Planktonic Foraminifera and Biostratigraphy of the Yorktown Formation, Lee Creek Mine

Scott W. Snyder, Lucy L. Mauger, and W.H. Akers

ABSTRACT

The open-pit phosphate mine of Texasgulf Inc. at Lee Creek provides the most nearly complete section of the Yorktown Formation in North Carolina. The Yorktown exposure at this locality has yielded a rich and diverse vertebrate fauna. However, the biostratigraphic position of this important exposure has been difficult to determine because previous studies of planktonic foraminifera have yielded too few species to provide a basis for precise interpretation. During this study 29 species and subspecies of planktonic foraminifera were identified from 42 samples taken at vertical intervals of 35 cm through a 15 m section of the Yorktown Formation. Concurrent portions of the range zones of eight taxa indicate an age of late early to early late Pliocene (from just below the base of Blow's zone N19 to the middle of his zone N20).

Introduction

The Yorktown Formation is the youngest of the four formations that compose the Chesapeake group. This group crops out in a broad belt across much of the Coastal Plain of Maryland, Virginia, and North Carolina. The oldest formation of the Chesapeake group, the Calvert, and its equivalents were deposited during a marine transgression that covered most of the middle Atlantic Coastal Plain, except for southeastern North Carolina. During two subsequent regressive stages the Choptank Formation and later the St. Marys Formation were deposited. These three formations are thickest in Maryland and in a small area of northeastern Virginia. Slightly before or during early Yorktown time tectonic movement resulted in a southward shift in the locus of deposition. Yorktown seas covered parts of southern Virginia and most of northeastern North Carolina (Gibson, 1962, 1967, 1970).

Surface exposures of the Chesapeake group are scarce because of Pleistocene cover, low regional relief, and the unconsolidated or weakly lithified nature of the formations that comprise it. Natural exposures occur along river and stream banks. Isolated exposures that have been interpreted as the Yorktown Formation are found from the Rappahannock River in Virginia to the Neuse River in North Carolina (Bailey, 1973:2, fig. 1).

Although some information on the nature of Yorktown sediments in the subsurface has been gathered from well cuttings, thick, richly fossiliferous surface exposures were not available south of the Meherrin-Chowan area of northeastern North Carolina until 1965, when Texas Gulf Sulphur Company (now Texasgulf Inc.) began open-pit mining at the mouth of Lee Creek on the south shore of the Pamlico River (Figure 1). Mining operations have exposed a remarkable Neogene fossil locality. The Yorktown Formation at this locality has yielded an exceptionally rich and diverse vertebrate fauna (C. Ray, pers.
comm.), knowledge of which will be enhanced by a precise biostratigraphic interpretation.

ACKNOWLEDGMENTS.—Permission to sample the ore cut was obtained largely through the efforts of Ralph Chamness, geologist for Texas-gulf Inc. Thomas Gibson of the U.S. Geological Survey and Clayton Ray of the Smithsonian Institution provided helpful suggestions and criticisms in their review of the manuscript.

Previous Work

The earliest widely accepted biostratigraphic subdivision of the Yorktown Formation was that of Mansfield (1943), in which he proposed a zonation based on the mollusks. The formation was divided into the following two biostratigraphic units: a lower zone 1 (*Placopecten clintonius*) and an upper zone 2 (*Turritella alticostata*). Despite criticism that some of his correlations involving certain units in zone 2 are not justified, Mansfield’s two-zone scheme has provided a workable zonation for the Yorktown Formation in Virginia (Bailey, 1973; Hazel, 1971). It has also been used frequently in North Carolina.

Although useful on a regional scale within the Atlantic Coastal Plain, the Yorktown molluscan fauna has proven inadequate for intercontinental correlation (Mongin, 1959:285, 287, 333). Early investigations of the Yorktown microfauna failed
to provide more accurate biostratigraphic interpretations. These studies, which dealt primarily with benthic Foraminifera, were summarized by McLean (1956).

The first published study of the exposure at Lee Creek was that of Gibson (1967). The planktonic foraminiferal assemblage from the lower part of the Yorktown section, although sparse, was interpreted as middle late Miocene in age, while the age of the upper part of the formation remained questionable. During the early 1970s several workers suggested that the age of the Yorktown Formation, traditionally considered to be Miocene, might be re-interpreted as younger. Hazel (1971) divided the formation into three ostracode assemblage zones and concluded that Yorktown sediments exposed along the Chowan River near Mount Gould, North Carolina, are Pliocene. Gibson (1971) emphasized the need to find adequate planktonic assemblages in order to determine whether or not upper Yorktown units range into the Pliocene. Akers (1972) examined planktonic Foraminifera from several Yorktown localities, including Lee Creek, and concluded that at least part of the formation (at Rice’s Pit, Virginia) is early to early middle Pliocene. He found the assemblages at Lee Creek to be too impoverished to serve as a basis for exact correlation. Akers and Koeppel (1973) analyzed the calcareous nannoplankton of the Yorktown section at Lee Creek as part of a study concerning Neogene formations of the Atlantic Coastal Plain. The flora recovered from the Lee Creek exposure includes *Gephyrocapsa caribbeanica*, a form then considered to indicate an early Pleistocene age. However, this species appears to be indigenous to several Pliocene formations, and they concluded that an age of middle Pliocene for the Yorktown is consistent with the total faunal and floral evidence. Gibson (p. 363, herein) has re-examined planktonic foraminiferal assemblages from Yorktown exposures as part of a study on key Foraminifera from sediments of the middle Atlantic Coastal Plain. He interpreted the age of the Yorktown Formation as ranging from early Pliocene through late Pliocene. However, he also applies the term “Yorktown” to sediments that are younger than those traditionally identified as part of this formation. Gibson’s “uppermost Yorktown,” exposed along the Chowan River in northeastern North Carolina, contains species indicative of an early Pleistocene age. Blackwelder (1980) removed these strata from the Yorktown Formation, designating them the Chowan River Formation.

**Objectives**

Although planktonic Foraminifera from the Yorktown Formation in North Carolina have been analyzed before, a detailed study of the assemblages at the Lee Creek exposure has not previously been undertaken. Akers (1972) recorded only seven species, which included too few marker species to support a precise biostratigraphic interpretation. Gibson (p. 355, herein) recorded 16 species from 8 localities in North Carolina and Virginia. However, his four samples from Lee Creek yielded only half of that total.

