Studies Related to the Charleston, South Carolina, Earthquake of 1886— Neogene and Quaternary Lithostratigraphy and Biostratigraphy

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1367

Prepared in cooperation with the
U.S. Nuclear Regulatory Commission

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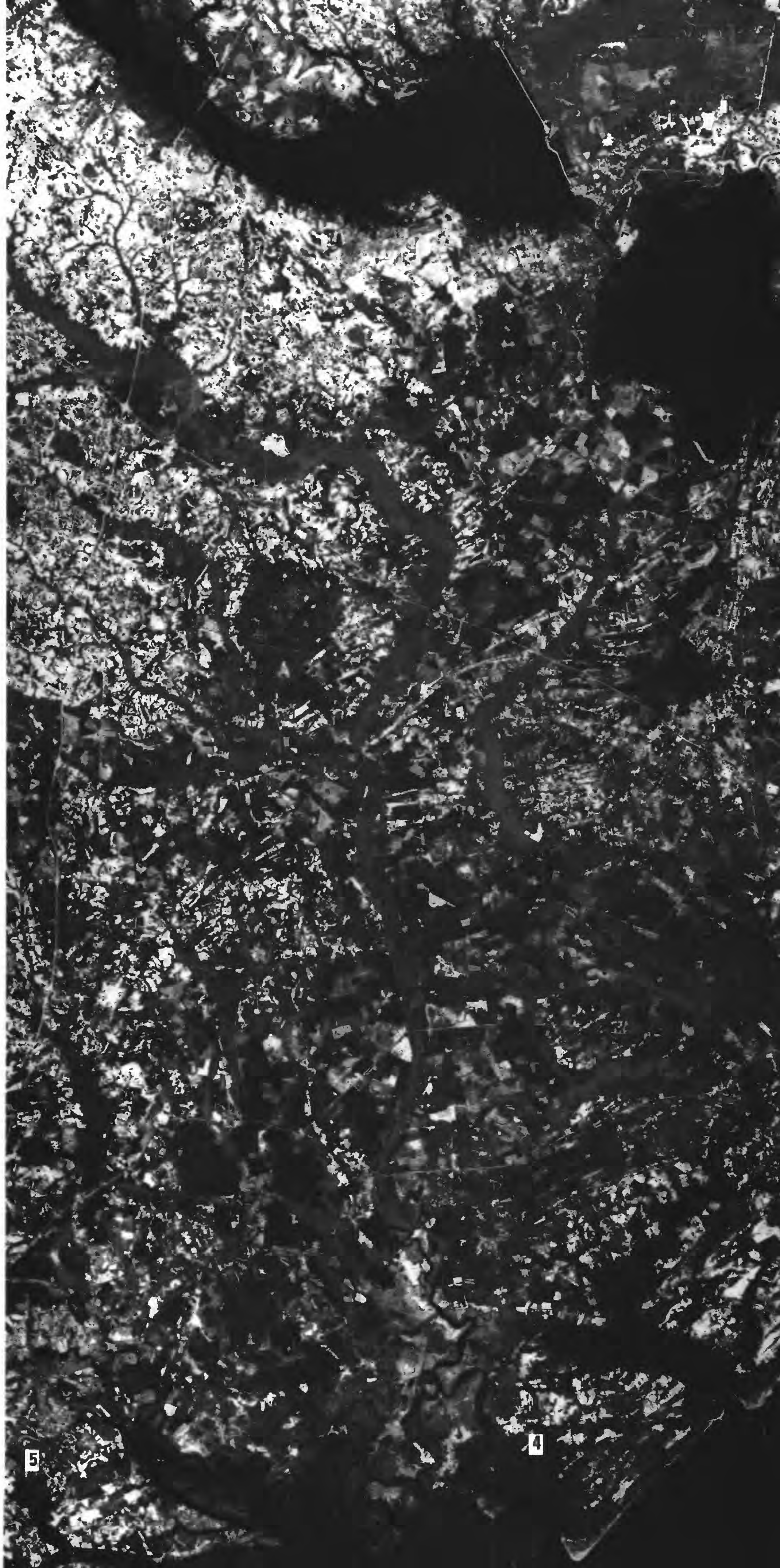
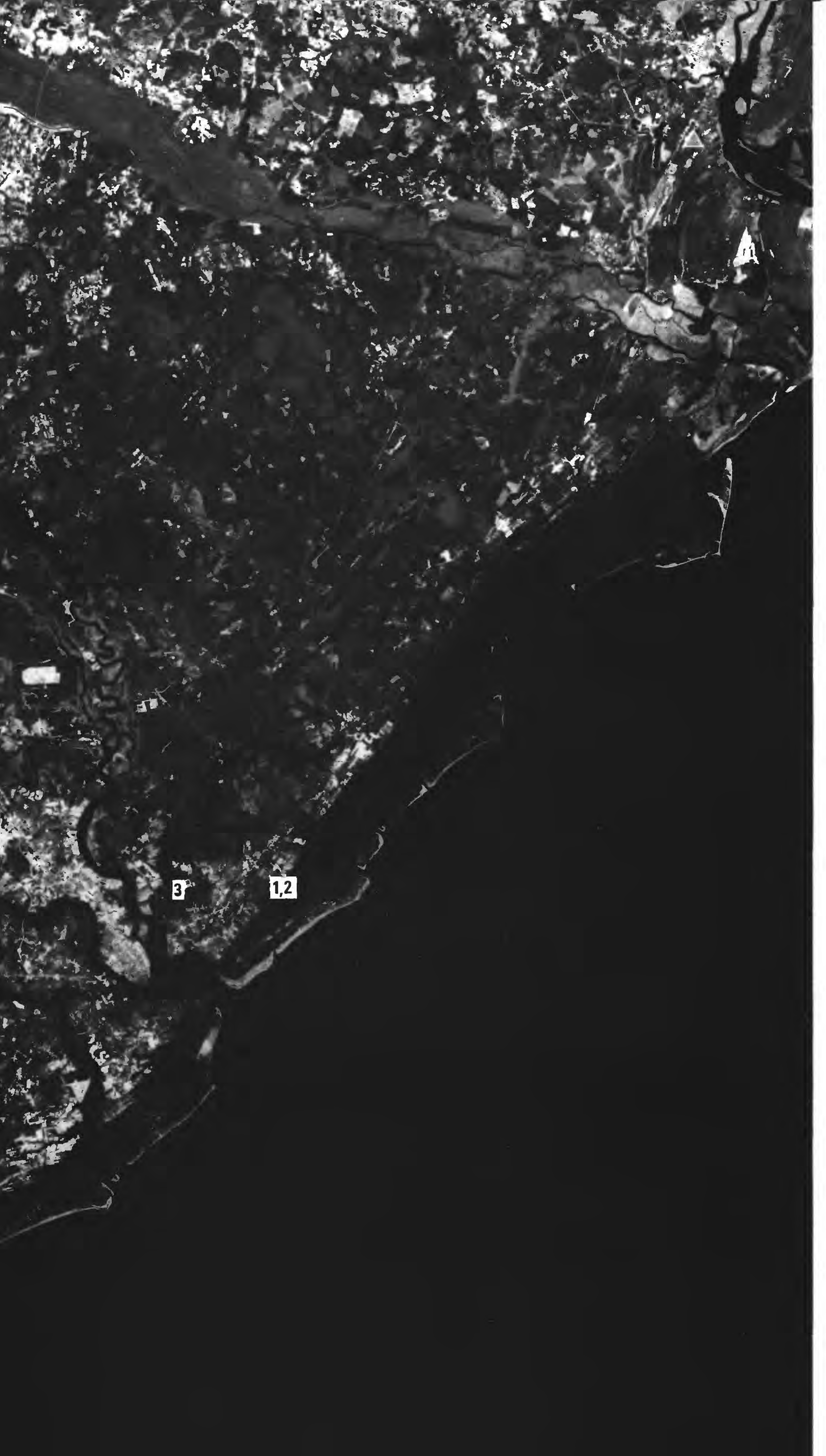
STUDIES RELATED TO THE CHARLESTON, SOUTH CAROLINA, EARTHQUAKE OF 1886—NEOGENE AND QUATERNARY LITHOSTRATIGRAPHY AND BIOSTRATIGRAPHY

Biostratigraphy is the essential chronologic basis of geologic maps of lithologic units in the Coastal Plain of South Carolina and elsewhere. Accuracy is achieved through the use of several fossil groups. Some of the Neogene species in the Charleston area are (1) *Momipites* sp. (pollen, ×1600, early Miocene; photograph by N.O. Frederiksen); (2) *Trinovantedinium capitatum* Reid, 1977 (dinocyst, ×400, early Miocene; photograph by L.E. Edwards); (3) *Cunearca brasiliana* (Lamarck) (pelecypod, ×1, late Pleistocene; photograph by Lucy McCartan); (4) *Paracytheridea altila* Edwards, 1944 (ostracode, ×86, late Pleistocene; photograph by T.M. Cronin); and (5) *Actinoptychus virginicus* (Grunow) Andrews (diatom, ×600, middle Miocene; photograph by G.W. Andrews).



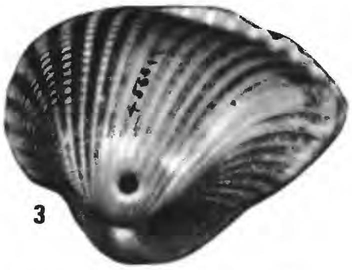


1

Momipites sp.

2

Trinovantedinium capitatum

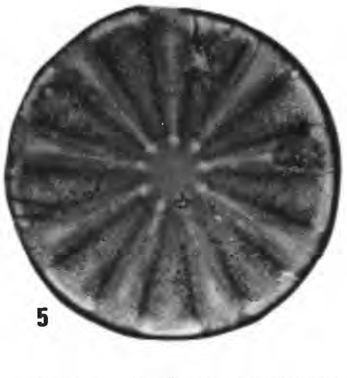


3

Cunearca brasiliana

4

Paracytheridea altila



5

Actinoptychus virginicus

Cliff face cut by a tidal creek at Scanawah Island, S.C., 50 km (31 mi) southwest of Charleston, S.C. The lithologic sequence is shelly, muddy, fine-grained quartz sand at the base (shallow-shelf environment, SH); quartz sand interbedded with montmorillonitic clay in the middle (lower intertidal environment, LI); and fine- to medium-grained quartz sand containing root casts at the top (upper intertidal environment, UI). This sequence records the upper part of a transgressive-regressive cycle, the depositional regression, which was caused by a rapid influx of sediment. Mollusks and ostracodes present suggest a late Pleistocene age for the unit (unit Q2), which extends from about 12 m (40 ft) below sea level to about 11 m (37 ft) above sea level in this area. The photograph was taken by J.P. Owens. Ostracode shown on previous page is from this locality.

Studies Related to the Charleston, South Carolina, Earthquake of 1886— Neogene and Quaternary Lithostratigraphy and Biostratigraphy

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Neogene and Quaternary surface and shallow-subsurface lithostratigraphy and biostratigraphy of parts of the middle and outer Coastal Plains of South Carolina and southern North Carolina

This volume is published as chapters A–G. These chapters are not available separately. Chapter titles are listed in the volume table of contents

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CONTENTS

[Letters designate the chapters]

METRIC CONVERSION FACTORS

For readers who wish to convert measurements from the metric system of units to the inch-pound system of units, the conversion factors are listed below:

Multiply metric unit	By	To obtain inch-pound unit
micrometer (µm)	0.00003937	inch (in.)
millimeter (mm)	.03937	inch (in.)
centimeter (cm)	.3937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	.6214	mile (mi)

STUDIES RELATED TO THE CHARLESTON, SOUTH CAROLINA, EARTHQUAKE OF 1886—NEOGENE AND QUATERNARY LITHOSTRATIGRAPHY AND BIOSTRATIGRAPHY

INTRODUCTION

By Lucy McCartan

This is the third volume in a series of Professional Papers describing the results of geologic studies conducted mainly from 1973 through 1984 of the Charleston, S.C., earthquake of 1886. Professional Paper 1367 presents in seven chapters interpretations of lithostratigraphic and biostratigraphic data accumulated by the U.S. Geological Survey in cooperation with the U.S. Nuclear Regulatory Commission. The two previous Professional Papers in the series contain discussions of subsurface stratigraphy and regional and local tectonism and seismicity (Rankin, 1977; Gohn, 1983).

The stratigraphic framework of the surface and shallow subsurface of the Charleston area is presented briefly in the following discussion as a context for the subsequent chapters.

LITHOSTRATIGRAPHIC UNITS

In the Charleston, S.C., area, there are at least 11 Neogene and Quaternary lithostratigraphic marine units (table 1). These units are bounded by unconformities and most are fossiliferous. From oldest to youngest, they are Edisto Formation, Marks Head Formation, Coosawhatchie Formation, Raysor Formation and Givhans beds, Goose Creek Limestone and Bear Bluff Formation, Waccamaw(?) Formation (equivalent to unit Q6 of McCartan and others, this volume), Penholoway Formation (unit Q5), Ladson Formation (unit Q4; Canepatch Formation), Ten Mile Hill beds (unit Q3; Socastee Formation), Wando Formation (unit Q2), and Holocene deposits (unit Q1). Names of regionally mapped surface units that are used widely in the Atlantic Coastal Plain at the time of this writing, such as Hawthorn Formation, Yorktown Formation, and Duplin Formation, are omitted from table 1 but are discussed in the text. Brief lithologic descriptions of the units, as well as our sense of the relationships among the regional and local units, are given below.

The lithostratigraphic units, shown in detail in McCartan and others (1984), were delineated and dated on the basis of textures, sedimentary structures, and mineralogy noted in outcrops and in samples from subsurface borings; biostratigraphic data; uranium-disequilibrium-series coral dates; and geomorphology.

EDISTO FORMATION

The Edisto Formation (Sloan, 1908; Ward and others, 1979; Ward and Blackwelder, this volume) is a soft, fine-grained quartz sandstone to quartzose calcarenite. It is separated from underlying fine-grained calcarenite of the Oligocene age Ashley Formation of the Cooper Group either by a bed of phosphate pebbles, which is a few centimeters thick, or by a burrowed surface. In the Charleston area, the Edisto Formation is a lower Miocene unit known only from a few outcrops, where the unit is less than a meter thick, and from subsurface patches, where the unit is less than 3 m thick.

MARKS HEAD FORMATION

The Marks Head Formation of early Miocene age (Sloan, 1905; Abbott and Huddlestun, 1980) has two interbedded lithofacies, fine-grained phosphatic quartz sand and cheese-textured clay, both of which have a distinctive brownish- to grayish-olive color. The lower contact of the unit is marked by a burrowed surface, and sparse phosphate pebbles and worn shell fragments occur just above the contact. Palygorskite and sepiolite are distinctive among the clay minerals. In Georgia, the Marks Head is found at the surface, but it is found in

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TABLE 1.—*Correlation and ages of Neogene and Quaternary lithostratigraphic units in the South Carolina Coastal Plain*

[ka, kilo-annum (10^3 years); Ma, Mega-annum (10^6 years)]

Colquhoun (1965, 1974)	DuBar (1971), DuBar and others (1974)[1]	This report		Series	System
South Carolina Coastal Plain	Myrtle Beach, S.C.	Charleston, S.C. (unit)	Age[2]		
Holocene	Ocean Forest Peat	Holocene deposits (Q1)	8–0 ka	Holocene	QUATERNARY
Silver Bluff Princess Anne Formation Pamlico Formation	Socastee Formation	Wando Formation[3] (Q2)	130–70 ka	Pleistocene	
Talbot Formation	Socastee Formation	Ten Mile Hill beds (Q3)	240–200 ka		
	Canepatch Formation	Ladson Formation (Qr)	450–400 ka		
Penholoway Formation	Waccamaw Formation, upper part	Penholoway Formation (Q5)	1.25? Ma–730 ka		
Wicomico Formation	Waccamaw Formation, lower part	Waccamaw(?) Formation (Q6)	1.6?–1.25? Ma		
		Bear Bluff Formation, Goose Creek Limestone		Pliocene	NEOGENE
		Givhans beds, Raysor Formation			
		Coosawhatchie Formation		Miocene	
		Marks Head Formation			
		Edisto Formation			

[1] Somewhat modified (see McCartan and others, 1982, and table 1 in McCartan and others, this volume).

[2] Based on uranium-disequilibrium-series coral age estimates (Szabo, 1985; McCartan and others, 1980, 1982; Cronin and others, 1981) and ^{14}C dates (McCartan and others, this volume), magnetostratigraphy (Liddicoat and others, 1981), and calcareous nannofossils (Gartner and others, 1983).

[3] Wando Formation (McCartan and others, 1980).

South Carolina only in the subsurface, mainly south and east of Charleston. It is as much as 15 m thick in the Charleston area.

The Marks Head Formation, as used by Abbott and Huddlestun (1980), is here adopted for use by the U.S. Geological Survey.

COOSAWHATCHIE FORMATION

In the Beaufort, S.C., area, the Coosawhatchie Formation of middle Miocene age overlies the Marks Head Formation. It consists of two parts, a lower sand unit and an overlying fine-grained clay unit. The lower quartz sand part is several meters thick, is phosphatic in places, and rarely is laterally more extensive than the clay (Heron and Johnson, 1966). The upper part of the Coosawhatchie Formation is as much as 7 m thick near Coosawhatchie, S.C., and is composed mainly of montmorillonitic clay and lesser amounts of illite, kaolinite, palygorskite, sepiolite, and, rarely, cristobalite. In the Charleston area, a sandy unit that may be part of the formation is present without the overlying clay; it contains dinoflagellates of middle or late Miocene age (L.E. Edwards, written commun., 1984).

The informal Coosawhatchie Clay (Heron and others, 1965), adopted for U.S. Geological Survey usage by Abbott and Andrews (1979) as the Coosawhatchie Clay Member of the Hawthorn Formation, is here redefined to include underlying or laterally detached sand beds of the same age in South Carolina and is raised to formational status as the Coosawhatchie Formation.

Abbott and Huddlestun (1980) raised the Hawthorn Formation of Dall (1892; see also Cooke, 1936) to a group consisting of five formations, among them the Marks Head Formation, Coosawhatchie Clay, and Edisto Formation. The Hawthorn Formation as now defined in its type area consists of a lower to middle Miocene phosphatic dolomite and dolomite-bearing phosphatic clay and sand (Scott, 1983, and Scott and MacGill, 1981). Because of the paucity of dolomite in beds of similar age in South Carolina, the name Hawthorn probably should not be used in South Carolina.

YORKTOWN AND DUPLIN FORMATIONS

The most frequently applied names for Pliocene units in the Atlantic Coastal Plain are the Yorktown Formation (Clark and Miller, 1906; LeGrand and Brown, 1955; Akers, 1972; Hazel, 1971, 1977, 1983) from Virginia to North Carolina and the Duplin Formation (Cooke, 1936, 1945; Akers, 1972; Hazel, 1977) from North Carolina to Florida. Blackwelder and Ward (1979) equated the Duplin only with the middle part of the Yorktown (type area), proposed substituting the names Yorktown and Raysor for Duplin in South Carolina, and suggested that the name Duplin be abandoned. Cronin and others (1984) correlated the type Duplin (Natural Well, N.C.) with the upper part of the Yorktown Formation, and they consider both units to be late Pliocene in age. Both the Raysor Formation and the Givhans beds, which are local lithic names used in this paper, are correlated faunally to parts of the Yorktown Formation.

RAYSOR FORMATION

The Raysor Formation (Cooke, 1936; Blackwelder and Ward, 1979) is a bluish- to greenish-gray, shelly, calcareous quartz sand to noncalcareous, micaceous, fine-grained sand of Pliocene age. Both aragonite and calcite shells are present, but the aragonite is more leached and appears chalky. Blackwelder and Ward (1979) equated the Raysor Formation with the Givhans beds (our usage) and correlated them with the Duplin Formation in North Carolina and the middle part of the Yorktown Formation in its type area in Virginia.

GIVHANS BEDS

The Givhans beds, an informal unit in this paper named from the Pliocene beds exposed just north of Givhans Ferry on the east bank of the Edisto River, Dorchester County, S.C., are composed of fine- to medium-grained quartzose calcarenite. Aragonite is absent in these beds, but molds and casts of aragonitic mollusk shells are present. The basal contact is below a 1- to 2-cm-thick bed of black, rounded phosphate pebbles. The unit is up to 7 m thick and is known from only a few outcrops and subsurface localities in the Charleston area. Although the unit is lithically distinct from the Raysor Formation, Blackwelder and Ward (1979) and Cronin (this volume) cannot separate this unit temporally from the Raysor Formation.

