of Rose Hill. A portion of the outlier, owned by Atlantic Limestone, Inc., and operated by Mr. Thomas H. Parker, has had 27 exploratory wells drilled in it. The data obtained from these wells and from the quarry itself provide convincing evidence that this particular outlier occupies an elongate branching depression. These data provide sufficient evidence to rule out faulting, solutioning, and submarine erosion as the major methods of formation of the depression.

## ATLANTIC LIMESTONE QUARRY OUTLIER

The Atlantic Limestone Quarry is located in a large outlier, elongate in shape, and at least 2 mi (3.2 km) long and 1 mi (1.6 km) wide. The long axis of the outlier runs approximately north-south (Fig. 1). Data from 27 wells show that the deepest known part of the outlier is on the north property line of the quarry. It is not known how far the outlier extends to the north. The limestone is overlain by 6 to 15 ft (1.8 to 4.5 m) of Pleistocene sediment and is underlain by Cretaceous sands. The limestone within the outlier can be divided into two major units, separated by a prominent erosional surface. These two units are termed hard marl and soft marl in the drilling logs. The lower hard unit, a highly cemented bryozoan rich biosparrudite, enriched in quartz sand at the base and top of the section, was probably highly cemented during Eocene erosion, when the disconformable surface separating the two units was formed. The upper soft unit, described in detail on page 54 contains a mixture of weakly consolidated fossiliferous micritic and sparitic limestones. The overall carbonate sediment composition, however, appears to be roughly the same. Four aspects of the outlier illustrate the nature of the depression and the history of its filling by sediments: (1) overall thickness and areal distribution of the two units, (2) insoluble residue of the limestones, (3) lithologic data and facies relationships in the exposed soft unit of the quarry, and (4) an exposed portion of the disconformable surface.

### Subsurface

Most of the 27 cores end in the Cretaceous Peedee Formation, thus giving essentially complete stratigraphic control for the Pleistocene sand, the Castle Hayne Limestone, and the upper portion of the Cretaceous sand. Four isopach maps have been constructed from the core data: (1) the contour of the depression before deposition of the lower, hard limestone (Fig. 1A), (2) the present thickness of the hard limestone (Fig. 1B), (3) the contour of the depression before deposition of the soft limestone (Fig. 1C), and (4) the present thickness of the soft limestone (Fig. 1D). Three cross sections have also been prepared (Fig. 1E), one north-south (Fig. 1H), and two east-west (Figs. 1F-G). Based on these figures the topographic feature in which the hard limestone was deposited is a deep, elongate depression. The hard limestone that remains is essentially confined to the basin itself, but enough of it extends

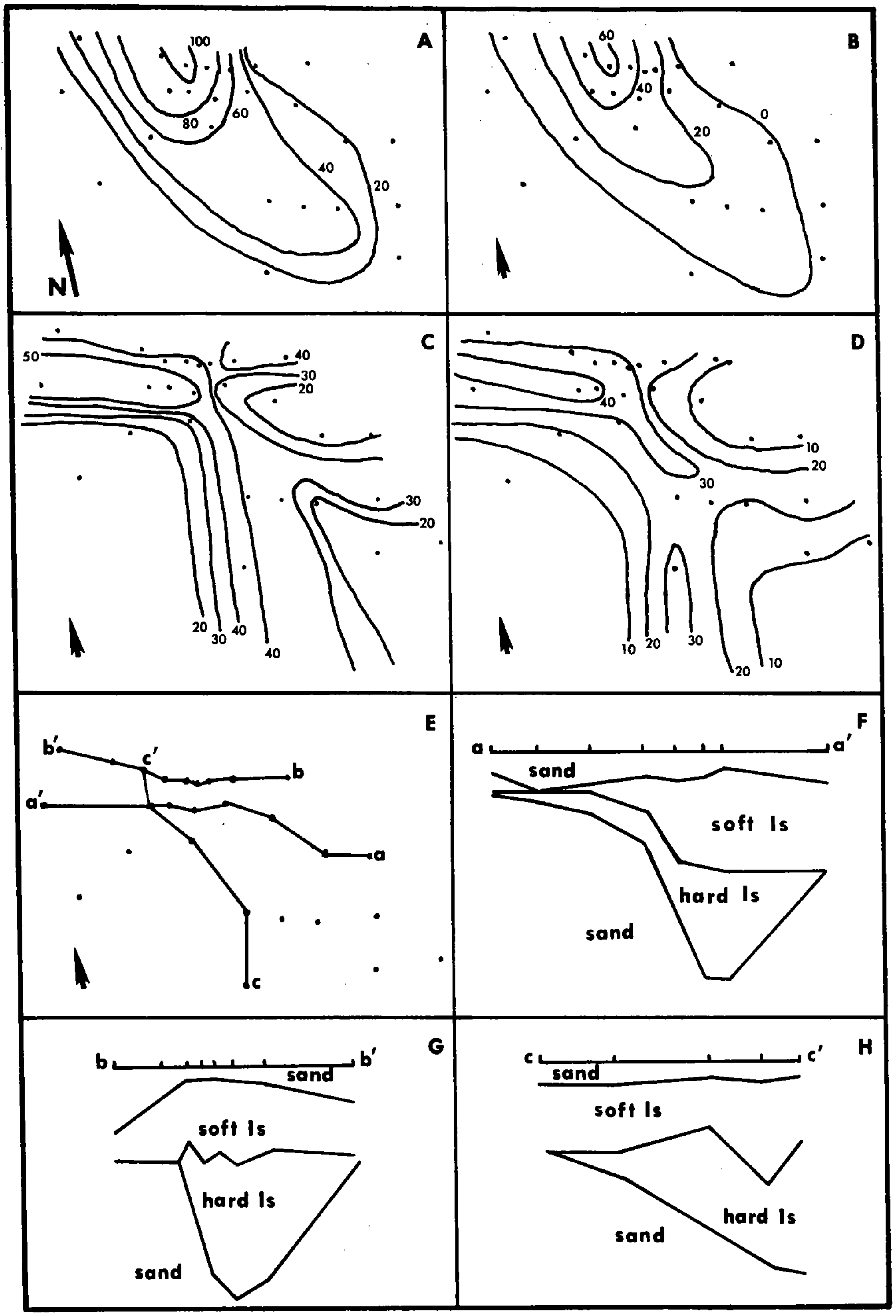

Figure 1. Subsurface stratigraphy of the Atlantic Limestone Quarry Outlier, north of Rose Hill, Duplin County, North Carolina. The dots on each diagram represent the location of individual wells. Horizontal scale: 1 cm = 1700 ft, vertical scale: 1 cm = 27.5 ft. Vertical exaggeration for F - H = 62. Thicknesses are in feet. (A) Contour of the depression prior to infilling by the lower hard limestone unit. (B) Present thickness of the hard limestone unit. (C) Contour of the depression prior to infilling by the upper soft limestone unit. (D) Present thickness of the soft limestone unit. (E) Location of the three cross sections illustrated in F - H. (F) East-west cross section, illustrating the hard and soft units extending out over the edge of the depression. (G) East-west cross section, illustrating an area where the hard limestone unit is confined to the depression. (H) North-south cross section, illustrating the position of the depression filled by the soft limestone.

out over the edge of the basin to suggest that it was at one time more extensive in distribution. Erosion during the middle Eocene produced a second, elongate, branching depression incised in the hard limestone unit and the surrounding Cretaceous sands. This second, shallower depression was subsequently filled with additional carbonate debris. Based on the cross sections (Figs. 1F-H) this unit was also originally more widespread.

## Insoluble Residue

The amount of quartz sand within the limestone shows dramatic, yet expected changes within a 106 ft (32.2 m) vertical composite section constructed from two cores and the quarry. Throughout this section quartz is present as very fine to very coarse sand, except at the base of the two limestone units, where pebble-sized quartz is found. The underlying Cretaceous sediments are all terrigenous clastic silicates, predominantly quartz. The lower 36 ft (11.0 m) of the hard limestone contains an average of 31% quartz. This changes to an average of 13.6% for the upper 30 ft (9.2 m) of hard limestone. The soft limestone, based on core samples and on quarry wall samples, contains 25% quartz in the lower 10 ft (3.0 m), 2.4% quartz in the next 10 ft (3.0 m) and 4.0% quartz in the upper 20 ft (6.1 m). This change in quartz content illustrates flow of clastic debris into the depression. Decrease in quartz upsection suggests that as waters rose up and over the top of the depression, carbonate debris became more widespread in distribution, covering the surrounding surficial Cretaceous sands to increasingly farther distances away from the depression.

## Lithology of the Quarry Walls

The lowest 10 to 15 ft (3.0-4.5 m) of the soft limestone are not exposed in the quarry. By starting at the base of the exposed section and working upward though, a pattern still emerges, outlining the history of the filling of the depression by the soft limestone unit. The lowermost 5 ft (1.5 m) of exposed rock, a bryozoan rich biomicrudite, contains numerous scattered, phosphatized pebbles and occasional concentrated zones of pebbles and cobbles of a composition similar to the rock found underlying the disconformity exposed on the nearby quarry wall. Pebble and cobble zones are not found in the upper portions of the section. It is safe to assume that the level at which the clasts of similar composition to the underlying hard limestone are no longer found marks the time when the erosion surface separating the two units was completely covered with new sediment and no longer subjected to erosion.

This pebble-rich zone grades upward into 4 ft (1.5 m) of bryozoan bearing biomicrite, dominated by very fine and fine sand-sized carbonate skeletal grains. This fine sediment changes rapidly upward into a loosely cemented, poorly washed, coarse bryozoan biosparrudite, with thin interbeds of highly cemented, molluscan rich biomicrudite, both of which contain much less fine carbonate sand than the underlying zone. This zone changes upward and inward, away from the sides of the depression and the disconformity, into a finer grained, coarse, loosely cemented bryozoan biosparrudite which exhibits low angle cross-bedding.

This lithology suggests current activity within the depression, with the irregularity of the depression sides possibly acting as a baffle to slow the cross-bed producing currents, enabling deposition of some micrite in with the coarser skeletal debris. The fauna growing on the depression walls may also have aided in trapping finer sediments, whereas the inner portion of the depression, in which current activity was more pronounced, does not contain micrite.

## Disconformity

The exposed portion of the disconformity separating the lower hard limestone from the overlying soft limestone is quite distinctive. Exposed on the northeast quarry wall, though now almost completely covered with water, the disconformity can be followed for an approximate horizontal distance of 100 ft (30.5 m), and originally could be followed vertically down the quarry wall for 30 ft (9.2 m). In profile the exposed portion of the disconformity cuts through the bedding planes of the underlying unit and ranges from very gently sloping near the top (about 5°) to very steep near the base (about 30°), illustrating deep erosion of the underlying unit. The lowest portion of the disconformity slope and the floor of the depression is not exposed in outcrop. Another unusual feature is a series of exposed, open fractures on the disconformity surface, now also covered with water, that are elongate, run parallel with the strike of the slope, and are at least 12 ft (3.7 m) long, 2 ft (0.6 m) deep, and 3 to 4 in (7.6-10 cm) wide. The opposite walls of each fracture would match if placed against each other, thus ruling out direct local erosion as an origin. These fractures appear to be the result of downslope slumping concurrent with the formation of the disconformity and indicates that the underlying limestone was already lithified when the slumping occurred, and thus also when the erosion was taking place.

The exposed portion of the disconformity is pitted with a microkarstic texture, consisting of small solution depressions and small subsurface solution channels, all of which are coated with phosphate and filled with sediment similar in composition to the overlying soft limestone. This entire surface is also coated with varying thicknesses of phosphate, in which is incorporated quartz sand, and reworked bioclasts and intraclasts. Also found in the thicker phosphate crusts are small pisolitic structures up to 1 cm in diameter, consisting of thin, concentric laminations of phosphate which were precipitated around a nucleus, usually a small intraclast. The pisolites are elongate in shape, with more pronounced growth on the lower side of the structure. This preferential downward growth suggests a downward flow of water from which the phosphate was precipitated, as would be expected in a vadose environment. Additional evidence is being sought to explore the possibility of subaerial exposure during the formation of the disconformity.

A large part of the erosion surface is biologically bored to a depth of about 5 mm with a series of small interconnected channels; localized concentrations of boring bivalves are also present. Numerous encrusting organisms, including oysters, bryozoans, alcyonarian corals, and sponges can be found on the surface of the diastem. These encrusting organisms are all found growing on the phosphate crusts. Nowhere are these organisms encrusted by the phosphate. Also found scattered on the disconformity are pebbles, cobbles, and boulders of ripped up rock from below the erosion surface.

## CONCLUSIONS

The shape of the outlier, the distribution pattern of the two major lithologic units, the distribution of quartz sands within the limestone, the facies pattern within the upper soft limestone, and the nature of the disconformity are convincing evidence that the depression was a negative topographic feature on the bottom of the Eocene sea floor. As stated earlier, only four common geologic processes could produce such a large depression: (1) faulting, (2) subaerial solutioning, (3) submarine erosion, and (4) fluvial erosion. Pre-, syn-, and post-depositional faulting as a method of formation is ruled out by the nature of the unconformity between the two limestone units, by the overall shape of the two depressions, and the inclusion of well rounded clasts of the underlying hard unit in the soft unit. The underlying muddy sand of the Cretaceous Peedee Formation belongs to the noncalcareous province of Swift (1964). This lack of underlying calcium carbonate rich sediments rules out solutioning as a method of formation. No direct evidence suggests submarine erosion as a major cause. For a depression over 100 feet deep to be carved out of the sea floor would require concentrated currents which would not be likely to exist as far up onto the then submerged Coastal Plain as the outliers are now found. The disconformity itself exhibits evidence of submarine erosion (boring and encrusting organisms, etc.), but this appears to be minor in relationship to the overall formation of the erosion surface and could have occurred after the depression was flooded with marine waters. A logical explanation attributes the depression to being part of a stream valley system. The shape of the depression in which the hard limestone was deposited, and especially the shape of the depression that the soft limestone fills clearly suggests a typical stream system, and hence subaerial erosion as the major method of formation.

Numerous additional outliers of Castle Hayne Limestone are found across the North Carolina Coastal Plain west of the major outcrop belt of the Castle Hayne Limestone. A concentrated drilling project around and within these outliers could determine their size, shape, and distribution. If such a study reveals other similarly shaped depressions, and if these depressions are found in alignment with each other, a whole network of Eocene aged stream channels could be located.

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# SPONGE-BEARING HARDGROUNDS IN THE CASTLE HAYNE LIMESTONE

by

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During the 1891 exploration voyage of the H.M.S. Challenger, Murray and Renard described some rocky areas of the sea floor and introduced the term hardgrounds. Hardgrounds have also been noted in Cretaceous chalk in England (Kennedy and Garrison, 1975), and Middle Ordovician limestone of Virginia (Read and Grover, 1977). With these and other publications citing the presence of submarine lithification in modern and ancient marine environments, there can be little doubt that the process does indeed occur. The Castle Hayne Limestone exposed at the Ideal Cement quarry in New Hanover County, North Carolina offers evidence that submarine cementation also occurred in the late Eocene.

The Castle Hayne contains two, well indurated, sponge-bearing biofacies near the upper portion of the exposed section (Fig. 1). The lower bed at 11-12 m is a sponge biolithite and the upper at 13-14 m is a sponge-bearing biomicrite. They occur as parallel units, each approximately one meter thick, separated by a friable sponge-bearing bryozoan biomicrudite. The units contain a large percentage of sponges (up to 90 percent) and bryozoans, many in growth position. The sponges, some broken and regenerated, are filled with micrite and small fossil allochems (Fig. 2). Many have been covered by encrusting bryozoa masking their true identity. In fact, these sponges have been called in earlier studies intraclasts (Cunliffe, 1967). Boring organisms penetrated the sponges producing bore holes up to 2 cm in diameter. The holes have very distinct edges even into the internal micrite. Bryozoa were also noted encrusting layers of micrite. Calcite spar rims, similar to that found in beach rock, surround most of the fossil allochems and serve as the cementing material.

By noting the cross-cutting relationships of the borings, bore hole fillings, and irregular diastemic surfaces, a sequence of depositional and diagenetic events has been established (Upchurch, 1973). This sequence, shown in a composite (Fig. 3), indicates that these two beds in the limestone existed as hardgrounds. Bore holes penetrate the sponge walls and extend sharply into the internal micrite filling, indicating that the boring had to have taken place after cementation. Because the holes are filled with micrite from sediment directly above the sponges, the boring had to have taken place before the sponges were covered. Had the sponges been cemented during subaerial exposure without a protective sediment cover, they probably would have been destroyed. The delicate sponge walls and bryozoa were not damaged, but perfectly preserved in growth position. No evidence of subaerial exposure was noted in the units except at the very top of each where small erosional surfaces and solution channels were found.

