

# LEE CREEK MINE

AURORA, NORTH CAROLINA

History, Mining Operations, Geology,  
Stratigraphy, and Paleontology

A Synthesis



**CAROLINA GEOLOGICAL SOCIETY**

**ANNUAL FIELD TRIP**

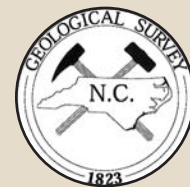
November 9-11, 2007

Guidebook Editor: Lauck W. Ward

Contributors

Lauck W. Ward

Ivan K. Gilmore



VMNH Guidebook Number 8

*Cover Figures:*

First photograph: General view of stripping operations in February 1972

Second photograph: L. W. Ward looking at the contact (head level) between the Chowan River Formation and the James City Formation. Cross-bedding reflecting a migrating inlet can be seen in the James City February 12, 1972.

To order publications from the Virginia Museum of Natural History, call (276) 634-4141.

Address postal orders to VMNH Publications Book Order, 21 Starling Ave, Martinsville, Virginia 24112.

Add 5% of total order amount to cover shipping and handling.

Virginia residents add 4% sales tax.

[www.vmnh.net](http://www.vmnh.net)

Pocket inset for Figure 4 (of Ward)

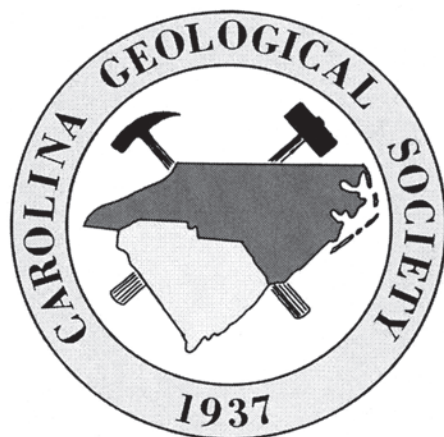


# **LEE CREEK MINE**

**AURORA, NORTH CAROLINA**

**History, Mining Operations, Geology  
Stratigraphy and Paleontology**

**A Synthesis**



**Carolina Geological Society  
Annual Field Trip  
November 9-11, 2007**

## **Leaders**

**Lauck W. Ward  
Ralph E. Eshelman  
Ivan K. Gilmore  
Kathleen M. Farrell**

## CAROLINA GEOLOGICAL SOCIETY

### 2007 Officers

President—Charles Trupe  
 Vice-President—Rick Wooten  
 Secretary-Treasurer—Duncan Heron

### Board Members

Mike Armour  
 Shield Engineering  
 4301 Taggart Creek Road  
 Charlotte, NC 28208-5483  
 704-394-6913 (W); 704-542-4759 (H)  
 E-mail: marmour@shieldengineering.com

Duncan Heron  
 Division of Earth and Ocean Science  
 Box 90230  
 Duke University  
 Durham, NC 27708-0230  
 919-684-5321 (W); 919-489-4402 (H)  
 E-mail: duncan.heron@duke.edu

Andy Bobyarchick  
 Dept. Geography & Earth Sciences  
 UNC-Charlotte  
 Charlotte, NC 28223  
 704-547-4264 (W); 704-545-1337 (H)  
 E-mail: arbobyar@email.uncc.edu

Charles Trupe  
 Dept. of Geology/Geography  
 Box 8149  
 Georgia Southern University  
 Statesboro, GA 30450  
 912-681-0337 (W); 912-842-9049 (H)  
 E-mail: chtrupe@georgiasouthern.edu

Bruce Campbell  
 US Geological Survey  
 720 Gracern Road, Suite 129  
 Columbia, SC 29210-7651  
 803-750-6161 (W) 803-727-9035 (Cell)  
 E-mail: bcampbel@usgs.gov

Rick Wooten  
 NC Geological Survey  
 2090 US Hwy 70  
 Swannanoa, NC 28778  
 828-296-8605 (W); 828-651-8605 (H)  
 E-mail: rick.wooten@ncmail.net

Alex Glover  
 Zemex Industrial Minerals  
 PO Box 99  
 Spruce Pine, NC 28777  
 828-765-8957 (W); 828-766-2683 (H)  
 E-mail: aglover@zemex.com

## 2007 GUIDEBOOK CONTRIBUTORS

IVAN K. GILMORE

Superintendent of Mine Planning and Chief Geologist  
PCS Phosphate–Aurora, North Carolina Mining Operations  
PO Box 48  
Aurora, NC 27806  
E-mail: [tgilmore@pophosphate.com](mailto:tgilmore@pophosphate.com)

LAUCK W. WARD

Curator of Invertebrate Paleontology  
Virginia Museum of Natural History  
21 Starling Avenue  
Martinsville, VA 24112  
E-mail: [lauck.ward@vmnh.virginia.gov](mailto:lauck.ward@vmnh.virginia.gov)





## CONTENTS

Forty Years of Mining at PCS Phosphate Mining Operations—Aurora, North  
Carolina.....1

Synthesis of Paleontological and Stratigraphic Investigations at the Lee Creek  
Mine, Aurora, NC (1958-2007)  
Lauck W. Ward.....15



# Forty Years of Mining at PCS Phosphate Mining Operations - Aurora, North Carolina

*Ivan K. Gilmore<sup>1</sup>*

## ABSTRACT

The Phosphate deposits in Beaufort County North Carolina were first discovered in the early 1950s. Many companies conducted exploration programs and attempted to initiate mining operations in the late 1950s and early 1960s. PCS Phosphate and its predecessors have mined and processed phosphate ore at the Aurora Phosphate Mine in Aurora, North Carolina since 1965. The open-pit mine is located in the central coastal plain, near the Pamlico River. The history of the mining operation is one of continuous change, expansion and improvement.

The current mining sequence includes the removal of forty feet of unconsolidated overburden using bucket wheel excavators followed by the removal of seventy-five feet of overburden and thirty-five feet of phosphate ore by three large walking draglines (77, 72 and 50 cubic-yard bucket capacities). The large draglines re-handle and stockpile the mined ore for further processing. The stockpiled ore is slurried and pumped to the mill for concentration.

Mining began in December of 1965. From 1965 to 1979, one 17 cubic-yard dragline and two 19 cubic-yard draglines were utilized to remove the unconsolidated overburden ahead of the draglines and to re-handle and stockpile the mined ore for pumping. One large (72 cubic-yard) dragline was used by the mining operation for the production requirements. A second large (50 cubic-yard) dragline was added to the mining operation in 1976 to increase production capacity.

From 1979 to 1990, two thirty-inch dredges were utilized to remove the unconsolidated overburden. A third large (77 cubic-yard) dragline was added to the mining operation in 1986 to increase production capacity.

From 1990 to present, two bucket wheel excavators are utilized to remove the unconsolidated overburden ahead of the draglines. The current mining operation handles approximately 38 million tons of total overburden, 11 million tons of phosphate ore and processes 5 million tons of phosphate concentrate.

## BACKGROUND

PCS Phosphate, formerly Texasgulf, Inc. (TGI), began phosphate exploration in eastern North Carolina (**Figure 1**) in 1958 and began acquiring land in 1961. In 1964, the company commenced construction of a mine, mill and mineral processing complex. The mill facilities included a washer, float plant, calciners, grinder, storage silos, and wet rock storage areas. The mineral processing facilities included plants to manufacture sulfuric and phosphoric acids, and solid fertilizer. The complex has undergone substantial expansion and modernization since 1965, including the addition of a 40-megawatt cogeneration facility, a purified acid plant and material storage facilities at the North Carolina State Ports Authority in Morehead City.

In 1985, the Aurora facility became the first phosphate mining and mineral-processing complex in the world to construct a by-product blending facility that combines mill clays and gypsum. The resulting gypsum/clay blend provides a sound reclamation base that consolidates rapidly, demonstrates soil characteristics, and supports a variety of grasses and trees. This unique solution to the material storage requirement enhances land reclamation timing and eliminates the need to consume new lands for separate clay and gypsum storage.

In 1985, TGI merged with North Carolina Phosphate Corporation (NCPC), a competitor preparing to mine from a 4,000-acre tract adjacent to the TGI complex. During 1987, TGI presented a modified mining plan to regulatory agencies which incorporated the more economical Bucket-Wheel Excavation System developed by NCPC, phased-out the dredges, and meshed the timing and logistics of mine progression, waste material storage, and land reclamation to the advance of the mining operation east into the NCPC tract. The Bucket-Wheel Excavation

---

<sup>1</sup> Superintendent of Mine Planning and Chief Geologist for PCS Phosphate-Aurora, North Carolina Mining Operations, P.O. Box 48, Aurora, NC 27806; Email - [tgilmore@pcsphosphate.com](mailto:tgilmore@pcsphosphate.com)

System began implementation in 1989. In April 1995, The Phosphate Division of TGI was purchased by Potash Corporation of Saskatchewan (PCS) and the mining operations resumed under the name of PCS Phosphate. With the permitted mining area comprising about 12,800 acres, a total of approximately 1,400 acres have been reclaimed and released from the mine permit. The mine location is shown on **Figure 1** in relation to the underlying geologic formations in Beaufort County, North Carolina.

The mining technique initiated in 1965 consisted of utilizing two draglines to remove the overburden and ore to depths of 100 to 140 feet below land surface (bls) or to elevations of 90 to 130 feet below mean sea level (msl). In 1977, the technique changed to utilize hydraulic dredges to excavate the overburden to a depth of about 30 to 40 feet bls. Once the first stage of overburden removal was completed, the dredge water was removed and the mine block allowed to dry for about 6 months before the draglines were moved into the excavation. The remaining overburden and the ore were then excavated by the draglines. In 1990, mining operations phased out the hydraulic dredges and began to utilize bucket-wheel excavators to excavate the upper section of the overburden. The Bucket Wheel – Dragline mining method has been in use since 1990.

## **GEOLOGY**

### **General Stratigraphy and Structure**

The Coastal Plain of North Carolina is underlain by a “wedge” of stratified sedimentary rocks as indicated in **Figure 1**. From a thin veneer along the western boundary of the Coastal Plain, the wedge of sediments thickens seaward to about 10,000 feet at Cape Hatteras, the easternmost point on the Outer Banks. The sediments lie unconformably on a basement of igneous and metamorphic rocks of the Precambrian or early Paleozoic age, similar or equivalent to the rocks of the Piedmont region of the state. The basement floor slopes generally southeastward at a gradient of 35 feet per mile (ft/mile) over much of the region, but the gradient is much steeper in the eastern part of the Coastal Plain.

The sedimentary rocks are subdivided into geologic formations or stratigraphic units that can be identified by their lithology, by their position in the sedimentary sequence, and by the fossils they contain. These units range in geologic age from recent to early Cretaceous or possibly

older. In general, the units have a northeastern strike and dip southeastward at a gradient of about 20 ft/mile.

In the Beaufort County area, the thickness of the sedimentary rock ranges from about 1,200 feet in the west to about 4,500 feet in the east. The sediments consist of clay, silt, sand, shells, limestone and combinations of these lithologies.

### **Local Mine Geology**

Changes are brought about to a mining operation through a numbers of variable factors. These factors include ore reserve availability, market conditions, and environmental regulations. In many mining operations, variation in the local mine geology is the greatest agent of change impacting major mining decisions. In order to understand the changes over the last forty years at the Aurora phosphate Operations, a good understanding of the local geology is required.

The mine geology is partitioned into three levels of excavation, prestrip overburden, strip overburden and the mined phosphate ore section. The underburden is not excavated but is important in any understanding of the local mine geology. See **Figure 2** regarding the general geologic column relating to the stratigraphic units at the PCS Phosphate mining operation.

### **DESCRIPTION OF TEST PIT AND EARLY MINE DEVELOPMENT 1963-1965**

When the phosphate deposit was discovered in eastern North Carolina in the early 1950s, several mining companies attempted to recover the rich deposit using hydraulic borehole well mining techniques. None were successful and further development was abandoned due to ground subsidence issues and inadequate production volumes.

PCS Phosphate’s predecessor, Texas Gulf Sulfur, conducted exploration activities in the late 1950s and early 1960s which lead to a decision to develop a test pit and pilot plant in 1963. The test pit, averaging 900 feet in diameter to a depth of 135 feet, was dug by the 20-inch dredge, named the Gillespie, to recover adequate volumes of phosphate ore matrix for metallurgical studies. See **Figure 3**. These pilot tests were successful and a development plan for the mine, mill and chemical plant complex was completed in late

1963. The major capital expenditures to implement the plan was approved by the corporation in April 1964 and construction began.

The initial mine development included land clearing, surface drainage, equipment construction and procurement of materials. The first step in the development of full scale mining operations was to remove approximately 50 feet of overburden over a 60 acre area adjacent to the 1963 test pit. This was done with a hydraulic dredge, named the Barlow. The Barlow removed over 4 million yards of overburden for the original mine pit.

A Bucyrus-Erie (BE) 480W 19 cubic-yard dragline was constructed onsite from 1964 to 1965, see **Figure 4**. This dragline was utilized to dig drainage canals, remove overburden, and mine the first ore until the larger mining dragline was completed. The 480W began to re-handle ore from the larger mining dragline, a BE 2550W, which was constructed onsite and put into service in April 1966.

The removal of the first phosphate ore matrix by a dragline occurred in December 1965. Mined phosphate ore was placed into an open sump, slurried by hydraulic monitors and pumped to the mill for beneficiation. The mill concentrator produced the first phosphate concentrate in March of 1966, see **Figure 5**, and the first product shipped from the complex in April 1966 (Chamness, 1985).

## **DESCRIPTION OF DRAGLINE – CHOPDOWN MINING METHOD**

From the beginning of the mining operations until 1977, the mine removed the upper unconsolidated overburden with draglines. Overburden is cast aside into a previously mined out excavation to expose the ore to be mined. In order to create the initial space for stacking the overburden, the dredge Barlow developed the first mine block of 60 acres. The mine progressed westward from the original development block, created by the dredge, at a rate of approximately 75 acres per year.

The original mine advance operated along a 3,600 foot wide pit. The original ore cuts were 150 feet wide. All the ore cuts were excavated from north to south with the dragline being walked back to begin each new cut. Originally the dragline operated from a mine bench located at approximately -50 msl and was located in the Upper Yorktown clay. This accommodated better reach

for casting the overburden. However it created problems at the surface of the mine bench. The clay surface became a problem for mine traffic and the dragline had frequent mobility problems. Sand from the mill tailings were hauled to the mine bench for a better operating bench. The geologic conditions were more favorable for a better mine bench located at the top of the Shell Bed (then the Boulder Bed) at approximately -25 msl. The draglines were moved to this level in early 1967.

The Dragline – Chopdown mining method consisted of three separate cycles. The chopdown overburden was removed and cast into the open pit. This required the dragline to strip above its operating bench. The next cycle required the dragline to excavate below its operating bench and remove the remaining overburden and cast it into the open pit. In the third cycle, the ore was recovered and placed in a stockpile located at ground level by the 19-cubic yard machine. See **Figure 6**. The ore was slurried with high pressure water at 225 psi and pumped to the mill for beneficiation. Handling the ore from this level, so close to the upper highwall, became a stability problem and, at times, inundated the draglines on the lower bench.

When the mine bench was moved up to -25 msl, it created a suitable mine bench to work from but increased the amount of stripped overburden below the mine bench. The unconsolidated chopdown overburden was saturated and tended to flow after being excavated and placed in the mine pit by the draglines. Eventually the removal of chopdown overburden by the draglines as a mining method led to ore loss in the form of small instu ore plugs that had to be left in order to shore up the fluid cast overburden. The in-flow of unstable overburden into the active mine cut also led to an increase in ore dilution. Any contamination of the phosphate ore by carbonate rich overburden increased the sulfuric acid requirements for creating phosphoric acid in the chemical processing complex. All these factors led to low production rates and high mining costs.

An attempt was made to pump the chopdown overburden by relaying it to ground level, slurried with water and pumped behind the mine. In 1974 a 17 cubic-yard Marion 7400 dragline was added to the mine in order to relay overburden for pumping, increase ore re-handle capacity and dig drainage canals around the perimeter of the mine advance. In 1975 a 50 cubic-yard Marion 8050 was constructed to increase capacity for stripping and mining

the phosphate ore. The 8050 dragline entered service in 1976.

The process of pumping chopdown overburden worked for a period of time until the additional water in the pumped chopdown slurry increased the movement of the cast spoils toward the mine face. Mining conditions became worse than it had been before the chopdown overburden was placed in the pit by the draglines. The chemical complex had seen expansions in 1969, 1973 and 1976. Pressure was on the mining operations to deliver increasing amounts of phosphate ore to meet the demands of the expansions. Another mining method was needed to remove the upper overburden to increase ore recovery, ore quality and dragline productivity. A review of available mining methods was undertaken in 1976 and utilization of a familiar method to the operation was chosen as the solution.

### **DESCRIPTION OF DREDGE – DRAGLINE MINING METHOD**

The mining operations reviewed methods for removing the upper overburden in 1976 that included dredging, bucket wheel excavators and backhoes with truck haulage. The analysis completed favored dredging with its high volume and low cost per cubic-yard moved.

A decision was made to purchase a 30-inch Ellicott cutter-suction dredge in 1976. The dredge, named Sam Houston, was put into service in 1977. The dredge was very successful with overburden removal and the draglines started mining the first dredged-over area in July 1977. Once dredging was proven, a decision was made in 1979 to construct another 30-inch dredge onsite. The second dredge, named Sir Walter Raleigh, was commissioned in 1981.

The Dredge - Dragline mining method uses a dredge to remove the saturated overburden ahead of the dragline. See **Figure 7**. This was accomplished in blocks of 100 to 150 acres in size. After the dredge block has been excavated to the top of the Shell Bed unit, the base of the entire block is swept by the dredge. This removes suspended materials from the original excavation that would be detrimental to a dragline operational bench. The final bottom must be stable and as flat as possible for the draglines. After sweeping, the dredge advances to the next block through a narrow channel excavated between dredge blocks. The channel is then backfilled with dredge spoil and stabilized. The completed block is then dewatered, ditched and drained (Hird, 1980).

The Dredge - Dragline method of mining allowed for

the removal of the overburden to take place ahead of the dragline advance. This allowed the draglines to concentrate their operational time stripping the Yorktown overburden and mining the phosphate ore matrix in an open pit free from handling chopdown spoils. Insitu ore plugs were no longer used as retaining walls for the cast overburden. The limestone above the ore was used to shore up the toe of the windrows of cast overburden.

An immediate increase in ore recovery and ore quality occurred in the areas where the dredge had removed the upper overburden. With the advent of dredging, the mine saw ore recovery increase from 60 to 90 percent. Better utilization of the phosphate reserves was finally made possible.

Because the draglines were relieved from removing chopdown overburden, their capacity to mine phosphate ore increased enough to surpass the capabilities of transporting and processing the ore. This was a major step forward for the mining operations. The economic benefits from improved ore recovery more than compensated for the cost of dredging. This method also allowed the ore stockpile to be located on the mine operation bench along with the 19 cubic-yard dragline and associated ore pumping equipment. The land surface bench no longer required preparation to place ore stockpiles that caused unstable conditions. Finally, reclamation activities improved with the placement of the upper overburden behind the mine by the dredge.

As a result of the merger with the North Carolina Phosphate Corporation in 1985, the mining operations added a Marion 8200 dragline with a 77 cubic-yard bucket capacity. The 8200 had been constructed onsite in 1982 through 1983 and was put into mining service in 1986.

In the Dredge – Dragline mining method, it was planned to have a dewatered dredge block between the active dredging and the draglines. This practice was not economical to have all the available mine acres setting idle for the length of time between dredging and mining. Therefore this practice was not always practical and mining closely followed the dewatering of dredge blocks. Seepage from the dredge block into the mine was a constant concern.

Concerns arose about dredging when cavities in the Shell Bed were discovered in the dike between the dredge pond and active mine bench in 1981. This presented a major safety concern for the entire mining operation. Other concerns arose regarding the turbidity of the

discharge water. The corporation had committed to an internal water recycle system to be in place in the early 1990s. This made the holding and discharging of large volumes of dredge water problematic. Dredging also caused the swelling of the upper overburden clays in the discharged materials behind the mine. This impacted the available waste material storage area and extended the timing of reclamation activities.

Once again, the mining operations were challenged to find an alternative solution to removing the upper overburden while doing it in an economical and practical manner.

### **DESCRIPTION OF BUCKET WHEEL – DRAGLINE MINING METHOD**

As a result of the merger with the North Carolina Phosphate Corporation (NCPC) in 1985, the mining operations acquired four PHB Wesserhutte bucket wheels with 12 cubic-yard digging wheel capacities. The other equipment associated with this system included mobile transfer conveyors, face conveyors, connecting conveyor, spoil bank conveyor and a Krupp Spreader mounted on a crawler tractor. A decision was made to implement the bucket wheel excavator system and construction occurred between 1988 and 1989. Only two of the bucket wheels were initially constructed. Originally in the NCPC plan, ore was to be reclaimed by two bucket wheels instead of using smaller draglines. The other two bucket wheels would remove the upper overburden referred to as prestripping.

The Bucket Wheel – Dragline method of mining uses two bucket wheel excavators (BWEs) to excavate the unconsolidated upper overburden, conveying the material on to a mobile transfer conveyor (MTC) then on to the face conveyor located behind the excavation and parallel to the digging face. The overburden is conveyed on the face conveyor via a 54-inch belt and up an incline conveyor from the mine bench to land surface. From land surface it is conveyed by the Connecting Conveyor (CC) to the Spoil Bank Conveyor (SBC) via a 72-inch conveyor belt. The overburden spoil is conveyed to the Spreader where the overburden is dumped into the reclamation area behind the mine off the discharge boom. See **Figure 8**.

The ore re-handle method was experimented with in 1989 but was not successful due to the large boulders of dolomite and limestone that are frequently found in the

ore stockpile. The bucket wheels primary role would be to remove the upper overburden ahead of the draglines.

Initially, the bucket wheels were not productive due to inadequate dewatering of the upper overburden and the large volume of clay present in the excavated overburden in 1990. Once adequate dewatering was established and geologic factors improved, the bucket wheel excavator system preformed as it was originally planned. The total system is capable of removing and conveying 14 million cubic-yards of overburden annually.

In 1992 the 19 cubic-yard draglines were retired from service and the three large draglines added ore re-handle to their function.

In years 2000 and 2001, it became necessary to implement contract dredging of the overburden to remove problematic soils and allow for the timely relocation of the bucket-wheel excavation system to a new mine development block (NCPC tract).

Major advantages to the bucket wheel excavator system over dredging have been realized. These advantages include the development of the mine bench in real time, allowing geologic conditions in the overburden to be seen that were hidden during dredging. Other advantages are excavated soils free from the introduction of water resulting in less swelling of overburden clays, no discharge of turbid waters, reduced electrical operating costs and the creation of an operational bench that is more effectively dewatered.

### **CONCLUSIONS**

The mining operation has expanded and improved over the course of forty years in order to increase efficiency, meet demands and adapt to environmental changes. Future challenges will be met by the mining operations in order to recover this valuable non-renewable resource.

### **REFERENCES**

1. Chamness, Ralph S., History of the Lee Creek Mine, Guidebook, International Geological Correlation Program, Project 156 – Phosphorites, Eighth International Field Workshop and Symposium, p. 33-40, May 1985.
2. Hird, John M., Overburden Stripping – Combination of Dredge and Dragline, Mining Engineering, Vol. 32, p.311-314, 1980.

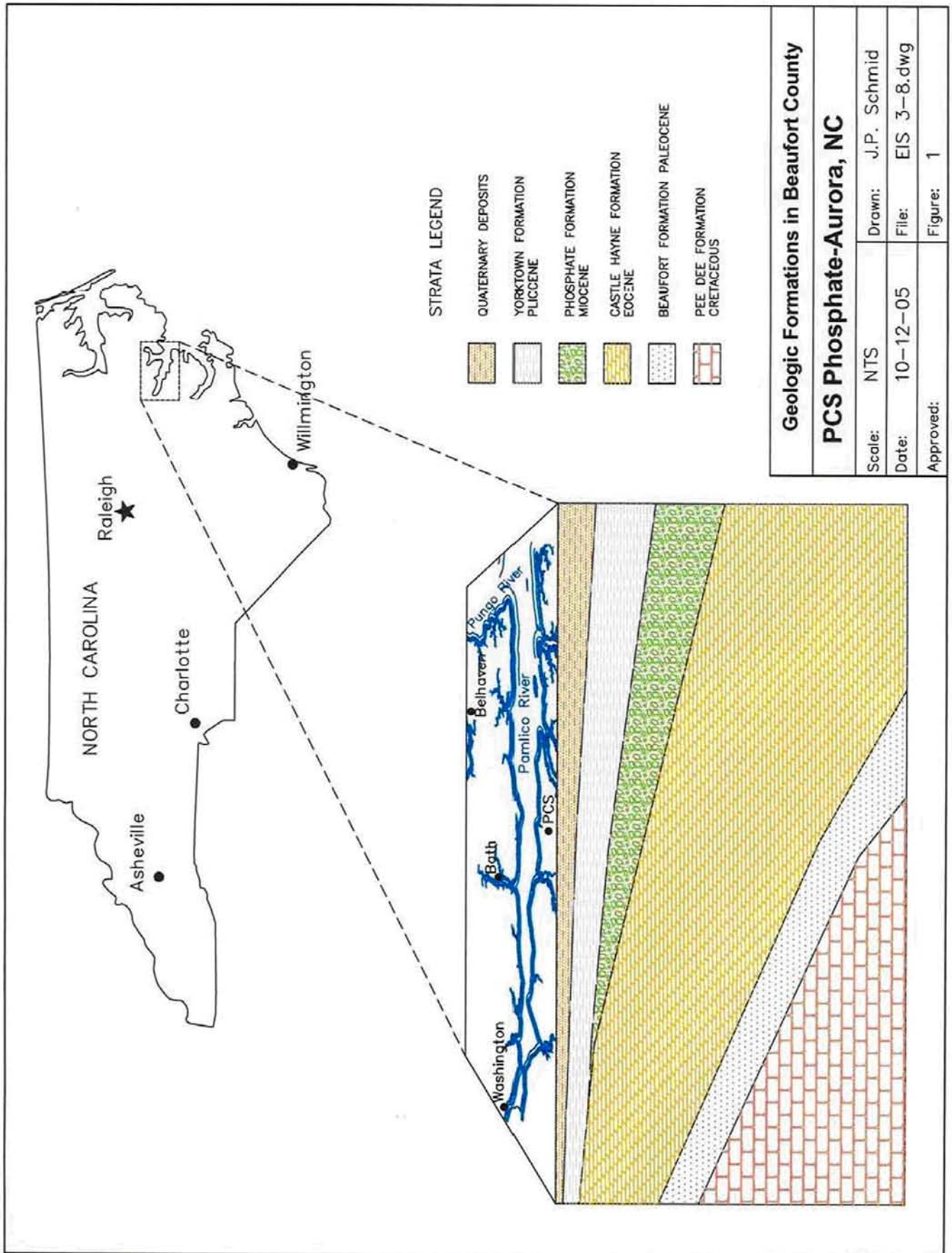


Figure 1 – Geologic Formations in Beaufort County



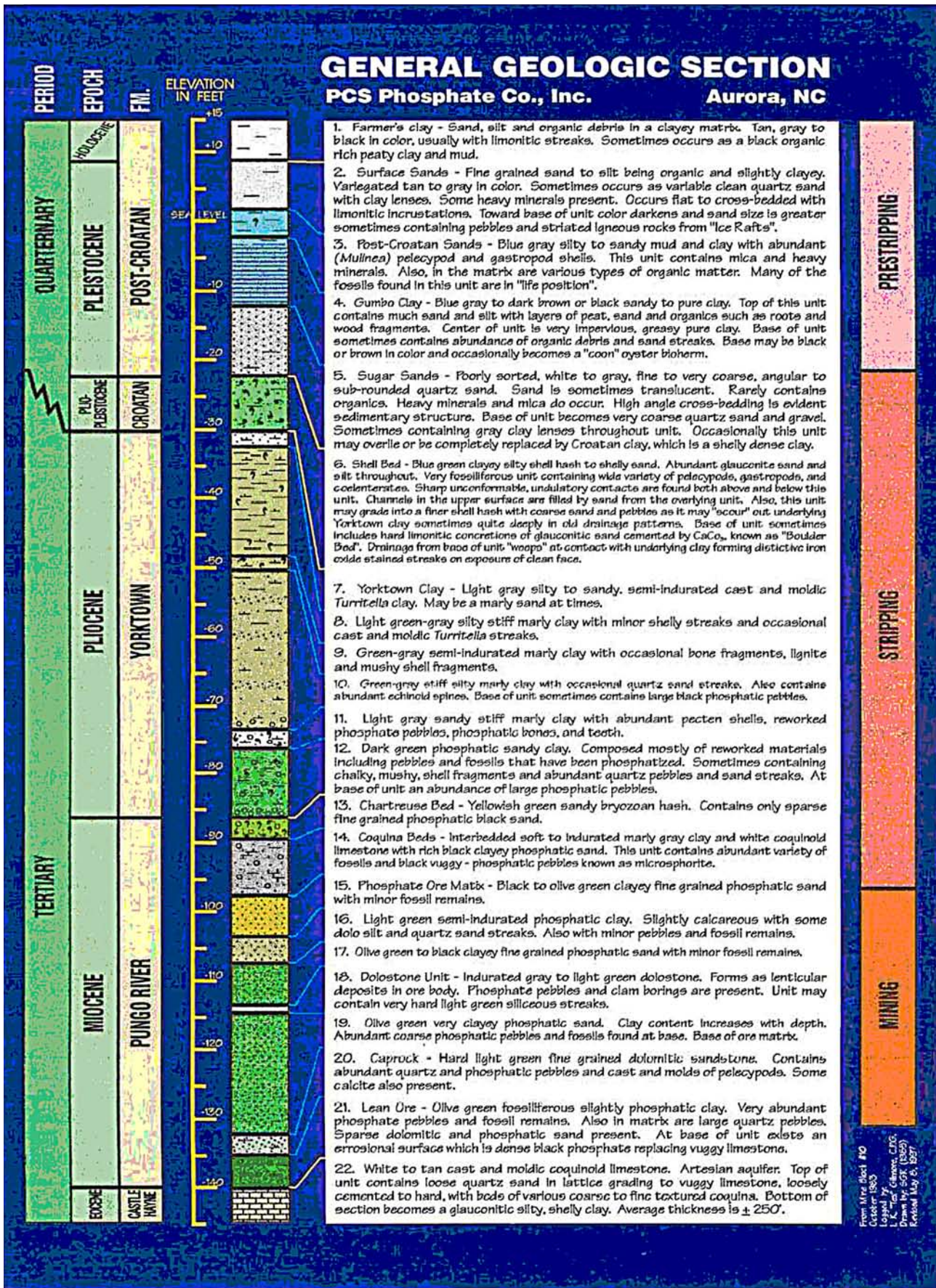


Figure 2 – General Geologic Section (Local Mine Geology) PCS Phosphate, Aurora NC

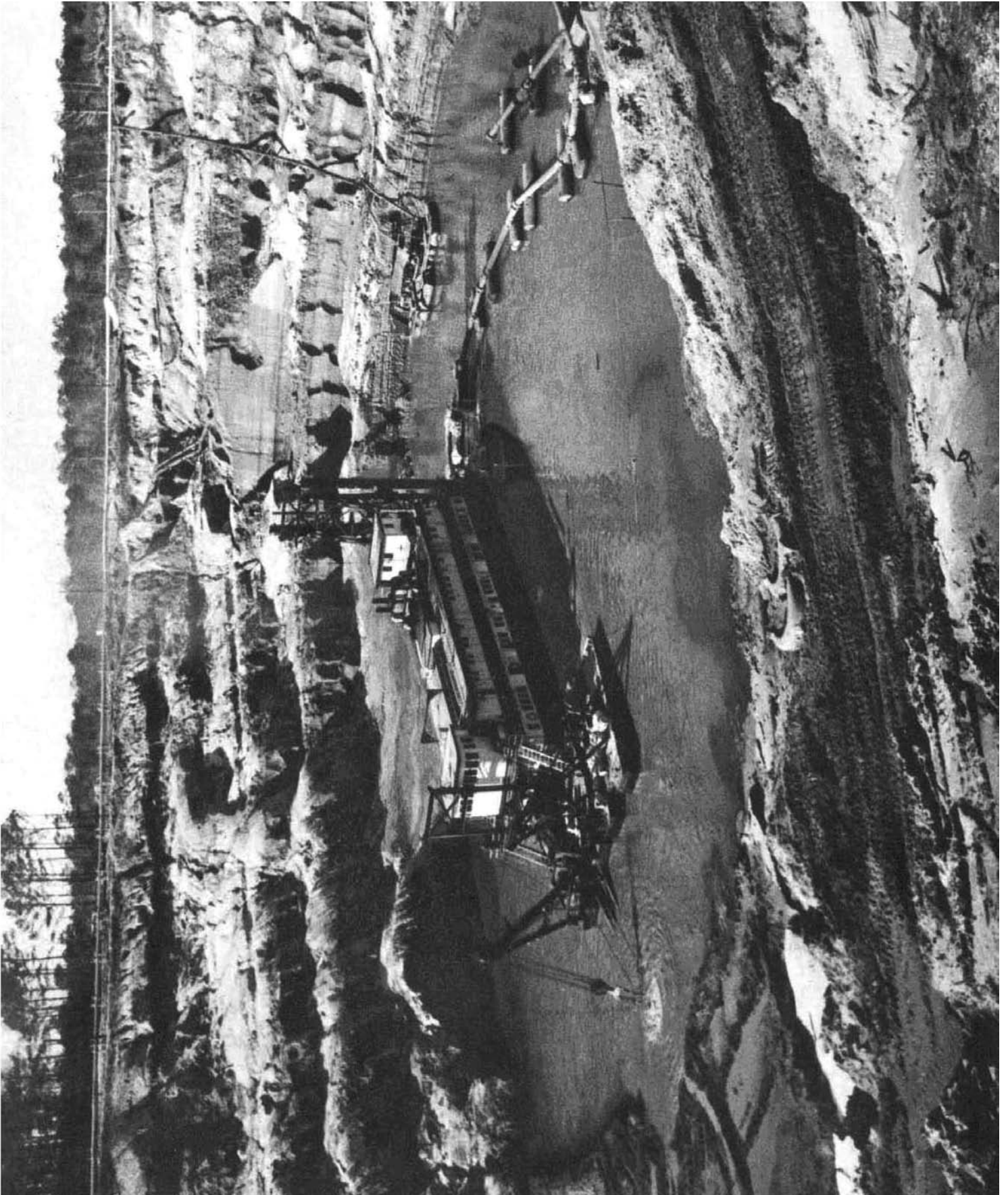


Figure 3 – 1963 Test Pit with Dredge Gillespie



Figure 4 – 1964 Construction of the BE 480W Dragline



Figure 5 – 1966 Aerial view of initial phosphate concentrate stockpile.

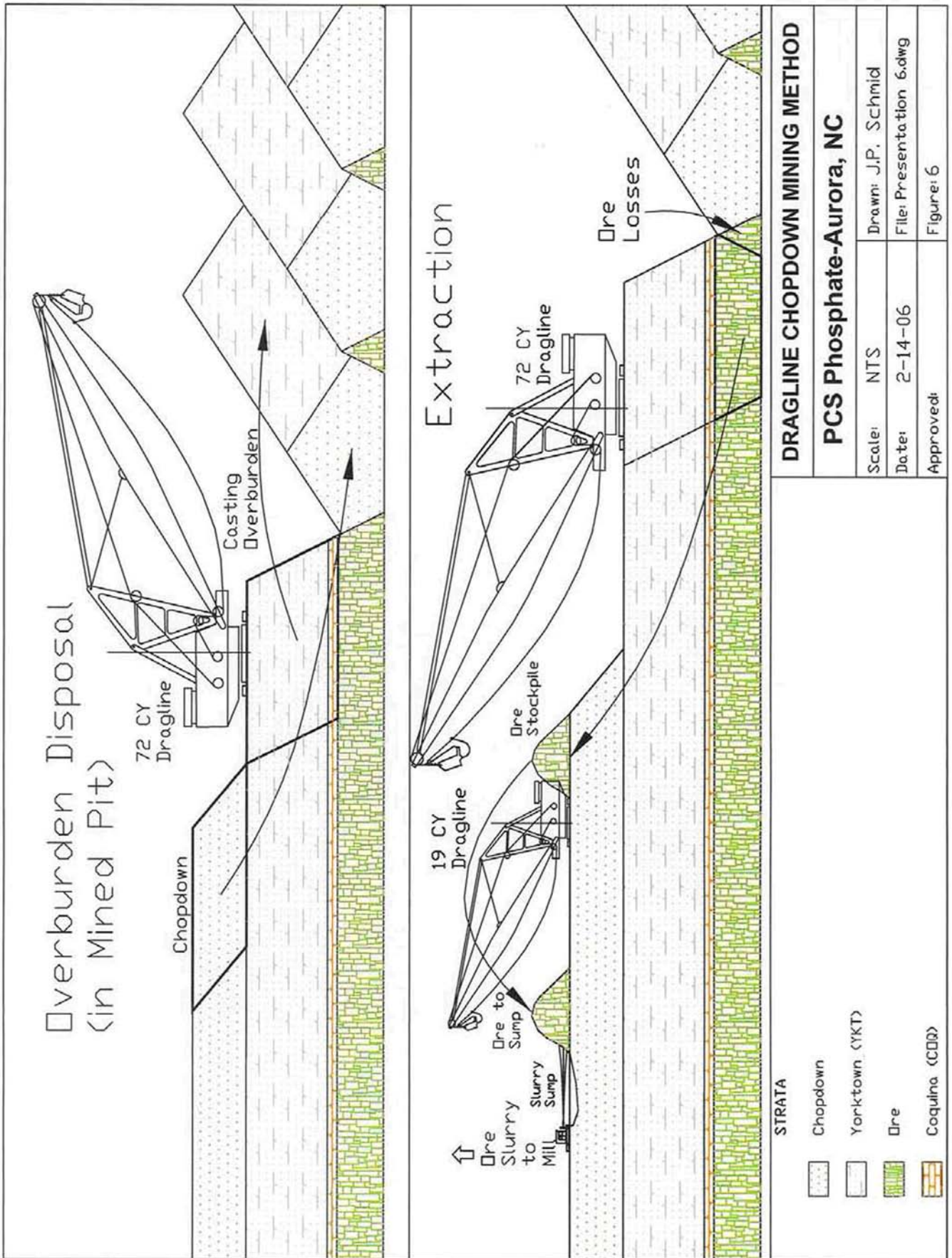


Figure 6 – Dragline - Chopdown Mining Method

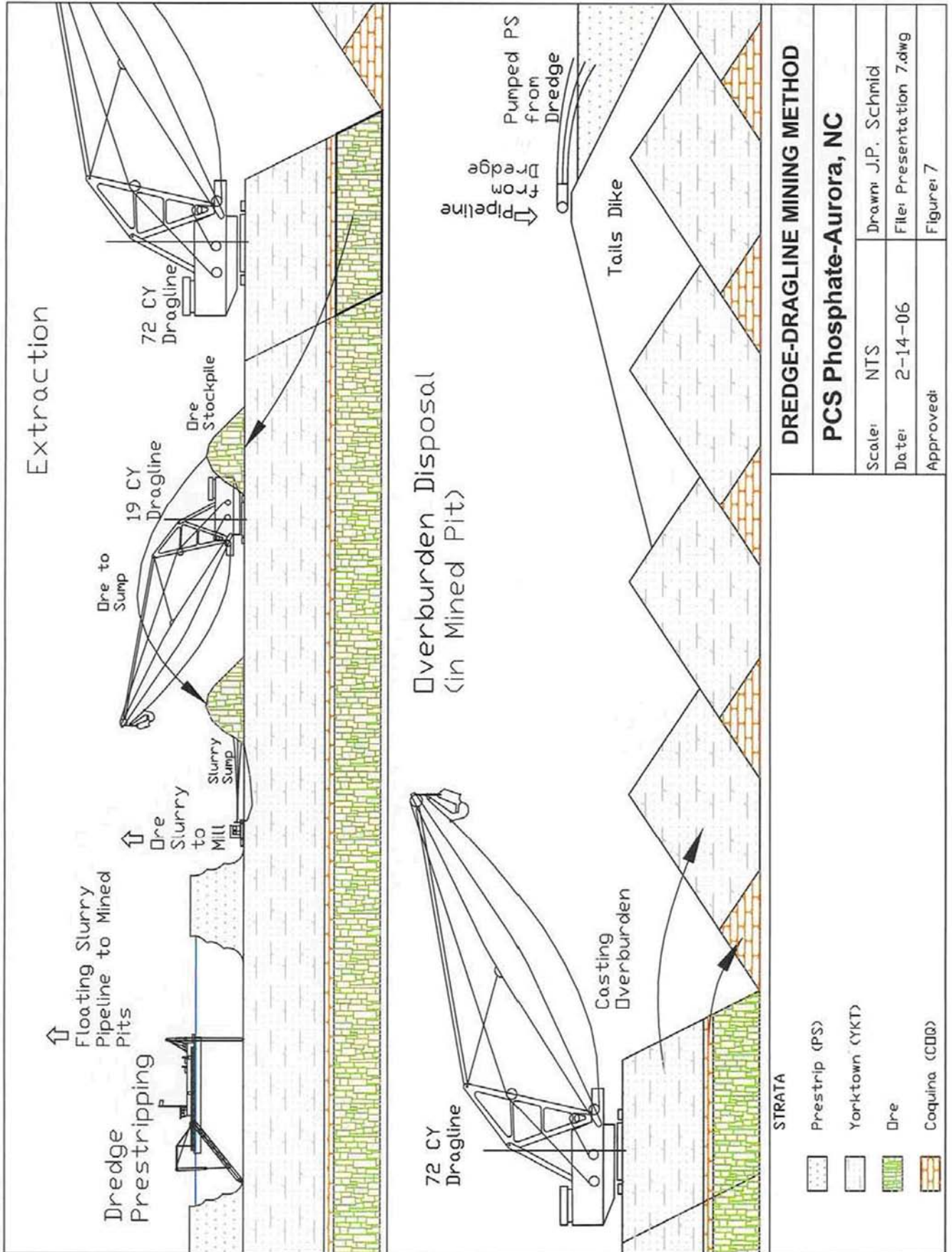


Figure 7 – Dredge – Dragline Mining Method

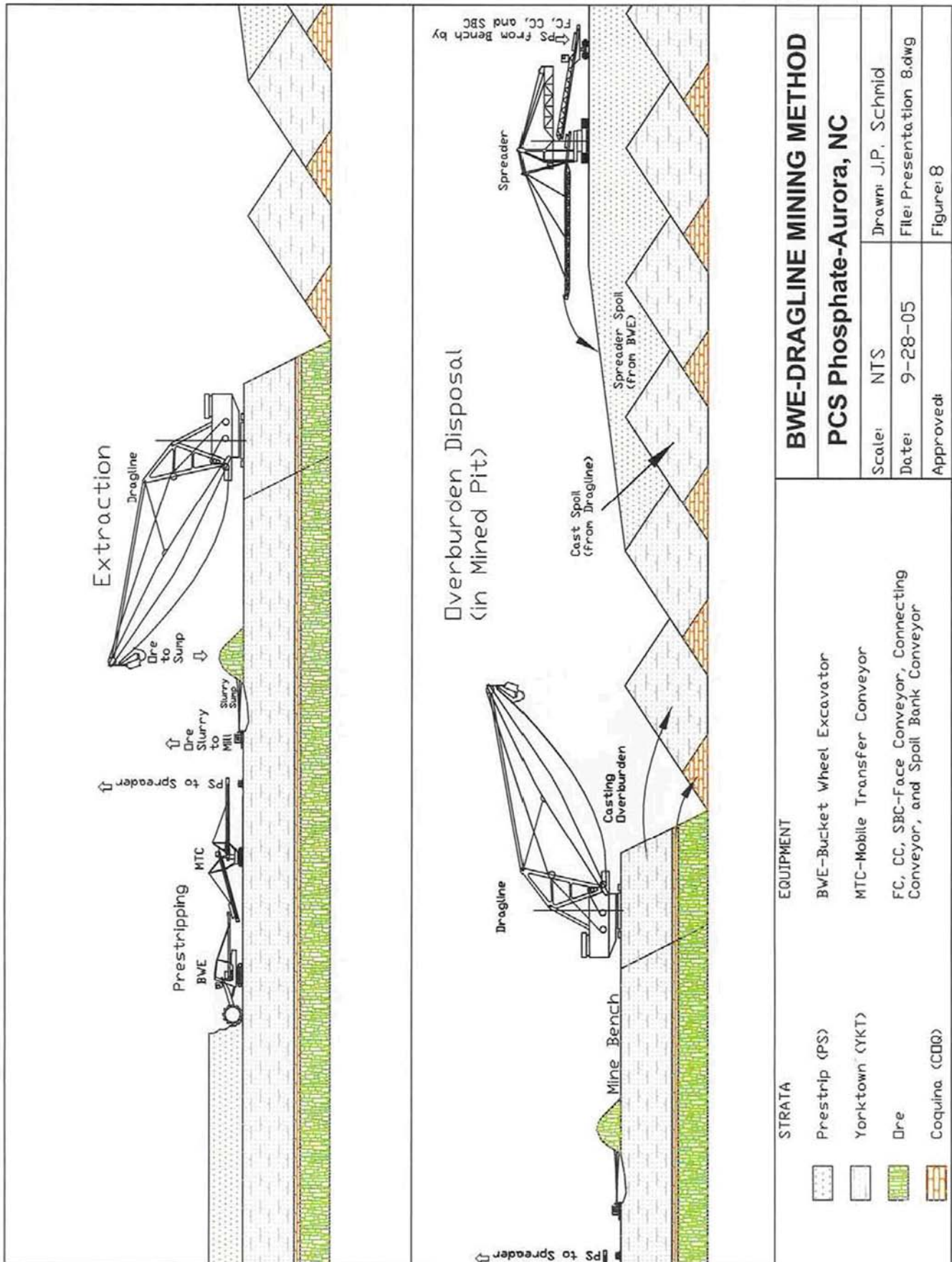


Figure 8 – Bucket Wheel – Dragline Mining Method





# Synthesis of Paleontological and Stratigraphic Investigations at the Lee Creek Mine, Aurora, N.C. (1958-2007)

*Lauck W. Ward*

---

## ABSTRACT

No paleontological site on the Atlantic Coastal Plain has received as much study and attention as the Lee Creek Mine near Aurora, North Carolina. Many articles have been devoted to illustrating and describing the diverse marine fauna and flora that is preserved in stratigraphic units exposed there. These beds, including the Pungo River, Yorktown, Chowan River, James City, and Flanner Beach Formations, range in age from more than 18.0 to 0.80 million years old.

Evolution of the stratigraphic terminology and refinement of the correlation of the units exposed at the Lee Creek Mine have made a new standardized section necessary. Each bed is described and a summary given of the significant contributions to each unit. The descriptions include physical analyses and paleontological studies. All taxa that have been identified from the various formations exposed at the Lee Creek Mine are listed by author and taxonomic group.

Suggestions as to future research are made based on the weakness of, or the lack of, solid data. This summary helps to show where those voids are and calls for a research program to address them.

---

## INTRODUCTION

The Lee Creek Mine, and all of the spectacular fossils found within, owe their existence and discovery to the economic importance of the Pungo River Formation. That phosphate-rich unit underlies much of Beaufort County, North Carolina, including the Aurora area (Figure 1). Strata now known as the Pungo River Formation were first reported by Philip M. Brown (1958a, 1958b). In those papers he stressed the economic implications of the phosphate-rich unit, he recognized the stratigraphic placement of the beds above the Castle Hayne Formation and below the Yorktown Formation, he correctly determined the age (late Oligocene to middle Miocene), he delineated the aerial extent of the unit, and he recognized the cyclical deposition of the beds in four cycles or depositional events. This seminal work has inspired an entire

industry and forty-five years of papers on the mineralogy, stratigraphy, and paleontology of the Pungo River Formation and the other strata at the Lee Creek Mine, where they can be viewed and studied.

Based on Brown's (1958b:11,12) description of a well drilled at Aurora where 80 feet (24.4 m) of phosphate beds were found from 100 to 180 feet (30.5 to 54.9 m) below ground level, the Texas Gulf Sulfur Company started an open-pit test pit at the mouth of Lee Creek, right bank of the Pamlico River. Kimrey (1964) named the Pungo River Formation and designated a type core, as there are no known surface outcrops. That core, taken near Belhaven, north of the Pamlico River about 19 miles (30.6 km) northeast of the present Lee Creek Mine, was later assigned the number BE-2-GRL by Kimrey (1965:19-23). The formation was described by the core log and included 50 feet (15.2 m) of olive-green calcareous clays, phosphatic clayey sands, phosphatic sands, and phosphatic limestones. The core descriptions, complete as they were, gave no indication of the rich fauna and flora which was later found in the Pungo River Formation at Aurora. Digging in the Lee Creek Test Pit had exposed 95 feet (29 m) of strata by January of 1964 and 121 feet (36.9 m) of strata by October, 1965 (Gibson, 1967).

Early in 1967, Jack McLellan of Texas Gulf Sulfur sent the first of many fossils to the Smithsonian Institution and in May of the same year, Gibson (1967) published a description of the Pungo River and Yorktown Formations based on the exposure in the Lee Creek Test Pit (see Figure 2).

It is the intent of this author to bring together all of the taxa listed or described from the Lee Creek Mine over the years. This work has covered almost 40 years and many of the papers on the subject are out of print. In addition, there are many that are obscure or not readily known to the amateur or professional worker.

It is not within the scope of this work to include the many popular articles, handbooks, and general educational fossil books that include Lee Creek fossils. Those sources have provided an invaluable service to the public and have served to incite the interest of amateurs and budding scientists. Among those are the handbook by Case (1972), the field guide

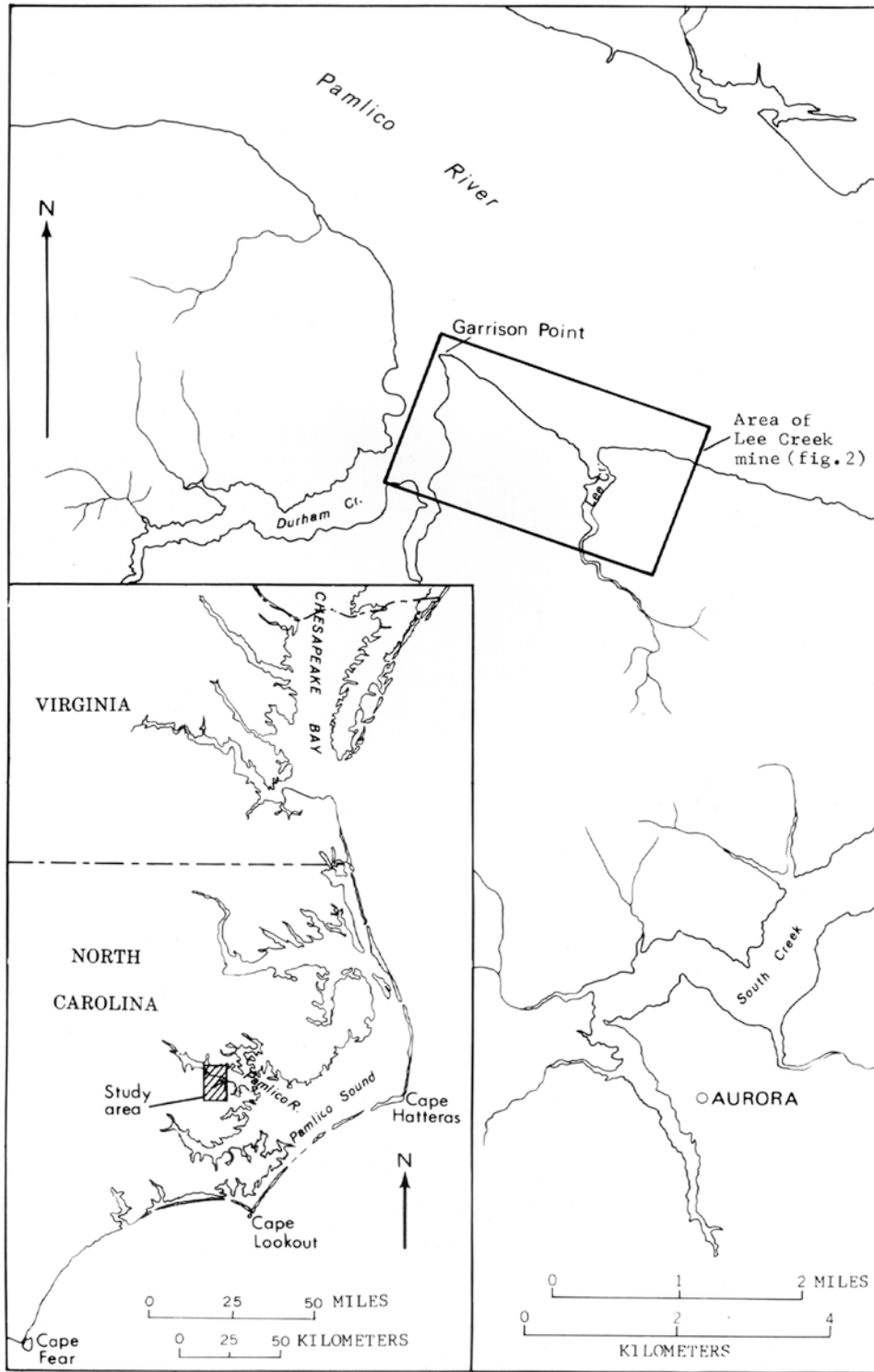


FIGURE 1. – Location of the Lee Creek Mine on the Pamlico River, North Carolina. The corner inset shows the study area on a regional map.

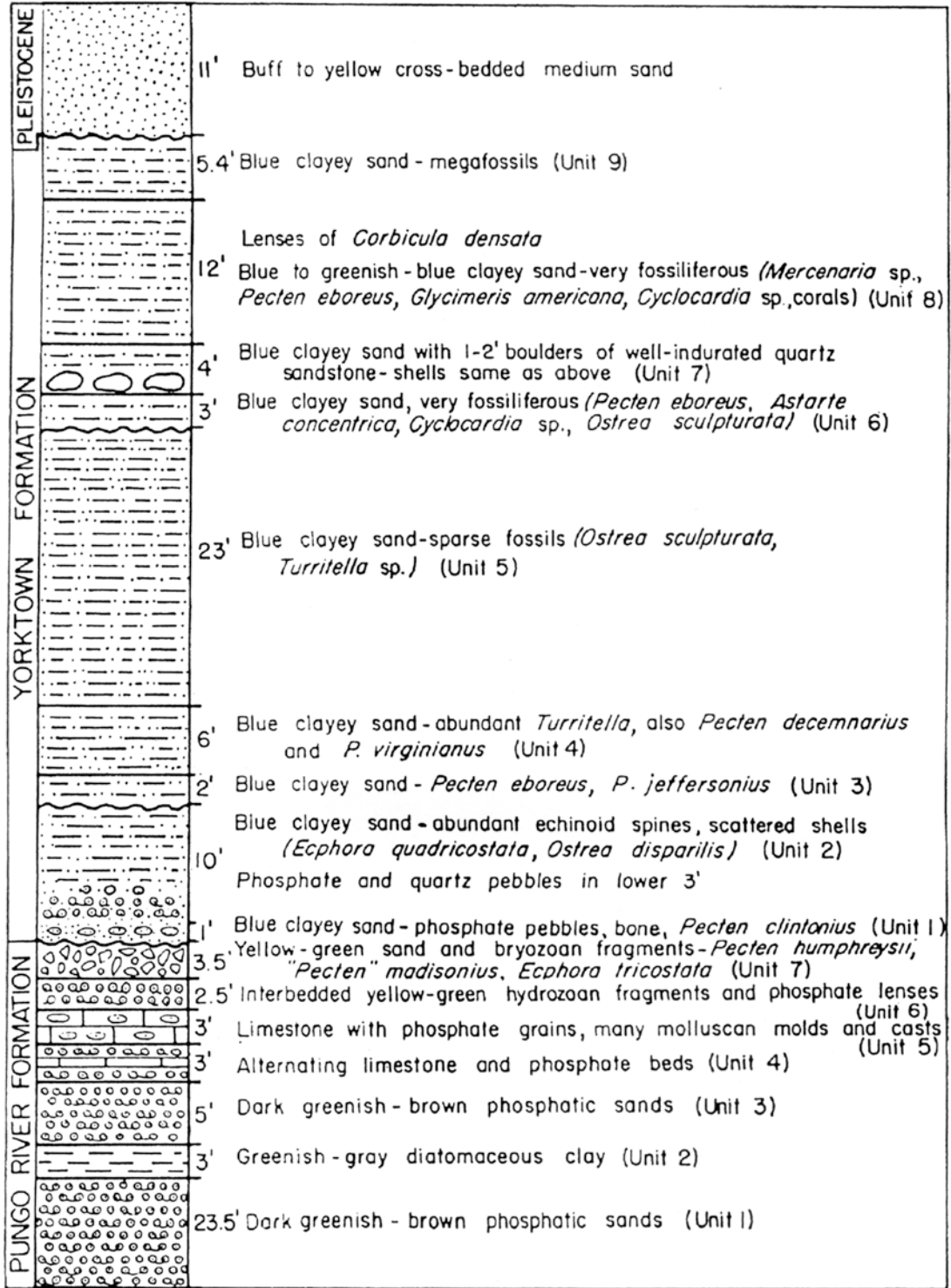


FIGURE 2. - Section of Miocene, Pliocene, and Pleistocene sediments exposed at the Lee Creek Mine as illustrated by Gibson (1967:639, fig. 4). Note the "Units" for each recognized bed. These "Units" have been used by numerous later workers. Key taxa are listed for each unit.

of Beddard (1991), the magazine article by Hope (1985), and the article by Culotta (1992).