This study is based on a large number of bulk samples taken at short stratigraphic intervals. The primary objective is to provide a more accurate biostratigraphic interpretation of this important Yorktown exposure than has previously been possible.

**Procedures**

Forty-two samples weighing from 1 to 2.5 kg each were collected from the Yorktown Formation at vertical intervals of 35 cm (Figure 2). In order to minimize the possibility of contamination, several centimeters of sediment were removed from the wall prior to collecting each sample. Each sample represents a stratigraphic thickness of 3 to 4 cm.

Samples were placed in distilled water for several days and then sieved through a No. 14 (1.41 mm) and a No. 230 (0.063 mm) U.S. Standard Sieve. The sample fraction trapped on the latter sieve was boiled in a Calgon-distilled water solution and washed to disperse clays.
<table>
<thead>
<tr>
<th>METERS</th>
<th>SAMPLE NUMBER</th>
<th>FORMATION</th>
<th>SECTION</th>
<th>LITHIC DESCRIPTION</th>
<th>SIZE FRACTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>CROATAN</td>
<td>UNIT 5</td>
<td>MUDDY, GRAVELY, FOSSILIFEROUS, INTERMITTENTLY INDURATED, COARSE TO VERY COARSE, LIGHT GRAY QUARTZ SAND</td>
<td>GRavel</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>CROATAN</td>
<td>UNIT 5</td>
<td>VERY MUDDY, SLIGHTLY GRAVELY, FOSSILIFEROUS, MEDIUM TO COARSE, BLUE-GRAY QUARTZ SAND</td>
<td>MUD</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>CROATAN</td>
<td>UNIT 5</td>
<td>VERY SANDY, SLIGHTLY GRAVELY, FOSSILIFEROUS, SLIGHTLY GLAUCONITIC, BLUE-GRAY MUD</td>
<td>SAND</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>CROATAN</td>
<td>UNIT 5</td>
<td>VERY MUDDY, GRAVELY, FOSSILIFEROUS, FINE TO MEDIUM, BLUE-GRAY QUARTZ SAND</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>CROATAN</td>
<td>UNIT 5</td>
<td>MUDDY, GRAVELY, MEDIUM TO COARSE, GRAY-BLACK PHOSPHATIC SAND</td>
<td></td>
</tr>
</tbody>
</table>

Figure 2.—Measured 15-meter section of the Yorktown Formation in the Lee Creek Mine.
Microfossils were then separated by flotation on a solution of sudsing detergent and distilled water. The soap float residue, which consisted of very fine to fine sand and microfossils, was boiled in 0.5 liter of distilled water to which a few drops of Quaternary “O” had been added. (Quaternary “O” is a highly active, low sudsing detergent that successfully disaggregates clays that persist throughout the washing process.) The clean residue from each sample was then dried and floated on carbon tetrachloride to further concentrate the microfossils. Spot checks of sample material that did not float revealed that the separation was clean and dependable. The entire microfossil concentrate from each sample was carefully examined to ensure that rare species would not be overlooked.

Lithologic Description

Weight percentages of the gravel, sand, and mud (silt + clay) fractions were determined for each sample and are plotted graphically in Figure 2. The Yorktown Formation at Lee Creek is generally a very muddy quartz sand. With the exception of the uppermost part of the section, the entire formation contains more than 15 percent mud. Ten samples from the middle part of the formation (Figure 2: unit 3) are more than 50 percent mud. The remainder of the section is sandier. Twenty-one of the samples contain at least 70 percent sand. The upper 5.3 m has the highest sand content; two samples in this upper part are more than 90 percent sand.

Gravel-sized pieces of shell material and cemented sediment comprise less than 3 percent of most samples. However, the gravel-sized fraction in parts of the “boulder bed” (Figure 2: unit 5) exceeds 20 percent. These “boulders” are not detrital; rather they are composed of calcite-cemented clumps of sediment and abundant shell hash, primarily bivalve and barnacle. The upper contact of the Yorktown Formation has generally been placed at the base of this “boulder bed,” which also has less mud and more sand than any of the underlying units. Groundwater steadily seeps from the quarry wall along the irregular lower boundary of this unit and stains the exposed surface of underlying sediments, thus creating a rather striking “contact.” However, the upper surface of this unit is also irregular and the entire unit is absent in places. The unit is best developed where the upper surface is at higher elevations, less conspicuous and thinner where it begins to dip, and absent in areas between local highs. Rather than being a primary depositional unit, the “boulder bed” may represent a zone of alteration developed on and immediately below a paleosurface, the exact nature of which is unknown. If so, the unconformity lies along its upper surface. More detailed work will be necessary to determine the origin of the unit. For the purposes of this study, however, it has been included as part of the Yorktown Formation. Including the “boulder bed,” the total thickness of the Yorktown exposure is 15 m.

The only part of the middle Yorktown section that contains a large amount of gravel-sized material (9 percent) is an extensively leached, partially indurated zone that contains abundant molds of turritellid gastropods and cemented clumps of sediment. A zone at the base of the formation contains gravel-sized material in the form of shell hash and phosphate granules, pebbles, and cobbles.

On the basis of sedimentological data, five lithologic units have been defined within the Yorktown section at Lee Creek (Figure 2). These range from a muddy phosphatic quartz sand (unit 1) at the base; through a very sandy blue-gray mud (unit 3) in the middle; to a light gray quartz sand with much gravel-sized material (unit 5) at the top. All units contain Foraminifera.

Results

P/P + B Ratios.—In order to determine the abundance of planktonic vs benthic Foraminifera within each sample, specimens of both were picked from a tray divided into a number of systematically arranged segments. A random
sampling was obtained by picking specimens from predetermined segments of the tray until 300 to 400 benthic Foraminifera had been recovered.

The P/P + B ratio values of each sample are plotted in Figure 3. Values range from nearly zero to a maximum of 0.65. The general pattern of these values supports evidence based on benthic Foraminifera that indicates marine transgression through the lower part of the section, a near stillstand in sea level through the middle part, followed by regression in the upper part (Mauger, 1979). Large-scale fluctuations in ratios through the middle part of the section reflect diagenetic alteration that preferentially destroyed planktonic species. For example, low values for samples 26–28 are related to a strongly leached zone characterized by calcite-cemented sediment fragments (Figure 2).

