1983

Observations on the Paleoecology and Formation of the “Upper Shell” Unit, Lee Creek Mine

H. Allen Curran
Smith College, acurran@smith.edu

Patricia L. Parker
Smith College

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

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]

Observations on the Paleoecology and Formation of the "Upper Shell" Unit, Lee Creek Mine

H. Allen Curran and Patricia L. Parker

ABSTRACT

The "Upper Shell" unit at the Lee Creek Mine (Pliocene age, maximum thickness 3 m) is remarkable for its concentration of well-preserved mollusk shells in a sparse quartz sand matrix, and it is dominated by several species of bivalves, with many shells articulated. The unit can be subdivided into three bivalve assemblage zones characterized by associations of dominant species. Zone 1 is dominated by *Mercenaria mercenaria*, an infaunal, shallow- to medium-burrowing, siphonate clam. Zone 2 is characterized by an epifaunal bivalve assemblage that includes *Glycymeris americana, Argopecten eboreus*, *Anomia simplex*, and *Ostrea meridionalis*. Thin but highly concentrated accumulations of *Argopecten* and *Anomia* form distinct layers within zone 2. Zone 3 is marked by a return of *Mercenaria mercenaria* accompanied by specimens of *Geukensia* sp. and an increase in oyster shells. The characteristics of the zones of the "Upper Shell" unit strongly suggest that these shell beds were formed by a series of localized catastrophic events that produced mass mortality of the molluscan assemblages, rather than by processes of gradual shell accumulation. The disappearance of *Mercenaria mercenaria* from the sequence may have been due largely to the inability of juveniles of this species to penetrate a shell pavement formed immediately after a mass mortality event. Return of *Mercenaria mercenaria* in zone 3 marks a change in bottom environmental conditions in the area. The overlying "Shell Hash" unit contains the bivalve *Corbicula densata,* representative of lower salinity conditions. This unit consists primarily of shell material reworked from the underlying "Upper Shell" unit and probably represents an accumulation formed in an estuarine tidal channel.

H. Allen Curran and Patricia L. Parker, Department of Geology, Smith College, Northampton, Massachusetts 01063.

Introduction

One of the most prominent units revealed by strip mining operations at the Lee Creek Mine of Texasgulf Inc. is a shell bed with a maximum thickness of 3 meters located toward the top of the exposed stratigraphic sequence. Known locally as the "Upper Shell" unit, these beds are remarkable for their abundant, well-preserved megafossils, consisting largely of bivalves, gastropods, and large coral heads. Many of the mollusk shells are whole and unworn, bivalves are frequently articulated, and some of the shells retain faint coloration patterns.

During the summers of 1971 and 1972, the actively worked and advancing western face of the mine (approximately 1100 m in length) was cut by a series of five equidistantly spaced, parallel drainage trenches of up to 240 meters in length, which ran normal to the mine's west wall (Figure 1). Each of these trenches cut to the base or slightly below the base of the "Upper Shell" unit and provided continuous and easily accessible exposures. At first glance the "Upper Shell" unit appeared to be a homogenous sequence, conspicuously dominated by large, flat-lying bivalve shells. Closer inspection revealed that the unit consisted of a sequence of three major shell

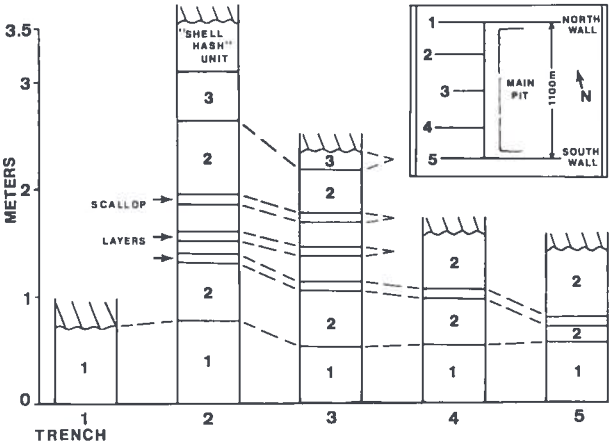

FIGURE 1.—Correlation of bivalve assemblage zones 1–3 of the "Upper Shell" unit between sections established in the five drainage trenches that ran normal to the west wall of the Lee Creek Mine in 1971–1972. Arrows mark positions of layers with concentrations of *Argopecten* and *Anomia* shells that cut zone 2. The "Shell Hash" unit also is exposed prominently on the south wall of the mine. Inset diagram shows the spatial distribution of the drainage trenches in 1971.

layers, each characterized by a distinctive assemblage of bivalve species.

The varied nature and good exposures of the "Upper Shell" unit presented an excellent opportunity for detailed sampling of the shell layers. Paleoecological data derived from the samples include the relative abundances of dominant species in each layer, changes in species abundances through the section, and size-frequency analyses of selected species. These data have enabled a paleoecological interpretation of the varying bivalve associations. The question of how extensive shell layers like this one are formed is intriguing, and our work has enabled us to speculate concerning mechanisms of origin of these shell beds.