To figure all of the taxa here would be impossible, but every known documented species is listed by taxonomic group and its stratigraphic horizon given, if known. These taxa are listed as presented by the original author with authors and dates if given, without revision, with one exception. The molluscan work of E.J. Petuch is so radical in its approach that the present author has sought to interpret his work. The many species of *Ephora* and other taxa described by Petuch are individually examined and assigned to their proper taxonomic identities. This editorial work is necessary because his work gives a skewed idea as to the molluscan composition of the fauna. In addition, he has shown in his Lee Creek work and his work elsewhere that he has given different localities for the same specimen in succeeding publications. He has given multiple names for the same specimen. His poorly rendered figures show alteration of the same specimen in succeeding publications. Finally, Petuch has named species from beds that are not present at the locality given or figured specimens that clearly did not come from beds indicated. Examples to demonstrate the nature of the problems encountered are given by Ward (2007) in the Lee Creek IV volume.

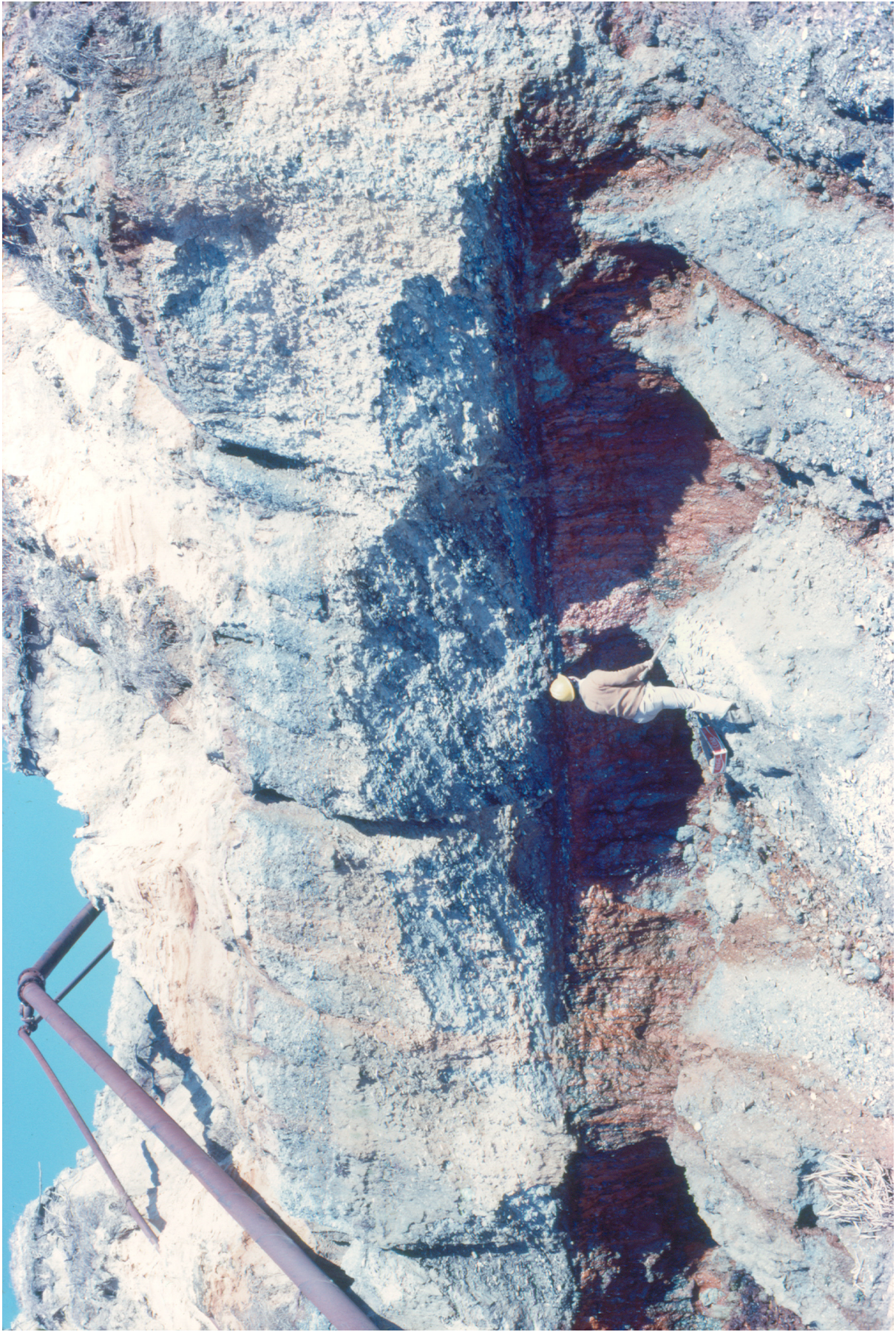
Because of these and other errors, I will attempt here to interpret Petuch's work as it pertains to the Lee Creek Mine and to correct all inconsistencies and misidentifications. This is done by retaining Petuch's original species lists with my corrections side by side.

**ACKNOWLEDGEMENTS.** - To acknowledge all of the people who have helped me to produce a synthesis such as this, would merely involve a listing of most of the authors who have worked on Lee Creek fossils. Several, though, stand out as most influential to my paleontological pursuits. First I must mention Druid Wilson for his and Dr. Thomas Gibson's early guidance, in the field, in the laboratory, and at the Lee Creek Mine. Dr. Joseph Hazel and Dr. Norman Sohl were also influential in the field of paleontology and biostratigraphy. I especially thank Dr. Clayton Ray and Dr. Frank Whitmore for their early guidance and for their introducing me to the Lee Creek Mine in 1972. For the most amount of time spent in field and laboratory work with me, as well as co-authoring numerous early attempts at stratigraphy and paleontology, I also thank Dr. Blake Blackwelder.

I would like to thank the readers of this manuscript, Dr. Warren Allmon and Dr. Lyle Campbell, who have suffered through a number of my papers, for their suggestions. These insightful suggestions prompted me to review, carefully, my stratigraphic assignments and paleontologic nomenclature. In doing so I corrected a number of errors. And finally, I would like to thank Susan Barbour Wood for her typing of the manuscript, her final rendering of the figures, and her enduring good humor.



General view of stripping operations in February 1972



L. W. Ward looking at the contact (head level) between the Chowan River Formation and the James City Formation. Cross-bedding reflecting a migrating inlet can be seen in the James City Formation. February 12, 1972.

## GEOLOGIC STRATA AT THE LEE CREEK MINE

The stratigraphic nomenclature for units exposed at the Lee Creek Mine and adjoining areas has undergone a steady evolution during the period of the mine's existence. One hopes that this evolution has led to a better understanding of the beds there and their correlation with the geographically adjacent stratigraphic units. With this refinement, the many fossils that come from the Lee Creek Mine take on added importance with their confident placement into units, beds, members, and formations (See Figures 3, 4). (Figure 4 is folded chart in inside back cover.)

Most of the specimens found at the Lee Creek Mine are found scattered across the spoil piles. Thus, they are totally disassociated from the beds that produced them. As such, many are interesting, but of severely limited scientific value. A thorough knowledge of the taxa in adjoining areas of Virginia, Maryland and North Carolina helps to recognize the exact stratigraphic position of the specimens. Without this background, most of the specimens would be unplaceable or best-guesses. In addition, some specimens have matrix attached to the specimens that makes their provenance clear. The lithology of the matrix is identifiable and in some cases microfossils can be gleaned from the matrix for further evidence.

Fossils are most common from five prominent stratigraphic units (oldest to youngest – at top):

Flanner Beach Formation (upper Pleistocene)  
James City Formation (lower Pleistocene)  
Chowan River Formation (upper Pliocene)  
Yorktown Formation (lower and upper Pliocene)  
Pungo River Formation (lower Miocene)

These formations are subdivided into a number of members, beds and units. In addition to these formations, there is a chance that specimens from the Castle Hayne Formation (middle Eocene), Belgrade (upper Oligocene), and Eastover (upper Miocene) Formations will be pulled up by the drag-line.

The stratigraphic units at the Lee Creek Mine will be described as to their texture and lithology, age, correlation, and associated fossils. The units will be addressed in order, from oldest to youngest and the fossil lists will be presented in phylogenetic order, that is, from simplest to most complex organisms. Varying techniques of sampling and limited field data have made it necessary, in many cases, for me to have to extrapolate proper (or standard) stratigraphic placement. The limitations imposed by spoil collecting have been the greatest hindrance to advancement of paleontological knowledge at the Lee Creek Mine.

The stratigraphic sequence here established for the beds exposed at the Lee Creek Mine is the work of this author and is a product of all the work by authors on Lee Creek related topics and a number of stratigraphic revisions and refinements on related areas. Some of the revisions, such as that by Ward et al. (1978), recognized the Spring Garden Member as the highest unit in the Castle Hayne Formation (middle Eocene). In the same publication they recognized and defined the Belgrade Formation and its members, the Pollocksville and Haywood Landing. Those units were originally reported to be lower Miocene but are now considered to be upper Oligocene. Ward and Blackwelder (1980) recognized and defined the Eastover Formation (upper Miocene) and redefined the Yorktown Formation. The Yorktown was divided into four members: Sunken Meadow (lower Pliocene), Rushmere (upper Pliocene), Morgarts Beach (upper Pliocene), and Moore House (upper Pliocene). Blackwelder (1981) named the Chowan River Formation for beds that had long been lumped into the Yorktown Formation, but did not fall within the original definition. Finally, Ward and Blackwelder (1987) recognized the presence of the Chowan River, James City, and Flanner Beach Formations at the Lee Creek Mine.

Though much of this stratigraphy was developed in areas somewhat distant from Lee Creek, it enabled the author to recognize the units exposed there and their proper stratigraphic position. The result is a composite stratigraphic section containing a number of formational and member terms not before applied to Lee Creek stratigraphy. It is expected that subsequent work will appraise this nomenclature and suggest changes where necessary.

### *Eocene*

#### **Middle Eocene**

#### **Castle Hayne Formation**

#### ***Spring Garden Member***

#### **STRATIGRAPHY**

The Spring Garden Member of the Castle Hayne Formation was named by Ward et al. (1978) for a tan to gray, arenaceous, molluscan-mold biocalcirudite that crops out along the Neuse and Trent Rivers in Craven and Jones Counties, North Carolina. The Spring Garden Member overlies the Comfort Member of the Castle Hayne Formation unconformably. It differs from that unit by its high content of sand-sized quartz. The Comfort Member has extremely low percentages of quartz and is bryozoan rich. Much of the Spring Garden

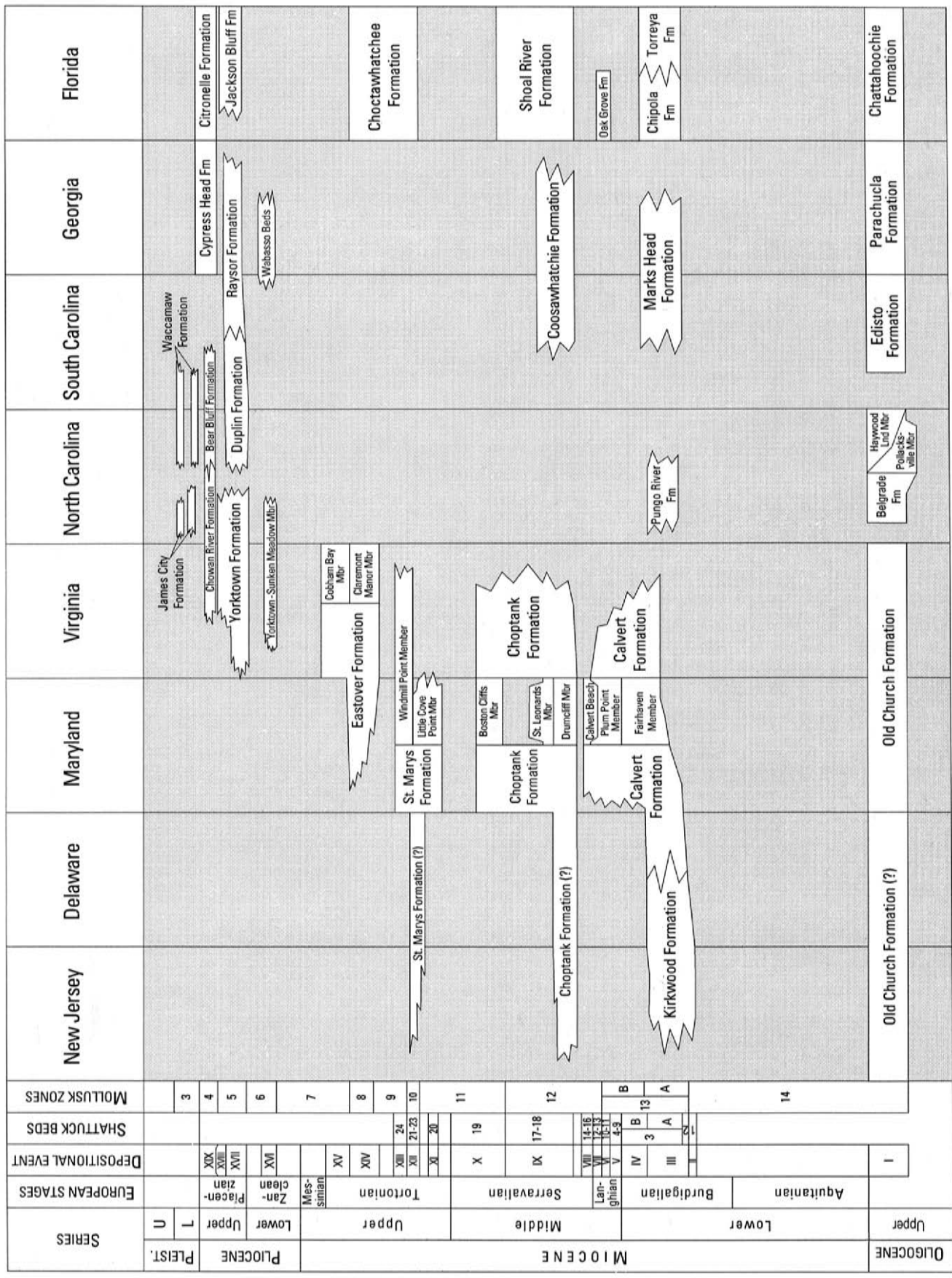


FIGURE 3. – Correlation chart showing stratigraphic relations of the outcropping units on the Atlantic Coastal Plain and a portion of the Gulf Coastal Plain from New Jersey to West Florida.

Member is indurated and packed with the unfilled molds of small *Macrocallista*. The Spring Garden Member is upper middle Eocene and stratigraphically equivalent to the Gosport Formation in Alabama. The underlying Comfort Member is also middle Eocene but is the equivalent of the Lisbon Formation in Alabama. The Spring Garden Member dips below sea level near New Bern.

Most authors who have dealt with the Pungo River Formation (to name a few: Brown, 1958a,b; Gibson, 1967; Riggs et al., 1982a,b; Gibson, 1983a,b; Hazel, 1983; Abbott and Ernissee, 1983) have considered the limestone upon which the Pungo River Formation lies to be the Castle Hayne Formation. Their descriptions support this conclusion.

Visits by the author to the Lee Creek Mine, since my first in February of 1972, have not resulted in the collection of any material, lithic or paleontologic, that would indicate what bed directly underlies the Pungo River Formation. A core exhibited at the plant site during an informal phosphate conference in Greenville, North Carolina, in 1985, contained sections of limestone just below the Pungo River Formation. That limestone was clearly the arenaceous, molluscan-mold biocalcirudite named the Spring Garden Member of the Castle Hayne Formation by Ward et al. (1978). The molds and casts were of the dominant fossil, a mollusk named *Macrocallista neusensis* (Harris).

The Spring Garden Member was deposited in a shallow, sandy, marine embayment during the late middle Eocene. The Gosport Sand in Alabama is believed to have been deposited at the same time. These middle Eocene beds are slightly younger than the Lisbon, Castle Hayne (Comfort Member), Piney Point, and Santee Formations (Moultrie Member and Cross Member, *sensu stricto*) that contain *Cubitostrea sellaeformis*. The Gosport Formation and Spring Garden Member lack that widespread guide fossil, which apparently became extinct at the end of the Lisbon. The Gosport Formation and Spring Garden Member do contain another important guide fossil, *Crassatella alta*, which is present in the Lisbon Formation and its equivalents, and present in the Gosport Formation, Spring Garden Member, and their equivalents, but which is lacking and apparently extinct in overlying upper Eocene and later beds.

Lee Creek Mine engineers apparently use the indurated top of the Spring Garden Member as their base. The massive dragline used to harvest the phosphatic sands of the Pungo River Formation apparently does not penetrate this caprock. The result, over the years, is that no collections from this unit are known to have been made. Beds of the Spring Garden Member can be viewed on the Neuse River from Rock Landing to near New Bern, on the Trent River from Trenton to Prettyman Landing, and in the flooded quarries of Martin Marietta Co. in the western portions of New Bern.

## PALEONTOLOGY

### *Invertebrates*

#### MOLLUSKS

The Spring Garden Member is dominated by the small bivalve mollusk *Macrocallista neusensis* (Harris). Several other taxa are commonly present. Most are preserved as internal and external molds. Commonly found mollusks include the following (see Plate 1):

*Macrocallista neusensis* (Harris) (= *M. perovata* (Conrad))

*Crassatella alta* Conrad

*Bathytormus protexta* Conrad

*Panopea* sp.

*Spondylus* sp.

No taxa from the Spring Garden Member have been reported from the tailings of the Lee Creek Mine. With this unit's proximity to the Pungo River Formation, it is not improbable that some limestone blocks may be dislodged in the mining operation and show up in collections. Collectors, therefore, should be aware of the unit's presence and recognize its provenance.

### *Oligocene*

#### Upper Oligocene

#### Belgrade Formation

#### *Haywood Landing Member*

#### STRATIGRAPHY

The Haywood Landing Member of the Belgrade Formation was named by Ward et al. (1978) for usually unconsolidated, gray to brown, moderately phosphatic, and, in some areas, very shelly, fine sands. The unit is exposed in a number of quarries near Belgrade and Silverdale, Onslow County, North Carolina. The type locality is at Haywood Landing on the Trent River, Jones County, North Carolina. That exposure is very small, but is the only known natural exposure of the unit.

At the Lee Creek Mine, Dr. J.G. Carter has collected mollusks from the "lower, dolomitic, sandy portion of the Pungo River Formation." Carter et al. (1988) illustrated several specimens of mollusks from those blocks that appear to be considerably older than the remainder of the Pungo River Formation. Carter et al. (1988) indicated that these lower, dolomitic rocks excavated from the Lee Creek Pit were lower Miocene in age, but identified *Pecten trentensis* which is now known only from the Oligocene River Bend Formation.



Carter (personal communication, 2003) now believes them to be Haywood Landing Member equivalents, which are now believed to be upper Oligocene (see Plate 2).

The molluscan taxa found in Unit A of the Pungo River Formation are also present in the Belgrade Formation. The Belgrade Formation and its Members, the Haywood Landing and the Pollocksville as described by Ward et al. (1978), appear to be equivalent to Unit A of the Pungo River of Riggs et al. (1982a,b). If that proves to be the case, then the name "Pungo River" as described by Kimrey (1964) may be the proper name for this unit or they may be treated as lateral equivalents.

The Belgrade, as characterized by its two members, consists of a very shelly, sometimes cross-bedded, shallow-shelf sand (Haywood Landing) and a back-barrier silty fine sand filled with the brackish-water *Crassostrea gigantissima* (Pollocksville). Those two lithologies are very different from that of Unit A of the Pungo River at the Lee Creek Mine.

Because of their different lithologies, the Belgrade and Unit A of the Pungo River Formation will be treated as distinct units while realizing that they are lateral equivalents that must grade into each other in a seaward direction.

See the Pungo River Formation, Unit A section for a listing of these taxa.

## *Miocene*

### Lower Miocene

#### Pungo River Formation

#### STRATIGRAPHY

Kimrey (1964) named and described the Pungo River Formation and designated a type core, as there are no known surface outcrops. That core, taken near Belhaven, north of the Pamlico River and about 19 miles (30.6 km) northeast of the present Lee Creek Mine, was later assigned the number BE-2-GRL by Kimrey (1965:19-23). The formation was described by the core log and included 50 feet (15.2 m) of olive-green calcareous clays, phosphatic clayey sands, phosphatic sands, and phosphatic limestones. A test pit at Lee Creek, north of Aurora, North Carolina, had exposed 95 feet (29 m) of strata by February 1964 and 121 feet (36.9 m) of strata by October, 1965 (Gibson, 1967).

Rooney and Kerr (1967) described, in detail, the mineralogic composition of the phosphate in the Pungo River Formation, and speculated on its origin and the origin of volcanic shards in the deposit. Gibson (1967) published a description of the Pungo River Formation at the Lee Creek Mine based on the exposure in the Lee Creek test pit (see Figure 2). Gibson differentiated and described seven "Units"

in the Pungo River Formation, numbering them from oldest (Unit 1) to youngest (Unit 7). This description was based on 43.5 feet (13.3 m) of Pungo River Formation strata exposed at that time (October, 1965). This system of units has been extensively used by authors in the Lee Creek volumes (Smithsonian Contributions to Paleobiology Nos. 53, 61, 90, and the present volume).

Brown's (1958b:11) well at Aurora and the AU-1-GRL well that Gibson (1983a:60) described indicate a thickness of 90 feet (27.4 m) for the Pungo River Formation in the Aurora area. This suggests that the section Gibson (1967) examined and described is only a little more than half of the entire unit. The bucket used to extract the ore, however, is operated deeply below the exposed beds. The probability exists, then, that some of the fossils obtained from the spoil piles at Lee Creek came from strata unexamined and not included in Gibson's (1967) "units." This would involve all of Unit A and part of Unit B of Riggs et al. (1982a,b) and of Scarborough et al. (1982).

Lithologic Units A-D were equivalent to Abbott's (1978) Atlantic Miocene Diatom Zones I-III. Unit A was found to be possibly Zone I, but could be older. Unit B was the equivalent of Zone I. Unit C was equivalent to Zone II and Unit D was equivalent to Zone III. The zonation proposed by Abbott in 1978 and expanded on in 1980 and 1982 was based on Shattuck's (1904) beds in the Maryland Miocene. That correlation is as follows:

Riggs et al. (1982 a,b) Units	Abbott (1978) Zones	Shattuck (1904) Beds	Gibson (1967) Units
Unit D	Zone III	Beds 4-9	Units 6,7
Unit C	Zone II	Bed 3-b	Units 3,4,5
Unit B	Zone I	Beds 2,3-a	Units 1,2
Unit A?			

Gibson (1967) named two members of the Pungo River Formation based on beds from the type core at Aurora (Well AU-1-GRL). The lower unit, the Belhaven Phosphatic Sand Member, occupies the lower 58 feet (17.7 m) and was described as a "dominantly medium greenish brown phosphatic sand with some gray-green clay and limestone and dolomite beds." The upper unit, the Bonnerton Member, was described as a "phosphatic limestone, calcareous clay, and coquina." Riggs et al. (1982a,b) found four cycles of deposition within the Pungo River Formation. (See Figure 5.) They each have a phosphatic, sandy, lower portion which grades into an upper dolosilt or moldic limestone. Each is separated from the others by a distinct contact marking a minor diastem. Beds with basal transgressive sands grading into finer silty and clayey beds also characterize Shattuck's (1904) beds in Maryland (Beds 4-9, Beds 10-11, Beds 12-13, Beds 14-16, Beds 17-18). Each is marked by a sharp,

burrowed contact that indicates a diastem (see Ward, 1992a). It does not appear that Gibson's two members have local or regional traceability and are not used here or by most subsequent authors. The phosphatic sands, clays and limestones occur at intervals throughout the entire section. Probably the best summary of the stratigraphic sequence of the Pungo River Formation at the Lee Creek Mine was given by Riggs et al. (1982a: table 3). Note that Unit A, in whole or in part, may be Oligocene and equivalent to the Belgrade Formation. Hoffman and Ward (1989) summarized and followed the stratigraphy of Riggs et al. (1982a,b). Riggs (1984) summarized his findings on the "Aurora Phosphate District" and described in detail the sequence of beds at the Lee Creek Mine. These he related to the global sea-level curves of Vail and Mitchum (1979).

Ward and Carter (1992) summarized the stratigraphy of the Pungo River Formation as exposed at the Lee Creek Mine for a Geological Society of America (Southeastern Section) Field Trip. A composite section was given which showed the Pungo River Formation to be about 28 meters thick.

Carter and Nekola (1992), in the same field trip, described the molluscan fauna in the Pungo River Formation. The faunal lists given are assigned to the various units of Gibson (1967) and Riggs et al. (1982a,b). The first list is interpreted to have come from the basal unit (= Belgrade Formation, Haywood Landing Member) The second list is from the uppermost calcareous unit (= Unit D of Riggs et al. 1982a,b).

The only age dates on the Pungo River Formation based on strontium isotopes were published by Denison et al. (1993). Those authors, taking a sample from near the top of the Pungo River Formation at Lee Creek, got an age of  $16.0 \pm 0.5$  MA or near the early-middle Miocene boundary.

## PALEONTOLOGY

### (Pungo River Formation, undifferentiated)

Several authors described, figured, or listed taxa from the Pungo River Formation without specifying the horizon from which they might have come. This is due mainly to the mining process in which fossils from the numerous stratigraphic units are scattered and mixed in the spoil piles behind the working face of the mine. Most of the macrofossils, therefore, are found disarticulated. In some instances some of the sediment in which they were embedded still adhered to the bones and made their stratigraphic position known. In some cases it has been possible to assign specimens to a given bed, and in others, only to the formation. This same problem affects stratigraphic placements of the macroinvertebrates, such as the mollusks. Pungo River Formation mollusks were studied briefly when the working face of the pit was exposed and available, but far more material was obtained from the spoil piles. Because of the knowledge of stratigraphy in the

Miocene of New Jersey, Delaware, Maryland and Virginia, most taxa from the Pungo River Formation can be safely identified and their provenance determined.

### *Invertebrates*

#### FORAMINIFERA

Gibson (1983b:360) listed the following as found in the Pungo River Formation:

*Cassigerinella chipolensis* (Cushman and Ponton)  
*Globigerina euapertura* Jenkins  
*Globigerina woodi woodi* Jenkins  
*Globigerina* sp. cf. *G. anguliofficialis* Blow  
*Globigerinoides altiapertura* Bolli  
*Globorotalia peripheroronda* Blow and Banner  
*Globorotalia scitula* Blow  
 "Turborotalia" *birnageae* (Blow)

In addition, he figured specimens of the following taxa which he said were present in the Pungo River Formation (Gibson, 1983b):

*Globigerina euapertura* Jenkins (pl. 4, fig. 15)  
*Spiroplectammia mississippiensis* (Cushman) (pl. 9, figs. 5, 9)  
*Bolivinopsis fairhavenensis* Gibson (pl. 20, figs. 1-4)  
*Bolivina pungoensis* Gibson (pl. 8, figs. 1-11)  
*Virgulinella miocenica* (Cushman and Ponton) (pl. 10, fig. 3)  
*Epistominella danvillensis* Howe and Wallace (pl. 20, figs. 10-12)

These species were described as common to present and characterized the Pungo River Formation, but were not assigned to any particular bed.

#### MOLLUSKS

Wilson (1987a:13) described a new species of oyster, *Pycnodonte (Gigantostrea) leeana*, but gave the horizon only as the Pungo River Formation.

Ward (1998:114, pl. 11: figs. 5, 6) figured two species of *Chesapecten* from the Pungo River Formation at the Lee Creek Mine. They were the following:

*Chesapecten sayanus* (Dall)  
*Chesapecten coccymelus* (Dall)

Ward was comparing the Pungo River Formation specimens with those from Delaware in the Calvert (Kirkwood) Formation, also lower Miocene (~18.0 my).

Unit	Thickness (Avg.)	Lithology	
Lower Yorktown	2-4 m	Clayey & shelly phosphorite quartz sand	
Pungo River	D	0-4 m (Unconformity) Yellowish-green, slightly phosphatic and quartz sandy, bioclastic-rich (barnacles, annelids, & bryozoans) dolosilt	
	C	5-8 m	Cream-colored, nonindurated to indurated, very fossiliferous & moldic, phosphatic calcareous mud or limestone interbeds which decrease downward. Interbedded, very dark greenish gray, slightly shelly, quartz phosphorite sand which becomes more massive downward Very dark greenish gray, massive, highly burrowed to mottled, clayey phosphorite quartz sand with only minor shell material
		3-5 m	
		2-4 m	
	B	8-10 m	Light olive green, semi-indurated to indurated, highly burrowed & locally silicified, slightly fossiliferous & moldic, phosphatic sandy, dolomite mud Moderate olive green, highly burrowed to mottled, dolomite muddy, phosphorite quartz sand Dark olive green, massive and mottled, clayey, phosphorite quartz sand which is locally gravelly (phosphorite granules) near the base
2-4 m			
5-9 m			
A	3-5 m	Light olive-green, non-indurated to indurated, highly burrowed and locally silicified, slightly fossiliferous & moldic, phosphatic sandy dolomite mud Moderate olive green, burrowed to mottled, muddy, phosphorite quartz mud	
Castle Hayne	(Unconformity)	Gray, indurated, very fossiliferous & moldic, quartz sandy limestone	

FIGURE 5. – Composite section describing the sedimentary units of the Pungo River Formation in the Aurora area, N.C. Dashed lines indicate major unconformities; stippled lines indicate minor unconformities or hiatuses. Adapted from Riggs et al.(1982a, table 3).

Petuch (1988a:10, pl. 2: figs. 10, 11) listed several taxa from the Pungo River Formation at the Lee Creek Mine. The following were mentioned:

- Ecphora (Trisecphora) tricostata* Martin, 1904:10, pl. 21; figs. 10, 11.
- Ecphorosycon pamlico* (Wilson, 1987): 12, no fig.
- Ecphorosycon aurora* (Wilson, 1987): 13, no fig.
- Ecphora (Trisecphora) prunicola*, n.sp.: 10,11, 15, pl.2; figs. 9, 13

Examination of Petuch’s (1988a) descriptions and figures produced this revised list of taxa:

Petuch’s Name	Amended Name
<i>Ecphora (Trisecphora) tricostata</i>	<i>Ecphora tricostata</i>
<i>Ecphorosycon pamlico</i>	<i>Ecphora tricostata</i>
<i>Ecphorosycon aurora</i>	<i>Stenomphalus aurora</i>
<i>Ecphora (Trisecphora) prunicola</i>	<i>Ecphora tricostata</i>

Petuch (1988b: pl. 9; figs. 7, 8) figured two specimens of *Ecphora* from the “Pungo River Formation, Lee Creek Mine, Aurora, North Carolina,” as follows:

- Ecphora (Trisecphora) tricostata* Martin, 1904:46, 47, pl. 9; fig. 7
- Ecphora (Trisecphora) prunicola* Petuch 1988:46, 47, pl. 9; fig. 8

Examination of the figures enabled this author to make the following revisions:

Petuch’s Name	Amended Name
<i>Ecphora (Trisecphora) tricostata</i>	<i>Ecphora tricostata</i>
<i>Ecphora (Trisecphora) prunicola</i>	<i>Ecphora tricostata</i>

Petuch (1988c [1989]: 3, fig. 1-A) reproduced Wilson’s (1987b) *Stenomphalus aurora* and placed it in a new genus, *Siphoecephora*. That genus was described on page 40 and figured again (fig. 15). In the description, he attributed the species to Unit 4 and possibly Unit 2 of Gibson (1987) of the Belhaven Member.

Petuch (1988c [1989]) also described and figured the following taxa:

- Ecphorosycon pamlico* (Wilson, 1987): 44, 47, fig. 17-B
- Ecphora (Trisecphora) chamnessi*, n. sp.:50, fig. 19-A, B, C
- Ecphora (Trisecphora) tricostata* Martin, 1904: 51, 56, fig. 20-C, D
- Ecphora (Trisecphora) prunicola* Petuch, 1988: 51, no fig. from Pungo River

He again listed those taxa as coming from the Pungo River Formation on pages 119 and 120. In an addendum, p. 129-136, he named additional taxa from the Pungo River Formation, Bonneron Member:

- Ecphora (Trisecphora) prunicola carolinensis* n. ssp.: 133, pl. A3: fig. B
- Ecphora (Trisecphora) xenos* n. sp.:134, pl. A3; fig. C

Examination of Petuch’s (1988c[1989]) descriptions and figures enabled the author to make the following revisions:

Petuch’s Name	Amended Name
<i>Ecphorosycon pamlico</i>	<i>Ecphora tricostata</i>
<i>Ecphora (Trisecphora) chamnessi</i>	<i>Ecphora tricostata</i>
<i>Ecphora (Trisecphora) tricostata</i>	<i>Ecphora tricostata</i>
<i>Ecphora (Trisecphora) prunicola</i>	<i>Ecphora tricostata</i>
<i>Ecphora (Trisecphora) prunicola carolinensis</i>	<i>Ecphora tricostata</i>
<i>Ecphora (Trisecphora) xenos</i>	<i>Ecphora quadricostata</i>
<i>Siphoecephora aurora</i>	<i>Stenomphalus aurora</i>

All of these taxa occur in the Pungo River Formation except *Ecphora xenos*, which is a fragment of a large specimen of *Ecphora quadricostata* from the Yorktown Formation.

Petuch (1997) listed and figured several taxa from the Pungo River Formation at the Lee Creek Mine. Below is a listing in order of appearance:

- Amaea prunicola* Martin:43, fig. 18; 45, poor figure
- Chesapecten coccymelus* (Dall):43, fig. 18; 45
- Calvertitella* sp.:43, 45 no figure
- Panopea parawhitfieldi* Gardner:43, 45, no figure
- Trisecphora* sp.:45, no figure
- Ecphorosycon* sp.:45, no figure
- Siphoecephora* sp.: 45, no figure
- Siphoecephora aurora* (Wilson):115, fig. 43-G
- Siphoecephora aurora* (Wilson):115, fig. 43-H
- Trisecphora chamnessi* (Petuch):115, fig. 43-I
- Trisecphora carolinensis* (Petuch):115, fig. 43-F, J; 121, fig. 42?
- Trisecphora* sp.:115, fig. 43-A
- Trisecphora* sp.:115
- Calvertitella* sp. (*indenta* ssp., molds only):115
- Ecphorosycon pamlico* (Wilson):117, fig. 43-B
- Trisecphora tricostata* (Martin):117, fig. 43-C, D
- Trisecphora schmidtii* (Petuch):117, fig. 43-M
- Ecphora wardi* Petuch:117, fig. 43-N
- Chesathais* cf. *whitfieldi* Petuch:117, fig. 43-K
- Amaea prunicola* (Martin):117, fig. 43-E
- Cirsostrema calvertensis* (Martin):117, fig. 43-L
- Stenorhytis pachypleura* (Conrad):117, fig. 43-O

From the specimens that were illustrated, I generated the following list:

Petuch's Name	Amended Name
<i>Siphoecphora aurora</i> (fig. 43-G, H)	<i>Stenomphalus aurora</i>
<i>Trisecephora chamnessi</i> (fig. 43-I)	<i>Ecphora tricostata</i>
<i>Trisecephora carolinensis</i> (fig. 43-F, J, fig. 42?)	<i>Ecphora tricostata</i>
<i>Trisecephora</i> sp.(fig. 43-A)	<i>Ecphora tricostata</i>
<i>Trisecephora schmidti</i> (fig. 43-M)	<i>Ecphora tricostata</i> (dorsal view?)
<i>Ecphora wardi</i> (fig. 43-N)	<i>Ecphora tricostata</i> (dorsal view?)
<i>Chesathais</i> cf. <i>whitfieldi</i> (fig. 43-K)	<i>Ecphora tricostata</i> (dorsal view?)
<i>Amaea prunicola</i> (fig. 43-E)	indet.; not an <i>Amaea</i>
<i>Cirsostrema calvertensis</i> (fig. 43-L)	<i>Epitonium calvertensis</i>
<i>Stenorhytis pachypleura</i> (fig. 43-O)	<i>Stenorhytis pachypleura</i>

Petuch (2004:95, 97) listed the following from the Bonnerton Member, Pungo River Formation at the Lee Creek Mine:

*Pecten maclellani* Gibson, 1987  
*Calvertitella indenta* (Conrad, 1841)  
*Chesapecten coccymelus* (Dall, 1898)  
*Trisecephora carolinensis* (Petuch, 1989)  
*Trisecephora tricostata* (Martin, 1904)  
*Ecphora wardi* (Petuch, 1989)  
*Trisecephora chamnessi* (Petuch, 1989)  
*Siphoecphora aurora* (Wilson, 1987)

Petuch (2004:98, pl. 25) figured the following taxa from the "Bonnerton Member, Pungo River Formation, in the Texasgulf Lee Creek Mine, Aurora, Beaufort County, North Carolina:"

Fig.	Petuch's Name	Amended Name
A, B	<i>Siphoecphora aurora</i> (Wilson)	<i>Ecphora tricostata</i>
C, D	<i>Trisecephora tricostata</i> (Martin)	<i>Ecphora tricostata</i>
E	<i>Trisecephora chamnessi</i> (Petuch)	<i>Ecphora tricostata</i>
F	<i>Pecten maclellani</i> Gibson	<i>Pecten humphreysii</i>
G, H	<i>Trisecephora carolinensis</i> (Petuch)	<i>Ecphora tricostata</i>
I, J	<i>Ecphora wardi</i> Petuch	<i>Ecphora tricostata</i>

Petuch (2004:99, pl. 26) figured the following taxa from the "Bonnerton Member, Pungo River Formation, in the Texasgulf Lee Creek Mine, Aurora, Beaufort County, North Carolina:"

Fig.	Petuch's Name	Amended Name
A, B	<i>Cirsostrema calvertensis</i> (Martin)	<i>Epitonium calvertensis</i>
C, D	<i>Trisecephora schmidti</i> (Petuch)	<i>Ecphora tricostata</i>
E	<i>Ecphorosycon pamlico</i> (Wilson)	<i>Ecphora tricostata</i>
F	<i>Calvertitella indenta</i> (Conrad)	Indet. Internal mold (back view)
G	<i>Chesathais whitfieldi</i> Petuch	<i>Ecphora</i> sp. indet. (back view)
H, I	<i>Stenorhytis pachypleura</i> (Conrad)	<i>Stenorhytis pachypleura</i>
J	<i>Amaea prunicola</i> (Martin)	indet., not an <i>Amaea</i>

Petuch (2004:125) stated that the oyster *Gigantostrea leeana* (Wilson, 1987a) came from unrecognized beds of the Eastover Formation and not the Pungo River Formation. However, Wilson's material has matrix attached that identifies it as coming from the Pungo River Formation. The species is probably an unusually flat, ovate form of *G. percrassa*, a pycnodont with which it co-occurs. That species occurs at the same stratigraphic level over a wide area: New Jersey, Maryland, and North Carolina.

Petuch (2004:133, pl. 41-E) figured a specimen from Florida that he thought was *Gigantostrea leeana* and used that identification to correlate the Bayshore fauna of south Florida with the "Eastover Formation" of North Carolina, the unit from which he thought *G. leeana* came. The other taxa illustrated by Petuch (2004: pl. 41) from the Bayshore are all found in the upper Yorktown Formation (upper Pliocene). (See Introduction, pages 325-330, for a list of those species.)

Furnish and Glenister (1987:9) figured the chamber fillings of a nautiloid from the Pungo River Formation but gave no information as to its precise horizon. That taxon was determined to be *Aturia* sp. These fossils are extremely rare and the authors had only four specimens. Martin (1904: pl. XXXIX, fig. 1) figured only a single septum from a nautiloid from the Calvert Formation in Maryland, further suggesting its rarity.

## BARNACLES

Zullo (1984) described a species of barnacle thought to be from the Pungo River Formation. That species, the Holotype of which is found adhering to a *Chesapecten jeffersonius*, is clearly not found in the Pungo River, but rather the Sunken Meadow Member of the Yorktown Formation (lower Pliocene). The species is *Fistulobalanus klemmi*.

### Vertebrates

Several fossil vertebrates have been found in Pungo River Formation beds. Some of those can be assigned to specific beds or horizons. Others cannot be specifically determined. The following are those listed by various authors from the Pungo River Formation, but no specific bed:

#### FISH

Müller (1999) is an extremely important publication on Eocene-Pliocene fish faunas of the Atlantic Coastal Plain, based on his collections of some 12,000 otoliths and 1,000 sharks teeth. Unfortunately, it came to the hands of authors of the Lee Creek ichthyofauna too late for adequate consideration by them (Purdy et al., 2001:194), and it is still not widely available in the USA. Thus, its full integration into the study of the paleontology of the coastal plain remains for future workers. In the meantime, the taxa reported for the Lee Creek Mine are listed here as presented by Müller. It should be noted that he did not himself cite his doctoral dissertation of 1992, on which Müller (1999) is based. Thus, his new taxa should be regarded as established in 1999. In addition to his systematic accounts, he presents major discussions of paleoecology, biostratigraphy (including proposed otolith zones), faunal development, paleoclimatology, and evolution.

The following taxa from the Lee Creek Mine were regarded by Müller as more or less certainly from the Pungo River Formation, although in part collected from surface spoil or reworked into the basal bed of the Yorktown Formation. Those followed by an asterisk (\*) are based on reports by previous authors:

- Neoselachii
- Hexanchidae
  - Hexanchus* aff. *griseus* (Bonaterre, 1788)
  - Notorynchus primigenius* (Agassiz, 1843)
- Odontaspidae
  - Carcharias acutissimus* Agassiz, 1843
  - Carcharias cuspidatus* (Agassiz, 1843)
- Otodontidae
  - Carcharocles megalodon* (Agassiz, 1843)\*
- Lamnidae
  - Carcharoides caticus* (Philippi, 1846)
  - Isurus retroflexus* (Agassiz, 1843)
- Alopiidae
  - Alopias latidens* (Leriche, 1909)
- Carcharhinidae
  - Carcharhinus egertoni* (Agassiz, 1843)
  - Carcharhinus priscus* (Agassiz, 1843)
  - Carcharhinus signatus* (Poey, 1868)
  - Galeocerdo aduncus* Agassiz, 1843

- Galeocerdo contortus* Gibbes, 1849
- Hemigaleidae
  - Hemipristis serra* Agassiz, 1843
- Sphyrnidae
  - Sphyrna laevisissima* (Cope, 1867)
- Rhynchobatidae
  - Rhynchobatus* sp. 2\*
- Myliobatidae
  - Aetobatus arcuatus* (Agassiz, 1843), listed only as Miocene of North Carolina without mention of Lee Creek Mine, or Pungo River Formation.
- Rhinopteraeidae
  - Rhinoptera* aff. *brasiliensis* Müller, 1835
  - Rhinoptera* sp. aff. *R. bonasus* (Mitchill, 1815)
- Mobulidae
  - Plinthicus stenodon* Cope, 1869
- Teleostei – Actinopterygii
- Diodontidae
  - Diodon* sp.

#### TURTLES

Zug (2001:215) listed a single taxon from the Pungo River Formation:

- Chelydra?

#### CROCODILES

Myrick (2001:219) listed a single taxon from the Pungo River Formation: *Thecachampsa antiqua* (Leidy, 1852). That author was unsure of the provenance of the taxon and expressed the possibility of its coming from the Pungo River Formation or Yorktown Formation. Crocodylian fossils, however, are not known from strata above the St. Marys Formation, except as lag reworked from older sediments. The Lee Creek material is, therefore, most probably from the Pungo River Formation.

#### BIRDS

Olson and Rasmussen (2001:233) identified at least 21 bird taxa more or less certainly from the Pungo River Formation (those followed by a query could be from the Yorktown Formation):

- Colymboides?* sp.
- Gavia egeriana* Svec
- Bulweria?* sp. ?
- Puffinus (Thyellodroma)* sp.

*Puffinus (Ardena)* sp.?  
*Puffinus* aff. *gravis* (O'Reilly) ?  
*Morus avitus* (Wetmore, 1938)  
*Morus atlanticus* (Shufeldt, 1915)  
*Morus loxostylus* (Cope, 1870)  
*Larus* sp.  
*Miocepphus mclungi* Wetmore, 1940  
*Miocepphus* sp.  
*Anas* sp.?  
 Anatidae, gen. and sp. indet.  
*Balearica?* sp. ?  
 Rallidae gen. and sp.? indet.  
*Ciconia* sp. 1  
 Ciconiidae gen. and sp.? indet.  
 Galliformes, fam., gen. and sp.? indet.  
*Ortalis?* sp.?  
 Phasianidae gen. and sp. indet.?

Olson (2003) described a first fossil record for the family Heliornithidae and the genus *Heliornis*. The family is tropical in America, Africa, and Asia. The identification is based on a single humerus and is referred to the following taxon:

*Heliornis* aff. *fulica* (Boddaert, 1983)

## Mammals

### WHALES

Boreske et al. (1972) described a whale skull, said to be *Squalodon* from the base of the Yorktown Formation. The partial skull was believed to be reworked from the upper portion of the Pungo River Formation and was partially indurated and bored by boring marine mollusks. The boring may have taken place when it was lying on the bottom of the Pungo River Formation sea or when it was exposed during the Yorktown transgression.

Whitmore and Kaltenbach (this volume:181-269) listed a number of whales from the Pungo River Formation without specific determination of horizon within that formation:

*Squalodon* cf. *S. tiedemani* J.A. Allen  
*Squalodon calvertensis* Kellogg  
*Squalodon* sp.  
*Phocageneus* cf. *P. venustus* Leidy  
*Choneziphius trachops* Leidy  
*Anoplomassa* sp.  
*Eurhinodelphis*  
*Liolithax*, cf. *L. pappus* (Kellogg)  
*Kentriodon schneideri* Whitmore and Kaltenbach  
*Delphinodon dividum* True  
*Pithanodelphis*

Aff. *Pithanodelphis*  
*Pomatodelphis* sp.  
*Nannolithax* sp.  
*Delphinodon* cf. *D. mento* (Cope)  
*Tretosphys* sp.  
*Tretosphys gabbi* (Cope)  
*Araeodelphis* cf. *A. natator* Kellogg  
 Cf. *Champsodelphis*  
 Cf. *Plesiocetus*

Kazár and Bohaska (this volume:271-323) described the humeri and ulnae of various odontocetes and discussed their use in identifying some whale material. Families mentioned from the Pungo River Formation are the following:

Squalodontidae  
 Eurhinodelphidae  
 Kentriodontidae  
 Physteridae (?)

## Plants

Nease and Wolf (1971) reported on the presence of a nonpetrified, filamentous alga from the Lee Creek Mine. It was described as having been formed inside of shells that were embedded in calcitic aggregates. It is not totally clear in which stratigraphic unit these calcitic aggregates were found. To this author, it seems from the description, to be most likely from the Pungo River Formation, but other units such as the upper Yorktown also are partially cemented and break out as calcitic aggregates. The reference is here presented tentatively, with an eye to future research possibilities.

Nease and Wolf (1971) reported the following marine, green alga:

*Ostreobium queketti* Bornet and Flahault

The age given was “approximately 15 million years old.”

## PALEONTOLOGY

### (Pungo River Formation, Bed by Bed)

Some authors have been specific about the beds within the Pungo River Formation from which their collections came. This is possible by collecting directly from the quarry wall (as in the case of Gibson, 1967) or by examination of the matrix adhering to the fossil. The matrix is sometimes texturally identifiable and sometimes contains diagnostic microfossils. Authors who have been specific include the following:

### Unit A (of Riggs et al., 1982a)

(See also Belgrade Formation, Haywood Landing Member).

Riggs et al. (1982a: table 3) described Unit A as having a “moderate olive-green, burrowed to mottled, muddy, phosphorite quartz sand” near its base and a “light olive-green, non-indurated to indurated, highly burrowed and locally silicified, slightly fossiliferous and moldic, phosphatic sandy dolomite mud” above. This unit is here believed to be the lateral equivalent of the Belgrade Formation of Ward et al. (1978).

#### Paleontology

##### *Invertebrates*

##### MOLLUSKS

Several authors have mentioned that basal sands included in the Pungo River Formation may be Oligocene (Brown, 1958a: 90; Gibson, 1967:637) or in the case of Carter et al. (1988: 84, figs. 59-61) that the lowest unit may be a lateral equivalent of the Belgrade Formation based on its contained fossils. Carter et al. (1988) figured the following mollusks:

*Pecten trentensis* Harris

*Venus* n. sp. aff. *Venus langdoni* Dall

There are no known taxa related to “*Pecten*” *trentensis* or *Venus* n. sp. in the stratigraphic equivalents of the Pungo River Formation to the north, i.e., the Calvert Formation and the Kirkwood Formation, even though the rich faunas of those units have been studied extensively (see publications of the Virginia, Maryland, Delaware and New Jersey Geological Surveys). “*Pecten*” *trentensis* is common in the lower portion of the River Bend Formation and present in the upper portion. A form very similar to “*P.*” *trentensis*, *Rebeccapecten berryae* (see Ward, 1992a), is present in the overlying upper Oligocene Haywood Landing Member of the Belgrade Formation. Young *Rebeccapecten* look very much like the specimen figured by Carter et al. (1988: fig. 59), and this author believes that the specimen is most likely *R. berryae*. *Rebeccapecten berryae* clearly is a member of the same lineage as “*Pecten*” *trentensis*, and that species is more properly referred to as *Rebeccapecten trentensis* (Harris).

Carter et al. (1988:84) described the matrix that adhered to their *Pecten trentensis* and *Venus langdoni* as a “lower dolomitic, sandy portion of the Pungo River Formation.” In a recent conversation with Carter (October 1, 2003), he described the sand as containing considerable glauconite and phosphate grains. In future field work, it is important to keep in mind that an Oligocene unit is present, though its

occurrence may be spotty. Oligocene vertebrate fossils may also be present.

Carter and Nekola (1992) listed the following taxa from the basal Pungo River Formation:

*Chione* n. sp.

*Tellidora* n. sp.

*Rebeccapecten berryae*

*Calyptraea* sp. cf. *C. aperta*

*Ecphora aurora* [= *Stenomphalus aurora*]

#### *Vertebrates*

##### SHARKS

Carter et al. (1988) figured a single tooth from “the basal (lower Miocene, Aquitanian or Burdigalian) part of the Pungo River Formation, or the underlying upper Oligocene or lower Miocene Belgrade Formation.” These authors identified the specimen as an intermediate between *Procarcharodon auriculatus* and *P. megalodon*. The specimen was 70.4 mm in height and was identified by them as *P. auriculatus* (Blaineville).

#### Mammals

##### WHALES

Carter et al. (1988) figured a single whale tooth from the “early Miocene, lower dolomitic, sandy portion of the Pungo River Formation” at the Lee Creek Mine. This tooth is believed to have come from the Belgrade Formation (upper Oligocene) or an equivalent. The tooth was identified by Carter et al. (1988) as *Squalodon atlanticus* Leidy.

### Unit B (of Riggs et al., 1982a)

(= Units 1, 2 of Gibson, 1967)

#### Paleontology

##### *Invertebrates*

##### FORAMINIFERA

Gibson (1967:639, 640) listed the following from his Bed 1 of the Pungo River Formation:

*Uvigerina subperegrina* Cushman and Kleinpell

*Nonionella auris* (d’Orbigny)

*Nonion pizarrense* Berry



Gibson (1967) extensively used benthic and planktonic Foraminifera to estimate marine water depths and proximity to shoreline. Leutze (1968) pointed out that foraminiferal content also depended on other factors such as temperature, bottom type, oxygen, and food supply, not just depth of water. Gibson (1968) defended his interpretations in a reply to Leutze.

#### MOLLUSKS

Gibson (1987:38) listed one molluscan species from this interval:

*Pecten humphreysii*

Wilson (1987b:24, pl. 2, figs. 1-5) named a gastropod, *Ecphora (Stenomphalus) aurora*, which was placed low in the Pungo River Formation section. See Plates 3-5 for Pungo River mollusks.

#### Vertebrates

Purdy et al. (2001:76) listed the following taxa from Gibson's Units 1 and 2, which this author believes to be equivalents to Unit B of Riggs et al. (1982a). The names are given as they were listed in their table 1:

#### RAYS

*Dasyatis say*  
*D. cf. D. americana*  
*Pteromylaeus* sp.  
*Rhinoptera* sp.  
*Plinthicus stenodon*  
*Mobula* sp.

#### SHARKS

*Notorynchus cepedianus*  
*Pristiophorus* sp.  
*Megascyliorhinus miocaenicus*  
*Rhinocodon* sp.  
*Carcharias cuspidata*  
*Carcharias* sp.  
*Odontaspis ferox*  
*Odontaspis cf. Odontaspis acutissima*  
*Isurus oxyrinchus*  
*Isurus hastalis*  
*Carcharodon subauriculatus*

*Scyliorhinus* sp.  
*Galeorhinus cf. G. affinis*  
*Hypogaleus* sp.  
*Mustelus* sp.  
*Paragaleus* sp.  
*Hemipristis serra*  
*Galeocerdo* sp.  
*Galeocerdo contortus*  
*Carcharhinus brachyurus*  
*Carcharhinus falciformis*  
*Carcharhinus leucas*  
*Carcharhinus macloti*  
*Rhizoprionodon?* sp.  
*Triaenodon obesus*

#### FISH

*Sphyrna cf. S. media*  
*Sphyrna zygaena*  
*Lagodon cf. L. rhomboides*  
*Sphyraena cf. S. barracuda*  
*Hemirhabdorrhynchus* sp.

#### Unit C (of Riggs et al., 1982a)

(= Units 3, 4, and 5 of Gibson, 1967)

#### Paleontology

#### Invertebrates

#### FORAMINIFERA

Gibson (1967:641) listed the following from his Unit 3:

*Textularia* sp.  
*Nonion pizarrense*  
*Hanzawaia concentrica* (Cushman)

Gibson (1967:641) listed the following from his Unit 4:

*Cassidulina crassa* d'Orbigny  
*Bolivina paula* Cushman and Ponton

#### MOLLUSKS

Gibson (1987:38) listed several molluscan taxa from this interval:

*Pecten mclellani* n. sp.  
*Pecten humphreysii humphreysii* Conrad  
*Chesapecten coccymelus* (Dall)  
*Amusium* sp.

Wilson (1987b: 21) described a gastropod as coming from beds lower than Unit 5 of Gibson (1967). It seems to come from Unit C of Riggs et al. (1982a). That taxon is the following:

*Ecphora (Ecphora) pamlico* n. sp.

See Plates 3-5 for Pungo River mollusks.

### Vertebrates

Purdy et al. (2001:76) listed the following taxa from Gibson's Units 3, 4, and 5 which are equivalents to Unit C of Riggs et al. (1982a). The names are given as they are listed in their table 1:

### RAYS

*Dasyatis say*  
*Dasyatis* cf. *D. americana*  
*Pteromylaeus* sp.  
*Rhinoptera* sp.  
*Plinthicus stenodon*  
*Mobula* sp.