The number of planktonic species present in individual samples is closely related to the P/P + B ratio. The number of species ranges from 1 to 22. Fifty percent of the samples yielded 10 or fewer species, which may explain why previous studies, based on a smaller number of samples, recorded so few species from Lee Creek.

**Planktonic Fauna.**—Twenty-nine species and subspecies of planktonic Foraminifera have been identified from the Yorktown exposure at Lee Creek. The stratigraphic occurrence and relative abundance of each is shown in Figure 4. Values of relative abundance, computed as a percentage of the total planktonic foraminiferal assemblage, fall into three categories: (1) rare, less than 1 percent; (2) few to common, 1 to 10 percent; (3) very abundant, greater than 70 percent. These categories are used because actual percentages, particularly for species with low relative abundance, have been strongly altered by solution. No species comprises more than 10 but less than 70 percent of the fauna in any of the samples.

The dominant species is *Globigerina bulloides bulloides*, which comprises 70 to 100 percent of each sample. Seven other species account for more than 1 percent of the assemblage in one or more samples. Thus, 21 of 29 species and subspecies are rare and occur only sporadically within the section.

Gibson (p. 355, herein) states that the Yorktown foraminiferal assemblage is indicative of cool water. In modern faunas *G. bulloides* attains maximum relative abundances in the cool-temperate faunal province (Bé, 1959:87, 88, figs. 25, 26; Boltovskoy, 1966:9, graphs 1–3, 1969:243, fig. 2; Cifelli and Smith, 1970:20). Its dominance in our samples, especially in those that are well preserved, supports Gibson's interpretation. Tropical and subtropical species, many of which are the most useful biostratigraphically, would logically be rare in such waters. However, the dominance of *G. bulloides bulloides* may be secondarily enhanced in some samples (those in which its relative abundance approaches 100 percent). These samples occur only in leached zones where solution has altered the fauna. An experimentally derived hierarchy of resistance to solution includes many of the modern planktonic foraminiferal species (Jenkins and Orr, 1972). Among those species from the Yorktown Formation for which information is available, four are less resistant, two are slightly more resistant, and one is substantially more resistant to solution than is *G. bulloides*. We are unaware of any such data for the extinct species encountered during this study.

Although *G. bulloides* is only intermediate in resistance to solution among modern planktonic foraminifera, its initial abundance in the Yorktown fauna may explain why it remains where other species have been destroyed. Indeed, specimens of *G. bulloides bulloides* are poorly preserved and often heavily encrusted with secondary calcite in these zones of alteration. Rarer species, if initially present, may not have survived the destructive processes. Initial abundance plays an important role in determining whether a species escapes a variety of potentially destructive processes (Snyder, 1978).

**Biostratigraphic Interpretation.**—Numerous studies of planktonic foraminiferal assemblages from Cenozoic sediments in various parts of the world show that the species composition of such faunas is not uniform. According to Bolli
Figure 3.—Abundance of planktonic and benthic Foraminifera in the measured section of the Yorktown Formation, based on counts of individuals from subsamples drawn randomly from each of the 42 samples, expressed in terms of the ratio of planktonic (P) to planktonic plus benthic (P + B) specimens. The number of planktonic species represented in each sample is indicated in the righthand column.
Figure 4.—Occurrence of planktonic foraminiferal species in samples from the Yorktown section at Lee Creek.
and Krasheninnikov (1977:438, 444), the primary factor in controlling species distributions is water temperature, which produces a latitudinal restriction of species that has intensified throughout the Cenozoic. Workers dealing with Neogene sediments, in which the effects of this provincialism are most pronounced, have proposed zonal schemes to supplement those originally based on tropical faunas. Examples include the zonations of Berggren (1971) for the North Atlantic and of Poore and Berggren (1975) for temperate regions of the northeastern Atlantic. However, the faunas from temperate (midlatitude) zones yield less biostratigraphic resolution than do those from tropical zones (Berggren, 1978:342).

Because maximum resolution and accuracy are the objects of any biostratigraphic study, it is desirable to correlate, if possible, with one of the zonal schemes based on tropical assemblages. Blow (1969) divided the Neogene into 23 planktonic foraminiferal zones. His zonal scheme has been used as a standard for correlation by numerous workers. The somewhat more detailed zonation of the Pliocene by Berggren (1973) is also based on tropical assemblages.

Although the planktonic foraminiferal assemblage from the Yorktown Formation at Lee Creek is numerically dominated by cool-temperate and cosmopolitan species, it contains a sufficient number of tropical species to permit correlation with the zones of Blow and Berggren. The assemblages from the Lee Creek exposure lend themselves to comparison with Berggren's zonation because many of the species present are used in his zonal boundary definitions. In contrast, virtually none of the species used to define Blow's zonal boundaries are present at Lee Creek. However, the first appearance of several species and the extinction level of others can be used to correlate with either of these zonal schemes. Blow's zonation has been emphasized in this report because it is better known, but correlation with both preceding zonal schemes is discussed below.

Anomalies in stratigraphic and paleogeographic species distributions, for example the temporary provincial predominance of certain taxa in Pliocene sediments of the Caribbean, limit the application of any established zonal scheme (Bolli and Krasheninnikov, 1977). For this reason, species stratigraphic ranges from Blow (1969) have been modified when more recent information from geographic localities closer to Lee Creek is available (Figure 5). This approach is the only way to compensate for irregularities in faunal distribution patterns until all local zonal schemes have been accurately correlated, either one to another or to some universal scheme for tropical and temperate areas.

The stratigraphic ranges of most planktonic foraminiferal species from the Yorktown section at Lee Creek are too long to be biostratigraphically useful (Figure 5). Those few forms that have restricted ranges are the same ones that are both rare and sporadic in occurrence (compare Figures 4 and 5).