The presence of sponges and encrusting bryozoa on micrite is another indication of subsea cementation as these organisms need a firm substrate for development.

Thus, it is deduced that the strata were cemented by calcite spar rims, bored and then covered by micrite which was later lithified before being subaerially exposed (Upchurch and Textoris, 1973).

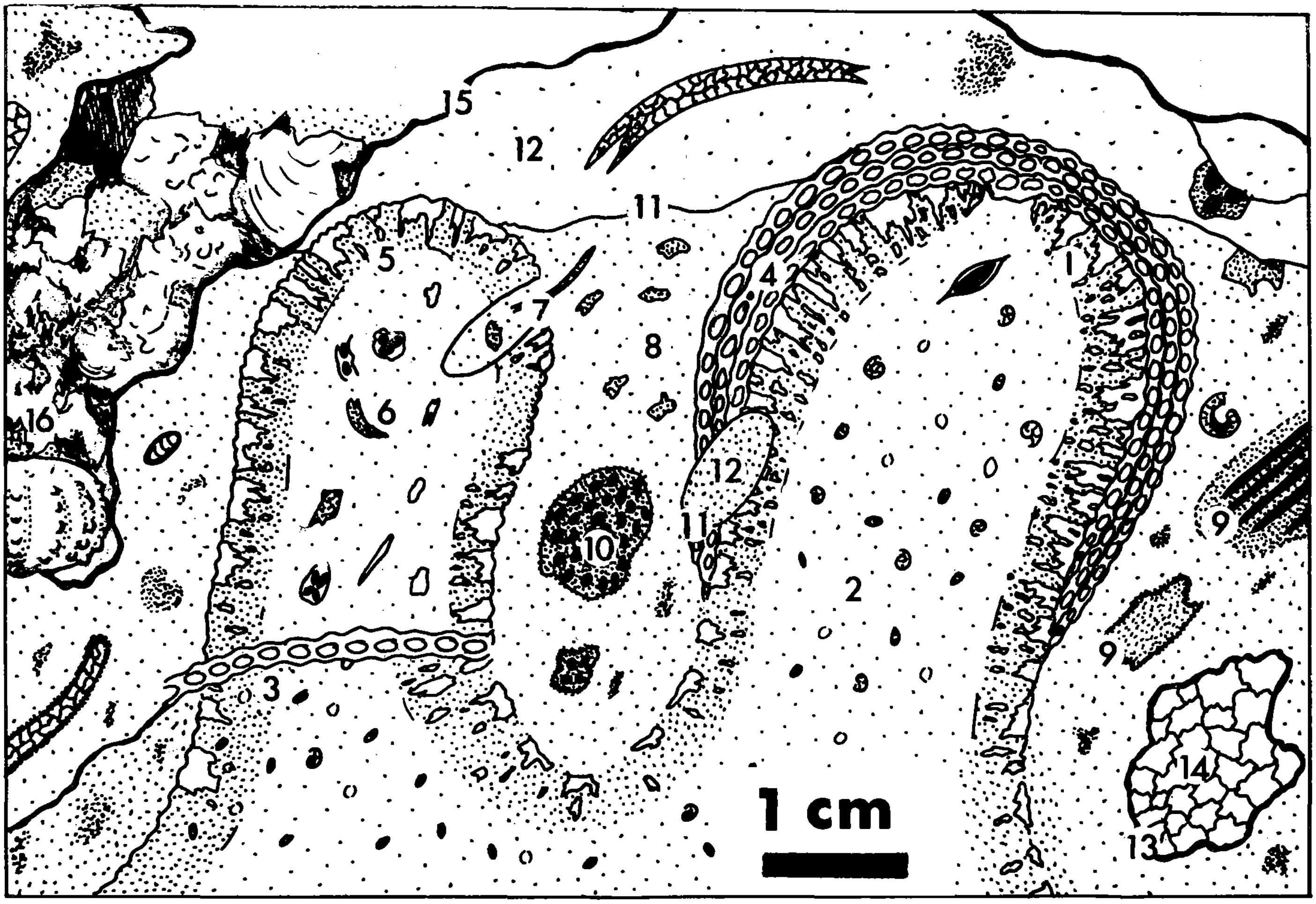

Figure 1. Composite section of Castle Hayne Limestone at Ideal quarry, New Hanover County.

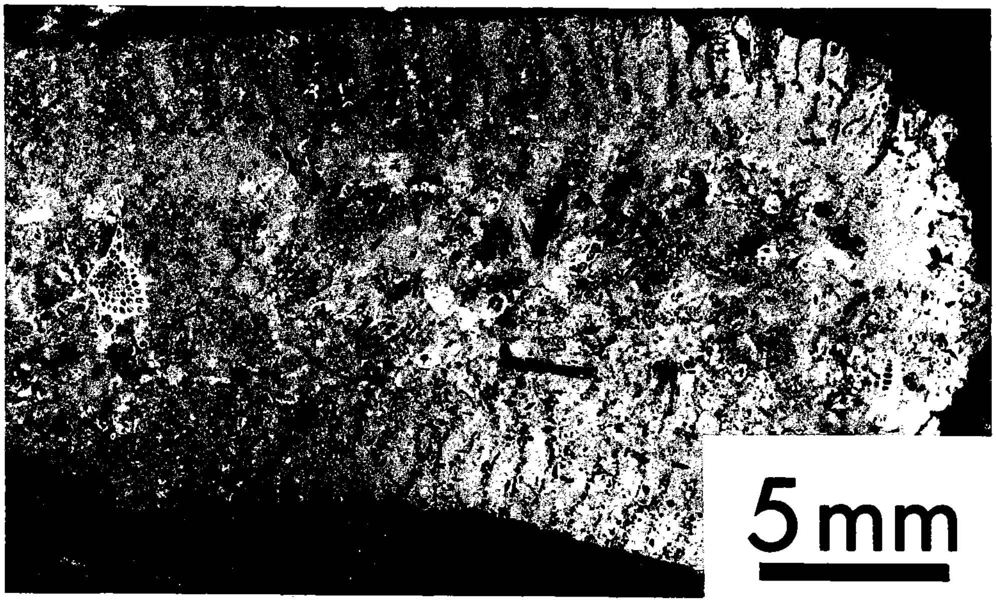

Figure 2.
Cross-section of sponge showing wall structures and biomicrite filling.

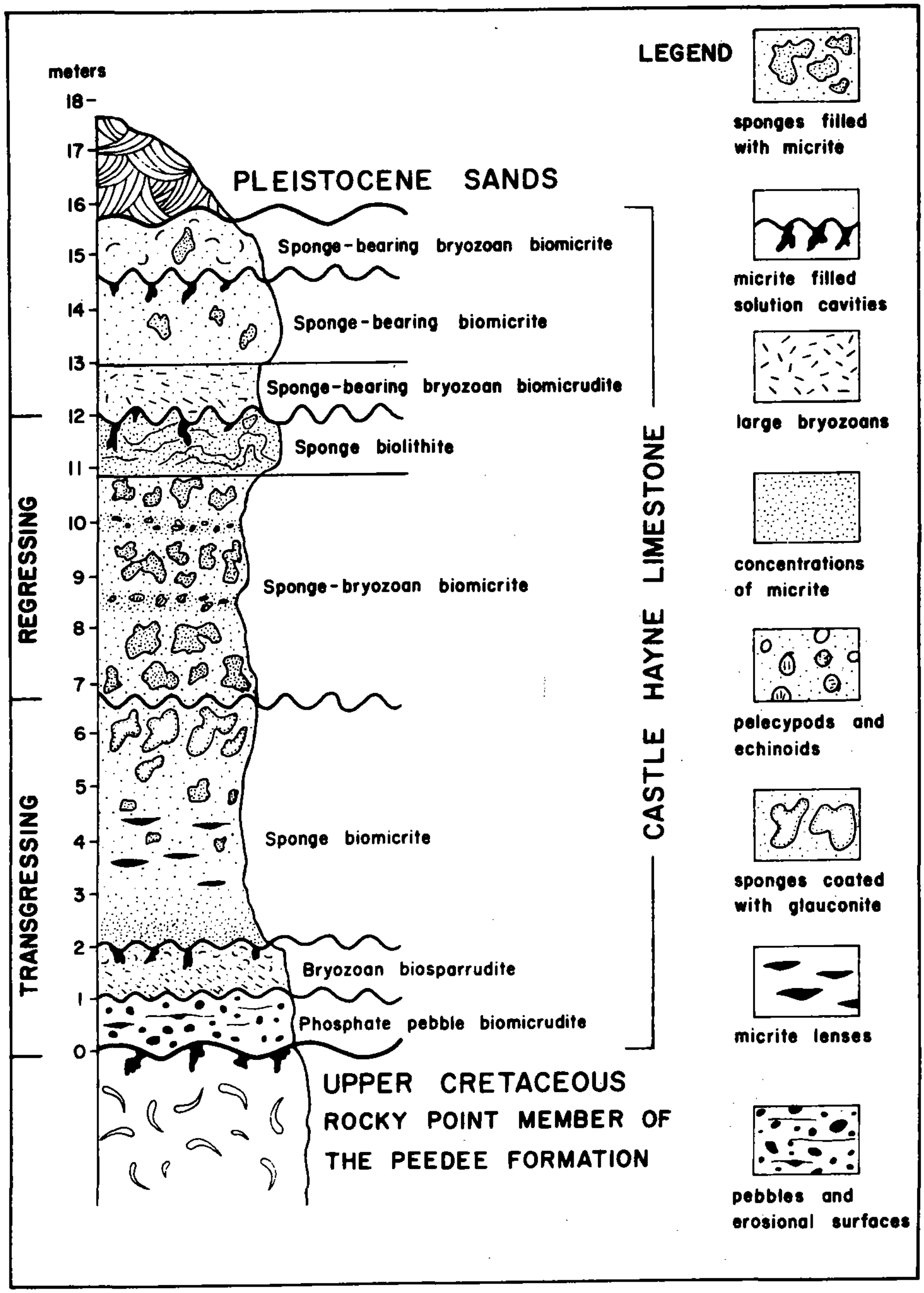

Figure 3.
Composite cross-section from the sponge biolithite facies showing stages of deposition and diagenesis:

1. Growth of sponges in very shallow water.
2. Filling of sponges with fine micrite.
3. Breaking or erosion of sponges.
4. Encrusting of whole and broken sponges by Cheilostomatous bryozoans.
5. Regrowth of sponge.
6. Filling of second generation sponge.
7. Boring of sponge.
8. Deposition of coarser biomicrite between sponges.
9. and 10. Micritization and glauconitization.
11. Minor diastem and boring of sponge and matrix.
12. Deposition of material over sponges filtering into bored hole.
13. Solution forming moldic to vug porosity.
14. Spar filling most remaining voids.
15. Subaerial exposure and formation of irregular upper surface and solution cavities.
16. Filling of solution cavities with coarse biomicrite and <u>Arbacia</u> <u>sp</u>.

Lithification of sponges and internal matrix occurred between stages 6 and 7 and the intersponge matrix between 13 and 15.

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# CALCAREOUS NANNOFOSSILS FROM THE LOWER TERTIARY OF NORTH CAROLINA

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## INTRODUCTION

Calcareous nannofossils, the minute (1-25μ) fossil remains of unicellular planktonic golden brown algae, are one of the more important biostratigraphic tools for both pelagic and neritic marine sediments of Mesozoic and Cenozoic age. They are abundant as a constituent of many sedimentary units and have been used extensively to subdivide the Cretaceous and Cenozoic of the Gulf Coastal Plain (see Gartner, 1977).

Little more than reconnaissance has thus far been done in the Atlantic Coastal Plain (see Roth, 1970; Worsley, 1974; Akers and Koeppel, 1973; Finneran and others, 1979; and Turco and others, 1979). Therefore, this study is a first attempt to use calcareous nannofossils to subdivide the Lower Tertiary Formations of the North Carolina section of the Atlantic Coastal Plain. In constructing the subdivision, we have used the Standard Zonation of Martini (1971), but have also relied on Roth (1970), Gartner (1977) and Bukry (1978). Our results are preliminary and based on minimal sampling from a small number of locations. Slight changes are expected as our sampling grid becomes more complete.

## REGIONAL STRATIGRAPHY

Fig. 1 summarizes several interpretations (including ours) of the stratigraphic column of the Lower Tertiary of North Carolina. According to Baum and others (1978), the Lower Tertiary consists of the Beaufort, Castle Hayne, New Bern and Trent formations, whereas Ward and others (1978) refer to these units as the Beaufort, Castle Hayne and River Bend formations. Each of these formations is irregular in thickness, and some of the differences between Ward and others, and Baum and others are in part nomenclatural. However, the two interpretations appear to be very different for the upper Eocene - lower Oligocene interval. Furthermore, our interpretations appear to differ from either of these stratigraphic frameworks for the middle and upper Eocene, perhaps because we have so far failed to recover nannofossils from strata assigned to the New Bern Formation of Baum and others. The reader is referred to these two references for a detailed review of the areal extent and detailed lithologic character of these formations.

## NANNOFOSSIL BIOSTRATIGRAPHY

Fig. 2 shows the sample localities from which nannofossil assemblages have been studied. Fig. 3 shows the generalized ranges of the more stratigraphically useful nannofossils recovered from these samples in the North Carolina Coastal Plain. Fig. 4 shows range charts of three fairly continuous sections of the upper Eocene - lower Oligocene interval. Nannofossils indicating Paleocene and possible middle Eocene are discussed in the text.

In compiling the stratigraphic ranges of the fossils shown in Fig. 3, we have made use of outcrops, cuttings and cores whose general locations are shown in Fig. 2. Fortunately, this part of the Lower Tertiary is a period of successive extinction of nannofossil species so that subdivisions rely

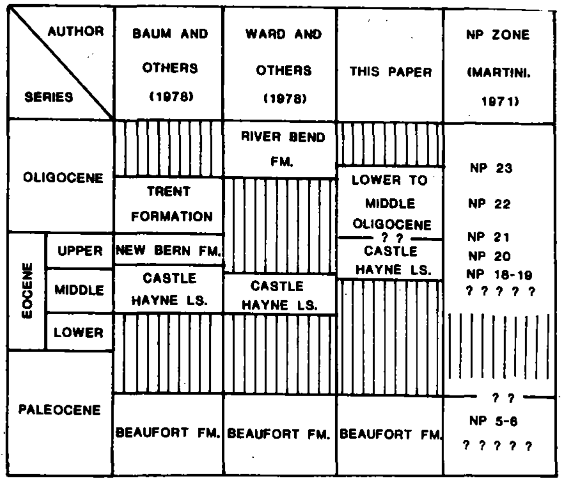


Figure 1. Suggested subdivisions of the North Carolina Coastal Plain. (? indicates lack of nannofossil control)