### SHARKS

*Notorynchus cepedianus*  
*Echinorhinus* cf. *E. blakei*  
*Pristiophorus* sp.  
*Rhinobatos* sp.  
*Squatina* sp.  
*Ginglymostoma* sp.  
*Rhincodon* sp.  
*Carcharias cuspidata*  
*Carcharias* sp.  
*Odontaspis ferox*  
*Odontaspis* cf. *Odontaspis acutissima*  
*Megachasma* sp.  
*Alopias* cf. *A. superciliosus*  
*Alopias* cf. *A. vulpinus*  
*Cetorhinus* sp.  
*Isurus oxyrinchus*  
*Isurus hastalis*

*Carcharodon megalodon*  
*Scyliorhinus* sp.  
*Galeorhinus* cf. *G. affinis*  
*Mustelus* sp.  
*Paragaleus* sp.  
*Hemipristis serra*  
*Galeocerdo* sp.  
*Galeocerdo contortus*  
*Carcharhinus brachyurus*  
*Carcharhinus falciformis*  
*Carcharhinus leucas*  
*Carcharhinus macloti*  
*Carcharhinus perezii*  
*Carcharhinus plumbeus*  
*Rhizoprionodon?* sp.  
*Negaprion brevirostris*  
*Triaenodon obesus*  
*Sphyrna* cf. *S. media*  
*Sphyrna zygaena*

### FISH

*Megalops* cf. *M. atlanticus*  
*Bagre* sp.  
*Lagodon* cf. *L. rhomboides*  
*Sphyrna* cf. *S. barracuda*  
*Hemirhabdorrhynchus* sp.

### Plants

### DIATOMS

Abbott and Ernissee (1983:287-353) investigated the diatom floras in the Pungo River Formation, but they were not provided with samples from the Lee Creek Mine. They sampled from two cores RA-13-GRL and PA-31-GRL north of the Pamlico River and downdip from the mine site. They identified two assemblages, which they called A and B. The A assemblage was the equivalent of Unit C of Riggs et al. (1982a) and the B assemblage was younger than any Pungo River Formation beds exposed in the pit. Assemblage A was correlated with Blow's (1969) foraminiferal zones N8 and N9. It is, therefore, the equivalent of Shattuck's Bed 10-11 in the Maryland Miocene. These zones are lower Miocene or straddle the lower-middle Miocene boundary. Assemblage B was the equivalent of Blow's N11 (= Shattuck's Bed 12-13) and is not present at the Lee Creek Mine. That younger bed may have been beveled off by later transgressions such as the Eastover Formation in the late Miocene, or the Yorktown Formation in the lower Pliocene.

The diatom species for Assemblage A are listed below. Assemblage B is not included because that unit is not present

at the Lee Creek Mine. The names are given as presented in their list (table 1) without authors or dates:

*Actinocyclus ingens*  
*Actinocyclus octonarius*  
*Actinocyclus tenellus*  
*Actinoptychus senarius*  
*Anaulus mediterraneus* var. *intermedia*  
*Anellus californicus*  
*Asteromphalus robustus*  
*Biddulphia aurita*  
*Biddulphia tuomeyii*  
*Bruniopsis mirabilis*  
*Cladogramma dubium*  
*Clavicula polymorpha* var. *aspicephala*  
*Coscinodiscus apiculatus*  
*Coscinodiscus asteromphalus*  
*Coscinodiscus curvatus*  
*Coscinodiscus gigas* var. *diorama*  
*Coscinodiscus marginatus*  
*Coscinodiscus monicae*  
*Coscinodiscus nodulifer*  
*Coscinodiscus oculus-iridis*  
*Coscinodiscus perforatus*  
*Coscinodiscus perforatus* var. *cellulosa*  
*Coscinodiscus plicatus*  
*Coscinodiscus praeyabei*  
*Coscinodiscus rothii*  
*Coscinodiscus stellaris*  
*Cussia paleacea*  
*Cussia praepaleacea*  
*Cymatogonia amblyoceros*  
*Cymatosira andersoni*  
*Cymatosira immunis*  
*Cymatosira* sp. A  
*Delphineis lineata*  
*Delphineis novaecaesaraea*  
*Delphineis ovata*  
*Delphineis penelliptica*  
*Denticula hustedtii*  
*Denticula lanta*  
*Denticula norwegica*  
*Di cladia pylea*  
*Dossetia hyalina*  
*Endictya robusta*  
*Goniothecium rogersii*  
*Hemiaulus* cf. *polymorphus*  
*Hyalodiscus laevis*  
*Liradiscus asperulus*  
*Liradiscus bipolaris*  
*Liradiscus ovalis*  
*Lithodesmium minusculum*  
*Macrora stella*

*Mediaria splendida*  
*Melosira westii*  
*Navicula directa*  
*Navicula hennedii*  
*Navicula pennata*  
*Nitzschia* sp. B  
*Paralia complexa*  
*Paralia sulcata*  
*Paralia sulcata* var. *coronata*  
*Periptera tetracladia*  
*Pleurosigma affine* var. *marylandica*  
*Pseudodimerogramma elliptica*  
*Pseudopyxilla americana*  
*Pyxilla johnsoniana*  
*Raphidodiscus marylandicus*  
*Rhaphoneis affinis*  
*Rhaphoneis biseriata*  
*Rhaphoneis elegans*  
*Rhaphoneis gemmifera*  
*Rhaphoneis rhombica*  
*Rhizosolenia bergonii*  
*Rhizosolenia miocenica*  
*Sceptroneis grandis*  
*Stephanogonia actinoptychus*  
*Stephanopyxis corona*  
*Stephanopyxis grunowii*  
*Stephanopyxis lineata*  
*Stephanopyxis turris*  
*Stictodiscus kittonianus*  
*Synedra jouseana*  
*Thalassionema nitzschioides*  
*Thalassiosira* sp. A  
*Thalassiosira* sp. B  
*Thalassiothrix longissima*  
*Triceratium condecorum*  
*Triceratium subrotundatum*  
*Triceratium tessellatum*  
*Trinacria excavata*  
*Trochosira concava*  
*Xanthiopyxis* spp.

#### SILICOFLAGELLATES

In addition to diatoms, Abbott and Ernissee (1983) identified a number of silicoflagellate species from the Pungo River Formation. Only those associated with their Assemblage A are listed here because beds containing Assemblage B are not found at the Lee Creek Mine:

*Cannopilus binoculus*  
*Cannopilus haeckelii*  
*Cannopilus hemisphaericus*  
*Cannopilus sphaericus*

*Cannopilus triommata*  
*Cannopilus* sp. A  
*Cannopilus* sp. B  
*Corbisema triacantha*  
*Dictyocha fibula, sensu lato*  
*Dictyocha rhombica, sensu lato*  
*Distephanus crux*  
*Distephanus speculum, sensu lato*  
*Distephanus speculum* var. *pentagonus*  
*Halicalyptra picasso*  
*Mesocena* cf. *M. elliptica*

#### Unit D (of Riggs et al., 1982a)

(= Units 6 and 7 of Gibson, 1967)

#### Paleontology

#### Invertebrates

#### FORAMINIFERA

Gibson (1967:637) listed the following planktonic Foraminifera that were abundant in the upper 10 feet (3 m) of the Pungo River Formation (Units 6 and 7 of Gibson, 1967):

*Globigerina angustiumbilitata* Bolli  
*Globigerina bulloides* d'Orbigny  
*Globigerina bulloides falconensis* Blow  
*Globigerina pachyderma incompta* Cifelli  
*Globigerina woodi* Jenkins  
*Globigerinita glutinata* (Egger)  
*Globorotalia birnageae* Blow  
*Globorotalia fohsi barisanensis* LeRoy  
*Globorotalia mayeri* Cushman and Ellisor  
*Globorotalia obesa* Bolli  
*Globorotalia scitula* (Brady)  
*Globigerinella aequilateralis* (Brady)  
*Globigerinoides bisphericus* Todd  
*Globigerinoides ruber* (d'Orbigny)  
*Globigerinoides trilobus altiaperatura* Bolli  
*Globigerinoides trilobus immatura* LeRoy  
*Globigerinoides trilobus trilobus* (Reuss)  
*Globoquadrina altispira globosa* Bolli  
*Globoquadrina dehiscens* (Chapman, Parr, and Collins)  
*Globoquadrina venezuelana* (Hedberg)  
*Cassigerinella chipolensis* (Cushman and Ponton)

In addition, Gibson listed the following benthics that were common:

*Siphogenerina lamellata* Cushman

*Siphogenerina spinosa* Bagg  
*Discorbis cavernata* Dorsey  
*Bolivina calvertensis* Dorsey

Gibson (1967:642) mentioned two taxa specifically from his Unit 6:

*Buliminella elegantissima* (d'Orbigny)  
*Cassidulina norcrossi*

In addition, from his Unit 7, Gibson (1967: 642) identified two taxa:

*Cibicides lobatulus* (Walker and Jacob)  
*Hanzawaia concentrica*

Gibson (1983b:368-386) described and figured a number of planktonic Foraminifera which he reported from the "upper part of the Pungo River Formation." This is interpreted to mean his Units 6 and 7 and Unit D of Riggs et al. (1982a):

*Cassigerinella chipolensis* (Cushman and Ponton)  
*Globigerina woodi woodi* Jenkins  
*Globigerina* sp. cf. *G. anguliofficialis* Blow  
*Globigerinita glutinata ambitacrena* (Loeblich and Tappan)  
*Globigerinoides altiaperatus* Bolli  
*Globorotalia scitula praescitula* Blow  
 "Turborotalia" *birnageae* (Blow)  
*Bolivina calvertensis* Dorsey  
*Bolivina pungoensis*, n. sp.  
*Siphogenerina lamellata* Cushman  
*Siphogenerina* sp.

#### MOLLUSKS

Carter et al. (1988: pl. 8) figured four species from the "upper moldic limestone portion of the Pungo River Formation." That bed is here interpreted to be within Unit D of Riggs et al. (1982a). The species are:

*Chesapecten coccymelus* (Dall)  
*Lucinoma contracta* (Say)  
*Hytissa percassa* (Conrad)  
*Ecphora tricostata* (Martin)

Carter and Nekola (1992:134) gave a list of the taxa from the upper Pungo River Formation. Most of these are interpreted from molds of aragonitic taxa. Others are calcitic and well preserved. Their asterisk (\*) indicates that the species is known from the Calvert Formation of Maryland and Delaware and Kirkwood Formation of Delaware and New

Jersey, but more taxa than they note are also found in those units. Carter and Nekola's (1992) list is as follows:

#### CEPHALOPOD

*Aturia* sp.

#### GASTROPODS

*Diodora* sp. cf. *D. catilliformis alumensis* (Gardner, 1930)

*Calliostoma* sp. cf. *C. bella* (Conrad)

*Turritella* sp. cf. *T. aequistriata* Conrad

*Turritella* sp. cf. *T. indenta* Conrad, 1841

*Turritella* sp. cf. *T. cumberlandia* (Conrad)

*Serpulorbis granifera* (Say, 1824)

*Calyptraea* sp. cf. *C. aperta* (Solander, 1766)

\**Ephora meganae meganae*? Ward and Gilinsky, 1988

[This subspecies includes *Ephora calvertensis* Petuch, 1988, *fide* Ward, 1992]

The bracketed note above is that of Carter and Nekola (1992). This is probably an *Echphora tricostata*.

\**Echphora tricostata tricostata* Martin, 1904 [This subspecies includes *Echphora prunicola* Petuch, 1988, *fide* Ward, 1992.]

The bracketed note above is that of Carter and Nekola (1992).

*Echphora tricostata pamlico* (Wilson, 1987)

*Siphonalia* sp. cf. *S. devexa* (Conrad)

*Cancellaria* sp. 1

*Cancellaria* sp. 2

*Terebra* sp.

*Drilla* sp. cf. *D. limatula* (Conrad, 1830)

#### BIVALVES

*Dallarca?* *subrostrata* (Conrad, 1841)

*Dallarca* aff. *D. elevata* (Conrad, 1840)

\**Glycymeris parilis* (Conrad, 1843)

*Isognomon (Hippochaeta)* sp.

*Atrina* sp.

*Pecten humphreysii humphreysii* Conrad, 1842

*Pecten mclellani* Gibson, 1987

*Rebeccapecten berryae*? Ward, 1992

\**Chesapecten coccymelus* (Dall, 1898)

*Chesapecten nefrens*? Ward and Blackwelder, 1975

*Ostrea mauricensis* Gabb, 1860

*Pycnodonte (Gigantostrea) leeana* Wilson, 1987

*Pycnodonte (Gigantostrea) percrassa* (Conrad, 1840)

*Mytilus conradinus* d'Orbigny, 1852

*Modiolus ducatellii* Conrad, 1840

*Lucinoma contracta* (Say, 1824)

*Timothyus subvexa* (Conrad, 1838)

\**Astarte cuneiformis* Conrad, 1840

*Astarte thisphila*? Glenn, 1904

*Astarte* cf. *A. thisphila* Glenn, 1904

*Marvacrassatella turgidula*? (Conrad, 1843)

\**Marvacrassatella melina* (Conrad, 1832)

\**Cyclocardia castrana* (Glenn, 1904)

*Chesacardium* n. sp. or subsp. 1

*Chesacardium* n. sp. or subsp. 2

*Tellina*? sp.

*Semele carinata* (Conrad, 1830) new subsp.

\**Melosia staminea* (Conrad, 1839)

*Dosinia acetabulum blackwelderi* Ward, 1992

*Lirophora latilirata* (Conrad, 1841)

*Bicorbula idonea* (Conrad, 1833)

*Corbula (Caryocorbula) inaequalis* Say, 1824

\**Varicorbula elevata* (Conrad, 1838)

*Panopea goldfussii* Wagner, 1839, n. subsp.

Gibson (1967:637) listed several mollusks as present in the upper few feet of the Pungo River Formation:

*Pecten humphreysii* Conrad

"*Pecten madisonius*" Say [prob. *Chesapecten coccymelus* (Dall)]

*Glycymeris parilis* (Conrad)

*Echphora tricostata* Martin

*Turritella* sp.

In a later paper, Gibson (1987:31-112) described the following mollusks from the upper Pungo River Formation:

*Pecten mclellani* n. sp.

*Pecten humphreysii humphreysii* Conrad

*Chesapecten coccymelus* (Dall)

*Chesapecten nefrens* Ward and Blackwelder

*Amusium* sp.

See Plates 3-5 for Pungo River mollusks.

#### ECHINOIDS

Kier (1983:499) identified the sand dollar *Abertella aberti* (Conrad) from the uppermost part of the Pungo River Formation. This identification was based on numerous fragments with no whole specimens known.

#### Vertebrates

Purdy et al. (2001:76) listed the following sharks and fish from Unit 6 of Gibson (1967), which is equivalent to Unit D of Riggs et al. (1982a). The names are given as they were listed in their table 1:

**RAYS**

*Plinthicus stenodon*

**SHARKS**

*Odontaspis ferox*  
*Odontaspis* cf. *O. acutissima*  
*Hemipristis serra*  
*Galeocerdo* sp.  
*Galeocerdo contortus*

**FISH**

*Megalops* cf. *M. atlanticus*  
*Lagodon* cf. *L. rhomboides*  
*Sphyraena* cf. *S. barracuda*  
*Aluterus* sp.

**Upper Miocene**

**Eastover Formation**

**STRATIGRAPHY**

The Eastover Formation, as a stratigraphic unit, is not known to be present at the Lee Creek Mine. However, the coarse lag deposit of phosphate nodules, some boulder-sized, that immediately overlies the Pungo River, may have originated in the Eastover Formation or have been concentrated from erosion of Eastover sediments. The Eastover Formation is exposed in small outcrops as far south as the Neuse and Trent Rivers below New Bern (Ward and Blackwelder, 1980: localities 47, 48). There are no known outcrops between that area and the Meherrin River, where it is well exposed above Murfreesboro, North Carolina. The outcrops on the Trent River, just below the mouth of Brice Creek, have molds and casts of mollusks indicative of the Eastover Formation:

*Spisula* sp. cf. *S. rappahannockensis*  
*Euloxa* sp.  
*Turritella plebia*

The outcrop on the Neuse River is exposed only at extreme low-water between the mouths of Mill Creek and Smith Fort,

Pamlico County. The marker species there is *Chesapecten middlesexensis*, known only from the Eastover Formation. It is clear, then, that the Eastover sea covered the Lee Creek Mine area. These beds must have been thin, as they were apparently beveled off by the transgressing Yorktown Formation (Sunken Meadow) sea. Large *Carcharocles megalodon* teeth that are characteristically black from being reworked, probably are a lag product derived from the Eastover Formation. No certain Eastover fossils have been found at the Lee Creek site, although some have been incorrectly identified and said to have come from the Eastover Formation (Petuch, 1988c, 1997, 2004). The following taxa figured by Petuch and by Uhen (2004) were reported from the Eastover:

**PALEONTOLOGY**

*Invertebrates*

**MOLLUSKS**

Petuch (1988c:67, 68, 76, fig. 31-B) figured a specimen that he assigned to *Ecphora (Ecphora) kochi* Ward and Gilinsky. From the misidentification of this species, which is found only in the Cobham Bay Member of the Eastover Formation (upper Miocene), Petuch inferred that the “basal unit” of the Yorktown Formation at Lee Creek was upper Miocene and lower Pliocene. The specimen figured by Petuch (fig. 31-B) is *Ecphora quadricostata*, a juvenile specimen, probably from the Sunken Meadow Member of the Yorktown Formation (lower Pliocene) (see Yorktown Formation Section, Sunken Meadow Member – Mollusks).

Petuch (1997:124, 125, fig. 44) figured a number of specimens said to have been collected from two members of the Eastover Formation at the Lee Creek Mine, as follows:

<i>Ecphora kochi</i> Ward and Gilinsky	p. 125, fig. 44-A	Upper Lee Creek Eastover bed
<i>Ecphora whiteoakensis</i> Ward and Gilinsky	p. 125, fig. 44-C	Lower Lee Creek Eastover bed
<i>Ecphora whiteoakensis</i> Ward and Gilinsky	p. 125, fig. 44-D	Lower Lee Creek Eastover bed
<i>Ecphora</i> sp.	p. 125, fig. 44-E	Upper Lee Creek Eastover bed
<i>Oliva idonea</i> Conrad	p. 125, fig. 44-F	Upper Lee Creek Eastover bed

My interpretation of this assemblage is the following:

Fig.	Petuch's Name	Amended Name
44-A	<i>Ecphora kochi</i>	<i>Ecphora quadricostata</i>
44-C	<i>Ecphora whiteoakensis</i>	<i>Ecphora quadricostata</i>
44-D	<i>Ecphora whiteoakensis</i>	<i>Ecphora quadricostata</i>
44-E	<i>Ecphora</i> sp.	<i>Ecphora quadricostata</i>
44-F	<i>Oliva idonea</i> Conrad	sp. indet., provenance suspect

The specimen of *Oliva* is small and immature, and its provenance is suspect. The Pungo River and Yorktown Formations have been subjected to ground-water conditions that have taken the aragonitic mollusks into solution. The Eastover Formation, even in its type area, has been partially affected by solution. It is doubtful that the Eastover, if it is found in the Lee Creek area, will contain preserved, aragonitic mollusks. The specimen may be an immature *O. carolinensis* from the James City Formation. Note that Petuch described such mixing in the same paper (1997:160, fig. 53). The figures of *Ecphora quadricostata* indicate that they came from the Yorktown Formation, possibly the Sunken Meadow Member, and are not evidence of the presence of the Eastover Formation.

Petuch (2004:125) discussed the occurrence of *Gigantostrea leeana* (Wilson) in the "Eastover beds in the Lee Creek Mine, Aurora, North Carolina . . ." *Gigantostrea leeana* [= *Pycnodonte percrassa*] is found in the Pungo River Formation (lower Miocene) at the Lee Creek Mine, not the Eastover Formation (upper Miocene). No pycnodontids are known from the Choptank, St. Marys, Eastover, Upper Yorktown, James City, or Flanner Beach Formations, at the Lee Creek site or elsewhere. There is a small, trigonal-shaped, deep-valved species in the lower Yorktown (see Plate 9) which occurs in the Lee Creek Mine, but that taxon is easily differentiated from *G. leeana* [= *Pycnodonte percrassa*]. Assuming that *G. leeana* is present in the Eastover Formation at the Lee Creek Mine, Petuch (2004) identified an ostreid in South Florida as that species and indicated that the unit from which it came (Bayshore Formation) was the same age. Examination of the Bayshore fauna illustrated by Petuch (2004: pl. 41) makes it clear that that unit is upper Pliocene and correlative with the Rushmere Member of the Yorktown Formation. (See Introduction.)

Mollusks from the Eastover Formation from other areas of North Carolina are illustrated on Plates 6 and 7.

### Vertebrates

### Mammals

### WHALES

Uhen (2004:179, 180, fig. 137, table 27) described and illustrated some vertebrae, ribs, jaws and limb bones of whales

from the Lee Creek Mine. These were cited as coming from the Eastover Formation. Communications (April 2004) from Uhen since this publication indicated that he was not sure why this citation was made to the Eastover Formation, that the specimens are in the USNM, and that they could be, and probably are, from the lower Yorktown Formation.

## Pliocene

### Yorktown Formation

Some of the early workers at the Lee Creek Mine (Gibson, 1967) and many of the amateur collectors (Beddard, 1991) have labeled essentially all of the shelly material as coming from the Yorktown Formation. Steady work by other workers, with experience in the type Yorktown in Virginia, the Chowan River in Virginia and North Carolina, and the James City and Flanner Beach along the Neuse River in North Carolina have allowed this author to identify the various shelly beds above the Pungo River Formation. Those beds reflect at least 6 sea-level highs and transgressive events from the early Pliocene to the late Pleistocene. Strata that have been lumped in with the Yorktown Formation include the Chowan River Formation, James City Formation, and Flanner Beach Formation. Those units are discussed separately here.

## STRATIGRAPHY

The Yorktown Formation was named by Clark and Miller (1906) and described more fully by those authors in 1912. Miller (1912) expanded this work into North Carolina. Miller (1912) miscorrelated the Yorktown and included Yorktown sediments in the "St. Marys Formation." Miller also included beds now known as the Chowan River Formation in the Yorktown Formation. Ward and Blackwelder (1980) studied the Yorktown in its type area, defined the unit, and subdivided it into four members, all of which are traceable into North Carolina and can be correlated with units exposed in the Lee Creek Mine.

The units described in Virginia are:

Moore House Member	Upper Yorktown
Morgarts Beach Member	
Rushmere Member	
Sunken Meadow Member	Lower Yorktown

The Sunken Meadow Member at the Lee Creek Mine was called Yorktown Units 1-2 by Gibson (1967) and the lower

Yorktown by Riggs et al. (1982a). Beds associated with the Rushmere/Morgarts Beach Members were called Units 3-5 by Gibson (1967) and the lower of two sub-units placed by Riggs et al. (1982a) in his upper Yorktown. The upper of his two sub-units is correlative with the Moore House Member. Gibson (1967) apparently did not observe the Moore House equivalent beds. The main haul road was built at this level and may have obscured the unit. Riggs et al. (1982a) stated that this bed was present only locally where not eroded off.

Riggs (1984) discussed the origin of phosphate in the Yorktown Formation and described the sequence of beds. Riggs correlated the Yorktown beds with the sea-level curves developed by Vail and Mitchum (1979).

Hoffman and Ward (1989) generally followed the stratigraphy of Riggs et al. (1982a) but recognized the Members named by Ward and Blackwelder (1980):

Morgarts Beach Member (upper)  
Rushmere Member (middle)  
Sunken Meadow Member (lower)

The Moore House Member was not recognized at the Mine at that time.

Denison et al. (1993) used strontium isotopes to date fossil shells in the Yorktown Formation. These they found to be close to the dates provided by planktonic Foraminifera.

## PALEONTOLOGY

### (Yorktown Formation, undifferentiated)

Many workers who have reported taxa from the Yorktown Formation have been unwilling or unable to specify the bed from which specimens were derived. The chaotic mix of fossils and sediments that results from strip mining makes the approach necessary in many cases.

#### *Vertebrates*

#### FISH

Fierstine (1999) named a billfish from the lower Yorktown at the Lee Creek Mine *Makaira purdyi*. Fierstine (2001:21-69) reported the following billfish from the Yorktown at large:

*Istiophorus platypterus* (Shan and Nodder, 1792)  
*Istiophorus* cf. *I. platypterus* (Shan and Nodder, 1792)  
*Makaira indica* (Cuvier, 1832)  
*Makaira* cf. *M. indica* (Cuvier, 1832)  
*Makaira nigricans* Lacépède, 1802  
*Makaira* cf. *M. nigricans* Lacepede, 1802

*Makaira purdyi* Fierstine, 1999  
*Makaira* sp.  
cf. *Makaira* sp.  
*Tetrapturus albidus* Poey, 1860  
*Tetrapturus* cf. *T. albidus* Poey, 1860

Weems (1985) figured and discussed a jaw of the ocean sunfish *Mola chelonopsis* from the Yorktown at the Lee Creek Mine but did not assign it to a more specific stratigraphic horizon.

## TURTLES

Zug (2001:203-218) figured and described the following turtles from the Yorktown:

*Bothremys* sp.  
*Caretta patriciae* n. sp.  
? *Chelonia* sp.  
*Lepidochelys* sp.  
*Procolpochelys* sp.  
*Syllomus aegyptiacus*  
*Psephophorus* sp.  
*Chrysemys* sp.  
*Geochelone*

## CROCODILES

Myrick (2001:219-225) left open the possibility that some of the crocodile material from the Lee Creek Mine might come from the Yorktown Formation, but none has been found by the present author above the St. Marys Formation in either the Eastover or Yorktown Formations. The reports of the taxon in the Bone Valley Formation in Florida are probably based on reworked older material that concentrated in the bone lag deposit (see Pungo River Formation – Undifferentiated – Paleontology – Crocodiles).

## BIRDS

Storer (2001:227-231) described a new species of grebe from the Yorktown:

*Podiceps howardae* Storer

Olson and Rasmussen (2001:233-365) reported an extensive bird fauna from the Yorktown Formation consisting of at least 100 species. It is believed that most of the specimens come from the Sunken Meadow Member of the Yorktown, but the following were listed only as the



“Yorktown Formation.” Those followed by a ? may also be from the Pungo River. The taxa identified are the following:

*Gavia howardae* Brodkorb, 1953  
*Gavia concinna* Wetmore, 1940  
*Podiceps aff. auritus* (Linnaeus)  
 Podicipedidae, genus and species indet.  
*Phoebastria aff. albatrus* (Pallas)  
*Phoebastria aff. nigripes* (Audubon)  
*Phoebastria aff. immutabilis* (Rothschild)  
*Phoebastria rexsularum* n. sp.  
*Pterodromoides minoricensis* Seguí et al.  
*Procellaria cf. aequinoctialis* Linnaeus  
*Procellaria cf. parkinsoni* Gray  
*Pterodroma magn. lessonii* (Garnot)  
*Bulweria?* sp. ?  
*Pachyptila* sp.  
*Calonectris krantzi* n. sp.  
*Calonectris aff. borealis* (Cory)  
*Calonectris aff. diomedea* (Scopoli)  
*Puffinus aff. pacificoides* Olson, 1975  
*Puffinus (Ardenna)* sp. ?  
*Puffinus aff. gravis* (O'Reilly) ?  
*Puffinus aff. tenuirostris* (Temminck)  
*Puffinus cf. puffinus* (Brünnich) *sensu lato*  
*Puffinus magn. lherminieri* Lesson  
*Pelagornis* sp. 1  
*Pelagornis* sp. 2  
*Morus peninsularis* Brodkorb, 1955  
*Morus* sp. 1  
*Morus* sp. 2  
*Phalacrocorax wetmorei* Brodkorb, 1955  
*Phalacrocorax*, large sp.  
*Catharacta* sp.  
*Stercorarius aff. pomarinus* (Temminck)  
*Stercorarius aff. parasiticus* (Linnaeus)  
*Stercorarius aff. longicaudus* Vieillot  
*Larus aff. argentatus* Pontoppidan  
*Larus aff. delawarensis* Ord  
*Larus aff. atricilla* Linnaeus  
*Larus magn. ridibundus* Linnaeus  
*Larus aff. minutus* Pallas  
*Sterna aff. maxima* Boddaert  
*Sterna aff. nilotica* Gmelin  
*Alca aff. torda* Linnaeus  
*Alca ausonia* (Portis, 1891)  
*Alca antiqua* (Marsh, 1870)  
*Alca*, undescribed sp.  
*Pinguinus alfrednewtoni* Olson

*Fratercula aff. arctica* (Linnaeus)  
*Fratercula aff. cirrhata* (Pallas)  
*Cygnus aff. columbianus* (Ord)  
*Anser cf. arizonae* Bickart, 1990  
*Branta aff. bernicla* (Linnaeus)  
 Anserini, gen. and sp. indet.  
*Anabernicula cf. minuscula* (Wetmore, 1924)  
*Anas magn. platyrhynchos* Linnaeus  
*Anas magn. acuta* Linnaeus  
*Anas magn. americana* Gmelin  
*Anas magn. clypeata* Linnaeus  
*Anas magn. discors* Linnaeus  
*Aythya aff. affinis* (Eyton)  
*Somateria aff. mollissima* (Linnaeus)  
*Somateria* sp.  
*Histrionicus aff. histrionicus* (Linnaeus)  
*Melanitta aff. perspicillata* (Linnaeus)  
*Melanitta aff. nigra* (Linnaeus)  
*Bucephala aff. clangula* (Linnaeus)  
*Bucephala aff. albeola* (Linnaeus)  
*Mergus aff. serrator* Linnaeus  
 Anatidae, gen. and sp. indet.  
*Grus aff. americana* (Linnaeus)  
*Grus aff. antigone* (Linnaeus, 1758)  
*Balearica?* sp. ?  
 Rallidae, gen. and sp. indet.  
*Haematopus aff. ostralegus* Linnaeus  
*Pluvialis aff. squatarola* Linnaeus  
*Numenius aff. borealis* Forster  
*Capella aff. media* (Latham)  
*Tringa magn. ochropus* Linnaeus  
*Calidris aff. melanotos* (Vieillot)  
*Phoenicopterus cf. floridanus* Brodkorb, 1953  
*Ardea aff. cinerea* Linnaeus  
*Ciconia* sp. 2  
 Ciconiidae, gen. and sp. indet.  
 Vulturidae, gen. and sp. indet.  
*Buteo magn. jamaicensis* (Gmelin)  
*Buteo* ? sp.  
*Neophrontops* ? sp.  
 Accipitridae, gen. and sp. indet. 1  
 Accipitridae, gen. and sp. indet. 2  
*Pandion* sp.  
*Ortalis* ? sp. ?  
 Phasianidae, gen. and sp. indet.  
*Meleagris* sp.  
*Ectopistes aff. migratorius* (Linnaeus)  
*Corvus aff. ossifragus* Wilson

*Alle aff. alle* (Linnaeus)  
 Aethiinae, gen. and sp. indet.

## Mammals

**WALRUSES**

Kohno and Ray (this volume:39-80) reported a single species of walrus from the Yorktown:

*Ontocetus emmonsii* Leidy

**SEALS**

Koretsky and Ray (this volume:81-139) identified six species of seals from the Yorktown at the Lee Creek Mine:

*Platyphoca vulgaris*  
*Phocanella pumila*  
*Gryphoca similis*  
*Callophoca obscura*  
*Pliophoca etrusca*  
*Homiphoca capensis*

**WHALES**

Whitmore and Kaltenbach (this volume:181-269) identified a large number of cetaceans (whales and porpoises) from the Yorktown at the Lee Creek Mine:

*Mesoplodon longirostris* (Cuvier)  
*Ziphius* cf. *Z. cavirostris* Cuvier  
*Ninziphius* cf. *N. platyrostris*  
 Cf. *Pontoporia*  
*Delphinus* sp.  
*Lagenorhynchus harmatuki* n. sp.  
*Lagenorhynchus* sp.  
*Stenella rayi* n. sp.  
 Cf. *Stenella*  
*Tursiops* sp.  
*Globicephala* sp.  
*Pseudorca* sp.  
*Delphinapterus* sp.  
*Aprixokogia kelloggi* n. sp.  
 Kogiinae incertae sedis  
 Physeterinae incertae sedis  
*Herpetocetus transatlanticus* n. sp.  
*Balaenoptera acutorostrata* Lacépède  
*Megaptera* sp.  
*Gricetoides aurorae* n. sp.  
*Balaenula* sp.  
*Balaena* sp.

Whitmore (1994) used fossil whales as evidence of climatic change during the Miocene to Recent period. He drew heavily

from the fossil material obtained from the Yorktown at the Lee Creek Mine. Whitmore (1994: table 1) gave a list of the Yorktown taxa:

Odontoceti  
 Ziphiidae  
*Mesoplodon longirostris* (Cuvier)  
*Ziphius*, cf. *Z. cavirostris* Cuvier  
 Ziphiidae incertae sedis  
 Pontoporiidae  
 Cf. *Pontoporia*  
 Delphinidae  
 Cf. *Delphinus*  
 Aff. *Lagenorhynchus*  
*Stenella* n. sp.  
*Tursiops* sp.  
*Globicephala* sp.  
*Pseudorca* sp.  
 Monodontidae  
*Delphinapterus* sp.  
 Physeteridae  
 Kogiinae n. gen. and sp.  
 Physeterinae incertae sedis  
 Mysticeti  
 Cetotheriidae  
*Herpetocetus* n. sp.  
 Balaenopteridae  
*Balaenoptera acutorostrata* Lacépède  
*Balaenoptera borealina* Van Beneden  
*Megaptera* sp.  
 ?Eschrichtiidae  
 n. gen. and sp.  
 Balaenidae  
*Balaenula* sp.  
*Balaena* n. sp.

Kazár and Bohaska (this volume:271-323) described the humeri and ulnae of various odontocetes in the Yorktown. They discussed their use in identifying the various taxa found in that unit. The following families were identified and studied:

Kogiinae  
 Monodontidae  
 Pontoporiidae  
 Delphinidae  
 Ziphiidae (?)

Geisler and Luo (1996) described in detail the petrosal and inner ear of the mysticete *Herpetocetus* sp. from the Yorktown at the Lee Creek Mine.

Luo and Marsh (1996) described the petrosal and inner ear of a kogiine whale from the Lee Creek Mine. The specimen, from the Yorktown Formation, belongs to a new species.

### Lower Pliocene

#### *Sunken Meadow Member*

### STRATIGRAPHY

The Sunken Meadow Member of the Yorktown Formation was named by Ward and Blackwelder (1980) for shelly sands found in the lower portion of the Yorktown Formation in Virginia. Beds now recognized as the Sunken Meadow were included in the original description of the Yorktown Formation by Clark and Miller (1906, 1912) and were retained in that unit by Ward and Blackwelder (1980). Those authors recognized the different nature of this bed, as did Mansfield (1943) before them who called the unit his "Zone 1" or *Pecten clintonius* zone.

The Sunken Meadow, in its type area, unconformably overlies the Eastover Formation and is overlain unconformably by the Rushmere Member of the Yorktown Formation. At the Lee Creek Mine the Sunken Meadow directly overlies the Pungo River Formation with a sharp contact marked by burrows and a phosphatic pebble and cobble conglomerate. The Eastover Formation probably extended across this area and can be identified on the Trent and Neuse Rivers, but erosion or beveling during the Sunken Meadow transgression has reduced the unit to a basal lag deposit. Large black phosphatic teeth of *Procarcharodon megalodon* found in this basal layer are probably derived from the Eastover. This lower contact is shown graphically in Gibson (1983a:62, fig. 24) where his Unit 1 overlies Unit 7 of the Pungo River Formation. Gibson's (1983a) arrow points to the very sharp contact. Three pockets are visible that cut into the surface of the Pungo River Formation and contain concentrations of large phosphate clasts. The upper contact of the Sunken Meadow with the overlying Rushmere Member is visible in the upper portion of Gibson's figure 24. That contact is also very sharp and marked by burrows into the underlying Sunken Meadow and a basal lag at the base of the Rushmere. The burrows from the Rushmere penetrating down into the Sunken Meadow are filled with Rushmere-aged sediment and microfossils (Foraminifera and ostracodes). Likewise the burrows excavated in the Sunken Meadow surface by various crustaceans, worms, etc. cause a large amount of the older material to be reworked into the younger Rushmere sediment. The result is a mixing on both sides of the contact, especially involving microfossils but also larger material. That effect is documented in Hazel's (1983:81-199) treatment of the ostracodes, where his guide fossils *Pterygocythereis*

*inexpectata* and *Orionina vaughani* are mixed into adjacent units.

The Sunken Meadow/Rushmere contact has been described and mapped by Welby and Leith (1969) by use of a high resolution "Boomer" survey on the Pamlico River in the vicinity of the Lee Creek Mine. Those authors believed the unconformity to indicate a basin shift at that time.

### PALEONTOLOGY

#### *Invertebrates*

#### FORAMINIFERA

Gibson (1967:637) listed the following planktonic Foraminifera from the lowest part of the Yorktown Formation (= Sunken Meadow) from the Lee Creek Mine:

*Globigerina bulloides bulloides*  
*Globigerina bulloides falconensis*  
*Globigerina pachyderma incompta*  
*Globorotalia mayeri* Cushman and Ellisor  
*Globorotalia punctulata* (d'Orbigny)  
*Globoquadrina altispira altispira* (Cushman and Jarvis)  
*Sphaeroidinella seminula seminula* (Schwager)

In addition, Gibson (1967:645) identified benthic Foraminifera in his Units 1 and 2 (= Sunken Meadow), as follows:

Unit 1:  
*Cassidulina laevigata*  
*Uvigerina subperegrina*  
*Angulogerina angulosa* (Williamson)  
*Cassidulina crassa*  
*Nonion pizarrense*  
*Nonionella auris*  
*Elphidium clavatum* Cushman

Unit 2:  
*Buliminella elegantissima*  
*Elphidium clavatum*  
*Cassidulina norcrossi*  
*Reusella spinulosa* (Reuss)  
*Discorbis floridana* Cushman

Gibson (1983b:355-453) figured three other foraminiferal taxa from the lower Yorktown (= Sunken Meadow), as follows:

*Globorotalia puncticulata* (Deshayes)

“*Turborotalia*” *acostaensis humerosa* (Takayanagi and Saito)

*Epistominella danvillensis* (Howe and Wallace)

Snyder et al. (1983:455–481) concentrated on the planktonic Foraminifera of the Yorktown at the Lee Creek Mine. Their samples 28-42 came from their Units 1 and 2 (=Sunken Meadow) and included the following taxa as tabulated in their figure 4:

*Globigerina bulloides apertura*  
*Globigerina bulloides bulloides*  
*Globigerina calida praealida*  
*Globigerina decoraperta*  
*Globigerina juvenilis*  
*Globigerinita glutinata*  
*Globigerinita uvula*  
*Globigerinoides bollii*  
*Globigerinoides conglobatus conglobatus*  
*Globigerinoides obliquus extremus*  
*Globigerinoides obliquus obliquus*  
*Globigerinoides quadrilobatus quadrilobatus*  
*Globigerinoides ruber*  
*Globoquadrina altispira globosa*  
*Globoquadrina venezuelana*  
*Turborotalia acostaensis acostaensis*  
*Turborotalia acostaensis humerosa*  
*Turborotalia praeoscitans*  
*Globorotalia crassula*  
*Globorotalia hirsuta praehirsuta*  
*Globorotaloides hexagona hexagona*  
*Hastigerina siphonifera siphonifera*  
*Orbulina suturalis*  
*Orbulina universa*  
*Sphaeroidinellopsis subdehiscens subdehiscens*  
*Turborotalita humilis*  
*Turborotalita quinqueloba*

The authors concluded that the Yorktown units were of late early to early late Pliocene age. Three taxa identified by them in the Sunken Meadow (samples 28–42) were:

*Globigerina calida praealida*  
*Globigerinoides conglobatus conglobatus*  
*Globorotalia crassula*

These species are not known above Zone N19 and are early Pliocene in age.

Snyder, et al. (2001) finished a study on the Pliocene benthic Foraminifera at the Lee Creek Mine. The following is a list of the taxa reported from the Sunken Meadow Member:

*Alliatina glabrella*  
*Ammonia beccarii*  
*Amphycoryna* sp.  
*Angulogerina angulosa occidentalis*  
*Anomalinoidea* cf. *A. riveroae*  
*Astrononion stelligerum*  
*Bolivina marginata*  
*Bolivina paula*  
*Bolivina* sp.  
*Bolivina* sp. “A”  
*Bolivina subexcavata*  
*Buccella frigida*  
*Buccella inusitata*  
*Buccella mansfieldi*  
*Buccella* cf. *B. parkerae*  
*Buccella vicksburgensis*  
*Bulimina aculeata*  
*Bulimina marginata*  
*Buliminella brevior*  
*Buliminella elegantissima*  
*Cancris sagra*  
*Cassidulina caribeana*  
*Cassidulina laevigata*  
*Caucasina gracilis*  
*Caucasina preacanthia*  
*Ceratobulimina* sp.  
*Cibicides lobatulus*  
*Cibicoides floridanus*  
*Dentalina communis*  
*Discorbis* cf. *D. farishi*  
*Elphidium excavatum*  
*Elphidium poeyanum*  
*Epistominella danvillensis*  
*Epistominella pontoni*  
*Fissurina* cf. *F. laevigata*  
*Fissurina lucida*  
*Fissurina marginato-perforata*  
*Fissurina* cf. *F. pseudoglobosa*  
*Fissurina quadrata*  
*Fissurina* cf. *F. submarginata*  
*Fissurina* sp. “A”  
*Fissurina* sp. “C”  
*Fissurina* sp. “D”  
*Fursenkoina fusiformis*  
*Fursenkoina pontoni*  
*Fursenkoina punctata*  
*Galwayella trigono-marginata*  
*Globocassidulina crassa*  
*Globocassidulina subglobosa*  
*Globulina gibba*  
*Globulina inequalis*  
*Guttulina austriaca*  
*Guttulina* cf. *G. elegans*

*Guttulina* cf. *G. lactea*  
*Guttulina problema*  
*Guttulina rectiornata*  
*Hanzawaia concentrica*  
*Lagena* aff. *L. clavata*  
*Lagena globulohispida*  
*Lagena intermedia*  
*Lagena laevis*  
*Lagena palmerae*  
*Lagena* cf. *L. striaticollis*  
*Lagena substriata*  
*Lagena tenuis*  
*Laryngosigma williamsoni*  
*Lenticulina americana*  
*Lenticulina* sp.  
*Marginulina* sp.  
*Neoconorbina terquemi*  
*Nodosaria catesbyi*  
*Nonion* cf. *N. granosum*  
*Nonionella* aff. *N. danvillensis*  
*Nonionella miocenica*  
*Oolina globosa*  
*Oolina laevigata*  
*Oolina melo*  
*Oolina* cf. *O. striatopunctata*  
*Parafissurina bidens*  
*Parafissurina* sp. "B"  
*Planulina* sp.  
*Polymorphina* sp.  
 Polymorphinidae (fistulose forms)  
*Pseudononion grateloupi*  
*Pseudononion pizarrensis*  
*Pyrulina albatrossi*  
*Quinqueloculina seminula*  
*Reusella glabrata*  
*Reusella miocenica*  
*Rosalina concinna*  
*Rosalina globularis*  
*Rosalina subaraucana*  
*Rosalina* sp. "B"  
*Saracenaria* cf. *S. acutaauricularis*  
*Sigmavirgulina tortuosa*  
*Sigmomorphina nevirifera*  
*Sigmomorphina pearceyi*  
*Sigmomorphina semitecta*  
*Textularia agglutinans*  
*Textularia candeiana*  
*Textularia concia*  
*Textularia mayori*  
*Textularia* sp.  
*Trochulina bassleri*  
*Uvigerina calvertensis*  
*Uvigerina juncea*

*Uvigerina subperegrina*  
*Valvulineria floridana*  
*Valvulineria olssoni*  
*Valvulineria* sp.  
*Ventrostoma fovigera*

## MOLLUSKS

Gibson (1987:31-112) figured and described two of the mollusks found in the Sunken Meadow Member (his Units 1 and 2). Those species were:

*Placopecten clintonius clintonius* (Say)  
*Chesapecten jeffersonius jeffersonius* (Say)

See Plates 8 and 9 for mollusks from the Sunken Meadow Member.

Both of these taxa are restricted to the Sunken Meadow Member in Virginia and North Carolina. The two taxa are not known elsewhere, although larger-ribbed specimens of *Chesapecten* have been reported from South Carolina, Georgia, and Florida as being *C. jeffersonius*. These specimens belong to the *C. madisonius* - *C. septenarius* species complex and are descendants of *C. jeffersonius*. *Chesapecten madisonius* - *C. septenarius* is younger (late Pliocene) and is always found with other molluscan taxa that are indicative of the upper Yorktown, which is late Pliocene in age.

Ray (1987:3) figured five specimens of *Ecphora quadricostata* from the Yorktown Formation at the Lee Creek Mine. Figure 1-E was collected in place from the "basal bed of Yorktown Formation" (= Sunken Meadow Member). The others were obtained from the spoil piles. All are clearly from the Yorktown Formation since the species did not appear until the early Pliocene in the Sunken Meadow and the genus and species does not occur above the Moore House Member of the Yorktown Formation. The species of *Ecphora* present in the underlying Pungo River Formation is *E. tricostata*, a taxon very different by its uncoiling nature and its diminished or absent fourth rib. Figures 1-A, B of Ray (1987) appear to come from the Sunken Meadow Member. In that unit, young specimens of *Ecphora* tend to have slightly thicker, lower ribs in their early stages.

Petuch (1988c: 28) figured a specimen (44 mm) of what he called "*Ecphora (Ecphora) quadricostata leecreekensis*, new species" from the Yorktown Formation. He described the subspecies in an addendum, p. 131, 132, pl. A2, fig. E. From this bed he also described *Ecphora (Ecphora) pachycostata* n. sp. (p. 130, 131, pl. A1, fig. D) (35mm).

These two species are interpreted as follows:

Petuch's Name	Amended Name
<i>Ecphora (Ecphora) quadricostata leecreekensis</i>	<i>Ecphora quadricostata</i>
<i>Ecphora (Ecphora) pachycostata</i>	<i>Ecphora quadricostata</i>

The two specimens are from the Yorktown Formation, probably from the Sunken Meadow Member.

Petuch (1988c:67, fig. 31-b [1989]) described and figured the following specimen from the "Yorktown (?) Formation in the Lee Creek Mine, Aurora, North Carolina; earliest Zanclian Pliocene (latest Messinian Miocene?):"

*Ecphora (Ecphora) kochi* Ward and Gilinsky

This specimen appears to be a young *Ecphora quadricostata*, probably from the Sunken Meadow Member of the Yorktown Formation. The specimens lower in the section tend to have thicker ribs in their early stages and grade into the typical thin ribs with adulthood. Significantly, Petuch does not give a size for his specimen but lists an average for the "species" as 85 mm. The size he lists for our reproduced figure (Petuch, 1988c: fig. 31-A) was 90 mm. The size given for that specimen was 89.6 mm (Ward and Gilinsky, 1988).

Identification of the specimen by Petuch (1988c [1989]) as *Ecphora kochi* made him speculate that there were beds of the Eastover Formation at the Lee Creek Mine, but this deduction was based on an incorrect identification (See Eastover Section). The specimen is an *Ecphora quadricostata*, probably from the Sunken Meadow Member.

Ward, in 1971 and 1972, made a small collection of calcitic mollusks from the Sunken Meadow Member at Lee Creek and identified the following (not previously published):

*Chesapecten jeffersonius*  
*Placopecten clintonius*  
*Carolinapecten* sp.  
*Ostrea compressirostra*  
*Pycnodonte* sp.

All of these taxa are restricted to the Sunken Meadow as reported by Ward and Blackwelder (1980). The *Pycnodonte* is common in the Sunken Meadow from localities on the Piankatank, James, Nottoway and Meherrin Rivers and is not known from any other unit. Ward and Blackwelder (1980: pl. 4: figs. 3, 4) figured the species.

Other taxa have been observed in blocks of Sunken Meadow material at the Lee Creek Mine. These species are aragonitic and, as such, are very soft and poorly preserved. Species identified in the field by the author, but not preserved well enough to be collected, were the following:

*Costaglycymeris subovata*

*Lucinoma contracta*  
*Glossus fraterna*  
*Marvacrassatella cyclopterus*

The data have not been previously published by the author. These species can also be seen in the southernmost natural exposure of the Sunken Meadow Member in the vicinity of Murfreesboro, North Carolina, along the Meherrin River.

Petuch (1997: fig. 44) figured four specimens of *Ecphora quadricostata* that he assigned to other species. Those taxa were:

*Ecphora kochi* (fig. 44-A)  
*Ecphora whiteoakensis* (fig. 44-C)  
*Ecphora whiteoakensis* (fig. 44-D)  
*Ecphora* sp. (fig. 44-E)

These incorrect identifications led him to the conclusion that they came from the Eastover Formation. The specimens came from the Yorktown Formation, probably the Sunken Meadow Member (see Eastover Section).

Petuch (1997:125, fig. 44) figured three specimens from the "lowermost Yorktown Formation (Mansfield Zone 1 or "Sunken Meadow Member") in the Texasgulf, Inc. Lee Creek Mine, Aurora, Beaufort County, North Carolina." They are the following:

*Ecphora leecreekensis* Petuch p. 125, fig. 44-G, H; p. 161  
*Ecphora pachycostata* Petuch p. 125, fig. 44-I; p. 161  
*Globecphora xenos* (Petuch) p. 125, fig. 44-J; p. 161

*Ecphora leecreekensis* and *Ecphora pachycostata* are juvenile specimens, while *Globecphora xenos* is a large adult. Note that *G. xenos* was originally described from a fragment (Petuch, 1988c:134, 139, pl. A3, fig. C) from the "Pungo River Formation in Lee Creek Mine . . ." All three specimens are properly placed in the species *Ecphora quadricostata* and appear to be from the Sunken Meadow Member.

Petuch (1997:160, fig. 53) reproduced a photograph by E. Gerrard of the exposed Sunken Meadow Member at Lee Creek. Two species that he mentions are easily seen in the figure:

*Chesapecten jeffersonius* (Say)  
*Placopecten clintonius* (Say)

Three other species were listed (Petuch, p. 160) as coming from this bed:

*Globecphora xenos*  
*Ecphora leecreekensis*

*Ecphora pachycostata*

Those three taxa are figured elsewhere by Petuch and are *Ecphora quadricostata*.

Petuch (2004:138, pl. 42) figured the following taxa from the “Sunken Meadow Member (Yorktown Zone 1) of the Yorktown Formation in the Lee Creek Texasgulf Mine, Aurora, Beaufort County, North Carolina:”

Fig.	Petuch's Name	Amended Name
A, B	<i>Ecphora pachycostata</i> Petuch	<i>Ecphora quadricostata</i>
C	<i>Chesapecten jeffersonius</i> (Say)	<i>Chesapecten jeffersonius</i>
D, E	<i>Globecphora xenos</i> (Petuch)	<i>Ecphora quadricostata</i>
F	<i>Carcharocles megalodon</i> (Charlesworth)	<i>Carcharocles megalodon</i>
G	<i>Placopecten clintonius</i> (Say)	<i>Placopecten clintonius</i>
H, I	<i>Ecphora leecreekensis</i>	<i>Ecphora quadricostata</i> (juvenile)

**BARNACLES**

Zullo (1984) described a species of barnacle thought to be from the Pungo River Formation. The Holotype of that species is attached to a *Chesapecten jeffersonius* and actually comes from the Sunken Meadow Member. Zullo's new species is *Fistulobalanus klemmi*.

**OSTRACODES**

Hazel (1983:81-199) studied the ostracodes of the Yorktown Formation and sampled the interval now identified as the Sunken Meadow Member. That interval involved Hazel's Samples 1–6. Hazel (1971) had previously studied the Yorktown Formation in its type area and proposed a zonation based on ostracodes. The unit now known as the Sunken Meadow Member (= lower Yorktown or “Zone 1” of Mansfield) was placed in the *Pterygocythereis inexpectata* Zone. That index fossil is present in the Sunken Meadow at the Lee Creek Mine as is seen in the following fossil lists from Samples 1 - 6. Note that *P. inexpectata* is also found in the overlying Rushmere Member (Hazel's Sample 7). That sample was taken just above the Sunken Meadow - Rushmere contact and *P. inexpectata* was clearly reworked upward into the younger bed. Likewise, Hazel's Samples 5 and 6 contained the Zone Fossil *Orionina vaughani*, which is indicative of the

Rushmere, Morgarts Beach, and Moore House Members (= upper Yorktown or “Zone 2” of Mansfield). The upper surface of the Sunken Meadow was extensively burrowed at the time the Rushmere transgression took place. The burrowing animals excavated and ejected material from the Sunken Meadow and it became incorporated into the Rushmere. The burrows into the Sunken Meadow became filled with Rushmere sediment as they were abandoned. This two-way mixing of sediments creates a time-averaged assemblage and gives the impression of gradual change, even where abrupt contacts and appreciable amounts of time are indicated.

The following are Hazel's (1983) ostracode lists:

## Sample 1

*Actinocythereis dawsoni*  
*Actinocythereis marylandica*  
*Bairdoppilata triangulata*  
*Bensonocythere blackwelderi*  
*Bensonocythere calverti*  
*Bensonocythere trapezoidalis*  
*Cytherella* sp. B  
*Cytheridea campwallacensis*  
*Cytheromorpha ? warneri*  
*Cytheromorpha* sp. I  
*Cytheropteron talquinensis*  
*Cytheropteron ? yorktownensis*  
*Cytherura elongata*  
*Cytherura forulata*  
*Cytherura howei*  
*Cytherura* sp. D  
*Echinocythereis planibasalis*  
*Eucythere declivis*  
*Hulingsina rugipustulosa*  
*Hulingsina* sp. C  
*Loxoconcha* sp. C  
*Loxoconcha* sp. S  
*Malzella evexa*  
*Microcytherura choctawhatcheensis*  
*Microcytherura* sp. H  
*Muellerina canadensis petersburgensis*  
*Muellerina ohmertii*  
*Muellerina wardi*  
*Murrayina mcleani*  
*Orionina vaughani*  
*Paracytheridea altita*  
“Pontocythere” sp. G  
*Proteoconcha multipunctata, sensu lato*  
*Proteoconcha* sp. Z  
*Pseudocytheretta burnsi*  
*Pterogocythereis inexpectata*  
*Puriana carolinensis*

## Sample 2

*Actinocythereis captionis*  
*Actinocythereis mundorffi*  
*Cytheridea virginiensis*  
*Cytheropteron talquinensis*  
*Hulingsina americana*  
*Loxoconcha* sp. C  
*Muellerina canadensis petersburgensis*  
*Murrayina macleani*  
*Pseudocytheretta burnsi*  
*Pterygocythereis inexpectata*

## Sample 3

*Actinocythereis dawsoni*  
*Actinocythereis mundorffi*, small form  
*Bensonocythere rugosa*  
*Cytheridea virginiensis*  
*Cytheridea* aff. *C. virginiensis*  
*Cytheropteron ? yorktownensis*  
*Cytherura elongata*  
*Cytherura* sp. D  
*Loxoconcha* sp. C  
*Loxoconcha* sp. H  
*Malzella evexa*  
*Microcytherura minuta*  
*Muellerina canadensis petersburgensis*  
*Muellerina ohmertii*  
*Muellerina wardi*  
*Murrayina macleani*  
*Peratocytheridea sandbergi*  
 “*Pontocythere*” sp. G  
*Propontocypris* sp. D  
*Pterygocythereis inexpectata*  
*Puriana carolinensis*

## Sample 4

*Bensonocythere gouldensis*  
*Cytheridea campwallacensis*  
*Hulingsina americana*  
*Muellerina* sp. P  
*Murrayina macleani*  
*Peratocytheridea sandbergi*  
*Pseudocytheretta burnsi*

## Sample 5

*Actinocythereis dawsoni*  
*Actinocythereis marylandica*  
*Actinocythereis mundorffi*, small form  
*Bensonocythere trapezoidalis*  
*Campylocythere laeva*  
*Cytherella* sp. A  
*Cytheridea virginiensis*  
*Cytheromorpha warneri*

*Cytheropteron talquinensis*  
*Cytheropteron ? yorktownensis*  
*Cytherura forulata*  
*Cytherura howei*  
*Cytherura* sp.  
*Cytherura* sp. D  
*Echinocythereis planibasalis*  
*Echinocythereis gibba*  
*Eucythere* sp. F  
*Hulingsina* sp. R  
*Loxoconcha* sp. C  
*Loxoconcha* sp. M  
*Malzella evexa*  
*Microcytherura* sp. H  
*Muellerina canadensis petersburgensis*  
*Muellerina ohmertii*  
*Murrayina macleani*  
 \**Orionina vaughani* (reworked downward, burrows)  
*Paracyprideis* sp. C  
*Paracypris* sp. B  
*Paracytheridea cronini*  
*Peratocytheridea sandbergi*  
 “*Pontocythere*” sp. G  
*Propontocypris* sp. D  
*Proteoconcha multipunctata, sensu lato*  
*Pseudocytheretta burnsi*  
*Pterygocythereis inexpectata*

## Sample 6

*Actinocythereis dawsoni*  
*Actinocythereis marylandica*  
*Actinocythereis mundorffi*, small form  
*Aurila laevicula*  
*Bairdoppilata triangulata*  
*Bensonocythere blackwelderii*  
*Campylocythere laeva*  
*Cytheridea campwallacensis*  
*Cytheridea virginiensis*  
*Cytheridea* aff. *C. virginiensis*  
*Cytheromorpha warneri*  
*Cytheropteron talquinensis*  
*Cytheropteron wardensis*  
*Echinocythereis planibasalis*  
*Echinocythereis gibba*  
*Hulingsina americana*  
*Loxoconcha reticularis*  
*Loxoconcha* sp. H  
*Malzella evexa*  
*Microcytherura choctawhatchiensis*  
*Muellerina canadensis petersburgensis*  
*Neocaudites triplistriatus*  
 \**Orionina vaughani* (reworked downward from burrows)  
*Paracyprideis* sp. C



*Paracytheridea altila*  
*Paracytheridea cronini*  
*Peratocytheridea bradyi*  
*Peratocytheridea sandbergi*  
 "Pontocythere" sp. G  
*Proteoconcha multipunctata, sensu lato*  
*Pseudocytheretta burnsi*  
*Pterygocythereis inexpectata*  
*Puriana carolinensis*  
*Puriana rugipunctata*

#### ECHINOIDS

Kier (1983:499-507) studied the echinoids found at the Lee Creek Mine. He identified three species which were determined to have come from Unit 2 of Gibson (1967). This bed contains numerous small, hollow echinoid spines probably from *Echinocardium*. The three species identified are:

*Echinocardium kelloggi* Kier  
*Arbacia improcera* (Conrad)  
*Psammechinus philanthropus* (Conrad)

#### Vertebrates

Müller (1999) reported a large number of shark teeth and otoliths from the Rushmere Member of the Yorktown Formation. It may be possible that the origin of these specimens is the Sunken Meadow Member. Fitch and Lavenberg (1983, see below) record all of their otoliths as coming from the upper part of the Sunken Meadow Member. Müller's lists are given in the Rushmere section.