The full extent of the "Upper Shell" unit was examined in each of the drainage trenches and the thickness of each faunal zone measured and recorded. Bulk samples were taken from each shell layer and all trenches in the 1971 trench positions (Figure 1). The trench network permitted close correlation of faunal zones between the five trenches. Samples of 1 cubic foot (0.028 m^3) volume (dimensions 1×1×1 ft where possible) were dug from the trench faces and placed in a large wooden wash box similar to that described by McKenna (1965). Samples were then field washed in the drainage stream at the base of each trench and boxed for laboratory study. One sample was taken from each layer thinner than 0.3 meter and two samples from layers thicker than 0.3 meter.

ACKNOWLEDGMENTS.—We wish to thank the personnel of Texasgulf Inc. for permission to work in the mine. June Crawford and Jack Hird of Texasgulf Inc. were particularly helpful in making arrangements for us. Edward Belt and John Welch of Amherst College and Jeremy Reiskind of Mt. Holyoke College assisted in the field work and provided much helpful discussion. Useful criticism of the manuscript was provided by Robert Gernant of the University of Wisconsin-Milwaukee, Druid Wilson of the National Museum of Natural History, Smithsonian Institution, and Blake Blackwelder and Lauck Ward of the U.S. Geological Survey. The project was supported by National Science Foundation COSIP Grant GY-7657 to Amherst, Mt. Holyoke, Smith, and Williams Colleges.

The Stratigraphic Setting

The "Upper Shell" unit consists dominantly of flat-lying, well-preserved bivalve shells in a poorly consolidated matrix of light gray, fine to coarse quartz sand and fragmented shell. At most points of exposure the shells and shell fragments are tightly packed with little surrounding matrix (Figure 2A, B), although the amount of fine sand, silt, and clay increases greatly at some places. Designated by Gibson (1967:639, fig. 4) as unit 8 of the Yorktown Formation, the "Upper Shell" unit directly overlies a partly indurated, medium to coarse, carbonate cemented quartz sandstone known locally as the "Boulder Bed" (unit 7 of Gibson). The detailed stratigraphy of the entire section above the "Boulder Bed" of the Yorktown Formation, including all units recognized in this study, is presented in Figures 3 and 4 of Belt, Frey, and Welch (this volume).

Questions concerning the age and formational assignment of the "Upper Shell" unit have not been entirely resolved. Although the shell bed previously has been assigned to the Yorktown Formation (Gibson, 1967), the contact between the "Upper Shell" unit and the underlying "Boulder" bed is easily recognized and may represent a significant break in the local stratigraphic sequence. Hazel (p. 84, herein) refers Gibson's units 6–9 of the Yorktown Formation to the Croatan Formation and considers these beds to be late Pliocene-early Pleistocene in age. The "Upper Shell" unit has been traced regionally to the south through samples from auger drillings reported on by Wheeler, Daniels, and Gamble (this volume). They use the name James City Formation (or Croatan Formation) for these shell deposits and consider them to be of Pliocene age. This correlation is supported by DuBar, Solliday and Howard (1974:109).

Description of the Shell Bed

At the time of this study (1971–1972), weathering and ground water percolation had caused considerable slumping and iron oxide discoloration of the trench walls. On fresh surfaces, the bivalve shells formed distinct horizontal layers dominated by one or two species. We were able to recognize three distinct bivalve faunal assemblages in the "Upper Shell" unit in the area of the trenches. The faunal zones were dominated by abundant, largely mutually exclusive occurrences of three species: *Mercenaria mercenaria* (Linnaeus), *Glycymeris americana* (DeFrance), and the scallop *Argopecten eboreus* (Conrad). We measured a maximum thickness of 3 meters for the "Upper Shell" unit at the 1971 location of trench 2 (Figure 1). At this location and in trench 3, three faunal assemblage zones could be recognized and established. Zone 2 is cut by several thin (0.15 m) layers dominated by *Argopecten eboreus*. Trenches 1, 4, and 5 had incomplete and thinner sections of the "Upper Shell" unit, but one or more zones of the unit were present in each of these trenches. Characteristics of the faunal zones are illustrated in Figure 2. The dominant faunal constituents and maximum thickness of each zone are as follows: ZONE 1 (maximum thickness 0.6 m): *Mercenaria mercenaria* (Linnaeus) dominant. ZONE 2 (maximum thickness 2.15 m): *Glycymeris americana* (DeFrance) dominant, zone cut by thin layers (0.15 m) composed primarily of shells of *Argopecten eboreus* (Conrad) and *Anomia simplex* d'Orbigny. ZONE 3 (maximum thickness 0.25 m): *Mercenaria mercenaria* (Linnaeus), dominant; *Ostrea meridionalis* Heilprin and *Geukensia* sp., common.