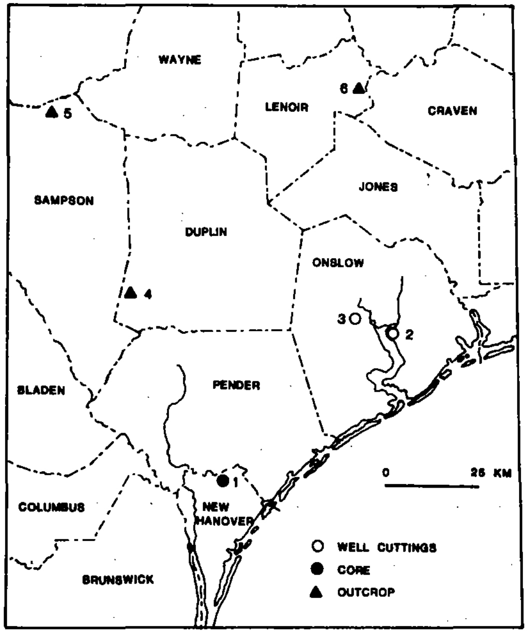
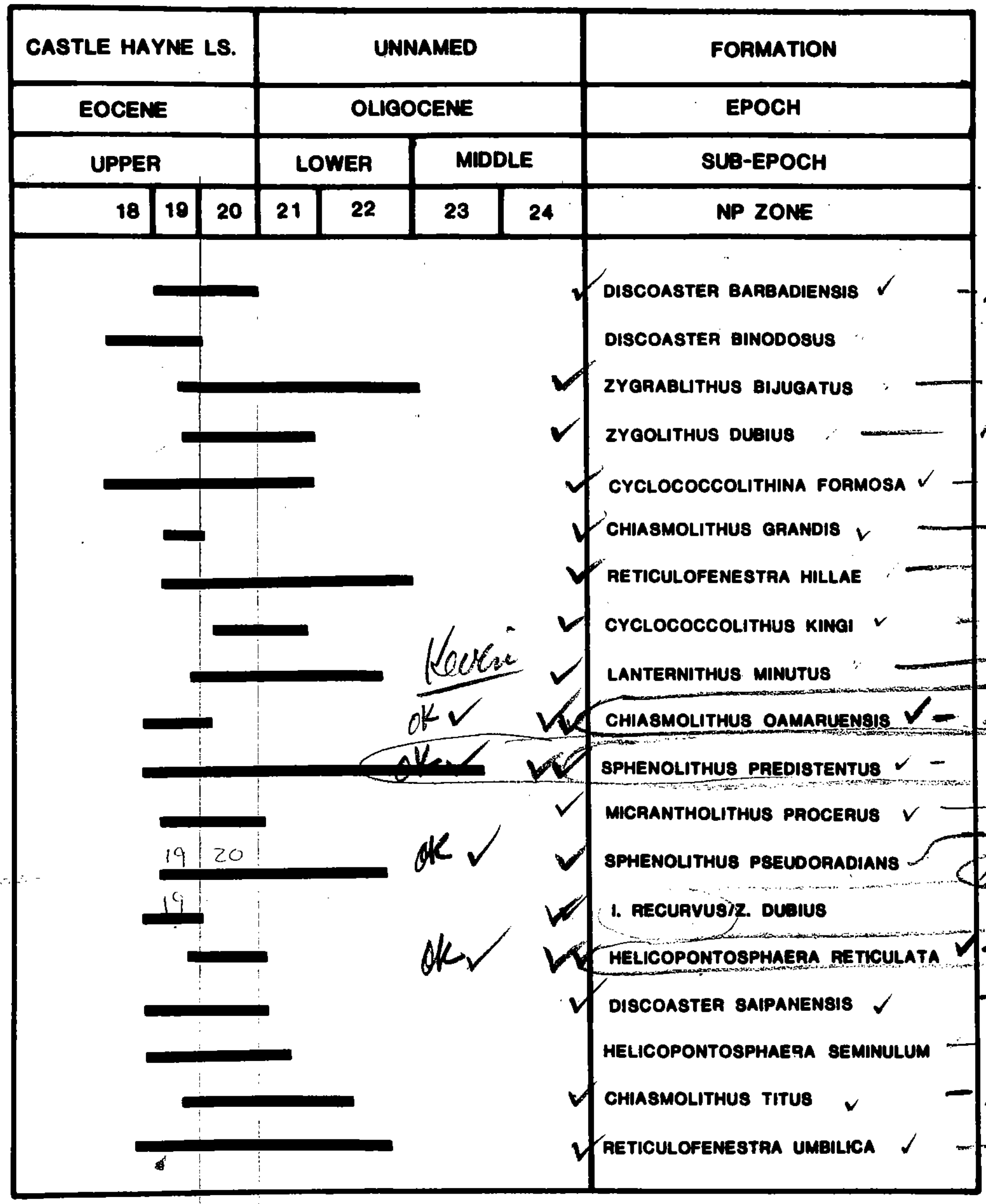


Figure 2. Sample localities (1 = 1-0 core; 2 = Evans #1 well; 3 = Onslow well; 4 = Sample Dup-2 at Natural Well; 5 = Sample 3 from near Newton Grove, Sampson Co.; 6 = Mosely Creek).



NP12-20
LE - UE
NP12-19
NP11-21
NP11-NP20
P14 - Oligocene
ME- LO
NP13-22
upper Eocene NP18-NP23
NP20-24 - ME
P14 of Alab.
NP20-23
UE - Olig. NP19-22
NP20-22
NP16-NP20
Paleocene - Pliocene
P11-14
NP15-NP22

Figure 3. Composite ranges of selected Lower Tertiary nannofossils in North Carolina.

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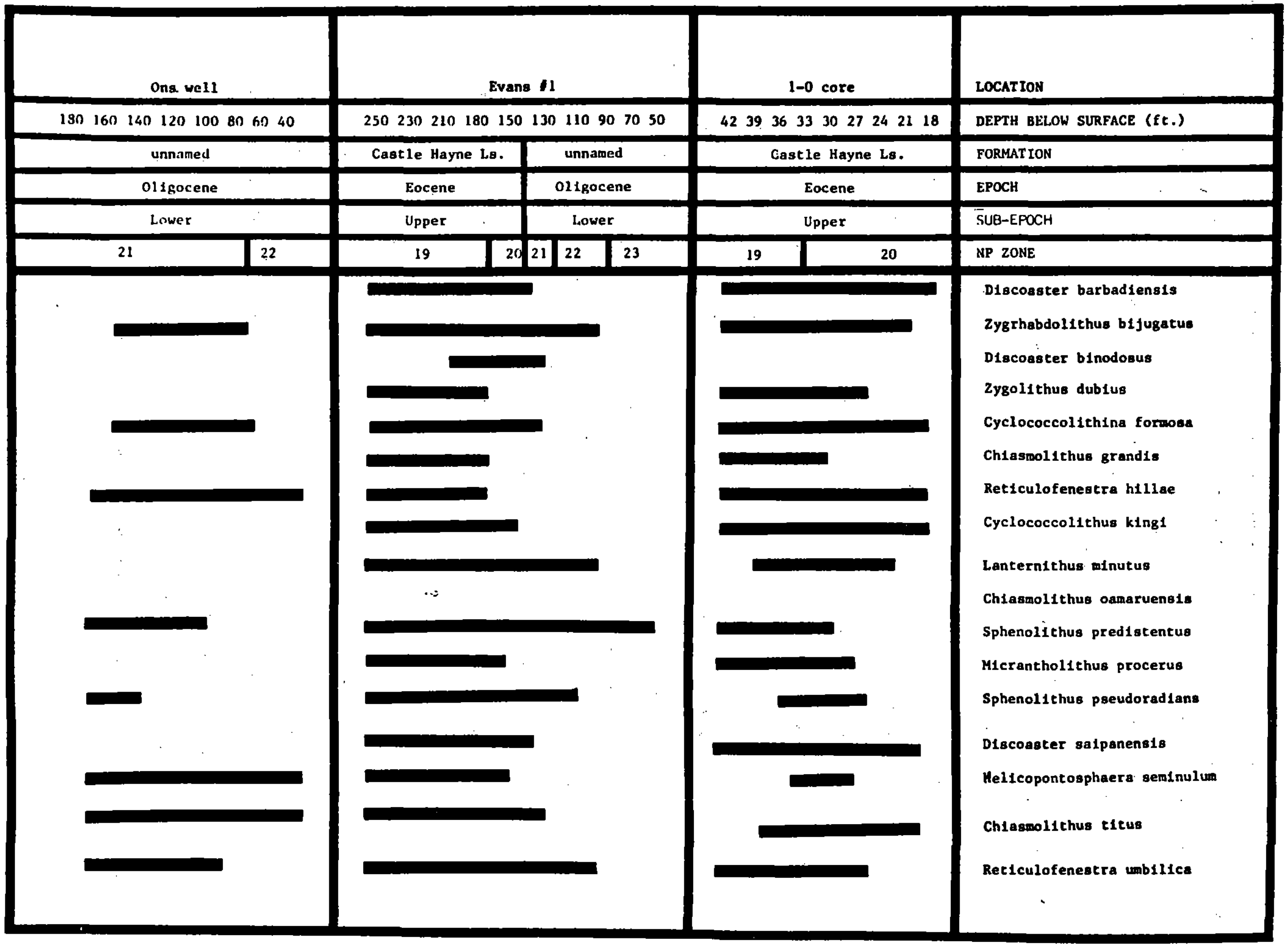

Figure 4. Calcareous nannofossil ranges for three wells in the North Carolina Coastal Plain.

mainly on range tops and not bases. The possibility of upward reworking in well cuttings is slight, so that we believe that the consecutive disappearance sequence in the two wells is stratigraphically reliable.

## DISCUSSION

As can be seen from inspection of Fig. 1 and Fig. 3, nannofossil age determinations of the Lower Tertiary of North Carolina differ slightly from those of earlier studies but offer a new degree of biostratigraphic refinement in those strata. Following is a brief discussion of our findings to date of the stratigraphic intervals we have studied.

### Paleocene

The single Paleocene sample we obtained was of the Beaufort Formation at Mosely Creek (Fig. 2). It contains a diverse nannoflora indicative of NP 5 or 6 based on the occurrence of well preserved *Ellipsolithis macellus*, *E. distichus*, *Cyclococcolithus robustus*, *Cruciplacolithus tenuis*, *Hornibrookia sp.*, *Biantholithus sparsus*, and *Fasciculithus tympaniformis*. Outcrop samples of the Jericho Run Member of this formation near Kinston have so far failed to yield any nannofossiliferous samples, although planktonic foraminifera suggest a lowest Paleocene age (P1 - P2).

### Middle Eocene To Middle Oligocene

Strata of upper Paleocene and lower Eocene are not known from outcrops in North Carolina; the mid-to-upper Eocene resting unconformably on the mid-Paleocene. However, an apparently continuous composite sequence of middle Eocene to middle Oligocene exists in the subsurface of Onslow County.

Nannofossils at the type section of the Castle Hayne Limestone, the Martin Marietta Quarry in New Hanover County (1-0 core), are moderately preserved at most sampled levels and many of the more stratigraphically important species can be recognized. These suggest an apparently short but continuous sequence within NP 19 and 20. Rare *Zygolithus dubius* and *Chiasmolithus grandis* in the lower half of the section suggest NP 19 and *Sphenolithus pseudoradians* in the middle portion suggests NP 20. The topmost 18 feet are leached of nannofossils.

Nannofossil preservation is better in the Evans #1 well where a possible continuous section representing NP 19-23 was encountered, as represented by the consecutive disappearance of *Chiasmolithus grandis*, *Discoaster saipanensis*, *Cyclococcolithina formosa*, and *Reticulofenestra umbilica*. However, the presence of *Sphenolithus pseudoradians* suggests that the base of the section may be as young as NP 20. The contact between the Castle Hayne Limestone and Oligocene beds occurs between samples collected from 130-140 feet and those collected between 140-150 feet. The simultaneous disappearance of many Eocene species 130-140 ft. to 140-150 ft. suggests the possibility of a small unconformity at the Eocene-Oligocene boundary that may be represented by the New Bern Formation of Baum and others (1978) elsewhere, but this cannot be determined unless nannofossiliferous samples of the New Bern Formation are discovered.

Two additional isolated outcrop samples, thought initially by Harris (per. comm.) to be laterally equivalent facies of the Castle Hayne Limestone also contained abundant nannoflora. The first sample (#4 on Fig. 2) is from the bottom of the Natural Well. This sample belongs to upper NP 19-lower NP 20 based on a nannoflora very similar to that in the lower Castle Hayne Limestone. The second sample is from an isolated outlier of Eocene chalk on State Route 701 near Newton Grove, Sampson County, North Carolina. This sample is devoid of megafossils although it contains an abundant nannoflora representing NP 18, based on the occurrence of Sphenolithus pseudoradians, and a form intermediate between Zygolithus dubius and Isthmolithus recurvus. If one accepts this outlier as Castle Hayne, then the Castle Hayne extends down into the middle Eocene.

## ACKNOWLEDGEMENTS

We thank Walter Wheeler for introducing us to North Carolina Coastal Plain studies, and W. B. Harris for providing both samples and field guidance for this survey. L. Ward offered interesting insights to the problems we encountered.

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# BIOSTRATIGRAPHY OF EOCENE THROUGH MIOCENE CIRRIPEDIA, NORTH CAROLINA COASTAL PLAIN

by

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## INTRODUCTION

Although barnacle remains are frequently encountered in Cenozoic deposits of the southeastern Atlantic Coastal Plain, little consideration has been given to their potential as stratigraphic indicators. Studies by Cheetham (1963) and Withers (1953) on North American Gulf Coast faunas, and by Zullo (1966, 1969, 1979) on North American Pacific Coast faunas demonstrate that lepadomorph ("goose") and balanomorph ("acorn") barnacles are useful stage and series guide fossils.

Stratigraphic paleontologists tend to ignore barnacle remains because of two traditional misconceptions: (1) barnacles are difficult to study because of extreme intraspecific variation; and (2) opercular or capitular plates necessary for precise identification are seldom preserved. Barnacle species are no more variable than species of other marine invertebrate groups, but, being based on numerous characteristics, often require a larger population sample to establish variation limits. Obtaining large population samples presents little difficulty, as barnacles are gregarious and, where preserved, abundant. Successful retrieval of opercular and capitular plates is dependent on knowing where and for what to look. Barnacles occur most frequently in sediments derived from moderate to high energy environments where hard substrata, such as rock and shell debris are found. Collecting in the North and South Carolina Coastal Plain indicates that barnacle remains are often concentrated above diastems and disconformities. Careful screening and hand-picking under the microscope usually yields a sufficient array of plate types for precise identification. Opercular plates of acorn barnacles are usually scattered in the barnacle-bearing sediment, but often can be recovered <u>in situ</u> from the base of the sediment-filled shell. Opercular and capitular plates have often been confused with echinoid lantern parts, chiton plates, bivalve shells, and gastropod opercula. Illustrations of commonly encountered plate types are provided in Plate 1. Familiarization with these plates is sufficient to enable ready determination of local barnacle species in bulk fossil samples.

The purposes of this report are to acquaint geologists with the types of barnacle remains found in southeastern Atlantic Coastal Plain sediments (pls. 1-3), to summarize available data concerning temporal distribution of barnacle species in North Carolina Coastal Plain units, and to discuss the significance of these distribution patterns with respect to current interpretations of North Carolina Coastal Plain stratigraphy (Fig. 2).

## DISTRIBUTION OF LEPADOMORPHA ("GOOSE BARNACLES")

Two genera, <u>Arcoscalpellum</u> <u>Hoek</u> and <u>Euscalpellum</u> <u>Hoek</u>, occur in Paleogene units in North and South Carolina (Zullo and Baum, in press). <u>Arcoscalpellum</u> is represented by two species previously known from the Gulf Coast Eocene. <u>Arcoscalpellum</u> <u>subquadratum</u> (Meyer and Aldrich) is tentatively identified from fragmentary carinae from the upper bryozoan biomicrudite facies of the Castle Hayne Limestone (= part of the Comfort Member of Ward et al., 1978) at the Martin Marietta Aggregate quarry, Castle Hayne, New Hanover County, North Carolina (loc. 1, Fig. 1). This species is a Clabornian (middle Eocene) guide fossil in the Gulf Coastal Plain, occurring in the Lisbon and Gosport equivalents from Alabama to Texas (Cheetham, 1963; Withers, 1953).

Well preserved plates of Arcoscalpellum jacksonense Withers are found in the same facies of the Castle Hayne Limestone at the Lanier quarry, Maple Hill, Pender County, North Carolina (loc. 2, Fig. 1). Arcoscalpellum jacksonense is a Jacksonian (upper Eocene) guide fossil found in the Moodys Branch and Pachuta marls of the eastern Gulf Coast (Cheetham, 1963; Withers, 1953).

Euscalpellum is represented by a new species at four localities in North and South Carolina (pl. 2, Figs. 3-5). In North Carolina this species occurs in the upper bryozoan biomicrudite facies of the Castle Hayne Limestone at the Castle Hayne Martin Marietta Aggregate quarry (loc. 1, Fig. 1), at the North Carolina Lime Excavating Company quarry near Comfort, Jones County (loc. 3, Fig. 1), and under State Route 1129 bridge crossing Chinquapin Branch, near Trenton, Jones County (loc. 4, Fig. 1). In South Carolina this species occurs in an unnamed upper Eocene molluscan limestone disconformably overlying the middle Eocene Santee Limestone at the Santee Portland Cement quarry near Holly Hill, Orangeburg County. The only other undoubted North American record of Euscalpellum is that of E. eocenense (Meyer) from lower Claibornian units in the Gulf Coastal Plain (Withers, 1953). Two Gulf Coast Jacksonian species attributed to Euscalpellum by Cheetham (1963) and Weisbord (1977) appear to represent other genera. The new species from North and South Carolina, although superficially similar to E. eocenense, bears characteristics that mirror evolutionary trends seen in geologically younger species of Euscalpellum.