Purdy et al. (2001:71-202) identified the following sharks, rays, and bony fish from Units 1 and 2 of the Yorktown Formation of Gibson (1967) (=Sunken Meadow Member):

#### SHARKS AND RAYS

*Notorynchus cepedianus*  
*Hexanchus* sp.  
*Echinorhinus* cf. *E. blakei*  
*Squalus* sp.  
*Isistius* sp.  
*Pristis* sp.  
*Pristis* cf. *P. pectinatus*  
*Raja* sp.  
*Dasyatis centroura*  
*Aetobatus* sp.  
*Mobula* sp.  
*Manta* sp.

*Squatina* sp.  
*Carcharias taurus*  
*Carcharias cuspidata*  
*Megachasma* sp.  
*Alopias* cf. *A. vulpinus*  
*Parotodus benedenii*  
*Isurus oxyrinchus*  
*Isurus hastalis*  
*Isurus xiphodon*  
*Lamna* sp.  
*Carcharodon megalodon*  
*Carcharodon carcharias*  
*Scyliorhinus* sp.  
*Galerohinus* cf. *G. affinis*  
*Paragaleus* sp.  
*Hemipristis serra*  
*Galeocerdo* cf. *G. cuvier*  
*Carcharhinus leucas*  
*Carcharhinus macloiti*  
*Carcharhinus obscurus*  
*Carcharhinus perezi*  
*Carcharhinus plumbeus*  
*Negaprion brevirostris*  
*Sphyrna* cf. *S. media*  
*Sphyrna zygaena*

#### BONY FISH

*Acipenser* cf. *A. oxyrinchus*  
*Conger* cf. *C. oceanicus*  
*Alosa* cf. *A. sapidissima*  
*Bagre* sp.  
*Opsanus tau*  
*Lophius* cf. *L. americanus*  
*Merluccius bilinearis*  
*Prionotus* cf. *P. evolans*  
*Ephinephelus* sp.  
*Mycteroperca* sp.  
*Caulolatilus* cf. *C. cyanops*  
*Lopholatilus rayus*  
*Pomatomus saltatrix*  
*Seriola* sp.  
*Archosargus* cf. *A. probatocephalus*  
*Lagodon* cf. *L. rhomboides*  
*Pagrus hyneus*  
*Pagrus* sp.  
*Stenotomus* cf. *S. chrysops*  
*Sciaenops* sp.  
*Pogonias* cf. *P. cromis*  
*Tautoga* cf. *T. onitis*  
*Astroscopus* sp.  
*Sphyraena* cf. *S. barracuda*

*Sarda* sp. aff. *S. sarda*  
*Auxis* sp.  
*Thunnus* sp.  
*Acanthocybium solandri*  
*Xiphias gladius*  
*Istiophorus* cf. *I. platypterus*  
*Makaira* cf. *M. indica*  
*Makaira nigricans*  
*Tetrapturus* cf. *T. albidus*  
*Hemirhabdorrhynchus* sp.  
*Paralichthys* sp.  
*Aluterus* sp.  
*Sphoeroides hyperostosus*  
*Chilomycterus schoepfi*  
*Mola chelonopsis*

Schneider and Fierstine (2004) described fossil tuna vertebrae that were punctured by istiophorid billfish. This conclusion was based on five vertebrae which had a single puncture mark on their centrum.

#### OTOLITHS

Fitch and Lavenberg (1983:509-529) identified a number of fish species based on their otoliths or “ear bones.” Specimens studied from these beds totaled more than 8000 and were said to come from “otolith-bearing overburden” . . . that “lies above the basal Yorktown, which” . . . was “found to be practically void of teleost otoliths.”

Gibson (1967) described two units in the lower Yorktown, his Units 1 and 2. Unit 1 is a coarse, phosphatic, basal conglomeratic lag. Unit 2 above it fines upward from a pebbly sand to a fine sand to a silty sand with abundant very small echinoid spines. It is believed that the bulk of Fitch and Lavenberg’s specimens came from this Unit 2 in the Sunken Meadow Member. The following is a list of the taxa identified:

Pterothrissidae  
*Pterothrissus* sp.  
 Congridae  
 Congrid sp. A  
 Congrid sp. B  
 Congrid sp. C  
 Congrid sp. D  
 Congrid sp. E  
 Myctophidae  
*Ceratospelus maderensis*  
 Gadidae  
*Gadus* cf. *morhua*  
*Melanogrammus* cf. *aeglefinus*  
*Merlandiogadus cognatus*

*Microgadus* cf. *tomcod*  
*Urophycis tenuis*  
 Merlucciidae  
*Merluccius albidus*  
*Merluccius* cf. *bilinearis*  
*Merluccius* sp.  
 Unidentifiable *Merluccius*  
 Ophidiidae  
*Brotula barbata*  
*Lepophidium* cf. *cervinum*  
*Ophidion grayi*  
 Brotulid sp. A  
 Brotulid sp. B  
 Ophidiid sp. A  
 Ophidiid sp. B  
 Serranidae  
*Centropristis* cf. *striata*  
*Diplectrum* cf. *formosum*  
 Serranid sp. A  
 Serranid sp. B  
 Branchiostegidae  
*Lopholatilus chamaeleonticeps*  
 Pomadasyidae  
*Anisotremus* sp.  
 Sciaenidae  
*Cynoscion* cf. *nebulosus*  
*Equetus* cf. *umbrosus*  
*Leiostomus* sp.  
*Micropogonias* sp.  
*Pogonias* cf. *cromis*  
*Sciaenops* cf. *ocellata*  
 Sciaenid sp. A  
 Uranoscopidae  
*Astroscopus* sp.  
*Kathetostoma* sp.  
 Ammodytidae  
*Ammodytes hexapterus*  
 Triglidae  
*Prionotus* spp.  
 Bothidae  
*Citharichthys* spp.  
 Pleuronectidae  
 Pleuronectid  
 Cynoglossidae  
*Symphurus* sp.  
 Agonidae?  
 Unknown

#### BIRDS

Olson (1977) described a new species of auk from the lower part of the Yorktown Formation (= Sunken Meadow Member).

That species is:

*Pinguinis* [sic] *alfrednewtoni* (= *Pinguinus alfrednewtoni*)

Olson and Steadman (1979) reported a fossil humerus from the lower Pliocene Yorktown Formation at the Lee Creek Mine. This record is the oldest for the Family Haematopodidae.

Olson (1999) described a new species of pelican from the lower Pliocene of North Carolina at the Lee Creek Mine. That specimen was named the following:

*Pelecanus schreiberi*

Olson and Rasmussen (2001:233-365) reported 101 species of birds from the Yorktown Formation. Only five of them were identified as specifically coming from the Sunken Meadow Member. Those species are:

*Gavia fortis* Olson and Rasmussen

*Phoebastria anglica* (Lydekker)

*Pelecanus schreiberi* Olson

*Haematopus* aff. *palliatu*s Temminck

*Eudocimus* sp.

Olson and Hearty (2003) discussed the distribution of albatross in the Atlantic and Pacific. Five species were noted as occurring in the early Pliocene (Sunken Meadow Member) in North Carolina. Three of those species are extant but living only in the North Pacific:

*Phoebastria albatrus*

*Phoebastria immutabilis*

*Phoebastria nigripes*

The other two are extinct, but were known only from the North Atlantic.

### Mammals

Tedford and Hunter (1984) discussed the terrestrial vertebrate mammal assemblage from the "basal Yorktown" at the Lee Creek Mine. The following were mentioned from this locality as being in the "Lee Creek Local Fauna:"

*Osteoborus* cf. *dudleyi* canid

*Nannippus* cf. *ingenus* horse

*Synthetoceras* sp. protoceratid

*Hemiauchenia* sp. camelid

Cervid

Antilocaprid

Gomphotheriid mastodont

The authors said that this assemblage indicated a late Hemphillian age for the lower Yorktown.

Eshelman and Whitmore (this volume:17-38) identified the following mammals from the lower Yorktown (=Sunken Meadow Member):

Order Xenartha

Order Carnivora

Family Canidae

*Borophagus* cf. *B. dudleyi*

*Borophagus* cf. *B. orc*

Family Felidae

Family Ursidae

Order Artiodactyla

Family Tayassuidae

Family Protoceratidae

*Kyptoceras amatorum*

Family Camelidae

Family Palaeomerycidae

*Pediomeryx* sp.

Family Antilocapridae

Order Perissodactyla

Family Tapiridae

*Tapirus* sp.

Family Rhinocerotidae

Family Equidae

*Nannippus lenticularis*

*Neohipparion* cf. *N. eurystyle*

*Pseudhipparion* cf. *P. simpsoni*

Order Proboscidea

Family Gomphotheriidae

*Rynchotherium* cf. *R. euhypodon*

*Gomphotherium* sp.

The authors labeled this fauna as the second largest land mammal fauna described from the Atlantic Coastal Plain north of Florida. The largest, the Pollock Farm Site in Delaware, comes from the lower Miocene Kirkwood/Calvert Formation (= Riggs et al., 1982a, Unit B of the Pungo River Formation at Lee Creek Mine). The fauna that Eshelman and Whitmore described came from a different horizon, the lower Pliocene, making it an important addition to the vertebrate record.

### WHALES

Uhen (2004:179, 180, fig. 137, table 27) described and illustrated some vertebrae, ribs, jaws and limb bones of whales from the Lee Creek Mine. These were cited as coming from the Eastover Formation. Communications (April 2004) from Uhen since this publication indicated that he was not sure why this citation was made to the Eastover Formation, that the

specimens are in the USNM, and that they could be, and probably are, from the lower Yorktown Formation.

### **Plants**

Hueber (1983:269-285) studied and described a number of terrestrial plant specimens from the Lee Creek Mine. This material was in the form of lithified wood and resin. The following taxa were identified:

*Pinus* sp. cf. *P. palustris* Miller  
*Juniperus* sp. cf. *J. virginiana* Linnaeus  
*Taxodium distichum* Richards  
*Gleditsia* sp.

The provenance of only the three specimens of *Gleditsia* could be determined. Foraminifera from the matrix on the wood indicated that the specimens, USNM 267218, USNM 298768, and USNM 298767 came from the lower 10 feet of the Yorktown Formation (= Sunken Meadow Member).

### **Upper Pliocene**

#### ***Rushmere/Morgarts Beach Member***

#### **STRATIGRAPHY**

Ward and Blackwelder (1980) named the Rushmere and Morgarts Beach Members of the Yorktown Formation for beds exposed along the James River in Virginia. The Rushmere represents the very shelly, poorly-sorted sands of a transgression in the late Pliocene and the Morgarts Beach represents the quiet-water, fine, well-sorted sands of the highstand that followed that transgression. This sequence can be seen updip as far as Petersburg and can be seen on the Piankatank, York (now covered), James, Blackwater, Nottoway, Meherrin, and Tar Rivers. South of the Neuse River these beds are represented, but there they are not readily recognized as members and are lumped under the term "Duplin Formation."

The Rushmere/Morgarts Beach sequence is present in the Lee Creek Mine and is comprised of Gibson's (1967) Units 3 - 5 and Riggs et al. (1982a) "Upper Yorktown (lower sub-unit)." Gibson's (1967: pl. 1 and 1983a:62, fig. 24) photograph clearly shows the burrowed contact between the Sunken Meadow Member and the overlying Rushmere. The Rushmere correlates only with Gibson's Units 3 and 4, while Unit 5 is equivalent with the Morgarts Beach. There is no contact marking a diastem between the two units, just a transition

from one environmental regime that is abrupt in some areas and very gradual in others.

The uppermost section of the Yorktown Formation (= Moore House Member) was described by Riggs et al. (1982b: 72) as their Upper Yorktown, upper sub-unit. The lower sub-unit was said to grade into the upper sub-unit. A trip by this author in 1992 enabled him to observe and collect the upper part of the Yorktown Formation. The section at that time showed 20 feet of silty sand (Morgarts Beach Member) unconformably overlain by 10 feet of very calcareous, partly lithified sand (Moore House Member). The contact between the two units was sharp, burrowed, and marked by a concentration of *Chesapecten madisonius*.

### **PALEONTOLOGY**

The Rushmere/Morgarts Beach Members at Lee Creek do not contain the broad suite of fossil taxa of the older Sunken Meadow Member. Part of this is because the aragonitic invertebrates in the upper Yorktown are mostly poorly preserved or only molds and casts. This apparently is a result of diagenesis and is common in the more southern areas such as in the Raysor Formation in South Carolina. In that instance, clastic-rich, nearer-shore sediments preserve aragonitic fossils perfectly (Duplin Formation). Farther off-shore, carbonate-rich sediments preserve only the calcitic fossils while the aragonitic forms are removed by solution (Raysor Formation). The Rushmere and Morgarts Beach to the north, in Virginia, contain a large and diverse molluscan fauna that exceeds 200 species.

The relative lack of vertebrates is especially noticeable. The numbers of rays, sharks, and bony fish are notably lacking or scarce. This is not a local preservational problem, but rather an indication of a large-scale, perhaps cosmopolitan, traumatic event that reduced their numbers. The most obvious of the taxa that became extinct worldwide during the lowstand between the lower (Sunken Meadow Member) and upper (Rushmere Member) Yorktown is *Carcharocles megalodon*. (This is *Carcharodon megalodon* of Purdy et al., 2001). That species does not occur in the upper Pliocene and is found along the base of those units only as a lag deposit derived from older beds. Whales also decline in numbers of taxa and frequency of individuals at this time.

The following appear to be from the Rushmere Member:

#### ***Invertebrates***

#### **FORAMINIFERA**

Gibson (1983b:387) figured and described only one species from the part of the Yorktown Formation at the Lee Creek

Mine now known as the Rushmere/Morgarts Beach. That species is *Epistominella danvillensis* (Howe and Wallace). Gibson (1967:646) mentioned the occurrence of several benthic species in this interval at the Lee Creek Mine:

*Elphidium* sp.  
*Nonion* sp.  
*Nonionella* sp.  
*Cassidulina* sp.

Snyder et al. (1983:455-481) listed several planktonic Foraminifera from their Samples 28-23, which appear to come from the Rushmere Member:

*Globigerina bulloides apertura*  
*Globigerina bulloides bulloides*  
*Globigerina calida praecalida*  
*Globigerina decoraperta*  
*Globigerina juvenilis*  
*Globigerinita glutinata*  
*Globigerinita uvula*  
*Globigerinoides conglobatus conglobatus*  
*Globigerinoides obliquus extremus*  
*Globigerinoides obliquus obliquus*  
*Globigerinoides quadrilobatus quadrilobatus*  
*Globigerinoides ruber*  
*Globoquadrina venequelana*  
*Turborotalia acostaensis acostaensis*  
*Turborotalia acostaensis humerosa*  
*Globorotalia margaritae*  
*Hastigerina siphonifera siphonifera*  
*Orbulina suturalis*  
*Orbulina universa*  
*Sphaeroidinellopsis subdehiscens subdehiscens*  
*Turborotalita humilis*  
*Turborotalita quinqueloba*

Snyder et al. (2001) listed the following benthic Foraminifera from their Samples 23-25. This interval appears to be the Rushmere Member although they reported Samples 16-25 from that bed. This author believes that Samples 16-22 came from the Morgarts Beach Member.

*Alliatina glabrella*  
*Ammonia beccarii*  
*Amphycoryna* sp.  
*Angulogerina angulosa occidentalis*  
*Anomalinoidea* cf. *A. riveroae*  
*Bolivina marginata*  
*Bolivina* sp.  
*Bolivina subexcavata*  
*Buccella frigida*  
*Buccella* cf. *B. parkerae*

*Buccella vicksburgensis*  
*Bulimina* cf. *B. ovula*  
*Cancris sagra*  
*Cassidulina caribeana*  
*Cassidulina laevigata*  
*Caucasina preacanthia*  
*Cibicides lobatulus*  
*Cibicoides floridanus*  
*Discorbis* cf. *D. farishi*  
*Discorbis* sp.  
*Elphidium advenum depressulum*  
*Elphidium excavatum*  
*Elphidium* sp.  
*Fissurina* cf. *F. laevigata*  
*Fissurina marginato-perforata*  
*Fissurina* cf. *F. pseudoglobosa*  
*Fissurina quadrata*  
*Fursenkoina pontoni*  
*Galwayella trigono-marginata*  
*Globocassidulina crassa*  
*Globulina gibba*  
*Globulina inequalis*  
*Guttulina* cf. *G. elegans*  
*Guttulina* cf. *G. lactea*  
*Hanzawaia concentrica*  
*Lagena intermedia*  
*Lagena laevis*  
*Lagena palmerae*  
*Lagena substriata*  
*Laryngosigma williamsoni*  
*Neoconorbina terquemi*  
*Nonionella miocenica*  
*Oolina laevigata*  
*Oolina melo*  
*Oolina* cf. *O. striatopunctata*  
*Parafissurina bidens*  
*Parafissurina* sp. "B"  
*Planulina* sp.  
 Polymorphinidae (fistulose form)  
*Pseudononion grateloupi*  
*Pseudononion pauperatum*  
*Rosalina candeiana*  
*Rosalina globularis*  
*Rosalina subaraucana*  
*Rosalina* sp. "B"  
*Sigmomorphina nevifera*  
*Sigmomorphina pearceyi*  
*Sigmomorphina semitecta*  
*Texularia* sp.  
*Trochulina bassleri*  
*Uvigerina calvertensis*  
*Uvigerina juncea*  
*Uvigerina subperegrina*

*Valvulineria floridana*  
*Valvulineria olssoni*  
*Webbinella concava*

### MOLLUSKS

Gibson (1967:646) reported several mollusks from his Unit 5 of the Yorktown (= Morgarts Beach Member). He mentioned that most of the specimens were soft due to solution, were scattered, and were mainly *Turritella* sp. *Ostrea sculpturata* Conrad [= *Conradostrea sculpturata*] are said to be scattered through the unit.

Most mollusks having aragonitic shells were subject to solution, rendering them mostly unidentifiable. The Rushmere and Morgarts Beach, in their type areas, contain a very diverse fauna of more than 200 species. When this author studied the upper part (upper 20 feet) of the Morgarts Beach Member at Lee Creek Mine in 1992, no mollusks were observed, calcitic or molds and casts.

See Plates 10 and 11 for mollusks from the Rushmere/Morgarts Beach Members.

Gibson (1987:31-112) figured the following pectinids from the Yorktown Formation (= Rushmere Member) at the Lee Creek Mine:

*Argopecten eboreus watsonensis* (Mansfield)  
*Placopecten* sp. aff. *P. magellanicus* (Gmelin)  
*Chlamys decemnaria* (Conrad)  
*Chesapecten jeffersonius septenarius* (Say)  
*Chesapecten madisonius* (Say)

Petuch (1988c, [1989]) described and figured the following from the middle of the Yorktown at Lee Creek (= Rushmere, Morgarts Beach):

*Ecphora* (*Ecphora*) *quadricostata quadricostata* (Say, 1824), p. 68, 69, 77, fig. 32-A,B  
*Ecphora* (*Ecphora*) *rachelae*, p. 69, 70, 78, fig. 33-C  
*Ecphora xenos* n. sp. (p. 134, pl. A3, fig. C)

[Figured fragment, supposedly from the Pungo River Formation, but actually from the Yorktown Formation. Compare fragment with Petuch's figure of *Ecphora* (*E.*) *floridana* (p. 75, fig. 30-A), which also is an *Ecphora quadricostata*.]

These three specimens are properly assigned to *Ecphora quadricostata*.

Petuch (1997:28) figured a specimen of a *Chesapecten septenarius* said to be from "Zone 2 of the Yorktown

Formation, Lee Creek Mine, Aurora, North Carolina." Petuch (1997:168, 169, fig. 57) figured the following from "Zone 2, Yorktown Formation in the Lee Creek Mine, Aurora, North Carolina:"

*Ecphora quadricostata* (Say) p. 168, 169, fig. 57-A  
*Ecphora quadricostata rachelae* Petuch p. 168, 169, fig. 57-C  
*Ecphora mansfieldi* Petuch p. 168, 169, fig. 57-D  
*Globecphora parvicostata* (Pilsbry) p. 168, 169, fig. 57-E

These figured specimens belong to a single species, *Ecphora quadricostata*.

Petuch (2004:151, pl. 48) figured the following specimens from the upper Yorktown at the Lee Creek Mine:

*Globecphora parvicostata* (Pilsbry) fig. A, B  
*Planecphora mansfieldi* (Petuch) fig. C, D  
*Ecphora quadricostata* (Say) fig. G, H  
*Ecphora quadricostata rachelae* Petuch fig. I, J

These figured specimens belong to a single species, *Ecphora quadricostata*.

### OSTRACODES

Hazel (1983:81-199) listed the ostracode species from the basal part of the upper Yorktown (= Rushmere Member) in his Sample 7. Those taxa are:

*Actinocythereis dawsoni*  
*Actinocythereis mundorffi*, small form  
*Acuticythereis laevissima*  
*Cytheridea virginienis*  
*Cytheridea* aff. *virginienis*  
*Cytheromorpha warneri*  
*Cytheropteron talquinensis*  
*Cytherura* sp. D  
*Hulingsina americana*  
*Hulingsina* sp. U  
*Loxoconcha* sp. H  
*Microcytherura choctawhatcheensis*  
*Muellerina canadensis petersburgensis*  
*Muellerina ohmertii*  
*Murrayina barclayi*  
*Murrayina mcleani*  
*Murrayina* sp. E  
*Paracyprideis* sp. C  
*Peratocytheridea bradyi*  
*Peratocytheridea sandbergi*  
 "Pontocythere" sp. G  
*Propontocypris* sp. D

*Pseudocytheretta burnsi*  
*Pterygocythereis inexpectata*  
*Puriana carolinensis*

Hazel's (1983) Sample 7 was taken about a foot above the Sunken Meadow/Rushmere contact in the Rushmere. At least one species, the marker species for the Sunken Meadow Member, *Pterygocythereis inexpectata*, was reworked upward into the Rushmere probably as a result of the burrowing along the contact.

### Vertebrates

Purdy et al. (2001:71-202) listed a few species from Unit 3 of the Yorktown Formation (= Rushmere Member) and that list shows a dramatic reduction in species when compared to the Sunken Meadow taxa. The period of time (~ 0.5 mya) represented by the Sunken Meadow/Rushmere contact was a time of extinction for some long-lived taxa (i.e. *Carcharocles megalodon*), and an extreme reduction of populations for most others. The marine strata from the Atlantic Coastal Plain in the upper Pliocene or Pleistocene contain only a small fraction of the fauna present in the Miocene and the lower Pliocene (Sunken Meadow Member). Purdy et al. (2001) identified the following sharks and bony fish from the Rushmere (? indicates a questionable occurrence or identification):

### SHARKS

*Isistius* sp.  
*Isurus hastalis*  
*Hemipristis serra*?  
*Galeocerdo* cf. *G. cuvier*  
*Carcharhinus leucas*  
*Carcharhinus obscurus*  
*Sphyrna lewini*  
*Sphyrna zygaena*

### BONY FISH

*Prionotus* cf. *P. evolans*  
*Stenotomus* cf. *S. chrysops*?  
*Scienops ocellatus*?  
*Pogonias* cf. *P. cromis*?  
*Sarda* sp. aff. *S. sarda*  
*Aluterus* sp.  
*Sphoeroides hyperostosus*  
*Chilomycterus schoepfi*  
 Emmons's "fish tooth"

Tyler et al. (1992) described a new species of pufferfish from Unit 3 of the Yorktown (of Gibson, 1967) (= Rushmere Member). That species is the following:

*Sphoeroides hyperostosus*

The species is based on a nearly intact skull. The nature of the hyperostosis of bones of this fish was described by Weiler (1973) based on specimens from the Lee Creek Mine.

Müller (1999) reported the following taxa from the Lee Creek Mine as occurring in the Rushmere Member of the Yorktown Formation. All records of bony fish are based on otoliths; those followed by an asterisk (\*) are based on specimens reported by Fitch and Lavenberg (1983):

Neoselachii  
 Squalidae  
*Squalus* aff. *acanthias* (Linnaeus, 1758)  
 Squatinidae  
*Squatina* aff. *dumeril* LeSueur, 1818  
 Otodontidae  
*Parotodus benedeni* (Le Hon, 1871)  
 Lamnidae  
*Carcharodon carcharias* (Linnaeus, 1758), not explicitly noted as Lee Creek Mine.  
 Triakidae  
*Mustelus* sp. 2  
 Carcharhinidae  
*Galeocerdo cuvier* (Peron & Lesueur, 1822)  
*Pterolamiops longimanus* (Poey 1861)  
 Hemigaleidae  
*Hemipristis serra* Agassiz, 1843, not explicitly noted as North Carolina or Lee Creek Mine  
 Rajidae  
*Raja* sp. 3, 4, 5, 6  
 Dasyatidae  
*Dasyatis* sp. 2, 3  
 Teleostei – Actinopterygii  
 Pterothrissidae  
*Pterothrissus* sp. 3  
 Congridae  
*Gnathopis* sp.  
*Hildebrandia* aff. *gracilior* (Ginsburg, 1951)  
*Hildebrandia* aff. *flava* (Goode and Bean, 1896)  
*Hildebrandia* sp.  
 genus aff. *Pseudophichthys laevis* n. sp.  
 Myctophidae  
*Diaphus* sp. 2  
*Ceratocopelus maderensis* (Lowe, 1839)  
 Bregmacerotidae  
*Bregmaceros* sp.

## Gadidae

- Urophycis* aff. *tenuis* (Mitchill, 1815)\*  
*Ciliata* aff. *mustela* (Linnaeus, 1958)  
*Melanogrammus* n. sp.  
*Microgadus* cf. *tomcod* (Walbaum, 1792)\*  
 (record doubted by Müller, p. 106)  
*Micromesistius cognatus* (Koken, 1891)  
*Merluccius algidus* (Mitchill, 1817)  
*Merluccius* aff. *bilinearis* (Mitchill, 1817)

## Sphidiidae

- Brotula* (*Brotula*) *barbata* (Bloch and Schneider, 1801)\*  
*Lepohidium* aff. *cervinum* (Goode and Beane, 1885)  
*Ophidion* aff. *grayi* (Fowler, 1948)  
*Ophidion* aff. *welshi* (Nichols and Breder, 1922)  
*Otophidium* aff. *lagochila*  
 Genus aff. *Otophidium lacinius* n. sp.  
 Genus aff. *Otophidium* sp. 1  
*Neobythites* aff. *gilli* Goode and Bean, 1886\*

## Triglidae

- Prionotus* sp. 3, 4

## Serranidae

- Centropristis* cf. *striata*\*  
*Diplectrum* sp. 1

## Pomadasyidae

- Haemulon* sp.  
*Pomadasys* sp.\*  
 Genus *Pomadasyidarum* ? sp. 2

## Branchiostegidae

- Lopholatilus chamaeleonticeps* Goode and Bean, 1879

## Sparidae

- Archosargus* sp. 2

## Sciaenidae

- Pogonias* aff. *cromis* (Linnaeus, 1758)\*  
*Sciaenops* aff. *ocellata* (Linnaeus, 1758)\*  
*Leiostomus xanthurus* Lacepede, 1802  
*Equetus* aff. *umbrosus* Jordan and Eigenmann\*,  
 (identification questioned by Müller, p. 190)  
 Genus aff. *Pachyurus* aff. *breviformis*  
 Genus aff. *Pachyurus jeanae* n. sp.  
*Micropogonias* aff. *undulatus*  
*Larimus* aff. *fasciatus* Holbrook, 1855  
*Cynoscion nebulosus* (Cuvier, 1830)  
 Genus aff. *Cynoscion fitchi* n. sp.

## Uranoscopidae

- Astroscopus* sp.\*  
*Kathetostoma* sp.\*

## Ammodytidae

- Ammodytes* aff. *hexapterus*  
*Ammodytes* sp. (Müller cites as St. Marys Formation,  
 Maryland, in text, p. 207, but as Yorktown Formation,  
 Rushmere Member, Lee Creek Mine, in pl. 17, fig. 7)

## Paralichthyidae

- Citharichthys* sp. 2

*Citharichthys* sp. 5

## Cynoglossidae

*Symphurus* sp. 2

The following taxa appear to be from the Morgarts Beach Member:

*Invertebrates*

## FORAMINIFERA

Unit 5 of the Yorktown Formation of Gibson (1967) is equivalent to the Morgarts Beach Member. Gibson (1967: 646) stated that the following benthic Foraminifera made up more than 50 percent of the fauna:

*Elphidium*  
*Nonion*  
*Nonionella*  
*Cassidulina*

Snyder et al. (1983:455-481) reported the following planktonic Foraminifera from the beds now known as the Morgarts Beach Member (their Samples 11-22). The taxa are as follows:

*Globigerina bulloides apertura*  
*Globigerina bulloides bulloides*  
*Globigerina calida praecalida*  
*Globigerina decoraperta*  
*Globigerina juvenilis*  
*Globigerinita glutinata*  
*Globigerinita uvula*  
*Globigerinoides bollii*  
*Globigerinoides obliquus extremus*  
*Globigerinoides obliquus obliquus*  
*Globigerinoides quadrilobatus quadrilobatus*  
*Globigerinoides ruber*  
*Globoquadrina altispira globosa*  
*Turborotalia acostaensis acostaensis*  
*Turborotalia acostaensis humerosa*  
*Globorotalia crassula*  
*Globorotalia cultrata limbata*  
*Globorotalia hirsuta praehirsuta*  
*Globorotalia margaritae*  
*Globorotaloides hexagona hexagona*  
*Hastigerina siphonifera siphonifera*  
*Orbulina universa*  
*Sphaeroidinellopsis subdehiscens subdehiscens*  
*Turborotalita humilis*  
*Turborotalita quinqueloba*



Snyder et al. (2001) listed a number of benthic Foraminifera from their Samples 16–22. This author interprets those samples to be from the Morgarts Beach Member though they listed them as being from the Rushmere Member. The unit that they called “Morgarts Beach” is probably the Moore House Member (see under Moore House Member). The taxa from Samples 16-22 are the following:

*Alliatina glabrella*  
*Ammonia beccarii*  
*Amphycoryna* sp.  
*Angulogerina angulosa occidentalis*  
*Anomalinoidea* cf. *A. riveroae*  
*Astrononion stelligerum*  
*Bolivina marginata*  
*Bolivina paula*  
*Bolivina* sp.  
*Bolivina* sp. “A”  
*Bolivina spissa*  
*Bolivina subexcavata*  
*Buccella mansfieldi*  
*Buccella frigida*  
*Buccella* cf. *B. parkerae*  
*Buccella vicksburgensis*  
*Bulimina aculeata*  
*Bulimina* cf. *B. ovula*  
*Bulimina* sp.  
*Buliminella elegantissima*  
*Cancris sagra*  
*Cassidulina caribeana*  
*Cassidulina laevigata*  
*Cibicides lobatulus*  
*Cibicidoides floridanus*  
*Coryphostoma limbata costulata*  
*Discorbis* sp.  
*Elphidium advenum depressulum*  
*Elphidium compressulum*  
*Elphidium excavatum*  
*Elphidium poeyanum*  
*Elphidium* sp.  
*Epistominella danvillensis*  
*Fissurina* cf. *F. laevigata*  
*Fissurina lagenoides*  
*Fissurina lucida*  
*Fissurina marginato-perforata*  
*Fissurina* cf. *F. pseudoglobosa*  
*Fissurina quadrata*  
*Fissurina* cf. *F. submarginata*  
*Fissurina* sp. “A”  
*Fursenkoina fusiformis*  
*Fursenkoina pontoni*  
*Fursenkoina punctata*  
*Galwayella trigono-ornata*

*Globocassidulina crassa*  
*Globulina gibba*  
*Globulina inequalis*  
*Guttulina austriaca*  
*Guttulina* cf. *G. caudata*  
*Guttulina* cf. *G. elegans*  
*Guttulina* cf. *G. lactea*  
*Guttulina problema*  
*Guttulina rectorinata*  
*Guttulina* sp.  
*Gyroidinoides* cf. *G. nipponica*  
*Hanzawaia concentrica*  
*Hanzawaia* cf. *H. nipponica*  
*Lagena acuticostata*  
*Lagena globulohispida*  
*Lagena intermedia*  
*Lagena laevis*  
*Lagena pseudosulcata*  
*Lagena rancocasensis*  
*Lagena substriata*  
*Lagena tenuis*  
*Laryngosigma williamsoni*  
*Marginulina* sp.  
*Nonionella miocenica*  
*Oolina globosa*  
*Oolina hexagona*  
*Oolina laevigata*  
*Oolina melo*  
*Oolina* cf. *O. striatopunctata*  
*Parafissurina bidens*  
*Parafissurina* sp. “B”  
*Planulina* sp.  
*Polymorphina* sp.  
*Pseudononion grateloupi*  
*Pseudononion pauperatum*  
*Pseudononion pizarrensis*  
*Quinqueloculina seminula*  
*Reusella miocenica*  
*Rosalina globularis*  
*Rosalina subaraucana*  
*Rosalina* sp. “A”  
*Rosalina* sp. “B”  
*Sigmomorphina nevirera*  
*Sigmomorphina pearceyi*  
*Sigmomorphina semitecta*  
*Textularia concia*  
*Textularia* sp.  
*Trochulina bassleri*  
*Uvigerina calvertensis*  
*Uvigerina juncea*  
*Uvigerina subperegrina*  
*Valvulineria floridana*  
*Valvulineria* sp.

*Ventrostoma fovigera*  
*Webbinella concava*

### OSTRACODES

Hazel (1983:81-199) sampled the upper Yorktown (= Morgarts Beach Member) with his Sample 8. The following taxa were identified by Hazel:

*Actinocythereis mundorffi*, small form  
*Acuticythereis laevis*  
*Aurila laevicula*  
*Bairdoppilata triangulata*  
*Bensonocythere blackwelderi*  
*Bensonocythere gouldensis*  
*Bensonocythere rugosa*  
*Cytheridea virginensis*  
*Cytheromorpha warneri*  
*Cytheropteron talquinensis*  
*Cytheropteron? yorktownensis*  
*Cytherura forulata*  
*Cytherura howei*  
*Cytherura* sp.  
*Cytherura* sp. D  
*Cytherura* sp. L  
*Echinocythereis planibasalis*  
*Hermanites ascitus*  
*Hulingsina americana*  
*Loxoconcha reticularis*  
*Loxoconcha* sp. M  
*Malzella conradi*, angulate form  
*Malzella evexa*  
*Microcytherura choctawhatcheensis*  
*Microcytherura* sp. H  
*Muellerina blowi*  
*Muellerina canadensis petersburgensis*  
*Muellerina ohmertii*  
*Neocaudites subimpressus*  
*Neocaudites triplistriathus*  
*Orionina vaughani*  
*Paracytheridea cronini*  
*Paranasidea* sp. B  
*Proteoconcha multipunctata*, sensu lato  
*Pseudocytheretta burnsi*  
*Puriana carolinensis*

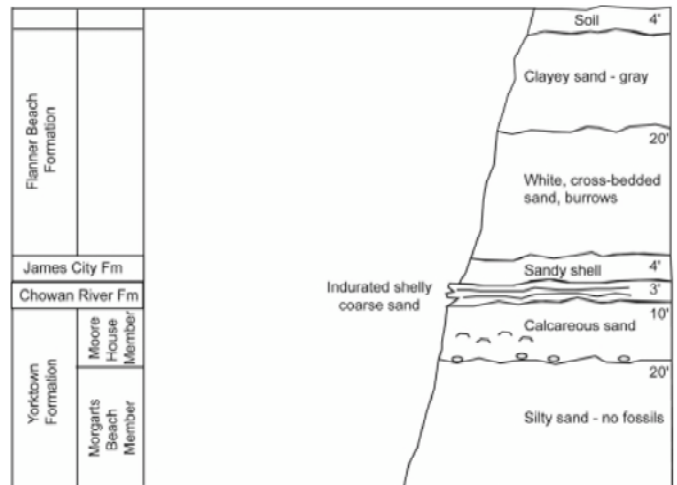
### *Moore House Member*

#### STRATIGRAPHY

The Moore House Member, in its type area on the York

River below Yorktown, Virginia, is a very shelly, bioclastic and quartz sand. It unconformably overlies the Morgarts Beach Member and the contact between the two units is sharp and burrowed, and in some areas channelled. The Moore House is not as extensive as the underlying Rushmere/Morgarts Beach. In Virginia it extends only a short distance west of Williamsburg and is not known to overlie the Morgarts Beach on the Nottoway, Meherrin, or Chowan Rivers. On Wiccacoon Creek, a tributary to the Chowan River, the Chowan River Formation directly overlies the Morgarts Beach Member.

The Moore House Member has been recognized in North Carolina only at the Lee Creek Mine where it is overlain by the Chowan River Formation. This upper Yorktown unit was recognized by Ward and Blackwelder (1987:115, Unit A), but not assigned to any Member. A trip to Lee Creek on December 18, 1992 by the author afforded the section illustrated below:



The contact between the Moore House and Morgarts Beach is sharp, as is seen in Virginia, and indicates a brief diastem. The lower portion of the 10-foot-thick bed is poorly sorted and ranges from pebble to clay-sized. Coarse sand-sized quartz and phosphate is concentrated in the lower 7 feet. In the upper several feet, the sediment is finer, but ranges from clay to coarse sand. Much calcareous material occurs in the interstices, and the bed is cemented in some places, particularly around calcitic mollusks such as *Chesapecten* or *Ostrea*.

#### PALEONTOLOGY

##### *Invertebrates*

##### FORAMINIFERA

No Foraminifera have previously been clearly attributed to the Moore House Member at the Lee Creek Mine. During most of the time the study was in progress, the Moore House interval was at the same horizon as the access roads and, as such, was covered. The planktonic Foraminifera reported by Snyder et al. (1983) from his Samples 10-15 may be from the Moore House. The study by Snyder et al. (2001) on benthic Foraminifera figured (their figure 4) a distinct unit at the top of the Yorktown Formation that comprised their Samples 10-15. I believe this interval to be the Moore House Member. The authors gave the following list from that unit:

*Acervulina* cf. *A. inhaerens*  
*Alliatina glabrella*  
*Angulogerina angulosa occidentalis*  
*Bolivina marginata*  
*Bolivina paula*  
*Bolivina* sp.  
*Bolivina subexcavata*  
*Buccella frigida*  
*Buccella inusitata*  
*Buccella mansfieldi*  
*Buccella* cf. *B. parkerae*  
*Buccella vicksburgensis*  
*Bulimina aculeata*  
*Bulimina marginata*  
*Bulimina* cf. *B. ovula*  
*Buliminella elegantissima*  
*Cancris sagra*  
*Cassidulina caribeana*  
*Cassidulina laevigata*  
*Cibicides lobatulus*  
*Cibicidoides floridanus*  
*Discorbis* sp.  
*Elphidium excavatum*  
*Elphidium limatum*  
*Elphidium poeyanum*  
*Elphidium* sp.  
*Epistominella danvillensis*  
*Epistominella pontoni*  
*Fissurina* cf. *F. laevigata*  
*Fissurina lucida*  
*Fissurina* cf. *F. pseudoglobosa*  
*Fissurina* sp. "A"  
*Fissurina* sp. "C"  
*Fursenkoina pontoni*  
*Galwayella trigono-marginata*  
*Globocassidulina crassa*  
*Globulina gibba*  
*Globulina inequalis*  
*Guttulina austriaca*  
*Guttulina* cf. *G. caudata*  
*Guttulina* cf. *G. elegans*

*Guttulina* cf. *G. lactea*  
*Guttulina palmerae*  
*Guttulina problema*  
*Guttulina rectornata*  
*Gyroidinoides* cf. *G. limbata*  
*Gyroidinoides* cf. *G. nipponica*  
*Hanzawaia concentrica*  
*Lagena* aff. *L. clavata*  
*Lagena intermedia*  
*Lagena laevis*  
*Lagena palmerae*  
*Lagena pseudosulcata*  
*Lagena substriata*  
*Lagena tenuis*  
*Laryngosigma williamsoni*  
*Lenticulina* sp.  
*Neoconorbina terquemi*  
*Nonion* cf. *N. granosum*  
*Nonionella* aff. *N. danvillensis*  
*Nonionella miocenica*  
*Oolina globosa*  
*Oolina laevigata*  
*Oolina melo*  
*Orthomorphina* (?) sp.  
*Parafissurina bidens*  
*Parafissurina* sp. "A"  
*Parafissurina* sp. "B"  
*Planulina* sp.  
*Polymorphina* sp.  
 Polymorphinidae (fistulose form)  
*Pseudononion grateloupi*  
*Pseudononion pauperatum*  
*Pseudononion pizarrensis*  
*Pseudopolymorphina rutila*  
*Ramulina* sp.  
*Reusella glabrata*  
*Rosalina floridana*  
*Rosalina globularis*  
*Rosalina* sp. "B"  
*Sigmomorphina* aff. *S. flintii*  
*Sigmomorphina nevirera*  
*Sigmomorphina pearceyi*  
*Sigmomorphina semitecta*  
*Textularia candeiana*  
*Textularia* sp.  
*Trochulina bassleri*  
*Uvigerina auberiana*  
*Uvigerina calvertensis*  
*Uvigerina juncea*  
*Uvigerina subperegrina*  
*Valvulineria allomorphinoides*  
*Valvulineria floridana*  
*Valvulineria olssoni*

*Ventrostoma fovigera*  
*Webbinella concava*

### OSTRACODES

Hazel (1983:81-199) was able to obtain two samples, combined into his Sample 9, from Yorktown beds just below the indurated sandstone stratum now known to be the Chowan River. The Yorktown interval sampled is now recognized to be the Moore House Member. Hazel's (1983:85-90) list of species is as follows:

*Actinocythereis dawsoni*  
*Actinocythereis marylandica*  
*Bairdoppilata triangulata*  
*Bensonocythere blackwelderi*  
*Bensonocythere gouldensis*  
*Bensonocythere trapezoidalis*  
*Campylocythere laeva*  
*Cytheridea virginensis*  
*Cytheromorpha incisa*  
*Cytheromorpha suffolkensis*  
*Cytheromorpha warneri*  
*Cytheropteron talquinensis*  
*Cytheropteron ? yorktownensis*  
*Cytherura elongata*  
*Cytherura forulata*  
*Cytherura reticulata*  
*Cytherura wardensis*  
*Cytherura* sp. D  
*Cytherura* sp. L  
*Cytherura* sp. N  
*Echinocythereis planibasalis*  
*Eucythere gibba*  
*Hermanites ascitus*  
*Hulingsina americana*  
*Hulingsina rugipustulosa*  
*Hulingsina* sp. C  
*Loxoconcha reticularis*  
*Loxoconcha* sp. C  
*Loxoconcha* sp. M  
*Malzella conradi*, angulate form  
*Malzella evexa*  
*Microcytherura choctawhatcheensis*  
*Microcytherura similis*  
*Microcytherura* sp. H  
*Muellerina blowi*  
*Muellerina canadensis petersburgensis*  
*Muellerina ohmertii*  
*Muellerina wardi*  
*Murrayina barclayi*  
*Neocaudites angulatus*

*Neocaudites triplistriatus*  
*Orionina vaughani*  
*Paracyprideis* sp. C  
*Paracytheridea altila*  
*Paracytheridea cronini*  
*Paracytheridea* sp. F  
*Peratocytheridea sandbergi*  
 "Pontocythere" sp. J  
*Proteoconcha jamesensis*  
*Proteoconcha mimica*  
*Proteoconcha multipunctata, sensu lato*  
*Pseudocytheretta burnsi*  
*Puriana carolinensis*  
*Puriana rugipunctata*

### MOLLUSKS

No lists of mollusks from the uppermost Yorktown Formation (= Moore House Member) at the Lee Creek Mine have been published. This horizon in the pit is usually at road level and is obscured by that structure. In addition, the unit is leached of aragonitic mollusks and low in diversity of the calcitic forms. A fortuitous visit to Lee Creek in 1992 allowed the author to collect directly from the Moore House Member and to see the bounding unconformities with the Morgarts Beach below and the Chowan River above. The top of the Moore House was exposed in 1972 and 1973 when the author made the molluscan collections of the James City Formation described by Ward and Blackwelder (1987). In that study, the Moore House was shown as Bed A in fence diagrams (fig. 3) and photographs (figs. 4 and 6). The bed exposed at that time contained no mollusks and was identified by use of ostracodes by Joseph E. Hazel (personal communication, 1975).

The mollusks obtained in 1992 are the following:

*Chesapecten madisonius* (Say)  
*Leptopecten leonensis* (Mansfield)  
*Carolinapecten eboreus* (Conrad)  
*Plicatula* sp.  
*Ostrea raveneliana* Tuomey and Holmes  
*Mercenaria* sp., partial mold

All of the specimens have sediment cemented to them with calcite. See Plate 12 for mollusks from the Moore House Member.

### Chowan River Formation

#### STRATIGRAPHY

The Chowan River Formation was named by Blackwelder (1981) for beds exposed along the Chowan River from Colerain Landing to Edenhouse Landing. Previous authors had referred those beds to the Yorktown Formation (Miller, 1912; Mansfield, 1943; Gibson, 1967; Hazel, 1971; Bailey, 1977; Gibson, 1983a).

Work by these authors and by Blackwelder indicated that the molluscan assemblages found on the Chowan River were distinctly different from those in the type Yorktown Formation. Blackwelder (1981) concluded that these beds were not included in the definition of Yorktown Formation described by Clark and Miller (1906, 1912). Work by Blackwelder and this author at Deep Creek, Virginia, and Tar Ferry on Wiccacon Creek, a tributary to the Chowan River in North Carolina, revealed an unconformity between the Yorktown and Chowan River.

Hazel (1971) found that a specific ostracode, *Puriana mesacostalis*, was a zonal indicator for the Chowan River beds and their lateral equivalents in Virginia at Deep Creek (Yadkin Pit). Ward and Blackwelder (1987) recognized the Chowan River Formation at the Lee Creek Mine and plotted the bed as their Unit B. It was shown to overlies unconformably the Yorktown Formation (Unit A) and to be unconformably overlain by the James City Formation (Units C, D, E).

The Chowan River is a partially indurated coarse sand at the Lee Creek Mine and was called the 'boulder bed' by Gibson (1967). Gibson (1967) referred the beds of the Chowan River at the pit to his Units 6 and 7 of the Yorktown Formation. Hazel (1983) called the bed his Unit 5. Hoffman and Ward (1989) briefly discuss the Chowan River Formation and depict the unit in their figure 4.4.

## PALEONTOLOGY

### *Invertebrates*

### FORAMINIFERA

Gibson (1967:646) found the following taxa in the lower part of the Chowan River Formation (his "Unit 6 of the Yorktown Formation"):

*Cibicides floridanus*  
*Cibicides lobatulus*  
*Elphidium clavatum*  
*Nonion pizarrense*  
*Nonionella auris*  
*Reusella spinulosa*  
*Textularia mayori*  
*Elphidium advenum*

Gibson (1967) interpreted this assemblage as indicating 30-

40 meters depth and warming temperatures. From his Unit 7, Gibson listed the following:

*Ammonia beccarii* (Linneus)  
*Textularia conica* d'Orbigny  
*Bolivina pulchella primitiva* Cushman

*Ammonia beccarii* was said to indicate marginal marine to brackish water and the others to indicate warm water.

The Chowan River Formation was sampled at the Lee Creek Mine for planktonic Foraminifera by Snyder et al. (1983). Their Samples 1-9 were considered by them to be from their Unit 5 of the Yorktown Formation, but their diagram (figure 2, p. 458) makes it clear that they were sampling the indurated Chowan River. The scarcity of taxa and low diversity of the assemblage shows that they were sampling a nearshore unit, different from the Yorktown Formation. The following taxa were reported:

*Globigerina bulloides apertura*  
*Globigerina bulloides bulloides*  
*Globigerina calida praeacalida*  
*Globigerina decoraperta*  
*Globigerinita glutinata*  
*Globigerinoides quadrilobatus quadrilobatus*  
*Globorotalia crassula*  
*Turborotalita quinqueloba*

Snyder et al. (2001) reported on the benthic Foraminifera from the Chowan River Formation. They used the same Samples 1-9 from which they obtained their planktonic Foraminifera. The following taxa were identified:

*Acervulina* cf. *A. inhaerens*  
*Alliatina glabrella*  
*Amphistegina* cf. *A. gibbosa*  
*Angulogerina angulosa occidentalis*  
*Baggina* sp.  
*Bolivina marginata*  
*Bolivina paula*  
*Bolivina* sp.  
*Bolivina subexcavata*  
*Buccella frigida*  
*Buccella inusitata*  
*Buccella mansfieldi*  
*Buccella* cf. *B. parkerae*  
*Buccella vicksburgensis*  
*Bulimina* cf. *B. ovula*  
*Bulimina* sp.  
*Buliminella* aff. *B. bassendorffensis*  
*Buliminella elegantissima*

*Cancris* cf. *C. danvillensis*  
*Cancris sagra*  
*Cassidulina caribea*  
*Cassidulina laevigata*  
*Caucasina preacanthia*  
*Ceratobulimina* sp.  
*Cibicides lobatulus*  
*Cibicidoides floridanus*  
*Dentalina communis*  
*Discorbis* sp.  
*Elphidium advenum depressulum*  
*Elphidium compressulum*  
*Elphidium excavatum*  
*Elphidium limatulum*  
*Elphidium poeyanum*  
*Elphidium* sp.  
*Epistominella danvillensis*  
*Faujisina* cf. *F. compressa*  
*Fissurina* cf. *F. laevigata*  
*Fissurina lagenoides*  
*Fissurina lucida*  
*Fissurina marginato-perforata*  
*Fissurina* cf. *F. pseudoglobosa*  
*Fissurina quadrata*  
*Fissurina* sp. "A"  
*Fissurina* sp. "B"  
*Fursenkoina fusiformis*  
*Fursenkoina punctata*  
*Globocassidulina crassa*  
*Globulina gibba*  
*Globulina inequalis*  
*Guttulina austriaca*  
*Guttulina* cf. *G. caudata*  
*Guttulina* cf. *G. elegans*  
*Guttulina* cf. *G. lactea*  
*Guttulina palmerae*  
*Guttulina problema*  
*Guttulina rectiornata*  
*Gyroidina soldanii*  
*Gyroidinoides* cf. *G. limbata*  
*Hanzawaia concentrica*  
*Lagena* aff. *L. clavata*  
*Lagena globulohispida*  
*Lagena intermedia*  
*Lagena laevis*  
*Lagena palmerae*  
*Lagena pseudosulcata*  
*Lagena substriata*  
*Lagena tenuis*  
*Laryngosigma williamsoni*  
*Marginulina* sp.  
*Nodosaria catesbyi*  
*Nonionella miocenica*

*Oolina globosa*  
*Oolina laevigata*  
*Oolina melo*  
*Parafissurina bidens*  
*Parafissurina* sp. "A"  
*Parafissurina* sp. "B"  
*Planulina* sp.  
*Polymorphina* sp.  
 Polymorphinidae (fistulose form)  
*Pseudononion grateloupi*  
*Pseudononion pizarrensis*  
*Rosalina candeiana*  
*Rosalina floridana*  
*Rosalina globularis*  
*Rosalina subaraucana*  
*Rosalina* sp. "A"  
*Rosalina* sp. "B"  
*Sigmomorphina nevirera*  
*Sigmomorphina pearceyi*  
*Sigmomorphina semitecta*  
*Textularia agglutinans*  
*Textularia articulata*  
*Textularia candeiana*  
*Textularia gramen*  
*Textularia* sp.  
*Trochulina bassleri*  
*Valvulineria floridana*  
*Valvulineria* sp.  
*Webbinella concava*

#### OSTRACODES

Hazel (1983) reported on a sample (Sample 10) from the Chowan River provided by Ward. See Ward and Blackwelder (1987:116, fig. 3, sec. 2, bed B). The following taxa were present in that sample:

*Actinocythereis captionis*  
*Bairdoppilata triangulata*  
*Bensonocythere rugosa*  
*Bensonocythere whitei*  
*Bensonocythere* sp. PP  
*Bensonocythere* sp. QQ  
*Campylocythere laeva*  
*Cytheridea carolinensis*  
*Cytheridea virginensis*  
*Cytheromorpha warneri*  
*Cytheropteron* ? *yorktownensis*  
*Cytherura reticulata*  
*Cytherura* sp. L  
*Echinocythereis leecreekensis*  
*Eucythere declivis*

*Hirschmannia ? hespera*  
*Hirschmannia ? quadrata*  
*Hulingsina americana*  
*Hulingsina glabra*  
*Hulingsina rugipustulosa*  
*Hulingsina* sp. C  
*Loxoconcha reticularis*  
*Malzella conradi*, angulate form  
*Malzella evexa*  
*Microcytherura choctawhatcheensis*  
*Microcytherura expanda*  
*Microcytherura similis*  
*Microcytherura* sp. H  
*Microcytherura* sp. R  
*Muellerina bassiounii*  
*Muellerina blowi*  
*Muellerina ohmertii*  
*Muellerina wardi*  
*Orionina vaughani*  
*Paracytheridea altila*  
*Paracytheridea cronini*  
*Peratocytheridea bradyi*  
*Peratocytheridea sandbergi*  
 “*Pontocythere*” sp. I  
*Proteoconcha multipunctata*, *sensu lato*  
*Pseudocytheretta burnsi*  
*Puriana carolinensis*  
*Puriana convoluta*  
*Radimella confragosa*  
*Thaerocythere schmidtiae*  
*Xestoleberis ventrostriata*

#### MOLLUSKS

Ward and Blackwelder (1987) provided an extensive list of molluscan taxa from the Chowan River at Lee Creek. The taxa were collected from their Unit B at their Sections 2, 4, and 5 (see Ward and Blackwelder, 1987:116, fig. 3). The fauna is made up principally of small taxa or the young of the larger species. This distribution seems to have been accomplished by size-sorting in a relatively high-energy environment. The Chowan River is mostly cemented into irregularly-shaped masses, but enough of the unit is uncemented to provide a list of mollusks. The following were identified:

#### Class Pelecypoda

*Abra aequalis* (Say)  
*Aligena striata* Lea  
*Anadara aequicostata* (Conrad)  
*Anisodonta carolina* Dall  
*Anomia simplex* d'Orbigny  
*Astarte berryi* Gardner  
*Astarte concentrica* Conrad

*Bornia triangula* Dall  
*Carditamera arata* (Conrad)  
*Carolinapecten eboreus* (Conrad)  
*Caryocorbula auroraensis* Ward and Blackwelder  
*Caryocorbula contracta* (Say)  
*Cavilinga trisulcata* (Conrad)  
*Cochlodesma emmonsii* Ward and Blackwelder  
*Conradostrea lawrencei* Ward and Blackwelder  
*Crassinella dupliniana* (Dall)  
*Crassinella johnsoni* Ward and Blackwelder  
*Crassinella lunulata* (Conrad)  
*Crenella decussata* (Montagu)  
*Cumingia tellinoides* (Conrad)  
*Cyclocardia* sp. cf. *C. granulata* (Say)  
*Cyrtopleura* sp.  
*Diplodonta acclinis* (Conrad)  
*Donax fossor* Say  
*Ensis directus* (Conrad)  
*Ensitellops elongata* Olsson and Harbison  
*Erycinella ovalis* Conrad  
*Gemma magna majorina* Gardner  
*Glycymeris americana* (Defrance)  
*Glycymeris arata* (Conrad)  
*Glycymeris hummi* Ward and Blackwelder  
*Glycymeris sloani* Ward and Blackwelder  
*Gouldia metastriatum* (Conrad)  
*Laevicardium sublineatum* (Conrad)  
*Leptopecten? auroraensis* Ward and Blackwelder  
*Lithophaga yorkensis* Olsson  
*Macrocallista greeni* Ward and Blackwelder  
*Mercenaria permagna* (Conrad)  
*Modiolus* sp. cf. *M. modiolus* (Linnaeus)  
*Musculus lateralis* (Say)  
*Mysella beaufortensis* Ward and Blackwelder  
*Mytilus* sp.  
*Noetia limula* (Conrad)  
*Nucula proxima* Say  
*Nucula taphria* Dall  
*Nuculana acuta* (Conrad)  
*Pandora tuomeyi* Gardner and Aldrich  
*Paramya subovata* (Conrad)  
*Parvilucina multilineata* (Tuomey and Holmes)  
*Pitar chioneformis* (Gardner)  
*Pleuromeris auroraensis* Ward and Blackwelder  
*Pleuromeris decemcostata* Conrad  
*Plicatula marginata* Say  
*Pteromeris perplana* (Conrad)  
*Raeta plicatella* (Lamarck)  
*Semele bellastrata* (Conrad)  
*Spisula similis* (Say)  
*Tellina agilis* Stimpson  
*Thracia brioni* Ward and Blackwelder  
*Transennella stimpsoni* Dall

## Class Scaphopoda

*Cadulus quadridentatus* (Dall)

## Class Gastropoda

*Acetocina candei* (d'Orbigny)  
*Aesopus gardnerae* Ward and Blackwelder  
*Aesopus stearnsii* (Tryon)  
*Anachis milleri* Gardner  
*Arene pergemma* (Gardner)  
*Balcis biconica* (Gardner)  
*Balcis eborea* (Conrad)  
*Busycon adversarius* Conrad  
*Caecum flemingi* Gardner and Aldrich  
*Caecum imbricatum* Carpenter  
*Caecum pulchellum* Stimpson  
*Calyptrea centralis* (Conrad)  
*Crepidula aculeata* (Gmelin)  
*Crepidula fornicata* (Linnaeus)  
*Crepidula plana* Say  
*Crucibulum lawrencei* Ward and Blackwelder  
*Cyclostremiscus obliquestriatus* (Lea)  
*Cymatosyrinx lunata* (Lea)  
*Dentimargo polyspira?* (Olsson and Harbison)  
*Didianema carolinae* (Gardner)  
*Diodora nucula* (Dall)  
*Epitonium carolinae* Gardner  
*Epitonium leai* Ward and Blackwelder  
*Epitonium sohli* Ward and Blackwelder  
*Granulina ovuliformis* (d'Orbigny)  
*Lunatia heros* (Say)  
*Nassarius chowanensis* (Gardner)  
*Nassarius cornelliana* (Olssen)  
*Oliva carolinensis* (Conrad)  
*Olivella mutica* (Say)  
*Polinices duplicata* (Say)  
*Prunum limatulum* (Conrad)  
*Pyrgiscus daedaleum* (Lea)  
*Pyrgiscus* sp.  
*Seila adamsi* (Lea)  
*Serpulorbis granifera* (Say)  
*Strioterebrum* sp.  
*Tectonatica pusilla* (Say)  
*Teinostoma beaufortensis* Ward and Blackwelder  
*Teinostoma goniogyrus* Pilsbry and McGinty  
*Teinostoma smirkon* Gardner  
*Turbonilla abrupta* Bush  
*Turritella beaufortensis* Ward and Blackwelder  
*Turritella perexilis* Conrad  
*Urosalpinx* sp. cf. *U. perrugata* (Conrad)  
*Vermicularia spirata* (Philippi)  
*Vexillum wandoense* (Holmes)  
*Volvarina avena* (Kiener)

See Plate 13 for illustrations of mollusks from the Chowan River Formation.