The horizontal bedding pattern of the "Upper Shell" unit is broken by steeply dipping (up to 30°), shell-dominated cross-beds along much of the north wall of the mine. Shells in these beds are disarticulated and often broken. The large valves and valve fragments that make up the bulk of these beds typically exhibit worn surfaces resulting from transport under high energy conditions. The anomalous bedding pattern and worn condition of shells forming these cross-beds indicates that these beds were deposited after formation of the "Upper Shell" unit. As one moves laterally away from the cross-beds into the area of trench 1 (west), beds of zone 1, characterized by flat-lying, often articulated *Mercenaria mercenaria*, become visible.

We interpret these cross-beds as representative of a localized event of reworking and redeposition of shells derived primarily from the "Upper Shell" unit. This reworking event possibly occurred during the formation and filling of a tidal channel as part of the general reworking of shells associated with the formation of the overlying "Shell Hash" unit. A common component of the cross-bedded shell accumulation is large valves of the oyster *Crassostrea virginica* (Gmelin). This species does not occur in the beds of the "Upper Shell" unit, but the species may have flourished in the vicinity of or along the banks of the now-filled tidal channel, thus explaining its occurrence with the reworked shells. Modern analogs supporting this interpretation have been reported by Howard and Frey (1973:1177, fig. 8) and Wiedemann (1972) from estuaries of the Georgia coast. Here Holocene shells and shells reworked

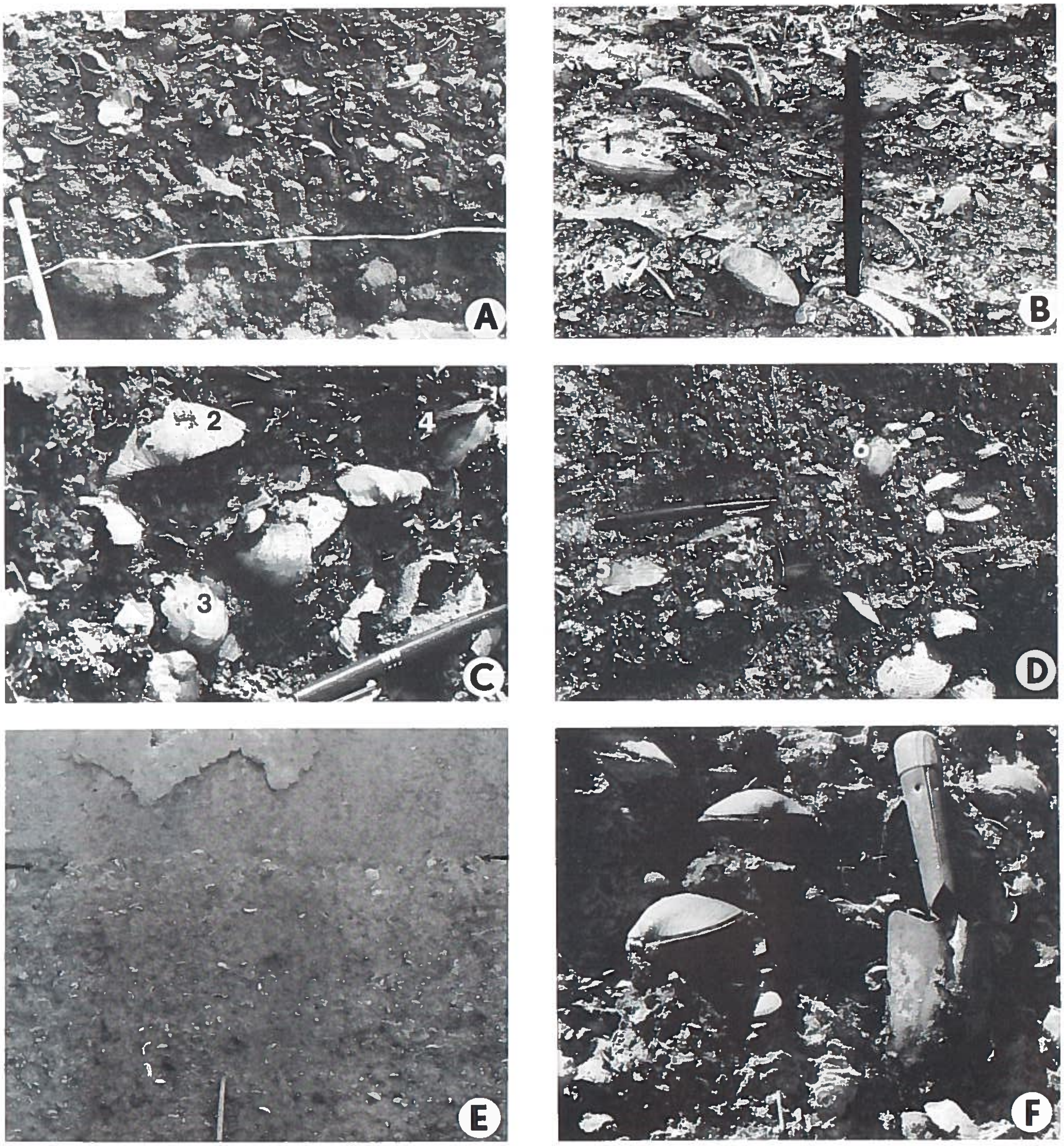

FIGURE 2.—A, Contact between the "Boulder Bed" and *Mercenaria* dominated zone 1 of the "Upper Shell" unit. B, Close-up of zone 1 showing large *Mercenaria* valves (1) which form a hard shell pavement at top of the zone. C, Concentration of epifaunal bivalves, *Glycymeris* (2), *Anomia* (3), and *Argopecten* (4) characterize zone 2. D, Thin layers of concentrated valves of *Argopecten* (5) and *Anomia* (6) form a subassemblage within zone 2. E, South wall of mine showing sharp contact (arrows) between "Upper Shell" unit and overlying "Shell Hash" unit. F, Close-up of zone 2 showing articulated *Glycymeris* specimens.