## DISTRIBUTION OF BALANOMORPHA ("ACORN BARNACLES")

Typical acorn barnacles (Balanus-like forms) first appear in middle and upper Eocene units in Europe, South America, and North America (Newman et al., 1969; Zullo and Baum, in press). Most of the described species are placed in the solid-walled subgenus Hesperibalanus Pilsbry of the genus Solidobalanus Hoek. Hesperibalanids are the dominant balanomorphs of the Paleogene, are common in the North American Neogene, and survive today in the North Pacific basin (Zullo, 1966, 1979). Eocene species of Hesperibalanus possess relatively thin and featureless opercular plates, and are notable in lacking a scutal adductor ridge (Pl 2, fig. 1). Oligocene and Neogene species have more robust plates with scutal adductor ridges and/or prominent internal callosities (Pl. 2, figs. 6, 11, 12, 14).

Three new hesperibalanid species are recognized in the North Carolina Coastal Plain. Species A, lacking a scutal adductor ridge, occurs in the upper bryozoan biomicrudite facies of the Castle Hayne Limestone at the Chinquapin Branch locality (loc. 4, Fig. 1; Pl. 2, figs. 1, 2). This species is morphologically similar to Solidobalanus cornwalli (Zullo) from the upper Eocene Cowlitz Formation of south-

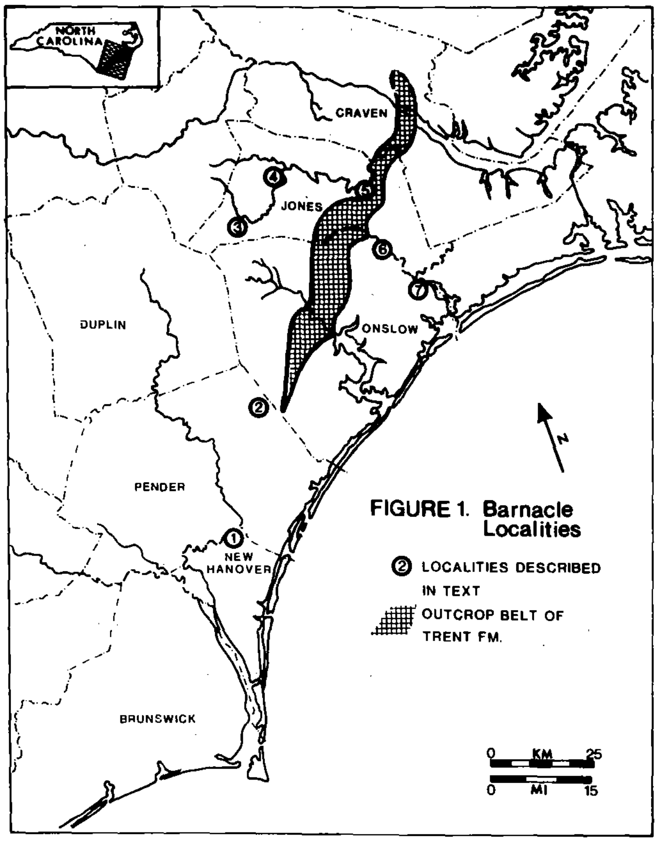

Figure 1. Barnacle localities in the North Carolina Coastal Plain.

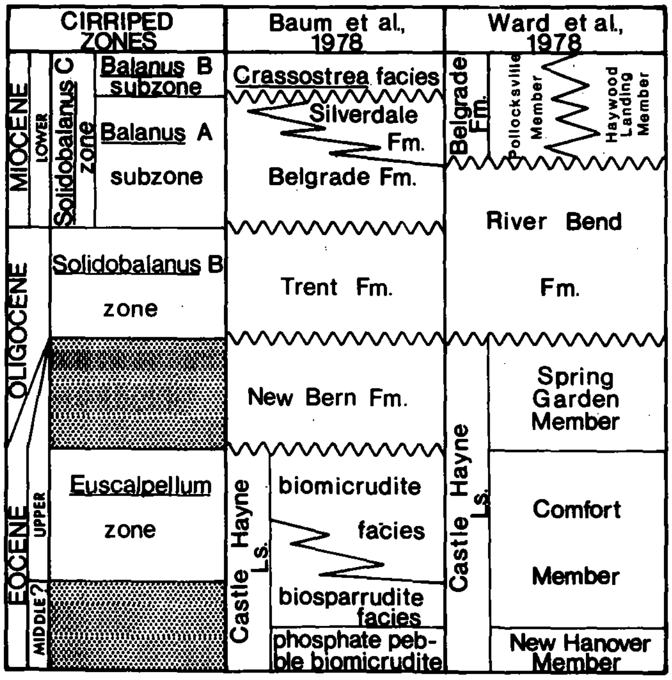

Figure 2. Upper Eocene through Lower Miocene cirriped zones, North Carolina Coastal Plain.

ern Washington, and to an undescribed species from the Gosport Sand and overlying Jacksonian units in Alabama.

Two species characterized by the presence of scutal adductor ridges occur in overlying units. Species *B* is found throughout the Trent Formation (Fig. 1; = part of River Bend Fm. of Ward *et al.*, 1978). Species *C* occurs both in the overlying Belgrade Formation of Baum *et al.* (1978) (= part of River Bend Fm. of Ward *et al.*, 1978) at the Martin Marietta Aggregate quarry at Belgrade, Onslow County (loc. 6, Fig. 1), and in the "*Crassostrea gigantissima*" channel deposit (= Pollocksville Member, Belgrade Fm. of Ward *et al.*, 1978) at Pollocksville, Jones County (loc. 5, Fig. 1). Species *B* and *C* are readily distinguished by the form of the tergum and internal details of the scutum (compare Pl. 2, figs. 6-14).

The porous-walled *Balanus concavus* Bronn species complex of apparent Tethyan origin is well represented in the North American and Eurasian Neogene. Upper Oligocene records of this group are doubtful, as they are based on specimens without opercular plates from localities of questionable age. Pilsbry (1916) described species from the Neogene of the Atlantic Coastal Plain, including *B. concavus chesapeakensis* Pilsbry from the middle Miocene St. Marys and Choptank formations of Maryland, *B. concavus proteus* Conrad from the Pliocene Yorktown Formation of Virginia and (?) the Pleistocene Caloosahatchie Formation of Florida. Ross (1964a) added five species to the Virginia Yorktown fauna, including *B. pacificus prebrevicalcar* Ross and *B. oppidieboraci* Ross, that are part of the *B. concavus* complex. Ross (1964b) described *B. tamiamiensis* from the ? Miocene Tamiami Formation of southwestern Florida, and Weisbord (1965) described *B. talquinensis* Weisbord and *B. leonensis* Weisbord from the upper Miocene Choctawhatchee Formation of northern Florida that also appear to be members of the *B. concavus* complex.

In North Carolina the *B. concavus* complex is represented by species in the Belgrade Formation at the Martin Marietta Aggregate quarry, Belgrade, Onslow County (loc. 5, Fig. 1), in the Silverdale Formation (= Haywood Landing Member, Belgrade Formation of Ward *et al.*, 1978) at the Silverdale Marl Company quarry, Silverdale, Onslow County (loc. 7, Fig. 1), and in the "*Crassostrea gigantissima*" channel deposit at Pollocksville (loc. 5, Fig. 1). At least two species are present throughout the Belgrade Formation at Belgrade. The more abundant of these, here designated Balanus species *A*, is characterized by a distinctively ribbed shell and a broad, flat, indistinctly striate scutum (Pl. 3, figs. 1-6). A single species, here designated *Balanus* species *B*, is found in the overlying channel deposit at Pollocksville. *Balanus* species *B* has an irregularly ribbed shell with red color stripes and a narrow, thickened, distinctly striate and nodose scutum (Pl. 3, figs. 7-11). To date, no barnacles have been recovered from the type locality of the Haywood Landing Member of the Belgrade Formation of Ward *et al.* (1978). The beds at Silverdale and at Belgrade, referred to the Haywood Landing Member by Ward *et al.* (1978), contain several balanomorph species, including shells referable to *Solidobalanus* and the *Balanus concavus* complex, but the few opercular plates recovered from these units do not permit specific comparison with the species described above.

## BIOSTRATIGRAPHIC INTERPRETATIONS

Barnacles recovered from exposed Eocene through Miocene strata in the North Carolina Coastal Plain permit the recognition of three cirriped assemblage zones: an Eocene Euscalpellum zone, an Oligocene Solidobalanus B zone, and a Miocene Solidobalanus C zone (see Fig. 2).

The Euscalpellum zone is characterized by Euscalpellum n. sp., and includes Arcoscalpellum jacksonense, ?A. subquadratum, and Solidobalanus (Hesperibalanus) n. sp. A. Representative species of this zone have been found only in the upper bryozoan biomicrudite facies of the Castle Hayne Limestone in North Carolina. With the exception of the tentatively identified specimens of Arcoscalpellum subquadratum, the species in the Euscalpellum zone suggest a Jacksonian (late Eocene) age. This age assignment is supported by the presence of the new Euscalpellum species in association with a Jacksonian micro- and mega-fauna in an unnamed formation disconformably overlying the middle Eocene Santee Limestone near Holly Hill, South Carolina. The stratigraphic range of the Euscalpellum zone is not known. The underlying biosparrudite facies of the Castle Hayne Limestone has not yielded barnacles. Solidobalanus shell wall plates occur in the basal calcareous quartz arenite facies of the overlying New Bern Formation (= Spring Garden Member of the Castle Hayne Limestone of Ward et al., 1978), but their specific identity cannot be determined. The age of the Castle Hayne Limestone (as defined by Baum et al., 1978) has been regarded as late Eocene (e.g., Canu and Bassler, 1920; Cheetham, 1961; Kellum, 1926), medial Eocene (e.g., Brown et al., 1972; Ward et al., 1978), or both medial and late Eocene (e.g., Baum et al., 1978; Brown, 1958; Cooke and MacNeil, 1952). The barnacles of the Euscalpellum zone indicate that at least the upper bryozoan biomicrudite facies is of late Eocene (Jacksonian) age.

The single species known for Solidobalanus B zone is found only in the Trent Formation that disconformably overlies the New Bern Formation. The lower limit of this zone is unknown because of the lack of identifiable barnacles in the New Bern Formation. Solidobalanus (Hesperibalanus) n. sp. B, found both in outcrop and in subsurface in all facies of the Trent Formation, is similar morphologically to North American Pacific Coast Oligocene species of the genus (Pl. 2, figs. 6, 7). A number of shell wall plates found in association with typical wall and opercular plates of Solidobalanus n. sp. B resemble those of Kathpalmeria Ross (Pl. 2, figs. 8, 9). Kathpalmeria georgiana Ross, the type and only described species of the genus, occurs in Cooke's (1943) unit 6 at Shell Bluff Landing, Burke County, Georgia in association with Crassostrea gigantissima (Finch) [= C. georgiana (Conrad)]. The age of unit 6 at Shell Bluff is in question. Traditionally, this bed has been considered Eocene in age, and referred either to the Jacksonian (Cooke, 1943; Herrick, 1964) or to the Claibornian (F. Stearns MacNeil, personal communication, 1978). Ward et al. (1978) indicate that the Crassostrea bed at Shell Bluff overlies a middle to upper Oligocene siliceous limestone and is overlain by the middle Miocene Hawthorn Formation. This interpretation would suggest an early Miocene age for unit 6 at Shell Bluff. MacNeil (personal communication, 1978) is of the opinion that the "Crassostrea gigantissima" of the Belgrade Formation and of the overlying channel deposits is unrelated to C. gigantissima from Shell Bluff; a conclusion that is readily apparent when the oysters from the two areas are compared. The Shell Bluff C. gigantissima is a long and narrow form, one and one-half to two feet in length and only four inches in width. The Belgrade-channel deposit oyster is nearly as broad as it is long. MacNeil suggests that the Belgrade-channel deposit oysters are related to (if not conspecific with) species of the C. blanpiedi (Howe) - C. vaughani (Dall) stock; species characteristic of the Tampa stage (lower Miocene).

The possible presence of Kathpalmeria in the Solidobalanus B zone provides no additional information as to the age of this zone. However, the overlying Solidobalanus C zone is characterized by the presence of species of the Balanus concavus complex, and of oysters here identified with the Crassostrea blanpiedi-C. vaughani stock. The Balanus concavus complex makes its first appearance in the Miocene. Balanus n. sp. A from the Belgrade Formation is related and probably ancestral to B. concavus chesapeakensis from the middle Miocene of Virginia. The molluscan faunas of the Belgrade and Silverdale formations, including the oysters, are recognized as Tampa (lower Miocene) equivalents (e.g., Richards, 1950). Thus, the underlying Solidobalanus B zone, based on superposition and on the affinities of Solidobalanus n. sp. B, would appear to be of Oligocene age. This conclusion is in agreement with that derived from the associated molluscan fauna (Baum et al., 1978).

Species characteristic of the Solidobalanus C zone are found in the Belgrade and Silverdale formations as well as in the overlying Crassostrea channel. Solidobalanus n. sp. C occurs both throughout the Belgrade Formation and in the overlying Crassostrea channel at Pollocksville. Balanus n. sp. A is definitely known only from the Belgrade Formation, but shell wall plates probably referable to this distinctive species occur in the Silverdale Formation. Balanus n. sp. B from the Crassostrea channel, known from scuta, fragmentary terga, and shell wall plates, is somewhat similar to B. glyptopoma from ?Miocene and Pliocene formations in Virginia and Florida, but precise comparison is dependent upon examination of well preserved terga that currently are unavailable.

Baum et al. (1978) and Ward et al. (1978) disagree in their interpretation of the stratigraphic relationships of the rocks exposed at the Belgrade quarry (see Figure 2). Baum et al. (1978) regard the basal 7.5 m of section exposed in the quarry as a lower Miocene formation (their Belgrade Formation) that disconformably overlies their Oligocene Trent Formation, and is overlain disconformably by Crassostrea channel deposits correlative with those at Pollocksville. Ward et al. (1978) regard the lower 7.5 m of section at Belgrade as the upper part of their Oligocene River Bend Formation. The lower River Bend Formation is equivalent to the Trent Formation of Baum _et al_. (1978). Ward _et al_. (1978) consider the 2.1 m section disconformably overlying their upper River Bend Formation at Belgrade as the Haywood Landing Member of their Belgrade Formation. They consider the Haywood Landing Member as a penecontemporaneous facies of the _Crassostrea_ channel deposits at Pollocksville. Thus, the two interpretations of the stratigraphic relationships of the upper part of the Miocene sequence at Belgrade are similar, differing only in nomenclature and in details of facies relationships. On the basis of the distribution of species characteristic of the _Solidobalanus C_ zone, however, it would appear that the lower 7.5 m of section at Belgrade is more closely related to the deposits at Silverdale and Pollocksville (the Belgrade Formation of Ward _et al_., 1978) than do the underlying Trent/lower River Bend formations.

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## ACKNOWLEDGMENTS

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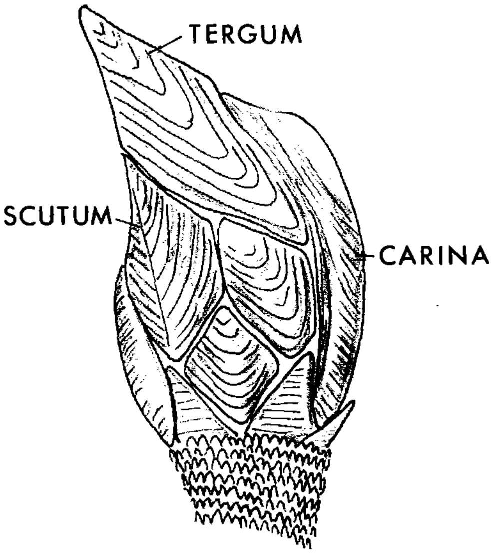
(facing page)
Plate 1. Morphologic features of lepadomorph and balanomorph barnacles discussed in text.