Petuch (1994) figured four specimens and named two, reported by him to be from the Chowan River Formation at Lee Creek Mine, Aurora, North Carolina:

Petuch's Name	Amended Name
<i>Busycon auroraensis</i> n. sp. p. 162, 163, pl. 60-L, p. 309, 310	<i>Busycon carica</i>
<i>Sinistrofulgur adversarium</i> p. 164, 165, pl. 61-J	<i>Sinistrofulgur adversarium</i>
<i>Volutifusus typus</i> Conrad p. 198, 199, pl. 78-E	<i>Volutifusus typus</i>
<i>Volutifusus auroraensis</i> n. sp. p. 198, 199, pl. 78-M, p. 339.	<i>Volutifusus mutabilis</i>

The first three species are large taxa and probably came from the James City Formation, not the Chowan River.

The specimen, named *Volutifusus auroraensis* by Petuch, is incomplete and its height is given as 82 mm. The figure given (pl. 78-M) is clearly enlarged and is still only 68 mm in height. The specimen, too fragmentary to warrant a new name, appears to be a *Volutifusus mutabilis* (= *Volutifusus emmonsii* Petuch, 1994). Specimens of *Volutifusus mutabilis* are not known in the Chowan River or James City at the Lee Creek Mine. Because of its identity and preservation, the specimen probably did not come from the Chowan River Formation or the Lee Creek Mine.

Petuch figured (1997:166, 167, fig. 56) several taxa that he indicated were collected from the "Chowan River Formation (upper beds, as proposed by Campbell, 1993) in the Lee Creek Mine, Aurora, North Carolina." The expression "upper beds, as proposed by Campbell" is the possible key to the provenance of some of the taxa. Five of the taxa (see list, \*) are believed to have come from the Deep Creek Pit in Chesapeake, Virginia where the Chowan River Formation ("upper beds") unconformably overlies the Moore House Member of the Yorktown. The five species are derived, however, from the Yorktown, and are not found in the Chowan River at the Deep Creek Pit, in the type Chowan River, or at the Lee Creek Mine in any unit.

In addition, the other taxa figured by Petuch are from the James City Formation at the Lee Creek Mine, not the Chowan River Formation. Specimens in the Chowan River at Lee Creek are generally very small and size-sorted. No large specimens, such as the *Busycon* shown by Petuch, are known from the Chowan River at the Lee Creek Mine. The taxa reported from the "Chowan River Formation" by Petuch are the following:



Petuch's Name	Amended Name
<i>Busycotypus concinnum</i> (Conrad) p. 167, fig. 56-A	<i>Busycotypus concinnum</i>
<i>Sinistrofulgur adversarium</i> (Conrad) p. 167, fig. 56-B	<i>Sinistrofulgur adversarium</i>
<i>Calliostoma philanthropus</i> (Conrad) p. 167, fig. 56-C	<i>Calliostoma philanthropus</i>
<i>Ptychosalpinx tuomeyi</i> (H.C. Lea) p. 167, fig. 56-D	* <i>Ptychosalpinx tuomeyi</i>
<i>Trivia lindae</i> Petuch p. 167, fig. 56-E	<i>Trivia floridana</i>
<i>Volutifusus typus</i> Conrad p. 167, fig. 56-F	<i>Volutifusus typus</i>
<i>Volutifusus auroraensis</i> Petuch p. 167, fig. 56-G	* <i>Volutifusus mutabilis</i>
<i>Fasciolaria (Cinctura) beaufortensis</i> Ward and Blackwelder p. 167, fig. 56-H	<i>Fasciolaria (Cinctura) beaufortensis</i>
<i>Crepidula costata chamnessi</i> Petuch p. 167, fig. 56-I	* <i>Crepidula costata</i>
<i>Pterorhytis conradi</i> Dall p. 167, fig. 56-J	<i>Pterorhytis conradi</i>
<i>Diodora (Glyphis) auroraensis</i> Ward and Blackwelder p. 167, fig. 56-K	<i>Diodora pamlicoensis</i>
<i>Busycon auroraensis</i> Petuch p. 167, fig. 56-L	<i>Busycon carica</i>
<i>Urosalpinx suffolkensis</i> Gardner p. 167, fig. 56-M	<i>Urosalpinx stimpsoni</i>
<i>Heilprinia malcolmi</i> Ward and Blackwelder p. 167, fig. 56-N	<i>Heilprinia malcolmi</i>
<i>Ptychosalpinx chesapeakeensis</i> Campbell p. 167, fig. 56-O	* <i>Ptychosalpinx altilis</i>
<i>Trossulasalpinx moniliferus</i> (Emmons) p. 167, fig. 56-P, possibly from Deep Creek In Yorktown	* <i>Urosalpinx trossulus</i>

\* D, G, I, O and P are not present in the Yorktown, Chowan River or James City Formation at the Lee Creek Mine. Specimens like these taxa were present in the Deep Creek Pit in Chesapeake, Virginia, in the Moore House Member of the Yorktown Formation. That pit, now flooded, had a thin layer of Chowan River overlying the Moore House. The specimens were attributed to the Chowan River Formation but were derived from the Yorktown Formation.

Specimens A, B, C, E, F, H, J, K, L, M and N on figure 56 in Petuch (1997:167) are derived from the James City Formation and are not known from the Chowan River

Formation at the Lee Creek Mine (See James City Formation section).

Petuch (2004:204, pl. 72) figured the following taxa from the "Chowan River Formation, in the Lee Creek Texasgulf Mine, Aurora, Beaufort County, North Carolina."

Fig.	Petuch's Name	Amended Name
A, B	<i>Volutifusus auroraensis</i> Petuch	* <i>Volutifusus mutabilis</i>
C, D	<i>Pterorhytis conradi</i> (Dall)	<i>Pterorhytis conradi</i>
E	<i>Urosalpinx gilmorei</i> Petuch	<i>Urosalpinx suffolkensis</i>
F	<i>Urosalpinx suffolkensis</i> Gardner	<i>Urosalpinx stimpsoni</i>
G	<i>Serpulorbis granifera</i> (Say)	<i>Serpulorbis granifera</i>
H	<i>Glyphis pamlicoensis</i> (Ward and Blackwelder)	<i>Diodora pamlicoensis</i>
I, J	<i>Contraconus petiti</i> n. sp., p. 291, 292	<i>Contraconus adversarius</i>
K	<i>Ptychosalpinx chesapeakeensis</i> Campbell	* <i>Ptychosalpinx laqueata</i>

C, D, E, F, G, H, I and J came from the James City Formation, probably from the Lee Creek Mine (See James City Formation section).

\* A, B and K probably came from the upper Yorktown Formation in Virginia. These taxa are not found at the Lee Creek Mine because of solution of aragonitic shells in the Yorktown at that site (see comments on Petuch, 1997).

Petuch (2004:206, pl. 73) figured another group of mollusks said to be from the "Chowan River Formation in the Lee Creek Texasgulf Mine, Aurora, Beaufort County, North Carolina," as follows:

Fig.	Petuch's Name	Amended Name
A, B	<i>Volutifusus typus</i> Conrad	<i>Volutifusus typus</i>
C	<i>Sinistrofulgur adversarium</i> (Conrad)	<i>Sinistrofulgur adversarium</i>
D	<i>Fasciolaria (Cinctura) beaufortensis</i> Ward and Blackwelder	<i>Fasciolaria (Cinctura) beaufortensis</i>
E	<i>Ptychosalpinx tuomeyi</i> (H.C. Lea)	<i>Ptychosalpinx tuomeyi</i>
F	<i>Busycon auroraensis</i> Petuch	<i>Busycon carica</i>
G	<i>Busycotypus concinnum</i> (Conrad)	<i>Busycotypus concinnum</i>
H	No name	<i>Glycymeris americana</i>
I	<i>Brachysycon canaliferum</i> (Conrad)	<i>Busycotypus concinnum</i>
J	<i>Torcula perexilis</i> (Conrad)	<i>Turritella (Torcula) perexilis</i>

A, B, C, D, F, G, H, I and J are from the James City Formation at the Lee Creek Mine, not the Chowan River. E is from the upper Yorktown in Virginia. H was not identified, but is *Glycymeris americana* (DeFrance) and is from the James City.

### *Pleistocene*

#### Lower Pleistocene

#### James City Formation

#### STRATIGRAPHY

The James City Formation was named by DuBar and Solliday (1963) for deposits exposed on the right bank of the Neuse River about 3.0 miles (4.8 km) below the mouth of the Trent River. The type section was their Station WA30 and is 0.6 miles (1 km) downstream from Ft. Point and 1.3 miles (2.1 km) east of the center of James City, Craven County, North Carolina. The James City was described as a fine to medium, silty, argillaceous, calcareous sand with abundant fossils including corals. The name Croatan had been applied to shelly beds along the Neuse River, but only to those exposures from 9 to 15 miles (14.5 to 21.1 km) below New Bern (for a historical summary see Mansfield, 1928). DuBar and Solliday showed those beds to be younger and to overlie the James City unconformably. Those authors termed the younger beds the Flanner Beach Formation since the Croatan, as used, was a "catch-all" lithic unit.

DuBar et al. (1974) were the first to identify the James City Formation at the Lee Creek Mine. Previously, authors such as Gibson (1967) referred these beds to the Yorktown Formation (Beds 8, 9) while others placed them in the Croatan (Hazel, 1971, 1983). Ward and Blackwelder (1987) placed the fossiliferous sands above the semi-indurated Chowan River Formation in the James City and figured 194 species of mollusks.

Wheeler et al. (1983) used the term "Small Sequence" for strata that are now termed the James City Formation. Wheeler et al. (1983) believed that the Small Sequence, James City Formation, and Croatan were all the same unit.

Curran and Frey (1977) and Curran and Parker (1983) referred to the James City beds at the Lee Creek Mine as the "Upper Shell" unit and described the paleoecology of the bed as recorded in the large numbers of fossil mollusks. Those authors divided the unit into three "zones" characterized by the common molluscan components. They noted the presence of a dominantly marine fauna followed by the abrupt appearance of the freshwater mollusk *Corbicula*. This sequence, to them, indicated a marine regression ending with brackish, estuarine conditions.

Belt et al. (1983) studied both the James City Formation (their "Upper Shell Unit" and "Shell Hash Unit") and younger beds herein referred to as the Flanner Beach Formation. These authors also addressed the origin of the shell beds and their inferred ecology. They described in detail the trace fossils found in the James City and the textures of the sediments in which they are found.

Hoffman and Ward (1989) briefly described the James City Formation and graphically illustrated its stratigraphic relationships in their figure 4.4.

#### PALEONTOLOGY

##### *Invertebrates*

##### FORAMINIFERA

Gibson (1967:646) mentioned a few taxa from his "Unit 8" of the "Yorktown Formation" (herein considered to be the James City Formation). Those mentioned are the following:

*Ammonia beccarii* (Linnaeus), marine to brackish water  
*Textularia conica* d'Orbigny, warm water  
*Bolivina pulchella primitiva* Cushman, warm water

From "Unit 9" Gibson reported that *Elphidium clavatum* composes about 70 percent of the fauna, while *Ammonia beccarii* varies between 10 and 15 percent. With this foraminiferal composition, Gibson interpreted the water depth to be shallow and less than 15 meters.

Gibson (1983b) described and figured eight foraminiferal taxa from the "Croatan Formation" at the Lee Creek Mine, three of which were new species:

*Globorotalia hirsuta hirsuta* (d'Orbigny)  
*Globorotalia peripherorondo* Blow and Banner  
*Globorotalia* sp. cf. *G. truncatulinoides truncatulinoides* (d'Orbigny)  
*Elphidium gunteri* Cole  
*Elphidium limatum* Copeland  
*Elphidium neocrespiniae* Gibson n. sp.  
*Cibicides croatanensis* Gibson n. sp.  
*Svratkina croatanensis* Gibson n. sp.

#### CORALS

Petuch (1997:260, fig. 94) published a photograph taken by E. Gerrard of the exposed James City Formation at the Lee Creek Mine. From this figure Petuch identified the following coral:

*Astrohelix* [sic] *palmata*

## BIVALVES

*Astrhelix palmata* is a temperate-water coral that is present in the Calvert, Choptank, and Eastover formations. It is not known stratigraphically higher than the Eastover, specifically the Cobham Bay Member. The coral seen in the photograph is “*Septastrea*” *bella* (Conrad). *Septastrea*, *sensu stricto*, is a cool-temperate coral and is present in the late Miocene and lower and upper Pliocene. The coral appearing first in the Chowan River and then in the James City is sub-tropical and probably belongs in a different genus. Figures of specimens of corals described by Weisbord (1974: pls. 42-44) as *Solenastrea* from the Pliocene of Florida appear to be identical with the James City and Chowan River specimens. If so, then the correct name should be *Solenastrea bella* (Conrad). *Astrea bella* was named by Conrad (1841:33) from “Near New Bern, North Carolina.” Two miles below New Bern, the type James City crops out and contains many specimens of coral of the same species present in the James City at the Lee Creek Mine. The specimens figured by Tuomey and Holmes (1855) and Holmes (1858) as *Astrea bella* are not *Asrea bella* of Conrad (1841). Recently the name *Septastrea crassa* (Holmes, 1858) has been applied to the Lee Creek, James City species (see Miller, 1997). That species is based on a small, worn fragment of unknown provenance from “Charleston” (Holmes, 1858: 2). The locality given by Conrad for “*Astrea bella*” is clear and is still available for study. More importantly, that name predates that of Holmes by 17 years.

## MOLLUSKS

Gibson (1987) described and figured a single pectinid from the James City Formation (Gibson’s, 1967, Units 8 and 9 of the Yorktown Formation). That species he referred to *Argopecten eboreus* aff. *A. eboreus solarioides* Heilprin.

Ward and Blackwelder (1987) described and figured 193 species of mollusks from the James City Formation at the Lee Creek Mine. This assemblage came from their Units C, D, and E. The entire assemblage was interpreted as marginal-marine and shallow-water. The presence of fresh-water taxa (*Corbicula*) and brackish-water taxa (*Rangia* and *Crassostrea*) in an otherwise open-marine, normal-saline fauna is now believed to be the result of an offshore, barrier-bar with migrating channels that intermittently opened and closed as is common today. The effect of closing would cause the back-barrier to become increasingly fresh water. With the breach of that barrier by a storm forming an open inlet, the back-barrier conditions would return to near-normal saline conditions.

The following mollusks were reported from the James City Formation at Lee Creek:

*Abra aequalis* (Say)  
*Aligena striata* Lea  
*Anadara aequicostata* (Conrad)  
*Anisodonta carolina* Dall  
*Anomia simplex* d’Orbigny  
*Argopecten vicenarius vicenarius* (Conrad)  
*Astarte berryi* Gardner  
*Astarte concentrica* Conrad  
*Bellucina waccamawensis* (Dall)  
*Bornia triangula* Dall  
*Brachidontes* sp.  
*Callucina keenae* (Chavan)  
*Carditamera arata* (Conrad)  
*Carolinapecten eboreus* (Conrad)  
*Caryocorbula auroraensis* Ward and Blackwelder  
*Caryocorbula contracta* (Say)  
*Cavilinga trisulcata* (Conrad)  
*Chama gardnerae* Olsson and Harbison  
*Chione cribraria* (Conrad)  
*Chione grus* (Holmes)  
*Cochlodesma emmonsii* Ward and Blackwelder  
*Conradostrea lawrencei* Ward and Blackwelder  
*Corbicula densata* (Conrad)  
*Crassinella dupliniana* (Dall)  
*Crassinella johnsoni* Ward and Blackwelder  
*Crassinella lunulata* (Conrad)  
*Crassostrea virginica auroraensis* Ward and Blackwelder  
*Crenella decussata* (Montagu)  
*Cumingia tellinoides* (Conrad)  
*Cyclocardia* sp. cf. *C. granulata* (Say)  
*Cyrtopleura* sp.  
*Dinocardium robustum hazeli* Ward and Blackwelder  
*Diplodonta acclinis* (Conrad)  
*Diplodonta berryi* McGavock  
*Divalinga* sp.  
*Donax fossor* (Say)  
*Dosinia* sp.  
*Ensis directus* (Conrad)  
*Ensitellops elonga* (Olsson and Harbison)  
*Gastrochaena hians* (Gmelin)  
*Gemma magna majorina* Gardner  
*Glycymeris americana* (DeFrance)  
*Glycymeris arata* (Conrad)  
*Glycymeris sloani* Ward and Blackwelder  
*Gouldia metastriatum* (Conrad)  
*Laevicardium sublineatum* (Conrad)  
*Leptopecten? auroraensis* Ward and Blackwelder  
*Lithophaga yorkensis* Olsson  
*Macoma holmesii* Dall  
*Macrocallista greeni* Ward and Blackwelder  
*Marvacrassatella kauffmani* Ward and Blackwelder

*Mercenaria mercenaria* (Linnaeus)  
*Mercenaria permagna* (Conrad)  
*Modiolus* sp. cf. *M. modiolus* (Linnaeus)  
*Mulinia lateralis* (Say)  
*Musculus lateralis* (Say)  
*Mya arenaria* Linnaeus  
*Mysella beaufortensis* Ward and Blackwelder  
*Noetia limula* (Conrad)  
*Nucula pilkey* Ward and Blackwelder  
*Nucula proxima* Say  
*Nucula taphria* Dall  
*Nuculana acuta* (Conrad)  
*Pandora tuomeyi* Gardner and Aldrich  
*Panopea floridana* Heilprin  
*Paramya subovata* (Conrad)  
*Parvilucina multilineata* (Tuomey and Holmes)  
*Petricola pectorosa* (Conrad)  
*Petricola pholadiformis* Lamarck  
*Phlyctiderma heroni* Ward and Blackwelder  
*Pitar chioneformis* (Gardner)  
*Pleuromeris auroraensis* Ward and Blackwelder  
*Pleuromeris decemcostata* Conrad  
*Pliculata marginata* Say  
*Pododesmus fragosus* (Conrad)  
*Pteromeris perplana* (Conrad)  
*Quadrilatera adamsi* (Dall)  
*Raeta plicatella* (Lamarck)  
*Rangia clathrodonta* (Conrad)  
*Semele bellastrata* (Conrad)  
*Sphenia dubia* (Lea)  
*Spisula similis* (Say)  
*Spisula solidissima* (Dillwyn)  
*Stewartia anodonta floridana* (Conrad)  
*Tagelus plebeius carolinensis* (Conrad)  
*Tellina agilis* Stimpson  
*Thracia brioni* Ward and Blackwelder  
*Transennella stimpsoni* Dall  
*Verticordia lockei* Ward and Blackwelder\*

#### GASTROPODA

*Acetocina candei* (d'Orbigny)  
*Aesopus gardnerae* Ward and Blackwelder  
*Aesopus ithitoma* (Dall)  
*Aesopus stearnsii* (Tryon)  
*Anachis milleri* Gardner  
*Arene pergemma* (Gardner)  
*Balcis beaufortensis* Ward and Blackwelder  
*Balcis biconica* (Gardner)  
*Balcis eborea* (Conrad)  
*Balcis?* sp.  
*Bittium podagrinum* Dall

*Brachyothyra reidenbachi* Ward and Blackwelder  
*Busycon adversarius* Conrad  
*Busycon carica* (Gmelin)  
*Busycon concinnum* Conrad  
*Busycon spiratus pyruloides* (Say)  
*Caecum beaufortensis* Ward and Blackwelder  
*Caecum flemingi* Gardner and Aldrich  
*Caecum imbricatum* Carpenter  
*Caecum pulchellum* Stimpson  
*Calliostoma philanthropum pontoni* Mansfield  
*Calyptrea centralis* (Conrad)  
*Chrysallida auroraensis* Ward and Blackwelder  
*Chrysallida beaufortensis* Ward and Blackwelder  
*Conus adversarius* Conrad  
*Crepidula aculeata* (Gmelin)  
*Crepidula fornicata* (Linnaeus)  
*Crepidula plana* Say  
*Crucibulum lawrencei* Ward and Blackwelder  
*Cyclostremiscus obliquistriatus* (Lea)  
*Cymatosyrinx lunata* (Lea)  
*Dentimargo polyspira?* (Olsson and Harbison)  
*Didianema carolinae* (Gardner)  
*Diodora auroraensis* Ward and Blackwelder  
*Diodora nucula* (Dall)  
*Diodora pamlicoensis* Ward and Blackwelder  
*Epitonium carolinae* Gardner  
*Epitonium fractum* Dall  
*Epitonium leai* Ward and Blackwelder  
*Epitonium rupicolum* (Kurtz)  
*Epitonium* sp. cf. *E. foliaceicostum* (d'Orbigny)  
*Eulima juncea* (Gardner)  
*Eupleura caudata* (Say)  
*Fasciolaria beaufortensis* Ward and Blackwelder  
*Fasciolaria cronlyensis* Gardner  
*Glabrocythara* sp.  
*Granulina ovuliformis* (d'Orbigny)  
*Heilprinia caloosaensis malcolmi* Ward and Blackwelder\*  
*Littorina carolinensis* Conrad  
*Lunatia heros* (Say)  
*Macromphalina hansenii* Ward and Blackwelder  
*Macromphalina pierrot* Gardner  
*Mitrella gardnerae* (Olsson and Harbison)  
*Mitrella gardnerae ecarinata* (Olsson and Harbison)  
*Mitrella waccamawensis* Gardner  
*Murexiella macgintyi* (M. Smith)  
*Nassarius chowanensis* (Gardner)  
*Nassarius granifera* (Conrad)  
*Nassarius scalaspira?* (Conrad)  
*Nassarius schizopyga?* (Dall)  
*Odostomia simplex* (Lea)  
*Odostomia turbinatus* (Lea)  
*Olivella mutica* (Say)  
*Orinella beaufortensis* Ward and Blackwelder

*Polinices duplicata* (Say)  
*Prunum limatum* (Conrad)  
*Pterorhytis conradi* (Dall)  
*Ringicula semistriata* d'Orbigny  
*Rissoa geraea* Dall  
*Sedilia* sp. aff. *S. sedilia* (Dall)  
*Seila adamsi* (Lea)  
*Serpulorbis granifera* (Say)  
*Strioterebrum* sp. cf. *S. petiti* Olsson  
*Tectonatica pusilla* (Say)  
*Teinostoma beaufortensis* Ward and Blackwelder  
*Teinostoma smirkon* Gardner  
*Teinostoma tectispira* Pilsbry  
*Trigonostoma* sp.  
*Triphora dupliniana* (Olsson)  
*Trivia floridana* Olsson and Harbison  
*Turbonilla abrupta* Bush  
*Turritella beaufortensis* Ward and Blackwelder  
*Turritella perexilis* Conrad  
*Urosalpinx* sp. cf. *U. perrugata* (Conrad)  
*Urosalpinx stimpsoni* Gardner  
*Urosalpinx suffolkensis* Gardner  
*Vermicularia spirata* (Philippi)  
*Vexillum wandoense* (Holmes)  
*Vitricythara micromeris* (Dall)  
*Volutifusus typus* Conrad

See Plates 14, 15 for illustrations of mollusks from the James City Formation.

Ward and Gilinsky (1993) published a study on the mollusks of the Chowan River Formation. The authors produced extensive lists of mollusks from the type area of the Chowan River and compared those taxa with the assemblages in the adjoining units, immediately preceding (Moore House Member) and immediately following (James City Formation). The James City lists were taken from manuscripts used to produce the work by Ward and Blackwelder (1987) on the James City at the Lee Creek Mine. The manuscript list contained two taxa, *Verticordia kelloggi* and *Heilprinia caloosaensis kelloggi*, that were properly named *Verticordia lockei* and *Heilprinia caloosaensis malcolmi* when published in 1987 (see asterisks \* in preceding lists). The two names listed by Ward and Gilinsky (1993) are, therefore, *nomina nuda*, and should read *V. lockei* and *H. c. malcolmi*. I offer no excuse for this error other than a mental lapse and the two authors separated by 1200 miles by the time it was published.

Because the list by Ward and Gilinsky (1993) was the same as Ward and Blackwelder (1987) already given, with the exception of the two taxa mentioned above, that list is not repeated here.

Petuch (1994) figured four specimens and named two said to come from the Chowan River Formation at Lee Creek Mine, Aurora, North Carolina. Three of the species are large taxa and probably came from the James City Formation, not the Chowan River.

Petuch's Name		Amended Name
<i>Busycon auroraensis</i> n. sp.	p. 162, 163, pl. 60-L, p. 309, 310	<i>Busycon carica</i>
<i>Sinistrofulgur adversarium</i> (Conrad)	p. 164, 165, pl. 61-J	<i>Sinistrofulgur adversarium</i>
<i>Volutifusus typus</i> Conrad	p. 198, 199, pl. 78-E	<i>Volutifusus typus</i>

Petuch (1994) figured seven specimens and named five of them from the James City Formation at the Lee Creek Mine:

Petuch's Name		Amended Name
<i>Urosalpinx auroraensis</i> n. sp.	p. 132, 133, 284, pl. 45-H	<i>Urosalpinx suffolkensis</i>
<i>Urosalpinx suffolkensis</i> Gardner	p. 132, 133, pl. 45-K	<i>Urosalpinx stimpsoni</i>
<i>Urosalpinx gilmorei</i> n. sp.	p. 134, 135, pl. 46-Q	<i>Urosalpinx suffolkensis</i>
<i>Trossulasalpinx moniliferous</i> (Emmons)	p. 134, 135, pl. 46-K	Indeterminate
<i>Busycon carica gilmorei</i> n. ssp.	p. 162, 163, pl. 60-G, p. 310	<i>Busycon carica</i>
<i>Sinistrofulgur pamlico</i> n. sp.	p. 164, 165, pl. 61-F, p. 315, 316	<i>Sinistrofulgur adversarium</i>
<i>Volutifusus halscotti</i> n. sp.	p. 198, 199, pl. 78-H, p. 340	<i>Volutifusus typus</i>

*Urosalpinx trossula*, or as Petuch has termed it "*Trossulasalpinx*," does not occur stratigraphically higher than the Moore House Member. It is not present in the James City Formation. Emmons' (1858) figure is not sufficient to make a certain specific determination.

Petuch (1997:166, 167, fig. 56) figured eleven taxa as coming from the Chowan River Formation at the Lee Creek Mine. After studying the figures I have determined that the following came from the James City Formation:

Petuch's Name		Amended Name
<i>Busycotypus concinnum</i> (Conrad)	p. 167, fig. 56-A	<i>Busycotypus concinnum</i>
<i>Sinistrofulgur adversarium</i> (Conrad)	p. 167, fig. 56-B	<i>Sinistrofulgur adversarium</i>
<i>Calliostoma philanthropum</i> (Conrad)	p. 167, fig. 56-C	<i>Calliostoma philanthropum pontoni</i>
<i>Trivia lindae</i> Petuch	p. 167, fig. 56-E	<i>Trivia floridana</i>
<i>Volutifusus typus</i> Conrad	p. 167, fig. 56-F	<i>Volutifusus typus</i>
<i>Fasciolaria (Cinctura) beaufortensis</i> Ward and Blackwelder	p. 167, fig. 56-H	<i>Fasciolaria (Cinctura) beaufortensis</i>
<i>Pterorhytis conradi</i> Dall	p. 167, fig. 56-J	<i>Pterorhytis conradi</i>
<i>Diodora (Glyphis) auroraensis</i> Ward and Blackwelder	p. 167, fig. 56-K	<i>Diodora pamlicoensis</i>
<i>Busycon auroraensis</i> Petuch	p. 167, fig. 56-L	<i>Busycon carica</i>
<i>Urosalpinx suffolkensis</i> Gardner	p. 167, fig. 56-M	<i>Urosalpinx stimpsoni</i>
<i>Heilprinia malcolmi</i> Ward and Blackwelder	p. 167, fig. 56-N	<i>Heilprinia malcolmi</i>

Petuch (1997:258, 259, fig. 93) illustrated eight other taxa from the James City Formation in the Lee Creek Mine, Aurora, North Carolina:

Fig.	Petuch's Name	Amended Name
A	<i>Busycon gilmorei</i> Petuch	<i>Busycon carica</i>
B	<i>Urosalpinx gilmorei</i> Petuch	<i>Urosalpinx suffolkensis</i>
D	<i>Terebraspira cronleyensis</i> (Gardner)	<i>Pleuroploca cronleyensis</i>
E	<i>Sinistrofulgur pamlico</i> Petuch	<i>Sinistrofulgur adversarium</i>
F	<i>Volutifusus halscottii</i> Petuch	<i>Volutifusus typus</i>
G	<i>Urosalpinx auroraensis</i> Petuch	<i>Urosalpinx stimpsoni</i>
H	<i>Conus (Ximeniconus) waccamawensis</i>	<i>Conus waccamawensis</i>
I	<i>Ilyanassa wilmingttonensis</i> Gardner	<i>Nassarius granifera</i>

Petuch (1997:260, fig. 94) published a photograph taken by E. Gerrard of the exposed James City Formation at the Lee Creek Mine. From this figure Petuch identified the following taxa:

*Mercenaria permagna* (Conrad)  
*Ventriolia betsiae* (Olsson and Petit)  
*Cyclocardia granulata* (Say)  
*Astarte concentrica* Conrad  
*Glycymeris americana* (DeFrance)

Petuch (2004:204, pl. 72) figured the following taxa from the "Chowan River Formation" at the Lee Creek Mine. After studying the figures and checking the collections, I have determined that the following are derived from the James City Formation, not the Chowan River:

Fig.	Petuch's Name	Amended Name
C, D	<i>Pterorhytis conradi</i> (Dall)	<i>Pterorhytis conradi</i>
E	<i>Urosalpinx gilmorei</i> Petuch	<i>Urosalpinx suffolkensis</i>
F	<i>Urosalpinx suffolkensis</i>	<i>Urosalpinx stimpsoni</i>
G	<i>Serpulorbis granifera</i> (Say)	<i>Serpulorbis granifera</i>
H	<i>Glyphis pamlicoensis</i> (Ward and Blackwelder)	<i>Diodora pamlicoensis</i>
I	<i>Contraconus petiti</i> n. sp.	<i>Contraconus adversarius</i>

Petuch (2004:206, pl. 73) figured another group of mollusks said to be from the "Chowan River Formation" at the Lee Creek Mine. After studying the figures and checking the collections, I have determined that the following are derived from the James City Formation, not the Chowan River Formation:

Fig.	Petuch's Name	Amended Name
A, B	<i>Volutifusus typus</i> Conrad	<i>Volutifusus typus</i>
C	<i>Sinistrofulgur adversarium</i> (Conrad)	<i>Sinistrofulgur adversarium</i>
D	<i>Fasciolaria (Cinctura) beaufortensis</i> (Ward and Blackwelder)	<i>Fasciolaria (Cinctura) beaufortensis</i>
F	<i>Busycon auroraensis</i> Petuch	<i>Busycon carica</i>
G	<i>Busycotypus concinnum</i> (Conrad)	<i>Busycotypus concinnum</i>
H	No name given	<i>Glycymeris americana</i>
I	<i>Brachysycon canaliferum</i> (Conrad)	<i>Busycotypus concinnum</i>
J	<i>Torcula perexilis</i> (Conrad)	<i>Turritella (Torcula) perexilis</i>

Fig. 73-E is a *Ptychosalpinx* from the Yorktown Formation, but not from the Lee Creek Mine.

Petuch (2004:207, pl. 74) illustrated eight taxa from the “James City Formation, in the Lee Creek Texasgulf Mine, Aurora, Beaufort County, North Carolina.” They are the following:

Fig.	Petuch’s Name	Amended Name
A, B	<i>Terebraspira cronleyensis</i> (Gardner)	<i>Pleuroploca cronleyensis</i>
C, D	<i>Trivia lindae</i> Petuch	<i>Trivia floridana</i>
E	<i>Heilprinia malcolmi</i> (Ward and Blackwelder)	<i>Heilprinia caloosaensis malcolmi</i>
F,G	<i>Volutifusus halscotti</i> Petuch	<i>Volutifusus typus</i>
H	<i>Ventrilia betsiae</i> (Olsson and Petit)	<i>Ventrilia betsiae</i>
I	<i>Ilyanassa granifera</i> (Conrad)	<i>Nassarius granifera</i>
J	<i>Ventrilia elizabethae</i> (Olsson and Petit)	<i>Ventrilia elizabethae</i>
K	<i>Ximeniconus waccamawensis</i> (B. Smith)	<i>Conus waccamawensis</i>

Miller (1997) made a paleoecologic study of the mollusks associated with the abundant coral thickets in the James City Formation. The coral was identified as *Septastrea crassa*. As pointed out earlier in connection with Petuch (1997:260, fig.94), the species in the James City Formation is neither *Septastrea* nor the species *crassa*. It probably is *Solenastrea* (as figured by Weisbord, 1974) and the species is *bella* as described by Conrad (1841) from the Neuse River just below New Bern from what is now known as the type James City.

Miller (1997:78, table 1) listed the following as most abundant bivalve taxa:

*Nucula proxima*  
*Nuculana acuta*  
*Anadara aequicostata*  
*Noetia limula*  
*Glycymeris americana*  
*Glycymeris arata*  
*Glycymeris sloani*  
*Crenella decussata*  
*Carolinapecten eboreus*  
*Plicatula marginata*  
*Conradostrea lawrencei*  
*Cavilinga trisulcata*  
*Diplodonta* spp.  
*Bornia triangula*

*Anisodonta carolina*  
*Ensitellops elongata*  
*Carditamera arata*  
*Pleuromeris auroraensis*  
*Pleuromeris decemcostata*  
*Pteromeris perplana*  
*Cyclocardia granulata*  
*Astarte concentrica*  
*Astarte* sp. aff. *A. castanea*  
*Crassinella* spp.  
*Laevicardium sublineatum*  
*Spisula* spp.  
*Ensis directus*  
*Tellina agilis*  
*Donax fossor*  
*Semele bellastrata*  
*Abra aequalis*  
*Cumingia tellinoides*  
*Gouldia metastriatum*  
*Transennella stimpsoni*  
*Macrocallista greeni*  
*Mercenaria permagna*  
*Sphenia* sp.  
*Caryocorbula* spp.  
*Gastrochaena hians*  
*Hiatella arctica*  
*Pandora* sp. cf. *P. tuomeyi*  
*Cochlodesma emmonsii*

Miller (1997:88-90, appendix) listed all of the molluscan taxa identified from his 4 bulk samples. Those taxa are the following:

#### BIVALVES

*Nucula proxima*  
*Nucula taphria*  
*Nuculana acuta*  
*Anadara aequicostata*  
*Quadrilatera* sp. cf. *Q. adamsi*  
*Noetia limula*  
*Glycymeris americana*  
*Glycymeris arata*  
*Glycymeris sloani*  
*Crenella decussata*  
*Modiolus* sp.  
*Lithophaga yorkensis*  
*Amusium* sp.  
*Leptopecten? auroraensis*  
*Carolinapecten eboreus*  
*?Propeamusium* sp.  
*Plicatula marginata*

*Anomia simplex*  
*Conradostrea lawrencei*  
*Parvilucina multilineata*  
*Bellucina vaccamawensis*  
*Cavilinga trisulcata*  
*Callucina keenae*  
*Diplodonta* spp. (*D. acclinis* and *D. berryi*, undifferentiated owing to mostly poor preservation)  
 ?*Phyciderma* sp.  
*Chama gardnerae*  
*Aligena striata*  
*Bornia triangula*  
*Mysella beaufortensis*  
*Anisodonta carolina*  
 ?*Sportella* sp.  
*Ensitellops elongata*  
*Carditamera arata*  
*Pleuromeris auroraensis*  
*Pleuromeris decemcostata*  
*Pteromeris perplana*  
*Cyclocardia granulata* (Identified as *C.* sp. cf. *C. granulata* by Ward and Blackwelder (1987))  
*Astarte concentrica*  
*Astarte* sp. cf. *A. undulata*  
*Astarte* sp. aff. *A. castanea* (*Astarte* resembling the modern *A. castanea*, possibly an undescribed new species)  
*Marvacrassatella kauffmani*  
*Crassinella* spp. (Mostly *Crassinella lunata*, but probably includes some *C. dupliniana* and *C. johnsoni* as described by Ward and Blackwelder (1987))  
*Laevicardium sublineatum*  
*Mulinia lateralis*  
*Spisula* spp. (*S. solidissima* and *S. similis*, undifferentiated)  
*Raeta plicatella*  
*Ensis directus*  
*Strigilla* sp.  
*Tellina agilis*  
*Tellina* sp.  
*Macoma holmesii*  
*Donax fossor*  
*Semele bellastrata*  
*Semele nuculoides*  
*Abra aequalis*  
*Cumingia tellinoides*  
*Gouldia metastratum*  
*Transennella stimpsoni*  
*Pitar* sp.  
*Macrocallista greeni*  
*Gemma magna* (Ward and Blackwelder (1987) recognize the subspecies *Gemma magna majorina*)  
*Chione grus*  
*Chione cribraria*  
*Mercenaria permagna*

*Petricola pectorosa*  
*Petricola pholadiformis*  
 ?*Mya* sp.  
*Paramya subovata*  
*Sphenia* sp.  
*Caryocorbula* spp. (*C. contracta* and a few *C. auroraensis*, undifferentiated)  
*Gastrochaena hians*  
*Hiatella arctica*  
 ?*Panope* sp.  
 ?*Cyrtopleura* sp.  
*Pandora* sp. cf. *P. tuomeyi*  
*Cochlodesma emmonsii*  
*Thracia brioni*  
*Verticordia lockei*

#### SCAPHOPODA

*Cadulus quadridentatus*

#### AMPHINEURA

?*Chaetopleura* sp.

#### GASTROPODA

*Diodora nucula*  
*Diodora* sp.  
*Calliostoma* sp.  
*Arene pergemma*  
*Cyclostremiscus obliquistriatus*  
*Didianema carolinae*  
 ?*Solariorbis* sp.  
*Caecum pulchellum*  
*Caecum imbricatum*  
*Caecum* sp. cf. *C. flemingi*  
*Turritella perexilis*  
*Vermicularia* sp.  
*Serpulorbis granifera*  
*Seila adamsii*  
*Triphora* sp.  
*Epitonium leai*  
*Epitonium sohli*  
*Epitonium* sp. cf. *E. carolinae*  
*Strombiformis bartschi*  
*Strombiformis dalli*  
*Crucibulum* sp. cf. *C. lawrencei*  
*Calyptraea centralis*  
*Crepidula aculeata*  
*Crepidula fornicata*



*Crepidula convexa*  
*Crepidula plana*  
*Trivia floridana*  
*Polinices duplicata*  
*Lunatia heros*  
*Tectonatica pusilla*  
 ?*Murexiella* sp.  
*Urosalpinx perrugata*  
 ?*Pterorhytis* sp.  
 ?*Eupleura* sp.  
*Mitrella gardnerae*  
*Anachis milleri*  
*Aesopus gardnerae*  
*Aesopus ithitoma*  
*Aesopus stearnsii*  
*Nassarius chowanensis*  
*Nassarius cornelliana*  
*Nassarius fargoii*  
*Nassarius schizopyrga?*  
*Busycon* sp.  
 ?*Fasciolaria* sp.  
 ?*Fusinus* sp.  
*Oliva carolinensis*  
*Olivella mutica*  
*Vexillum wandoense*  
*Scaphella* sp.  
 ?*Cancellaria* sp.  
*Granulina ovuliformis*  
*Prunum limatulum*  
*Dentimargo polyspira*  
*Dentimargo* sp.  
*Volvarina* sp.  
*Conus* sp.  
*Strioterebrum* sp.  
*Cymatosyrinx lunata*  
*Sedilia* sp.  
 ?*Glabrocythara* sp.  
*Brachyocythara reidenbachi*  
*Odostomia* sp.  
*Pyrgiscus* spp. (At least two species)  
*Turbonilla abrupta*  
*Turbonilla* sp.  
*Acteocina candei*

#### CRUSTACEAN ?

Wilson (1983) described an unusual blister-like growth in some specimens of *Mercenaria permagna* from the James City Formation (referred to as the “Croatan Formation” by Wilson) at the Lee Creek Mine. He compared these features with those in other Miocene-Pleistocene *Mercenaria*. Wilson believed these aberrations to be the result of a thoracican

barnacle that lived as a parasite. The origin of the “enigmatic fossil” is still unknown. Its presence is here noted with no conclusion as to its origin or affinities.

#### OSTRACODES

Hazel (1983) took six samples from the “Croatan Formation” which are herein considered to be from the James City Formation. Those samples (Samples 11, 12, 13, 14, 15, 16) contained the following ostracodes:

##### Sample 11

*Actinocythereis captionis*  
*Anchistrocheles* sp. C  
*Bairdoppilata triangulata*  
*Bensonocythere blackwelderi*  
*Bensonocythere bradyi*  
*Bensonocythere gouldensis*  
*Bensonocythere whitei*  
*Bensonocythere* sp. OO  
*Campylocythere laeva*  
*Cytheridea carolinensis*  
*Cytheridea virginensis*  
*Cytheromorpha? incisa*  
*Cytheromorpha? macroincisa*  
*Cytheromorpha? suffolkensis*  
*Cytheropteron? yorktownensis*  
*Echinocythereis leecreekensis*  
*Echinocythereis gibba*  
*Echinocythereis triangulata*  
*Hirshmannia? hespera*  
*Hirshmannia? quadrata*  
*Hulingsina americana*  
*Hulingsina glabra*  
*Hulingsina rugipustulosa*  
*Hulingsina* sp. F  
*Leptocythere* sp. F  
*Malzella evexa*  
*Microcytherura choctawhatcheensis*  
*Microcytherura expanda*  
*Microcytherura similis*  
*Microcytherura* sp. R  
*Muellerina bassiounii*  
*Muellerina blowi*  
*Muellerina ohmertii*  
*Muellerina wardi*  
*Neocaudites variabilis*  
*Orionina vaughani*  
*Paracytheridea altila*  
*Paradoxostoma* sp. E  
*Peratocytheridea bradyi*  
*Proteocoeloccha multipunctata, sensu lato*

*Pseudocytheretta burnsi*  
*Puriana carolinensis*  
*Radimella confragosa*  
*Schlerochilus* sp. B  
*Xestoleberis ventrostriata*

## Sample 12

*Actinocythereis captionis*  
*Bairdoppilata triangulata*  
*Bensonocythere blackwelderi*  
*Bensonocythere ricespitensis*  
*Bensonocythere whitei*  
*Campylocythere laeva*  
*Cytheridea carolinensis*  
*Cytheridea virginiensis*  
*Cytheromorpha suffolkensis*  
*Cytheropteron talquinensis*  
*Cytheropteron?* yorktownensis  
*Cytherura forulata*  
*Cytherura howei*  
*Cytherura* sp. N  
*Echinocythereis leecreekensis*  
*Echinocythereis gibba*  
*Eucythere declivis*  
*Eucythere gibba*  
*Hirshmannia?* hespera  
*Hirshmannia?* quadrata  
*Hulingsina americana*  
*Hulingsina rugipustulosa*  
*Hulingsina* sp. C  
*Hulingsina* sp. F  
*Loxoconcha edentonensis*  
*Loxoconcha purisubrhomboidea*  
*Loxoconcha reticularis*  
*Loxoconcha* sp. H  
*Malzella evexa*  
*Microcytherura choctawhatcheensis*  
*Microcytherura similis*  
*Microcytherura* sp. M  
*Muellerina bassiounii*  
*Muellerina blowi*  
*Muellerina ohmerti*  
*Muellerina wardi*  
*Neocaudites variabilis*  
*Orionina vauhani*  
*Paracytheridea altila*  
*Paracytheridea cronini*  
*Peratocytheridea sandbergi*  
*Peratocytheridea bradyi*  
*Proteoconcha multipunctata, sensu lato*  
*Puriana carolinensis*  
*Puriana rugipunctata*  
*Radimella confragosa*

*Thaerocythere carolinensis*  
*Thaerocythere schmidtae*  
*Xestoleberis* sp. E

## Sample 13

*Actinocythereis captionis*  
*Bairdoppilata triangulata*  
*Bensonocythere blackwelderi*  
*Bensonocythere whitei*  
*Bensonocythere* sp. PP  
*Bensonocythere* sp. RR  
*Campylocythere laeva*  
*Caudites paraasymmetricus*  
*Cytheridea carolinensis*  
*Cytheridea virginiensis*  
*Cytheromorpha?* curta  
*Cytheromorpha?* incisa  
*Cytherura forulata*  
*Cytherura howei*  
*Cytherura reticulata*  
*Cytherura* sp. AA  
*Cytherura* sp. BB  
*Cytherura* sp. M  
*Cytherura* sp. N  
*Cytherura* sp. U  
*Cytherura* sp. W  
*Eucythere gibba*  
*Eucythere triangulata*  
*Hirshmannia?* quadrata  
*Hulingsina americana*  
*Hulingsina glabra*  
*Hulingsina rugipustulosa*  
*Hulingsina* sp. C  
*Hulingsina* sp. F  
*Leptocythere* sp. E  
*Loxoconcha edentonensis*  
*Loxoconcha matagordensis*  
*Loxoconcha reticularis*  
*Loxoconcha* sp. H  
*Malzella evexa*  
*Microcytherura choctawhatcheensis*  
*Microcytherura similis*  
*Microcytherura* sp. D  
*Muellerina bassiounii*  
*Muellerina blowi*  
*Muellerina ohmerti*  
*Muellerina wardi*  
*Orionina vauhani*  
*Palaciosia minuta*  
*Paracytheridea altila*  
*Paracytheridea cronini*  
*Paracytheridea mucra*  
*Paracytheridea rugosa*

*Paracytheroma stephensoni*  
*Paradoxostoma delicata*  
*Paranesidea? laevicula*  
*Peratocytheridea bradyi*  
*Peratocytheridea sandbergi*  
 "Pontocythere" sp. I  
 "Pontocythere" sp. J  
*Proteoconcha gigantea*  
*Proteoconcha multipunctata, sensu lato*  
*Proteoconcha tuberculata*  
*Pseudocytheretta burnsi*  
*Puriana carolinensis*  
*Puriana convoluta*  
*Puriana mesacostalis*  
*Puriana rugipunctata*  
*Radimella confragosa*  
*Xestoleberis ventrostriata*

#### Sample 14

*Actinocythereis captionis*  
*Bairdoppilata triangulata*  
*Bensonocythere ricespitensis*  
*Bensonocythere whitei*  
*Bythocythere* sp. B  
*Campylocythere laeva*  
*Caudites paraasymmetricus*  
*Cushmanidea* sp. C. *seminuda*  
*Cytherelloidea* sp. A  
*Cytheridea carolinensis*  
*Cytheridea virginensis*  
*Cytheridea? yorktownensis*  
*Cytherura forulata*  
*Cytherura reticulata*  
*Cytherura* sp. L  
*Cytherura* sp. N  
*Hirshmannia? hespera*  
*Hirshmannia? quadrata*  
*Hulingsina americana*  
*Hulingsina glabra*  
*Hulingsina* sp. C  
*Hulingsina* sp. F  
*Leptocythere nikraveshae*  
*Loxoconcha matagordensis*  
*Loxoconcha* sp. H  
*Loxoconcha* sp. T  
*Malzella evexa*  
*Microcytherura choctawhatcheensis*  
*Microcytherura similis*  
*Muellerina ohmertii*  
*Muellerina wardi*  
*Orionina vauhani*  
*Paracytheridea altila*  
*Paracytheroma stephensoni*

*Peratocytheridea bradyi*  
*Peratocytheridea sandbergi*  
*Peratocytheridea* sp. J  
*Proteoconcha multipunctata, sensu lato*  
*Pseudocytheretta burnsi*  
*Puriana carolinensis*  
*Puriana convoluta*  
*Sclerochilus* sp. B  
*Thaerocythere schmidtae*  
*Xestoleberis ventrostriata*

#### Sample 15

*Actinocythereis captionis*  
*Bairdoppilata triangulata*  
*Bensonocythere gouldensis*  
*Bensonocythere* sp. M  
*Campylocythere laeva*  
*Caudites paraasymmetricus*  
*Cyprideis* sp. B  
*Cytheridea carolinensis*  
*Cytheridea virginensis*  
*Cytheromorpha macroincisa*  
*Cytheropteron? yorktownensis*  
*Cytherura elongata*  
*Cytherura forulata*  
*Cytherura howei*  
*Cytherura reticulata*  
*Cytherura wardensis*  
*Cytherura* sp. AA  
*Cytherura* sp. M  
*Cytherura* sp. N  
*Hulingsina rugipustulosa*  
*Hulingsina* sp. C  
*Hulingsina* sp. F  
*Loxoconcha matagordensis*  
*Loxoconcha* sp. H  
*Microcytherura choctawhatcheensis*  
*Microcytherura expanda*  
*Microcytherura similis*  
*Microcytherura* sp. P  
*Microcytherura* sp. R  
*Muellerina ohmertii*  
*Neocaudites angulatus*  
*Orionina vauhani*  
*Paracytheridea altila*  
*Paracytheridea rugosa*  
*Paracytheroma stephensoni*  
*Paradoxostoma delicata*  
*Peratocytheridea sandbergi*  
*Peratocytheridea setipunctata*  
 "Pontocythere" sp. I  
*Proteoconcha multipunctata, sensu lato*  
*Pseudocytheretta burnsi*

*Puriana carolinensis*  
*Puriana mesacostalis*  
*Radimella confragosa*  
*Xestoleberis* sp. E

Sample 16

*Actinocythereis captionis*  
*Actinocythereis mundorffi*, small form  
*Bairdoppilata triangulata*  
*Bensonocythere whitei*  
*Campylocythere laeva*  
*Cnestocythere?* sp.  
*Cyprideis* sp. B  
*Cytherelloidea* sp. A  
*Cytherura* sp. N  
*Hulingsina americana*  
*Hulingsina rugipustulosa*  
*Loxoconcha matagordensis*  
*Loxoconcha* sp. H  
*Loxoconcha* sp. T  
*Malzella evexa*  
*Microcytherura choctawhatcheensis*  
*Microcytherura expanda*  
*Microcytherura similis*  
*Muellerina bassiounii*  
*Muellerina ohmerti*  
*Muellerina wardi*  
*Orionina vaughani*  
*Paracytheridea altila*  
*Peratocytheridea bradyi*  
*Peratocytheridea sandbergi*  
 "Pontocythere" sp. I  
*Puriana carolinensis*  
*Radimella confragosa*

Based upon these extensive assemblages of ostracodes, Hazel concluded that the James City Formation at the Lee Creek Mine (upper Croatan Formation of Hazel) is within the *Puriana mesacostalis* Assemblage Zone and was correlative with the Waccamaw Formation in the Carolinas and with the type Caloosahatchee in Florida.