GOOSE CREEK LIMESTONE

The Goose Creek Limestone of Pliocene age (Sloan, 1908; Weems and others, 1982) is a quartzose, phosphatic, medium- to coarse-grained calcarenite that has sparse to abundant, calcitic shells and large, calcitic shell fragments. It is pale orange to chalk white in outcrop but is blue gray in some subsurface samples. The base of the unit has a 2- to 10-cm-thick bed of rounded phosphate pebbles, and some beds contain abundant, sand-sized phosphate grains. The unit is up to 12 m thick and is found as remnant channel fill beneath Quaternary deposits in the Charleston area; a few outcrops are present along Goose Creek in Charleston and Berkeley Counties, S.C. The oldest known horizons of the Goose Creek are possibly slightly older than the oldest known horizons of the Bear Bluff (Bybell, this volume), but poor preservation of most fossils in both the Goose Creek Limestone and the Bear Bluff Formation precludes firm relative stratigraphic placement of these two units at present. Mollusks suggest that the Raysor and lower part of the Givhans beds are older than the Bear Bluff, Goose Creek, and upper part of the Givhans (L.W. Ward, written commun., 1985).

BEAR BLUFF FORMATION

The most extensive surficial unit inland from Charleston, between 35 m and 45 m altitude, correlates with the Bear Bluff Formation. The unit includes interbedded coarse- to fine-grained sand, muddy sand, and minor clay beds containing sand-filled burrows. The colors range from orange, red, and white at the top to medium gray and greenish black at the base. Fossils, present only in some places at the base, include a mixture of Eocene to Pliocene, open-bay, shallow-shelf taxa. The name is extended southward from the type area (DuBar, 1971; DuBar and others, 1974) partly on the basis of unpublished data (J.P. Owens, oral commun., 1984).

QUATERNARY UNITS

The six Quaternary lithostratigraphic units discussed in this volume (units Q1–Q6) include Holocene deposits (table 1) and consist of unconsolidated, well-sorted quartz sand, muddy sand, and interbedded sand, mud, and shell beds (McCartan and others, this volume). Although the lithologies grade into one another, the dominant depositional lithofacies have typical lithologies: shelf deposits are burrowed, fine- to medium-grained sand containing interbedded mud and shells at some localities; beach deposits are typically well-sorted, fine- to medium-grained sand; backbarrier deposits are mainly muddy, fine- to medium-grained sand or interbedded sand, mud, and sparse wood and shells; fluvial deposits are muddy, fine- to coarse-grained sand containing pebbles; and swamp deposits are muck or clean, fine-grained sand of Holocene age. The oldest unit (Q6, Waccamaw(?) Formation) is found farthest inland and at the highest altitude; the youngest unit (Q1, Holocene deposits) is present at the coast and along modern swamps and rivers.

The Waccamaw(?) Formation (DuBar, 1971; DuBar and others, 1974) is a northern South Carolina name equivalent to unit Q6 mainly on the basis of stratigraphic position. Penholoway Formation as used by Weems and Lemon (1984a, b) is equivalent to unit Q5. Canepatch Formation and Socastee Formation (DuBar, 1971; DuBar and others, 1974), names originally used in northern South Carolina, are correlated with units Q4 and Q3, respectively, in the restricted sense of McCartan and others (1982). The Ladson Formation of Malde (1959) was divided and restricted by Weems and Lemon (1984a, b) as follows: the part of Malde's Ladson Formation that includes the type section but excludes the Ten Mile Hill beds is equivalent to unit Q4, and the Ten Mile Hill beds are equivalent to unit Q3. The Wando Formation (McCartan and others, 1980) as amended in McCartan and others (this volume) is equivalent to unit Q2, and Holocene deposits are equivalent to unit Q1.

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Quaternary Stratigraphy in the Vicinity of Charleston, South Carolina, and Its Relationship to Local Seismicity and Regional Tectonism

By LUCY McCARTAN, R.E. WEEMS, *and* E.M. LEMON, Jr.

STUDIES RELATED TO THE CHARLESTON, SOUTH CAROLINA,
EARTHQUAKE OF 1886—NEOGENE AND QUATERNARY
LITHOSTRATIGRAPHY AND BIOSTRATIGRAPHY

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1367–A

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QUATERNARY STRATIGRAPHY IN THE VICINITY OF CHARLESTON, SOUTH CAROLINA, AND ITS RELATIONSHIP TO LOCAL SEISMICITY AND REGIONAL TECTONISM

By LUCY MCCARTAN, R.E. WEEMS, and E.M. LEMON, JR.

ABSTRACT

The outer Coastal Plain of South Carolina is covered by a thin blanket of marine, estuarine, and fluvial sediment of Quaternary age that has been divided into six lithostratigraphic units deposited in separate transgressive-regressive cycles. Depositional lithofacies, such as shelf, beach, backbarrier, and fluvial sediments, are differentiated within the lithostratigraphic units. In the Charleston area, Holocene age marginal marine deposits, unit Q1, occur on the modern shelf below sea level, in beach dunes as high as 5 m above sea level, and in backbarrier flats as much as 2 m above sea level. Deposits of unit Q2 are about 100,000 years old; dunes on unit Q2 beach ridges reach an altitude of 11 m. Deposits of unit Q3, about 200,000 years old, include beach ridges as much as 16 m above sea level. Deposits of unit Q4, about 450,000 years old, reach 19 m, and deposits of unit Q5, more than 730,000 years old, reach 28 m. Beach dunes of the oldest Quaternary unit, Q6, are found as high as 32 m above sea level.

Each unit rests mainly on pre-Quaternary bedrock, remnants of older Quaternary units being preserved beneath younger Quaternary units in only a few places. The freshest sediment from the marine facies of all the formations is chiefly fine quartz sand containing variable amounts of shell, heavy minerals derived from a metamorphic terrane, and mud containing kaolinite, illite, and illite-smectite mixed-layer clay. As age of the deposits increases, weathered sediment of the six Quaternary lithostratigraphic units shows progressive depletion of certain minerals, such as ilmenite, hornblende, epidote, and illite-smectite, and secondary enrichment of others, such as leucoxene, kaolinite, dioctahedral vermiculite, and gibbsite. Relative and absolute ages of the units are based on mollusk and ostracode biostratigraphy, uranium-disequilibrium-series age estimates on corals, mineralogic trends, magnetic polarity, and amino-acid ratios. Unit boundaries are based on morphologic factors, mainly slope and altitude, and on distribution of lithofacies in three dimensions.

The pattern of successive Quaternary deposits in the Charleston area reflects the sporadic upward movement of the Cape Fear Arch to the north, the relative downward movement of the southeast Georgia embayment to the south, and the overall uplift of the entire South Carolina coastal area, relative to modern sea level, throughout the Quaternary. Smaller scale domes and basins are part of the complex pattern. Recent Charleston seismicity, including the 1886 earthquake, may be caused by release of energy during tectonic movement involving one or more of these structures.

INTRODUCTION

On August 31, 1886, an earthquake that occurred in the Charleston, S.C., area killed 60 people and was felt widely over the eastern half of the United States. The magnitude of the earthquake is estimated to have been 6.5–6.8 (Bollinger, 1977). Although no major earthquake has taken place there since, a large number of small earthquakes, to magnitude 4, continue to be recorded in the area between Charleston and Orangeburg, S.C. (Tarr, 1977). The Charleston Project, a study conducted by the U.S. Geological Survey (USGS) in conjunction with the U.S. Nuclear Regulatory Commission, seeks to understand the tectonic setting of the Charleston-area seismicity, to estimate the likelihood of other major earthquakes near Charleston, and to determine whether the seismic risk near Charleston is unique or whether such a risk actually extends to other areas of the Atlantic Coastal Plain. As part of this project, this volume and a geologic map of the area between Charleston and Orangeburg (McCartan and others, 1984) summarize the results of lithostratigraphic, mineralogic, and biostratigraphic investigations of the surface and shallow-subsurface geology of the Charleston area with emphasis on Quaternary stratigraphy. This chapter describes the regional Quaternary stratigraphic framework and depositional history and relates them to the continuing late Cenozoic tectonism and seismicity of the Charleston area. The relationships among these factors are assessed

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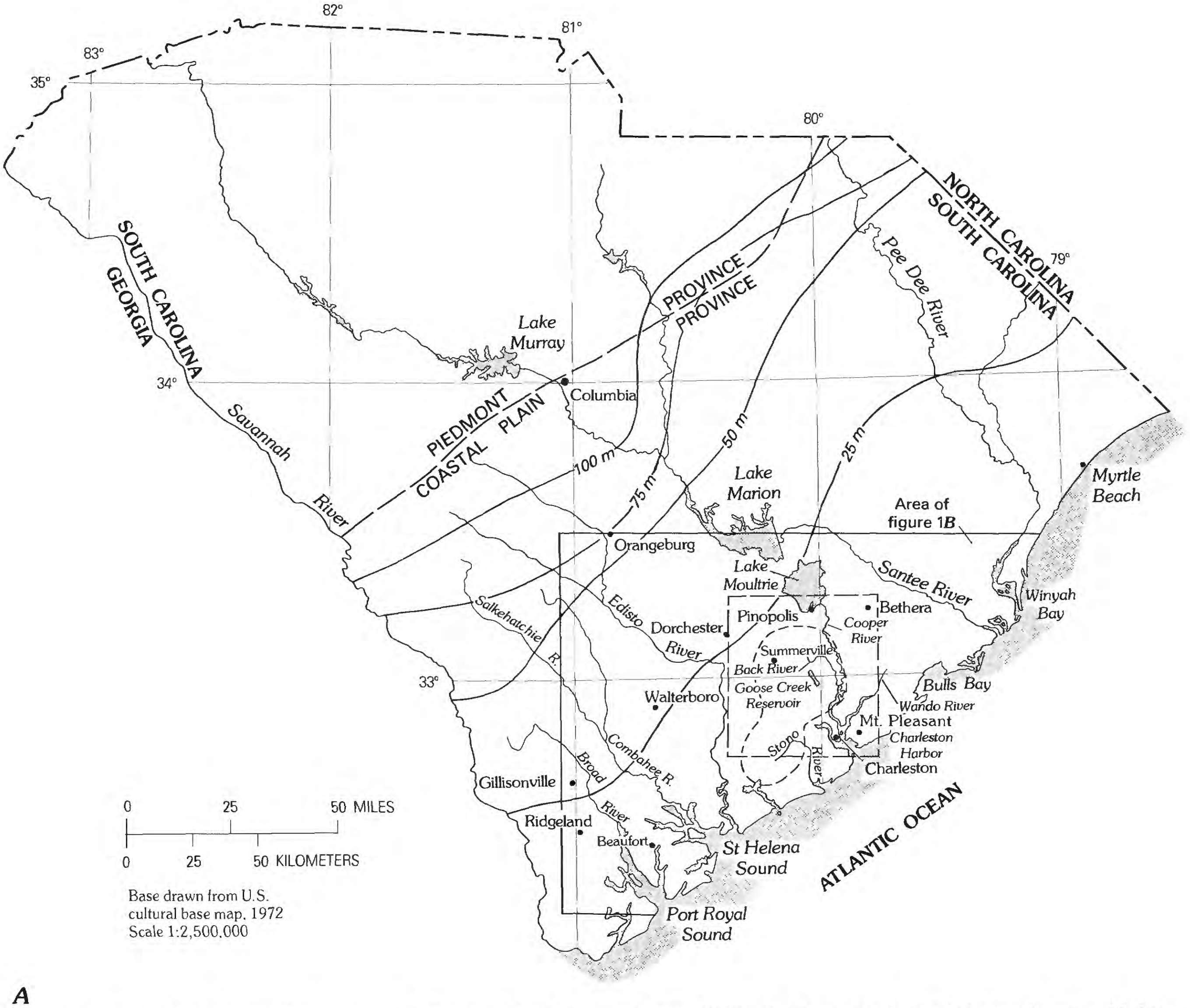

Base drawn from U.S.
cultural base map, 1972
Scale 1:2,500,000

FIGURE 1.—Maps of South Carolina and part of the Coastal Plain province of South Carolina. *A*, Localities mentioned in text and generalized Coastal Plain topography (25-m contour interval). Locality labeled "Area of figure 1*B*" shows area discussed in this chapter: long dashes outline area of detailed mapping, and curved, short dashes enclose area of greatest intensity of 1886 earthquake (Dutton, 1889). *B*, Geomorphology of the study area. Modern swamps and coastal marshes are screened; sand ridges are generalized as rows of short dashes; and scarps at seaward edge of the major sand ridges are shown as solid curved line segments. Geomorphology modified from Colquhoun (1965, 1969).

in the context of the Cenozoic tectonic history of the entire Atlantic Coastal Plain.

MAPPING AND LABORATORY TECHNIQUES

The distribution of map units and the subsurface extent of and relationships among lithofacies presented in this chapter are based on a combination of detailed and reconnaissance mapping. Surface and shallow-subsurface geology principally of the area between Summerville and Charleston was mapped at a scale of 1:24,000 by Weems and Lemon (for example, 1984a, b) (fig. 1). Lithofacies that have distinct morphologic expression, especially beach and dune deposits, and contacts along scarps between lithostratigraphic units were mapped by "surface expression."

Mapping of surface and shallow-subsurface units was aided by more than 600 power auger holes and coreholes and by published drill logs (Pooser, 1965) and logs in the files of the South Carolina Geological Survey and other agencies.

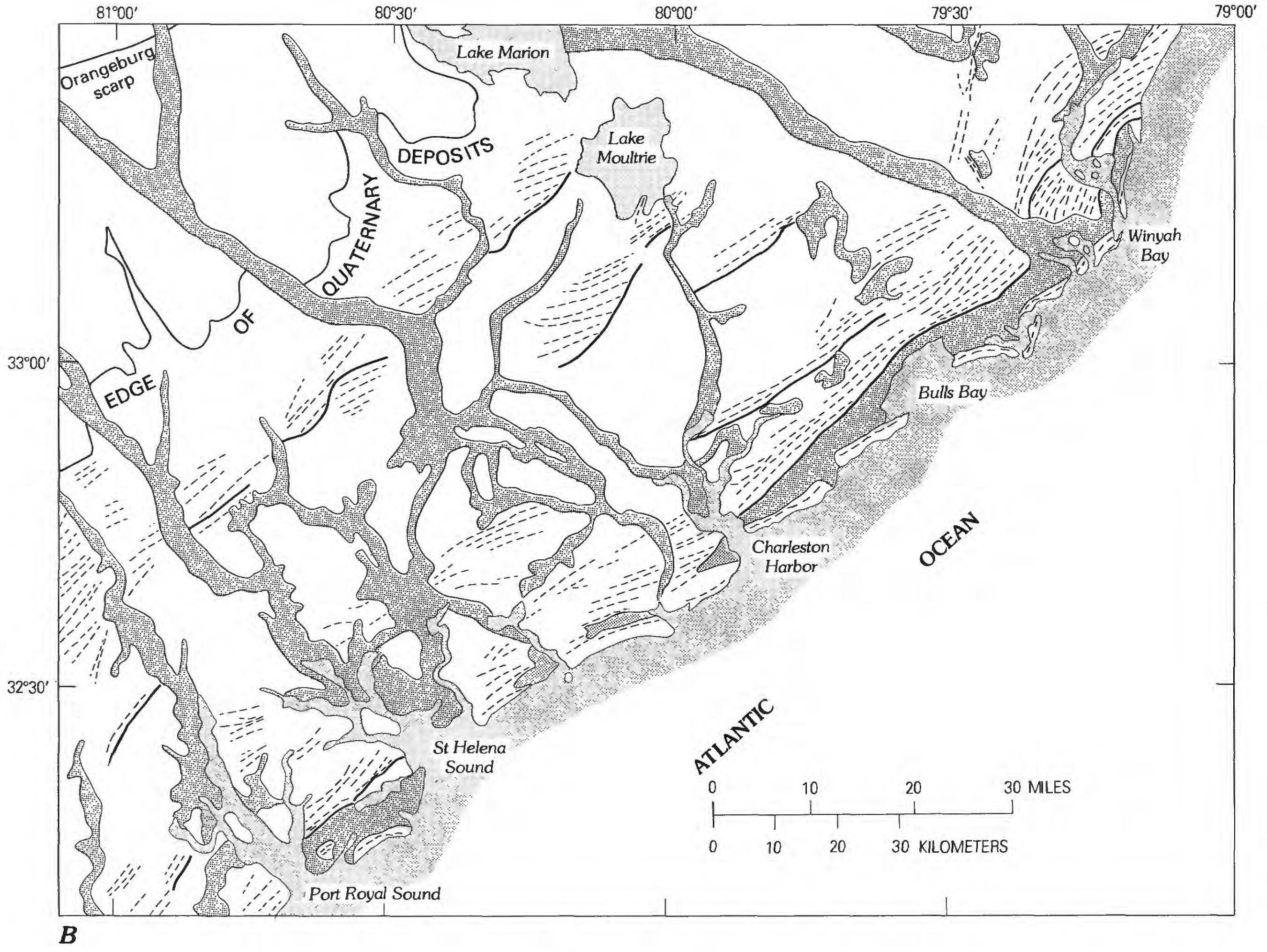

FIGURE 1.—Continued.

Laboratory analyses for this report include microscope identification of the sand grains, ^{14}C and uranium-disequilibrium-series age determinations, and paleomagnetic studies. The results of Neogene and Quaternary biostratigraphic studies related to the 1886 Charleston earthquake are presented in chapters B through G of this volume.

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GEOMORPHOLOGY

This report covers an area of about 15,000 km^2 between Charleston, on the coast, and Orangeburg, 125 km inland (fig. 1*A*). The average surface slope decreases from 5 m/km at the Orangeburg Scarp (Colquhoun, 1965) to 0.2 m/km between Summerville and Charleston. The very low gradient coastal belt is dissected by tidal creeks and estuaries. Most of the estuaries are fed by Coastal Plain streams. The Santee River, flowing southeastward across the northeast part of the map area, and the Savannah River, flowing along the southwest border of the area, rise in the Piedmont.

Most rural land is covered by cultivated pine forests and field crops. Swamps are common, particularly in forests, and are usually drained by networks of large open ditches.

Several discontinuous belts of sand ridges as much as several kilometers long and 3 to 5 m high roughly parallel the coastline (fig. 1*B*). The top of the highest ridge is about 32 m above sea level; the lowest, about 5 m, is the line of dunes on the Holocene barriers. Many ridges or groups of ridges are at intermediate positions and altitudes. Most of these highs coincide with Pleistocene beach ridges, but some are erosional remnants of other types of deposits, such as backbarrier flats.

Colquhoun (1965, 1969) discussed South Carolina geomorphology in detail. Figure 1*B* is based partly on Colquhoun's maps.

PREVIOUS WORK

Work directly related to the Charleston seismicity was initiated by Dutton (1889), who described the surface effects and estimated the positions of two epicenters for the 1886 events. Many results of the present Charleston Project have been summarized by Rankin (1977) and Gohn (1983).

Cooke's (1936) classic "Geology of the Coastal Plain of South Carolina" is the earliest thorough account of Quaternary deposits in South Carolina. His work was based partly on the pioneering morphology studies of Shattuck (1901), who differentiated several terraces that he ascribed to interglacial marine highstands, and partly on the stratigraphy of Stephenson (1926, 1928). Cooke mapped surficial deposits as high as 82 m altitude as Pleistocene on the basis of geomorphic evidence. Other stratigraphic interpretations were expressed by MacNeil (1950), Colquhoun and Pierce (1971), and DuBar, Johnson, and others (1974).

Colquhoun (1965, 1974) and his students have compiled and interpreted a large body of data on the South Carolina Coastal Plain. A major contribution of Colquhoun is the concept of primary and secondary beach deposits, a concept applied in the present report. Primary beaches are deposited when the sea level is highest during a transgressive-regressive cycle, and secondary beaches are deposited during the regressive phase. Colquhoun's lithostratigraphic interpretations were based mainly on geomorphology and textural analyses of slurry samples from rotary drill holes (oral commun., 1982). Lithostratigraphic analysis in the present report differs from the previous workers' interpretations (table 1) and is based on lithologic sections, subsurface extent and nature of contacts between lithofacies, and mineralogic and textural analyses from stratigraphic auger and core samples.

Malde (1959) examined the Quaternary geology of the Charleston phosphate mining district, centered on the Ladson quadrangle, which he mapped at 1:24,000 on the basis of outcrops and shallow auger holes. This was the first detailed map in the Charleston area. Malde recognized lithofacies mainly on the basis of texture and drew boundaries at geomorphic breaks. His geologic map and cross sections reflect an interpretation of the lithologic data that is different from the interpretation in the present report. In particular, Malde's Ladson Formation, shown over most of the Ladson quadrangle, is part of three lithostratigraphic map units (Q2, Q3, Q4) in the present report. One reason for Malde's interpretation is the presence of a phosphate pebble bed at the base of the Quaternary deposits in most of his sections. The pebble bed is misleading, however, as it is present also at the base of pre-Quaternary deposits.