(following pages)
Plate 2. Euscalpellum, Solidobalanus, and (?)Kathpalmeria.
- Figs. 1 and 2. Interiors of scutum and tergum of Solidobalanus n. sp. A, loc. 4 (x 6).
- Figs. 3, 4, and 5. Tergum, scutum, and carina of Euscalpellum n. sp., unnamed formation near Holly Hill, Orangeburg County, South Carolina (x 1.7).
- Figs. 6 and 7. Interiors of scutum and tergum of Solidobalanus n. sp. B, Trent Formation near Bells Landing, Trent River, Jones County, North Carolina (x 6).
- Figs. 8 and 9. Exterior and interior of lateral wall plates of (?)Kathpalmeria sp., Martin Marietta Aggregate quarry, New Bern, Craven County, North Carolina (x 6).
- Fig. 10. Interior of lateral wall plate of Solidobalanus n. sp. C, loc. 5 (x 6).
- Figs. 11 and 14. Interior of scuta of Solidobalanus n. sp. C, loc. 5 (x 6).
- Figs. 12 and 13. Interiors of scutum and tergum of Solidobalanus n. sp. C, 10c. 6 (x 6).

Plate 3. Balanus from the Belgrade Formation and the "Crassostrea gigantissima" channel deposit.
- Figures 1 - 6, Balnaus n. sp. A, loc. 6.
  - Figs. 1 and 3. Interior and exterior of scutum (x 6).
  - Figs. 2 and 5. Interior and exterior of tergum (x 6).
  - Fig. 4. Shell, oblique view (x 1.5).
  - Fig. 6. Interior of lateral wall plate showing pores (x 1.5).
- Figures 7 - 11, Balanus n. sp. B, loc. 5.
  - Fig. 7. Detail of exterior ornament of scutum (x 1.5).
  - Figs. 8 and 9. Exterior and interior of scutum (x 6).
  - Fig. 10. Exterior of broken tergum (x 6).
  - Fig. 11. Exterior of rostral wall plate showing pores (x 1.5).

# PLATE 1



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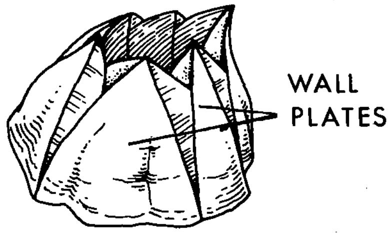
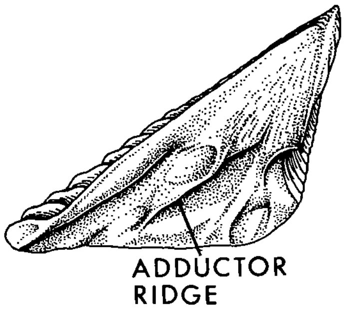


BALANOMORPH SHELL



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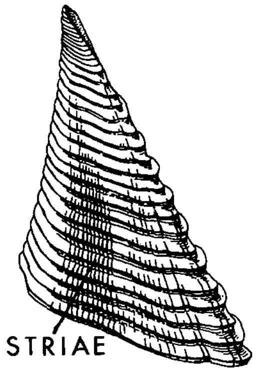

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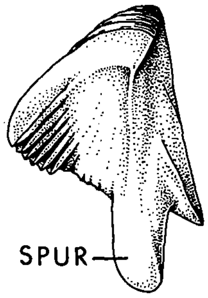

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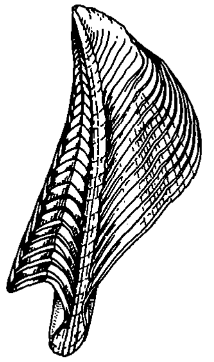
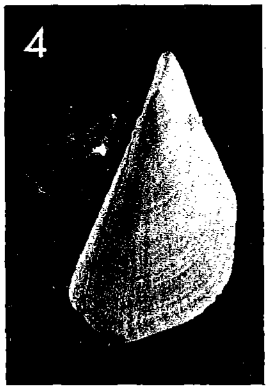
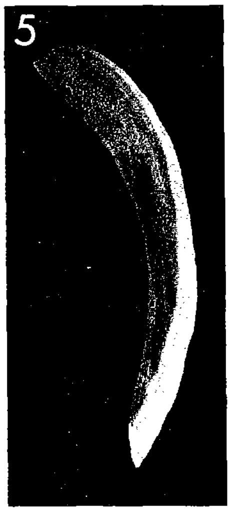


TERGUM EXTERIOR

# PLATE 2





EUSCALPELLUM ZONE

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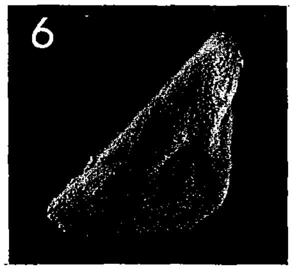

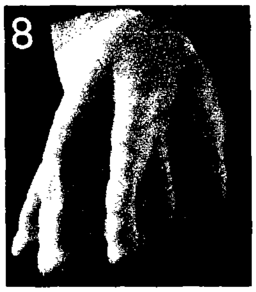

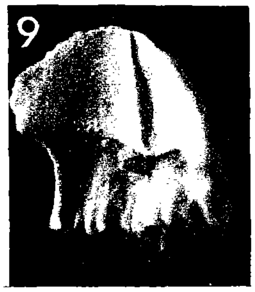

SOLIDOBALANUS B ZONE

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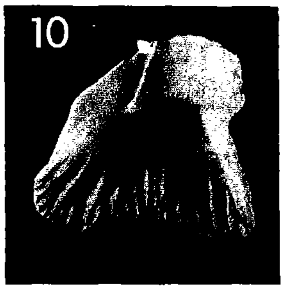
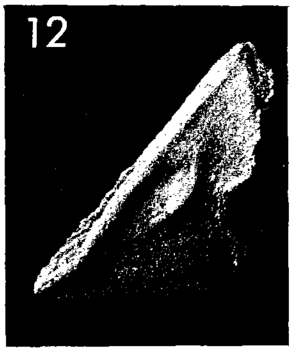
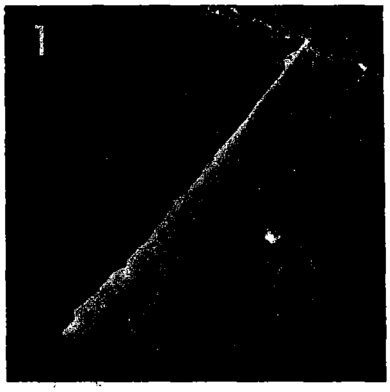
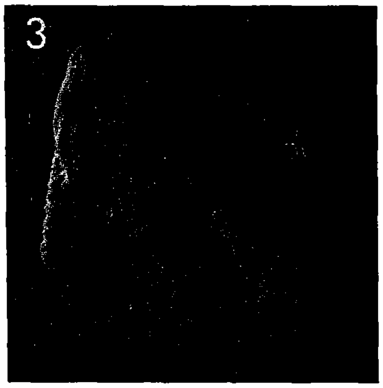


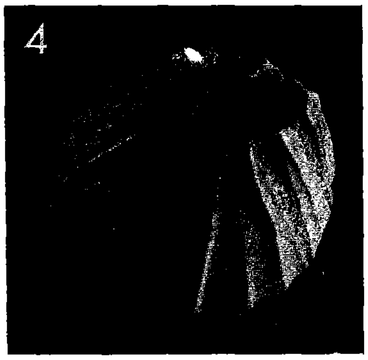


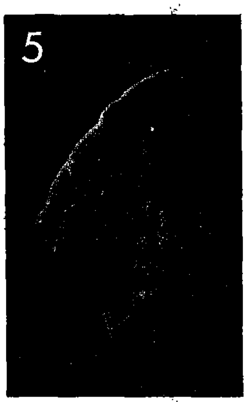
SOLIDOBALANUS C ZONE

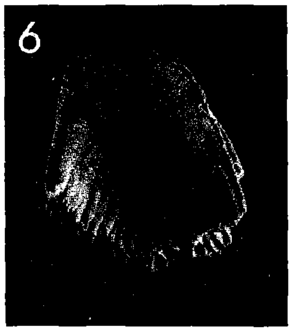
# PLATE 3



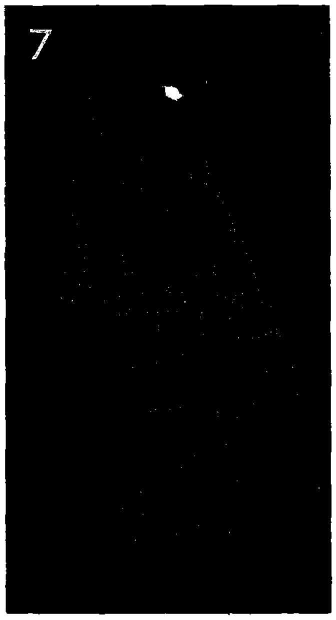


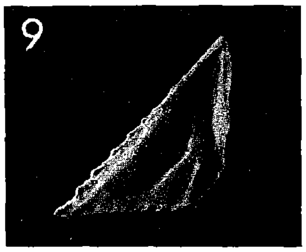


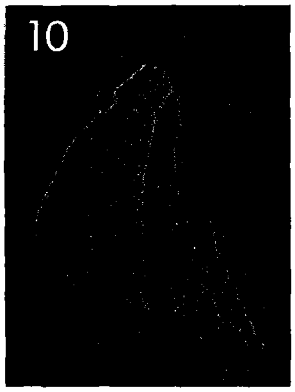


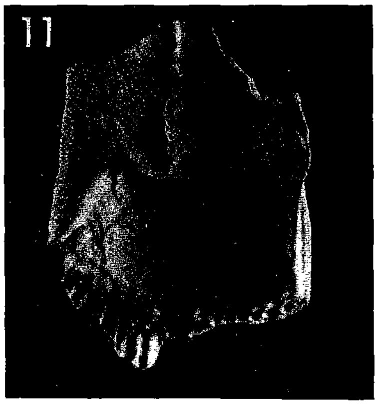


BALANUS N. SP. A









BALANUS N. SP. B

# TECTONIC HISTORY AND CORRELATION OF THE EOCENE STRATA OF THE CAROLINAS: PRELIMINARY REPORT*

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## INTRODUCTION

The Eocene strata of the Coastal Plain of South Carolina have been variously mapped under the names Congaree, Warley Hill, Santee, McBean and Barnwell. Sloan (1907; 1908) first introduced these terms as "phases" in the Coastal Plain of South Carolina. Subsequently, Cooke (1936) and Cooke and MacNeil (1952) formalized the stratigraphic nomenclature for the Coastal Plain of South Carolina. These formations have either been mapped as facies equivalents (Cooke, 1936; Pooser, 1965; Colquhoun et al., 1969); as formations separated by unconformities (Cooke and MacNeil, 1952); or partially as faunal zones within the Santee Limestone (Banks, 1978).

The purpose of this report is to present preliminary results of mapping in the Coastal Plain of South Carolina and assimilate these observations with completed research in North Carolina. It is hoped that this report will help orient future research toward the resolution of stratigraphic and tectonic problems.

## CORRELATIONS

Much of the confusion within the Coastal Plain of the Carolinas has centered on certain faunal elements that are considered diagnostic of the Eocene Gulf Coast Stages (Sabine, Claiborne, Jackson), as well as the seemingly random distribution of facies and formations. The faunal elements which have generated the greatest confusion are Crassostrea gigantissima, Crassatella alta and Chlamys cawcawensis (?=C. deshaysii). Faunal elements considered diagnostic of the Gulf Coast Stages are apparently not diagnostic in the Carolinas.

### Crassostrea Gigantissima

Mapping that has been completed in North Carolina has shown that units containing Crassostrea gigantissima (?=Barnwell Formation) are channel sands that cut disconformably into lower Miocene units (Belgrade and Silverdale formations); thus these oyster channels are no older than early Miocene (Baum, 1977; Baum et al., 1978). Either these large oysters found in the Carolinas are misidentified as C. gigantissima, or the Barnwell Formation of South Carolina is not Eocene in age and cannot be considered a facies of any of the Eocene formations of South Carolina.

### Upper Eocene

Studies completed in North Carolina indicate that the carbonates that contain the faunal assemblage Crassatella alta and Chlamys cawcawensis lie disconformably on the middle Eocene Castle Hayne Limestone and were subsequently designated the New Bern Formation of late Eocene age (Baum, 1977; Baum et al., 1977; 1978) (Fig. 1).

Preliminary mapping in South Carolina reveals a disconformity between the bryozoan dominated carbonates of the Santee Limestone and the overlying mollusc dominated carbonates containing C. alta

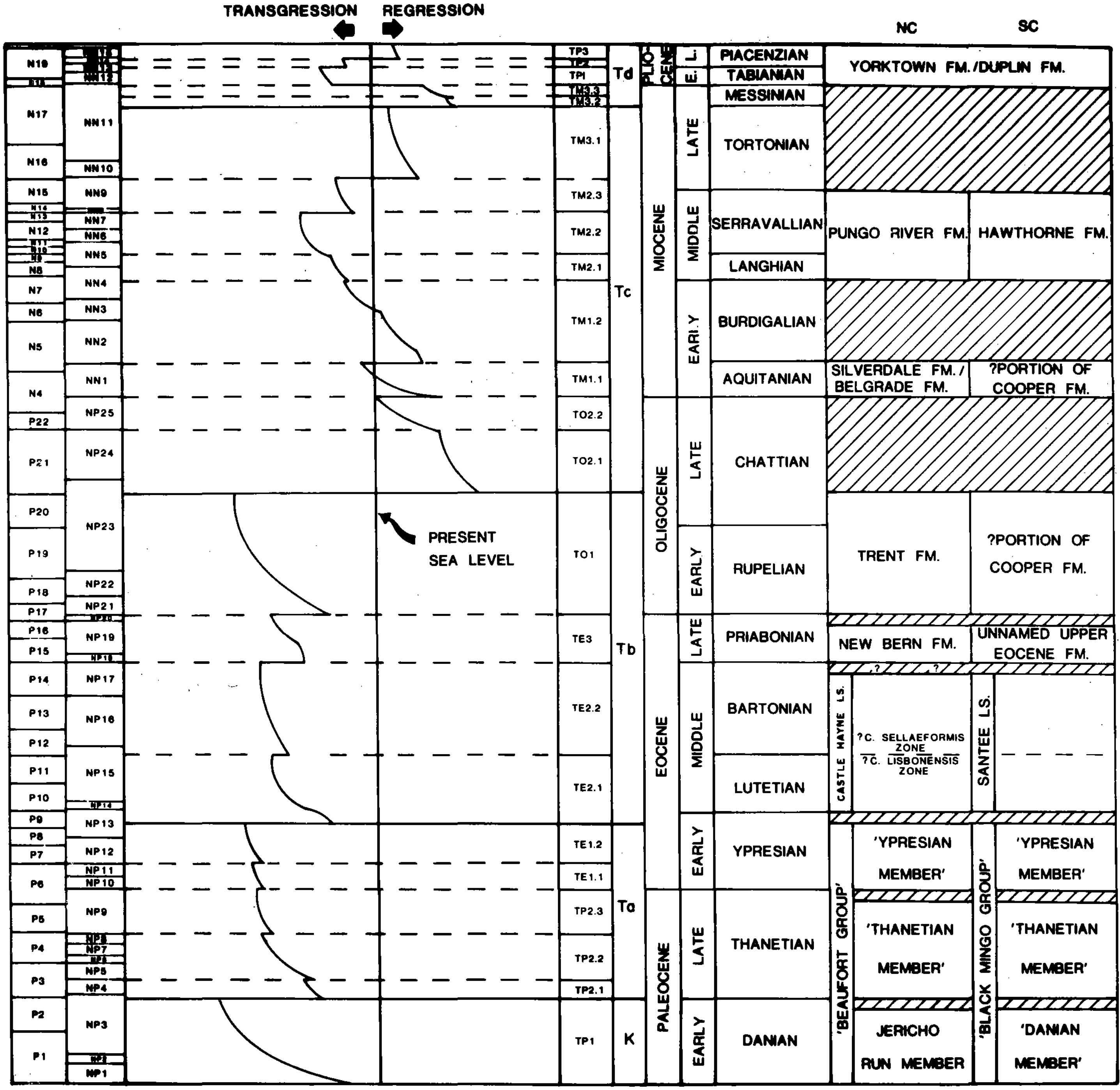

Figure 1. Comparison of eustatic sea curves with stratigraphic units in the Coastal Plain of the Carolinas. Partial listing of data sources include: Abbott (1974); Akers (1972; 1974); Baum and Wheeler (1977); Baum *et al.* (1972); Brown *et al.* (1977); Gibson (1967); Hazel (1971); Rankin (1977); Vail *et al.* (1977)

and C. cawcawensis in western Berkeley County (Martin Marietta quarry); southeastern Orangeburg County (Santee Portland Cement quarry); and southern Dorchester County (U.S.G.S. Clubhouse Crossroads core) (Fig. 2). This overlying carbonate has been traditionally mapped as part of the underlying Santee Limestone (Cooke, 1936; Pooser, 1965; Colquhoun et al., 1969; Banks, 1978); or as the Castle Hayne Limestone (Cooke and MacNeil, 1952). The underlying Santee Limestone has a middle Eocene fauna (Cubitostrea sellaeformis); whereas the overlying carbonate has a late Eocene nannoplankton fauna (Laurel Bybell, personal communication). Thus, the carbonate overlying the Santee Limestone is a distinct, mappable chrono- and lithostratigraphic unit bounded by disconformities. The formation name McBean cannot be applied since it represents the C. sellaeformis zone by definition (Cooke and MacNeil, 1952; see Connell, 1968) and is therefore equivalent to the Santee Limestone (restricted). In this report, this formation is informally referred to as the unnamed upper Eocene Formation. The mega-invertebrate fauna of the Unnamed Upper Eocene Formation is correlative with the New Bern Formation of North Carolina (Baum and Powell, 1979)(Fig. 1). These units are characterized by Crassatella alta and Chlamys cawcawensis.