from pre-Holocene deposits occur in tidal channel accumulations, with valves of *C. virginica* frequently dominating the accumulation.

Overlying the "Upper Shell" unit is a shell hash bed of variable thickness (maximum thickness 0.4 m in trench 2; 1.2 m along south wall of mine, see Figure 2E). This zone is referred to as the "Shell Hash" unit by Belt, Frey, and Welch (this volume). It consists of poorly sorted, fine to coarse quartz sand with variable amounts of silt and clay, woody debris, and abundant shell fragments, including whole, articulated valves of the clam *Corbicula densata* (Conrad). As will be discussed subsequently, the presence of *C. densata* indicates a significant change in paleodepositional conditions to an estuarine environment of lowered salinity. We interpret the "Shell Hash" unit to represent an episode of shell reworking with the major part of the fragmented shell derived from the underlying "Upper Shell" unit. As Howard and Frey (1973:1177) have pointed out, stratigraphic mixing of this type probably has occurred repeatedly in the Cenozoic history of the Atlantic Coastal Plain. Belt, Frey, and Welch relate the "Shell Hash" unit to the depositional cycle that includes their overlying "Mud and Sand" unit. At many locations in the pit, we found that the upper part of the shell hash increased markedly in silt and clay content and formed a gradational contact with the overlying "Mud and Sand" unit, whereas at other points, the "Shell Hash" unit is cut by channels now filled with mud and sand. It is, therefore, difficult to establish precise timing for the reworking event, but the evidence for reworking as represented by the "Shell Hash" unit is strong.

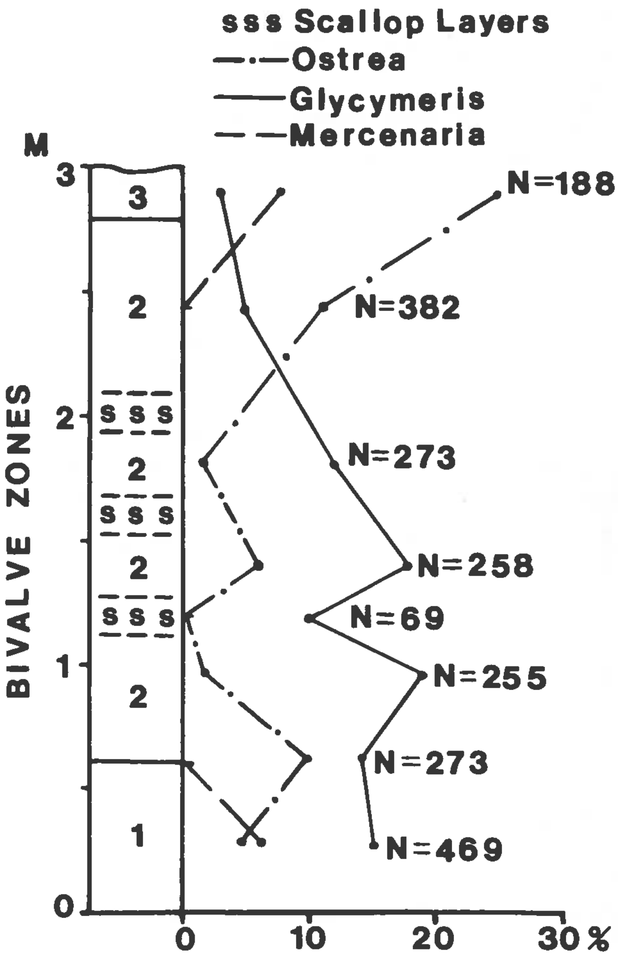

FIGURE 3.—Plot of the relative abundances of *Glycymeris americana*, *Mercenaria mercenaria*, and *Ostrea meridionalis* based on the number of specimens of each species in bulk samples from trench 3. (N = total number of identifiable bivalve specimens in each sample.)

Paleoecology and Paleodepositional Environments

Based on its foraminiferal assemblage, Gibson (1967:646) postulated that the "Upper Shell" unit was deposited in warm-temperate subtidal waters of 15 meters or less. Blackwelder and Ward (in prep.) have completed a detailed taxonomic study of the molluscan fauna of the "Upper Shell" unit and adjacent beds, and they suggest that these beds, including the overlying "Shell Hash" unit, originated during the development of an offshore bar system. We agree that shallow subtidal conditions existed during the time of formation of the "Upper Shell" unit, but we propose that the overlying "Shell Hash" unit represents an accumulation of primarily reworked shells that formed in an estuarine tidal channel. The pronounced transition that occurs in the composition of the molluscan assemblages of the "Upper Shell" unit (Figure 3) indicates that significant changes occurred in the molluscan bottom communities during formation of this shell bed.