Other work in the Charleston area that has influenced the present study is by Hayes and Kana (1976) on modern coastal processes and by Wojtal and Tye (1980) on the depositional environment of unit Q2 near Mount Pleasant (just east of Charleston) as inferred from sedimentary structures. Reports by Pooser (1965) on pre-Quaternary ostracodes, Sanders and others (1982) on vertebrates, and Heron and Johnson (1966) on pre-Quaternary structure and stratigraphy helped us delineate the extent of Quaternary deposits.

On a broader scale, some workers have noted tectonic effects (Cooke, 1936; Hoyt and Hails, 1971; Winker and Howard, 1977) on the broad Coastal Plain terraces outlined by Shattuck (1901) and Cooke (1931, 1932, 1935) or have investigated the interplay between rates of deposition and tectonism (Curray, 1964; Pitman, 1978; Owens, 1983).

QUATERNARY STRATIGRAPHY

INFORMAL STRATIGRAPHIC NOMENCLATURE USED IN THIS REPORT

This report describes the stratigraphy shown on the geologic map of the area between Charleston and Orangeburg at 1:250,000 scale (McCartan and others,

TABLE 1.—*Correlation chart of Quaternary stratigraphic units in the South Carolina Coastal Plain*

[Correlations with previous publications are approximate. ka, kilo-annum (10^3 years); Ma, Mega-annum (10^6 years)]

Cooke (1936)	Colquhoun (1965, 1974)	DuBar (1971), DuBar, Johnson, and others (1974)[1]	This report (and McCartan and others, 1984)		Quaternary chronostratigraphy
South Carolina Coastal Plain	South Carolina Coastal Plain	Myrtle Beach, S.C.	Charleston, S.C.	Age estimate	
Recent terrace	Holocene	Ocean Forest Peat	Unit Q1	<8 ka	Holocene
Pamlico Formation	Silver Bluff Princess Anne Formation Pamlico Formation	Socastee Formation	Unit Q2[2]	About 100 ka	Pleistocene
Talbot Formation	Talbot Formation	Socastee Formation Canepatch Formation	Unit Q3 Unit Q4	About 200 ka About 450 ka	
Penholoway Formation	Penholoway Formation	Waccamaw Formation, upper part	Unit Q5	>730 ka	
Wicomico Formation	Wicomico Formation	Waccamaw Formation, lower part	Unit Q6	>1 Ma	

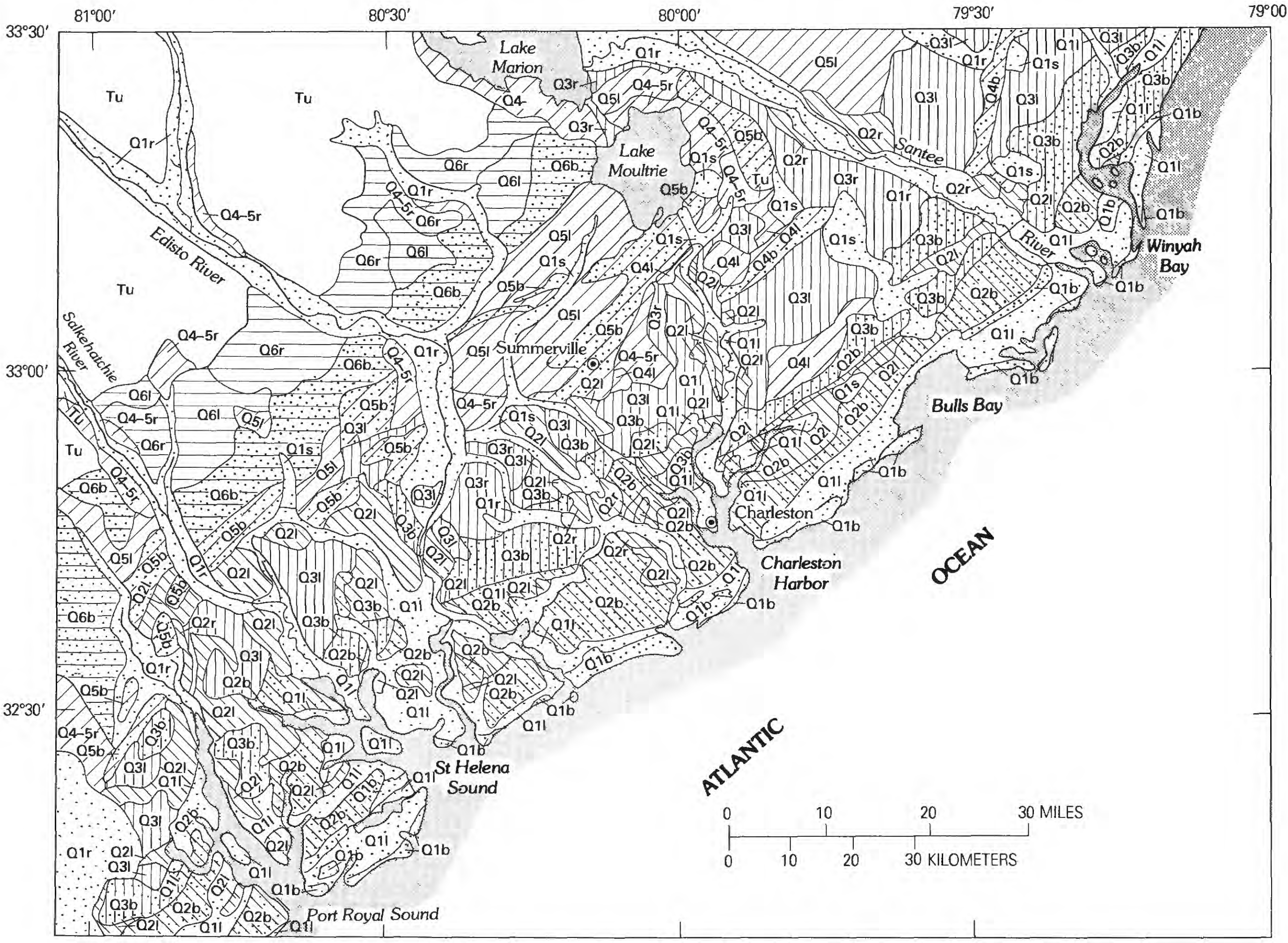
[1] Modified from DuBar (1971) and McCartan and others (1982). There is a small patch of deposits equivalent to unit Q2 in the Myrtle Beach area, but it was not distinguished by DuBar (1971) or DuBar, Johnson, and others (1974). DuBar incorrectly correlated his Socastee Formation with the Pamlico Formation of Cooke (1936) (J.P. Owens, oral commun., 1987), and DuBar did not recognize two parts in the Waccamaw Formation (J.P. Owens and L.W. Ward, oral commun., 1987).

[2] Wando Formation (McCartan and others, 1980).

1984). The generalized geologic map (fig. 2) shows the main lithostratigraphic units of the 1:250,000-scale map. Informal map units Q1–Q6 are used in this report instead of formation names for Quaternary units in Charleston for two reasons. First, units previously defined or used in the Charleston area (for example, Colquhoun, 1965), around Myrtle Beach (for example, DuBar, 1971), or along the whole South Carolina Coastal Plain (for example, Cooke, 1936) are similar generally to units described in this report but do not have exactly the same boundaries and stratigraphic extent as the units described in this paper (table 1). Second, we suggest that Quaternary stratigraphy in the Charleston area is best understood in the context of the entire Atlantic Coastal Plain. When regional names are applied to Quaternary units in the future, a formal process will be necessary to suppress formal local names, whereas informal local designations such as units Q1–Q6 will be more easily superseded.

Symbols, such as Q1, Q2, Q3, are used to designate mappable units, each of which was deposited during a single marine transgressive-regressive cycle. These are the major lithostratigraphic units and may be thought of as informal equivalents of formations. In Holocene and pre-Holocene deposits, lowercase letters, as in Q1b (b, beach, which may or may not be on a barrier spit or island), Q1l (l, backbarrier), Q1r (r, fluvial), and Q1s (s, swamp), are used to designate depositional lithofacies, which are subunits within lithostratigraphic units. In pre-Holocene deposits, swamps are incorporated in the fluvial lithofacies (Q2r–Q6r), and shelf and open-bay deposits (Q2o–Q6o) are differentiated in the lower part of some sections. Each lithostratigraphic unit (Q1–Q6) records a distinct depositional cycle, inferred from the distribution of the member lithofacies. The genetic and descriptive term “depositional lithofacies” is used to indicate that the environment of deposition has been inferred from several of the properties of each lithofacies and that the lithology is distinguishable from that of adjacent lithofacies. Properties that characterize a depositional lithofacies are texture, primary and secondary mineralogy, sedimentary structures, shape of deposit, and fossil content. The altitude and orientation of the deposit, the position of the deposit relative to deposits of other depositional lithofacies, and the nature of the contacts between deposits are additional properties that serve to differentiate lithofacies and lithostratigraphic units. The relative positions of the lithofacies are not random; the lateral and vertical succession of associated lithofacies of a single lithostratigraphic unit, such as shelf, beach, and backbarrier facies, strongly suggests that the lithofacies were deposited during a single depositional cycle.

Although the range of some of the properties in one depositional lithofacies may overlap the range of properties in other depositional lithofacies, the sum of the



EXPLANATION

	Lithostratigraphic units	Depositional lithofacies	Coral dates
Holocene	Q1	Q1b	
		Q1l, Q1r, Q1s	
Pleistocene	Q2	Q2b	~ 100 ka
		Q2l, Q2r	
	Q3	Q3b	~200 ka
		Q3l, Q3r	
	Q4, Q5	Q4b, Q5b	~450 ka
		Q4l, Q5l, Q4–5r	
	Q6	Q6b	>1 Ma
		Q6l, Q6r	
Tertiary	Tu	Undifferentiated	

b Beach facies—Clean, fine- to medium-grained sand deposited parallel to modern coast. Includes shelf and open-bay facies (o) of clean to muddy, fine- to medium-grained sand and medium- to coarse-grained, shelly sand deposited adjacent to and seaward of beaches; found in lower part of some sections

l Backbarrier facies—Muddy, fine- to medium-grained sand containing clay layers, clean sand layers, shells, and sparse wood; deposited in flats landward of beaches

r Fluvial facies—Muddy, fine- to coarse-grained sand containing pebbles; deposited in belts oriented 45° to 90° to coastline. Includes swamp facies (s) in pre-Holocene deposits

s Swamp facies—Muck or clean, fine-grained sand of Holocene age

FIGURE 2.—Generalized Quaternary stratigraphy in the Charleston, S.C., area. Depositional lithofacies are emphasized. Coral dates according to McCartan and others (1982). Abbreviations: ka, kilo-annum (10^3 years); Ma, Mega-annum (10^6 years).

properties of each mapped lithofacies serves to distinguish mappable genetic members that constitute a lithostratigraphic unit.

The estimates of the absolute ages of each lithostratigraphic unit (fig. 2, table 1) are based on one or more of the following: ^{14}C (unit Q1, 8 kilo-annum (ka, 10^3 years) to the present); uranium-disequilibrium-series coral dates (unit Q2, about 100 ka; unit Q3, about 200 ka; unit Q4, about 450 ka by extrapolation from corals in the Canepatch Formation at Myrtle Beach); and reversed magnetic polarity (units Q5 and Q6, older than 730 ka). On the basis of trends of weathered minerals, unit Q6 is judged to be significantly older than unit Q5. Unit Q6 also appears to occupy a stratigraphic position similar to that of the Waccamaw Formation near Myrtle Beach, S.C., which is in turn a biostratigraphic correlative of the Caloosahatchee Formation in Florida. M.L. Bender (written commun. to B.W. Blackwelder in McCartan and others, 1982) dated Caloosahatchee corals at older than 1 Mega-annum (Ma, 10^6 years) by the U–He method, so unit Q6 is probably older than 1 Ma.

The dates and age ranges are discrete and reproducible and are supported by mollusk and ostracode biostratigraphy and weathering studies. Biostratigraphy is the subject of chapters B through G of this volume, and weathering studies are discussed in detail in this chapter.

COMPARISON OF THIS REPORT, THE 1:250,000-SCALE GEOLOGIC MAP, AND 1:24,000-SCALE MAPPING IN THE CHARLESTON AREA

The most significant difference between figure 2 and the 1:250,000-scale geologic map by McCartan and others (1984) is the portrayal of the offshore facies. In the 1:250,000-scale geologic map, offshore deposits that occur at the land surface are shown separately; in figure 2, they are incorporated with the beach facies of the same age. Subsurface shelf deposits are shown separately in the cross sections for both maps. Since the 1:250,000-scale geologic map was published, the narrow belt of shelly sand just seaward of lithofacies Q3b, labeled lithofacies Q3o on the larger scale map, has been dated by Szabo (1985). This belt is part of unit Q2, not unit Q3 as reported on the larger scale map, and is designated lithofacies Q2b in figure 2 (lithofacies Q2b here includes lithofacies Q2o of the larger scale map).

Detailed mapping at a scale of 1:24,000 in the immediate Charleston area reveals more stratigraphic complexity than is presented in this report, but it supports the general stratigraphic framework. In particular, detailed mapping suggests that unit Q2 includes a short hiatus and that some pre-Quaternary units can be delineated that would be difficult to show at scales of 1:250,000 or less (Weems and Lemon, 1984a, b).

The location of samples and subsurface logs used in this report are shown in figure 3.

DESCRIPTION OF LITHOSTRATIGRAPHIC UNITS

The six Quaternary lithostratigraphic units in the Charleston area, Q1–Q6, are described in this section in terms of (1) the distribution and lateral and vertical succession of the depositional lithofacies in each lithostratigraphic unit, (2) altitude, (3) texture, (4) sedimentary structures, (5) shape of deposit, and (6) presence or absence of fossils. Primary mineralogy and secondary weathering effects of each lithostratigraphic unit are discussed in the next section.

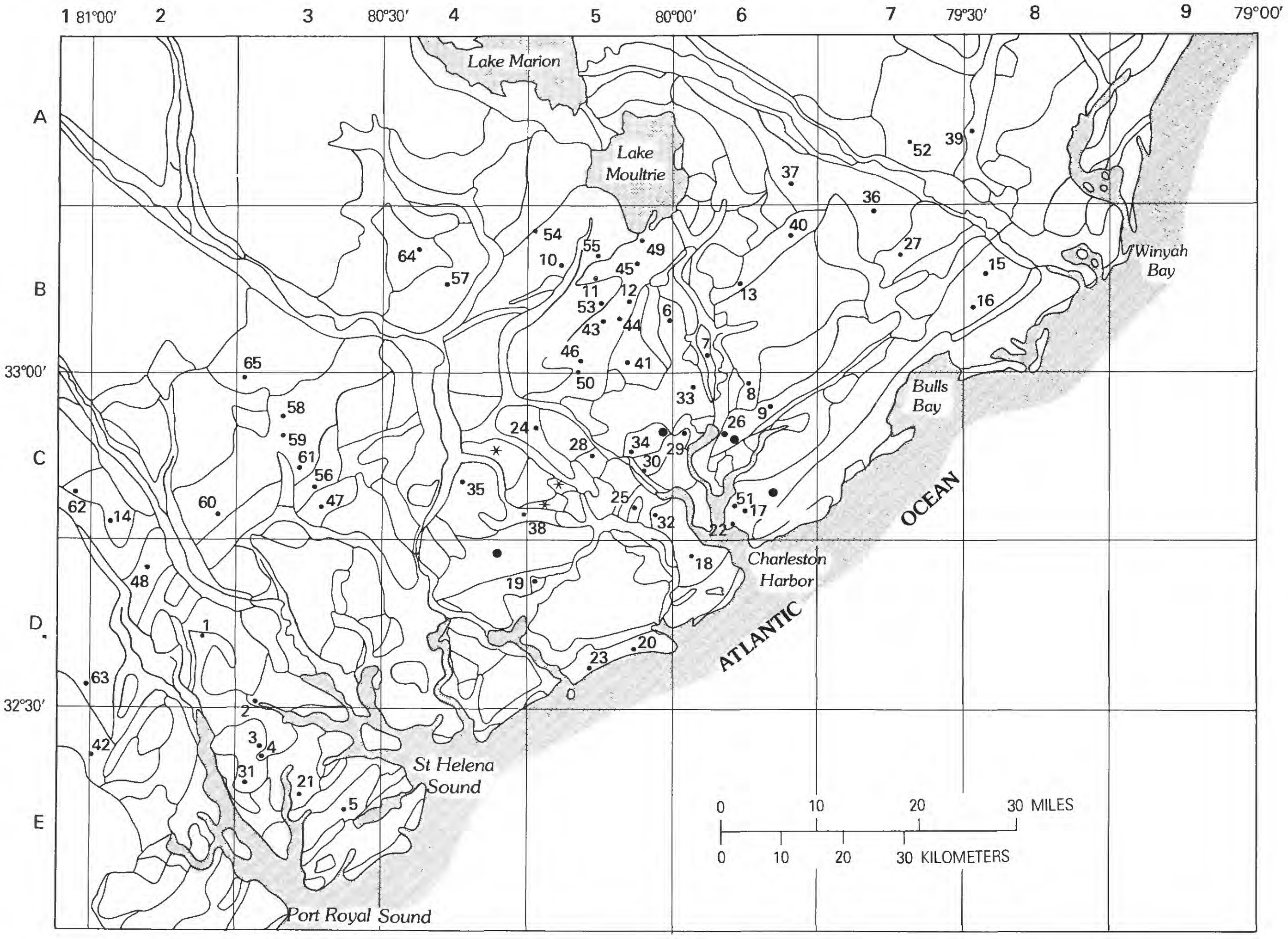
A thin blanket (less than 25 m over most of the area) of unconsolidated Quaternary sediment covers unconsolidated to lithified Tertiary deposits in the Charleston area (fig. 4). The basal contact of this thin cover is an irregular erosional surface (fig. 5) that dips gently toward the sea; this surface was beveled repeatedly by marine erosion and incised by rivers. Quaternary sediment is youngest, freshest, and least eroded at the coast, where Holocene deposits have been accumulating for about 8,000 years.

UNIT Q1

The distribution of depositional lithofacies in lithostratigraphic unit Q1 of Holocene age (McCartan and others, 1984) is similar to that of older Quaternary deposits. The Holocene deposits are used in this study as a model with which older deposits are compared.

Modern rivers debouch on a barred coast that has a tidal fluctuation of 1.5 m. Behind the sandy bars, muddy sand accumulates in tidal flats up to several kilometers wide. The bars are punctuated by tidal inlets that are as deep as 20 m and are associated with sandy ebb and flood deltas. Sand moves southward in the wave-zone longshore drift and describes wide seaward arcs as it moves through the ebb deltas. Mud winnowed out in the surf zone moves into the backbarrier and shelf deposits. Tidal flats and storm-generated washover fans incorporated into beach deposits or on the landward side of the bars are reworked continually by tidal distributary creeks.

If sediment is supplied at the rate necessary to compensate for a slowly rising sea level, deposition equals erosion and no net change occurs in the shape of the shoreline despite accretion. More rapid deposition results in accretion of all facies, and slower deposition leads to net erosion and landward retreat of the shoreline. Plants tend to stabilize dunes, sand flats, and river bars, but a century of stabilization may be eliminated during a single hurricane or flood.



1	D2	14	C2	27	B7	40	B6	53	B5
2	D3	15	B8	28	C5	41	B5	54	B5
3	E3	16	B8	29	C6	42	E2	55	B5
4	E3	17	C6	30	C5	43	B5	56	C3
5	E3	18	D6	31	E3	44	B5	57	B4
6	B5	19	D5	32	C5	45	B5	58	C3
7	B6	20	D5	33	C6	46	B5	59	C3
8	C6	21	E3	34	C5	47	C3	60	C2
9	C6	22	C6	35	C4	48	D2	61	C3
10	B5	23	D5	36	B7	49	B5	62	C1
11	B5	24	C5	37	A6	50	C5	63	D1
12	B5	25	C5	38	C4	51	C6	64	B4
13	B6	26	C6	39	A8	52	A7	65	C3

EXPLANATION

•6 Sample location

∗ Sand blow discussed in text

● Suspected sand blow

1 D2 Locality number and grid coordinates:

FIGURE 3.—Localities of samples and subsurface logs discussed in this report. Contacts on base map are as shown in figure 2. Grid coordinates for each locality are shown in table.

During the Holocene, sediment has accumulated in the coastal zone in a belt as wide as 12 km (north of Bulls Bay and south of St. Helena Sound) (figs. 2, 6). Unit Q1 contains marine and marginal marine deposits and fluvial sand. Incorporated into the belt, which is punctuated by tidal inlets, are a few erosional remnants of deposits of units Q2 and Q3.