### Middle Eocene

The Santee Limestone (as restricted in this report) correlates in part with the Castle Hayne Limestone of North Carolina. Only the Cubitostrea sellaeformis zone has been recognized in the Castle Hayne Limestone (Kellum, 1926; Ward et al., 1978); whereas, both the C. lisbonensis and C. sellaeformis zones have been recognized in the Santee Limestone (Banks, 1978). However, if the presence of the echinoid Santeelampas oviformis is indicative of and correlative with the Cubitostrea lisbonensis zone, then the updip outliers of the Castle Hayne Limestone in Duplin County may represent the Cubitostrea lisbonensis zone, even though this diagnostic oyster appears to be absent in North Carolina (Fig. 1).

## TECTONIC FRAMEWORK

The total thickness of the "Thanetian Black Mingo Formation," as well as the total thickness of the middle Eocene Santee Limestone remains the same throughout the study area (Fig. 3). Additionally, the individual lithofacies of these two formations appear to remain the same thickness. However, the Unnamed Upper Eocene Formation thickens rapidly to the SW from 1 m in western Berkeley County to 42 m in the U.S.G.S. Clubhouse Crossroads core in Dorchester County. This rapid thickening of the Unnamed Upper Eocene Formation suggests the presence of a fault in the vicinity of the Martin Marietta quarry in western Berkeley County (Fig. 2). Downfaulting to the SW apparently occurred after the deposition of the middle Eocene Santee Limestone, but prior to the deposition of the overlying Unnamed Upper Eocene formation. Possible additional movement along this fault is suggested by the updip pinchout of the "Ypresian Black Mingo Formation" and the Cooper Formation.

Although more data are necessary to confirm the exact location of the fault, the subsurface and outcrop data suggest that the fault lies parallel to the Santee River in a NW-SE orientation, and passes through the vicinity of the Martin Marietta quarry in western Berkeley County (Fig. 2). Outcrops of both the Unnamed Upper Eocene Formation and the Cooper Formation thin to the NE in the vicinity of the proposed fault. Additionally, the depositional strike of these two formations appears to be deflected southeastward toward the present day coast.

Movement along the Santee fault appears to have been synchronous with movement along the Neuse fault in North Carolina (Harris et al., 1979). Both faults appear to have constricted their respective basins of deposition so that the late Eocene New Bern Formation of North Carolina is restricted to the NE of the Neuse fault; whereas the Unnamed Upper Eocene Formation of South Carolina is restricted to the SW of the Santee fault. Initial movement along the Santee fault is perhaps associated with the development of the Southeast Georgia Embayment.

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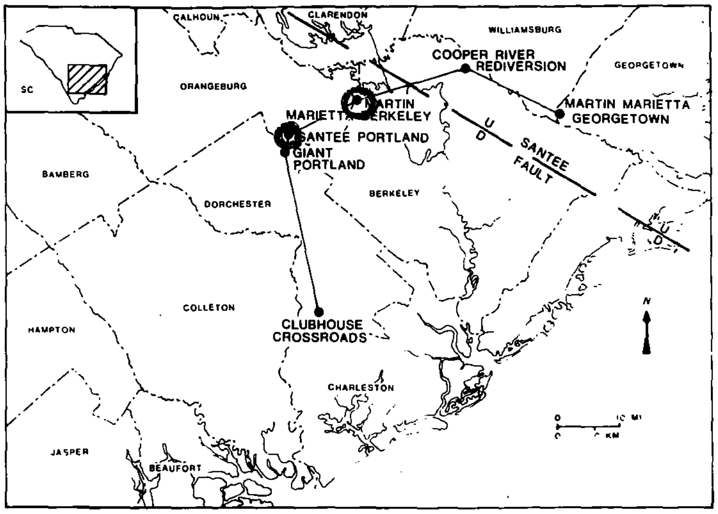

Figure 2. Location map for cores and quarries.

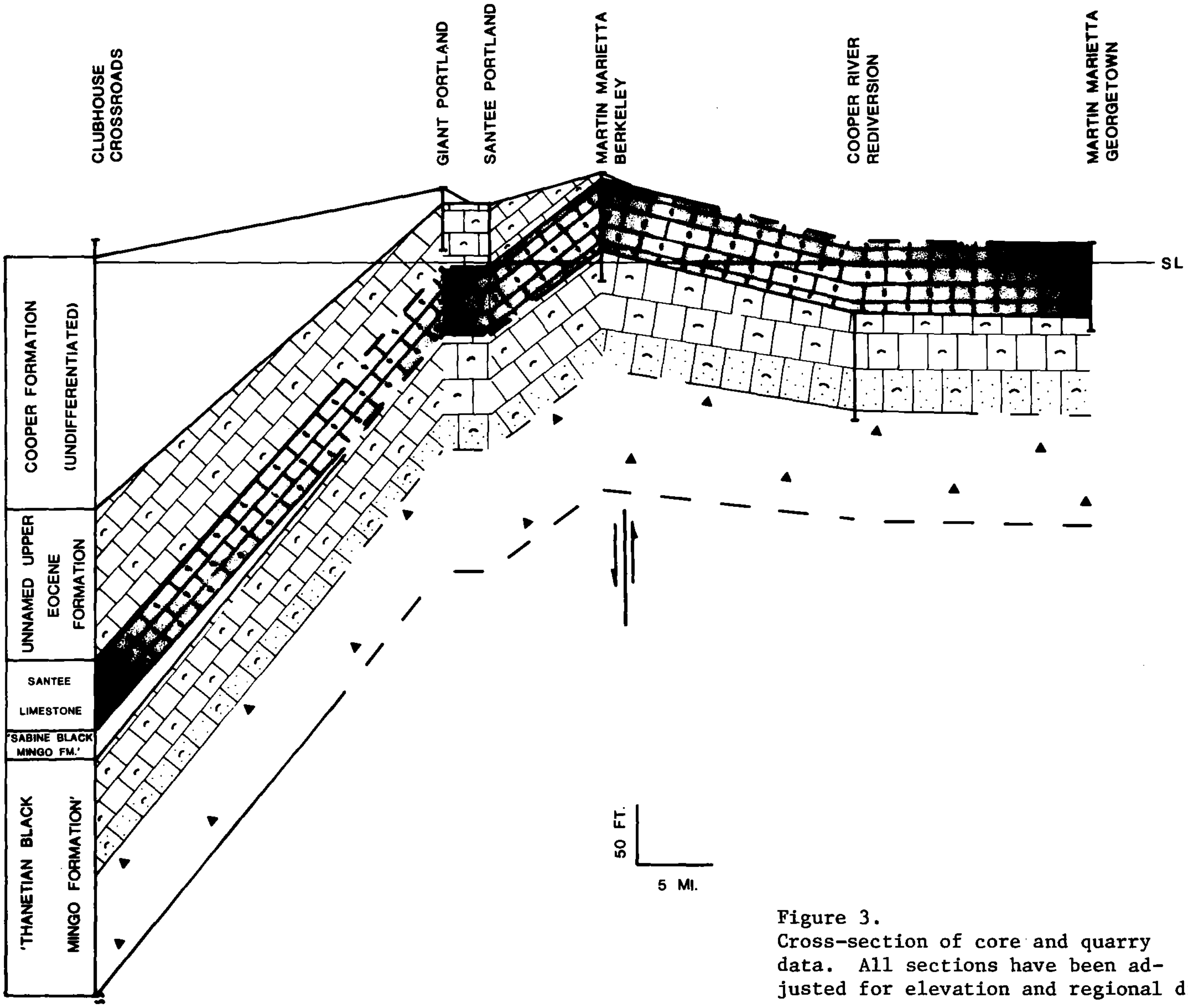

Figure 3.
Cross-section of core and quarry data. All sections have been adjusted for elevation and regional dip.

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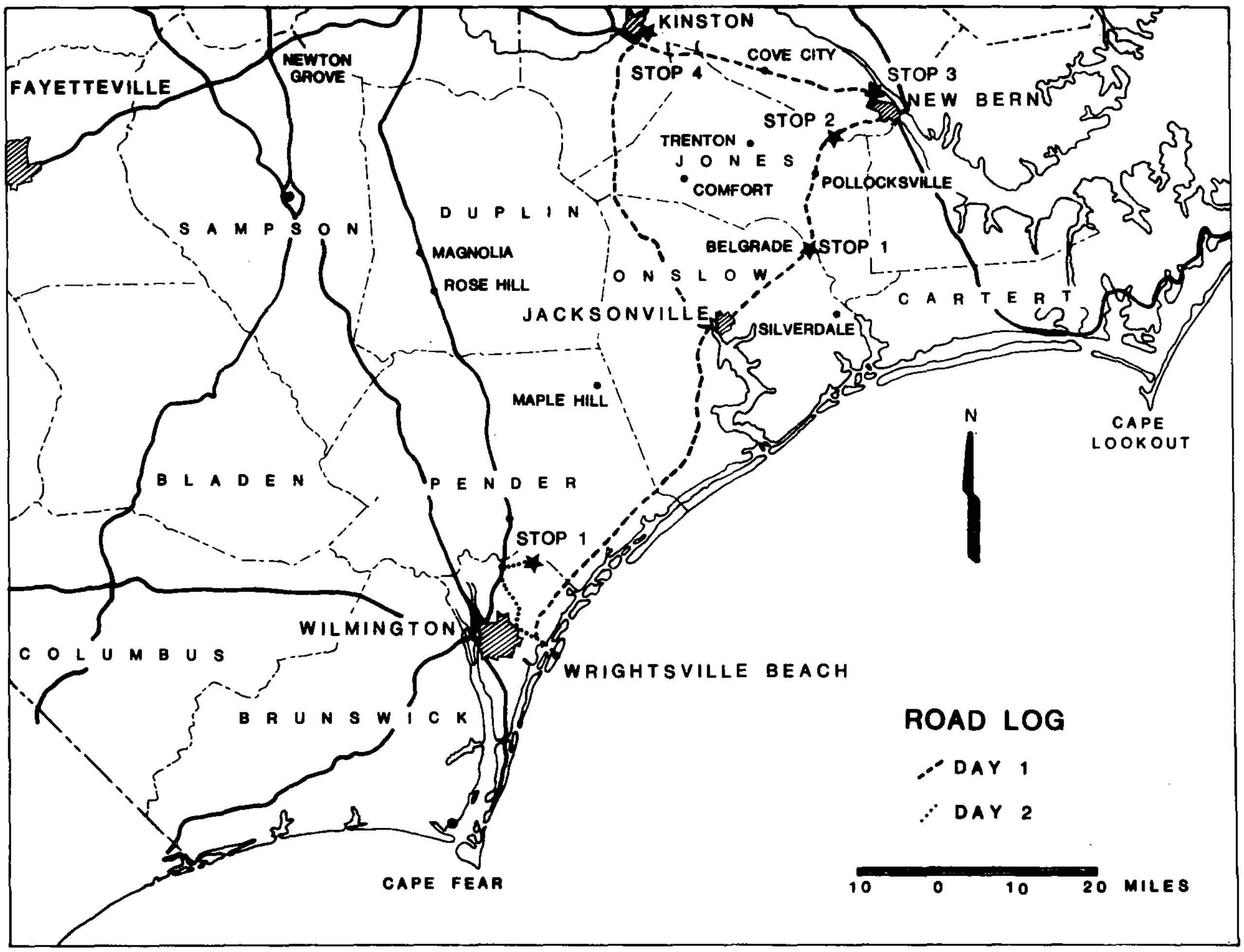
# ROAD LOG


KINSTON
COVE CITY
STOP 4
STOP 3
NEW BERN
FAYETTEVILLE
NEWTON GROVE
STOP 2
TRENTON
J O N E S
COMFORT
POLLOCKSVILLE
D U P L I N
S A M P S O N
MAGNOLIA
ROSE HILL
BELGRADE
STOP 1
O N S L O W
C A R T E R T
JACKSONVILLE
SILVERDALE
MAPLE HILL
N
CAPE LOOKOUT
B L A D E N
P E N D E R
STOP 1
WILMINGTON
C O L U M B U S
WRIGHTSVILLE BEACH
B R U N S W I C K
ROAD LOG
DAY 1
DAY 2
CAPE FEAR
10 0 10 20 MILES

## FIELD TRIP LOG FOR FIRST DAY

October 20, 1979

| Cumulative Mileage | |
|---|---|
| 0.0 | LEAVE Holiday Inn, Wrightsville Beach; TURN LEFT onto North Lumina Avenue (U.S. 74). |
| 0.5 | TURN RIGHT at stoplight at Salisbury Street; CONTINUE on U.S. 74. |
| 0.8 | Bridge across Banks Channel. |
| 1.3 | Desalination pilot plant on left. |
| 1.6 | U.S. 74 merges with U.S. 76. |
| 1.8 | Drawbridge across Intracoastal Waterway; low shoreline bluff on west side of waterway is the Suffolk (or Bogue) Scarp; land surface inland of Suffolk Scarp is the Waccamaw-Canepatch plain (7.6 m, 25 ft. elevation). |
| 2.1 | STAY ON U.S. 74 at stoplight (U.S. 76 bears left). |
| 3.0 | TURN RIGHT at stoplight onto SSR 1409 (Military Cut Off Road, U.S. 17 Truck Route). |
| 5.8 | BEAR RIGHT onto U.S. 17 N; U.S. 17 follows crest of Hanover Scarp; land surface to left is Duplin plain (12.2-13.7 m, 40-45 ft. elevation). |
| 6.3 | Ogden stoplight; CONTINUE on U.S. 17. |
| 15.4 | Junction N.C. 210; CONTINUE on U.S. 17. |
| 21.1 | Dug pits behind Al's Woodside Grocery (to right) have yielded an extensive Waccamaw fauna of molluscs, corals, echinoids and barnacles; this fossiliferous deposit is seaward of Hanover Scarp; CONTINUE on U.S. 17. |
| 24.2 | Junction N.C. 210; CONTINUE on U.S. 17. |
| 28.5 | Junction N.C. 50; CONTINUE on U.S. 17. |
| 32.8 | Junction N.C. 172 (to Sneads Ferry); CONTINUE on U.S. 17. |
| 36.7 | Junction N.C. 210 (to West Onslow Beach); CONTINUE on U.S. 17. |
| 42.4 | Verona; CONTINUE on U.S. 17. |
| 49.1 | Junction with U.S. 258, N.C. 24, Jacksonville; CONTINUE on U.S. 17. |
| 50.0 | New bridge over New River in Jacksonville; Trent Formation is exposed to right of bridge on northeast bank of New River behind second house downstream from old bridge; CONTINUE on U.S. 17. |
| 50.4 | Junction N.C. 24; CONTINUE on U.S. 17. |
| 64.9 | TURN RIGHT across SSR 1434 into entrance of Martin Marietta Belgrade quarry. |

## STOP 1

### Martin Marietta Aggregates Quarry at Belgrade (Fig. 1)

At present, the Martin Marietta quarry is located on the southwest bank of the White Oak River. Periodically, as quarry activity changes, the White Oak River is diverted so that the quarry is located on the northeast bank of the White Oak River. The Belgrade quarry is located 14.2 km (8.8 mi) northwest of the Silverdale quarry (type section of the Silverdale Formation) and is the type section of the Belgrade Formation of Baum _et al_. (1978), as well as of the Belgrade Formation of Ward _et al_. (1978).