The stratigraphic ranges of eight species and subspecies provide a basis for biostratigraphic interpretation. None of these forms has a total range zone that is restricted enough to indicate the exact relative age of the exposure. However, their concurrent range zone, based on the first appearance of five forms and the extinction level of three forms, indicates an age of late early to early late Pliocene (Figure 6). In terms of the planktonic foraminiferal zonation scheme of Blow (1969), the age of the Yorktown sediments at Lee Creek lies within an interval from just below the base of zone N19 to approximately the middle of zone N20. This corresponds to an interval from the early part of zone PL 1 to the middle part of zone PL 3 in Berggren's (1973) zonation. We do not suggest that the Yorktown section at this locality necessarily encompasses this entire span of time. It may represent only some portion of that span. However, this is the most precise interpretation that can be made on the basis of the planktonic foraminiferal fauna.

Our interpretation of the biostratigraphic position of Yorktown sediments at Lee Creek is consistent with that of Akers (1972) for the Yorktown at Rice's Pit, Virginia. It is also similar to that of Gibson (p. 363, herein). However, Gibson suggests that the age of Yorktown sediments at Lee Creek ranges well into the late Pliocene.
Figure 5.—Stratigraphic ranges of planktonic species present in the Lee Creek section (data from Parker, 1967; Blow, 1969; Poag, 1967; Postuma, 1971; Miles, 1972; Berggren, 1978).

<table>
<thead>
<tr>
<th>N</th>
<th>ZONE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Globigerina</td>
</tr>
<tr>
<td></td>
<td>Globigerinina glutinato</td>
</tr>
<tr>
<td></td>
<td>Globigerinina uvula</td>
</tr>
<tr>
<td></td>
<td>Globigerinina bolbi</td>
</tr>
<tr>
<td></td>
<td>Globigerinina conglobatus</td>
</tr>
<tr>
<td></td>
<td>Globigerinina obliquus externus</td>
</tr>
<tr>
<td></td>
<td>Globigerinina obliquus</td>
</tr>
<tr>
<td></td>
<td>Globigerinina quadrilobatus</td>
</tr>
<tr>
<td></td>
<td>Globigerinoides</td>
</tr>
<tr>
<td></td>
<td>Globigerinoides globulus</td>
</tr>
<tr>
<td></td>
<td>Globigerinoides venezuelana</td>
</tr>
<tr>
<td></td>
<td>acostaensis acostaensis</td>
</tr>
<tr>
<td></td>
<td>acostaensis humeroso</td>
</tr>
<tr>
<td></td>
<td>praespicans</td>
</tr>
<tr>
<td></td>
<td>crassula</td>
</tr>
<tr>
<td></td>
<td>cultuta limbata</td>
</tr>
<tr>
<td></td>
<td>hirsuta praehirsuta</td>
</tr>
<tr>
<td></td>
<td>margaritae</td>
</tr>
<tr>
<td></td>
<td>Globorotaloides hexagona</td>
</tr>
<tr>
<td></td>
<td>Hastigerina siphonifera</td>
</tr>
<tr>
<td></td>
<td>Siphonifera</td>
</tr>
<tr>
<td></td>
<td>Orbulina suturalis</td>
</tr>
<tr>
<td></td>
<td>Orbulina universa</td>
</tr>
<tr>
<td></td>
<td>Spheroidinellapins subdehiscens</td>
</tr>
<tr>
<td></td>
<td>Turborotalita humilis</td>
</tr>
<tr>
<td></td>
<td>Turborotalita quinquellaba</td>
</tr>
</tbody>
</table>
Figure 6.—Partial stratigraphic ranges of selected planktonic species (arrows denote continuation of range).

We find no faunal evidence for an age as young as zone N21. If one accepts the “boulder bed” as part of the Yorktown Formation, its age may range later into the Pliocene. However, the planktonic foraminiferal fauna in this unit is too impoverished (Figure 4) either to support or contradict that possibility. Thus, our biostratigraphic interpretation applies only to units 1 through 4 of Figure 2. These units at Lee Creek are, however, much older than those of Gibson’s “Uppermost Yorktown” exposures along the Chowan River.

One species encountered during our study, Globorotalia (Turborotalia) praeoscitans, merits further comment. It is restricted to the lowermost 3 m of Yorktown sediments at Lee Creek (Figure 4). Here it is a common and conspicuous element of the fauna. Although the reasons for its sudden exclusion or extinction are unknown, it may be a reliable indicator of lower Yorktown sediments in other exposures within the middle Atlantic Coastal Plain.

Summary

Detailed sampling of the Yorktown section at Lee Creek and careful sample preparation have made possible the recognition of greater diversity than was noted in earlier studies. An exposure generally considered to have an impoverished planktonic fauna has yielded 29 species and sub-

Systematic Paleontology

The following section lists the species and sub-species identified during this study. A brief discussion of occurrence in the Lee Creek section is included for each taxon. The accompanying synonymies are brief, but distinguishing morphologic characters are mentioned in order to clarify the authors’ concept of some of the taxa. Because the taxonomy of this paper follows Blow (1969) and Akers (1972), these references can be consulted for more extensive synonymies and more detailed discussions. Stratigraphic distribution is discussed only for those forms that were most useful in the biostratigraphic interpretation.

All illustrated specimens, with the exception of two that were lost subsequent to photography, have been designated as hypotypes and are deposited at the National Museum of Natural History, Smithsonian Institution. The USNM catalog numbers include 306816 through 306877.

Order FORAMINIFERIDA Eichwald, 1830
Superfamily GLOBIGERINACEA Carpenter, Parker, and Jones, 1862
Family GLOBIGERINIDAE Carpenter, 1862
Genus Globigerina d’Orbigny, 1826
Genus Globigerinita Bronnimann, 1951
Genus Globigerinoides Cushman, 1927
Genus Globoquadnna Finley, 1947
Genus Orbulina d’Orbigny, 1839
Genus Sphaeroindellopsis Banner and Blow, 1959
Family GLOBOROTALIIDAE Cushman, 1927
Genus Globorotalia Cushman, 1927
Genus Globorotalioides Bolli, 1957
Genus Turborotalita Banner and Blow, 1962
Genus Hastigerina Thomson, 1876

Genus Globigerina d'Orbigny, 1826

**Globigerina bulloides apertura** Cushman

**PLATE 1: FIGURES 1–3**

*Globigerina apertura* Cushman, 1918:57, pl. 12: fig. 8a–c.