Well-sorted sand of depositional lithofacies Q1b occurs mainly in beach and dune, tidal-delta, and shallow-shelf deposits. The elongate sand bodies that are barrier islands are broader on the north, upcurrent end, and backbarrier deposits are widest farthest from inlets.

Beach deposits as high as 1.5 to 2 m above sea level, topped by as much as 3 m of dune sand, compose lithofacies Q1b. Fine- to medium-grained sand containing some mud and shells (lithofacies Q1o) extends offshore in open bays and on the shelf. The base of the deposits is as much as 10 m below sea level at the modern shoreline.

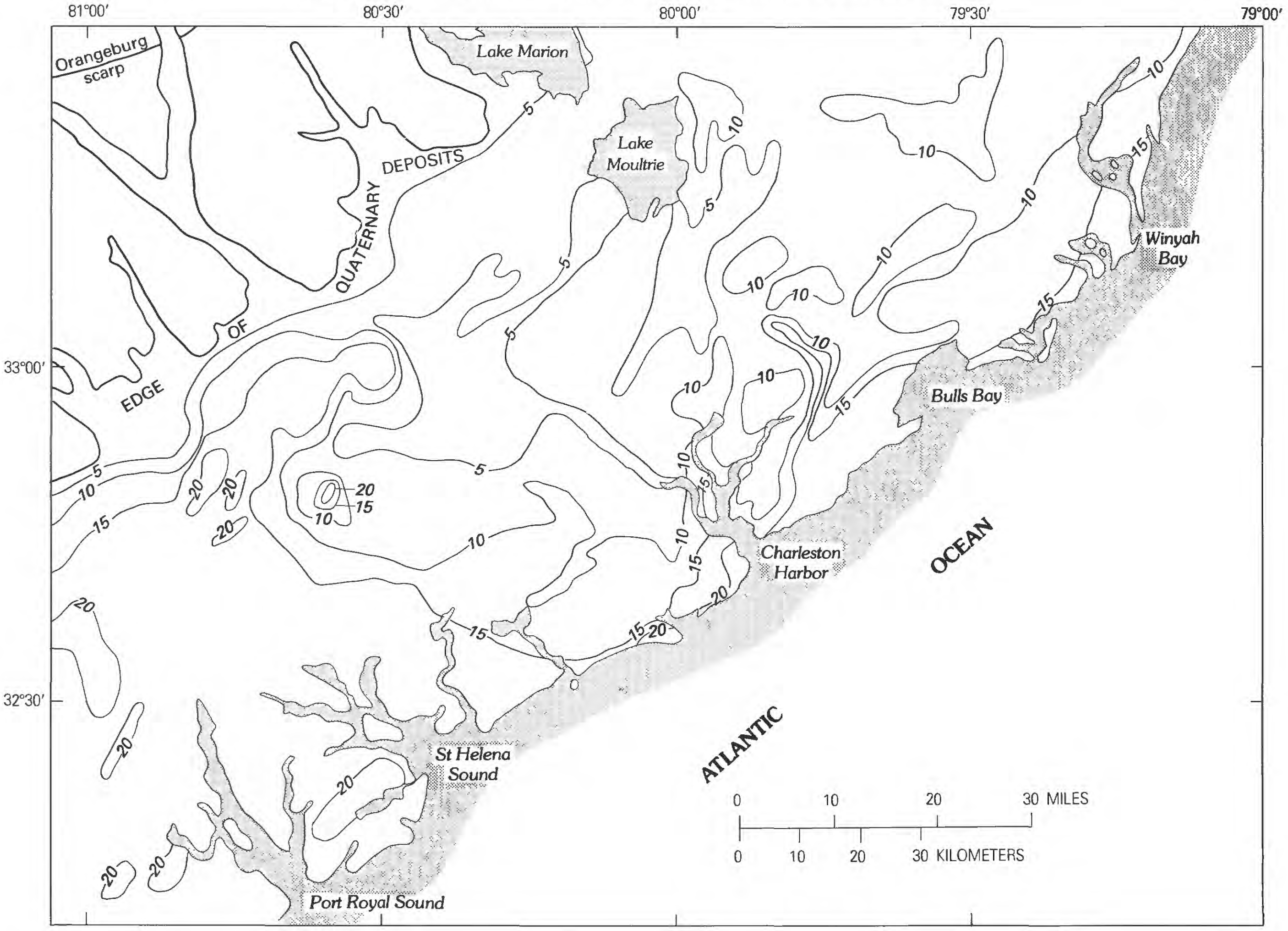


FIGURE 4.—Thickness of Quaternary deposits in the Charleston, S.C., area. Modified from Force (1978b). Contour interval, 5 m.

Sand above sea level is pale orange (10*YR* 7/2) (Goddard and others, 1948); below sea level, it is blue gray (5*BG* 5/1). Sedimentary structures associated with beaches include (1) long, low-angle planar crossbeds delineated by heavy-mineral laminae in sets as much as several centimeters thick; (2) several sizes and shapes of ripples and crossbeds in ridge and runnel systems; and (3) high- to low-angle crossbeds, planar to arcuate, in the dunes (not preserved in older dune deposits).

Muddy sand and sandy mud occupying backbarrier flats (depositional lithofacies Q1l) are found from 10 m below to 2 m above sea level. These deposits are dark gray (*N*4) to grayish brown (5*YR* 4/1) where organic rich. Holocene mud and clay deposits are soft and noncompacted, in contrast with the stiff, dewatered muds and clays of Pleistocene deposits.

Holocene fluvial deposits of lithofacies Q1r are most notable along the Santee, Edisto, and Combahee-Salkehatchie Rivers (fig. 1*A*). The sediment grades from fine gravel at the base of a sequence, through coarse to fine, locally muddy sand in the middle, to overbank mud at the top. Muck, chiefly organic-rich mud, fills cutoff meanders. Point bars in channels display megaripples containing high-angle planar crossbeds and festoon crossbeds in small channels. The southwest part of the map area is covered by 1929 flood deposits of the Savannah River. The color of fluvial deposits varies from the light gray (*N*7) of the sands to brownish black (5*YR* 2/1) in the organic-rich clays.

Swamps (depositional lithofacies Q1s) are ubiquitous in the low-lying area around Charleston. The deposits in most of them consist of a thin layer of clean, fine-grained sand. Locally a thin layer of clay or peat is at the base.

Deposits of unit Q1, unlike those of Pleistocene units, are young enough to be dated by ^{14}C radiometry (table 2) (Weems and others, 1986). Dates were estimated for four types of deposits: marginal marine (mainly backbarrier marsh), fluvial, eolian sand redeposited from old beach ridges, and ovoid depressions.

Dates associated with marginal-marine marshes in backbarrier deposits are younger than 8 ka, similar to ages of other Atlantic Coastal Plain lower estuary depos-

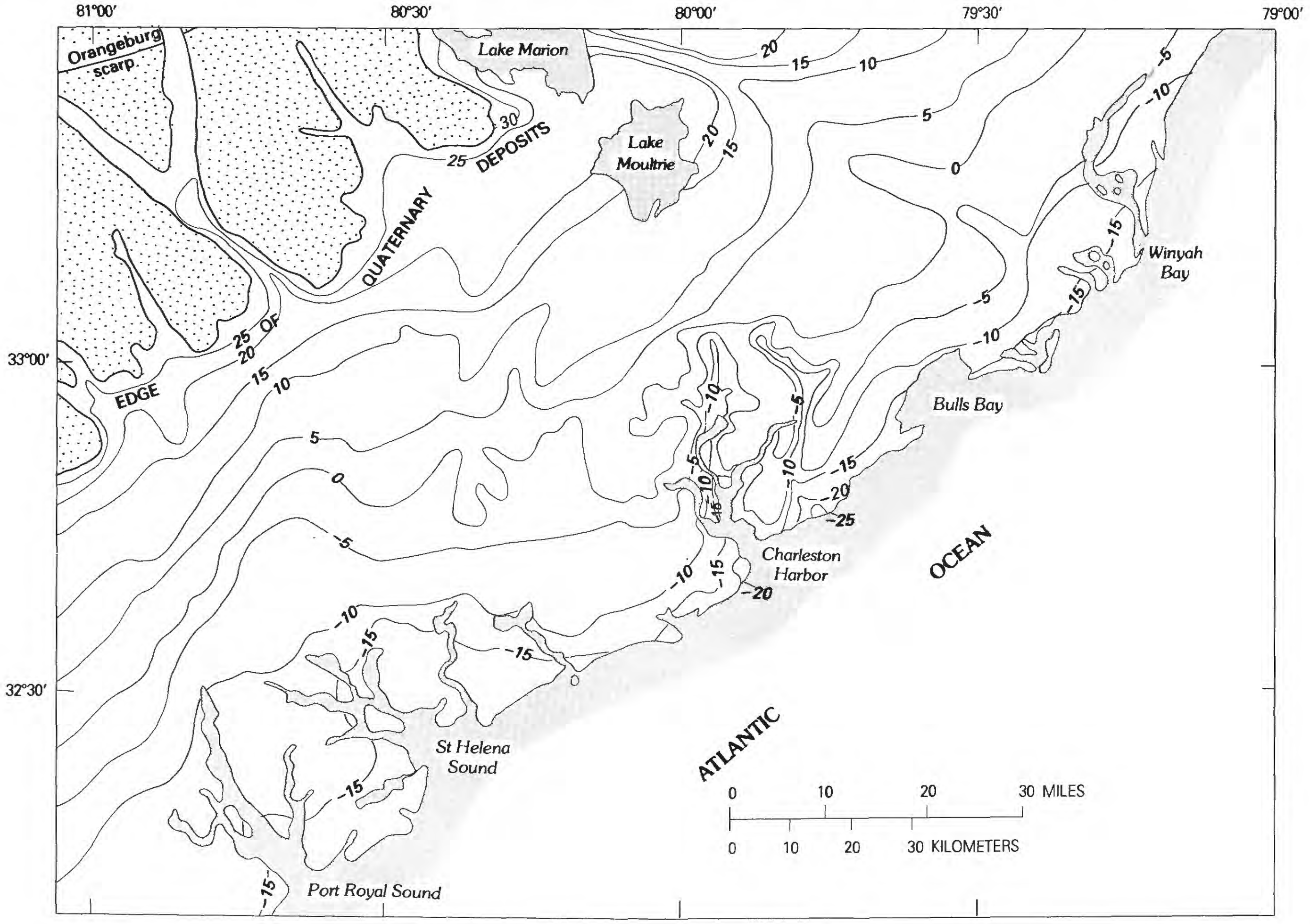


FIGURE 5.—Contour map of the erosional surface underlying Quaternary deposits in the Charleston, S.C., area. Modified from Force (1978a). Contour interval, 5 m.

its (Cinquemani and others, 1982). The absence of 30-ka dates near Charleston contrasts sharply with the numerous 30-ka dates from similar deposits in the Chesapeake Bay area (Owens and Denny, 1979). Unlike the Chesapeake Bay area, mid-Wisconsin (30 ka) marginal-marine deposits are not preserved above modern sea level near Charleston.

Reoccupation of pre-Holocene river valleys during the Holocene is noted elsewhere in this report and is used by Sanders and others (1982) as evidence of structural control of these coastal valleys. The two ^{14}C dates on upright buried cypress stumps in the Santee River valley (>40 ka, 2.09 ka) are further evidence for the antiquity of the valley and the sporadic deposition of terraces.

Dates associated with stumps in thin eolian sand sheets suggest that sand derived from Holocene and Pleistocene beach ridges has moved over much of the surface several times during the Holocene. Two and possibly three layers of buried trees, preserved as upright stumps, have been found some places in the Charleston area (fig. 7). The sand sheets are thin, patchy, and difficult to delineate, except in plowed fields or sand pits; therefore, they are not shown in figure 2. Rapid invasion of a forest by sand implies a rather dry climate with little understory—unlike the wet climate and dense vegetation found today in the South Carolina Coastal Plain—for a period of at least several years.

UNIT Q2

The youngest and best preserved Pleistocene deposits are contained in a northeast-trending belt immediately landward of Holocene coastal deposits (figs. 2, 6, 8). The belt widens from about 10 km at the Santee River to more than 45 km at St. Helena Sound. The longest continuous sand body in the map area is the Mount Pleasant barrier, over 60 km long, which extends from Charleston Harbor to the Santee River (fig. 2). Unit Q2 consists of generally fossiliferous, sandy marine deposits mostly between surface altitudes of 11 m and 2 m and fluvial sand at altitudes higher than 3 m. Unit Q2 is most

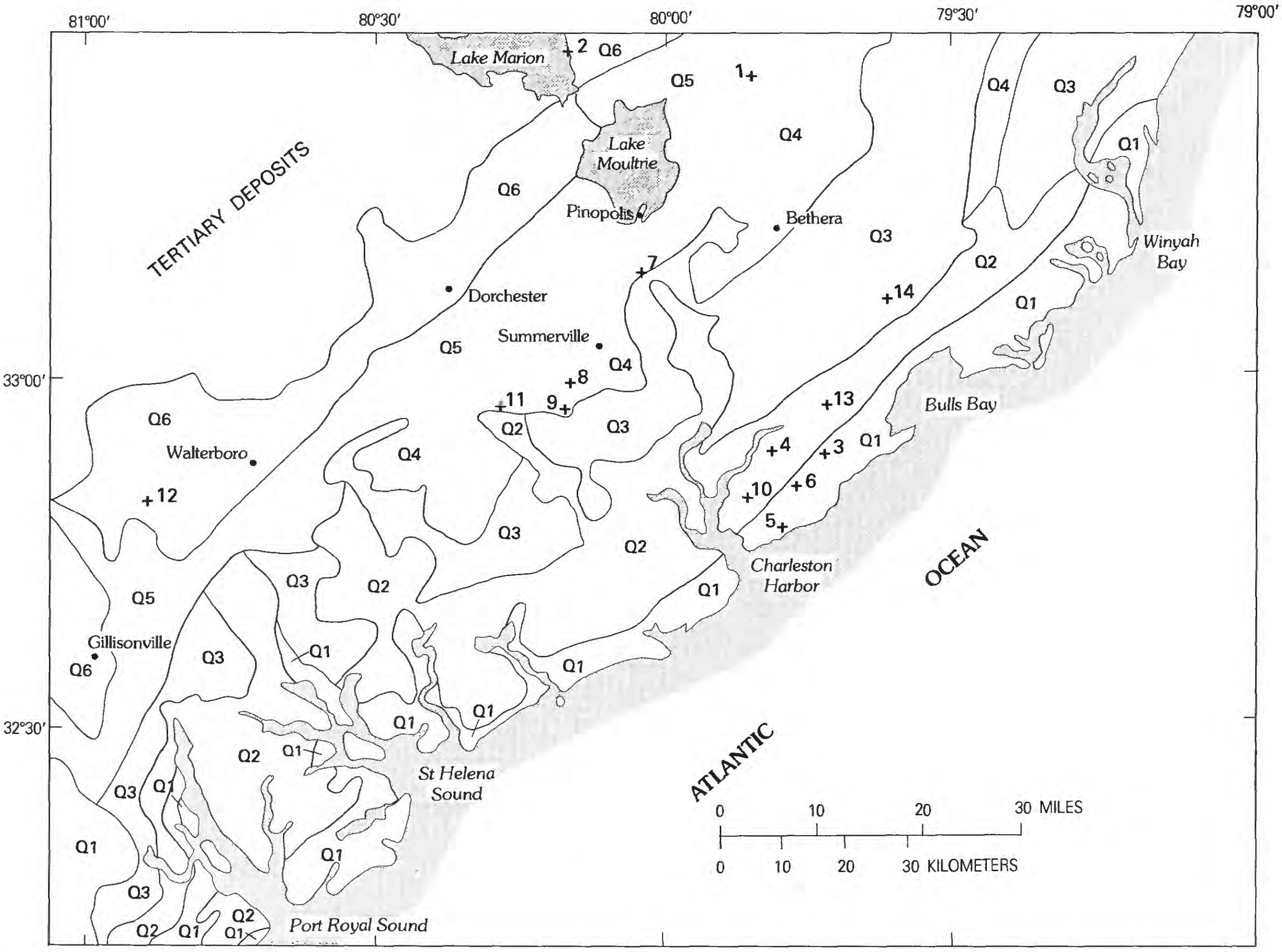


FIGURE 6.—Time-stratigraphic map of generalized Quaternary geologic units in the Charleston, S.C., area (simplified from fig. 2). Belts of marine and marginal marine deposits of units Q2–Q6 are emphasized. Crosses indicate ^{14}C sample localities (see table 2).

disrupted by Holocene erosion and deposition in the vicinity of St. Helena Sound.

Four depositional lithofacies constitute unit Q2 (figs. 2, 8): well-sorted, fine- to medium-grained quartz sand containing some shells (lithofacies Q2b, deposits from beach and associated environments); shelly, gray, fine- to medium-grained quartz sand, locally having a mud matrix and clay layers (lithofacies Q2o, shelf deposits, fig. 8; in fig. 2, Q2o is included in Q2b); muddy quartz sand with clay, shell, and sand layers (lithofacies Q2l, backbarrier deposits); and gravelly, coarse quartz sand (lithofacies Q2r, fluvial deposits).

The sand of lithofacies Q2b is found as much as 11 m above sea level and as low as 12 m below sea level. The top 2 m of sand is massive and is commonly humate rich. In some places, this upper material of probable eolian origin may be about the same age as deposits of unit Q2, but elsewhere it encloses trees in life position that are younger than 2 ka (table 2, sample locs. 10 and 13).

Lower in lithofacies Q2b, planar laminations outlined by heavy minerals are common up to 2 m from the surface. Burrows up to 2 cm across interrupt the heavy-mineral laminae in some places (fig. 9), and some burrows are filled with small shells. Planar laminae grade laterally into festoon crossbed sets a few centimeters thick. Shells occur individually and concentrated in lenses within the beach deposits (Wojtal and Tye, 1980). The top part of uneroded deposits of lithofacies Q2b is locally pale grayish orange (10*YR* 7/3), but the bulk of the sand is yellowish gray (5*Y* 8/1) above the water table and gray (*N* 5) below.

Lithofacies Q2l sediment occurs in flat, irregular patches up to 8 m above sea level and down to 10 m below sea level. Whereas some of these patches, such as along the Wando River (fig. 1*A*), are parallel to unit Q2 barriers, many are elongate toward the northwest and aligned with Holocene rivers. This alignment indicates that Holocene rivers occupy Pleistocene tidal channels.

TABLE 2.—^{14}C *dates from Holocene deposits in the Charleston, S.C., area*

[Data from Meyer Rubin, written commun., 1975–82]

Type of deposit	Sample locality (see fig. 6)	USGS ^{14}C lab. no.	Quadrangle[1]	Lat (°N.)	Long (°W.)	^{14}C date	Material
Fluvial and swamp	1	W–4593	Santee	33°24′00″	79°52′00″	2,090±70	Wood in sand.[2]
	2	W–4157	Eadytown	33°25′30″	80°08′	>40,000	Wood in sand.[2]
Backbarrier	3	W–4590	Sewee Bay	32°55′30″	79°43′30″	430±50	Shell in mud.
	4	W–4591	Cainhoy	32°55′45″	79°48′	940±60	Wood in sandy mud.[2]
	5	W–5039	Fort Moultrie	32°47′30″	79°47′30″	950±100	Wood in sandy mud.[2]
	6	W–5038	Fort Moultrie	32°51′	79°46′	7,860±80	Peat.
Eolian sand sheet	7	W–4219	Moncks Corner	33°09′15″	80°03′30″	210±70	Wood in sand.[2]
	8	W–4217	Stallsville	32°59′30″	80°11′30″	317±50	Wood in sand.[2]
	9	W–4461	Stallsville	32°58′	80°12′	670±70	Wood in sand.[2]
	10	W–3963	Fort Moultrie	32°49′30″	79°49′30″	900±200	Wood in sand.[2]
	11	W–4220	Stallsville	32°58′30″	80°14′30″	1,560±70	Wood in sand.[2]
	12	W–4457	Cummings	33°55′	81°00′	1,840±70	Charcoal in sand.
	13	W–3817	Sewee Bay	32°55′	79°43′30″	1,960±200	Wood in sand.[2]
Ovoid depressions	14	W–5022	Awendaw	33°06′	79°36′	2,900±60	Peat.

[1] The Cummings quadrangle is a 15-minute quadrangle; remainder are 7½-minute quadrangles.

[2] Upright buried stumps.

Muddy, fine-grained quartz sand is the usual texture, but the unit also contains common layers of clay, shell, and well-sorted fine-grained quartz sand. Burrows are common, and crossbeds are almost absent. Weathered muddy sand of lithofacies Q2l, at the top of unstripped sections, is dark yellowish orange (10*YR* 6/6). This color changes downward to grayish orange (10*YR* 7/4), and below the water table, it changes to gray (*N*5 to *N*4).