Approximately 11 m of section is exposed along the quarry face. The lower 8 m of the section is the type section for the Belgrade Formation of Baum _et al_. (1978). Ward _et al_. (1978) consider this as part of their River Bend Formation (Trent Formation of Baum _et al_., 1978). The basal 2.5 m of the section consists of unconsolidated quartz arenite containing lenses of _Anomia_ and _Balanus_ that are locally indurated. This lithofacies grades upward into approximately 5.5 m of a sandy, pelecypod-mold biomicrudite. Holotypes described from these beds include: _Modiolus stuckeyi_ Richards 1948; _Panopea intermedia_ Richards 1948; and _Cardium belgradensis_ Richards 1948. Barnacles from this unit belong to Zullo's (this volume) _Solidobalanus_ zone C. Ward _et al_. (1978) also report the presence of _Chlamys waynesis_ Mansfield and _Anomia taylorensis_ Mansfield (= _Anomia ruffini_ Conrad according to the authors).

Disconformably overlying this sequence is the Haywood Landing Member of the Belgrade Formation of Ward _et al_. (1978). This unit was not recognized by Baum _et al_. (1978c). It consists of approximately 1 m of a sandy, molluscan calcarenite that grades into 1 m of unfossiliferous clay. This sequence is the type section of the Belgrade Formation of Ward _et al_. (1978).

According to Ward _et al_. (1978) the Haywood Landing Member is also represented by the sequence exposed in the Silverdale quarries, and is a lateral facies of the "_Crassostrea gigantissima_" channel deposit at Pollocksville (their Pollocksville Member). Baum _et al_. (1978c) also regarded the _Crassostrea_-bearing sediments disconformably overlying their Belgrade Formation as equivalent to the _Crassostrea_ channel deposit at Pollocksville, but considered the Silverdale sequence (their Silverdale Formation) as an offshore equivalent of their Belgrade Formation. Well defined _Crassostrea_-bearing channels at Belgrade were described by Lawrence (1976), but were not mentioned by Ward _et al_. (1978), and are not exposed in the quarry today.

The disconformity between the Belgrade Formation and the _Crassostrea_ beds is marked by a phosphatized surface to which oysters are attached. This surface is exposed on the east side of the quarry.

| | |
|---|---|
| 64.9 | _RETURN_ to U.S. 17; _TURN RIGHT_ onto U.S. 17 N. |
| 65.4 | Bridge across White Oak River. |

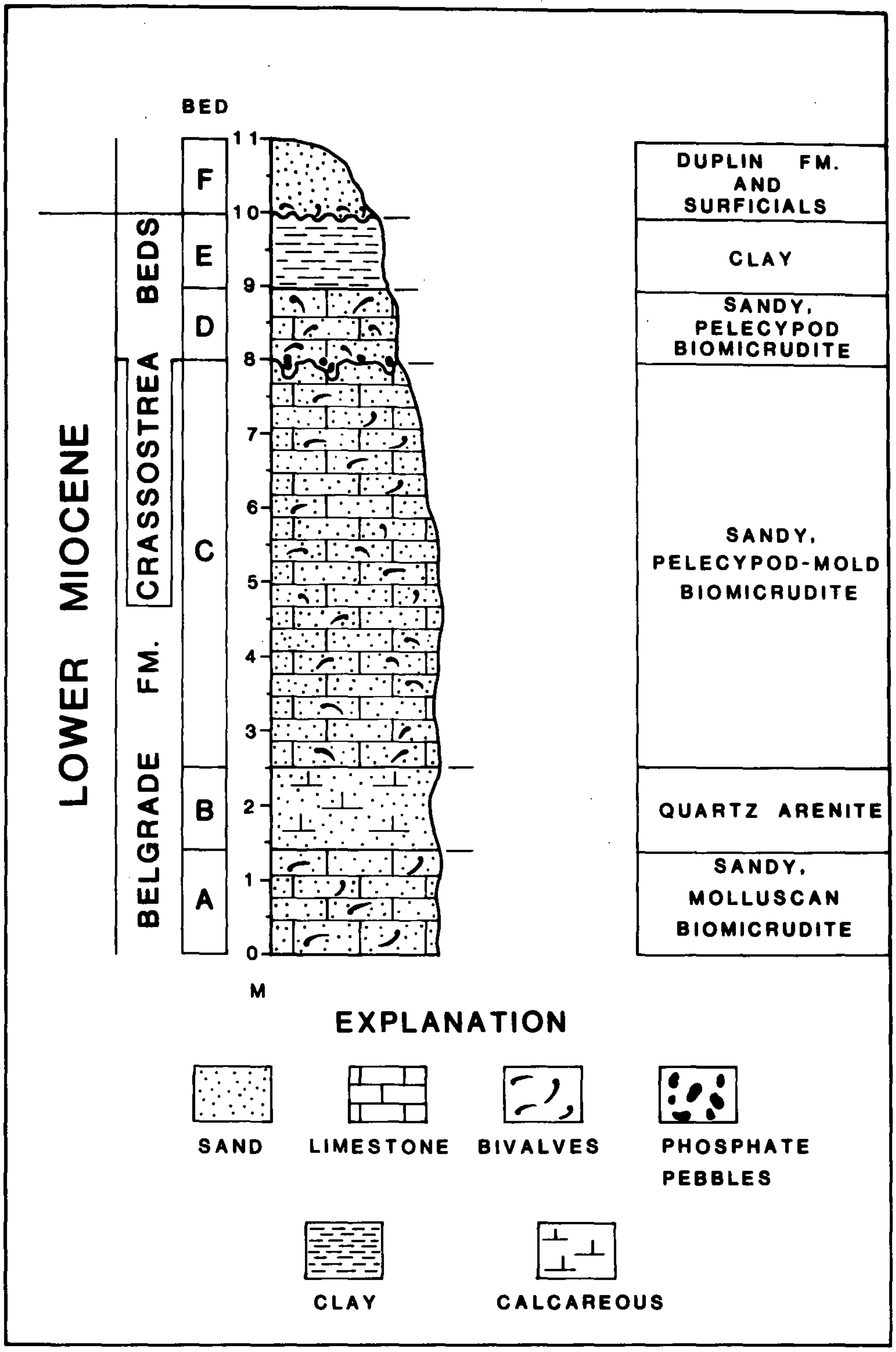


Figure 1. Composite section for the Martin Marietta Aggregates quarry at Belgrade.

| | |
|---|---|
| 66.1 | Junction N.C. 58, Maysville; *CONTINUE* on U.S. 17 N. |
| 73.2 | Junction N.C. 58 (to Trenton); *CONTINUE* on U.S. 17 N. |
| 74.2 | Bridge over Trent River; the restricted type section of the Trent Formation extends approximately from this point downstream to New Bern. The "*Crassostrea gigantissima*" channel deposit (Pollocksville Member of the Belgrade Formation of Ward *et al*., 1978) disconformably overlies the Trent Formation upstream from the railroad bridge (to the right). To the left, the New Bern Formation is exposed along the river upstream to Trenton. |
| 74.9 | Junction SSR 1336; *CONTINUE* on U.S. 17. |
| 75.3 | *TURN RIGHT* onto asphalt apron leading to dirt road. |
| 76.9 | *STOP* at quarry. |

## STOP 2

### North Carolina Department of Transportation Quarry

This quarry is located on the west bank of the Trent River and is within the type section of the Trent Formation as proposed by Baum *et al*. (1978c). This locality represents part of the River Bend Formation of Ward *et al*. (1978).

The Trent Formation consists of three facies, in ascending stratigraphic order: sandy, echinoid biosparite; sandy, pelecypod-mold biomicrudite; and barnacle, pelecypod-mold biosparrudite. The fauna includes the holotype of *Chlamys trentensis*, together with *Pecten* aff. *P. perplanus poulsoni* (Ward *et al*., 1978, consider this *P. perplanus byramensis*) and barnacles belonging to Zullo's (this volume) *Solidobalanus* B zone. At this locality, Ward *et al.* (1978) consider the Trent Formation to be late Vicksburgian.

Depending on the water level within the quarry, the section exposes 3.2 m of the Trent Formation. The basal lithology consists of 1.9 m of the sandy, echinoid biosparite which grades up into 1.3 m of the sandy, pelecypod-mold biomicrudite lithofacies. The upper barnacle, pelecypod-mold biosparrudite is not exposed in the quarry; however, excellent exposures occur downstream along the Trent River. The basal lithofacies is characterized by low angle planar cross-bedding and *Callianassa* burrows.

| | |
|---|---|
| 78.5 | *RETURN* to U.S. 17 and *TURN RIGHT*. |
| 78.8 | Junction SSR 1336; *CONTINUE* on U.S. 17. |
| 79.4 | *TURN RIGHT* onto dirt road leading to Jones Marl and Sand, Inc. |
| 80.4 | *TURN LEFT* into Jones quarry entrance. |

## ALTERNATE STOP 2

### Jones Marl and Sand, Inc.

This quarry exposes essentially the same section of the Trent Formation as the Department of Transportation quarry. Refer to description of Stop 2.

| | |
|---|---|
| 81.4 | RETURN to U.S. 17 and TURN RIGHT. |
| 82.7 | Junction SSR 1002; CONTINUE on U.S. 17 N. |
| 92.0 | TURN LEFT onto N.C. 55 W (towards Kinston) at New Bern. |
| 93.7 | TURN RIGHT onto SSR 1402 at stoplight. |
| 94.3 | TURN LEFT into entrance of Martin Marietta Aggregates quarry, New Bern. |

## STOP 3

### Martin Marietta Aggregates Quarry, New Bern (Fig. 2)

The Martin Marietta Aggregates quarry at this locality was designated the type section of the New Bern Formation by Baum *et al*. (1978c). This same unit was designated the Spring Garden Member of the Castle Hayne Limestone by Ward *et al*. (1978), with their type section 10.0 km (6.2 mi) to the northwest along the south bank of the Neuse River. These two formations are equivalent; however, Baum *et al*. (1978; this volume) demonstrated that the New Bern Formation lies disconformably on the Castle Hayne Limestone (restricted). It is considered equivalent to an unnamed upper Eocene Formation in South Carolina by Baum and Powell (1979) and Baum *et al*. (this volume, page 83).

The basal 9 m exposes the upper sandy, pelecypod-mold biomicrosparrudite lithofacies of the New Bern Formation. The fauna is dominated by the pelecypod *Callista*. Other forms include *Crassatella* cf. *C. alta*, *Chlamys* aff. *C. cawcawensis*; *Calyptraea*, *Lucinia*, *Panopea*, *Glycymeris*, *Ostrea* and possible *Solidobalanus* barnacles. Ward *et al*. (1978) report the presence of *Macrocallista neusensis* and *Bathytormus protextus*.

Exposed in the southwest corner of the quarry is a 1 m section of the Trent Formation that reveals the three lithofacies described by Baum *et al*. (1978c): the basal, sandy, echinoid biosparite; the sandy, molluscan-mold biomicrudite; and the upper barnacle, pelecypod-mold biosparrudite. Barnacles from this locality belong to Zullo's (this volume) *Solidobalanus* B zone. This exposure is also part of the River Bend Formation of Ward *et al*. (1978). *

Originally, the stratigraphically "compressed" nature of the Trent Formation at this quarry suggested that this area was uplifted by faulting after deposition of the New Bern Formation but prior to the deposition of the overlying Trent Formation. Thus, the trace of the Neuse fault was placed in the vicinity of the Trent River (Baum *et al*., 1978c) with the downthrown side to the southeast. However, subsequent data (Harris *et al*., 1979 Zullo and Harris, 1979) ~~this volume)~~ indicate that the Neuse Fault is probably

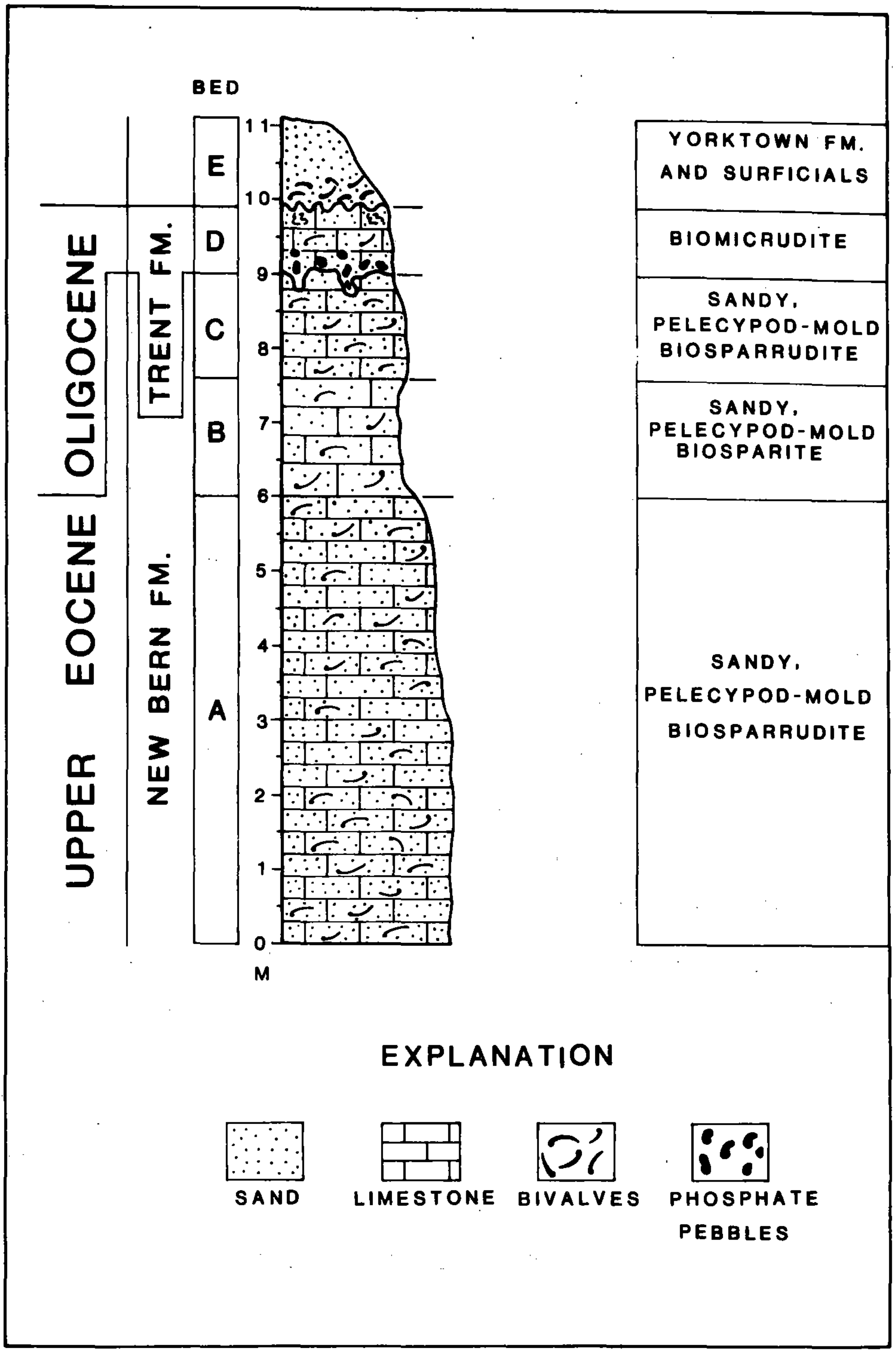


Figure 2. Composite section for the Martin Marietta Aggregates quarry at New Bern.

a fault zone whose effects on deposition can be recognized between the Neuse and New Rivers. The abrupt thickening of the New Bern Formation to the northeast, the abrupt termination of the Yorktown/Duplin formations in this area, and Pleistocene scarp and terrace morphology at New River suggest that the northeast side is down.