The molluscan assemblage zones can be grouped into several different types based on the life mode of the dominant bivalve species. The first of these assemblages, represented by zone 1, consists dominantly of infaunal suspension feeders characterized by a population of large *Mercenaria mercenaria* (Figure 2A, B). These shallow- to moderately deep-burrowing, siphonate clams were sediment-surface suspension feeders. Large numbers of specimens of the shallow-infaunal, nonsiphonate suspension feeders *Astarte concentrica* Conrad and *Venericardia granulata* Say also were present. Other shallow-infaunal suspension feeders include species of the bivalve genera *Abra*, *Anadara*, *Corbula*, *Diplodonta*, *Macrocallista*, *Noetia*, and *Spisula,* all of which occurred in small numbers. Numerous juveniles of *Glycymeris americana*, small oysters, and a few scallops were the major epifaunal suspension feeding bivalves. Carnivorous and herbivorous gastropods in low numbers also formed part of the epifauna.

Zone 2 represents a second bivalve assemblage dominated by abundant epifaunal/semi-infaunal suspension feeders, particularly *Glycymeris americana* (Figure 2C, F). Most species of *Glycymeris* have had or have a life mode similar to that of the modern species *G. pectinata* (Gmelin). Stanley (1970:127–128) found that in the Florida Keys living individuals of *G. pectinata* commonly lie free on coarse bottom sediments or buried under a thin layer of sediment with posterior current openings and sometimes the shell margin itself exposed. Indeed, Thomas (1975) has postulated that glycymerids, with their evolutionarily conservative and functionally generalist traits, have occupied coarse bottom and current-swept shallow marine environments throughout their history. Thomas' studies (summarized 1975:223–225) of the occurrence of *G. americana* in Neogene beds of the Atlantic Coastal Plain show that *G. americana* favored an unstable shell gravel-sandy substrate. Although *G. americana* may have been covered by a thin layer of sediment, it lived essentially unprotected from strong current or wave action sufficient to cause burial and mass mortality. Other epifaunal suspension feeders present in zone 2 include numerous specimens of *Ostrea meridionalis* which are larger (10–14 cm) than those of zone 1, and concentrations of large numbers of *Anomia simplex* d'Orbigny, *Argopecten eboreus*, and the gastropod *Crepidula aculeata* (Gmelin). *Mercenaria mercenaria* is completely absent from this zone, although specimens of the shallow-infaunal, nonsiphonate bivalves *Astarte concentrica* and *Venericardia granulata* remained common.

Within zone 2 are thin but persistent shell layers of a bivalve subassemblage, composed almost exclusively of flat-lying, frequently articulated valves of the scallop *Argopecten eboreus* and single valves of *Anomia simplex* (Figures 2D, 4), both epifaunal suspension feeders. The origin of these layers will be discussed in the following section.

An intriguing paleoecological question presented by this sequence within the "Upper Shell"

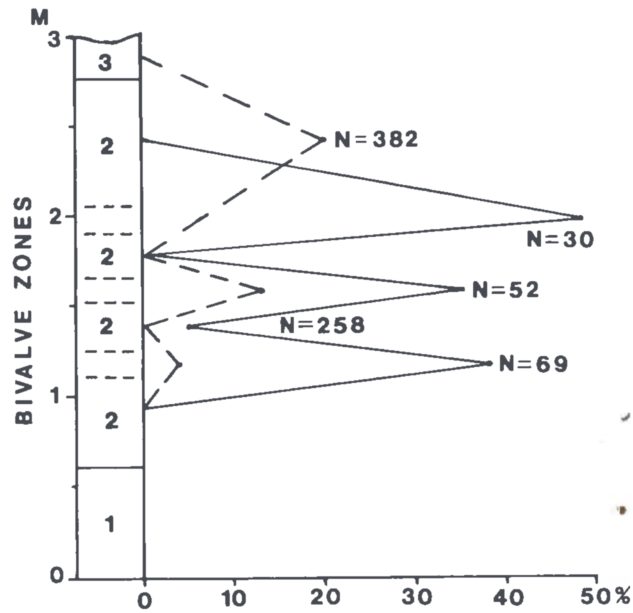

FIGURE 4.—Plot of the relative abundances of *Argopecten eboreus* and *Anomia simplex* indicating the concentrations of these epifaunal bivalves in thin layers within zone 2. (N = total number of identifiable bivalve specimens in each sample; dashed line = *Anomia*; solid line = *Argopecten*.)