#### ECHINOIDS

Kier (1983) described a single species of echinoid from the James City Formation (Croatan Formation of Kier). Kier compared the specimens to *Mellita acclinensis* and *M. caroliniana* and found them to be intermediate between those species. He concluded that the James City species should be referred to the following:

*Mellita* cf. *M. acclinensis* Kier

#### Vertebrates

##### SHARKS

Purdy et al. (2001) listed two species of sharks, based on teeth, from the James City Formation. Those taxa are:

*Carcharias taurus*  
*Carcharodon carcharias*

The scarcity of shark, ray and bony fish remains in units above the Sunken Meadow Member of the Yorktown Formation (lower Pliocene) is reflected in all of the stratigraphic units along the Atlantic Coastal Plain. The James City Formation is typical in this regard. In many cases, teeth found in the lower part of the formations, or along their lower contacts, are reworked from lower units as a lag deposit. This is common where young beds directly overlie units of the lower Pliocene or older.

##### BONY FISH

Purdy et al. (2001) listed two species of bony fish from the James City Formation. They are:

*Lepisosteus osseus*  
*Chilomycterus schoepfi*

#### Upper Pleistocene

##### Flanner Beach Formation

##### STRATIGRAPHY

The Flanner Beach Formation was named by DuBar and Solliday (1963) for exposures along the lower Neuse River in Craven County. The formation is seen in intermittent outcrops from the Trent River to Cherry Point where it overlies the James City. At the type section at Flanner Beach, on the Neuse River, the series of beds included in the unit range from carbonaceous sands with cypress stumps, to brown, poorly-sorted sands with brackish-water mollusks (*Rangia*), to fine sands containing a diverse marine molluscan assemblage. The term "Flanner Beach" was proposed to replace Croatan which was considered too broadly defined to be of stratigraphic value.

This same type of sequence occurs at the Lee Creek Mine, but only in a few places can the marine units be observed. In most of the pit, the horizon in which the marine mollusks occur grades into a poorly-sorted, fine, muddy sand, which is

leached of fossils or did not contain them. (See Ward and Blackwelder, 1987:116, fig. 3, units F and B.)

Hoffman and Ward (1989) briefly described the Flanner Beach Formation at the Lee Creek Mine. It was depicted as a crossbedded quartz sand in their figure 4.4. The estuarine and marine fossiliferous beds at the Lee Creek Mine were not exposed at that time.

## PALEONTOLOGY

### Trace Fossils

Curran (1976) described a notable trace fossil from the “wavy-flaser bedded member” of the “current unit.” This burrow was interpreted to be a fossil brood structure of probable callianassid origin.

Belt et al. (1983) and Curran and Frey (1977) described the beds overlying the Chowan River Formation (their “Boulder Bed”) and the James City Formation (their “Upper Shell Unit”) in detail. In ascending order, they described a “Mud and Sand Unit,” a “Current Unit” cut into by a “Channel Unit,” a “Peat and Clay Unit,” a “Mottled Unit,” and a “Rooty Unit.” These latter four units are interpreted to be in the Flanner Beach Formation. In these units, they found a number of trace fossils in the form of burrows.

These trace fossils were the following with their probable constructors:

#### Mud and Sand Unit

*Ophiomorpha nodosa*, *Callianassa major*  
*Thalassinoides*, *Alpheus heterochaelis*  
*Skolithos linearis*, *Onuphis* sp.

#### Current Unit

*Ophiomorpha nodosa*  
*Skolithos linearis*  
“sitz marks”

#### Channel Unit

*Ophiomorpha*  
*Skolithos*

#### Peat and Clay Unit

*Thalassinoides*

#### Mottled Unit

*Ophiomorpha nodosa*  
*Skolithos linearis*  
*Planolites beverlyensis*  
crab burrows poss. ocyopode, *Cardisoma*

Molds of mollusks were present in the indurated burrows. Some of the taxa identified were the following:

*Oliva* sp.  
*Terebra* sp.  
*Tellina* sp.  
*Mulinia* sp.  
*Ensis* sp.

## Invertebrates

### MOLLUSKS

Ward and Blackwelder (1987) referred their Units F and G to the Flanner Beach ? Formation. Unit F was described as a “Dark olive gray (5Y 3/1) fine sandy clay, burrowed, with wood stumps at the top surface.” This unit, which appeared very dark in most of the walls of the pit in the early 1970’s, occupies channels cut into the underlying James City and, in some cases, the Chowan River Formation. Some of these cuts are narrow and irregular and some are seen as broad, gently sloping channels. At the top of Unit F cypress stumps are commonly rooted. These stumps protrude into Unit G, which was described as a “tan to orange fine sand, cross bedded.” Unit F is a clean, fine, light-colored, current-bedded sand that is seen over much of the area of the pit as the capping bed which is overlain by the surface soil. In the early 1970’s, the area where Ward and Blackwelder (1987:figures 4-6, 8) worked did not exhibit the “Mottled Unit” described by Belt et al. (1983).

During a visit to the Lee Creek Mine by the author on December 18, 1992, with Warren Allmon, the south wall exhibited a 14-foot bed similar to the “Mottled Unit” of Belt et al. (1983) that directly overlay their “Current Unit” (Ward and Blackwelder’s Unit G). On the north wall that 14-foot bed was differentiated into the following:

“Mottled Unit”	1 foot	soil
	4 feet	sand, gray, silty, fine, with abundant <i>Mulinia lateralis</i>
	6 feet	silt, dark, clayey
	3 feet	silt; very fine, sandy, carbonaceous; many <i>Crassostrea</i>
“Current Unit,” upper part	6 feet	white, cross-bedded sand, burrowed

This was the first observation at the Lee Creek Mine of preserved fossiliferous beds in the Flanner Beach Formation by this author. The collections from the *Crassostrea* bed and from the *Mulinia* bed produced an assemblage of molluscan

taxa previously unrecorded. They are, therefore, reported here for the first time. This is a departure from the main theme of this paper, which is to synthesize previously published data, but it is the only known molluscan list from this horizon.

The molluscan composition present in the *Crassostrea* bed and the *Mulinia* bed established the correlation of these beds with the Flanner Beach Formation in its type area. The following are the lists of mollusks identified from the two beds:

#### ***Crassostrea* bed**

##### Bivalves

*Crassostrea virginica* (Gmelin)  
*Anadara transversa* (Say)  
*Lunarca ovalis* (Bruguière)  
*Noetia ponderosa* (Say)  
*Anomia simplex* (d'Orbigny)  
*Rangia cuneata* (Sowerby)  
*Brachidontes exustus* (Linnaeus) – young, fragment  
*Caryocorbula swiftiana* (C. B. Adams) – fragment  
*Anadara transversa* (Say) – young, fragment  
*Anomia simplex* (d'Orbigny) – young  
*Mulinia lateralis* (Say)

##### Gastropods

*Nassarius* sp.  
*Pyrgocythara plicosa* (C.B. Adams)  
*Seila* sp.  
*Acteocina candei* (d'Orbigny)  
*Odostomia* sp.  
*Triphora* sp.

##### Arthropods

*Balanus* – young, detached plates

#### ***Mulinia* bed**

##### Bivalves

*Anadara transversa* (Say)  
*Lunarca ovalis* (Bruguière)  
*Noetia ponderosa* (Say)  
*Brachidontes exustus* (Linnaeus)  
*Argopecten irradians* (Lamarck)  
*Carolinapecten eboreus solarioides* (Heilprin)  
*Anomia simplex* (d'Orbigny)  
*Crassostrea virginica* (Gmelin)  
*Parvilucina multilineata* (Tuomey and Holmes)  
*Divaricella quadrisulcata* (d'Orbigny)  
*Diplodonta punctata* (Say)  
*Mysella beaufortensis* Ward and Blackwelder  
*Cyclocardia granulata* (Say)  
*Dinocardium robustum* (Lightfoot)

*Mulinia lateralis* (Say)  
*Mactrellona* sp. ?  
*Raeta plicatella* (Lamarck)  
*Ensis directus* Conrad  
*Tellina alternata* Say  
*Tellina agilis* Stimpson  
*Macoma* sp.  
*Abra aequalis* (Say)  
*Mercenaria mercenaria* (Linnaeus) – open-marine form  
*Mercenaria mercenaria* (Linnaeus) – back-barrier form  
*Dosinia discus* (Reeve)  
*Paramya subovata* (Conrad)  
*Caryocorbula contracta* (Say)  
*Caryocorbula swiftiana* (C. B. Adams)  
*Panopea bitruncata* Conrad  
*Cyrtopleura costata* (Linnaeus)  
*Pandora trilineata* Say

##### Gastropods

*Serpulorbis granifera* (Say)  
*Epitonium* sp.  
*Seila* sp.  
*Crepidula fornicata* (Linnaeus)  
*Crepidula plana* Say  
*Polinices (Neverita) duplicata* (Say)  
*Sinum perspectivum* (Say)  
*Urosalpinx cinereus* (Say)  
*Anachis* sp.  
*Nassarius trivittatus* (Say)  
*Nassarius vibex* (Say)  
*Ilyanassa obsoleta* (Say)  
*Nassarius* sp.  
*Nassarius* sp.  
*Oliva sayana* Ravenel  
*Busycon carica* (Gmelin)  
*Pyrgocythara plicosa* (C.B. Adams)  
*Terebra dislocata* (Say)  
*Terebra concava* Say  
*Acteocina candei* (d'Orbigny)

##### Miscellaneous

Bryozoans indet.  
*Balanus* sp.  
*Callianassa* sp. – free fingers  
*Myliobatis* sp.

The appearance of *Lunarca ovalis* coincides with Blackwelder's (1981) Mollusk Zone M2 or his *Anadara ovalis* – *Anadara brasiliensis* Interval-Zone. It marks the first appearance of *L. ovalis* at about 0.5 mya and shows the Flanner Beach to be the stratigraphic equivalent of the Canepatch Formation in northeastern South Carolina. It may be noted here that this bed, and those correlative, such as the

Canepatch Formation, mark the last appearance of the *Carolinapecten* lineage. The species contained in the Flanner Beach was *Carolinapecten solarioides*, specimens of which are more than 7 inches (179 mm) wide and double-valved. This lineage ended when it had reached its maximum size and was common to abundant from the Carolinas to Florida.

The *Crassostrea* bed clearly reflects a brackish-water, probably back-barrier, muddy, estuarine regime. It is dominated by *Crassostrea*, which never grew to full adult size. The other taxa mentioned from this bed fall in the very small size range and consist of a tiny fraction of the biomass.

The *Mulinia* bed reflects more open-bay conditions, though that area was still probably in a protected, quiet, lagoonal setting. The increase in diversity indicates a nearly normal saline marine condition, but most of the taxa are near-shore, shallow-shelf species.

See Plates 16 and 17 for illustrations of mollusks from the Flanner Beach Formation.

### Plants

Whitehead (1983) studied a peat bed near the top of the Flanner Beach Formation and found it to be greater than 42000 years old. He concluded that the following pollen assemblage was deposited in a very wet, freshwater environment:

#### Arboreal

*Pinus*

*Picea*

*Abies*

Cupressaceae

*Quercus*

*Carya*

*Betula*

*Fraxinus*

*Corylus*

*Nyssa*

*Liquidambar*

*Ostrya-Carpinus*

*Castanea*

*Populus*

#### Shrub

*Alnus*

*Lonicera*

Ericaceae

*Viburnum*

#### Herb

Gramineae

Cyperaceae

Compositae

Liguliflorae

*Ambrosia*

*Artemisia*

Rosaceae

*Ranunculus*

*Thalictrum*

Umbelliferae

*Sanguisorba canadensis*

Chenopod-amaranth

#### Aquatic

*Polygonum* (*Persicaria* type)

*Potamogeton*

*Brasenia*

*Nuphar*

*Myriophyllum heterophyllum*

*Pontederia*

*Isoetes*

*Sagittaria*

*Nymphaea*

*Typha-Sparganium* type

#### Algae

*Botryococcus*

*Pediastrum boryanum*

*Tetraedron*

#### Miscellaneous

*Sphagnum*

*Botrychium* cf. *dissectum*

*Osmunda regalis*

Monolete fern

Trilete fern

Unknown

Unidentifiable

### Flanner Beach Formation (?)

Wolf and Nease (1970) examined the accumulated sediment in two of these marsh-sediment settings that occurred at a depth of 12-15 feet (3.7 – 4.6 m) below the present land surface. They stated that the unit was discontinuous and of coal-black color. The bed, they said, occurred immediately above a “shell bed” containing *Neotia* [sic *Noetia*], *Modiolus*, *Ostrea*, *Anomia*, *Chlamys*, and *Corbicula*. I believe that it is possible that Wolf and Nease were referring to the estuarine channel unit in the base of the Flanner Beach series. That unit, which has cypress stumps rooted in it, was Bed F of Ward and Blackwelder (1987).

Wolf and Nease (1970) reported numerous plant and animal remains as listed below:

#### *Invertebrates*

#### FORAMINIFERA

Rare

**SPONGES**

Spicules

Gemmules (attached to leaves)

**BRANCHIOPODS**

Rare

**INSECTS***Paratrechina* sp. (ant)

Beetles (elytra abundant)

**Plants****WOOD***Chamaecyparis thyroides* (Linnaeus)- white cedar*Taxodium distichum*- bald cypress*Nyssa aquatica* Linnaeus- cotton gum*Pinus* sp.- pine*Hicoria* sp.- hickory*Quercus rubra* Linnaeus- red oak*Diospyros virginiana* Linnaeus- persimmon*Alnus incana* (Linnaeus)- alder**LEAVES***Potamogeton* sp.*Vallisneria* sp.

Numerous broad-leaf trees, shrubs, pine needles, and ferns

**SEEDS***Taxodium distichum**Ruppia maritima* Linnaeus (ditch grass)*Zannichellia palustris* Linnaeus (horned pond weed)*Vallisneria americana* Michx (eel grass)**POLLEN***Pinus* and other conifers*Quercus**Myrica**Betula*Fragmented *Betula* and *Myrica**Carya**Ulmus**Acer**Liquidambar**Artemisia**Ambrosia**Senecio*

Cyperaceae

Gramineae

Reniform fern

Polypodiaceae

Unknown

**MOSSES***Leptodictyum riparium**Leskia australis**Distichum lineare***ALGAE**

20 or more genera of diatoms

50 species of diatoms

Coleochaete

Microspora

Chrysophyta

**FUNGI**

Spores indicated the following taxa:

*Asterina**Capnodium**Cercospora**Trichocladium**Cordana**Chaetomium**Leptosphaeria**Xylaria**Torula**Tetraploa**Meliola**Pleospora**Melanospora**Exosporium*

Wolf and Nease (1971) also reported on the presence of chlorophyll preserved in the leaves in this same deposit.



## CONCLUSION

The enormous amount of work that has been accomplished on the geology and paleontology of the Lee Creek Mine is reflected in the Literature Cited section of this paper, and the exhausting lists of studied fossils in the text. This work has covered many specialties and countless thousands of specimens. But, the volume of work outlined here also highlights, though not intentionally, the serious omissions and holes in the data.

First of all, there is no preserved section where present or future geologists can examine the whole sequence exposed at the Lee Creek Mine. This would be difficult for a number of reasons:

1. Recovery operations dictate that mined areas be sloped and covered.
2. Walls left vertical would be inherently unsafe and would, over time, slump and cover themselves due to weathering and groundwater. This could be alleviated by terracing.
3. Continuous pumping would be required to keep the groundwater level down.

Some might suggest the use of cores to accomplish this kind of study, but anyone who has had continuous exposures of beds over miles (or even yards) would never say that cores are a better way of study. They can be a blessing, but only when other options are unavailable.

I would hope that, at some not-so-distant time, a portion of the pit could be left open to accomplish some of the unfinished work. Among those goals I can see the following:

1. Collect lithologic samples (~1 cubic meter) vertically from top to bottom, with as many additional samples horizontally as possible at crucial intervals. Long term storage of those samples would be essential.
2. Collect paleontologic samples, in place, for the groups as

yet unstudied or nearly so. Several of these are:

Pollen – From the Castle Hayne to the Flanner Beach.

Dinoflagellates – From the Castle Hayne to the Flanner Beach.

Diatoms – From the whole sequence at the Lee Creek Mine. Previous work was on cores at some distance from the Lee Creek Mine and did not cover all of the Pungo River exposed there.

Foraminifera – Extensive sampling from the Pungo River and lists of all taxa, not just key taxa.

Mollusks – Carter and Nekola (1992) did a preliminary study on the Pungo River, but more work needs to be done on this important interval which extends north to New Jersey and south to West Florida. In addition, the Yorktown and Flanner Beach fauna is mostly undocumented.

Bryozoans – Some of the units have concentrations of bryozoans, but none have been systematically treated.

Corals – The coral in the James City and other units has never been systematically treated and has been misidentified in numerous papers.

Vertebrates – Although thoroughly studied, most specimens are fragmented and most are of uncertain provenance. Better specimens with better data would certainly clear up some of the poor record.

These are just some of the areas, but certainly not all, that are ripe for study in the Lee Creek Mine, given the advantage of access to the working wall and “in place,” undisturbed fossils. The indefinite accessibility of such an exposure may not be economically feasible or physically possible. One would hope that Plant officials could provide a window of time, however short, when such a study could be implemented. By carefully timing the movement or repair of equipment (down time) with a preselected group of scientists that stand ready, this important work could be accomplished. Those scientists, then, would make their samples available to any serious geologists and paleontologists.

## LITERATURE CITED

Abbott, W.H.

1978. Correlation and zonation of Miocene strata along the Atlantic margin of North America using diatoms and silicoflagellates. *Marine Micropaleontology*, 3:15-34, figures 1-4, plates 1,2.
1980. Diatoms and stratigraphically significant silicoflagellates from the Atlantic Margin Coring Project and other Atlantic margin sites. *Micropaleontology*, 26(1):49-80, plates 1-6.

1982. Diatom Biostratigraphy of the Chesapeake Group, Virginia and Maryland. In Scott, T.M., and S.B. Upchurch (Eds.), Miocene of the Southeastern United States. *Florida Department of Natural Resources, Bureau of Geology Special Publication*, 25:23-34, figures 1-7, table 1.

Abbott, W.H., and J.J. Ernissee

1983. Biostratigraphy and paleoecology of a diatomaceous clay unit in the Miocene Pungo River

- Formation of Beaufort County, North Carolina. In Ray, C.E. (Ed.), *Geology and Paleontology of the Lee Creek Mine, North Carolina, I. Smithsonian Contributions to Paleobiology*, 53:287-353, figures 1-4, plates 1-26, 1 table.
- Bailey, R.H.  
1977. Neogene molluscan assemblages along the Chowan River, North Carolina. *Southeastern Geology*, 18(3):173-189, figures 1-3, tables 1,2.
- Beddard, L.B.  
1991. *A field guide to fossil finds for the young paleontologist*. 19 pages. Published by Linda Beddard.
- Belt, E.S., R.W. Frey, and J.S. Welch  
1983. Pleistocene coastal marine and estuarine sequences, Lee Creek Mine. In Ray, C.E. (Ed.), *Geology and Paleontology of the Lee Creek Mine, North Carolina, I. Smithsonian Contributions to Paleobiology*, 53:229-263, figures 1-17, 1 table.
- Blackwelder, B.W.  
1981. Late Cenozoic stages and molluscan zones of the U.S. middle Atlantic Coastal Plain. *Journal of Paleontology Memoir*, 12:1-34, figures 1-9, plates 1-10, table 1.
- Blow, W. H.  
1969. Late Middle Eocene to Recent Planktonic Foraminiferal Biostratigraphy. In *Proceedings of the First International Conference on Planktonic Microfossils, Geneva, Switzerland, 1967*, 1:199-422, 54 plates, 43 figures. Leiden:E. J. Brill.
- Boreske, J.R., L. Goldberg, and B. Cameron  
1972. A reworked cetacean with clam borings: Miocene of North Carolina. *Journal of Paleontology*, 46(1):130-139, figures 1-6, plate 1.
- Brown, P.M.  
1958a. The relation of phosphorites to ground water in Beaufort County, North Carolina. *Economic Geology and the Bulletin of the Society of Economic Geologists*, 53(1):85-101.  
1958b. Well logs from the Coastal Plain of North Carolina. *North Carolina Department of Conservation and Development, Division of Mineral Resources Bulletin*, 72:1-67, figures 1-9, plates 1-8, 1 table.
- Campbell, L.D.  
1993. Pliocene Molluscs from the Yorktown and Chowan River Formations in Virginia. *Virginia Division of Mineral Resources Publication* 127:1-259, figures 1-3, plates 1-43, tables 1-5.
- Carter, J.G., P.E. Gallagher, R.E. Valone, T.J. Rossbach, P. G. Gensel, W.H. Wheeler, and D. Whitman  
1988. Fossil collecting in North Carolina. *North Carolina. Department of Natural Resources and Community Development, Division of Land Resources, Geological Survey Section Bulletin*, 89:1-89, figures 1-34, plates 1-10. [Figures 1-80 are on Plates 1-10.]
- Carter, J.G., and J. Nekola  
1992. Molluscan fauna of the Pungo River Formation, Lee Creek Mine, North Carolina. In Dennison, J.M., and K.G. Stewart (Eds.), *Geologic field guides to North Carolina and vicinity*, pages 131-137. Geological Society of America, Southeastern Section, Raleigh, March, 1992.
- Case, G.R.  
1972. *Handbook of fossil collecting*. 64 pages, 145 figures. Published by Gerald R. Case.
- Clark, W.B., and B.L. Miller  
1906. A brief summary of the geology of the Virginia Coastal Plain. *Virginia Geological Survey Bulletin*, 2:11-24.  
1912. The physiography and geology of the Coastal Plain Province of Virginia. *Virginia Geological Survey Bulletin*, 4:13-222.
- Clark, W.B., B.L. Miller, L.W. Stephenson, B.L. Johnson, and H.N. Parker  
1912. The Coastal Plain of North Carolina. *North Carolina Geological and Economic Survey*, III:1-552.
- Conrad, T.A.  
1841. Twenty-six new species of fossil shells . . . in the medial Tertiary deposits of Calvert Cliffs, Maryland. *Proceedings of the Academy of Natural Sciences of Philadelphia*, 1(3):28-33.
- Culotta, E.  
1992. A glimpse of oceans. *Earth*, 1(5):56-61.
- Curran, H.A.  
1976. A trace fossil brood structure of probable Callianassid origin. *Journal of Paleontology*, 50(2):249-259, 5 figures, 2 plates.
- Curran, H.A., and R.W. Frey  
1977. Pleistocene trace fossils from North Carolina (U.S.A.), and their Holocene analogues. In Crimes, T.P., and J.C. Harper (Eds.), *Trace fossils 2*, pages 139-162, figures 1,2, plates 1-5. *Liverpool: Geological Journal Special Issue*, 9, Seel House Press.
- Curran, H.A., and P.L. Parker  
1983. Observations on the paleoecology and formation of the "Upper Shell" Unit, Lee Creek Mine. In Ray, C.E. (Ed.), *Geology and Paleontology of the Lee Creek Mine, North Carolina, I. Smithsonian Contributions to Paleobiology*, 53:219-228, figures 1-5.

- Denison, R.E., E.A. Hetherington, B.A. Bishop, D.A. Dahl, and R.B. Koepnick  
1993. The use of strontium isotopes in stratigraphic studies; an example from North Carolina. *Southeastern Geology*, 33(2):53-69, figures 1-10, tables 1,2.
- DuBar, J.R., and J.R. Solliday  
1963. Stratigraphy of the Neogene deposits, lower Neuse Estuary, North Carolina. *Southeastern Geology*, 4(4):213-233.
- DuBar, J.R., J.R. Solliday, and J.F. Howard  
1974. Stratigraphy and morphology of Neogene deposits, Neuse River Estuary, North Carolina. In Oaks, R.Q., Jr., and J.R. DuBar (Eds.), *Post-Miocene stratigraphy, central and southern Atlantic Coastal Plain*, pages 102-122, figures 1-4, tables 1-8, appendix. Logan, Utah: Utah State University Press.
- Emmons, Ebenezer  
1858. *Report of the North-Carolina Geological Survey*. Henry D. Turner, Raleigh:1-314, 256 figures.
- Eshelman, R.E., and F.C. Whitmore, Jr.  
2007. Early Pliocene (Late Hemphillian) Land Mammals from the Lee Creek Mine, Aurora, North Carolina. In Ray, C. E., D. J. Bohaska, I.A. Koretsky, L.W. Ward, and L.G. Barnes (Eds.), *Geology and Paleontology of the Lee Creek Mine, North Carolina, IV. Virginia Museum of Natural History Special Publication*, 14:17-38, 12 figures, 3 tables.
- Fierstine, H.L.  
1999. A new shortbilled marlin of the genus *Makaira*, from the Yorktown Formation (Early Pliocene), Eastern North Carolina at Lee Creek Mine, U.S.A. *Tertiary Research*, 19(344):71-77.  
2001. Analysis and new records of billfish (Teleostei; Perciformes; Istiophoridae) from the Yorktown Formation, early Pliocene of eastern North Carolina at Lee Creek Mine. In Ray, C.E., and D.J. Bohaska (Eds.), *Geology and Paleontology of the Lee Creek Mine, North Carolina, III. Smithsonian Contributions to Paleobiology*, 90:21-69, figures 1-7, plates 1-12, tables 1-8.
- Fitch, J.E., and R.J. Lavenberg  
1983. Teleost fish otoliths from Lee Creek Mine, Aurora, North Carolina (Yorktown Formation; Pliocene). In Ray, C.E. (Ed.), *Geology and Paleontology of the Lee Creek Mine, North Carolina, I. Smithsonian Contributions to Paleobiology*, 53:509-529, figures 1-4, 1 table.
- Furnish, W.M., and B.F. Glenister  
1987. Miocene cephalopods from North Carolina. In Ray, C.E. (Ed.), *Geology and Paleontology of the Lee Creek Mine, North Carolina, II. Smithsonian Contributions to Paleobiology*, 61:9-11, 1 figure.
- Geisler, J.H. and Zhexi Luo  
1996. The petrosal and inner ear of *Herpetocetus* sp. (Mammalia: Cetacea) and their implications for the phylogeny and hearing of archaic mysticetes. *Journal of Paleontology*, 70(6):1045-1066, 7 figures.
- Gibson, T.G.  
1967. Stratigraphy and paleoenvironment of the phosphatic Miocene strata of North Carolina. *Geological Society of America Bulletin*, 78:631-650, 4 figures, 2 plates.  
1968. Stratigraphy and paleoenvironment of the phosphatic Miocene strata of North Carolina: Reply. *Geological Society of America Bulletin*, 79:1437-1448.  
1983a. Stratigraphy of Miocene through lower Pleistocene strata of the United States Central Atlantic Coastal Plain. In Ray, C.E. (Ed.), *Geology and Paleontology of the Lee Creek Mine, North Carolina, I. Smithsonian Contributions to Paleobiology*, 53:35-80, figures 1-37.  
1983b. Key Foraminifera from upper Oligocene to lower Pleistocene strata of the Central Atlantic Coastal Plain. In Ray, C.E. (Ed.), *Geology and Paleontology of the Lee Creek Mine, North Carolina, I. Smithsonian Contributions to Paleobiology*, 53:355-453, figures 1-2, plates 1-22.  
1987. Miocene and Pliocene Pectinidae (Bivalvia) from the Lee Creek Mine and adjacent areas. In Ray, C.E. (Ed.), *Geology and Paleontology of the Lee Creek Mine, North Carolina, II. Smithsonian Contributions to Paleobiology*, 61:31-112, figures 1-25, plates 1-31, tables 1-19.
- Hazel, J.E.  
1971. Ostracode biostratigraphy of the Yorktown Formation (upper Miocene and lower Pliocene) of Virginia and North Carolina. *U. S. Geological Survey Professional Paper 704*:1-13, figures 1-6, table 1.  
1983. Age and correlation of the Yorktown (Pliocene) and Croatan (Pliocene and Pleistocene) formations at the Lee Creek Mine. In Ray, C.E. (Ed.), *Geology and Paleontology of the Lee Creek Mine, North Carolina, I. Smithsonian Contributions to Paleobiology*, 53:81-199, figures 1-4, plates 1-38.
- Hoffman, C.W., and L.W. Ward  
1989. Upper Tertiary and Pleistocene deposits of northeastern North Carolina. In Harris, W.B., V.J. Hurst, P.G.J. Nystrom, and L.W. Ward (Eds.), *Upper Cretaceous and Cenozoic geology of the*

- Southeastern Atlantic Coastal Plain, Atlanta, Georgia to Chesapeake, Virginia. *28th International Geological Congress, Field Trip Guidebook T172:53-90*, July 1-9, 1989: *American Geophysical Union*.
- Holmes, F.S.  
1858. *Post-Pliocene Fossils of South-Carolina*, Nos. 1 and 2. Russell and Jones, 251 King-Street, Charleston, S.C., pages 1-?
- Hope, R.C.  
1985. North Carolina Fossils. *Rocks and Minerals*, 60(2):68-71, 6 figures.
- Hueber, F.M.  
1983. Fossil woods and resin-like substances from the Lee Creek Mine. In Ray, C.E. (Ed.), *Geology and Paleontology of the Lee Creek Mine, North Carolina, I. Smithsonian Contributions to Paleobiology*, 53:269-285, plates 1-4.
- Kazár, E., and D.J. Bohaska  
2007. Toothed Whale (Mammalia: Cetacea: Odontoceti) Limb Bones of the Lee Creek Mine, North Carolina. In Ray, C.E., D.J. Bohaska, I.A. Koretsky, L.W. Ward, and L.G. Barnes (Eds.), *Geology and Paleontology of the Lee Creek Mine, North Carolina, IV. Virginia Museum of Natural History Special Publication*, 14:271-324, 24 figures, 20 tables.
- Kier, P.M.  
1983. Upper Cenozoic echinoids from the Lee Creek Mine. In Ray, C.E. (Ed.), *Geology and Paleontology of the Lee Creek Mine, North Carolina, I. Smithsonian Contributions to Paleobiology*, 53:499-507, plates 1,2.
- Kimrey, J.O.  
1964. The Pungo River Formation, a new name for middle Miocene phosphorites in Beaufort County, North Carolina. *Southeastern Geology*, 5(4):195-205.  
1965. Description of the Pungo River Formation in Beaufort County, North Carolina. *North Carolina, Department of Conservation and Development, Division of Mineral Resources Bulletin* 79:1-131, figures 1-8, plates 1-11, 1 table.
- Knapp, Jane  
2007. Remington Kellogg: Bibliography of the Scientific Works and Index to Scientific and Common Names. In Ray, C.E., D.J. Bohaska, I.A. Koretsky, L.W. Ward, and L.G. Barnes (Eds.), *Geology and Paleontology of the Lee Creek Mine, North Carolina, IV. Virginia Museum of Natural History Special Publication*, 14:433-507.
- Kohno, N., and C.E. Ray  
2007. Pliocene Walruses from the Yorktown Formation of Virginia and North Carolina, and a Systematic Revision of the North Atlantic Pliocene Walruses. In Ray, C.E., D.J. Bohaska, I.A. Koretsky, L.W. Ward, and L.G. Barnes (Eds.), *Geology and Paleontology of the Lee Creek Mine, North Carolina, IV. Virginia Museum of Natural History Special Publication*, 14:39-80, 28 figures, 8 tables, appendices I-III.
- Koretsky, I.A., and C.E. Ray  
2007. Phocidae of the Pliocene of Eastern USA. In Ray, C.E., D.J. Bohaska, I.A. Koretsky, L.W. Ward, and L.G. Barnes (Eds.), *Geology and Paleontology of the Lee Creek Mine, North Carolina, IV. Virginia Museum of Natural History Special Publication*, 14:81-139, 51 figures, 16 tables.
- Leutze, W.P.  
1968. Stratigraphy and paleoenvironment of the phosphatic Miocene strata of North Carolina; discussion. *Geological Society of America Bulletin*, 79(10):1433-1436.
- Luo, Zhexi, and K. Marsh  
1996. Petrosal (periotic) and inner ear of a Pliocene Kogiine whale (Kogiinae, Odontoceti): Implications on relationships and hearing evolution of toothed whales. *Journal of Vertebrate Paleontology*, 16(2):328-348, 9 figures.
- Mansfield, W.C.  
1928. Notes on Pleistocene faunas from Maryland and Virginia and Pliocene and Pleistocene faunas from North Carolina. *U.S. Geological Survey Professional Paper* 150-F:129-140, plates 24,25.  
1943. Stratigraphy of the Miocene of Virginia and the Miocene and Pliocene of North Carolina. In Gardner, J., *Mollusca from the Miocene and lower Pliocene of Virginia and North Carolina, Part I. Pelecypoda. U.S. Geological Survey Professional Paper*, 199:1-19, figures 1-3, tables 1,2. [Published January, 1944.]
- Martin, G.C.  
1904. Mollusca – Cephalopoda. In Clark, W.B., G.B. Shattuck, and W.H. Dall (Eds.), *The Miocene deposits of Maryland, Maryland Geological Survey, Miocene*, 94 pages, figure 1, plate XXXIX.
- McLellan, J.H.  
1983. Phosphate mining at the Lee Creek Mine. In Ray, C.E. (Ed.), *Geology and Paleontology of the Lee Creek Mine, North Carolina, I. Smithsonian Contributions to Paleobiology*, 53:25-33, figures 1-3.

- Miller, B.L.  
1912. The Tertiary Formations. In Clark, W.B. B.L. Miller, L.W. Stephenson, B.L. Johnson, and H.N. Parker (Eds.), *The Coastal Plain of North Carolina. North Carolina Geological and Economic Survey*, III:171-258.
- Miller, W., III  
1997. Bivalve fauna of a Plio-Pleistocene coral biostrome in eastern North Carolina; paleoecologic stability, change, and scaling. *Southeastern Geology*, 37(2):73-90, figures 1-9, tables 1-3, appendix.
- Müller, A.  
1992. *Ichthyofaunen aus dem Atlantischen Tertiär der USA: Systematik, paläoökologie, biostratigraphie, evolution und palaobiologie*. Münster, Westfälischen Wilhelms-Universität, Doctoral Thesis, pages 1-393, plates 1-17.  
1999. Ichthyofaunen aus dem Atlantischen Tertiär der USA. *Leipziger Geowissenschaften*, 9(10):1-360, plates 1-17.
- Myrick, A.C., Jr.  
2001. *Thecachamps* *antiqua* (Leidy, 1852) (Crocodylidae; Thoracosaurinae) from fossil marine deposits at Lee Creek Mine, Aurora, North Carolina, USA. In Ray, C.E. and D.J. Bohaska (Eds.), *Geology and Paleontology of the Lee Creek Mine, North Carolina, III. Smithsonian Contributions to Paleobiology*, 90:219-225, figures 1-5.
- Nease, F.R. and F.A. Wolf  
1971. A nonpetrified alga from a phosphate mine site in Eastern North Carolina. *Journal of the Elisha Mitchell Scientific Society*, 87(2): 51,52.
- Olson, S.L.  
1977. A great Auk, *Pinguinis*, from the Pliocene of North Carolina. *Proceedings of the Biological Society of Washington*, 90(3):690-697, 3 figures.  
1999. A new species of pelican (Aves: Pelecanidae) from the lower Pliocene of North Carolina and Florida. *Proceedings of the Biological Society of Washington*, 112(3):503-509, 2 figures.  
2003. First fossil record of a finfoot (Aves: Heliornithidae) and its biogeographical significance. *Proceedings of the Biological Society of Washington*, 116(3):732-736.
- Olson, S.L., and P.J. Hearty  
2003. Probable extirpation of a breeding colony of short-tailed albatross (*Phoebastria albatrus*) on Bermuda by Pleistocene sea-level rise. *Proceedings of the National Academy of Science*, 100(22):12825-12829, 3 figures.
- Olson, S.L., and P.C. Rasmussen  
2001. Miocene and Pliocene birds from the Lee Creek Mine, North Carolina. In Ray, C.E., and D.J. Bohaska (Eds.), *Geology and Paleontology of the Lee Creek Mine, North Carolina, III. Smithsonian Contributions to Paleobiology*, 90:233-365, figures 1-15, plates 1-33, tables 1-15.
- Olson, S.L. and D.W. Steadman  
1979. The fossil record of the Glareolidae and Haematopodidae (Aves: Charadriiformes). *Proceedings of the Biological Society of Washington*, 91(4):972-981, 3 figures, 1 table.
- Petuch, E.J.  
1988a. New species of *Ecphora* and Ecphorine Thaidids from the Miocene of Chesapeake Bay, Maryland, U.S.A. *Bulletin of Paleomalacology*, 1(1):1-16, plates 1,2. [March 16, 1988 – earliest known postmark from Boca Raton, Florida.]  
1988b. *Neogene history of tropical American mollusks*. 217 pages, figures 1-23, plates 1-39. Charlottesville, Virginia. Coastal Education and Research Foundation.  
1988c. *Field guide to the Ecphoras*. 140 pages, figures 1-52, plates A1 - A3, inside back cover, outside back cover. Charlottesville, Virginia. Coastal Education and Research Foundation. [Species validation date: February 15, 1989.]  
1991. New gastropods from the Plio-Pleistocene of Southwestern Florida and the Everglades Basin. *W.H. Dall Paleontological Research Center Special Publication*, 1:1-64, plates 1-10.  
1994. *Atlas of Florida fossil shells (Pliocene and Pleistocene marine gastropods)*. Dania, Florida, Graves Museum of Archeology and Natural History, 394 pages, plates 1-100.  
1997. *Coastal paleoceanography of Eastern North America (Miocene - Pleistocene)*. 373 pages, 120 figures. Dubuque, Iowa, Kendall/Hunt Publishing Co.  
2004. *Cenozoic seas, the view from Eastern North America*. 308 pages, 96 plates. Boca Raton, Florida, CRC Press.
- Powers, E.R.  
1988. Diatom biostratigraphy and paleoecology of the Miocene Pungo River Formation, Onslow Bay, North Carolina continental shelf. In Snyder, S.W. (Ed.), *Micropaleontology of Miocene sediments in the shallow subsurface of Onslow Bay, North Carolina continental shelf. Cushman Foundation for Foraminiferal Research Special Publication*, 25:97-161, figures 1-13, plates 1-12.

- Purdy, R.W., V.P. Schneider, S.P. Applegate, J.H. McLellan, R.L. Meyer, and B.H. Slaughter  
 2001. The Neogene sharks, rays, and bony fishes from Lee Creek Mine, Aurora, North Carolina. *In* Ray, C.E., and D.J. Bohaska (Eds.), *Geology and Paleontology of the Lee Creek Mine, North Carolina, III. Smithsonian Contributions to Paleobiology*, 90: 71-202, figures 1-84.
- Ray, C.E.  
 1983. Prologue. *In* Ray, C.E. (Ed.), *Geology and Paleontology of the Lee Creek Mine, North Carolina, I. Smithsonian Contributions to Paleobiology* 53:1-14.  
 1987. Foreword. *In* Ray, C.E. (Ed.), *Geology and Paleontology of the Lee Creek Mine, North Carolina, II. Smithsonian Contributions to Paleobiology*, 61:1-8, figures 1-3.  
 2001. Prodrumus. *In* Ray, C.E., and D.J. Bohaska (Eds.), *Geology and Paleontology of the Lee Creek Mine, North Carolina, III. Smithsonian Contributions to Paleobiology*, 90:1-20, figures 1-6.  
 2007. Mantissa. *In* Ray, C.E., D.J. Bohaska, I.A. Koretsky, L.W. Ward, and L.G. Barnes (Eds.), *Geology and Paleontology of the Lee Creek Mine, North Carolina, IV. Virginia Museum of Natural History Special Publication*, 14:1-15, 2 figures.
- Ray, C.E., Editor  
 1983. *Geology and Paleontology of the Lee Creek Mine, North Carolina, I. Smithsonian Contributions to Paleobiology*, 53:1-529, 95 figures, 101 plates, 8 tables.  
 1987. *Geology and Paleontology of the Lee Creek Mine, North Carolina, II. Smithsonian Contributions to Paleobiology*, 61:1-283, 49 figures, 80 plates, 21 tables.
- Ray, C.E., and D.J. Bohaska, Editors  
 2001. *Geology and Paleontology of the Lee Creek Mine, North Carolina, III. Smithsonian Contributions to Paleobiology*, 90:1-365, 127 figures, 45 plates, 32 tables.
- Ray, C.E., D.J. Bohaska, I.A. Koretsky, L.W. Ward, and L.G. Barnes, Editors  
 2007. *Geology and Paleontology of the Lee Creek Mine, North Carolina, IV. Virginia Museum of Natural History Special Publication*, 14:507 pages, frontispiece, 273 figures, 17 plates, 48 tables.
- Riggs, S.R.  
 1984. Paleooceanographic model of Neogene phosphorite deposition; U.S. Atlantic continental margin. *Science*, 223(4632):123-131.
- Riggs, S.R., D.W. Lewis, A.K. Scarborough, and S.W. Snyder  
 1982a. Cyclic deposition of Neogene phosphorites in the Aurora area, North Carolina, and their possible relationship to global sea-level fluctuations. *Southeastern Geology*, 23(4):189-204, figures 1-5, tables 1-3.  
 1982b. Cyclic deposition of the upper Tertiary phosphorites of the Aurora area, North Carolina, and their possible relationship to global sea level fluctuations. *In* Scott, T.M., and S.B. Upchurch (Eds.), *Miocene of the southeastern United States; proceedings of a symposium, Florida Bureau of Geology Special Publication*, 25:65-84, figures 1-4.
- Rooney, T.P., and P.F. Kerr  
 1967. Mineralogic nature and origin of phosphorite, Beaufort County, North Carolina. *Geological Society of America Bulletin*, 78(6):731-748, 8 figures, 3 plates.
- Scarborough, A.K., S.R. Riggs, and S.W. Snyder  
 1982. Stratigraphy and petrology of the Pungo River Formation, central Coastal Plain of North Carolina. *Southeastern Geology*, 23(4):205-215, figures 1-9.
- Schneider, V.P., and H.L. Fierstine  
 2004. Fossil tuna vertebrae punctured by Istiophorid billfishes. *Journal of Vertebrate Paleontology*, 24(1):253-255, 1 figure.
- Shattuck, G.B.  
 1904. Geological and paleontological relations, with a review of earlier investigations. *In* Clark, W.B., G.B. Shattuck, and W.H. Dall (Eds.), *The Miocene deposits of Maryland*. Maryland Geological Survey, Miocene: pages XXXIII-CXXXVII.
- Snyder, S.W., L.L. Mauger, and W.H. Akers  
 1983. Planktonic Foraminifera and biostratigraphy of the Yorktown Formation, Lee Creek Mine. *In* Ray, C.E. (Ed.), *Geology and Paleontology of the Lee Creek Mine, North Carolina, I. Smithsonian Contributions to Paleobiology*, 53:455-481, figures 1-6, plates 1-4.
- Snyder, S.W., L.L. Mauger, and D. Ames  
 2001. Benthic Foraminifera and paleoecology of the Pliocene Yorktown and Chowan River formations, Lee Creek Mine, North Carolina, USA. *Journal of Foraminiferal Research*, 31(3):244-274, figures 1-11, tables 1,2, appendices 1,2.
- Storer, R.W.  
 2001. A new Pliocene grebe from the Lee Creek deposits. *In* Ray, C.E., and D.J. Bohaska (Eds.), *Geology and Paleontology of the Lee Creek Mine, North Carolina, III. Smithsonian Contributions to Paleobiology*, 90:227-231, figure 1, tables 1,2.

- Tedford, R.H., and M.E. Hunter  
1984. Miocene marine-nonmarine correlations, Atlantic and Gulf Coastal Plains, North America. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 47(1-2):129-151, figures 1-3.
- Tuomey, M. and F. S. Holmes  
1855. *Fossils of South-Carolina*, No. 1. John Russell, 251 King-Street, Charleston, SC., pages 1-8, plates 1 and 2.
- Tyler, J.C., R.W. Purdy, and K.H. Oliver  
1992. A new species of *Sphoeroides* pufferfish (Teleostei: Tetradontidae) with extensive hyperostosis from the Pliocene of North Carolina. *Proceedings of the Biological Society of Washington*, 105(3):462-482, 8 figures.
- Uhen, M.D.  
2004. Form, function, and anatomy of *Dorudon atrox* (Mammalia, Cetacea); an archaeocete from the middle to late Eocene of Egypt. *University of Michigan Papers on Paleontology*, 34:1-222, figures 1-141, tables 1-27, appendices I-VIII.
- Vail, P.R., and R.M. Mitchum, Jr.  
1979. Global cycles of relative changes of sea level from seismic stratigraphy. In Watkins, J.S., L. Montadert, and P.W. Dickerson (Eds.), Geological and geophysical investigations of continental margins, *American Association of Petroleum Geologists Memoir*, 29:469-472.
- Ward, L.W.  
1992a. Molluscan biostratigraphy of the Miocene, middle Atlantic Coastal Plain of North America. *Virginia Museum of Natural History Memoir*, 2:1-159, figures 1-36, plates 1-26.  
1992b. Diagnostic mollusks from the APAC Pit, Sarasota, Florida. In Scott, T.M., and W.D. Allmon (Eds.), Plio-Pleistocene stratigraphy and paleontology of Southern Florida. *Florida Geological Survey Special Publication*, 36:161-165.  
1998. Mollusks from the lower Miocene Pollack Farm Site, Kent County, Delaware; a preliminary analysis. In Benson, R.N. (Ed.), Geology and paleontology of the lower Miocene Pollack Farm fossil site, Delaware. *Delaware Geological Survey Special Publication*, 21:59-131, figures 1-10, plates 1-19, tables 1-2.  
2007. Synthesis of Paleontological and Stratigraphic Investigations at the Lee Creek Mine, Aurora, N.C. (1958-2007). In Ray, C.E., D.J. Bohaska, I.A. Koretsky, L.W. Ward, and L.G. Barnes (Eds.), Geology and Paleontology of the Lee Creek Mine, North Carolina, IV. *Virginia Museum of Natural History Special Publication*, 14:325-432, 4 figures, 17 plates.
- Ward, L.W., and B.W. Blackwelder  
1980. Stratigraphic Revision of upper Miocene and lower Pliocene beds of the Chesapeake Group, Middle Atlantic Coastal Plain: *U.S. Geological Survey Bulletin*, 1482-D:1-61, figures 1-25, plates 1-5.  
1987. Late Pliocene and early Pleistocene Mollusca from the James City and Chowan River formations at the Lee Creek Mine. In Ray, C.E. (Ed.), Geology and Paleontology of the Lee Creek Mine, North Carolina, II. *Smithsonian Contributions to Paleobiology*, 61:113-283, figures 1-14, plates 1-47, tables 1,2.
- Ward, L.W., and J.G. Carter  
1992. Cenozoic molluscan biostratigraphy of the North Carolina Coastal Plain, introduction and geologic setting. In Dennison, J.M., and K.G. Stewart (Eds.), *Geologic Field Guides to North Carolina and vicinity*, pages 115-130. *Raleigh: Geological Society of America, Southeastern Section*, (March, 1992).
- Ward, L.W., and N.L. Gilinsky  
1988. *Ecphora* (Gastropoda; Muricidae) from the Chesapeake Group of Maryland and Virginia. *Notulae Naturae of the Academy of Natural Sciences of Philadelphia*, 469:1-21, plates 1-5. [Published 15 March 1988.]  
1993. Molluscan assemblages of the Chowan River Formation, Part A, Biostratigraphic analysis of the Chowan River Formation (upper Pliocene) and adjoining units, the Moore House Member of the Yorktown Formation (upper Pliocene) and the James City Formation (lower Pleistocene). *Virginia Museum of Natural History Memoir*, 3, Part A:1-21, 6 figures, 1 plate, 8 tables.
- Ward, L.W., D.R. Lawrence, and B.W. Blackwelder  
1978. Stratigraphic revision of the middle Eocene, Oligocene, and lower Miocene - Atlantic Coastal Plain of North Carolina. *U.S. Geological Survey Bulletin* 1457-F:1-23, 3 figures.
- Weems, R.E.  
1985. Miocene and Pliocene Molidae (*Ranzania*, *Mola*) from Maryland, Virginia, and North Carolina (Pices: Tetradontiformes). *Proceedings of the Biological Society of Washington*, 98(2):422-438, 8 figures.
- Weiler, W.  
1973. Hyperostotic swollen fish bones from the upper Sarmatian of North Carolina. *Senckenbergiana Lethaea*, 53(6):469-477, 11 figures.

- Weisbord, N.E.  
1974. Late Cenozoic corals of South Florida. *Bulletins of American Paleontology*, 66(285):259-544, plates 21-57, tables 1,2.
- Welby, C.W., and C.J. Leith  
1969. Miocene unconformity, Pamlico River area, North Carolina. *Geological Society of America Bulletin*, 80:1149-1154, 4 figures, 1 plate.
- Wheeler, W.H., R.B. Daniels, and E.E. Gamble  
1983. The post-Yorktown stratigraphy and geomorphology of the Neuse-Pamlico area, eastern North Carolina. In Ray, C.E. (Ed.), *Geology and Paleontology of the Lee Creek Mine, North Carolina, I. Smithsonian Contributions to Paleobiology*, 53:201-218, figures 1-12.
- Whitehead, D.R.  
1983. Pollen analysis of the peat member from the Lee Creek Mine. In Ray, C.E. (Ed.), *Geology and Paleontology of the Lee Creek Mine, North Carolina, I. Smithsonian Contributions to Paleobiology*, 53:265-268, 2 tables.
- Whitmore, F.C., Jr.  
1983. Remington Kellogg, 1892-1969. In Ray, C.E. (Ed.), *Geology and Paleontology of the Lee Creek Mine, North Carolina, I. Smithsonian Contributions to Paleobiology*, 53:15-24, 1 plate.  
1994. Neogene climatic change and the emergence of the modern whale fauna of the North Atlantic Ocean. *Proceedings of the San Diego Society of Natural History*, 29:223-227, 2 figures, 1 table.
- Whitmore, F.C., Jr., and L.G. Barnes  
2007. The Herpetocetinae, a New Subfamily of Extinct baleen whales (Mammalia, Cetacea, Cetotheriidae). In Ray, C.E., D.J. Bohaska, I.A. Koretsky, L.W. Ward, and L.G. Barnes (Eds.), *Geology and Paleontology of the Lee Creek Mine, North Carolina, IV. Virginia Museum of Natural History Special Publication*, 14:141-180, 37 figures, 2 tables.
- Whitmore, F.C., Jr., and J.A. Kaltenbach  
2007. Neogene Cetacea of the Lee Creek Phosphate Mine, North Carolina. In Ray, C.E., D.J. Bohaska, I.A. Koretsky, L.W. Ward, and L.G. Barnes (Eds.), *Geology and Paleontology of the Lee Creek Mine, North Carolina, IV. Virginia Museum of Natural History Special Publication*, 14:181-269, 112 figures.
- Wilson, D.  
1983. The Lee Creek enigma, *Mclellania aenigma*, a new taxon in fossil Cirrhipedia. In Ray, C.E. (Ed.), *Geology and Paleontology of the Lee Creek Mine, North Carolina, I. Smithsonian Contributions to Paleobiology*, 53:483-498, plates 1-3.
- 1987a. A new pycnodont oyster from the Pungo River Formation, and an annotated list of the Cenozoic pycnodonts of the Atlantic and Gulf Coastal Plain. In Ray, C.E. (Ed.), *Geology and Paleontology of the Lee Creek Mine, North Carolina, II. Smithsonian Contributions to Paleobiology*, 61:13-20, figures 1-5.
- 1987b. Species of *Ecphora*, including the subgenus *Stenomphalus*, in the Pungo River Formation. In Ray, C.E. (Ed.), *Geology and Paleontology of the Lee Creek Mine, North Carolina, II. Smithsonian Contributions to Paleobiology*, 61:21-29, 1 figure, plates 1,2.
- Wolf, F.A., and F.R. Nease  
1970. Nonpetrified fossils from the site of a phosphate mine in eastern North Carolina. *Journal of the Elisha Mitchell Scientific Society*, 86(1):44-48, 5 plates, 1 table.  
1971. Assimilatory pigments in leaves of Pleistocene age from Eastern North Carolina. *Journal of the Elisha Mitchell Scientific Society*, 87(1):18,19.
- Zug, G.R.  
2001. Turtles of the Lee Creek Mine (Pliocene: North Carolina). In Ray, C.E., and D.J. Bohaska (Eds.), *Geology and Paleontology of the Lee Creek Mine, North Carolina, III. Smithsonian Contributions to Paleobiology*, 90:203-218, figures 1-9, tables 1-3.
- Zullo, V.A.  
1984. New genera and species of balanoid barnacles from the Oligocene and Miocene of North Carolina. *Journal of Paleontology*, 58(5):1312-1338, 7 figures.



## PLATES

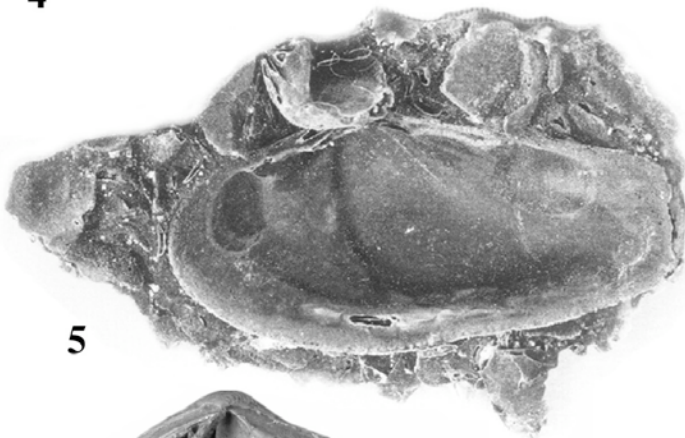
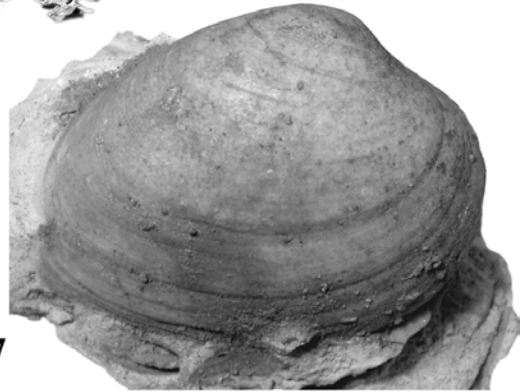
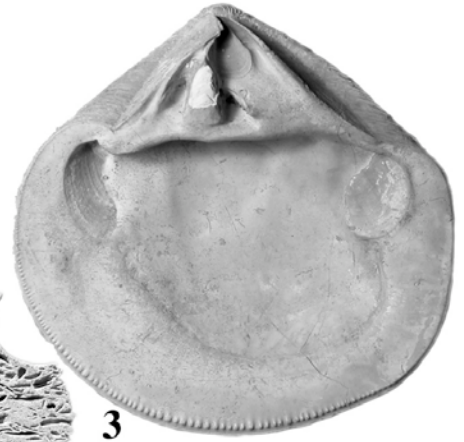
The specimens selected for these plates are chosen for their usefulness as guides to the various stratigraphic units present at the Lee Creek Mine. These are "index fossils" that are present only in one bed or so common as to characterize a bed. It is hoped that their recognition in the field will help the worker to pin down the provenance of less well known fossils found with them. These taxa may be especially useful in deducing the source of some of the elusive vertebrate specimens.

**Plate 1**

Castle Hayne Formation  
Spring Garden Member

These specimens were not collected at the Lee Creek Mine. The mining stops on the Castle Hayne Formations surface. Molds and casts of these taxa are in the cores from Lee Creek.