The Yorktown/Duplin formation ranges to 1 m in thickness. It lies disconformably on the Trent Formation; however, where the Trent Formation is absent, the Yorktown/Duplin Formation rests disconformably on the New Bern Formation.

| | |
|---|---|
| 94.3 | RETURN to SSR 1402 and TURN RIGHT. |
| 94.9 | Junction of N.C. 55 at stoplight; CONTINUE across intersection on SSR 1402 (S. Glenbourne Road). |
| 96.0 | TURN RIGHT onto U.S. 70 West freeway ramp (to Kinston). |
| 125.9 | Junction N.C. 58 at stoplight; CONTINUE on U.S. 70. |
| 126.7 | TURN RIGHT onto U.S. Business 70 W, U.S. Business 258 N and N.C. 58. |
| 126.9 | Bridge over Neuse River. |
| 128.5 | TURN RIGHT onto W. Veron Avenue, following U.S. Business 70 W, U.S. Business 258 N. |
| 129.0 | TURN LEFT at stoplight onto N.C. Business 11 N, N.C. 55 E. |
| 129.7 | TURN RIGHT at first stoplight onto SSR 1845 (J.P. Harrison Boulevard). |
| 130.9 | STOP at intersection of Secrest and Cogdell. |

## STOP 4

### Jericho Run Fault Scarp and Paleocene Beaufort Formation
(see Harris et al., this volume, Fig. 3)

Paleocene strata were unrecognized in outcrop in North Carolina when Brown (1959) named the Beaufort Formation from a well drilled at Chocowinity, Beaufort County. A glauconitic interval between 32.3 and 52.1 m (subsea) was designated the type section and assigned a Midway age. Subsequently, Paleocene strata were recognized in outcrop (Swift, 1964; U. S. Geological Survey, 1972). As presently recognized, the Beaufort Formation consists of a Danian member (Jericho Run Member) and an unnamed Thanetian member (Harris et al., 1976; Brown et al., 1976; Harris and Baum, 1977; Brown et al., 1977; see Baum et al., this volume, page 1 ). The Beaufort Formation probably should not be extended into South Carolina as suggested by Gohn et al. (1977) and Hazel et al. (1977).

This exposure of the Beaufort Formation was first described by Brown et al. (1977; locality NC-LEN-0-23-75) and was part of an extensive drilling project undertaken by the U. S. Geological Survey. At this locality, Brown et al. (1977) report approximately 4.6 m (15 ft.) of siliceous mudstone, chert and sandstone of the Danian Jericho Run Member. The remaining 1.8 m (6 ft.) was reported as surficial; however, close inspection reveals a highly weathered, clayey, glauconitic sand that may be the unnamed Thanetian member; however, attempts to recover diagnostic nannoplankton were unsuccessful (T. R. Worsley, personal communication).

Where both the Danian Jericho Run Member and unnamed Thanetian member are present in the same section, the contact between the two units presents conflicting interpretations: at places, the contact appears gradational; at others, the contact is sharp and appears disconformable (absence of intervening calcareous nannofossil zones between the units indicate a hiatus). At some localities, the Danian Jericho Run Member is absent, and the unnamed Thanetian member rests disconformably on the Cretaceous Peedee Formation (see Harris and Baum, 1977).

At this locality, the Jericho Run fault scarp is exposed. This scarp is a surface expression of the more extensive Graingers wrench zone (Brown et al., 1977), and can be traced from the DuPont plant east of Graingers, southward to this locality (approximately 12 km). The fault scarp is southeast facing and up to the northwest. Evidence presented by Brown et al. (1977) for faulting includes:

- average relief of fault scarp (13.4 m).
- offset of key marker horizons (see Harris et al., this volume, Fig. 3).
- locally developed breccias at toe of scarp.
- triangular faceting of scarp.
- fracture patterns.

| | |
|---|---|
| 130.9 | RETURN to N.C. 11; N.C. 55. |
| 132.1 | TURN LEFT onto N.C. Business 11 S, N.C. 55 W. |
| 133.4 | TURN RIGHT onto E. King, following N.C. 11 S. |
| 133.9 | TURN LEFT onto U.S. Business 258 S. |
| 135.0 | Junction U.S. 70, N.C. 58; CONTINUE on U.S. 258. |
| 153.4 | Junction N.C. 41; CONTINUE on U.S. 258. |
| 160.6 | Junction N.C. 24; CONTINUE on U.S. 258, N.C. 24. |
| 174.7 | Junction N.C. 53 at stoplight; CONTINUE on U.S. 258. |
| 176.0 | TURN RIGHT onto U.S. 17 S at Jacksonville. |
| 219.2 | TURN LEFT onto U.S. 17 Truck Route (SSR 1409; Military Cut Off Road). |
| 222.0 | TURN LEFT onto U.S. 74 at stoplight. |
| 224.5 | TURN LEFT onto Lumina Avenue, Wrightsville Beach. |
| 225.0 | TURN RIGHT into Holiday Inn. |

END FIRST DAY

## FIELD TRIP LOG FOR SECOND DAY

October 21, 1979

| Cumulative Mileage | |
|---|---|
| 0.0 | LEAVE Holiday Inn, Wrightsville Beach; TURN LEFT onto North Lumina Avenue (U.S. 74). |
| 0.5 | TURN RIGHT at stoplight at Salisbury Street; CONTINUE on U.S. 74 W. |
| 1.6 | U.S. 74 merges with U.S. 76. |
| 2.1 | STAY ON U.S. 74 at stoplight (U.S. 76 bears left). |
| 3.0 | CONTINUE on U.S. 74 at stoplight. |
| 5.6 | TURN LEFT at stoplight onto U.S. 17 S and remain in left lane. |
| 5.7 | TURN LEFT at stoplight onto ramp for N.C. 132 N overpass; CONTINUE on N.C. 132 N. |
| 9.2 | Junction Murraysville Road; CONTINUE on N.C. 132. |
| 11.7 | TURN RIGHT onto SSR 1318 (Blue Clay Road). |
| 14.3 | TURN RIGHT onto SSR 1002. |
| 14.8 | TURN LEFT into entrance of Martin Marietta Aggregates quarry, SSR 2023. |
| 15.3 | TURN LEFT into entrance of quarry. |

## STOP 1

### Martin Marietta Aggregates Quarry, Castle Hayne
(Fig. 3; Fig. 4; Table 1)

The Martin Marietta quarry at Castle Hayne is the type section of the Rocky Point Member of the Cretaceous Peedee Formation (Swift and Heron, 1969); the Eocene Castle Hayne Limestone (Baum et al., 1978c); and the New Hanover Member of the Eocene Castle Hayne Limestone (Ward et al., 1978) (phosphate pebble biomicrudite facies of Baum et al., 1978c).

The basal 10 m of the quarry exposes the sandy, pelecypod-mold biosparrudite of the Rocky Point Member of the Peedee Formation. The megafauna includes Cardium penderense, C. spillmani, Exogyra costata spinifera, Ostrea subspatulata, Pholadomya littlei, Trigonia haynensis, Belemnitella americana and Hardouinia mortonis, as well as a typical Maestrichtian foraminiferal fauna (see Stephenson, 1923; Fallaw and Wheeler, 1963; Wheeler and Curran, 1974). Harris and Bottino (1974) determined a Maestrichtian age for the Rocky Point Member at this locality using Rb-Sr glauconite dates. At different points in the quarry, a typical Peedee lithology can be seen overlying the Rocky Point Member.

The upper 11 m of section reveals the three lithofacies of the type Castle Hayne Limestone: 0-1 m of the lower phosphate pebble biomicrudite; 0-1 m of the bryozoan biosparrudite; 9 m of the bryozoan biomicrudite (Baum et al., 1978). The two lower lithofacies are separated by a diastem in the vicinity of the Cape Fear fault; however, to the northeast, away from the Cape Fear fault, these lithofacies interfinger. At this stop, the bryozoan biomicrudite facies is partially to completely dolomitized (see Baum et al., 1978a; 1978b) (Fig. 4).

The fauna in the Castle Hayne Limestone is extremely diverse (Baum, in press; Table 1); however, despite the diversity, the age of the Castle Hayne Limestone is still in doubt. Most recently, Brown et al. (1972) and Ward et al. (1978) consider the Castle Hayne Limestone middle Eocene; whereas, Harris et al. (in press), Worsley and Turco (this volume), Zullo (this volume), and Zullo and Baum (in press) indicate a late Eocene age for the biomicrudite facies.

Ward et al. (1978) considered their New Hanover Member (the basal phosphate pebble biomicrudite) to be equivalent to the Cubitostrea sellaeformis zone. Overlying this member is their Comfort Member (bryozoan biosparrudite and biomicrudite lithofacies of Baum et al., 1978) to which they ascribe the updip outliers of the Castle Hayne Limestone in Duplin County (see Otte, this volume). These Duplin County outliers are characterized by the echinoid Santeelampas oviformis. In the Santee Limestone of South Carolina, Santeelampas oviformis is concurrent with Cubitostrea lisbonensis (Baum and Powell, 1979; Baum et al., this volume, page 83). In the standard Gulf Coast sequence, the C. lisbonensis zone is below the C. sellaeformis zone, and this superpositional relationship is also observed in South Carolina. If Santeelampas oviformis is restricted to the C. lisbonensis zone, then Ward et al. (1978) may have their biostratigraphy reversed from that of the standard Gulf Coast sequence.

| | |
|---|---|
| 15.3 | RETURN to quarry entrance; TURN RIGHT onto SSR 2023. |
| 15.8 | TURN RIGHT onto SSR 1002. |
| 16.3 | TURN LEFT onto SSR 1318 (Blue Clay Road). |
| 18.9 | TURN LEFT onto N.C. 132 S. |
| 24.5 | TURN RIGHT onto off ramp on overpass to Wilmington/Wrightsville Beach. |
| 24.7 | TURN RIGHT onto U.S. 17 N, U.S. 74 E at stoplight. |
| 24.9 | TURN RIGHT at fork with U.S. 17 N; STAY ON U.S. 74 E; CONTINUE to Holiday Inn, Wrightsville Beach. |
| 30.5 | Holiday Inn. |

END SECOND DAY

Have a safe trip home.

Gerald R. Baum
W. Burleigh Harris
Victor A. Zullo

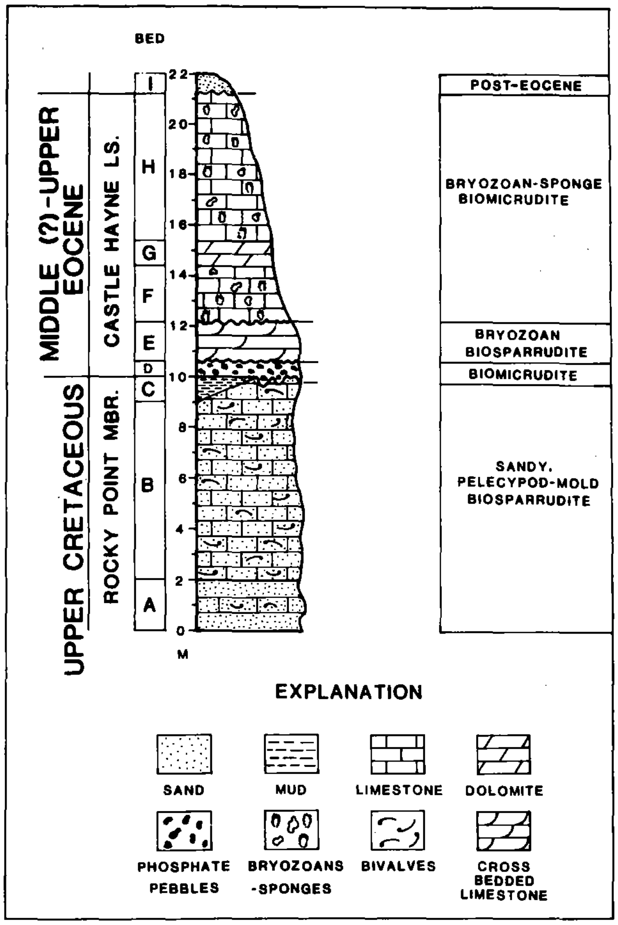


Figure 3.
Composite section for the Martin Marietta Aggregates quarry at Castle Hayne.

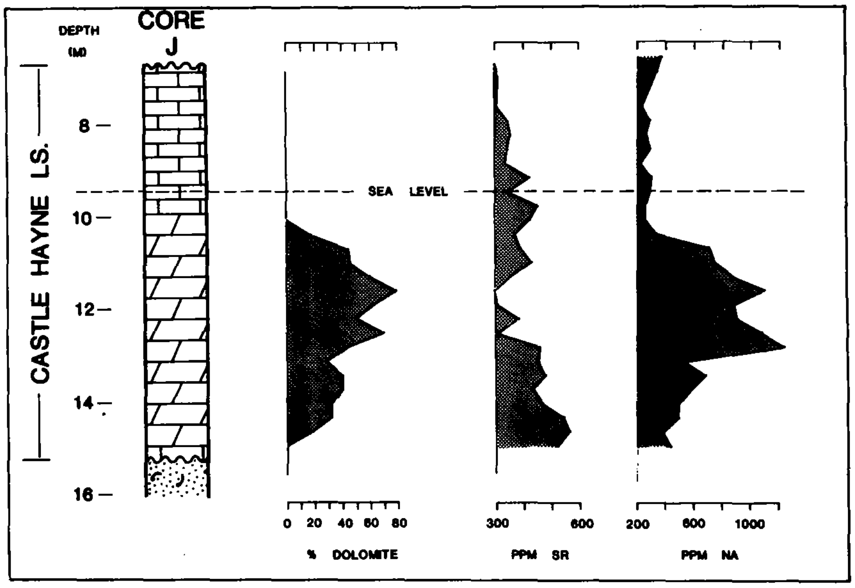


Figure 4. Percent dolomite, ppm Sr and ppm Na for a core drilled at the Martin Marietta quarry at Castle Hayne.

Table 1. Partial listing of fauna from the Castle Hayne Limestone (from Baum, in press). See Canu and Bassler (1920) for list of bryozoans.

GASTROPODS

*Agaronia*
*Architectonica*
*Athleta*
*Calyptraea*
*Caricella*
*Conus*
?*Crucibulum*
*Cypraea*
*Diodora*
*Emarginula*
*Epitonium*
*Ficopsis*
*Fusimitra*
*Galeodea*
*Marginella*
?*Neosimnia*
*Phalium*
*Pleurotomaria*
?*Pseudoliva*
*Puncturella*
?*Sconsia* (*Doliocassis*)
*Serpulorbis*
?*Strombus*
*Tenagodus* cf. *T*. *vitis* (Conrad) 1833
*Trigonostoma*
*Turritella*
*Xenophora*

CEPHALOPODS

*Aturia* *alabamanensis* (Morton) 1834
"*Belosaepia*"
*Eutrephoceras* *carolinensis* Kellum 1926

PELECYPODS

*Barbatia* cf. *B*. (*Cucullaearca*) *cuculloides* (Conrad)
*Cardiinae*
*Chama*
*Chlamys* *deshayesii* (Lea) 1833
*Chlamys* *membranosus* (Morton) 1834
*Corbula*
*Crassatella* cf. *C*. *texalta* Harris
Crassatellinae
?*Glossus*
*Gryphaeostrea* cf. *G*. *subeversa* Conrad 1866
?*Lirodiscus*
Modiolinae
*Ostrea* *falco* Dall 1895
*Ostrea* *trigonalis* Conrad 1854
*Pecchiolia* *dalliana* Harris 1919
*Pholadomya*
*Plicatula* *filamentosa* Conrad 1833
*Solena*
*Spondylus* *lamellacea* Kellum 1926
?*Venericardia*

## SCAPHOPODS

*Dentalium*

## BRACHIOPODS

*Argyrotheca*
*Probolarina holmesii* (Dall) 1903
*P. salpinx* (Dall) 1903
"*Terebratula*" *wilmingtonensis* Lyell and Sowerby 1845
*Terebratulina*

## CORALS

*Balanophyllia*
*Endopachus*
*Flabellum*

## ECHINOIDS

*Agassizia* (*Anisaster*) *wilmingtonica* Cooke 1942
*Arbacia*
*Cidaris pratti* (Clark) 1915
*Echinocyamus parvus* (Emmons)
*Echinolampus appendiculata* Emmons 1858
*Eupatagus* (*Gymnopatagus*) *carolinensis* (Clark) 1915
*Eurhodia rugosa* (Ravenel) 1848
*Linthia hanoverensis* Kellum 1926
*L. wilmingtonensis* Clark 1915
*Maretia subrostrata* (Clark) 1915
*Periarchus lyelli* (Conrad) 1934
*Phymosoma* cf. *P. dixie* Cooke, 1941
*Protoscutella conradi* (Cotteau) 1891
*Rhyncholampas* cf. *R. conradi* (Conrad) 1850

## OPHIUROIDS

Euryale (cf. *Asteronyx*)
Ophuirinae- broad and narrow arm species

## ASTEROIDS

?*Metopaster*
*Recurvaster*

## CRINOIDS

*Amphorometra*
*Democrinus*
*Microcrinus conoideus* Emmons 1858

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