Lithofacies Q2r sediment is preserved along the Santee, Stono, and Broad Rivers (fig. 1*A*). The limited extent of the fluvial deposits of lithofacies Q2r, as compared with that of older river deposits, may be due to erosion by Holocene rivers. Poorly sorted, gravelly, coarse quartz sand and muddy, medium-grained quartz sand containing pebbles make up the bulk of lithofacies Q2r sediment. The deposits are commonly under modern forest or swampy vegetation, and weathering characteristics are not well known. Unweathered lithofacies Q2r deposits are gray (*N*4).

◀ FIGURE 7.—Buried Holocene trees in a sand pit 8 km south of Pinopolis, S.C. (fig. 1*A*). Below the modern vegetation and above the interbedded sand and clay of unit Q5 are two sand sheets containing upright, rooted stumps. Wood from a trunk in the upper sheet yielded a ^{14}C age of about 210 years before present (Meyer Rubin, written commun., 1979, USGS laboratory no. W–4219). Outcrop is about 4 m high.

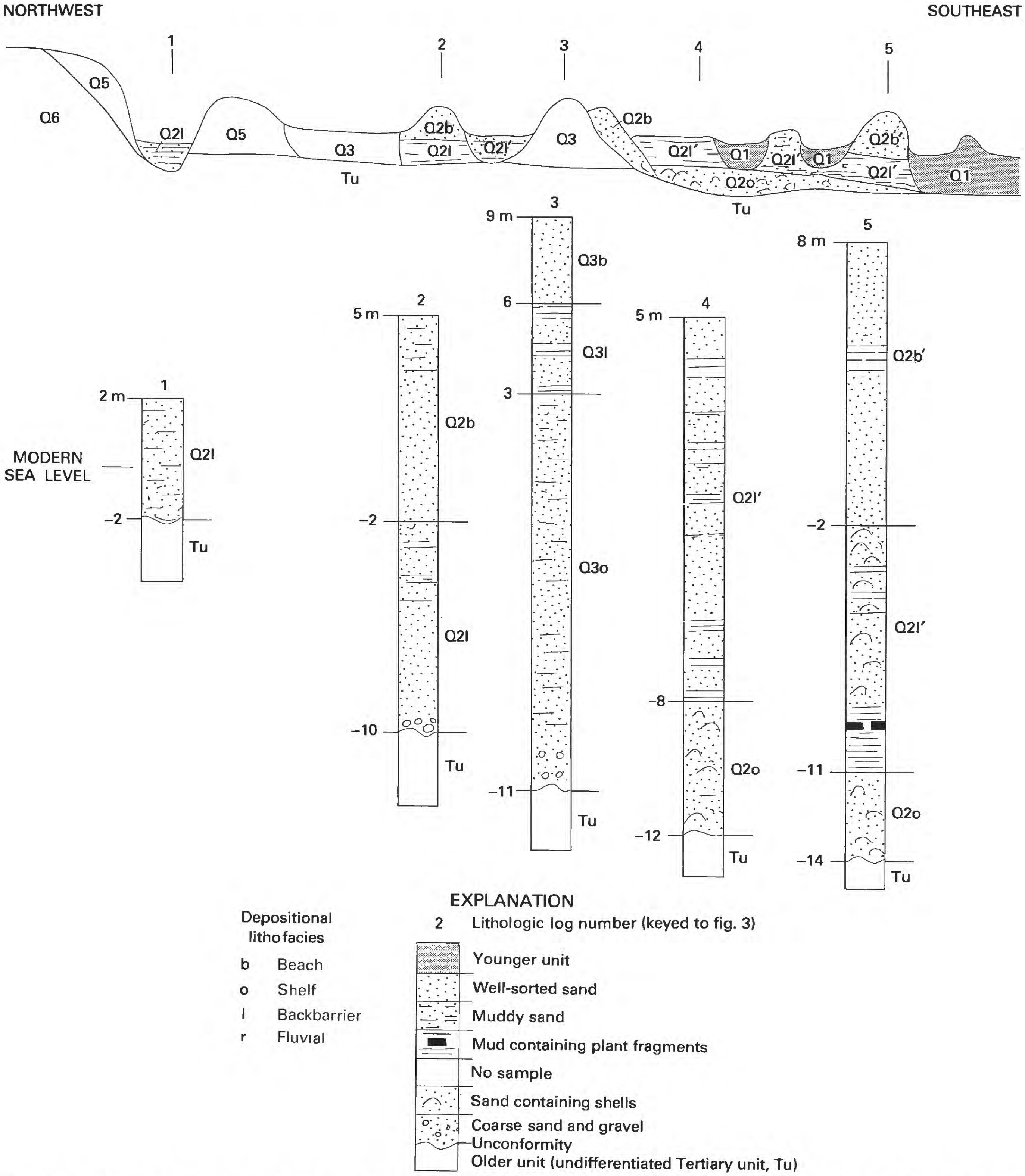


FIGURE 8.—Schematic cross section and graphic lithologic logs of auger-hole and corehole samples showing Quaternary unit Q2 lithofacies in the Charleston, S.C., area (locations of logs shown in fig. 3). The youngest shoreline deposits of unit Q3 preserved in the area are at the same altitude as the oldest deposits of lithofacies Q2l and Q2b. In the broad sounds in the southwest part of the map area, tidal deltas of lithofacies Q2b accumulated landward of unit Q3 deposits. Seaward of unit Q3, early unit Q2 beach and shelf deposits are overlain by later deposits of the same unit that are as much as 30,000 years younger (Q2b′, Q2l′) (coral date spread of 120 to 90 ka; McCartan and others, 1980).

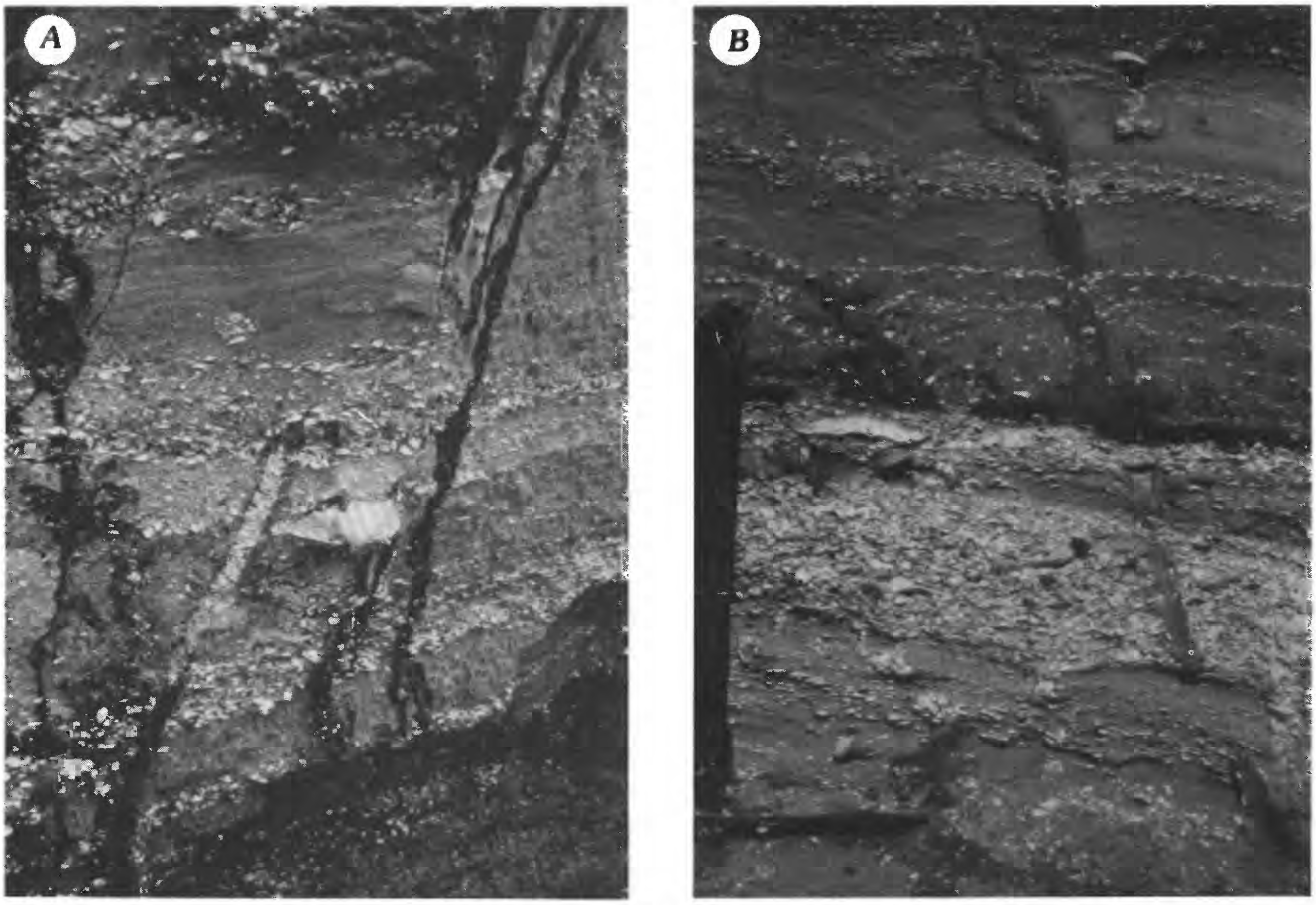


FIGURE 9.—*Ophiomorpha nodosa* burrows in shelly sand of unit Q2. Locality is the Venning pit at Mount Pleasant east of Charleston, S.C. *A*, Large *Dinocardium* shell is about 10 cm across. *B*, Several types of burrows appear in upper part of photograph; shovel handle is 40 cm long.

The age of unit Q2 is judged to be late Pleistocene on the basis of mollusk and ostracode faunas (Ward and Blackwelder, this volume; Cronin, this volume; Lyon, this volume; see also Cronin, 1981) and normal magnetic polarity (Liddicoat and others, 1981). A late Pleistocene age is supported also by several corals from unit Q2 that have uranium-disequilibrium-series dates of about 90 ka and some as old as 120 ka (McCartan and others, 1980; Szabo, 1985), intermediate amino-acid epimerization and racemization ratios from *Mercenaria* (McCartan and others, 1982), and the relatively fresh minerals above the water table.

UNIT Q3

A third northeast-trending belt of Quaternary sediment, unit Q3, extends from the coast just north of Winyah Bay to the southwest corner of the mapped area (figs. 2, 6, 10). Unit Q3 locally contains fossiliferous marine and marginal marine deposits between surface altitudes of 16 m and 5 m and unfossiliferous fluvial sand at altitudes above 5 m. The outcrop belt is typically 25 km wide and is more continuous in the north than the south, where it is more extensively embayed and overprinted by younger units. Deposits of unit Q3 unconformably overlie fossiliferous pre-Quaternary sediment in most places (fig. 10), but remnants of older Pleistocene units occupy the lower part of a few channels beneath unit Q3 sediments.

Four depositional lithofacies are associated with unit Q3 (figs. 2, 10): well-sorted, fine- to medium-grained quartz sand (lithofacies Q3b, beach and associated environments); well-sorted to silty, fine- to medium-grained quartz sand containing sparse mud lenses and shell fragments concentrated in layers mainly near the base (lithofacies Q3o, shelf; shown separately in fig. 10, but combined with lithofacies Q3b in fig. 2); muddy, fine-grained quartz sand (lithofacies Q3l, backbarrier); and muddy, medium-grained quartz sand to gravelly, coarse-grained sand (lithofacies Q3r, fluvial).

Sediment of lithofacies Q3b is found as high as 16 m above sea level and as low as 5 m below sea level, and its

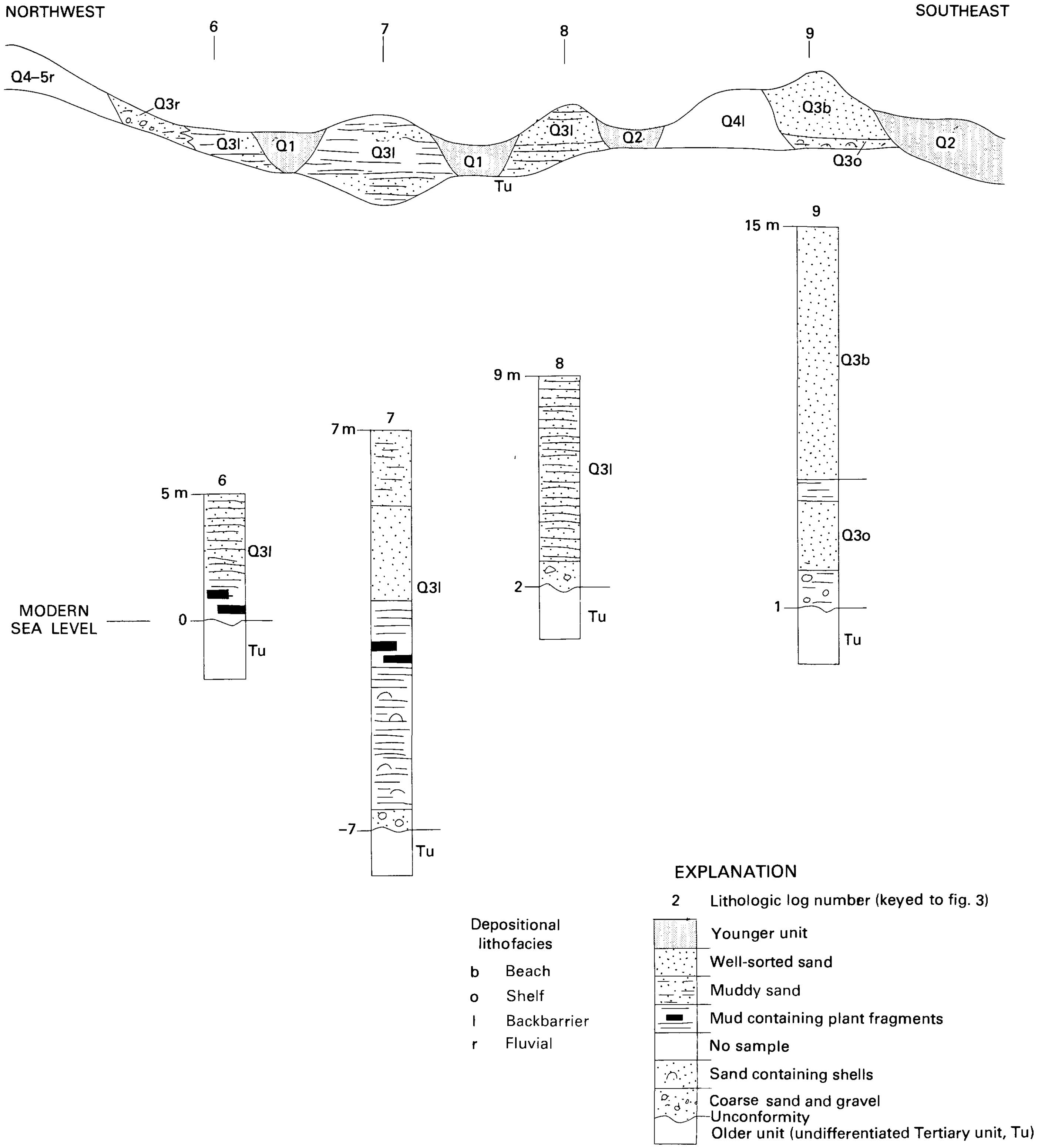


FIGURE 10.—Schematic cross section and graphic lithologic logs showing unit Q3 lithofacies in the Charleston, S.C., area (see fig. 3 for locations). Beach deposits of unit Q3 accumulated just seaward of unit Q4 sediment, in some places remobilizing all of unit Q4 beach (Q4b) and some backbarrier (Q4l) deposits. Unit Q3 backbarrier deposits (Q3l) have been embayed and dissected by deposits of units Q2 and Q1, particularly southwest of Charleston, S.C.

outcrop belt varies between 3 and 12 km wide. Lithofacies Q3b deposits consist mainly of one or more beach and dune ridges. For example, between the Stono and Edisto Rivers is a large sand plain that has several ridges trending east-northeast. This deposit consists of coalesced beach ridges that were supplied with sediment mainly by the Edisto River. Detailed mapping north of the Santee River suggests that lithofacies Q3b may be divided by Winyah Bay. However, the seaward part may belong with unit Q2 instead.

Within lithofacies Q3b, planar laminations outlined by heavy minerals, indicative of a beach environment, are evident below the water table in some places but are rusted out above the water table. Shells are abundant locally at the base of lithofacies Q3b, and silt is abundant especially in the lower part of some sections. Shells and fine matrix are characteristic of the shallow-shelf environment (McCartan and others, 1984), which is designated lithofacies Q3o in figure 10, but is combined with lithofacies Q3b in figure 2. Burrows are common in some places, and massive, well-sorted sand containing disseminated heavy minerals is interpreted as thoroughly bioturbated beach, open-bay, or shallow-shelf sand. Colors range from light brown (5*YR* 5/6) at the surface to very pale orange (10*YR* 8/2) below.

Lithofacies Q3l deposits occur between 11 m above sea level and 5 m below sea level. They occur in flat, irregular patches typically 3 to 10 km across showing marked internal dissection. Muddy, fine-grained quartz sand and more than 15 percent clay is the usual texture, but lenses of well-sorted, fine- to medium-grained quartz sand and mud without sand are also present. Burrows are common. The unit weathers to light brown (5*YR* 5/6) at the surface but is gray (*N*5) in fresher material below.

Deposits of lithofacies Q3r are present in a large patch east of the Edisto River, in an old channel of the Cooper River (fig. 1*A*) that lies west of the present course, and along the south bank of the Santee River. Lithofacies Q3r fluvial sediment is generally poorly sorted and varies from muddy, medium-grained quartz sand containing pebbles to gravelly, coarse-grained quartz sand. The deposits are typically light brown (5*YR* 5/6) at the surface and gray (*N*4) below.

The age of unit Q3 sediment is judged to be late Pleistocene on the basis of the clams *Lunarca ovalis* and *Cunearca brasiliana*, other mollusk and ostracode taxa (Ward and Blackwelder, this volume; Cronin, this volume; see also Cronin, 1981), and normal magnetic polarity (Liddicoat and others, 1981). A late Pleistocene age is supported also by two corals from unit Q3 that have uranium-disequilibrium-series dates of about 200 ka (McCartan and others, 1982; Szabo, 1985), amino-acid ratios from *Mercenaria* (McCartan and others, 1982), and the limited extent of weathering. The faunas and other evidence support correlation with upper Pleistocene units, such as the Socastee Formation at Myrtle Beach.

UNIT Q4

The town of Bethera, S.C. (fig. 1*A*), is on the largest barrier of unit Q4, from which lithofacies Q4l backbarrier material extends northwestward. Seaward of Bethera, a patch of lithofacies Q4l remains, although its associated barrier deposits have been eroded. In addition, a remnant of a unit Q4 barrier that trends north is surrounded by unit Q3 deposits on the north edge of the map (figs. 2, 6, 11). Unit Q4 consists of marine and marginal marine deposits between surface altitudes of 19 m and 15 m; the highest sea level for deposits of unit Q4 was about 10 m below deposits of the unit Q5 high stand. Fluvial deposits of unit Q4 could not be separated from those of unit Q5, and so they were combined in the unit designated Q4–5r (fig. 2).

Lithofacies Q4b sand, found up to 19 m in altitude, is coarser and less muddy than lithofacies Q5b sand, and it forms a single, large, low sand body. These characteristics suggest that the younger beach sand was deposited closer to the mouth of the old Santee River drainage at a slower rate that allowed winnowing of mud. Sand of lithofacies Q4b weathers from very pale orange (10*YR* 8/2) to grayish orange (10*YR* 7/4).

Sediment of lithofacies Q4l is similar in texture and weathering characteristics to the sediment of lithofacies Q5l, but it occurs in the subsurface below 15 m altitude and is restricted to the area between the Cooper and Santee Rivers. Northwest of the Bethera barrier, lithofacies Q4l sediment is very gritty. Lithofacies Q4l muddy, medium-grained sand weathers to light brown (5*YR* 5/6).

Unit Q4 is correlated with the Canepatch Formation at Myrtle Beach, S.C., on the basis of mollusk and ostracode faunas (Ward and Blackwelder, this volume; Cronin, this volume; see also Cronin, 1981), weathering studies, and geomorphology. The Canepatch has yielded several corals with uranium-disequilibrium-series dates of about 450 ka (Cronin and others, 1981; McCartan and others, 1982; Szabo, 1985).