1. *Crassatella alta* Conrad, 1832  
Internal mold of the right valve (VMNH IP 3579). This is the last appearance of the *C. alta* lineage which is common in the Lisbon, Santee, and Castle Hayne Formations (New Hanover and Comfort Members) all of which are middle middle Eocene in age. It is also common in the Gosport, in unnamed middle Eocene beds in South Carolina, and in the Castle Hayne Formation (Spring Garden Member), all of which are upper middle Eocene. The lineage is not found in the upper Eocene or later units. This specimen is from Rock Landing, Neuse River, upriver from New Bern in the Spring Garden Member.  
Height 102.5 mm (incomplete).
2. Spring Garden Rock (VMNH IP 3580), sectioned to show the mold and cast nature of the sandy limestone. Most of the molds are of *Macrocallista*.
3. *Crassatella alta* Conrad, 1832  
Right valve (VMNH IP 3581) from Gosport Landing, Alabama River, Clarke County, Alabama. Type section of the Gosport Formation.  
Height: 97.2 mm, Length: 99.2 mm.
4. *Bathytormus protexta* (Conrad, 1832)  
Interior mold of a right valve (VMNH IP 3582) from the Martin Marietta – New Bern Quarry, where they are common.  
Height: 22.6 mm, Length: 44.6 mm (slightly incomplete).
5. *Bathytormus protexta* (Conrad, 1832)  
Latex cast of the specimen in Figure 4.
6. *Bathytormus protexta* (Conrad, 1832)  
Right valve (VMNH IP 3583) from Gosport Landing, Alabama River, Clarke County, Alabama. Type section of the Gosport Formation.  
Height: 21.1 mm, Length: 36.6 mm.
7. *Macrocallista perovata* (Conrad, 1833)  
Exterior of a right valve (VMNH IP 3584) from Martin Marietta – New Bern Quarry in the Spring Garden Member. The specimen was dissolved by groundwater, and then the cast was partially refilled by calcite, producing a pseudomorph (= *Macrocallista neusensis* Harris).  
Height: 30.8 mm, Length: 49.2 mm, approximately.
8. *Macrocallista perovata* (Conrad, 1833)  
Interior of a right valve (VMNH IP 3585) from the same locality as Figure 7. Pseudomorph of calcite. This species is present in large numbers and dominates the fauna over the entire outcrop area of the Spring Garden Member.  
Height: 48.0 mm, Length: 49.2 mm, approximately.
9. *Macrocallista perovata* (Conrad, 1833)  
Right valve (VMNH IP 3586) from Gosport Landing, Alabama River, Clarke County, Alabama. Type section of the Gosport Formation.



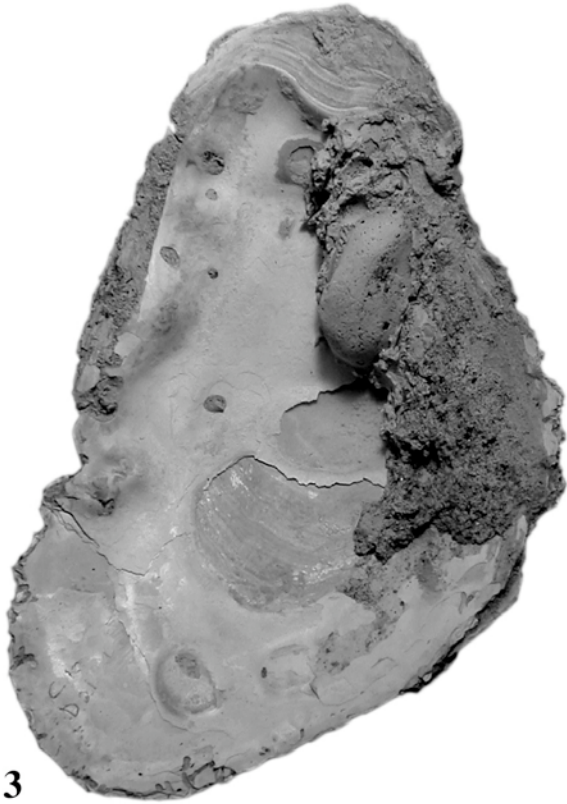
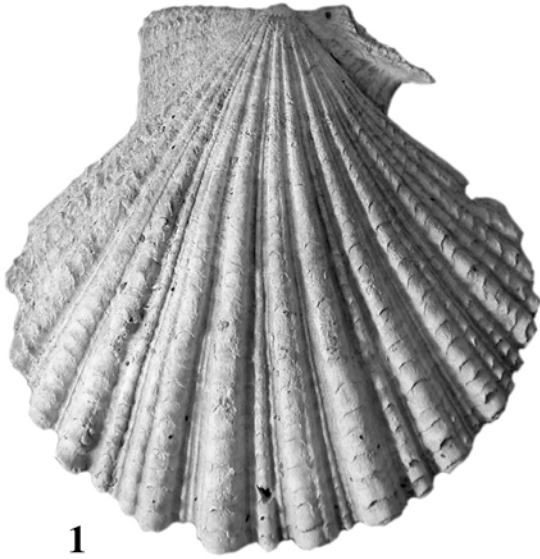
**Plate 2**

Pungo River Formation

Unit A of Riggs et al. (1982a)

(Belgrade Formation Equivalent)

1. *Rebeccapecten berryae* Ward, 1992  
Exterior of a right valve (VMNH IP 3587) from Martin Marietta – Belgrade Quarry. This species is common in the Haywood Landing Member of the Belgrade Formation. The same species, or a very similar one, is found in the upper portion of the River Bend Formation.  
Height: 61.2 mm, Length: 59.2 mm
2. *Rebeccapecten berryae* Ward, 1992  
Exterior of a latex cast of a right valve from the “lower dolomitic, sandy portion of the Pungo River Formation,” after Carter et al. (1988:84,85, pl. 8, fig. 59). [Originally reported to be *Pecten trentensis* Harris, a related species in the lower part of the River Bend Formation.]
3. *Crassostrea gigantissima* (Finch, 1824)  
Interior of a left valve (VMNH IP 3588) from Martin Marietta – Belgrade Quarry. These large oysters (up to 50 cm) are common in the Belgrade Formation. Because of their massive size, they stand a good chance of surviving the mining process at Lee Creek.  
Height: 169 mm
4. *Mercenaria* sp. aff. *M. langdoni* (Dall, 1903)  
Latex cast of a left valve from the “lower dolomitic, sandy portion of the Pungo River Formation,” after Carter et al. (1988:84,85, pl. 8, fig. 61).

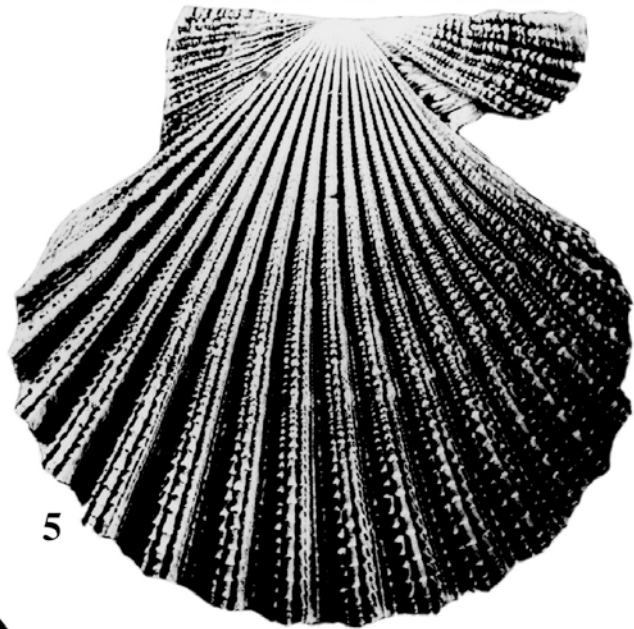
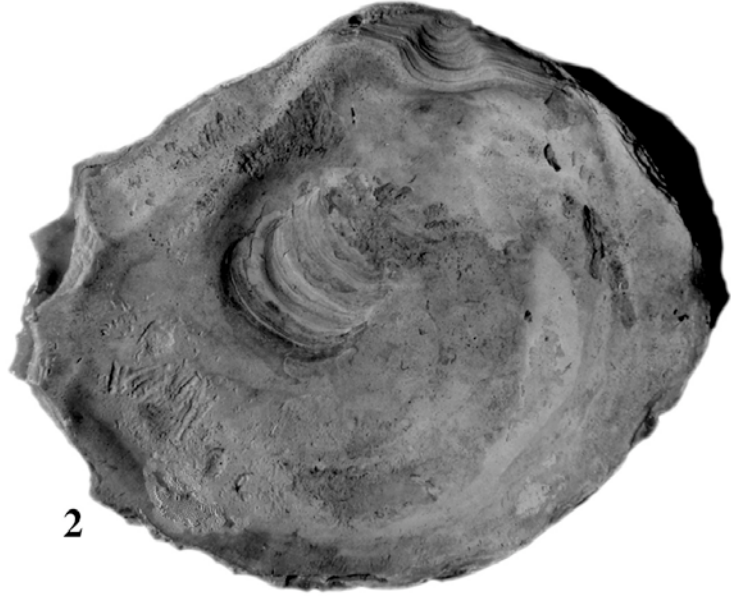
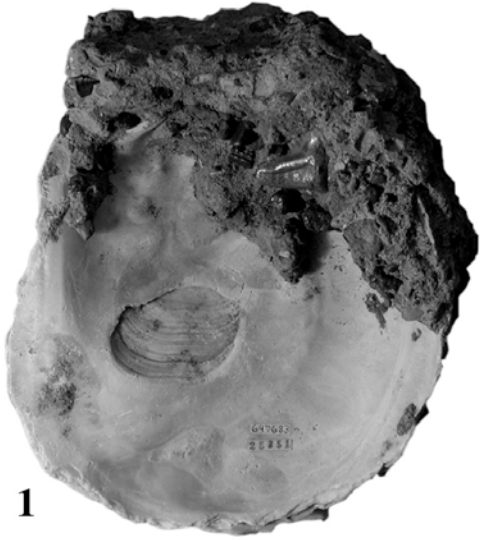


**Plate 3**

## Pungo River Formation

Riggs et al. (1982a) Units B, C, and D, undifferentiated

1. *Pycnodonte percrassa* (Conrad, 1840)  
Interior of a left valve (VMNH IP 3589) from Lee Creek Mine. This species was originally named from Stow Creek, New Jersey, from the unit later to become the Kirkwood Formation. This unit is the stratigraphic equivalent of Beds 2 and 3-A in Maryland (Calvert Formation, lower Fairhaven Member), and the upper portion of the Pungo River Formation at the Lee Creek Mine. The species is known as high as Bed 10 in the Calvert Formation, but is common only at Hollin Cliff, on the Patuxent River, in that unit.  
Height: 85.9mm
2. *Pycnodonte percrassa* (Conrad, 1840)  
Interior of a left valve (USGS 25351). "Lee Creek Mine, Texas Gulf Sulfur Co., Aurora, Beaufort Co., North Carolina; float from 'ore sumps': believed to come from Gibson's Unit No. 2 of Pungo River Fm. J.H. McLellan" as recorded in USGS Cenozoic Locality Register in 1973 by Druid Wilson. This specimen was in the same lot as *Gigantostrea leeana* (Wilson, 1987).  
Height: 119.2 mm
3. *Dallarca* (?) *subrostrata* (Conrad, 1841)  
Internal mold of a left valve (VMNH IP 3590); this species is common to abundant in the Kirkwood Formation of Delaware and the equivalent upper Pungo River Formation. It occurs as high as Bed 10 of the Calvert Formation in Maryland.  
Length: 41.2 mm
4. *Panopea whitfieldi* Dall, 1898  
Internal mold of a complete specimen (VMNH IP 3591) showing the right valve. Type specimen is from the Kirkwood Formation of New Jersey; also present in that unit in Delaware, both stratigraphic equivalents of the Pungo River Formation.  
Length: 69.8 mm
5. *Chesapecten coccymelus* (Dall, 1898)  
Right valve (USNM 218925) after Gibson (1987: pl. 28, fig. 1). The species is common in the Kirkwood Formation of Delaware and Pungo River Formation in North Carolina. It is common in Bed 10 of the Calvert Formation, above which it is not known to occur.  
Height: 58 mm



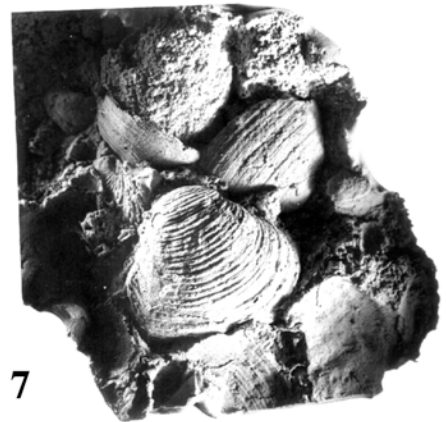
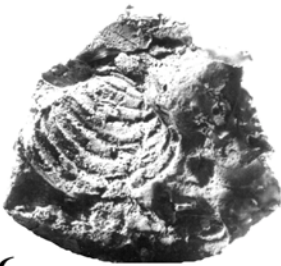
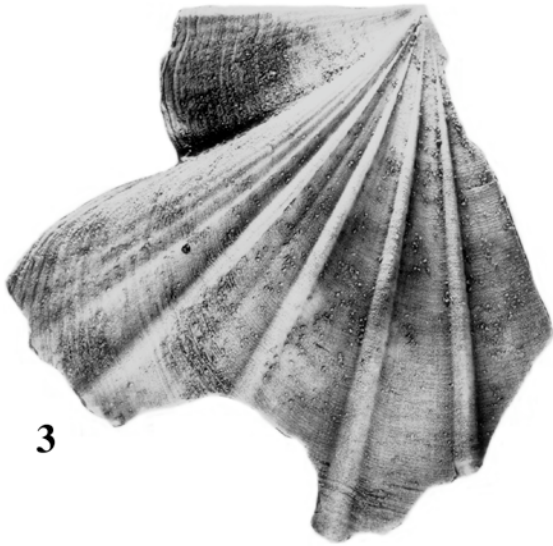
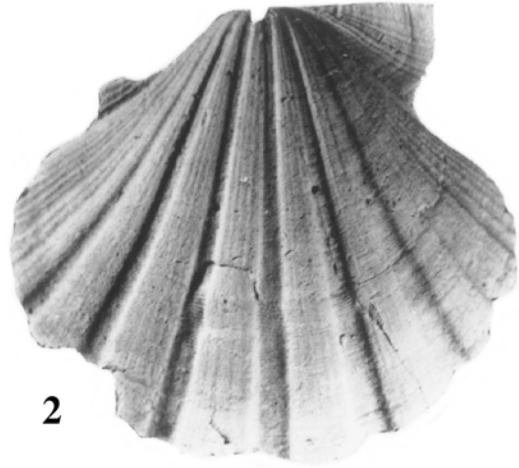
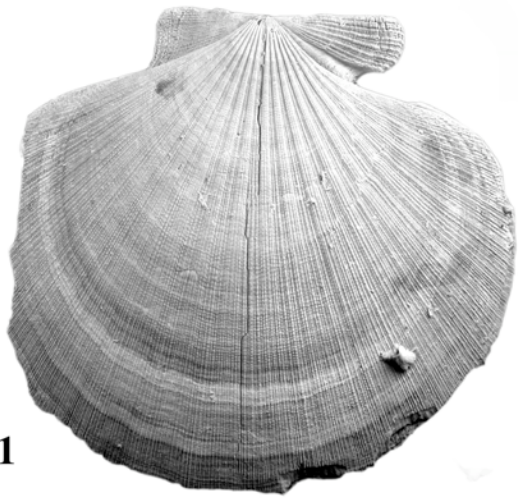
**Plate 4**

## Pungo River Formation

Riggs et al. (1982a) Units B, C, and D, undifferentiated

1. *Chesapecten sayanus* (Dall, 1898)  
Right valve (VMNH 1645) after Ward (1998: pl. 11, fig. 5). Species is common in the Kirkwood Formation in Delaware and in the Pungo River Formation.  
Height: 116.7 mm
2. *Pecten humphreysii* Conrad, 1842  
Right valve (USNM 218836) after Gibson (1987: pl. 3, fig. 5). The species complex including *Pecten humphreysii woolmani* (New Jersey) and *Pecten humphreysii mcclellani* is present in stratigraphic equivalents of the Pungo River Formation from New Jersey to North Carolina.  
Height: 22.3 mm
3. *Pecten humphreysii* Conrad, 1842  
Left valve (USNM 218839) after Gibson (1987: pl. 4, fig. 1).  
Height: 79.6 mm; incomplete
4. *Astarte distans* Conrad, 1862  
Exterior of a left valve and interior of a right valve (VMNH IP 3592), latex cast from Pungo River Formation limestone; collected by B. W. Blackwelder. Known to occur only in Kirkwood Formation equivalents in New Jersey, Delaware, Maryland, and in North Carolina in the Pungo River Formation. Is not known higher than Bed 3-A in Maryland.  
Length (incomplete): 18.5 mm
5. *Lirophora latilirata* (Conrad, 1841)  
Exterior of a left valve (VMNH IP 3593), latex cast from Pungo River Formation limestone; collected by B. W. Blackwelder. Common in the Kirkwood Formation of Delaware and Bed 10 of the Calvert Formation in Maryland, its last known occurrence. Not to be confused with "*L. latilirata*" of much fossil and Recent molluscan literature. The Type of *Lirophora latilirata* was collected from Bed 10 of "Calvert Cliffs, Md."  
Length: 40 mm
6. *Melosia staminea* (Conrad, 1839)  
Exterior of a right valve (VMNH IP 3594), latex cast from Pungo River Formation limestone; collected by B. W. Blackwelder. Common in Bed 10 of the Calvert Formation, but present in Bed 2 and Bed 3-A equivalents at Church Hill, Maryland. These units are the stratigraphic equivalents of the Pungo River Formation at Lee Creek.  
Length: 17 mm
7. *Varicorbula elevata* (Conrad, 1838)  
Exterior of a right valve (VMNH IP 3595), latex cast from Pungo River Formation limestone; collected by B. W. Blackwelder. The species was named from the Kirkwood Formation of New Jersey, is present though not abundant in the Kirkwood of Delaware, and is very abundant in Beds 4 - 9 in the Calvert Formation in Maryland. It is also common in Bed 10 there, its last known occurrence.  
Height: 10.5 mm





**Plate 5**

## Pungo River Formation

Riggs et al. (1982a) Units B, C, and D, undifferentiated

1. *Turritella indenta* Conrad, 1841  
Two nearly complete specimens (VMNH IP 3596), latex cast from Pungo River Formation limestone; collected by B. W. Blackwelder. Several other specimens are visible. The *Turritella indenta*/*T. tampae* species complex is present in the late Oligocene to early Miocene along the Atlantic Coastal Plain. *Turritella indenta* appears to be the last member of that lineage and occurs last in Bed 10 of the Calvert Formation.  
Upright specimen, incomplete, height: 37.0 mm; leaning specimen, incomplete, height: 42.0 mm
2. *Turritella plebia* Say, 1824  
Posterior view (VMNH IP 3597), latex cast from Pungo River Formation limestone; collected by B. W. Blackwelder. The species was named from the Cobham Bay Member of the Eastover Formation, but is present in the St. Marys, Choptank, and Calvert Formations. One variant is also present in the Kirkwood Formation of Delaware. It is not known stratigraphically higher than the Eastover Formation.  
Height: mostly complete, 23.0 mm
3. *Ecphora tricostata* (Martin, 1904)  
Apertural view of young specimen (VMNH IP 3598). The species, very variable in rib thickness, width, height and numbers, has received a number of synonyms. One characteristic common to all is the tendency to uncoil. Common in the Kirkwood Formation of New Jersey and Delaware, and is present in the Calvert Formation of Maryland in all sandy units from Bed 2 to Bed 10.  
Height: 25.0 mm, incomplete
4. *Ecphora tricostata* (Martin, 1904)  
Posterior view of the same specimen in Figure 3.  
Height: 25.0 mm
5. *Stenomphalus aurora* Wilson, 1987  
Apertural view of Wilson's (1987b:29, pl. 2, fig. 1) holotype (USNM 647654). This species and genus is known only from the Pungo River Formation at the Lee Creek Mine. It is not known from equivalent deposits in Maryland, Delaware, or New Jersey. Wilson pointed out similar taxa in the Miocene of France.



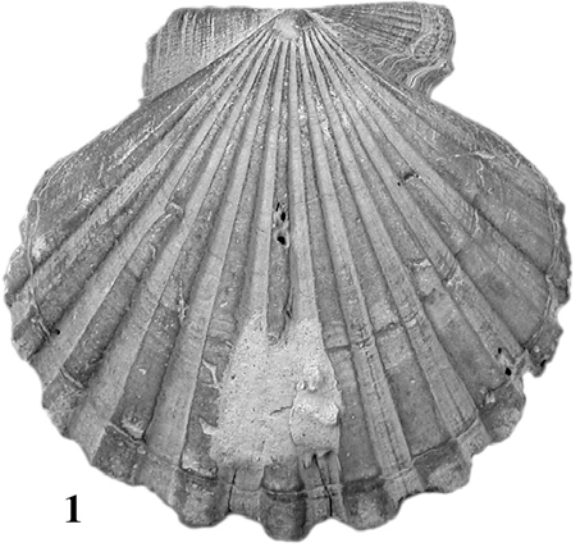
**Plate 6**

## Eastover Formation

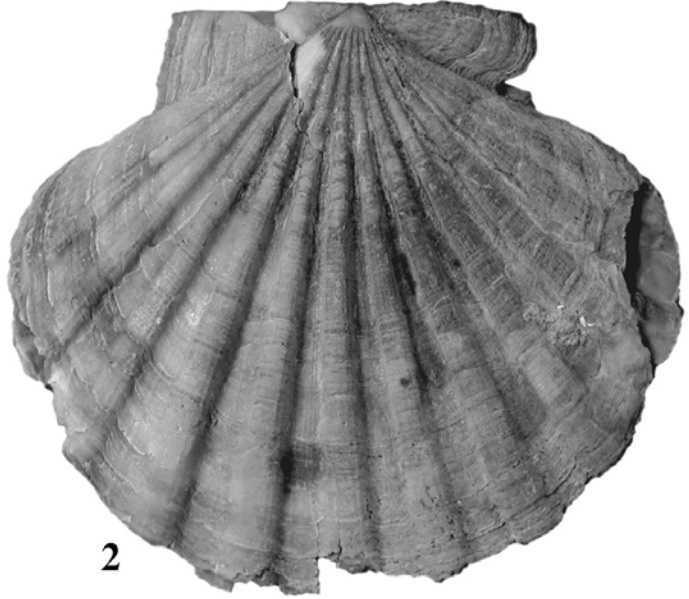
These specimens were not found at the Lee Creek Mine. They are figured here because there is a chance that Eastover sediments may be uncovered at some time. Low areas in the upper surface of the Pungo River Formation may preserve remnants of the Eastover Formation. The Eastover is exposed in surface outcrops along the Meherrin River at Murfreesboro to the north of the Lee Creek Mine. To the south of the mine, the Eastover is exposed near the mouth of the Trent River at New Bern. There, only molds and casts of aragonitic mollusks are present, one of which is "*Spisula*" *rappahannockensis*. On the left bank of the Neuse River, below Beard Creek, a number of preserved calcitic *Chesapectens* were collected by P.J. Harmatuk that clearly indicate the presence of the Eastover Formation or a stratigraphic equivalent. Those specimens, in some cases large individuals with both valves, are well preserved, making their identity certain: *Chesapecten middlesexensis*. Two of these specimens are figured, as well as some other specimens from Murfreesboro, in the hope that the taxa will be recognized if found at Lee Creek. Only calcitic specimens are illustrated because they stand the best chance at being preserved. Aragonitic mollusks would probably be leached out, as they are on the Trent River.

The distribution of the remnants of the Eastover sediments makes it certain that the Eastover sea once covered the Lee Creek area. The later Yorktown transgression apparently beveled these beds off. The lag deposits of large phosphatic clasts and reworked, black-phosphatized *Carcharocles megalodon* are probably derived from the eroded Eastover beds.

1. *Chesapecten middlesexensis* (Mansfield, 1936)  
Right valve of a specimen (VMNH IP 3599) collected by P.J. Harmatuk. Locality given as "Off north bank of Neuse River, adjacent to Mill Creek and Smith Gut, Pamlico County, N.C. NW corner of Cherry Point 7.5' quad." The specimen was received by C.E. Ray, March 13, 1979.  
Height: 115.8 mm
2. *Chesapecten middlesexensis* (Mansfield, 1936)  
Right valve of a specimen (VMNH IP 3600) (both valves cemented together) collected by P.J. Harmatuk. Locality given as "Bottom of Neuse River, near north side, downstream from Beard Creek, upstream from Minnesott Beach, Pamlico County, N.C." Cherry Point 7.5' sheet. The specimen was received by C.E. Ray, November 30, 1978. Matrix packed around the specimen appears to be from the Flanner Beach Formation. It is presumed that Eastover lag fossils are concentrated along the base of the Flanner Beach Formation in that area.  
Height: 154.0 mm
3. *Placopecten principoides* (Emmons, 1858)  
Right valve (VMNH IP 3601) of a complete (both valves) specimen. This species is present in the Eastover Formation from the Potomac River to the Meherrin River. On the Meherrin, at Murfreesboro, where this specimen was collected, it is very common. The species differs from *P. clintonius*, a common taxon in the overlying Sunken Meadow Member of the Yorktown Formation, by having much finer radial ribs, and by having those ribs repeatedly discontinuous and offset by growth interruptions. *Placopecten clintonius* has coarser ribs that are relatively continuous and uninterrupted.  
Height: 111 mm
4. *Placopecten principoides* (Emmons, 1858)  
Left valve of the specimen shown in Figure 3.  
Height: 113 mm



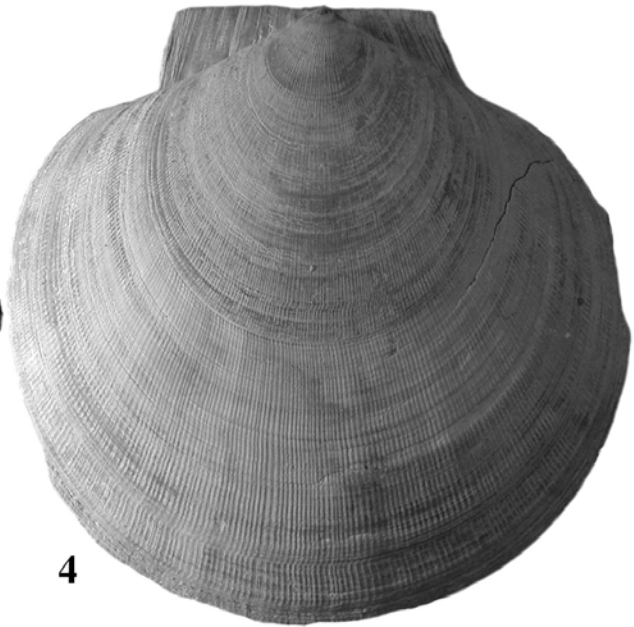
1



2



3



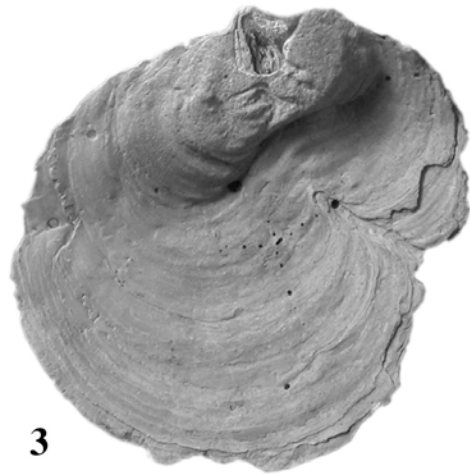
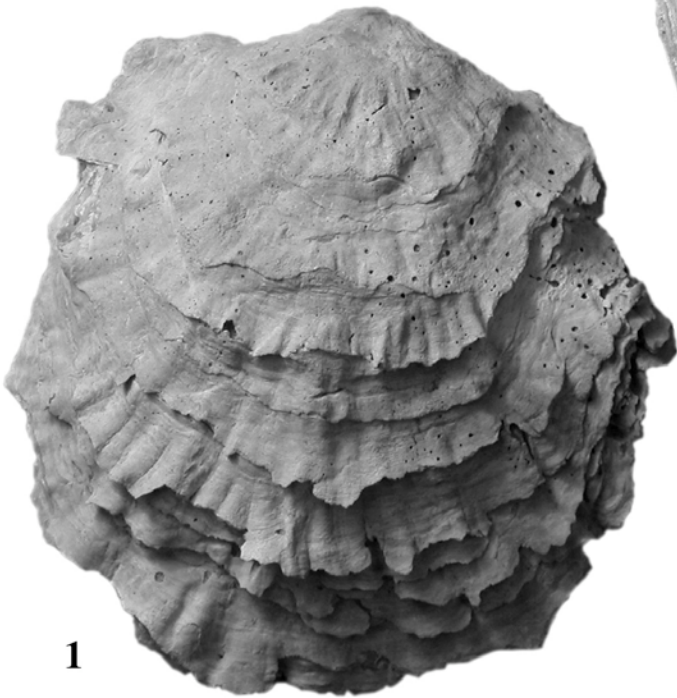
4

**Plate 7**

## Eastover Formation

These specimens were not found at the Lee Creek Mine. They are figured here because there is the chance that Eastover sediments may be uncovered at some time.

1. *Ostrea compressirostra geraldjohnsoni* Ward, 1992.  
Left valve of a complete (both valves) specimen (VMNH IP 3602) from the Eastover Formation, on the Meherrin River, at Murfreesboro, North Carolina. This species is less ornate than *O. c. compressirostra*. That subspecies has much more developed, high lamellae and has pronounced auricles. A succeeding species, the last of the lineage, called *O. raveneli* is less ornate than *O. c. geraldjohnsoni*, and lacks the auricle development. That species is present in the upper Yorktown and Bear Bluff Formations.  
Height: 85.7 mm
2. *Ostrea compressirostra geraldjohnsoni* Ward, 1992.  
Right valve of the same specimen in Figure 1.  
Height: 70.5 mm
3. *Pododesmus philippi* Gardner, 1944  
Right valve (VMNH IP 3603) from the Eastover Formation, on the Meherrin River, at Murfreesboro, North Carolina. Young specimens exhibit numerous radiating striae on the valves. Large specimens lack these striae. The left valve is deeply convex, the right valve is flat to slightly concave. Common in the Eastover Formation from the Rappahannock River to the Meherrin River.  
Height: 49.5 mm

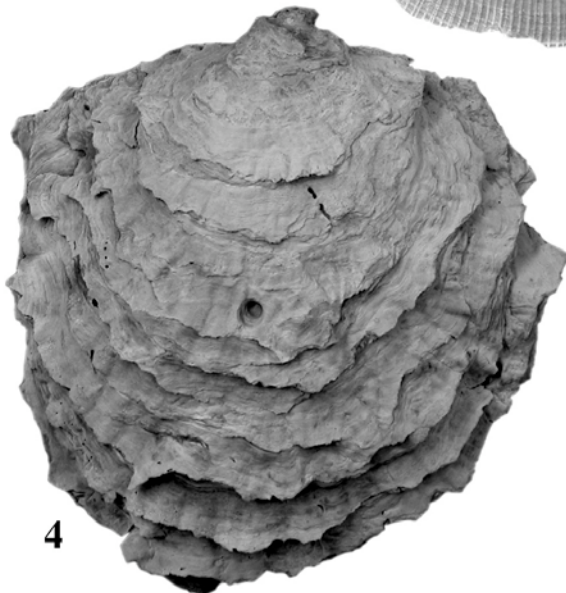
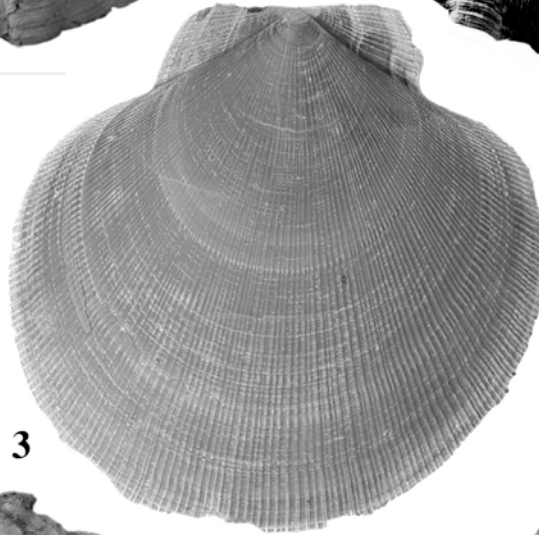
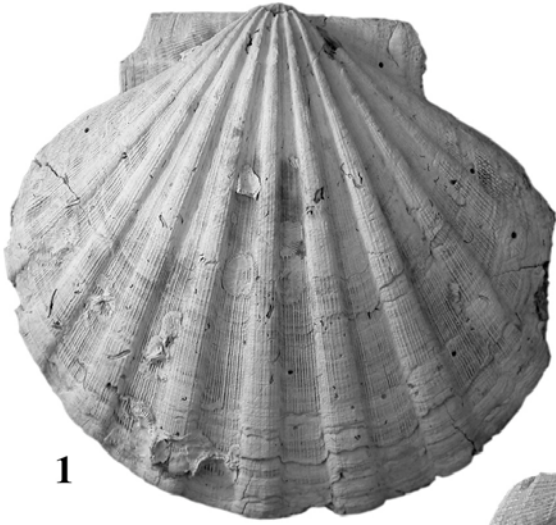


**Plate 8**

Yorktown Formation  
Sunken Meadow Member

1. *Chesapecten jeffersonius* (Say, 1824)  
Left valve (VMNH IP 3604) of a specimen found as float. The juveniles were active swimmers. Adult specimens attain enough size and thickness to thwart most enemies and settle down to a more benthic existence. As a result, many organisms use their shell as a firm substrate for attachment. Barnacles are the most abundant, but mollusks, bryozoans, worms, and sponges are common.  
Height: 136.8 mm
2. *Chesapecten jeffersonius* (Say, 1824)  
Right valve of a juvenile (after Gibson, 1987: pl. 21, fig. 3, USNM 218902). The early growth stages of *C. jeffersonius* exhibit very squared, sharp-sided ribs. With age, the ribs become progressively more rounded. *C. septenarius*, from the overlying Rushmere Member, is sometimes confused with *C. jeffersonius* from which the species is descended, but it has squared, sharp-sided ribs that do not become rounded with adulthood.  
Height: 34.0 mm
3. *Placopecten clintonius* (Say, 1824)  
Right valve of a specimen (VMNH IP 3605) found as float. *P. clintonius* has coarser, raised ribs that distinguish it from its predecessor *P. principoides*. In well-preserved specimens, small spines can be seen on the crests of the ribs. The species is common, especially along the base of the Sunken Meadow Member from the James River to the Meherrin and south to the Lee Creek Mine.  
Height: 95.0 mm
4. *Ostrea compressirostra compressirostra* Say, 1824  
Left valve of a whole individual (double valves) (VMNH IP 3606). Exterior of this valve is usually very ornate, when well preserved, with numerous, high, thin growth lamellae that exhibit small wrinkles and folds. Its predecessor *O. c. geraldjohnsoni* is found in the Eastover Formation and its descendant, *O. raveneli*, is found in the overlying Rushmere and Moore House Members as well as in the Chowan River/Bear Bluff Formations, but *O. c. compressirostra* is found only in the Sunken Meadow Member.  
Height: 92.0 mm
5. *Ostrea compressirostra compressirostra* Say, 1824  
Right valve of the specimen shown in Figure 4.  
Height: 82.5 mm

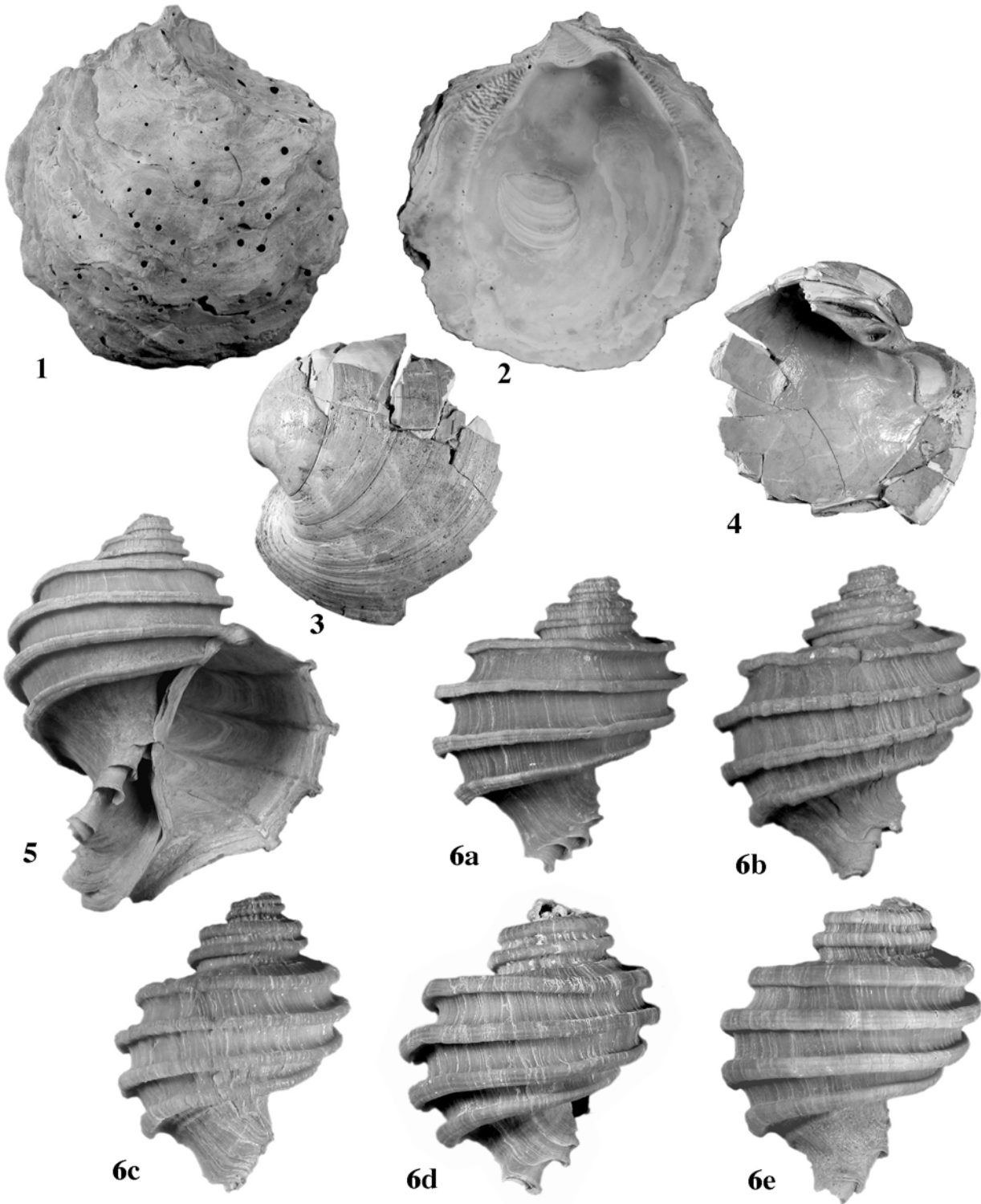




**Plate 9**

Yorktown Formation  
Sunken Meadow Member

1. *Pycnodonte* sp.  
Left valve of a specimen (VMNH IP 3607) found as float. This species, first figured by Ward and Blackwelder (1980) is common in the Sunken Meadow Member from the James River to the Meherrin River and can be found at the Lee Creek Mine as double and single valves. The species superficially resembles *Ostrea compressirosta*, except it does not have the lamellate exterior plications. The *Pycnodonte* has an ovate muscle scar, while the *Ostrea* has a lunate muscle scar. The *Pycnodonte* has a shelf formed along the edge of the shell and well-developed chomata just below the hinge-line. *Pycnodonte* shells, when broken open and examined by lens, have a vesicular structure, with the shell being made up of calcite bubbles. This species is found only in the Sunken Meadow Member.  
Height: 67.0 mm
2. *Pycnodonte* sp.  
Interior of the same specimen in Figure 1.
3. *Glossus fraterna* (Say, 1824)  
Exterior of a broken left valve (VMNH IP 3608). This is one of few aragonitic shells that survived the groundwater leaching and the trauma of the dragline. *Glossus* appeared in the Western Atlantic at around 18.0 my in the Kirkwood Formation of Delaware. The genus was successful in the Miocene and Pliocene, but is not seen stratigraphically higher than the Moore House Member, in which it is rare. The genus is not present today in the Western Atlantic and survives as a single species off of Europe.  
Broken height: 71.8 mm.
4. *Glossus fraterna* (Say, 1824)  
Interior of the same specimen in Figure 3.
5. *Ecphora quadricostata* (Say, 1824)  
Apertural view of a specimen (VMNH IP 3609) from the Lee Creek spoil piles. It appears that all specimens of *E. quadricostata* that are free of sediment or carbonate cement are from the Sunken Meadow Member. The overlying Rushmere, Morgarts Beach and Moore House Members are leached carbonates with only calcitic mollusks preserved, and those specimens usually have cemented matrix adhering to them. *E. quadricostata* commonly has low ribs in very young stages, high thin ribs during later stages, and at adulthood its ribs get lower and lower until they are just low ridges. When seen in the apertural view, they are just ridges, low to the body whorl.  
Height: 65.0 mm, incomplete
6. *Ecphora quadricostata* (Say, 1824)  
Posterior views of 5 specimens, a-e, showing the variation in rib thickness. All mature into the low, thin-ribbed form seen in Figure 5. The thicker ribbed juveniles are found principally in the Sunken Meadow Member.
  - 6a. (VMNH IP 3610) 42.8 mm
  - 6b. (VMNH IP 3611) 40.0 mm
  - 6c. (VMNH IP 3612) 37.9 mm
  - 6d. (VMNH IP 3613) 36.1 mm
  - 6e. (VMNH IP 3614) 37.8 mm

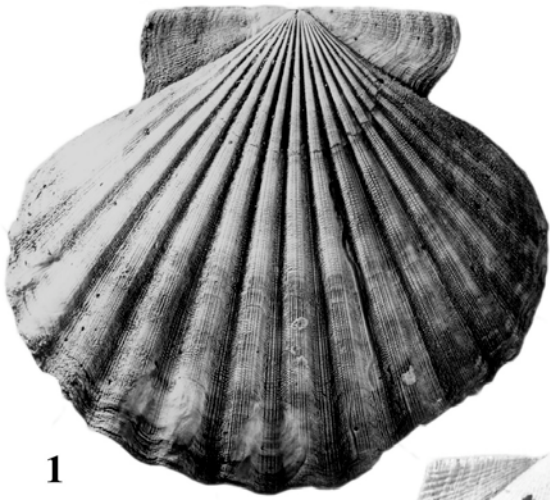


**Plate 10**

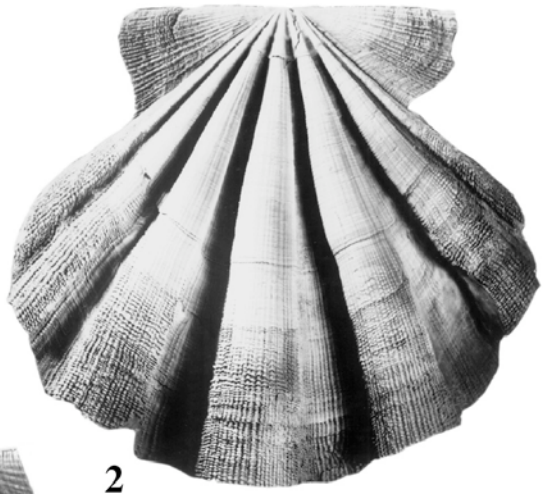
Yorktown Formation

Rushmere/Morgarts Beach Member

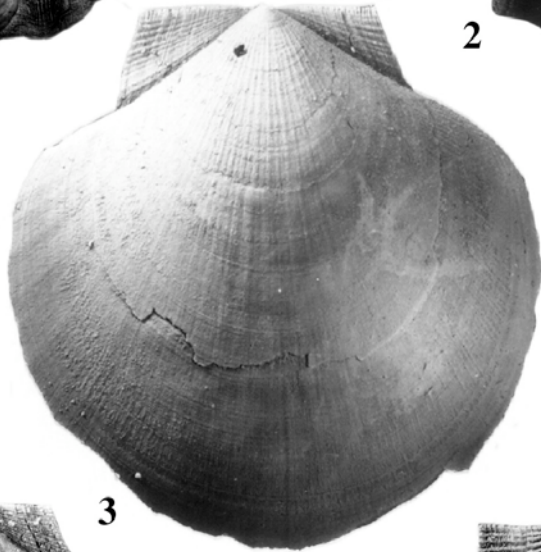
1. *Chesapecten madisonius* (Say, 1824)  
Right valve (USNM 218920) from the spoil piles, collected by T. Gibson in 1972. Specimen is from Gibson (1987: pl. 26, fig. 5). Typical *C. madisonius* have more and less robust ribs than *C. jeffersonius*. In addition, *C. madisonius* exhibits infilling and thickening of the valves, so that in many adult specimens, the ribs, internally, can be seen only along the ventral margins. Specimens of *C. septenarius* also show this infilling. Specimens of *C. jeffersonius* do not.  
Height: 130.0 mm
  
2. *Chesapecten septenarius* (Say, 1824)  
Right valve (USNM 218910) from the spoil piles, collected by T. Gibson in 1972. Specimen is from Gibson (1987: pl. 23, fig. 1). *C. septenarius* vary in numbers of ribs from 4 or 5 to 8 or 9. The ribs are very square and boxey in the juvenile stages and remain that way to adulthood, as opposed to *C. jeffersonius*, which become lower and rounded with age. In South Carolina, Georgia, and South Florida, *C. madisonius* and *C. septenarius* both occur, but with them are gradational specimens, or hybrids, that exhibit both sets of characteristics. These mimic *C. jeffersonius* in number and size of ribs, but still have coarser scaling than that species. In addition, the hybrid shows internal infilling of the ribs, a characteristic not seen in *C. jeffersonius*. See Plate 12, Figure 1, for an example.  
Height: 73.0 mm
  
3. *Chlamys decemnaria* (Conrad, 1834)  
Left valve (USNM 218893) from the spoil piles, collected by T. Gibson in 1967. Specimen is from Gibson (1987: 66, pl. 20: fig. 2). This species, which has received a variety of names, is extremely variable in sculpture from fine, incised lines suggesting *Placopecten*, to well-developed thin ridges, as in true *Chlamys*, and in some cases, showing distinct ribs superimposed on the thin ridges. Only a large suite of specimens, such as that I supplied to T. Gibson in 1972 and 1973, could make it possible to see that it was a single species and not numerous distinct taxa.  
Height: 45.1 mm?
  
4. *Chlamys decemnaria* (Conrad, 1834)  
Left valve (USNM 218894) from the spoil piles, collected by T. Gibson in 1967. Specimen is from Gibson (1987: pl. 20, fig. 3).  
Height: 69.0 mm?
  
5. *Chlamys decemnaria* (Conrad, 1834)  
Left valve (USNM 218897) from the spoil piles, collected by T. Gibson in 1967. Specimen is from Gibson (1987: pl. 20, fig. 6).  
Height: 61.0 mm?



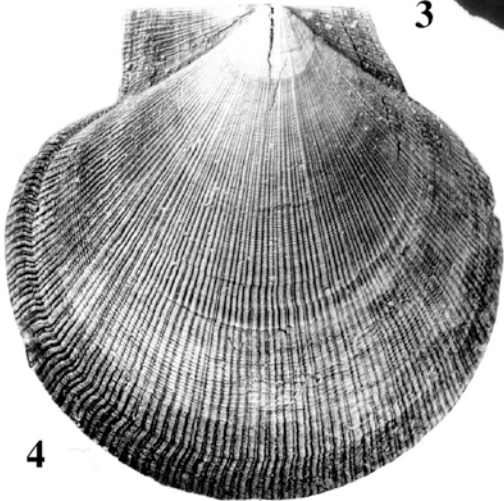
1



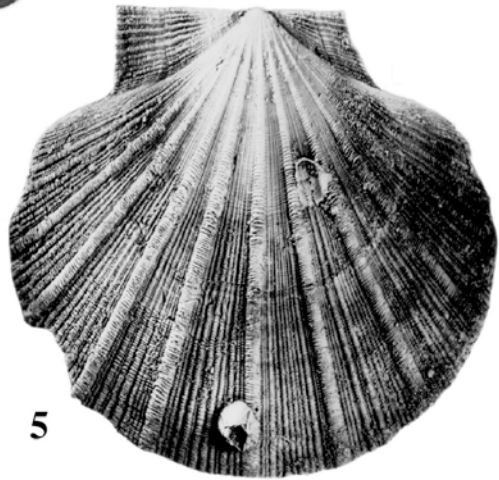
2



3



4



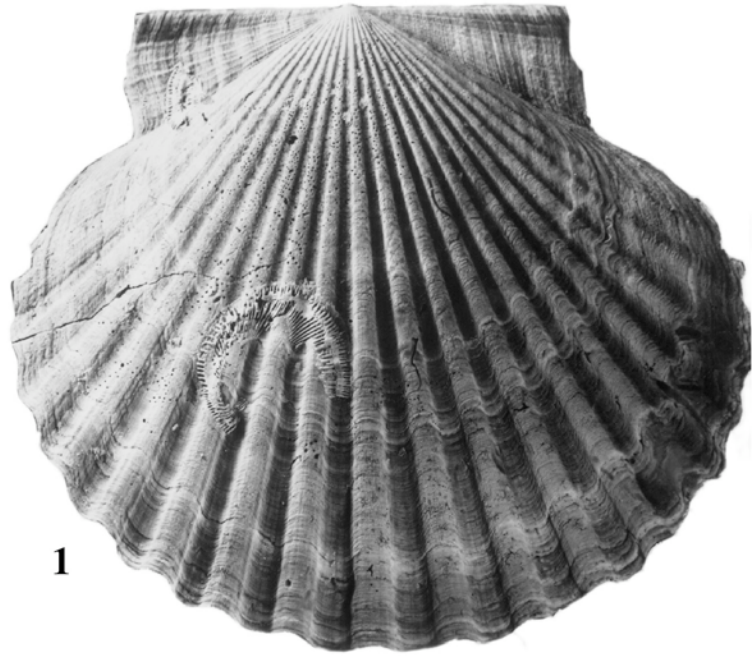
5

**Plate 11**

Yorktown Formation

Rushmere/Morgarts Beach Member

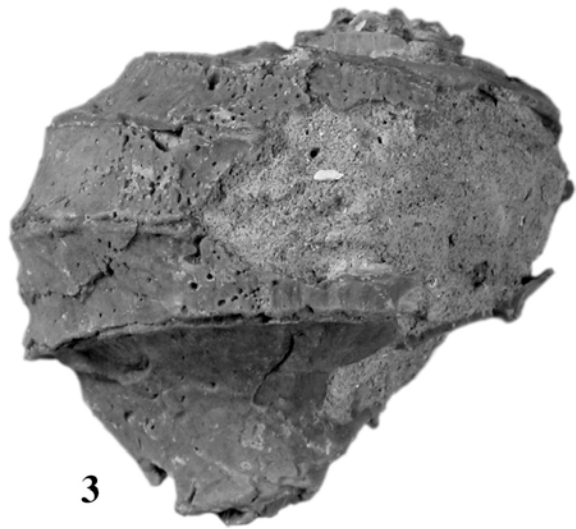
1. *Carolinapecten eboreus* (Conrad, 1833)  
Left valve (USNM 218857), taken in place (USGS 25746) from Gibson's Unit 3 (base of the Rushmere). This species is common in Rushmere/Morgarts Beach/Moore House equivalents from Virginia to West Florida. It is a slightly warmer-water to subtropical form and replaces *Chesapecten* south of the Neuse River. South of that axis, *Chesapecten* occurs only in the basal transgressive portion of the Duplin, Rasor, and Pinecrest Beds. Their presence indicates that the initial sea-level rise was cool-temperate, and they disappear upward as conditions warmed to subtropical. The specimen shown is from Gibson (1987: pl. 8, fig. 4).  
Height: 75.4 mm
2. *Ecphora quadricostata* (Say, 1824)  
Apertural view of a specimen (VMNH IP 3615) from the spoil piles. The calcareous matrix adhering to the specimen makes it certain that it came from the Rushmere/Morgarts Beach Member. Specimens from this horizon that reach adult size become increasingly globose as the rate of translation decreases until some coil at the level of the second rib.  
Height: 85.7 mm
3. *Ecphora quadricostata* (Say, 1824)  
Posterior view of a specimen (VMNH IP 3616) from spoil piles. The calcareous matrix makes it certain that it came from the Rushmere/Morgarts Beach. It has low, thin ribs typical of adult *E. quadricostata*.  
Height: 53.0 mm



1



2



3

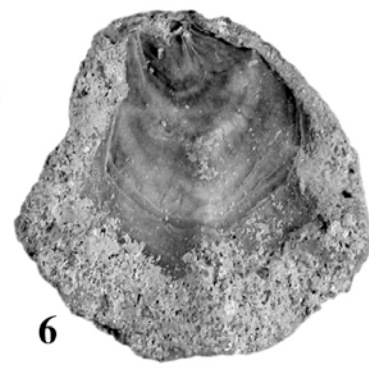
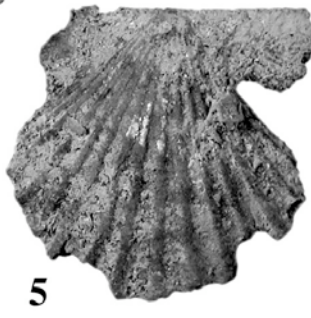
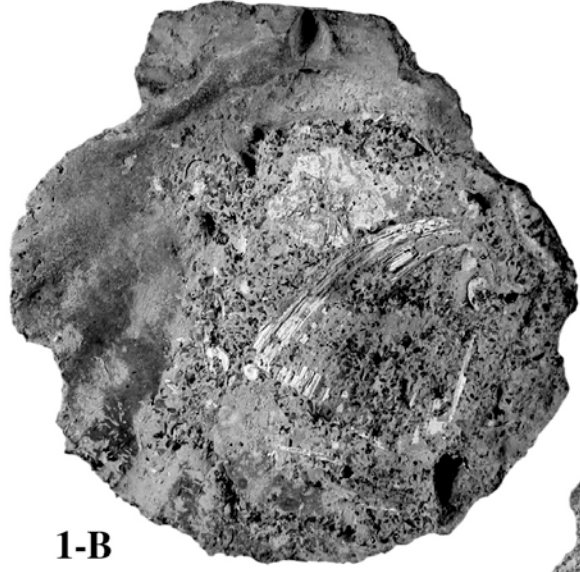
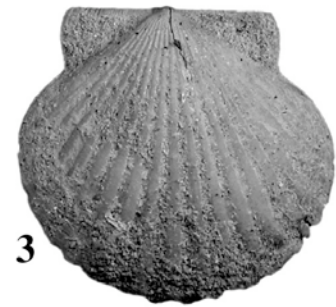
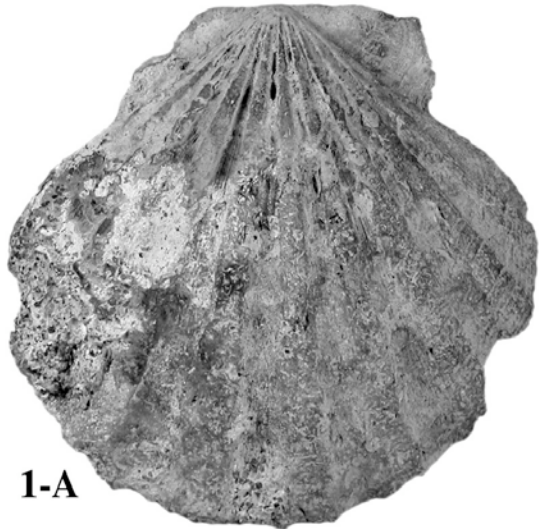
**Plate 12**

Yorktown Formation  
Moore House Member

All specimens found in the Moore House Member are coated by matrix cemented by calcite. Aragonitic specimens have been leached. Only calcitic taxa could be collected. All specimens were collected in place by L.W. Ward and W. Allmon, December 18, 1992.