unit is, "What caused the disappearance of the *Mercenaria mercenaria*-dominated infaunal assemblage and its replacement by the *Glycymeris americana*-dominated epifaunal assemblage?" The large number of articulated valves and the essentially unworn condition of the fossils strongly suggest that these clams were killed by a catastrophic event resulting in local mass mortality[1] without subsequent transport of the shells. Mass mortality of shallow-infaunal clams like *M. mercenaria* would likely result in the formation of a shell pavement on the substrate surface. As suggested by Gernant (1970:54), the formation of a shell pavement (Figure 2B) would make it difficult or impossible for shallow- to medium-depth burrowers, such as *M. mercenaria*, to resettle until a soft bottom substrate of sufficient depth is reformed. Thus a likely explanation for the disappearance of *M. mercenaria* above zone 1 would be that, following the formation of a shell pavement, juveniles of *M. mercenaria* were prevented from recolonizing because they could not penetrate the shell pavement. This would open the way for *G. americana*, an essentially epifaunal clam capable of colonizing the newly formed shell pavement, to establish itself and become the dominant bivalve of the overlying zone.

Juvenile specimens of some infaunal bivalves which reach large adult sizes, such as *Eucrassatella*, *Macrocallista*, and *Barbatia*, do occur with *Glycymeris americana* in small numbers. If lack of sufficient depth of sediment were the only deterrent to *Mercenaria mercenaria* survival, it would seem likely that some juveniles of *M. mercenaria* would be present. The disappearance of *M. mercenaria* may represent only local displacement of this clam to a nearby geographic area that presented more favorable bottom conditions for burrowing. On the other hand, this disappearance might also be related to more fundamental environmental changes, such as increased water depth and/or salinity that proved detrimental to *M. mercenaria*. The transition from zone 1 to zone 2 in the "Upper Shell" unit can be recognized clearly in the area of the Lee Creek Mine, but further work on the regional characteristics of the "Upper Shell" unit will be necessary before the true magnitude of this transition can be gauged.

In zone 3, *Mercenaria mercenaria* reappears (Figure 3), and this reappearance is coupled with a sharp decline in the population of *Glycymeris americana*. Specimens of the shallow-infaunal, suspension-feeding bivalve *Eucrassatella* sp. also increase in number, and specimens of the mussel *Geukensia* sp. and *Ostrea meridionalis* are abundant and possibly indicate a change to conditions of lowered salinity. This assemblage represents the final stage in the development of the "Upper Shell" unit.

The overlying "Shell Hash" unit contains abundant specimens of *Corbicula densata*, some of which are articulated. *Corbicula* has wide distribution in fresh- to brackish-water deposits of Cenozoic age (Gibson, 1967:646). The presence of this bivalve, the absence of planktonic Foraminifera, and the increased influx of fine-grained sediment formed the basis for Gibson's conclusion that this unit (top of Gibson's unit 8) was formed in a bay or sound of lowered salinity, less than 15 meters deep. We think that the "Shell Hash" unit represents a reworked deposit with the bulk of the shell derived from the underlying "Upper Shell" unit. If this reworking occurred in an estuarine tidal channel, as suggested earlier, the presence of species favoring lowered salinity conditions, such as *C. densata*, mixed with fully marine species would be expected.

Formation of the Shell Bed

A combination of several factors indicates to us that the zones of the "Upper Shell" unit were

[1] Kranz (1974:237) has used the term "anastrophe" to refer to catastrophes of limited scope and area that generally produce mass mortality in the affected area. Kranz attributed this definition of "anastrophe" to Brongersma-Sanders (1957). However, Brongersma-Sanders (1957:941) did not consider "anastrophe" to be the proper word to use in referring to localized catastrophes affecting marine organisms, although she noted that the word had been used previously in this sense. In this paper, we consider localized catastrophic events and catastrophic burial events to be "anastrophes" and "anastrophic burial" events as defined by Kranz, but we follow the recommendation of Brongersma-Sanders that the word "anastrophe" not be used.

formed by localized catastrophic events that produced mass mortality. These following factors are included. (1) The excellent preservational condition of the fossils, being largely unworn and some with traces of original coloration. Many bivalve and gastropod shells are complete, with the bivalves frequently articulated. The presence of delicate, thin-shelled clams such as *Anomia simplex* and articulated *Argopecten eboreus*, and echinoid plates, which are especially vulnerable to mechanical destruction, indicates little or no transportation and/or exposure to wave action following death. (2) A broad range of size classes is present for the abundant species in our collections. Figure 5 is a size-frequency plot for *Glycymeris americana* that is typical of those plotted for this species and several other abundant bivalves (*Astarte concentrica*, *Venericardia granulata*). The presence of many specimens of different sizes suggests that size-selective winnowing processes were not operative following death of the clams. (3) The majority of shells are generally free of encrusting organisms, such as bryozoans, barnacles, and worm tubes, and do not show the strong effects of marine borers, which normally attack molluscan shells exposed on the substrate following death of the animal.