*Globigerina bulloides apertura* is characterized by its very large, semicircular aperture. Although this form is considered to be a subspecies of *G. bulloides*, it has a remarkably stable morphology (Blow, 1969:317). Among those forms from the Yorktown Formation at Lee Creek that are biostratigraphically useful, *G. bulloides apertura* is the one most frequently encountered. It varies from rare to common in well-preserved samples; it is absent only in horizons altered by solution. The last appearance of this subspecies occurs in the middle to late part of Blow’s zone N20.

Figured hypotypes: USNM 306816, 306817, 306818.

**Globigerina calida praecalida** Blow

**PLATE 1: FIGURES 5–7**

*Globigerina calida praecalida* Blow, 1969:380, pl. 13: figs. 6, 7, pl. 14: fig. 3.

Specimens from Lee Creek compare well with Blow's figures and description, particularly with regard to the lack of radial elongation of chambers, the less widely open umbilicus, the smaller extraumbilical extent of the aperture and the lack of a clear approach to planispirality. All of these characters serve to distinguish *G. calida praecalida* from *G. calida calida* Parker. Specimens from Lee Creek have 4½ to 5 chambers in the final whorl, as compared to the 4 that Blow describes as typical. However, all other test characters correspond with his description. Large, well-preserved specimens are rare and occur sporadically throughout the section. *G. calida praecalida* first appears in the late part of Blow’s zone N17.

Figured hypotypes: USNM 306820, 306821, 306822.

**Globigerina decoraperta** Takayanagi and Saito

**PLATE 1: FIGURES 10–12**

*Globigerina druryi decoraperta* Takayanagi and Saito.—Akers, 1972:50; pl. 14: fig. 3, pl. 29: fig. 1, pl. 31: fig. 3, pl. 34: fig. 3, pl. 37: fig. 2.

This small, trochospiral species is rare, but it occurs in nearly all samples except those altered by solution.

Figured hypotypes: USNM 306825, 306826, 306827.

**Globigerina juvenilis** Bolli

**PLATE 1: FIGURES 8, 9**

*Globigerina juvenilis* Bolli, 1957:110, pl. 24: figs. 5a–c, 6.

*Globigerina juvenilis* can be readily distinguished from other species present at Lee Creek by its small umbilicus and low, slitlike aperture with a thin but distinct lip. Its occurrence in our samples closely parallels that of *G. decoraperta*.

Figured hypotypes: USNM 306823, 306824.
Genus **Globigerinita** Brönnimann, 1951

**Globigerinita glutinata** (Egger)

**Plate 1: figures 13-15**

*Globigerinita glutinata* (Egger).—Akers, 1972:70, pl. 21: fig. 2, pl. 33: fig. 3, pl. 38: fig. 2.

*Globigerinita glutinata* is the second most abundant planktonic foraminifer in the Yorktown sediments at Lee Creek. Its absence in eight samples is probably related to destruction by solution. Because it is the most cosmopolitan of living planktonic foraminiferal species (Bé, 1959, figs. 21, 22), its abundance in our samples is consistent with the interpretation of the Yorktown fauna as indicative of cool waters.

Figured hypotypes: USNM 306834, 306835.

**Globigerinita uvula** (Ehrenberg)

**Plate 1: figures 16, 17**

*Globigerinita uvula* (Ehrenberg).—Akers, 1972:72, pl. 1: fig. 2, pl. 15: fig. 2, pl. 29: fig. 3, pl. 52: fig. 1.

This small, high-spired species is rare and occurs sporadically throughout portions of the section where solution has been minimal.

Figured hypotypes: USNM 306830, 306831.

Genus **Globigerinoides** Cushman, 1927

**Globigerinoides bollii** Blow

**Plate 2: figures 1, 2**

*Globigerinoides bollii* Blow, 1959:189, pl. 10: fig. 65a–c.

*Globigerinoides bollii* can be most readily distinguished from other species of the genus by its small, almost completely circular aperture and its strongly embracing chambers. It occurs in only nine samples and it is rare when present.

Figured hypotypes: USNM 306832, 306833.

**Globigerinoides conglobatus conglobatus** (d'Orbigny)

**Plate 2: figures 3, 4**

*Globigerinoides conglobatus conglobatus* (d'Orbigny).—Akers, 1972:56, pl. 24: figs. 1, 2, pl. 58: figs. 1, 2.

Although large, well-developed specimens of this form are rare and occur in only seven samples, it is biostratigraphically significant because it first appears near the base of Blow’s zone N18. Distinctive characters include the subquadrate outline, the long but comparatively low and gently arched aperture, and the coarse surface texture.

Figured hypotypes: USNM 306834, 306835.

**Globigerinoides obliquus extremus**

**Bolli and Bermúdez**

**Plate 2: figures 5–7**

*Globigerinoides obliquus extremus* Bolli and Bermúdez, 1965:139, pl. 1: figs. 10–12.

*Globigerinoides obliquus extremus* differs from *G. obliquus obliquus* in that the chambers of the final whorl are more strongly compressed in a lateral, oblique manner. It is present but rare in eight samples that are irregularly distributed throughout the Yorktown section.

Figured hypotypes: USNM 306836, 306837, 306838.

**Globigerinoides obliquus obliquus** Bolli

**Plate 2: figures 8–10**

*Globigerinoides obliquus* Bolli, 1957:113, pl. 25: figs. 9, 10, text-fig. 21: no. 5.

Like the preceding subspecies, the later chambers of this form are compressed, albeit to a lesser extent, in a lateral, oblique manner. *G. obliquus obliquus* is present but rare in most samples where solution has not occurred.

Figured hypotypes: USNM 306839, 306840, 306841.

**Globigerinoides quadrilobatus quadrilobatus**

**(d'Orbigny)**

**Plate 2: figures 11, 12**

*Globigerinoides quadrilobatus quadrilobatus* (d'Orbigny).—Akers, 1972:62, pl. 3: fig. 4, pl. 6: fig. 2, pl. 11: figs. 2, 3, pl. 16:
Well-developed specimens of this long-ranging species occur in samples where solution has been minimal. It is, however, rare in all but one of these samples.

Figured hypotypes: USNM 306842, 306843.

**Globigerinoides ruber (d’Orbigny)**

*Plate 2: figures 13, 14*

*Globigerina rubra* d’Orbigny, 1839:82, pl. 4: figs. 12-14.