UNIT Q5

A fourth northeast-trending belt of Quaternary sediment, unit Q5, consists of sparsely fossiliferous, sandy marine deposits between surface altitudes of 28 m and 23 m (figs. 2, 6, 11). The outcrop pattern is about 5 km wide in the south and as much as 50 km wide adjacent to the Santee River (fig. 2). The largest patch of lithofacies Q5b sand (to the east) and lithofacies Q5l muddy sand (to the west) is the Summerville-Pinopolis barrier system

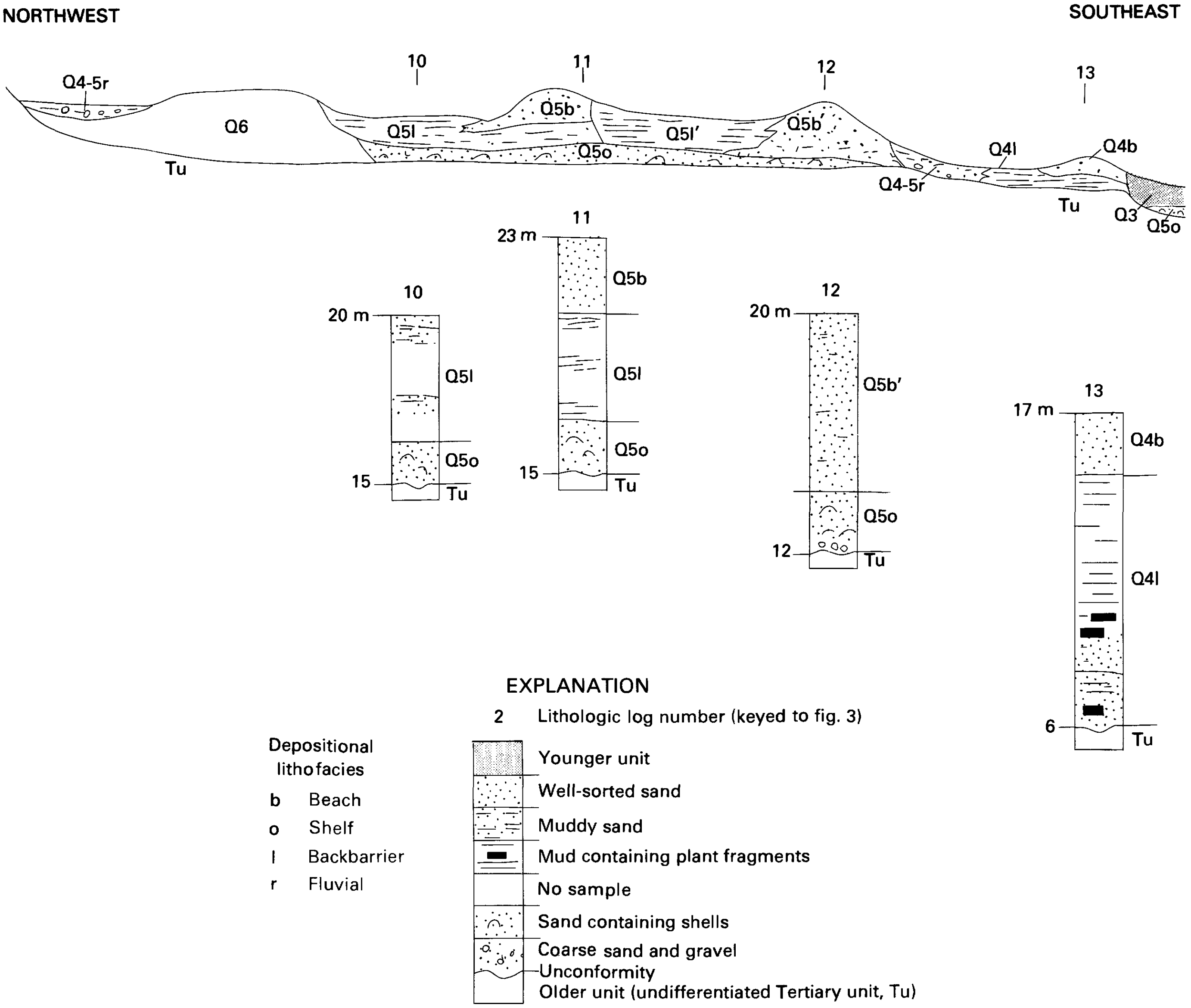


FIGURE 11.—Schematic cross section and graphic lithologic logs in the Charleston, S.C., area (see fig. 3 for locations) showing the lithofacies of units Q5 and Q4, which accumulated more than 730 ka and about 450 ka, respectively. In the area just west of section 12, clean sand remobilized from earliest Q5b deposits prograded seaward to form lithofacies Q5b′ and accumulated at the same time as the muddy sand of lithofacies Q5l′. Unit Q4 accumulated at least 300,000 years after unit Q5 deposits. River deposits from lithostratigraphic units Q5 and Q4 are combined in lithofacies Q4–5r.

between Lake Moultrie and the Edisto River. North of the Santee River, lithofacies Q5l backbarrier deposits remain, although beach sand in lithofacies Q5b has been eroded and has been replaced by younger material. South of the Edisto River, beach deposits of lithofacies Q5b lie adjacent to the beach deposits of unit Q6 with much less associated backbarrier material than farther north. Fluvial deposits associated geomorphically with unit Q5 marine deposits are prevalent along the south shores of Lakes Moultrie and Marion and along the Edisto and Salkehatchie Rivers but occur in the other major drainages as well. Fluvial deposits associated with deposits of units Q5 and Q4 could not be separated; therefore, the designation lithofacies Q4–5r is applied to them.

Four depositional lithofacies are recognized in this unit (figs. 2, 11): well-sorted, fine- to medium-grained quartz sand (lithofacies Q5b, beach and associated environments); muddy, fine- to medium-grained sand containing sparse to abundant shells and interbedded clay and sand (lithofacies Q5o, shelf; McCartan and others, 1984; shown separately in fig. 11, but combined with lithofacies Q5b in fig. 2); muddy, fine-grained quartz sand (lithofacies Q5l, backbarrier); and well-sorted to muddy, medium- to coarse-grained quartz sand (lithofacies Q4–5r, fluvial deposits).

Lithofacies Q5b is found between 28 m and 15 m above sea level in a series of sand ridges that form an outcrop belt about 2 to 20 km wide. Sand weathers from very pale orange (10*YR* 8/2) to grayish orange (10*YR* 7/4), and secondary clay lamellae are present in some outcrops. A large sand pit 8 km south of Pinopolis on U.S. route 17A exposes the beach and shelf deposits (both included in lithofacies Q5b) of the Summerville-Pinopolis barrier system. The upper part of lithofacies Q5b in the pit consists of medium-grained quartz sand in planar beds sloping eastward, which grades eastward and downward to short-wavelength festoon crossbeds, below which clay is interbedded with the sand. A few *Ophiomorpha* burrows were found in the interbedded clay and sand at this locality, but even more of these burrows were found in a ditch in the Sangaree housing development north of Summerville on U.S. route 17A.

Muddy quartz sand constitutes the bulk of the large recurved spit that prograded from north to south between Lake Moultrie and Summerville and is the barrier of the Summerville-Pinopolis system. Sediment from the Santee River drainage apparently was supplied faster than it could be winnowed by the waves that constructed the barrier; the sand of the lower part of lithofacies Q5b is much more poorly sorted than the sand in beach deposits older or younger than unit Q5b. Clean sand constitutes the top 2–3 m of this barrier and suggests a slowing of deposition and winnowing by wave action during the latter stages of deposition. Sand in deposits of lithofacies Q5b south of the Edisto River is better sorted than that north of the river and reflects the more thorough winnowing of Edisto River-derived material and the addition of sand reworked from adjacent lithofacies Q6b deposits.

Relatively unfossiliferous shelf deposits of lithofacies Q5o occur at the surface seaward of lithofacies Q5b (McCartan and others, 1984) and are combined with lithofacies Q5b in figure 2. However, in the subsurface, a shell-rich bed of lithofacies Q5o forms a thin, discontinuous sheet between about 11 m and 16 m (noted previously by Colquhoun and others, 1968) beneath the large recurved spit system extending from Lake Moultrie to Summerville. The shelly material of lithofacies Q5o also occupies the deeper parts of some channels under units Q3 and Q2. The lithology is typically coarse- to medium-grained, shelly quartz sand containing variable amounts of mud, quartz and phosphate granules, and blebs of waxy, green reworked clay. Fossils suggest two environments—shelf and restricted bay or backbarrier. In some drill holes, the fossils are mixed in one bed at the base of the section; in other holes, beds containing fossils from the restricted environments are overlain by beds containing open-marine fossils. The mixed or sequential assemblages and the upward-fining texture suggest deposition during transgression, possibly during a rise in sea level. The basal part of the shell bed contains fossils reworked from deposits of units Q6 and Tu (fig. 2).

Lithofacies Q5l deposits occupy fairly flat, irregular patches at altitudes below 23 m that are typically between 5 and 15 km across. Lithofacies Q5l is most extensive west of the Summerville-Pinopolis barrier system and north of the Santee River. This depositional lithofacies includes sandy mud and muddy, fine-grained sand containing more than 15 percent clay, and it has clean, fine-grained sand or clay lenses locally. Lithofacies Q5l interfingers with lithofacies Q5b and unconformably overlies Tertiary deposits. Lithofacies Q5l beneath the water table is generally a medium gray (*N*5); it weathers to light brown (5*YR* 5/6) and moderate reddish brown (10*R* 4/6) above the water table, and the color is most intense on steeper slopes.

Lithofacies Q4–5r sediment is clean to muddy, medium- to coarse-grained quartz sand and sparse gravel lenses distributed in elongate patches generally along the modern rivers. Northeast of Summerville, the deposit of lithofacies Q4–5r sediment adjacent to lithofacies Q5b is larger than would be suggested by the present drainage area. The Santee River may have contributed sediment to this area through a channel that is now filled with younger deposits. Fresh sediment of lithofacies Q4–5r is gray (*N*5) or pale orange (10*YR* 8/2), but it weathers to grayish orange (10*YR* 7/4) or dark yellowish orange (10*YR* 6/6).

South of the Santee River, the seaward limit of unit Q5 deposits is described by a broad arc that trends east to the north of the Edisto River and northeast to the south of the Edisto. The southern part of the outcrop belt is much narrower than the northern part. The narrowness suggests that the major sediment source was the Santee River and that more erosion took place toward the south in the relatively starved part of the Charleston depositional area.

Less sediment was deposited from the Santee River northward, apparently because longshore drift has been toward the south throughout the Quaternary. Deposits of lithofacies Q5b or Q4b seaward of lithofacies Q5l were removed during deposition of unit Q3 sediment; also removed were deposits of unit Q5 and possibly unit Q4 south of the Edisto River.

Unit Q5 deposits are magnetically reversed (Liddicoat and others, 1981), which indicates an age older than 730 ka. On the basis of weathering trends and fossils (Weems and McCartan, this volume), these deposits, however, are judged to be significantly younger than unit Q6 deposits.

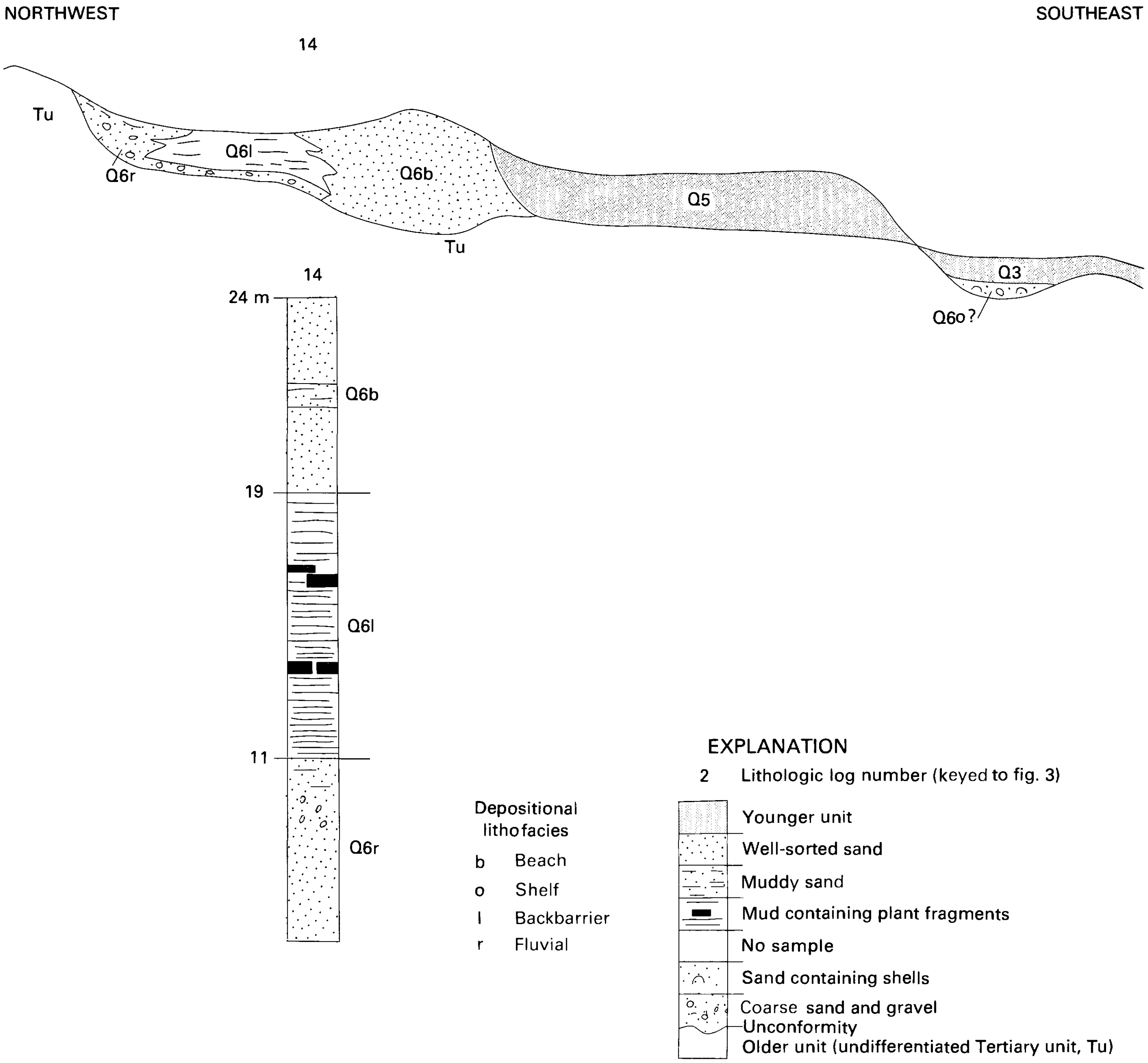


FIGURE 12.—Schematic cross section and graphic lithologic log (see fig. 3 for location) showing the lithofacies of the oldest Pleistocene deposits, unit Q6, in the Charleston, S.C., area.

UNIT Q6

The oldest Quaternary unit in the Charleston area, unit Q6 (figs. 2, 6, 12), is a northeast-trending belt of unfossiliferous, sandy marine deposits mostly between surface altitudes of about 27 m and 32 m and fluvial sand above about 27 m. The towns of Dorchester, Walterboro, and Gillisonville are located on the clean sand ridge of lithofacies Q6b, and the ridge is sharply truncated toward the northeast by the Santee River between Lakes Marion and Moultrie (fig. 1*A*).

Four depositional lithofacies are recognized in unit Q6 (figs. 2, 12): well-sorted, fine- to medium-grained sand without shells (lithofacies Q6b, beach and associated environments) and with shells (lithofacies Q6o, shelf deposits); muddy, fine- to medium-grained sand (lithofacies Q6l, backbarrier); and poorly sorted, muddy gravel to gravelly sand (lithofacies Q6r, fluvial).

Lithofacies Q6b deposits are as high as 32 m, are as low as 16 m, and vary in width between 4 km and 18 km. Primary depositional features are rare, other than the general shape of the deposit, and presumably were destroyed by postdepositional processes. Clay lamellae that accumulated during soil formation constitute less than 1 percent of the sediment. Colors range from very pale orange (10*YR* 8/2) at the surface to yellowish orange (10*YR* 7/6) at the base of loose sand. Where disseminated clay is most abundant (up to 10 percent), the sand is cemented, apparently by iron and aluminum oxides that formed postdepositionally. Colors there range from moderate reddish orange (10*YR* 4/6) at the surface to medium gray (*N*4) at depth. Minor, thin clay beds occur in the lower half of the sand body in some places, and planar zones enriched with iron oxide occur in the upper half of the body; the planar zones suggest weathered heavy-mineral laminae deposited in a beach face. Few burrows have been observed in lithofacies Q6b. The textural pattern, the overall shape of the body, and the bed forms suggest a shallow-shelf, open-bay, or backbarrier environment of deposition (interbedded clay and sand) succeeded by beach and possibly dune conditions.

Within the lithofacies Q6o shelf sediments, common colors are medium gray (*N*5) to greenish gray (5*GY* 5/1). In spoil piles, shells turn chalky within a few days and begin to break down into small fragments within a few weeks. The noncalcareous material becomes light gray (*N*7) during weathering.

Backbarrier deposits of lithofacies Q6l occur between 26 m and 9 m in irregular patches with fairly flat upper surfaces. The deposits are typically 8 km across. This facies includes interbedded silty clay; muddy, fine- to medium-grained quartz sand; and minor, clean, fine-grained sand, as well as massive muddy sand containing coarser lenses in some areas. Most samples contain more than 15 percent clay. Burrows are abundant in some places. Colors range from dark reddish brown (10*R* 3/6), red and white (*N*8), or pale pinkish gray (5*YR* 8/1) at the surface to light or medium gray (*N*7 to *N*6) at depth.

Lithofacies Q6r sediment is present in large patches in a belt just northwest of lithofacies Q6b and Q6l. These fluvial deposits are superimposed on and incised into sediment of early Pliocene and older ages. The generally poorly sorted, muddy, coarse-grained quartz sand is moderate reddish brown (10*R* 4/6) at the surface and medium gray (*N*5) at depth. At a few places, lenses of clean, coarse-grained quartz sand are yellowish orange (10*YR* 7/6). The present distribution of lithofacies Q6r deposits suggests that the Salkehatchie and Edisto Rivers contributed some sediment to the coast in unit Q6 time, but the Santee River, flowing through the Four Hole Swamp drainage about 20 km southwest of Lake Marion, delivered the largest amount of sediment to unit Q6 beaches.

Unlike younger units, depositional lithofacies in unit Q6 are distributed in a relatively simple pattern (figs. 2, 6, 12). This pattern strongly suggests that all of unit Q6 was deposited while the sea was at about 26 m altitude (fig. 5). Landward erosion during unit Q5 deposition was extensive and removed most, if not all, of the seaward extension of unit Q6 deposits.

The age of unit Q6 deposits is judged to be early Pleistocene on the basis of mollusk and ostracode faunas in isolated remnants of lithofacies Q6o and in a reworked zone at the base of lithofacies Q5o (Ward and Blackwelder, this volume; Cronin, this volume; see also Cronin, 1981), magnetic polarity (Liddicoat and others, 1981), and weathering profiles. Formations that have similar fossil assemblages are the Caloosahatchee Formation in Florida (DuBar, Solliday, and Howard, 1974) and the Waccamaw in northern South Carolina and southern North Carolina (DuBar, 1971; DuBar, Johnson, and others, 1974). The Caloosahatchee yielded U–He coral dates of older than 1 Ma (M.L. Bender, written commun. to B.W. Blackwelder in McCartan and others, 1982). An early Pleistocene age also is supported by ^{230}Th/^{234}U and ^{234}U/^{238}U ratios near unity, as determined by the uranium-disequilibrium-series technique for corals from unit Q6 and the Waccamaw Formation at Myrtle Beach, S.C. (Szabo, 1985), and by high amino-acid ratios for *Mercenaria* from unit Q6 and the Waccamaw Formation at Myrtle Beach (McCartan and others, 1982).

MINERALOGY AND WEATHERING

The mineralogy of the freshest material in each Quaternary lithostratigraphic sequence, units Q1–Q6, is essentially fine-grained quartz sand, typically 1 to 2 percent total heavy minerals (mainly ilmenite, phosphate minerals, sillimanite, hornblende, epidote, and staurolite) (table 3) and, in muddy facies, up to 75 percent clay minerals, mainly kaolinite, illite, and mixed-layer clay (illite-smectite) (table 4). The weathering profile, thicker in older deposits, contains a higher proportion of resistant minerals, such as quartz, rutile, and zircon, and secondary products, such as leucoxene, kaolinite altered postdepositionally, dioctahedral vermiculite, gibbsite, and goethite (compare Owens and others, 1983). Weathering and biological processes progressively remove primary sedimentary structures and produce characteristic soil structures.