Mass mortality of marine invertebrates may result from a variety of causes, including vulcanism, rapid temperature and/or salinity changes, toxic water conditions, and the action of severe storms (Brongersma-Sanders, 1957). As indicated by Brongersma-Sanders (1957:942), catastrophes capable of killing benthic organisms may occur repeatedly in a given area. In the fossil record the result of repeated kills would be a sequence of fossiliferous strata, probably much like the sequence of beds of the "Upper Shell" unit.

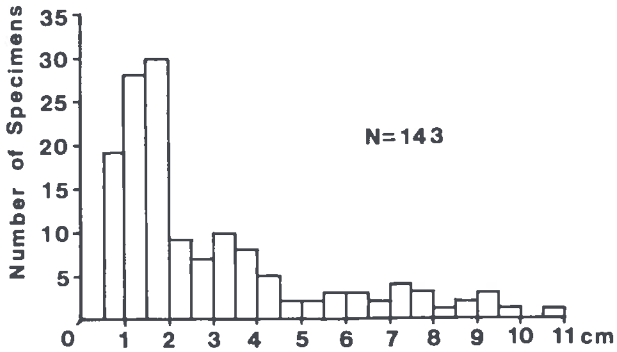

FIGURE 5.—Size-frequency distribution of specimens of *Glycymeris americana* from zone 2 of trench 2. Size measurement is of valve height; right and left valves are included with only one measurement from articulated specimens.

Recently Kranz (1974) has shown that rapid burial ("anastrophic burial") can be lethal to marine bivalves, leading Kranz to conclude that catastrophic burial events probably have been much more important in the formation of ancient shell deposits than previously realized. Severe winter storms and hurricanes occur frequently off the North Carolina coast today, and undoubtedly they also occurred during the time of formation of the "Upper Shell" unit. Such storms can be highly disruptive to shallow-bottom environments and are known to be causes of mass mortality (Brongersma-Sanders, 1957). The "Upper Shell" unit, characterized by its abundance of shell material with a minimal amount of sediment matrix, seems indicative of conditions of formation other than by gradual accumulation of shells in a quiet, subtidal environment.

Gernant (1970) described zones of well-preserved, highly concentrated fossils from the Choptank Formation (Miocene) of Maryland. He developed an explanation for these shell concentrations based on a swell-traction mechanism first suggested by Powers and Kinsman (1953) to explain the formation of concentrated shell layers found off the mouth of Chesapeake Bay today at depths of 15 to 45 meters. Powers and Kinsman postulated that large swells produced by offshore storms establish a pressure gradient capable of disrupting the substrate to the extent that epifaunal and shallow- to medium-depth infaunal bivalves would be exposed, relocated on their sides, and smothered by rapid sedimentation following passage of the storm. Experiments by Kranz (1974:260–261) on living bivalves indicate that epifaunal suspension feeders (such as, *Glycymeris* and *Argopecten*) and bivalves that cement to the substrate (such as *Ostrea* and *Anomia*) are particularly vulnerable to rapid burial and are generally unable to escape more than 1 cm of burial. Shallow-burrowing, siphonate suspension feeders (such as *Mercenaria*) are more adept at escape, being able to cope with and escape from 10–50 cm of rapidly deposited sediment.

The presence of the abundant flat-lying, often articulated valves of *Mercenaria mercenaria* that characterize zone 1 of the "Upper Shell" unit suggests that these clams were killed by a localized catastrophic event, possibly by relocation and rapid burial similar to the mechanism proposed by Powers and Kinsman (1953). As suggested earlier, the formation of a hard shell pavement probably inhibited the recruitment of juveniles of *Mercenaria* and favored the resultant resettlement of the area by epifaunal assemblages dominated by *Glycymeris* and *Argopecten*.

Bivalves of the epifaunal assemblages of zone 2 would have been highly vulnerable to rapid burial. Brenner and Davies (1973) described layers of whole shells of the pecten-like bivalve *Camptonectes* from the Jurassic of Wyoming and Montana. These layers are similar to the concentrated *Argopecten eboreus* layers within zone 2 (Figure 2D) of the "Upper Shell" unit. Brenner and Davies (1973:1694, fig. 12) suggest that "swell lag" deposits such as these were formed by the Powers-Kinsman mechanism.

Kranz (1974:263) noted that fossil assemblages can be biased by catastrophic burial. Thus, it may be possible to produce different fossil assemblages from a single life assemblage. A reasonable example might be the subassemblages of zone 2 of the "Upper Shell" unit dominated by *Glycymeris americana* and *Argopecten eboreus*. The catastrophic burial process may have resulted in the segregation of the epifaunal assemblage into the subzones dominated by *Glycymeris* and by *Argopecten* and *Anomia* (Figures 3, 4). This alternation of layers within zone 2 could well result from multiple anastrophic burial events capable of segregating the epifaunal bivalves of the "Upper Shell" unit.

Zone 3, as discussed earlier, represents a change in environmental conditions suitable for the return of *Mercenaria mercenaria*. However, the concentration of shells and the presence of many articulated valves of *Mercenaria*, *Guekensia*, and *Ostrea* suggest that localized catastrophic kill events continued to be important in the formation of this zone.