1. *Chesapecten madisonius* (Say, 1824)  
1-A. Right valve (VMNH IP 3617). Exterior view.  
Height: 112.0 mm  
1-B. Interior view of the same specimen showing infilling of interior, obscuring ribs except along the lower margin. This condition is present in most adult specimens of *C. madisonius* and *C. septenarius*. Note coarse matrix cemented by calcite. External mold of a *Mercenaria* is partially preserved.
2. *Ostrea raveneliana* Tuomey and Holmes, 1855.  
Exterior of a right valve (VMNH IP 3618).  
Height: 79.4 mm
3. *Carolinapecten eboreus* (Conrad, 1833)  
Left valve (VMNH IP 3619).  
Height: 47.4 mm.
4. *Carolinapecten eboreus* (Conrad, 1833)  
Right valve of the same specimen in Figure 3.  
Height: 49.0 mm
5. *Leptopecten leonensis* (Mansfield, 1932)  
Right valve (VMNH IP 3620). This is a West Coast genus that made its first appearance along the Atlantic Coast in the late Pliocene in the Rushmere Member, evidence of an Atlantic-Pacific connection at that time in the Panama area.  
Height: 17.6 mm
6. *Plicatula marginata* Say, 1824  
Right valve (VMNH IP 3621).  
Height: 20.9 mm



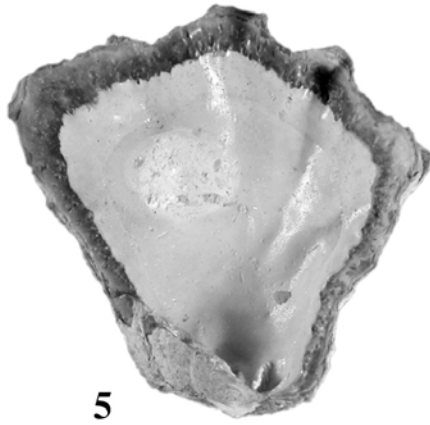
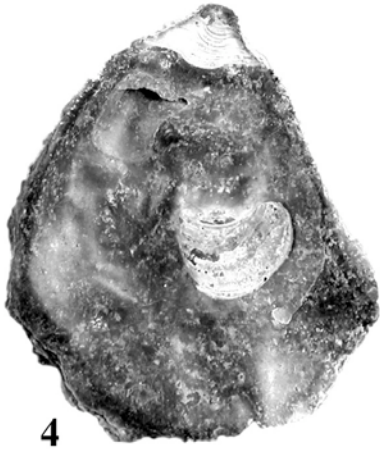
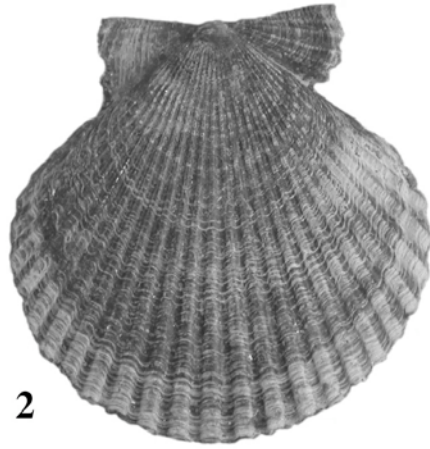
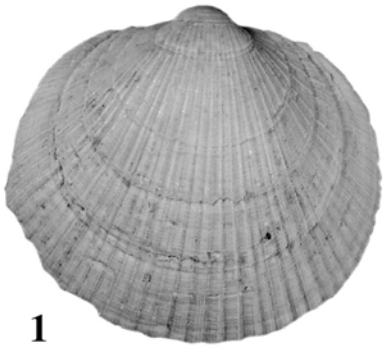


**Plate 13**

## Chowan River Formation

The Chowan River Formation at the Lee Creek Mine consists principally of a leached, semi-indurated coarse sandstone. Because it is cemented into irregularly shaped masses, it is widely called the "Boulder Bed." Where it is not leached, it contains an assortment of small mollusks, probably size-sorted. No specimens are much bigger than a quarter, though the young of large taxa are present.

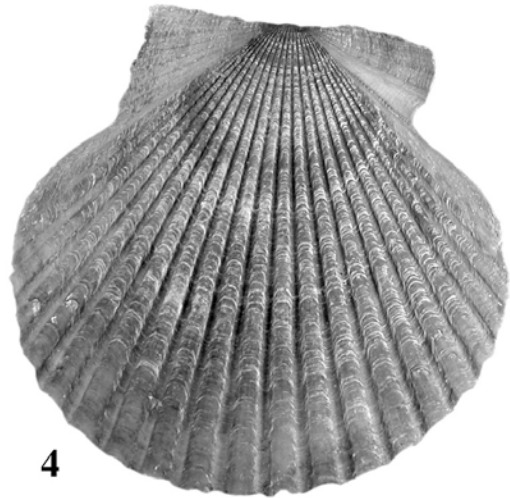
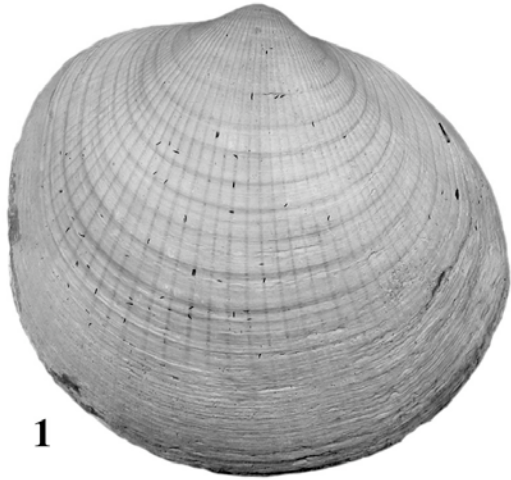
1. *Glycymeris americana* (DeFrance, 1826)  
Exterior of a left valve (VMNH IP 3622) of a young specimen.  
Height: 14.0 mm
2. *Carolinapecten eboreus* (Conrad, 1833)  
Exterior of a right valve (VMNH IP 3623) of a young specimen.  
Height: 17.7 mm
3. *Conradostrea sculpturata* (Conrad, 1840)  
Exterior of a right valve (VMNH IP 3624) of a young specimen.  
Height: 27.9 mm
4. *Conradostrea sculpturata* (Conrad, 1840).  
Interior of a right valve (VMNH IP 3625) of a young specimen.  
Height: 30.0 mm
5. *Plicatula marginata* Say, 1824  
Interior of a left valve (VMNH IP 3626) of an immature specimen.  
Height: 13.1 mm
6. *Astarte concentrica* Conrad, 1834  
Exterior of a right valve (VMNH IP 3627) of an adult specimen.  
Height: 21.2 mm
7. *Cyclocardia granulata* (Say, 1824)  
Exterior of a right valve (VMNH IP 3628) of an adult specimen.  
Height: 22.1 mm
8. *Lithologic specimen*  
Most of the Chowan River Formation consists of coarse, indurated sandstone like this fragment (VMNH IP 3629).  
Long dimension: 68 mm



**Plate 14**

## James City Formation

1. *Glycymeris americana* (DeFrance, 1826)  
Exterior of left valve of a very large individual (VMNH IP 3630). A very common taxon in the James City Formation. Common today in subtropical areas south of Cape Hatteras.  
Height: 110.0 mm
2. *Noetia limula* (Conrad, 1832)  
Exterior of a left valve of an adult specimen (VMNH IP 3631). *N. limula* is found only in the James City Formation and its equivalents. Its predecessor in the Chowan River Formation is *N. carolinensis* (Conrad) and its successor in the Flanner Beach Formation is *N. ponderosa* which is extant along the Mid-Atlantic coast.  
Height: 38.0 mm, Length: 60.0 mm
3. *Conradostrea lawrencei* Ward and Blackwelder, 1987  
Exterior of a left valve of an adult specimen (VMNH IP 3632). With this species, *Conradostrea* reached its peak size. Specimens are reported in the type Flanner Beach Formation (may be reworked), but at the Lee Creek Mine this is the last occurrence of the lineage.  
Height: 99.2 mm
4. *Carolinapecten eboreus* (Conrad, 1833)  
Exterior view of a left valve of a medium-sized specimen (VMNH IP 3633). Extremely abundant in the James City Formation.  
Height: 109.6 mm



**Plate 15**

## James City Formation

1. *Marvacrassatella kauffmani* Ward and Blackwelder, 1987  
Interior of a right valve (VMNH IP 3634). The genus *Marvacrassatella* first appeared in the lower Miocene (18.0 my) in the Pungo River, Calvert, and Kirkwood Formations. It is a cool temperate to subtropical taxon that is last seen in the James City Formation. There are no ecologic replacements for this genus.  
Height: 74.0 mm, Length: 101.2 mm
2. *Mercenaria permagna* (Conrad, 1838)  
Exterior of a left valve (VMNH IP 3635). Very abundant in the James City Formation.  
Height: 87.0 mm, Length: 112.1 mm
3. *Sinistrofulgur adversarius* (Conrad, 1863)  
Apertural view of an adult specimen (VMNH IP 3636). These and the whelk *Busycon* are common in the James City Formation.  
Height: 176.1 mm
4. *Volutifusus typus* Conrad, 1866  
Apertural view of specimen (USNM 204103).  
Height: 153.0 mm

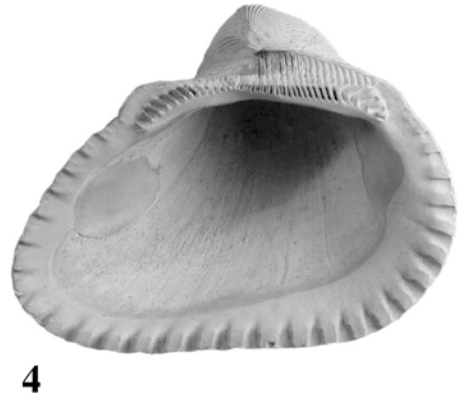
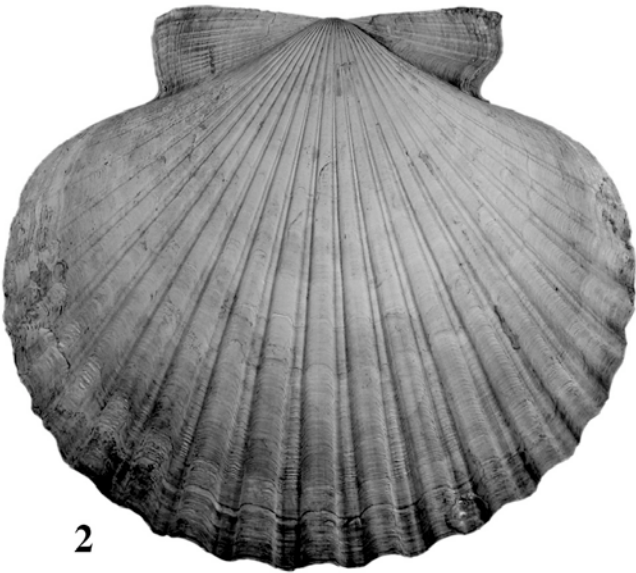
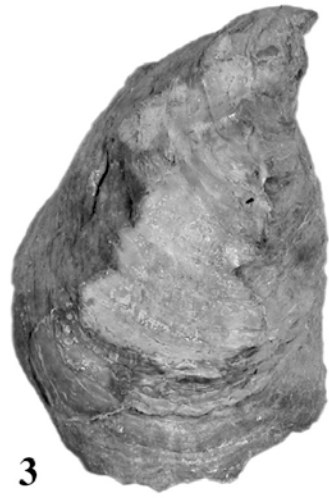
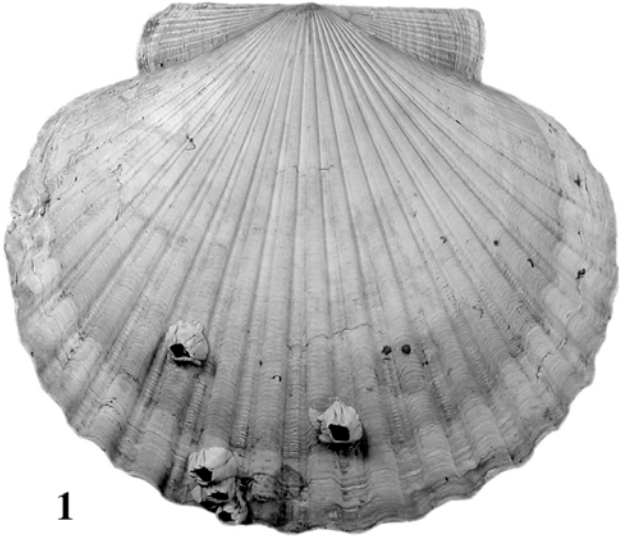


**Plate 16**

## Flanner Beach Formation

1. *Carolinapecten solarioides* (Heilprin, 1887)  
Right valve of a very large complete specimen (VMNH IP 3637). These are the last known occurrences of the genus *Carolinapecten*. A subtropical genus, there are no living taxa that have reoccupied their ecological niche.  
Height: 155.0 mm
2. *Carolinapecten solarioides* (Heilprin, 1887)  
Left valve of the specimen shown in Figure 1.  
Height: 156.0 mm
3. *Crassostrea virginica* (Gmelin, 1791)  
Right valve of a small specimen (VMNH IP 3638) probably living in brackish water. More brackish conditions resulted in beds with only *Crassostrea*.  
Height: 85.5 mm.
4. *Noetia ponderosa* (Say, 1822)  
Interior view of a left valve (VMNH IP 3639). This marks the first appearance of the species, still extant along the Atlantic Coast. A clear immediate descendant of *Noetia limula* found in the James City/Waccamaw Formations.  
Height: 42.0 mm
5. *Noetia ponderosa* (Say, 1822)  
Exterior view of the specimen (VMNH IP 3639) shown in Figure 4.

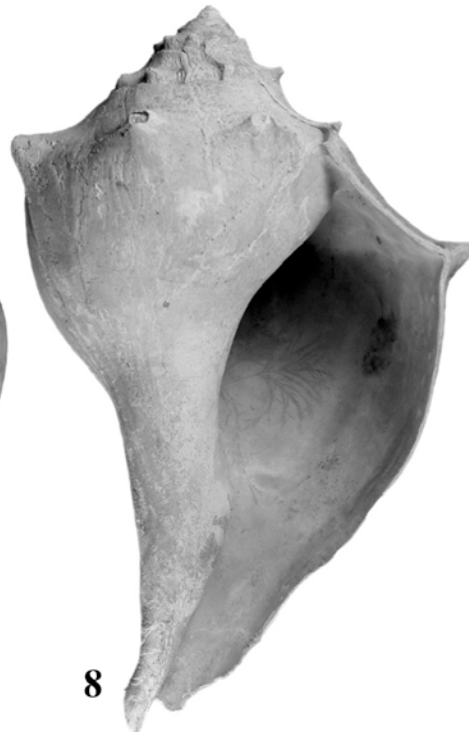
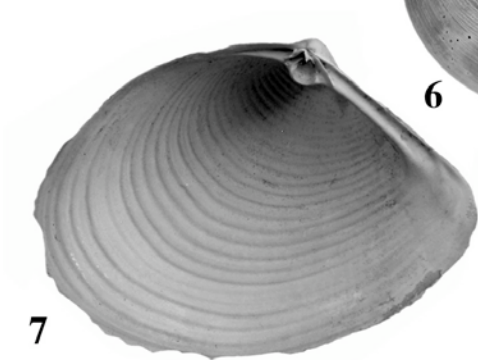
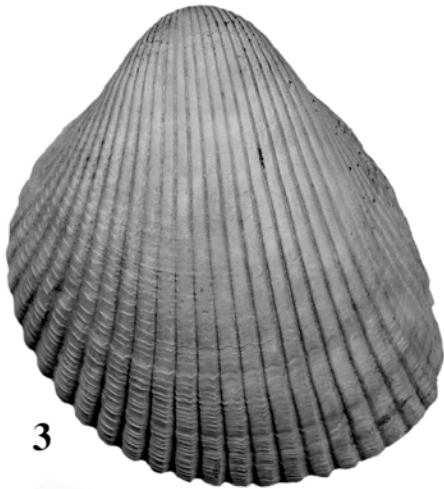




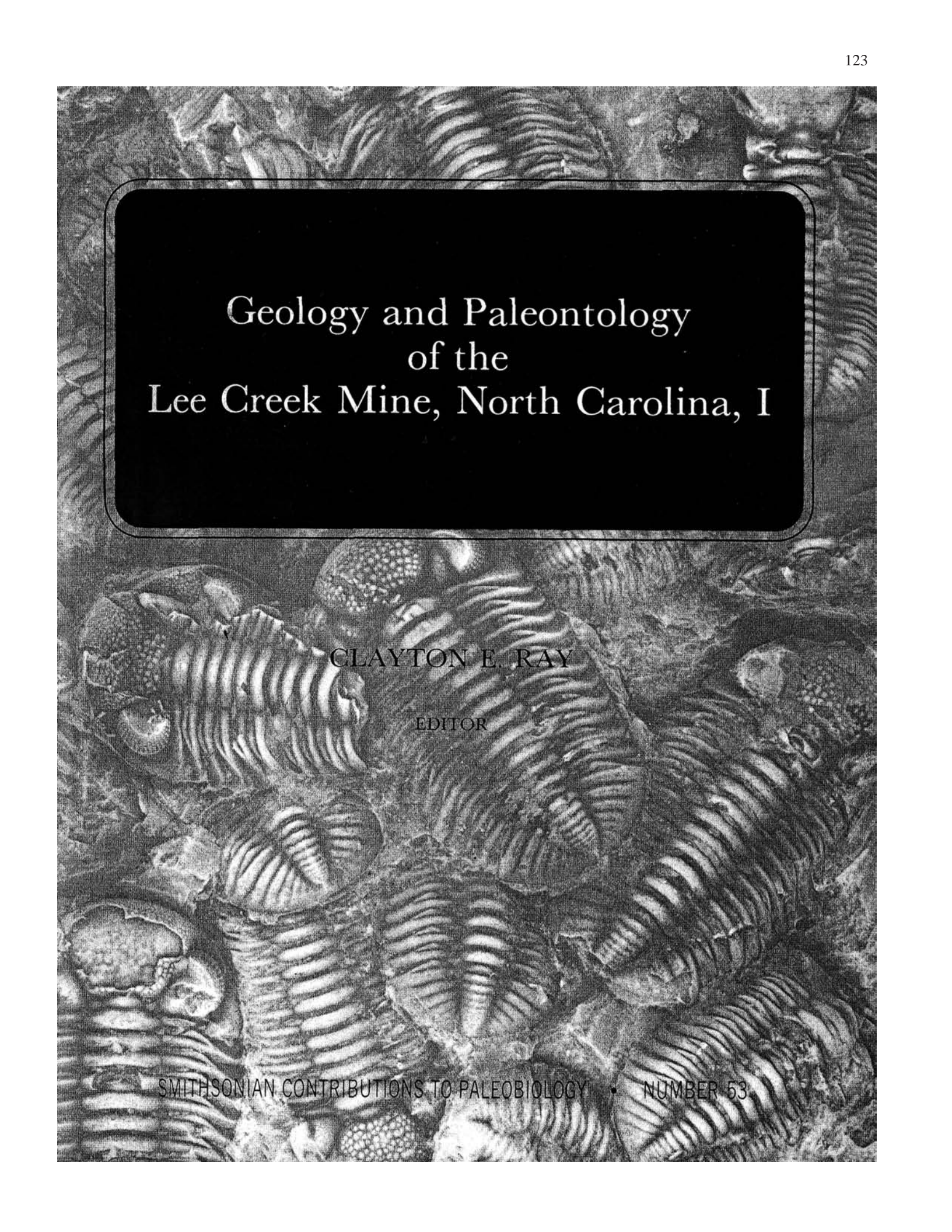
**Plate 17**

## Flanner Beach Formation

1. *Lunarca ovalis* Bruguière, 1789  
Interior of a right valve (VMNH IP 3640). This marks the first appearance of this genus, at least in the North Atlantic. It now ranges from the Middle Atlantic Coast south to Brazil.  
Height: 40.0 mm, Length: 48.8 mm
2. *Lunarca ovalis* Bruguière, 1789  
Exterior of specimen (VMNH IP 3640) shown in Figure 6.
3. *Dinocardium robustum* (Lightfoot, 1783)  
Exterior of a left valve (VMNH IP 3641). This genus is known back to the late Oligocene, always in subtropical to tropical settings.  
Height: 103.0 mm
4. *Mercenaria mercenaria* (Linnaeus, 1758)  
Exterior of a left valve (VMNH IP 3642). The unfused lamellae show that the species grew on open shelf with normal saline conditions.  
Height: 105.0 mm
5. *Mulinia lateralis* (Say, 1822)  
Interior of a left valve (VMNH IP 3643). Most common on fine silty sand substrates in quiet conditions.  
Height: 11.5 mm, Length: 16.5 mm
6. *Dosinia discus* (Reeve, 1850)  
Exterior of a left valve (VMNH IP 3644). This is the first sure appearance of this species in the Middle Atlantic. *D. acetabulum* appeared there around 18.0 my and dominated through until the upper Yorktown (3.5 my). In the Chowan River and James City seas, *Dosinia* was very scarce. *D. discus* is subtropical, from North Carolina to Texas.  
Height: 59.7 mm
7. *Raeta plicatella* (Lamarck, 1818)  
Interior of a left valve (VMNH IP 3645). This species lives in shallow water and, in spite of having a very thin shell, in fairly high energy conditions.  
Height: 42.0 mm
8. *Busycon carica* (Gmelin, 1791)  
Apertural view (VMNH IP 3646). The species first appears in the James City Formation and is still extant along most of the Atlantic Coast.  
Height: 132.0 mm





The background of the entire page is a detailed, black and white photograph of numerous fossilized trilobites. The trilobites are shown in various orientations, some facing left and some facing right, highlighting their characteristic three-lobed body structure. The fossils are embedded in a light-colored matrix, and the lighting creates strong shadows that emphasize the texture and form of the exoskeletons.

Geology and Paleontology  
of the  
Lee Creek Mine, North Carolina, I

CLAYTON E. RAY

EDITOR

SMITHSONIAN CONTRIBUTIONS TO PALEOBIOLOGY • NUMBER 53

Geology and Paleontology  
of the  
Lee Creek Mine, North Carolina, I

*Clayton E. Ray*

EDITOR



SMITHSONIAN INSTITUTION PRESS

City of Washington

1983

**SEP 13 1983**

## ABSTRACT

Ray, Clayton E., editor. *Geology and Paleontology of the Lee Creek Mine, North Carolina*, I. *Smithsonian Contributions to Paleobiology*, number 53, 529 pages, frontispiece, 95 figures, 101 plates, 8 tables, 1983.—This volume of papers on the geology and paleontology of the Lee Creek Mine is the first of three to be dedicated to the late Remington Kellogg, who initiated Smithsonian studies of the mine. It includes the first 14 papers, as well as a biography of Remington Kellogg by Frank C. Whitmore, Jr., and a prologue by Clayton E. Ray. This study places the Lee Creek Mine in the larger context of the history of Neogene geology and paleontology of the middle Atlantic Coastal Plain. Jack H. McLellan outlines the development and operation of Texasgulf's phosphate mine and manufacturing plant at Lee Creek, particularly as they relate to geological and paleontological studies. Thomas G. Gibson describes the regional patterns of Miocene-Pleistocene deposition in the Salisbury and Albemarle embayments of the central Atlantic Coastal Plain. On the basis of cluster analysis of 16 samples, including 149 taxa of ostracodes from fossiliferous beds above the Pungo River Formation, Joseph E. Hazel determines that the Yorktown Formation at the Lee Creek Mine is early Pliocene in age and the Croatan Formation spans the Plio-Pleistocene boundary. Among the ostracodes, 2 genera, 31 species, and one subspecies, are diagnosed as new. Walter H. Wheeler, Raymond B. Daniels, and Erling E. Gamble survey the post-Yorktown development in the region of the Neuse-Tar-Pamlico rivers. Primarily on the basis of auger holes, they begin with the Aurora paleoscarp marking the top of the Yorktown Formation, on which the organic-rich Small sequence (Croatan or James City Formation) was deposited, followed unconformably by the Pamlico morphostratigraphic unit; the inner edge of the Pamlico msu is associated with the Minnesott Ridge. H. Allen Curran and Patricia L. Parker divide the "Upper Shell" unit at the mine into three bivalve assemblage zones, probably formed through mass mortality in a series of local catastrophic events. Edward S. Belt, Robert W. Frey, and John S. Welch interpret Pleistocene deposition at the mine on the basis of biogenic and physical sedimentary structures, enabling them to recognize five major unconformities and four depositional sequences, indicative of a progradational shoreline under tectonically stable conditions. Their fourth depositional cycle includes a freshwater peat member thought to be of Sangamon interglacial age, on the basis of Donald R. Whitehead's pollen analysis. This analysis reveals high percentages of sedge and grass pollens, an absence of boreal indicators, tree pollen frequencies similar to those of interglacial deposits to the north and south, and general similarity of the fossil pollen spectrum to modern pollen assemblages of eastern North Carolina. Francis M. Hueber identifies the gymnospermous genera *Pinus*, *Juniperus*, and *Taxodium*, and tentatively the angiospermous genus *Gleditsia*, among the quartz-permineralized woods from the lower part of the Yorktown Formation at the mine; he also discusses the resin-like specimens, which are of unknown biological source and for which the stratigraphic source (Yorktown Formation, above the source of the woods) is known for only one specimen. William H. Abbott and John J. Ernissee report one silicoflagellate and two diatom assemblages (equivalent to Blow's zones N9 and N11) in a diatomaceous clay of the Pungo River Formation from two cores in Beaufort County; one new species of diatom is described. On the basis of 30 species of planktonic Foraminifera and a few radiometric dates, Thomas G. Gibson assigns ages from latest Oligocene through early Pleistocene to 10 stratigraphic units in the central Atlantic Coastal Plain; he describes 37 species and subspecies of benthic Foraminifera, of which 10 species and 2 subspecies are new. Scott W. Snyder, Lucy L. Mauger, and W.H. Akers assign an age of late-early to early-late Pliocene for a 15-meter section of the Yorktown Formation at the mine, based on 29 taxa of planktonic Foraminifera. Druid Wilson describes as a new genus and species of barnacle a puzzling fossil from inside the shell of the bivalve *Mercenaria* from the Croatan Formation. Porter M. Kier reports one species of echinoid from the Pungo River Formation, three from the Yorktown Formation, of which one is new, and two from the Croatan Formation. John E. Fitch and Robert J. Lavenberg record 45 taxa of teleost otoliths from the Yorktown Formation, representing 27 genera, of which 22 are new to the Pliocene of North America, and 6 are first fossil records.

OFFICIAL PUBLICATION DATE is handstamped in a limited number of initial copies and is recorded in the Institution's annual report, *Smithsonian Year*. SERIES COVER DESIGN: The trilobite *Phacops rana* Green.

## Library of Congress Cataloging in Publication Data

Main entry under title:

Geology and Paleontology of the Lee Creek Mine, North Carolina.

(Smithsonian contributions to paleobiology ; no. 53- )

Includes bibliographies.

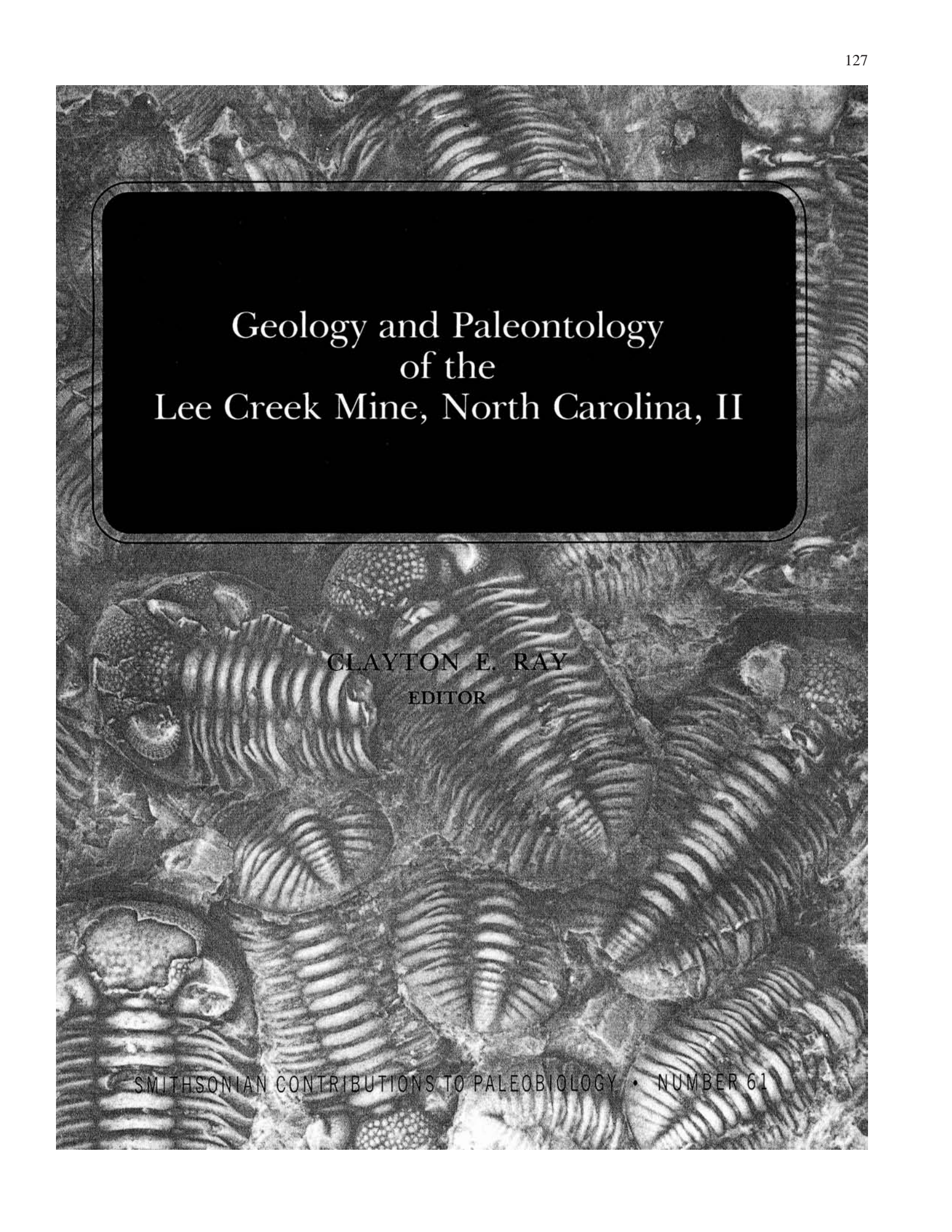
1. Geology, Stratigraphic—Tertiary—Addresses, essays, lectures. 2. Geology—Stratigraphic—Pleistocene—Addresses, essays, lectures. 3. Geology—North Carolina—Addresses, essays, lectures. 4. Paleontology—North Carolina—Addresses, essays, lectures. I. Ray, Clayton Edward. II. Series: Smithsonian contributions to paleobiology ; no. 53, etc.

QE701.S56 no. 53, etc. 560s [551.7'8'09756] 82-600265 [QE691]

## Contents

	<i>Page</i>
PROLOGUE, by Clayton E. Ray .....	1
REMINGTON KELLOGG, 1892-1969, by Frank C. Whitmore, Jr. ....	15
PHOSPHATE MINING AT THE LEE CREEK MINE, by Jack H. McLellan ..	25
STRATIGRAPHY OF MIOCENE THROUGH LOWER PLEISTOCENE STRATA OF THE UNITED STATES CENTRAL ATLANTIC COASTAL PLAIN, by Thomas G. Gibson .....	35
AGE AND CORRELATION OF THE YORKTOWN (PLIOCENE) AND CROATAN (PLIOCENE AND PLEISTOCENE) FORMATIONS AT THE LEE CREEK MINE, by Joseph E. Hazel .....	81
THE POST-YORKTOWN STRATIGRAPHY AND GEOMORPHOLOGY OF THE NEUSE-PAMLICO AREA, EASTERN NORTH CAROLINA, by Walter H. Wheeler, Raymond B. Daniels, and Erling E. Gamble .....	201
OBSERVATIONS ON THE PALEOECOLOGY AND FORMATION OF THE "UPPER SHELL" UNIT, LEE CREEK MINE, by H. Allen Curran and Patricia L. Parker .....	219
PLEISTOCENE COASTAL MARINE AND ESTUARINE SEQUENCES, LEE CREEK MINE, by Edward S. Belt, Robert W. Frey, and John S. Welch ....	229
POLLEN ANALYSIS OF THE PEAT MEMBER FROM THE LEE CREEK MINE, by Donald R. Whitehead .....	265
FOSSIL WOODS AND RESIN-LIKE SUBSTANCES FROM THE LEE CREEK MINE, by Francis M. Hueber .....	269
BIOSTRATIGRAPHY AND PALEOECOLOGY OF A DIATOMACEOUS CLAY UNIT IN THE MIOCENE PUNGO RIVER FORMATION OF BEAUFORT COUNTY, NORTH CAROLINA, by William H. Abbott and John J. Ernissee .....	287
KEY FORAMINIFERA FROM UPPER OLIGOCENE TO LOWER PLEISTOCENE STRATA OF THE CENTRAL ATLANTIC COASTAL PLAIN, by Thomas G. Gibson .....	355
PLANKTONIC FORAMINIFERA AND BIOSTRATIGRAPHY OF THE YORKTOWN FORMATION, LEE CREEK MINE, by Scott W. Snyder, Lucy L. Mauger, and W.H. Akers .....	455
THE LEE CREEK ENIGMA, <i>McLellana aenigma</i> , A NEW TAXON IN FOSSIL CIRRHIPEDIA, by Druid Wilson .....	483
UPPER CENOZOIC ECHINOIDS FROM THE LEE CREEK MINE, by Porter M. Kier .....	499
TELEOST FISH OTOLITHS FROM LEE CREEK MINE, AURORA, NORTH CAR- OLINA (YORKTOWN FORMATION: PLEISTOCENE), by John E. Fitch and Robert J. Lavenberg .....	509



The background of the entire page is a detailed, black and white photograph of numerous fossilized trilobites. The trilobites are shown in various orientations, some facing forward and others in profile, highlighting their characteristic three-lobed body structure and segmented thoraxes. The fossils are embedded in a light-colored rock matrix.

Geology and Paleontology  
of the  
Lee Creek Mine, North Carolina, II

CLAYTON E. RAY  
EDITOR

SMITHSONIAN CONTRIBUTIONS TO PALEOBIOLOGY • NUMBER 61

Geology and Paleontology  
of the  
Lee Creek Mine, North Carolina, II

*Clayton E. Ray*

EDITOR



SMITHSONIAN INSTITUTION PRESS

Washington, D.C.

1987

JUN 15 1987

## ABSTRACT

Ray, Clayton E., editor. Geology and Paleontology of the Lee Creek Mine, North Carolina, II. *Smithsonian Contributions to Paleobiology*, number 61, 283 pages, 80 plates, 49 figures, 21 tables, 1987.—Volume I of this projected series of three volumes included the prologue to the series, a biography of Remington Kellogg, and 13 papers on geology and paleontology other than Mollusca and Vertebrata (except otoliths). It was published in 1983 as *Smithsonian Contributions to Paleobiology* number 53. The present volume consists of a foreword and five chapters devoted to molluscan paleontology. The foreword recounts the earliest scientific publication of New World fossils, all mollusks, and reproduces Martin Lister's illustrations of them. William M. Furnish and Brian F. Glenister record the nautilid genus *Aturia* from the Pungo River Formation and discuss its occurrence elsewhere. Druid Wilson describes a new pycnodont oyster from the Pungo River Formation and lists the Cenozoic pycnodonts from the Atlantic and Gulf Coastal Plain; he also summarizes the stratigraphic and geographic occurrences of the subgenera of *Ecphora*, *Ecphora* and *Stenomphalus*, naming a new species of each from the Pungo River Formation, and a new species of the former from the St. Marys Formation of Maryland. Thomas G. Gibson clarifies the relationships and stratigraphic utility of 17 taxa (including one new species from the Pungo River Formation) of pectinid bivalves on the basis of biometric study of large samples from lower Miocene to lower Pleistocene beds in and near the mine. Lauck W. Ward and Blake W. Blackwelder describe a molluscan fauna of 194 species, including 30 new species and 3 new subspecies, from the Chowan River (upper Pliocene) and James City (lower Pleistocene) formations, and conclude that the fauna reflects a subtropical thermal regime and that it was deposited under open marine conditions at depths not exceeding 25 meters.

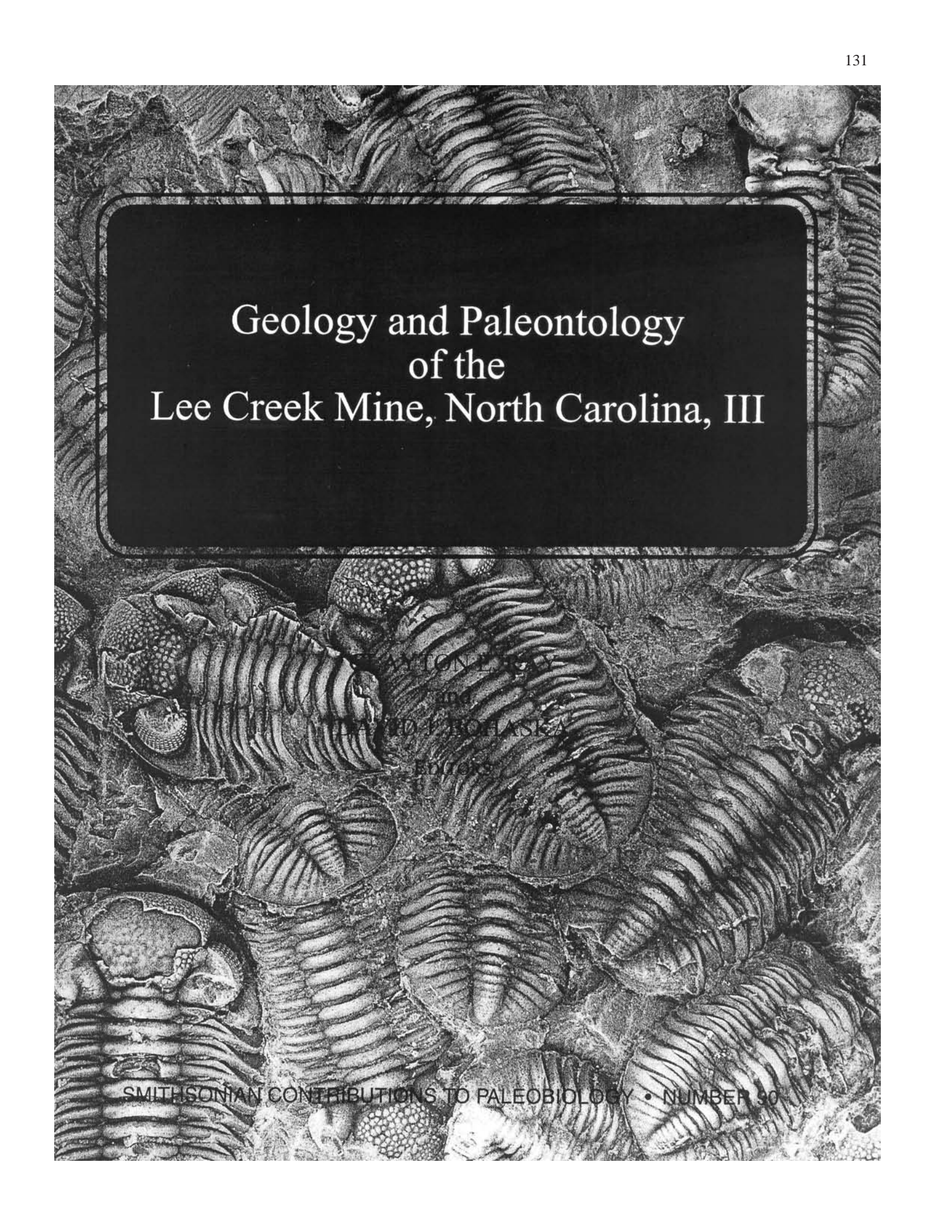
OFFICIAL PUBLICATION DATE is handstamped in a limited number of initial copies and is recorded in the Institution's annual report, *Smithsonian Year*. SERIES COVER DESIGN: The trilobite *Phacops rana* Green.

Library of Congress Cataloging in Publication Data  
 Geology and paleontology of the Lee Creek Mine, North Carolina.  
 (Smithsonian contributions to paleobiology ; no. 53)  
 Includes bibliographies.  
 Supt of Docs. no.: SI 1.30 : 61

1. Geology, Stratigraphic—Tertiary. 2. Geology, Stratigraphic—Pleistocene. 3. Geology—North Carolina—Lee Creek Mine Region. 4. Paleontology—North Carolina—Lee Creek Mine Region. I. Ray, Clayton Edward. II. Series: Smithsonian contributions to paleobiology ; no. 53, etc.  
 QE701.S56 no. 53, etc. [QE691] 560 s. 82-600265 [551.7'8'09756]

# Contents

	<i>Page</i>
FOREWORD, by Clayton E. Ray .....	1
MIOCENE CEPHALOPODS FROM NORTH CAROLINA, by William M. Furnish and Brian F. Glenister .....	9
A NEW PYCNODONT OYSTER FROM THE PUNGO RIVER FORMATION, AND AN ANNOTATED LIST OF THE CENOZOIC PYCNODONTS OF THE ATLANTIC AND GULF COASTAL PLAIN, by Druid Wilson .....	13
SPECIES OF <i>ECPHORA</i> , INCLUDING THE SUBGENUS <i>STENOMPHALUS</i> , IN THE PUNGO RIVER FORMATION, by Druid Wilson .....	21
MIOCENE AND PLIOCENE PECTINIDAE (BIVALVIA) FROM THE LEE CREEK MINE AND ADJACENT AREAS, by Thomas G. Gibson.....	31
LATE PLIOCENE AND EARLY PLEISTOCENE MOLLUSCA FROM THE JAMES CITY AND CHOWAN RIVER FORMATIONS AT THE LEE CREEK MINE, by Lauck W. Ward and Blake W. Blackwelder.....	113



Geology and Paleontology  
of the  
Lee Creek Mine, North Carolina, III

SMITHSONIAN CONTRIBUTIONS TO PALEOBIOLOGY • NUMBER 90

Geology and Paleontology  
of the  
Lee Creek Mine, North Carolina, III

*Clayton E. Ray and David J. Bohaska*

EDITORS  
*Clayton E. Ray* *David J. Bohaska*

**ISSUED**

**MAY 11 2001**

**SMITHSONIAN INSTITUTION**



Smithsonian Institution Press

Washington, D.C.

2001

## A B S T R A C T

Ray, Clayton E., and David J. Bohaska, editors. *Geology and Paleontology of the Lee Creek Mine, North Carolina, III. Smithsonian Contributions to Paleobiology*, number 90, 365 pages, 127 figures, 45 plates, 32 tables, 2001.—This volume on the geology and paleontology of the Lee Creek Mine is the third of four to be dedicated to the late Remington Kellogg. It includes a prodromus and six papers on nonmammalian vertebrate paleontology. The prodromus continues the historical theme of the introductions to volumes I and II, reviewing and resuscitating additional early reports of Atlantic Coastal Plain fossils. Harry L. Fierstine identifies five species of the billfish family Istiophoridae from some 500 bones collected in the Yorktown Formation. These include the only record of *Makaira purdyi* Fierstine, the first fossil record of the genus *Tetrapturus*, specifically *T. albidus* Poey, the second fossil record of *Istiophorus platypterus* (Shaw and Nodder) and *Makaira indica* (Cuvier), and the first fossil record of *I. platypterus*, *M. indica*, *M. nigricans* Lacépède, and *T. albidus* from fossil deposits bordering the Atlantic Ocean. Robert W. Purdy and five coauthors identify 104 taxa from 52 families of cartilaginous and bony fishes from the Pungo River and Yorktown formations. The 10 teleosts and 44 selachians from the Pungo River Formation indicate correlation with the Burdigalian and Langhian stages. The 37 cartilaginous and 40 bony fishes, mostly from the Sunken Meadow member of the Yorktown Formation, are compatible with assignment to the early Pliocene planktonic foraminiferal zones N18 or N19. The Pungo River fish fauna is dominated by warm water taxa; the Yorktown fauna includes warm and cool water species. These changes are attributed to increased upwelling waters in Yorktown time. The abundant fossils provide the basis for several changes in selachian taxonomy and for two new species of bony fishes. George R. Zug records 11 taxa of turtles from the Yorktown Formation: a sideneck (*Bothremys*); six sea turtles (*Caretta*, ?*Chelonia*, *Lepidochelys*, *Procolpochelys*, *Psephophorus*, *Syllomus*); a softshell turtle (trionychid); two pond turtles (probably *Pseudemys* and *Trachemys*); and a giant tortoise (*Geochelone*). Albert C. Myrick, Jr., records the crocodylian *Thecachampsa antiqua* (Leidy) on the basis of fragmentary float material from the Pungo River or Yorktown Formation, or both. Robert W. Storer describes a new species of grebe of the genus *Podiceps* from the Yorktown Formation. Storrs L. Olson and Pamela C. Rasmussen record some 112 species of birds from the Pungo River and Yorktown formations. Apart from an undetermined number of shearwaters, only a few species are thought to come from the Pungo River Formation. The marine species from the Yorktown Formation include three loons, two grebes, five albatrosses, at least 16 shearwaters and petrels, one pelican, two pseudodontorns, three gannets, two cormorants, 9–11 auks and puffins, one skua, three jaegers, five gulls, two terns, and 20 ducks, geese, and swans. The less common land and shore birds are represented by 29 species, including three cranes, one rail, two oystercatchers, one plover, four scolopacids, one flamingo, one ibis, one heron, three storks, one condor, five accipitrids, one osprey, one phasianid, one turkey, one pigeon, and one crow. The fauna is dominated by a radiation of auks of the genus *Alca*. The early Pliocene fauna is very modern in aspect, suggesting that most modern lineages of birds were already in existence.

OFFICIAL PUBLICATION DATE is handstamped in a limited number of initial copies and is recorded in the Institution's annual report, *Annals of the Smithsonian Institution*. SERIES COVER DESIGN: The trilobite *Phaecops rana* Green.

## Library of Congress Cataloging-in-Publication Data

Main entry under title:

Geology and Paleontology of the Lee Creek Mine, North Carolina.

(Smithsonian contributions to paleobiology ; no. 53— )

Includes bibliographies.

1. Geology, Stratigraphic—Tertiary—Addresses, essays, lectures. 2. Geology—Stratigraphic—Pleistocene—Addresses, essays, lectures. 3. Geology—North Carolina—Addresses, essays, lectures. 4. Paleontology—North Carolina—Addresses, essays, lectures. I. Ray, Clayton Edward. II. Series: Smithsonian contributions to paleobiology ; no. 53, etc.

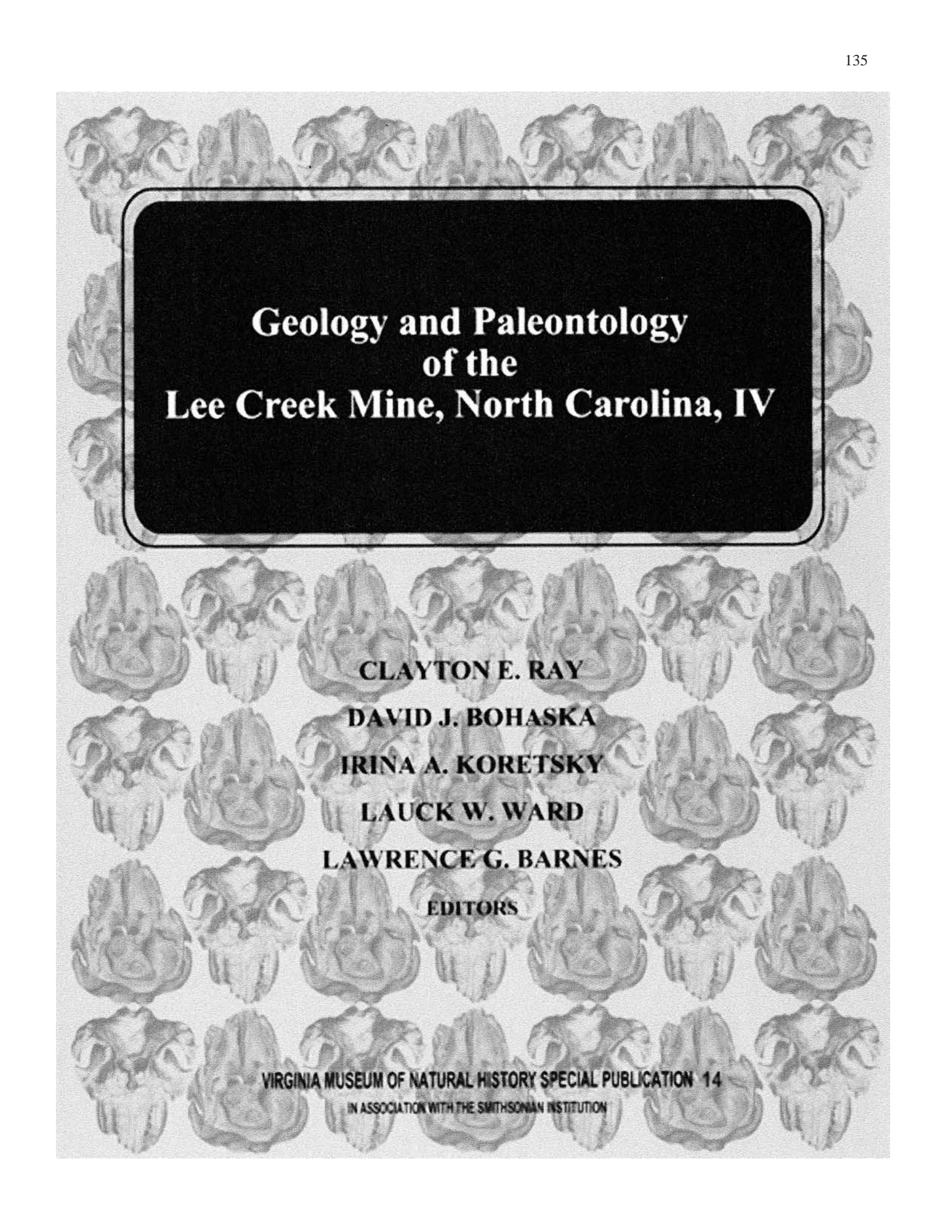
QE701.S56 no. 53, etc. 560s [551.7'8'09756] 82-600265 [QE691]

∞ The paper used in this publication meets the minimum requirements of the American National Standard for Permanence of Paper for Printed Library Materials Z39.48—1984.

## Contents

	<i>Page</i>
PRODROMUS, by Clayton E. Ray .....	1
ANALYSIS AND NEW RECORDS OF BILLFISH (TELEOSTEI: PERCIFORMES: ISTIOPHORIDAE) FROM THE YORKTOWN FORMATION, EARLY PLIOCENE OF EASTERN NORTH CAROLINA AT LEE CREEK MINE, by Harry L. Fierstine .....	21
THE NEOGENE SHARKS, RAYS, AND BONY FISHES FROM LEE CREEK MINE, AURORA, NORTH CAROLINA, by Robert W. Purdy, Vincent P. Schneider, Shelton P. Applegate, Jack H. McLellan, Robert L. Meyer, and Bob H. Slaughter .....	71
TURTLES OF THE LEE CREEK MINE (PLIOCENE: NORTH CAROLINA), by George R. Zug .....	203
<i>THECACHAMPSA ANTIQUA</i> (LEIDY, 1852) (CROCODYLIDAE: THORACOSAURINAE), FROM FOSSIL MARINE DEPOSITS AT LEE CREEK MINE, AURORA, NORTH CAROLINA, USA, by Albert C. Myrick, Jr. ....	219
A NEW PLIOCENE GREBE FROM THE LEE CREEK DEPOSITS, by Robert W. Storer .....	227
MIOCENE AND PLIOCENE BIRDS FROM THE LEE CREEK MINE, NORTH CAROLINA, by Storrs L. Olson and Pamela C. Rasmussen .....	233



The background of the entire page is a repeating pattern of trilobite fossils, specifically the cephalon (head) part, arranged in a grid. The fossils are rendered in a light gray, almost white, tone against a slightly darker gray background.

**Geology and Paleontology  
of the  
Lee Creek Mine, North Carolina, IV**

**CLAYTON E. RAY  
DAVID J. BOHASKA  
IRINA A. KORETSKY  
LAUCK W. WARD  
LAWRENCE G. BARNES  
EDITORS**

**VIRGINIA MUSEUM OF NATURAL HISTORY SPECIAL PUBLICATION 14**  
IN ASSOCIATION WITH THE SMITHSONIAN INSTITUTION

Geology and Paleontology  
of the  
Lee Creek Mine, North Carolina, IV

*Clayton E. Ray,*

*David J. Bohaska, Irina A. Koretsky,*

*Lauck W. Ward*

*and Lawrence G. Barnes*

*Editors*

## ABSTRACT

Ray, Clayton E., Bohaska, David J., Koretsky, Irina A., Ward, Lauck W., W., and Lawrence G. Barnes Editors.  
 Geology and Paleontology of the Lee Creek Mine, North Carolina, IV.

*Virginia Museum of Natural History*, Special Publication Number 14, 507 pages, 273 figures, 17 plates, 48 tables, 2007,

----This volume on the geology and paleontology of the Lee Creek Mine is the fourth and final volume to be dedicated to the late Remington Kellogg. It includes an introductory chapter (Mantissa), six chapters on fossil mammals, a review of work at the mine, and a systematically indexed bibliography of Remington Kellogg's publications. The mantissa continues the historical theme of the introductions to volumes I-III and suggests possible general implications of the Lee Creek project. Ralph E. Eshelman and Frank C. Whitmore, Jr. record no less than 16 kinds of land mammals from the lower Yorktown Formation, representing five orders, 12 families, and nine genera, indicative of Late Hemphillian age. Naoki Kohno and Clayton E. Ray review the Pliocene walruses of the North Atlantic region and assign all diagnosable nominal species to *Ontocetus emmonsii*. Irina A. Koretsky and Clayton E. Ray identify six species of phocid seals from the Yorktown formation, including *Platyphoca vulgaris*, *Phocanella pumila*, *Gryphoca similis*, *Callophoca obscura*, *Pliophoca etrusca*, and *Homiphoca capensis*. All but the last two were described first from the Antwerp basin of Belgium. The Belgian taxa are revised here. Frank C. Whitmore, Jr., and Lawrence G. Barnes erect the new subfamily Herpetocetinae, to accommodate small cetotheres from the latest Miocene to earliest Pliocene of the North Atlantic and North Pacific, of which one species each is described here, from North Carolina and California. From the late Early Miocene or early Middle Miocene Pungo River Formation, Frank C. Whitmore, Jr., and James A. Kaltenbach record 17 kinds of cetaceans of which only one is mysticete and 16 are odontocetes, including a new species of *Kentriodon*. From the early Pliocene Yorktown Formation, they record 21 kinds of cetaceans, of which seven are mysticetes, including a new genus and species of eschrichtiid, and of which 14 are odontocetes, including one new species each of *Lagenorhynchus* and *Stenella*, and one new genus and species of kogiine. The assemblage from the Pungo River Formation includes only extinct genera, whereas that from the Yorktown Formation includes mostly living genera, whose species differ only slightly from living ones. On the basis of some 500 humeri (and a few ulnae) Emese Kazár and David J. Bohaska identify 13 morphotypes of odontocete cetaceans of at least eight families, three or possibly four from the Pungo River Formation and four or possibly five from the Yorktown Formation. A single humerus may be older, possibly Oligocene, in age. The taxonomic results are generally consistent with those of Whitmore and Kaltenbach, based on cranial materials. Lauck W. Ward reviews and synthesizes the paleontology and stratigraphy of the Lee Creek Mine, placing the work in coastal plain context, and presents guide fossils to the strata known at the mine. He also highlights weaknesses in present knowledge, and makes recommendations for future work. Jane Knapp presents a bibliography of the scientific publications of Remington Kellogg including 183 titles, together with an index of more than 6,000 citations to common and scientific names.

## Contents

	<i>Page</i>
Mantissa, by Clayton E. Ray.....	1
Early Pliocene (Late Hemphillian) Land Mammals from the Lee Creek Mine, Aurora, North Carolina, by Ralph E. Eshelman and Frank C. Whitmore, Jr. ....	17
Pliocene Walruses from the Yorktown Formation of Virginia and North Carolina, and a Systematic Revision of the North Atlantic Pliocene Walruses, by Naoki Kohno and Clayton E. Ray .....	39
Phocidae of the Pliocene of Eastern USA, by Irina A. Koretsky and Clayton E. Ray.....	81
The Herpetocetinae, a New Subfamily of Extinct Baleen Whales (Mammalia: Cetotheriidae), by Frank C. Whitmore, Jr., and Lawrence G. Barnes.....	141
Neogene Cetacea of the Lee Creek Phosphate Mine, North Carolina, by Frank C. Whitmore, Jr., and James A. Kaltenbach.....	181
Toothed Whale (Mammalia: Cetacea: Odontoceti) Limb Bones of the Lee Creek Mine, North Carolina, by Emese Kazár and David J. Bohaska.....	271
Synthesis of Paleontological and Stratigraphic Work at the Lee Creek Mine, Aurora, N.C. (1958-2004), by Lauck W. Ward.....	325
Remington Kellogg: Bibliography of the Scientific Works and Index to Scientific and Common Names, by Jane Knapp.....	433