UNIT Q1

Quartz is the predominant mineral in the sand fraction of unit Q1 deposits. Heavy minerals are found mainly in the fine sand fraction (0.06–0.25 mm) and generally constitute less than 5 percent by weight of the total sand fraction. The heavy-mineral suite—mainly ilmenite and

TABLE 3.—*Summary of heavy minerals in Quaternary deposits (units Q1–Q6) in the Charleston, S.C., area, in percent of number of grains in the fine-grained sand fraction*

[0, not observed; tr, less than 0.5 percent of heavy fraction. "Nonresistant minerals" include the previous four columns (except spinel and corundum); "resistant minerals" include the previous seven columns]

Lithofacies	Age	Facies	Number of locations	Number of samples	Hornblende	Epidote	Garnet	Other[1]	Nonresistant minerals	Staurolite	Monazite	Kyanite	Sillimanite	Tourmaline	Rutile	Zircon	Resistant minerals	Opaque[2]
Q1b	Holocene	Beach	4	5	28	20	1	1	50	2	tr	1	7	2	3	4	19	31
Q1r		Fluvial (P[3])	1	1	33	31	5	1	70	5	0	2	9	1	1	1	19	11
		Fluvial (CP[3])	2	3	tr	7	1	0	8	5	2	tr	8	4	5	12	36	56
Q2b	~100,000	Beach	7	16	22	30	tr	tr	52	1	0	tr	7	1	3	6	18	30
Q2o		Shelf	2	3	19	39	1	0	59	3	0	0	4	2	1	5	15	26
Q2l		Backbarrier	3	5	9	21	1	3	34	1	0	1	8	2	4	4	20	46
Q3b	~200,000	Beach	7	11	9	32	1	0	42	3	tr	1	8	1	2	7	22	36
Q3o		Shelf	1	1	19	17	1	0	37	4	0	3	1	2	0	3	13	50
Q3l		Backbarrier	2	4	1	6	tr	0	7	1	1	1	8	1	1	3	16	77
Q3r		Fluvial	5	7	12	16	tr	tr	28	2	tr	tr	7	2	2	2	15	57
Q4b	~450,000	Beach	2	2	4	18	0	0	22	4	0	1	10	2	3	6	26	52
Q4–5r		Fluvial	3	5	0	5	0	tr	5	4	1	2	8	4	5	4	28	67
Q5b	>730,000	Beach	6	10	1	10	tr	4	15	4	tr	2	15	4	4	11	40	45
Q5o		Shelf	8	9	26	29	1	1	57	3	1	tr	4	1	2	5	16	27
Q5l		Backbarrier	5	6	tr	5	3	1	9	6	1	1	17	3	5	8	41	50
Q6b	>1 m.y.	Beach	7	9	0	5	0	1	6	8	tr	1	16	3	5	10	43	51
Q6l		Backbarrier	2	3	2	4	0	1	7	5	0	1	14	2	5	13	40	53
Q6r		Fluvial	1	2	1	tr	1	0	2	9	1	2	2	6	2	3	25	73

[1] Other nonopaque minerals: biotite, chlorite, chloritoid, pyroxene, glauconite, spinel, corundum.

[2] Opaque grains: oxides, sulfides, phosphates, shell fragments.

[3] P, headwaters in the Piedmont province; CP, headwaters in the Coastal Plain province.

varying amounts of hornblende, epidote, garnet, staurolite, monazite, kyanite, sillimanite, tourmaline, rutile, zircon (table 3)—reflects metamorphic source rocks. Small quantities of glauconite, oxides, sulfides, and phosphates were derived from Coastal Plain deposits. Piedmont rivers carry a larger proportion of labile minerals (less resistant to mechanical abrasion and chemical dissolution), such as hornblende, epidote, and garnet, in the sand fraction than do Coastal Plain rivers. Wave-action depletion of labile minerals in beaches is evident in lithofacies Q1b mineralogy (table 3). Reworking of older deposits by Coastal Plain rivers results in the most mature unit Q1 deposits (lithofacies Q1r, table 3). Although older Quaternary river deposits are not separated into Piedmont and Coastal Plain categories in table 3, the older deposits show the same trend as the Holocene river deposits in the maturity of the heavy-mineral suite.

Kaolinite is generally the dominant clay mineral in the fine fraction of unit Q1 deposits, and it is also the principal clay mineral in suspension in modern rivers that have headwaters in the Piedmont. Because of its relatively large crystal size, kaolinite tends to remain nearshore. Illite appears to be derived from weathered Piedmont rocks, as well as from pre-Holocene deposits on the shelf, and illite-smectite is reworked largely from Oligocene and Eocene deposits underlying the Coastal Plain in the Charleston area. Finer grained than kaolinite, illite and illite-smectite tend to accumulate in the quieter water environments behind the barriers and on the shelf. The same processes probably were operating in the past; despite subsequent weathering, the clay distribution in pre-Holocene Quaternary units is generally similar to that in unit Q1 deposits (table 4).

Weathering is slight in older Holocene deposits. The maximum depth of weathering in the earliest Holocene beaches is less than 2 m (fig. 13).

UNIT Q2

The mineralogy of deposits in unit Q2 is mainly quartz; heavy minerals constitute less than 5 percent of the sand fraction, and kaolinite is dominant in the clay-mineral

TABLE 4.—*Dominant clay minerals in selected Pleistocene units in the Charleston, S.C., area, in percent of total clay*

[Method of calculation of percentages among three clays taken from Reynolds and Hower (1970) and Perry and Hower (1970). Relative abundance of dioctahedral vermiculite and gibbsite given in McCartan and others (1984)]

Depositional environment	Lithofacies	Kaolinite	Illite	Illite-smectite
Beach	Q2b	60	26	14
	Q3b	82	12	6
	Q4b	100	0	0
	Q5b	100	0	0
Shelf	Q2o	52	14	34
	Q3o	42	36	22
	Q4o	66	23	11
	Q5o	46	28	26
Backbarrier	Q2l	46	18	36
	Q3l	50	18	32
	Q4l	52	32	17
	Q5l	42	56	3

assemblage. The heavy-mineral (fig. 14; tables 3, 5) and clay suites (table 4) are almost indistinguishable from those in modern deposits, although the depth of weathering in clean sand is about 3 m in unit Q2 and less than 2 m in unit Q1 (Holocene) (fig. 13). One distinguishing characteristic is that unit Q2 clay beds are more consolidated than clay beds of unit Q1, even below the water table.

UNIT Q3

The mineralogy of unit Q3 deposits is typical of the Charleston-area Quaternary deposits: mainly quartz with heavy minerals less than 5 percent and a clay-mineral assemblage dominated by kaolinite. The weathered material at the top of the most complete sections (least eroded) yields a much more weathered heavy-mineral suite (fig. 14; compare hornblende, epidote, garnet, and other nonresistant minerals to rutile, zircon, and other resistant minerals in tables 3 and 6) and a significantly more altered clay-mineral assemblage than younger units yield (kaolinite is 82 percent in Q3b, 60 percent in Q2b, table 4; dioctahedral vermiculite and gibbsite are developed deeper in unit Q3 than in unit Q2 (McCartan and others, 1984)). Weathering is detectable in clean sand to a depth of 7 m (fig. 13) and in muddy sediment is shallower. Flowing ground water, which enhances weathering, is impeded by a fine-grained matrix, so cleaner deposits of each age are more deeply weathered than are muddier deposits.

UNIT Q4

Although the mineralogy of unit Q4 was not investigated in detail, the heavy-mineral suite of the unit is intermediate in maturity between the heavy-mineral suites of units Q3 and Q5 (fig. 14; tables 3, 7). The proportion of kaolinite increases 20 percent from unit Q3 to unit Q4 beach deposits (table 4). Deposits of unit Q4 are weathered to a depth of about 8 m (fig. 13).

UNIT Q5

Heavy-mineral (fig. 14; tables 3, 8) and clay proportions of unit Q5 (table 4) reflect considerably more weathering than younger deposits, but they reflect less weathering than unit Q6 deposits. The nonresistant (hornblende, epidote, and garnet) heavy-mineral percentage, for example, decreases from more than 40 percent in the heavy fraction of lithofacies Q3b, to 22 percent in lithofacies Q4b, to 16 percent in the sand of lithofacies Q5b, and to 6 percent in the sand of lithofacies Q6b (table 3). Lithofacies Q5b is distinguished from all the other units by the high proportion of biotite and chlorite in many samples. Sillimanite is usually 10–30 percent of the heavy-mineral fraction in lithofacies Q5l and the muddier samples of lithofacies Q5b (table 8). Heavy-mineral, clay, and feldspar proportions, protected both by burial and by the chemical buffering action of abundant shell material, are probably closer to their original proportions in lithofacies Q5o than in the other unit Q5 facies. The presence of large amounts of hornblende and epidote in lithofacies Q5o reflects both the high calcium-ion concentration, abundant due to dissolution of shells, and the impeding of oxidizing ground-water flow by clay particles. In the clay fraction, gibbsite, which indicates long-term weathering, is absent from younger units, is present in lithofacies Q5b, and is ubiquitous in lithofacies Q6b (McCartan and others, 1984). The depth of weathering is typically 9–10 m in sand of both units Q5 and Q6 (fig. 13).

UNIT Q6

The mineralogy of unit Q6 deposits is basically the same as that of other Quaternary units (tables 3, 9); the differences are mainly due to the effects of weathering (fig. 14). Lithofacies Q6b is the most weathered facies because it is very permeable, contains few shells, and is at the surface. The weathering is pervasive, occurring from the surface to the base (fig. 13). Ilmenite, the main heavy mineral, has altered to leucoxene; hornblende and garnet have disappeared completely, and epidote is rare in most samples; micas and feldspars have altered postdepositionally to kaolinite, dioctahedral vermiculite, and gibbsite. In many deposits, iron derived from heavy minerals and dissolved in ground water is reprecipitated as goethite.

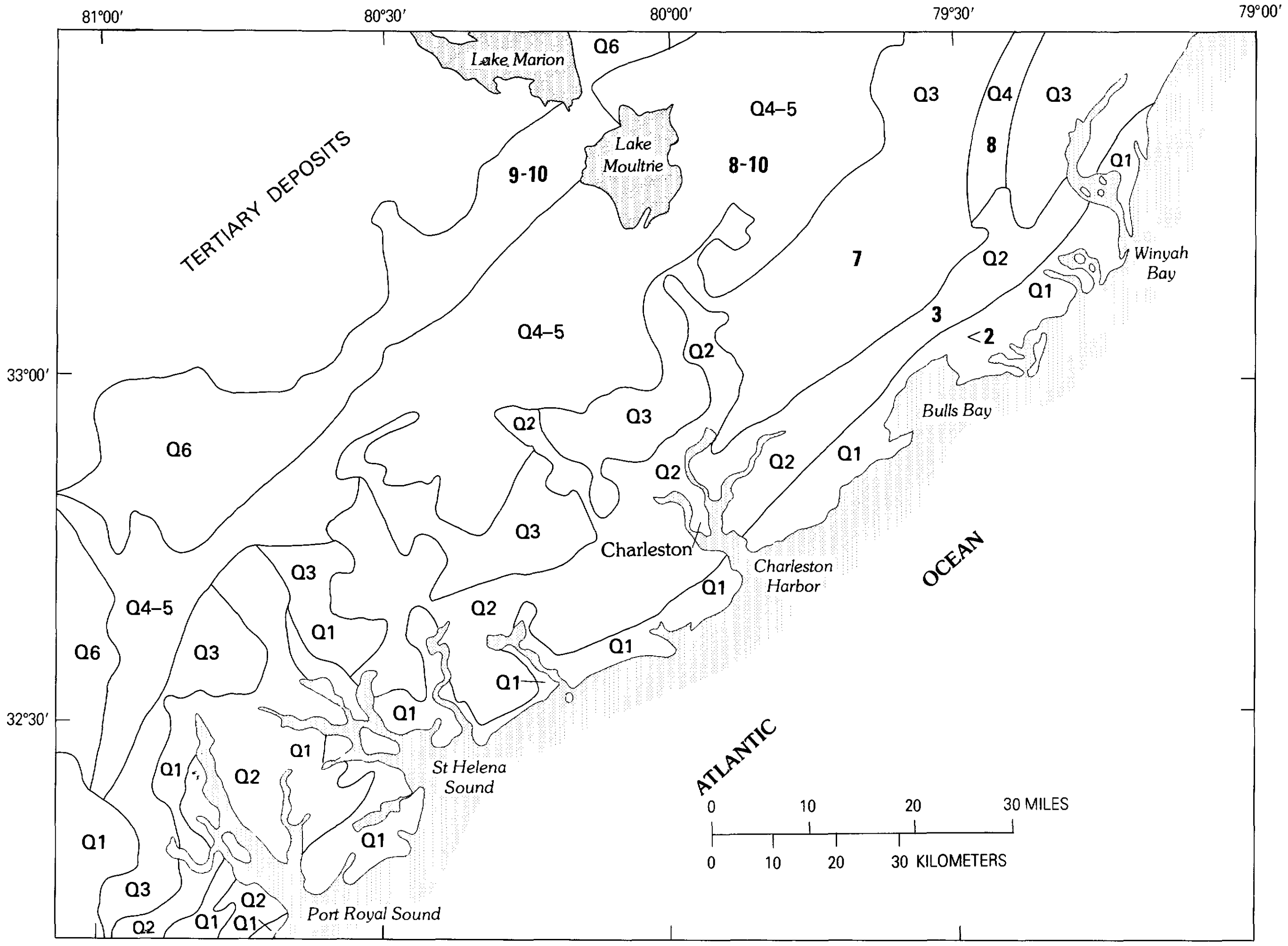
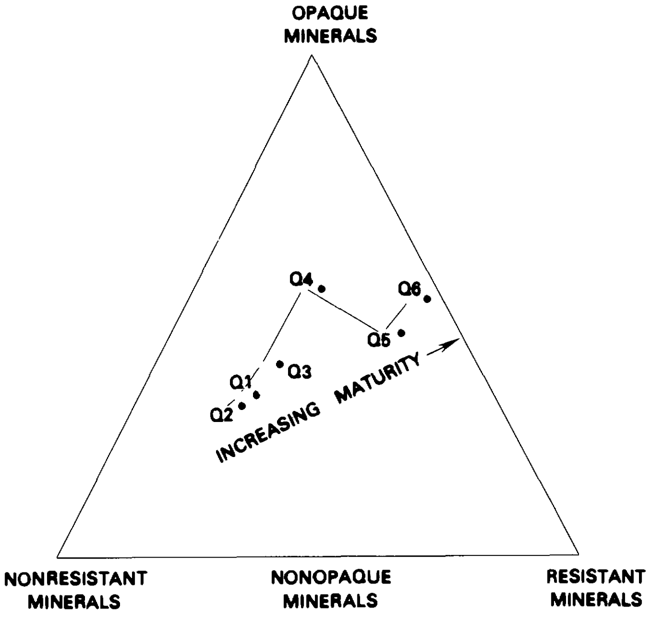


FIGURE 13.—Depth of weathering in Quaternary beach deposits in the Charleston, S.C., area. Numbers indicate depth, in meters, to which vermiculite has been detected, secondary iron oxide has accumulated, and (or) hornblende has been destroyed. Modified from McCartan and others (1984).



◀ FIGURE 14.—Heavy minerals (specific gravity greater than 2.85 g/cm^3) in Quaternary beach deposits in the Charleston, S.C., area. Because of intrastratal solution by moving ground water, older deposits contain lower proportions of more labile heavy minerals, such as hornblende, epidote, and garnet, and higher proportions of resistant heavy minerals, such as rutile and zircon. Percentages and definition of categories are in tables 3 and 5–9; ages, based partly on uranium-disequilibrium-series coral dates (McCartan and others, 1982) are Q1, <8 ka; Q2, about 100 ka; Q3, about 200 ka; Q4, about 450 ka; Q5, >730 ka; and Q6, >1 Ma.

TABLE 5.—*Heavy minerals in the fine-grained sand fraction of unit Q2 deposits in the Charleston, S.C., area, in percent of number of grains*

[0, not observed; tr, less than 0.5 percent. Localities shown in figure 3. "Nonresistant minerals" include the previous four columns (except corundum); "resistant minerals" include the previous seven columns]

Lithofacies	Facies	Locality	Depth (m) below surface	Altitude (m) above sea level	Hornblende	Epidote	Garnet	Other[1]	Nonresistant minerals	Staurolite	Monazite	Kyanite	Sillimanite	Tourmaline	Rutile	Zircon	Resistant minerals	Opaque[2]
Q2b	Beach	15	1	8	41	29	0	1	71	0	0	0	7	1	1	2	11	18
			4		29	39	tr	tr	68	1	0	0	9	0	2	3	15	18
			7		25	35	tr	tr	60	1	0	tr	10	1	1	7	20	20
		16	4	3	34	30	0	0	64	tr	0	0	12	tr	2	8	22	13
			5		23	36	1	0	60	1	0	0	5	0	1	6	13	25
		17	12	8	23	32	0	0	55	0	0	0	5	1	3	0	9	36
		18	3	5	13	50	0	0	63	5	0	0	3	1	1	1	11	26
			8.5		11	21	2	0	34	2	0	0	3	3	3	3	14	51
			9		19	27	0	0	46	0	0	3	5	0	0	2	10	44
			9.5		16	38	0	0	54	5	0	2	6	2	0	7	22	22
			10		12	37	tr	0	49	5	0	1	1	1	1	2	11	40
		19	3	5	31	29	tr	0	60	1	1	tr	7	1	3	5	18	22
		20	2	3	14	19	1	0	34	tr	tr	0	2	1	7	14	24	42
		21	.5	4	2	18	0	0	20	6	0	0	10	3	3	14	36	43
			1		6	45	1	0	52	1	0	1	11	0	2	5	20	26
			2		18	25	5	0	48	2	0	0	9	7	5	5	28	25
Q2o	Shelf	22	11	3	24	44	1	0	69	0	0	tr	7	0	1	6	14	16
		24	11	2	6	42	0	0	48	8	0	0	0	2	2	4	16	24
			14		21	23	2	0	46	4	0	0	0	4	0	2	10	44
Q2l	Backbarrier	24	3	7	1	8	0	2	11	0	0	0	9	2	6	0	17	71
		4	3	5	5	27	0	tr	32	1	0	4	18	1	8	15	47	22
			8		8	19	1	0	28	1	0	0	8	4	2	6	21	51
		25	3	5	23	34	1	0	58	9	0	tr	5	3	1	3	21	30
			6		18	33	1	2	54	1	0	1	0	1	0	2	5	41

[1] Other nonopaque minerals: biotite, chlorite, pyroxene, glauconite, corundum.

[2] Opaque grains: oxides, sulfides, phosphates, shell fragments.

Both lithofacies Q6l and Q6r have small amounts of hornblende and epidote, as well as the other heavy minerals. As in younger Quaternary deposits, kaolinite (mainly detrital, but not distinguishable by our techniques from kaolinite that formed postdepositionally) is the dominant clay in lithofacies Q6l. More accessory illite occurs in the clay of lithofacies Q6l than in lithofacies Q6b clay, both because lithofacies Q6l had more primary illite and because the clayier Q6l lithofacies is less permeable than the sandier Q6b lithofacies and is, therefore, less subject to weathering.

DISCUSSION OF DEPOSITIONAL HISTORY OF QUATERNARY UNITS

The Quaternary depositional record of the Charleston, S.C., area contains one Holocene and at least five Pleistocene sedimentary transgressive-regressive sequences (figs. 2, 6, 15). These sequences consist of several depositional lithofacies, including one or more long, low, well-sorted, fine- to medium-grained sand bodies (beaches and dunes, some of which are on barrier spits or islands); extensive thin sheets of locally upward-fining, fine- to coarse-grained sand that underlie the remainder of each cyclic deposit and that commonly contain a mixture of intertidal and subtidal shells (shelf and open bay); and muddy, fine- to medium-grained sand containing clay, shells, and wood—particularly in the lower half—that occupies thin wedges backed up behind sand bars or occupies channels or sheets beneath the bars (backbarrier) (fig. 16). The main channels continue landward (fluvial or estuarine); the minor channels die out or are double-ended without significant gradient (tidal channels not connected to freshwater streams).