*Globigerinoides ruber* is present in most samples, except those taken from horizons showing obvious effects of solution. Because it is one of the most dependable warm-water indicator species, its low relative abundances in our samples, even those showing no evidence of solution, suggest that the Yorktown sea was characterized by cool temperatures.

Figured hypotypes: USNM 306844, 306845.

**Genus Globoquadrina** Finley, 1947

**Globoquadrina altispira globosa** Bolli

*Plate 4: figures 1-3*

*Globoquadrina altispira globosa* Bolli, 1957:111, pl. 24: figs. 9, 10.

This form accounts for less than 1 percent of the planktonic assemblage in six samples, five from the lower part and one from the upper middle part of the Yorktown section. Its absence throughout the remainder of the section is probably due to its low initial abundance in waters of the Yorktown sea. Distinguishing characters include the spherical chambers and the moderately wide but very deep umbilicus. Specimens of this species from Lee Creek lack the very high spire that characterizes *G. altispira altispira*. Parker (1967:165) and Akers (1972:88) state that there is no special stratigraphic significance in the separation of these two subspecies. *G. altispira globosa* is biostratigraphically important because its last appearance is in the middle of Blow’s zone N20. According to Berggren (1978, figs. 5, 14), the *G. altispira* extinction level appears to be constant over wide geographic areas.

Figured hypotypes: USNM 306866, 306867, 306868.

**Globoquadrina venezuelana** (Hedberg)

*Plate 4: figures 4, 5*

*Globigerina venezuelana* Hedberg, 1937:681, pl. 92: fig. 7a,b.

Most specimens from Lee Creek have four inflated chambers in the final whorl, the last chamber being somewhat wider and more embracing than previous chambers. Small umbilical, toothlike projections are present on some specimens. This species comprises less than 1 percent of the planktonic assemblage in three samples from the lower and middle parts of the Yorktown section.

Figured hypotypes: USNM 306869, 306870.

**Genus Orbulina** d’Orbigny, 1839

**Orbulina suturalis** Brönnimann

*Plate 4: figure 8*

*Orbulina suturalis* Brönnimann [part], 1951:135, text-fig. 2: nos. 1, 2, 5-8, 10, text-fig. 3: nos. 3–8, 11, 13–16, 18, 20–22, text-fig. 4: nos. 2–4, 7–12, 15, 16, 19–22.

*Orbulina suturalis* occurs in seven samples that are irregularly distributed through the lower and middle portions of the Yorktown section. It never comprises more than 1 percent of the planktonic fauna.

Figured hypotype: USNM 306872.

**Orbulina universa** d’Orbigny

*Plate 4: figure 9*

*Orbulina universa* d’Orbigny, 1839-2, pl. 1: fig. 1.

*Orbulina universa* occurs sporadically throughout the lower and middle portions of the Yorktown
section. Specimens are rare and often show minor effects of solution.

Figured hypotype: USNM 306873.

**Genus Sphaeroidinellopsis** Banner and Blow, 1959

*Sphaeroidinellopsis subdehiscens subdehiscens* Blow

**PLATE 4: FIGURES 10, 11**

*Sphaeroidinella dehiscens subdehiscens* Blow, 1959:195, pl. 12: figs. 71, 72.

In all specimens from the Lee Creek section, the smooth outer cortex of this form has been destroyed, thus exposing the thick and coarsely perforate inner part of the wall. It is present but rare in most samples from stratigraphic intervals where solution has been minimal.

Figured hypotype: USNM 306874.

**Genus Globorotalia** Cushman, 1927

**Globorotalia (Turborotalia) acostaensis acostaensis** Blow

**PLATE 3: FIGURES 1–3**


Among the globorotaliids present in the Lee Creek section, this form, though it is always rare, occurs in the greatest number of samples. Its smaller umbilicus, more nearly planar spiral side, and greater displacement of the final chamber towards the umbilical side (partially obscuring the aperture when specimens are viewed from that side) serve to distinguish it from *G. acostaensis humerosa*.

Figured hypotypes: USNM 306855, 306856, 306857.

**Globorotalia (Globorotalia) crassula** Cushman and Stewart

**PLATE 3: FIGURES 4–12**

*Globorotalia acostaensis humerosa* Takayanagi and Saito.—Akers, 1972:108, pl. 17: fig. 4, pl. 19: fig. 3, pl. 25: fig. 2, pl. 26: fig. 3, pl. 28: fig. 2, pl. 36: fig. 2, pl. 40: fig. 2, pl. 44: fig. 2, pl. 48: fig. 1, pl. 54: fig. 2, pl. 57: fig. 1.

*Globorotalia acostaensis humerosa* occurs in nearly as many samples as does *G. acostaensis acostaensis*. It is a common member of the planktonic assemblage in three samples from the lower part of the Yorktown section.

Figured hypotypes: USNM 306852, 306853, 306854.

**Globorotalia (Turborotalia) praescitans** Akers

**PLATE 3: FIGURES 7–9**

*Globorotalia praescitans* Akers, 1972:116, pl. 32: fig. 3, pl. 45: fig. 106a–c, 107.

**Globorotalia praescitans** was described from the Yorktown sediments at Rice's Pit, Virginia, and at the same time was reported from the Jackson Bluff Formation (Akers, 1972:118). The abrupt inflation, both lateral and vertical, of the final chamber and the large semicircular aperture make it a distinctive and conspicuous element of the Yorktown planktonic assemblage. It is common within and restricted to the lowermost 3 m of the Lee Creek section, suggesting that it may be a useful marker for the lower Yorktown Formation elsewhere in the middle Atlantic Coastal Plain.

Figured hypotypes: USNM 306855, 306856, 306857.

**Globorotalia (Globorotalia) crassula** Cushman and Stewart

**PLATE 3: FIGURES 10–12**

*Globorotalia crassula* Cushman and Stewart.—Blow, 1969:397, pl. 5: figs. 4–9.

The taxonomy of the crassiform globorotaliids presents many difficulties (Cifelli and Glaçon, 1979). Rare specimens referable to *Globorotalia crassula* are present in five samples from Yorktown sediments at Lee Creek. Three of these samples are from the lower part of the section; two, from the upper part. *G. crassula* first appears just above the base of Blow's zone N18.
Figured hypotypes: USNM 306858, 306859, 306860.