Conclusions

The "Upper Shell" unit at the Lee Creek Mine can be subdivided into three zones based on distinctive bivalve assemblages. Zone 1 is characterized by an infaunal bivalve assemblage dominated by *Mercenaria mercenaria*. Zone 2 consists of an epifaunal/semi-infaunal assemblage characterized by *Glycymeris americana* and is cut repeatedly by thin, concentrated shell layers of *Argopecten eboreus* and *Anomia simplex*. A reappearance of *M. mercenaria* in the sequence along with the occurrence of *Geukensia* sp. and an increase of shells of the oyster *Ostrea meridionalis* define zone 3. The disappearance of *M. mercenaria* from the sequence probably resulted from the formation of a shell pavement, which prevented successful recolonization of infaunal bivalves and facilitated the establishment of an epifaunal bivalve assemblage. Later, environmental conditions changed sufficiently to permit the return of *M. mercenaria*. The bivalve assemblage zones can be recognized in the exposures of the mine area, but further regional work will be necessary before the full geographic extent of the zones can be established.

The preservation of fossils in excellent condition, the large number of articulated bivalves in a broad range of size classes, and the close packing of shells with generally little matrix suggest that zones of the "Upper Shell" unit were formed by localized catastrophic events causing mass mortality of the benthic communities. This mass mortality may have resulted from localized catastrophic burial events due to the action of severe winter storms or hurricanes, with resultant large swells causing disruption of the substrate and subsequent burial of the bottom dwellers. A mechanism of this type has been described by Gernant (1970). However, the possibility that sudden changes in other environmental conditions were responsible for mass mortality of the benthic fauna cannot be ruled out.

The "Shell Hash" unit is composed primarily of fragmented and worn shell material reworked from the underlying "Upper Shell" unit. The presence of the bivalve *Corbicula densata*, many specimens of which are articulated, suggests that this unit was deposited under conditions of lowered salinity; possibly in an estuarine tidal channel. Analogous reworked shell accumulations have been reported from the modern Georgia estuarine system (Howard and Frey, 1973). The timing of this episode of reworking cannot be established with certainty; it may represent a regression event following deposition of the "Upper Shell" unit, or it may be associated with the deposition of the overlying Pleistocene units as postulated by Belt, Frey, and Welch (this volume).

Literature Cited

Blackwelder, B.W., and L.W. Ward
In prep. Late Pliocene and Early Pleistocene Mollusca from the James City and Chowan River Formations at the Lee Creek Mine.

Brenner, R.L., and D.K. Davies
1973. Storm-generated Coquinoid Sandstone: Genesis of High-Energy Marine Sediments from the Upper Jurassic of Wyoming and Montana. *Geological Society of America Bulletin*, 84(5):1685–1697.

Brongersma-Sanders, M.
1957. Mass Mortality in the Sea. *Geological Society of America Memoir*, 67(1):941–1010.

DuBar, J.R., J.R. Solliday, and J.F. Howard
1974. Stratigraphy and Morphology of Neogene Deposits, Neuse River Estuary, North Carolina. *In* R.Q. Oaks, Jr., and J.R. DuBar, editors, *Post-Miocene Stratigraphy, Central and Southern Atlantic Coastal Plain*, pages 102–122. Logan: Utah State University Press.

Gernant, R.E.
1970. Paleoecology of the Choptank Formation (Miocene) of Maryland and Virginia. *Maryland Geological Survey Report of Investigations*, 12: 90 pages.

Gibson, T.G.
1967. Stratigraphy and Paleoenvironment of the Phosphatic Miocene Strata of North Carolina. *Geological Society of America Bulletin*, 78(5):631–650.

Howard, J.D., and R.W. Frey
1973. Characteristic Physical and Biogenic Sedimentary Structures in Georgia Estuaries. *American Association of Petroleum Geologists Bulletin*, 57(7):1169–1184.

Kranz, P.M.
1974. Anastrophic Burial of Bivalves and its Paleoecological Significance. *Journal of Geology*, 82(2):237–265.

McKenna, M.C.
1965. Collecting Microvertebrate Fossils by Washing and Screening. *In* Bernhard Kummel, and David Raup, editors, *Handbook of Paleontological Techniques*, pages 193–203. San Francisco: W. H. Freeman and Co.

Powers, M.C., and B. Kinsman
1953. Shell Accumulations in Underwater Sediments and Their Relation to the Thickness of the Traction Zone. *Journal of Sedimentary Petrology*, 23(4):229–234.

Stanley, S.M.
1970. Relation of Shell Form to the Life Habits of the Bivalvia (Mollusca). *Geological Society of America Memoir*, 125: 296 pages.

Thomas, R.D.K.
1975. Functional Morphology, Ecology, and Evolutionary Conservatism in the Glycymerididae (Bivalvia). *Palaeontology*, 18(2):217–254.

Wiedemann, H.U.
1972. Shell Deposits and Shell Preservation in Quaternary and Tertiary Estuarine Sediments in Georgia, U.S.A. *Sedimentary Geology*, 41(2):103–125.