**Globorotalia (Globorotalia) cultrata limbata**
*(Fornasini)*

**PLATE 3: FIGURES 19, 20**

*Globorotalia* *cultrata limbata* *(Fornasini).—Akers, 1972:98, pl. 33: fig. 2.*

*Globorotalia cultrata limbata* differs from other globorotalids present at Lee Creek in having an acute, strongly carinate periphery and a smooth surface, except for a pustulose area on the umbilical side of the first chamber of the final whorl. This moderately long-ranging form was recovered from only two samples, both of which are from the middle part of the section.

The figured specimen was lost subsequent to photography.

**Globorotalia (Globorotalia) hirsuta praehirsuta**
*Blow*

**PLATE 3: FIGURES 13-15**

*Globorotalia hirsuta praehirsuta* Blow, 1969:400, pl. 43: figs. 3-7.

*Globorotalia hirsuta praehirsuta* differs from *G. hirsuta hirsuta* in that the intercameral sutures of the spiral side are more strongly recurved in the posterior direction, the intercameral sutures of the ventral side are less deeply incised, and the test is more nearly plano-convex. Specimens from Lee Creek show some variation in the latter character but are otherwise consistent with Blow's description. *G. hirsuta praehirsuta* occurs in seven samples that range from the lower to the middle part of the Yorktown section. According to Blow (1969), *G. hirsuta praehirsuta* develops from *G. margaritae* in the middle part of zone N18, but both forms co-exist through zone N19. The extinction level of *G. margaritae* has been interpreted as constant over wide areas (Berggren, 1978, figs. 4, 5, 14). However, Parker (1967:180) stated that this species ranges into Blow's zone N20 in sediments from the tropical Indo-Pacific. Its range in the Caribbean and Gulf of Mexico extends into sediments equivalent to zone N20 (Lamb and Beard, 1972:45, 53, 54). In addition, one of us (Akers) has recently encountered it in sediments belonging within zone N20. In light of this evidence, the biostratigraphic interpretation of Snyder et al. (1980) has been slightly modified.

*G. margaritae* can be distinguished from *G. hirsuta praehirsuta* by its ventral side concavity, its more convex spiral side, and its more acute and thinly keeled periphery. Comparison with the three subspecies described as members of the *G. margaritae* lineage by Cita (1973) reveals that specimens from Lee Creek most closely resemble *G. margaritae margaritae*. Our material contains dextral and sinistral forms in approximately equal abundances, but specimens are too few for coiling direction ratios to be meaningful.

Figured hypotypes: USNM 306864, 306865.

**Genus Globorotaloides**
*Boilli, 1957*

**Globorotaloides hexagona hexagona** *(Natland)*

**PLATE 2: FIGURES 15-17**

*Globorotaloides hexagona hexagona* *(Natland).—Akers, 1972:124, pl. 28: fig. 1.*

The most distinctive morphologic feature of this form is its unique wall structure, which consists of hexagonal pits. *G. hexagona* occurs in several samples near the base of the Yorktown sec-
tion and again in several samples clustered in the middle part of the section. It first appears in the latter part of Blow's zone N18.

Figured hypotypes: USNM 306846, 306847, 306848.

**Genus Turborotalita** Banner and Blow, 1962

**Turborotalita humilis** (Brady)

**PLATE 4: figures 14, 15**

*Truncatulina humilis* Brady.—Barker, 1960:194, pl. 94: fig. 7.

Except that the test is slightly more inflated, specimens from the Yorktown Formation at Lee Creek compare closely to the concept of this species as it has been applied in the literature. It is present but rare in five samples ranging from the base to the upper part of the section.

Figured hypotype: USNM 306877.

**Turborotalita quinqueloba** (Natland)

**PLATE 4: figures 12, 13**

*Turborotalita quinqueloba* (Natland).—Akers, 1972:122, pl. 41: fig. 1, pl. 45: fig. 1.

*Turborotalita quinqueloba* can be easily identified by its extended final chamber and overhanging apertural lip that almost cover the umbilicus. It is present in most samples except those from horizons characterized by solution.

Figured hypotypes: USNM 306875, 306876.

**Genus Hastigerina** Thomson, 1876

**Hastigerina siphonifera siphonifera** (d'Orbigny)

**PLATE 4: FIGURES 6, 7**

*Globigerina siphonifera* d'Orbigny, 1839:83, pl. 4: figs. 15–18.

The planispiral or nearly planispiral coiling of this form serves to distinguish it from all other species present in the Lee Creek section. It is irregularly distributed from the lower through the middle part of the section.

Figured hypotype: USNM 306871 (Plate 4: figure 7). The other figured specimen (Plate 4: figure 6) was lost subsequent to photography.

**Literature Cited**

Akers, W.H.


Akers, W.H., and P.E. Koeppel


Bailey, R.H.


Barker, R.W.


Bé, A.W.H.


Berggren, W.A.


Blackwelder, B.W.

Blow, W.H.


Bolli, H.M.


Bolli, H.M., and P.J. Bermúdez

Bolli, H.M., and V.A. Krasheninnikov

Boltovskoy, E.


Brönnimann, P.

Cifelli, R., and G. Glagon

Cifelli, R., and R.K. Smith

Cita, M.B.

Cushman, J.A.

d'Orbigny, A.

Gibson, T.G.


Hazel, J.E.

Hedberg, H.D.

Jenkins, D.G., and W.N. Orr

Lamb, J.L., and J.H. Beard

Mansfield, W.C.
1943. Stratigraphy of the Miocene of Virginia and the

Mauger, L.L.


McLean, J.D., Jr.


Miles, G.A.


Mongin, D.


Parker, F.L.


Poag, C.W.


Poore, R.Z., and W.A. Berggren


Postuma, J.A.


Snyder, S.W.


Snyder, S.W., L.L. Mauger, and W.H. Akers

1-3. *Globigerina bulloides apertura* Cushman, hypotypes: 1, USNM 306816, umbilical view, sample 40; 2, USNM 306817, spiral view, sample 23; 3, USNM 306818, umbilical view, sample 23.

4. *Globigerina bulloides bulloides* d'Orbigny, hypotype, USNM 306819, umbilical view, sample 35.

5-7. *Globigerina calida praecalida* Blow, hypotypes: 5, USNM 306820, umbilical view, sample 23; 6, USNM 306821, spiral view, sample 23; 7, USNM 306822, edge view, sample 23.

8, 9. *Globigerina juvenilis* Bolli, hypotypes: 8, USNM 306823, umbilical view, sample 15; 9, USNM 306824, spiral view, sample 15.

10-12. *Globigerinita decoraperta* Takayanagi and Saito, hypotypes: 10, USNM 306825, umbilical view, sample 35; 11, USNM 306826, spiral view, sample 35; 12, USNM 306827, edge view, sample 35.


16, 17. *Globigerinita uvula* (Ehrenberg), hypotypes: 16, USNM 306830, apertural view, sample 35; 17, USNM 306831, spiral view, sample 35.

Each scale equals 100 microns.
PLATE 2

1, 2. *Globigerinoides bollii* Blow, hypotypes: 1, USNM 306832, umbilical view, sample 35; 2, USNM 306833, spiral view, sample 35.

3, 4. *Globigerinoides conglobatus conglobatus* (Brady), hypotypes: 3, USNM 306834, umbilical view, sample 40; 4, USNM 306835, spiral view, sample 40.

5–7. *Globigerinoides obliquus extremus* Bolli and Bermúdez, hypotypes: 5, USNM 306836, umbilical view, sample 37; 6, USNM 306837, spiral view, sample 35; 7, USNM 306838, edge view, sample 41.

8–10. *Globigerinoides obliquus obliquus* Bolli, hypotypes: 8, USNM 306839, umbilical view, sample 35; 9, USNM 306840, spiral view, sample 35; 10, USNM 306841, edge view, sample 35.

11, 12. *Globigerinoides quadrilobatus quadrilobatus* (d'Orbigny), hypotypes: 11, USNM 306842, umbilical view, sample 40; 12, USNM 306843, spiral view, sample 40.

13, 14. *Globigerinoides ruber* (d'Orbigny), hypotypes: 13, USNM 306844, umbilical view, sample 23; 14, USNM 306845, spiral view, sample 23.

15–17. *Globorotaloides hexagona hexagona* (Natland), hypotypes: 15, USNM 306846, umbilical view, sample 35; 16, USNM 306847, edge view, sample 40; 17, USNM 306848, spiral view, sample 23.

Each scale equals 100 microns.
PLATE 3

1–3. *Globorotalia (Turborotalia) acostaensis acostaensis* Blow, hypotypes: 1, USNM 306849, umbilical view, sample 35; 2, USNM 306850, spiral view, sample 35; 3, USNM 306851, edge view, sample 15.

4–6. *Globorotalia (Turborotalia) acostaensis humerosa* Takayanagi and Saito, hypotypes: 4, USNM 306852, umbilical view, sample 35; 5, USNM 306853, spiral view, sample 35; 6, USNM 306854, edge view, sample 35.

7–9. *Globorotalia (Turborotalia) praescitans* Akers, hypotypes: 7, USNM 306855, umbilical view, sample 35; 8, USNM 306856, spiral view, sample 35; 9, USNM 306857, edge view, sample 35.

10–12. *Globorotalia (Globorotalia) crassula* Cushman and Stewart, hypotypes: 10, USNM 306858, umbilical view, sample 40; 11, USNM 306859, spiral view, sample 35; 12, USNM 306860, edge view, sample 35.

13–15. *Globorotalia (Globorotalia) hirsuta praehirsuta* Blow, hypotypes: 13, USNM 306861, umbilical view, sample 41; 14, USNM 306862, spiral view, sample 21; 15, USNM 306863, edge view, sample 16.

16–18. *Globorotalia (Globorotalia) margaritae* Bolli and Bermúdez, hypotypes: 16, USNM 306864, umbilical view, sample 23; 17, USNM 306864, spiral view, sample 23; 18, USNM 306865, edge view, sample 25.

19, 20. *Globorotalia (Globorotalia) cultrata limbata* (Fornasini) (specimen lost subsequent to photography): 19, umbilical view, sample 16; 20, edge view, sample 16.

Each scale equals 100 microns.
PLATE 4

1-3. *Globoquadrina altispira globosa* Bolli, hypotypes: 1, USNM 306866, umbilical view, sample 40; 2, USNM 306867, spiral view, sample 40; 3, USNM 306868, edge view, sample 34.

4, 5. *Globoquadrina venezuelana* (Hedberg), hypotypes: 4, USNM 306869, umbilical view, sample 36; 5, USNM 306870, spiral view, sample 36.

6, 7. *Hastigerina siphonifera siphonifera* (d’Orbigny): 6, specimen lost subsequent to photography, side view, sample 35; 7, hypotype, USNM 306871, edge view, sample 15.

8. *Orbulina suturalis* Bronnimann, hypotype, USNM 306872, bottom view, early chambers, sample 23.

9. *Orbulina universa* d’Orbigny, hypotype, USNM 306873, top view, final chamber, sample 23.

10, 11. *Sphaeroidinellopsis subdehiscens subdehiscens* Blow, hypotypes: 10, USNM 306874, umbilical view, sample 40; 11, USNM 306874, spiral view, sample 40.

12, 13. *Turborotalita quinqueloba* (Natland), hypotypes: 12, USNM 306875, umbilical view, sample 15; 13, USNM 306876, spiral view, sample 35.

14, 15. *Turborotalita humilis* (Brady), hypotypes: 14, USNM 306877, umbilical view, sample 23; 15, USNM 306877, spiral view, sample 23.

Each scale equals 100 microns.

View This Item Online: https://www.biodiversitylibrary.org/item/267478
Permalink: https://www.biodiversitylibrary.org/partpdf/352152

Holding Institution
Smithsonian Libraries

Sponsored by
Smithsonian Institution

Copyright & Reuse
Copyright Status: In copyright. Digitized with the permission of the rights holder.
Rights Holder: Smithsonian Institution
License: http://creativecommons.org/licenses/by-nc-sa/4.0/
Rights: http://biodiversitylibrary.org/permissions

This document was created from content at the Biodiversity Heritage Library, the world’s largest open access digital library for biodiversity literature and archives. Visit BHL at https://www.biodiversitylibrary.org.