TABLE 6.—*Heavy minerals in the fine-grained sand fraction of unit Q3 deposits in the Charleston, S.C., area, in percent of number of grains*

[0, not observed; tr, less than 0.5 percent. Localities shown in figure 3. "Nonresistant minerals" include the previous four columns; "resistant minerals" include the previous seven columns]

Lithofacies	Facies	Locality	Depth (m) below surface	Altitude (m) above sea level	Hornblende	Epidote	Garnet	Other[1]	Nonresistant minerals	Staurolite	Monazite	Kyanite	Sillimanite	Tourmaline	Rutile	Zircon	Resistant minerals	Opaque[2]
Q3b	Beach	26	3	13	18	28	0	0	46	5	0	1	15	8	1	2	32	21
			5		0	14	5	0	19	5	0	0	0	0	12	26	43	38
		27	2	12	14	34	0	0	48	0	0	2	7	0	1	7	17	36
		28	1	15	2	13	0	2	17	6	0	5	12	7	1	1	32	50
			3		18	28	3	0	49	0	0	0	5	7	2	9	23	29
			7		20	26	0	0	46	2	0	6	11	0	1	4	24	29
			12		4	34	0	0	38	9	0	2	17	3	1	4	36	24
		29	4	1	0	25	1	0	26	3	3	tr	6	0	3	7	22	52
		30	4	9	11	47	0	0	58	1	0	0	9	tr	2	3	15	26
		31	2	5	5	41	1	0	47	4	0	1	6	2	3	7	23	30
			4		6	46	tr	0	52	2	0	0	10	tr	1	1	14	32
Q3o	Shelf	32	17	7	19	17	1	0	37	4	0	3	1	2	0	3	13	50
Q3l	Backbarrier	33	2	10	3	0	0	0	3	2	0	2	31	2	1	2	40	57
			3		6	16	0	0	22	4	6	2	3	2	2	7	26	52
			9		0	17	0	0	17	1	1	tr	13	3	3	5	26	57
		34	2	4	tr	1	tr	0	1	tr	0	0	0	0	0	0	tr	98
Q3r	Fluvial	35	5	13	1	4	0	0	5	1	0	0	5	1	1	0	8	87
		36	3	11	0	14	0	0	14	4	0	0	17	4	1	1	27	58
			6		6	55	0	0	61	0	0	0	8	0	1	1	10	30
		37	4	13	45	30	1	0	76	0	0	tr	8	4	tr	tr	12	12
		24	5	7	4	4	1	1	10	5	2	0	5	0	4	5	21	70
		38	3	4	15	9	0	0	24	0	0	0	1	0	0	4	5	71
			10		tr	0	0	1	1	1	0	0	3	1	11	6	22	76

[1] Other nonopaque minerals: glauconite, pyroxene.

[2] Opaque grains: oxides, sulfides, phosphates, shell fragments.

These transgressive-regressive sequences, preserved as lithostratigraphic units consisting of several depositional lithofacies, are complex deposits of beach, shallow-shelf, backbarrier, and estuarine to fluvial environments. Each sequence records a discrete period of deposition during the Quaternary. The transgressive phase of each cycle is recorded in the poorly sorted basal sand sheet of each unit. The regressive part of each unit includes one or more barrier-backbarrier pairs deposited during short-term, sea-level stillstands or possibly even slight rises in sea level. The result of discontinuously dropping sea level is a deposit that has an overall regressive appearance (for example, a tilted plain consisting of barrier sand ridges and intervening backbarrier deposits), which also has a transgressive sequence consisting of clean beach sand above muddy backbarrier sand at many localities.

The highest backbarrier deposits mark approximately the highest relative sea level for each period of deposition, and corals dated by the uranium-disequilibrium-series method give the age of most of the sequences. The oldest lithostratigraphic unit, Q6, is probably more than 1 Ma, and its backbarrier deposits occur up to 26 m above sea level; unit Q5, older than 730 ka (on the basis of reversed magnetic polarity), has backbarrier deposits as high as 23 m; unit Q4, probably about 500 ka (McCartan and others, 1982), includes backbarrier deposits up to 15 m; unit Q3, about 200 ka, is as high as 11 m; and unit Q2, about 100 ka, has backbarrier deposits as high as 8 m. Modern backbarrier deposits occur as extensive flats up to 2 m above sea level. The successive offlap of younger and lower deposits may be due in part to a long-term eustatic lowering of maximum sea level but is also probably a function of continuing upwarp of the crust.

TABLE 7.—*Heavy minerals in the fine-grained sand fraction of unit Q4 deposits in the Charleston, S.C., area, in percent of number of grains*

[0, not observed; tr, less than 0.5 percent. Localities shown in figure 3. "Nonresistant minerals" include the previous four columns; "resistant minerals" include the previous seven columns]

Lithofacies	Facies	Locality	Depth (m) below surface	Altitude (m) above sea level	Hornblende	Epidote	Garnet	Other[1]	Nonresistant minerals	Staurolite	Monazite	Kyanite	Sillimanite	Tourmaline	Rutile	Zircon	Resistant minerals	Opaque[2]
Q4b	Beach																	
	(S)[3]	39	7	18	7	33	0	0	40	0	0	0	9	1	1	4	15	44
	(N)[3]	40	3	13	tr	3	0	0	3	4	0	1	11	3	5	7	31	64
Q4–5r	Fluvial	41	1	13	0	5	0	0	5	3	0	1	9	5	5	12	35	63
		35	8	13	0	0	0	0	0	3	0	5	7	8	8	9	40	60
			10		0	0	0	1	1	1	1	2	0	0	4	5	13	87
		42	2	14	tr	1	0	0	1	9	1	3	12	2	2	2	31	67
			6		0	16	0	0	16	7	0	1	9	1	3	4	25	58

[1] Other nonopaque minerals: biotite.

[2] Opaque grains: oxides, sulfides, phosphates, shell fragments.

[3] S, just south of Santee River; N, just north of Santee River.

During the last 8,000 years, the coastline has prograded seaward as much as 12 km (for example, unit Q1 southeast of Beaufort, S.C., and immediately south of the mouth of the Santee River; figs. 1*A*, 2, 6, 15*A*) due to net accumulation of beach and backbarrier deposits. The sediment in these deposits was derived from the Piedmont by way of the Santee and Pee Dee Rivers, by erosion of pre-Holocene units in the Coastal Plain, and, to a smaller extent, by onshore movement of relict shelf sediment by tides and bottom currents running counter to the Gulf Stream. The second and third processes result in partial or complete destruction of older deposits. In general, older deposits are more dissected than younger deposits.

One aspect of earlier Quaternary deposition has no obvious Holocene analog, that is, the pattern of successively (seaward) lower tidal flats and beach deposits that mark a fall in maximum interglacial sea level. Holocene sea level is currently at its highest level for the middle and southern Atlantic Coastal Plain; therefore, no "lower deposits" have accumulated.

The result of progressive mineralogic (weathering) and physiographic (erosion and dissection) changes on the primary mineralogy, biota, and depositional style is a unique set of characteristics for each depositional sequence. These characteristics distinguish each lithostratigraphic unit within the Quaternary (Q1–Q6) and distinguish the Quaternary units from earlier units.

Quaternary units were deposited in generally northeast-trending belts (fig. 15) during interglacial periods that lasted thousands to tens of thousands of years. The strike of Pliocene deposits and their duration of deposition are similar to those of Quaternary units. Pliocene beach deposits are present at Orangeburg (fig. 1*A*), and shallow-shelf deposits are irregularly distributed landward (west) of and beneath Quaternary deposits. Pliocene beach ridges have not been preserved.

Miocene deposits are mostly eroded; therefore, contacts are indeterminate. The deposits are thicker and more continuous west of Beaufort (fig. 1*A*). Unusual minerals, such as palygorskite and sepiolite, suggest a unique environment of deposition for some of the Miocene sediment.

Oligocene and older units trend generally more easterly and, in some cases, represent time periods of several million years. Primarily nearshore and midshelf limestones, these deposits are easily distinguished from overlying shoreline sequences.

REGIONAL GEOLOGY OF THE SOUTH CAROLINA COASTAL PLAIN

Underlying the Quaternary deposits in South Carolina is a seaward-thickening wedge of Cretaceous and Tertiary sediment that is as much as a kilometer thick at the coast and about 350 m to 400 m thick just south of Orangeburg (fig. 1*A*). Cretaceous and Tertiary units, traced in surface exposures and wells, are generally thinner in the northern part of the area and thicker in the south. These units crop out in irregular east- or northeast-trending arcs (fig. 17). The outcrop belts consist of progressively older sediments toward the north. These patterns indicate the presence of a basin (southeast Georgia embayment) toward the south and an arch (Cape Fear Arch) toward the north. Occasional reversals

TABLE 8.—*Heavy minerals in the fine-grained sand fraction of unit Q5 deposits in the Charleston, S.C., area, in percent of number of grains*

[0, not observed; tr, less than 0.5 percent. Localities shown in figure 3. "Nonresistant minerals" include the previous four columns (except spinel); "resistant minerals" include the previous seven columns]

Lithofacies	Facies	Locality	Depth (m) below surface	Altitude (m) above sea level	Hornblende	Epidote	Garnet	Other[1]	Nonresistant minerals	Staurolite	Monazite	Kyanite	Sillimanite	Tourmaline	Rutile	Zircon	Resistant minerals	Opaque[2]
Q5b	Beach	43	3	25	1	1	2	tr	4	4	0	2	15	7	1	11	40	54
			5		6	48	1	2	57	tr	0	0	12	1	tr	3	16	28
		44	1	18	0	0	0	0	0	9	0	2	13	3	2	22	51	49
		45	1	25	0	1	0	0	1	0	0	2	43	5	1	1	52	47
			2		0	0	0	0	0	3	0	4	39	6	0	0	52	48
(Natural placer)			3		0	0	0	64[3]	64[3]	0	0	1	19	0	0	0	20	15
		46	1	15	1	1	0	1	3	1	tr	2	14	3	9	15	44	54
			2		0	tr	0	tr	tr	8	tr	4	15	4	5	8	44	56
		47	1	6	1	tr	0	0	1	6	1	2	10	7	9	17	52	47
		48	4	26	1	33	0	0	34	2	0	1	5	3	5	7	23	42
Q5o	Shelf	49	6	22	18	28	0	0	46	12	4	0	3	2	1	tr	22	33
		43	6	25	48	21	1	13	83	1	0	0	7	0	2	0	10	7
			9		35	23	1	tr	59	tr	0	1	2	tr	1	6	10	33
			13		20	21	1	0	42	2	0	0	6	2	0	2	12	47
		50	14	15	22	21	1	0	44	0	0	1	4	1	0	3	9	44
		26	17	13	8	26	1	0	35	0	0	0	0	1	0	8	9	55
		51	17	8	35	35	0	0	70	0	0	2	8	0	2	1	13	18
		52	6	9	35	33	4	0	72	1	0	tr	3	2	1	3	10	17
		53	7	27	13	38	tr	tr	51	tr	0	tr	7	tr	2	12	21	29
Q5l	Backbarrier	40	1	22	1	1	0	0	2	2	0	1	23	1	6	4	37	61
		45	4	25	0	15	0	6	21	0	tr	1	23	1	3	3	31	49
		54	4	23	tr	9	14	tr	23	17	0	tr	2	5	1	14	39	36
		55	1	24	tr	1	0	tr	1	5	0	2	23	3	4	9	46	52
			5		tr	2	tr	tr	2	4	0	0	28	1	2	6	41	57
		56	1	14	0	tr	tr	tr	tr	9	3	2	12	5	12	12	55	44

[1] Other nonopaque minerals: biotite, chlorite, chloritoid, spinel.

[2] Opaque grains: oxides, sulfides, phosphates, shell fragments.

[3] Chlorite.

in thickness and dip trends in these units (Gohn, Christopher, and others, 1978; Gohn, Bybell, and others, 1978) suggest sporadic differential movement in the direction opposite to the long-term motion (upward motion of "basins"; downward motion of "arches"). Unusually high seismicity in the Charleston area (Tarr, 1977) may reflect continuing modern tectonism.

Pre-Quaternary sediment, probably Pliocene, covers the northwest part of the map area above about 30 m altitude (figs. 2, 5). In addition, fossiliferous upper Pliocene shelf sediment occurs in depressions beneath the Quaternary cover near the coast. Miocene deposits are below the Quaternary sediment in the southwest and are thicker in the Ridgeland area (fig. 1*A*) (Ridgeland basin; Heron and Johnson, 1966) and westward into Georgia. The Cooper Group (Ward and others, 1979; Weems and Lemon, 1984b), a semilithified, calcareous, fine-grained unit of Oligocene and Eocene age, underlies about 7,500 km^2 of the Quaternary in the Charleston area (fig. 17). Older beds of the Cooper Group occur near the surface at the margin of this small depositional basin; toward the southwest, part of the Cooper Group may grade into the Ocala Limestone (fig. 17) (Counts and Donsky, 1963). The Santee Limestone, typically a well-cemented, medium-grained biocalcarenite of middle Eocene age, underlies the Cooper Group everywhere, except generally northeast of the Santee River where the Cooper is absent, although the Santee does underlie

TABLE 9.—*Heavy minerals in the fine-grained sand fraction of unit Q6 (oldest Pleistocene) deposits in the Charleston, S.C., area, in percent of number of grains*

[0, not observed; tr, less than 0.5 percent. Localities shown in figure 3. "Nonresistant minerals" include the previous four columns (except spinel); "resistant minerals" include the previous seven columns]

Lithofacies	Facies	Locality	Depth (m) below surface	Altitude (m) above sea level	Hornblende	Epidote	Garnet	Other[1]	Nonresistant minerals	Staurolite	Monazite	Kyanite	Sillimanite	Tourmaline	Rutile	Zircon	Resistant minerals	Opaque[2]
Q6b	Beach	57	1	33	0	2	0	0	2	3	1	1	8	1	5	14	33	65
			3		0	17	tr	0	17	4	0	1	8	6	6	12	37	46
		58	2	24	0	1	0	tr	1	7	1	3	22	5	5	6	49	50
		54	1	23	0	15	0	0	15	11	0	1	14	1	2	13	42	43
		60	.5	26	0	0	0	1	1	12	0	1	22	2	5	11	53	46
		61	.5	17	tr	1	0	tr	1	5	1	0	16	2	4	16	44	54
		62	2	26	0	1	0	6	7	8	0	1	14	1	7	5	36	59
			4		0	tr	0	0	tr	6	0	1	26	3	3	2	41	59
		63	1	21	0	6	0	0	6	9	0	3	13	6	11	5	47	46
Q6l	Backbarrier	64	1	26	2	2	0	2	6	5	0	1	11	1	7	16	41	53
		44	3	18	0	2	0	0	2	8	0	0	26	5	2	5	46	52
			4		2	7	0	0	9	1	0	tr	5	0	3	13	22	67
Q6r	Fluvial	65	1	26	0	0	tr	0	tr	12	1	1	3	12	3	4	36	63
			4		1	tr	2	0	3	6	0	3	2	1	1	2	15	83

[1] Other nonopaque minerals: biotite, chlorite, chloritoid, spinel.

[2] Opaque grains: oxides, sulfides, phosphates, shell fragments.

the seaward 40 km of the emerged part of the Santee River delta (Gohn, Bybell, and others, 1978). The Santee Limestone is underlain and succeeded at the surface in the northeast part of the area by the Black Mingo Formation of Paleocene age (Van Nieuwenhuise and Colquhoun, 1982) and consists of a sequence of fissile, dark, calcareous silts and fine-grained quartz sands.

THE RELATIONSHIP AMONG QUATERNARY SEDIMENTATION, CHARLESTON SEISMICITY, AND TECTONISM

Modern seismicity in the Charleston area originates at depths of 3 to 13 km (Tarr and Rhea, 1983). The seismic events occur beneath an area in which there are several small structures, such as domes, in older rocks, and these structures appear to have affected sedimentation during the Quaternary. In addition, large structures, such as the Cape Fear Arch, and small, near-surface features, such as sand blows, also controlled or interrupted Quaternary sedimentation or altered the shape of the deposit after deposition. As yet, no direct geologic evidence has been found of the cause of the 1886 earthquake. In view of this, all features possibly related to Quaternary seismicity and tectonism will be discussed.

QUATERNARY UPWARP OF THE CHARLESTON AREA AND ITS RELATIONSHIP TO THE CAPE FEAR ARCH

The most widespread feature of the Charleston area that may be related to regional tectonism and possibly to seismicity is the pattern of belts of Quaternary deposits that are progressively lower and younger toward the sea (figs. 2, 6). This pattern suggests either successively lower sea-level stands or progressive uplift or a combination of both. Although the Eastern United States Atlantic continental margin is a "trailing margin" (Pitman, 1978), it is not as stable as, for example, eastern Australia (Thom and others, 1981), where only two Quaternary depositional cycles are recorded—one about 125 ka and the other modern. The Australian pattern is the ideal pattern suggested by deep-sea oxygen-isotope studies; the Charleston pattern, however, strongly suggests significant, long-term uplift (Shackleton and Opdyke, 1973).

The Cape Fear Arch and southeast Georgia embayment (fig. 18) have influenced sedimentary patterns for at least 140 million years (m.y.). A comparison of figures 17, 18, and 19 reveals that Quaternary units Q6 and Q2 pinch out across the nose of the Cape Fear Arch, as do most Tertiary and some Cretaceous units. The pre-Quaternary pattern on the southern flank of the arch

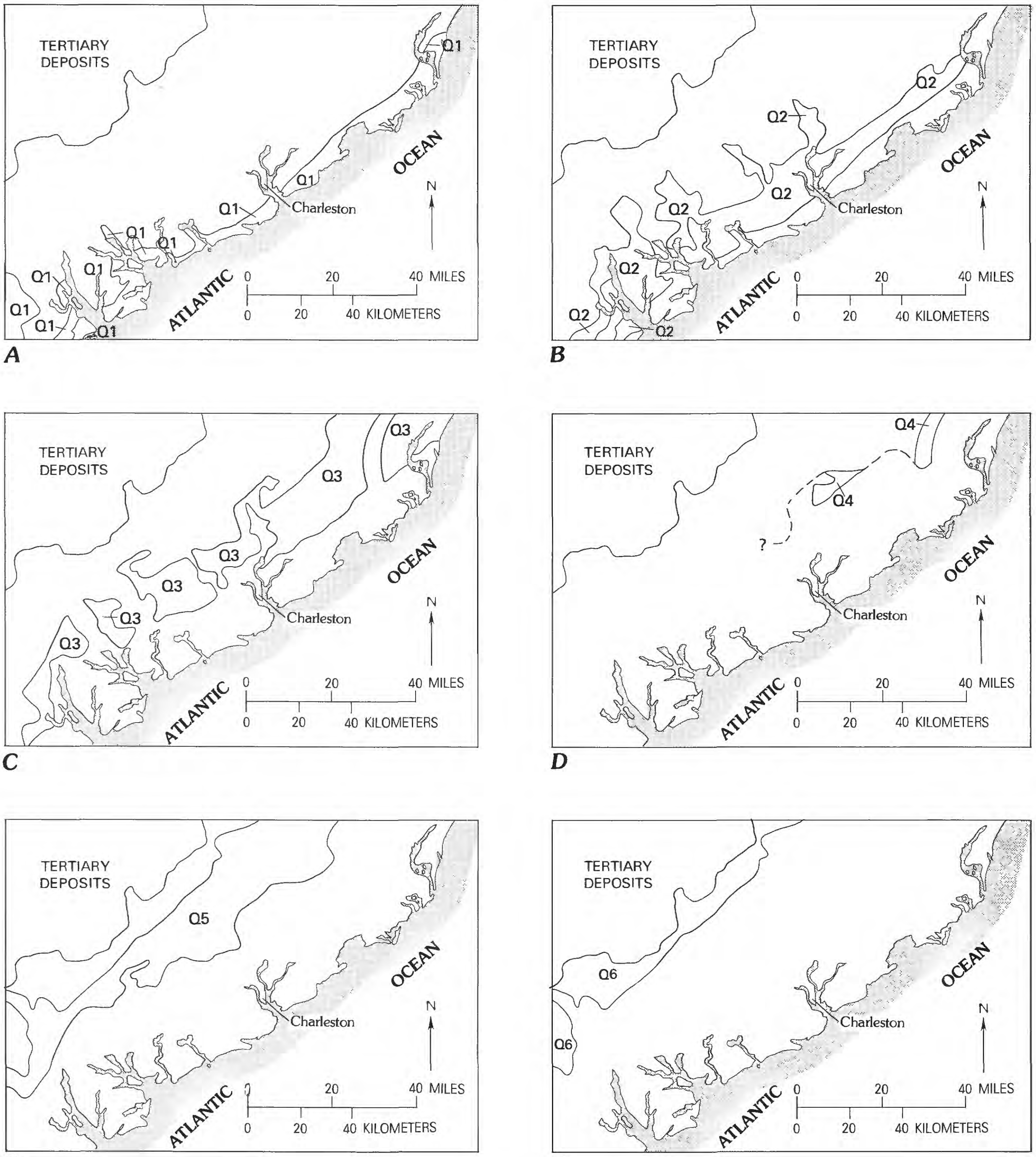
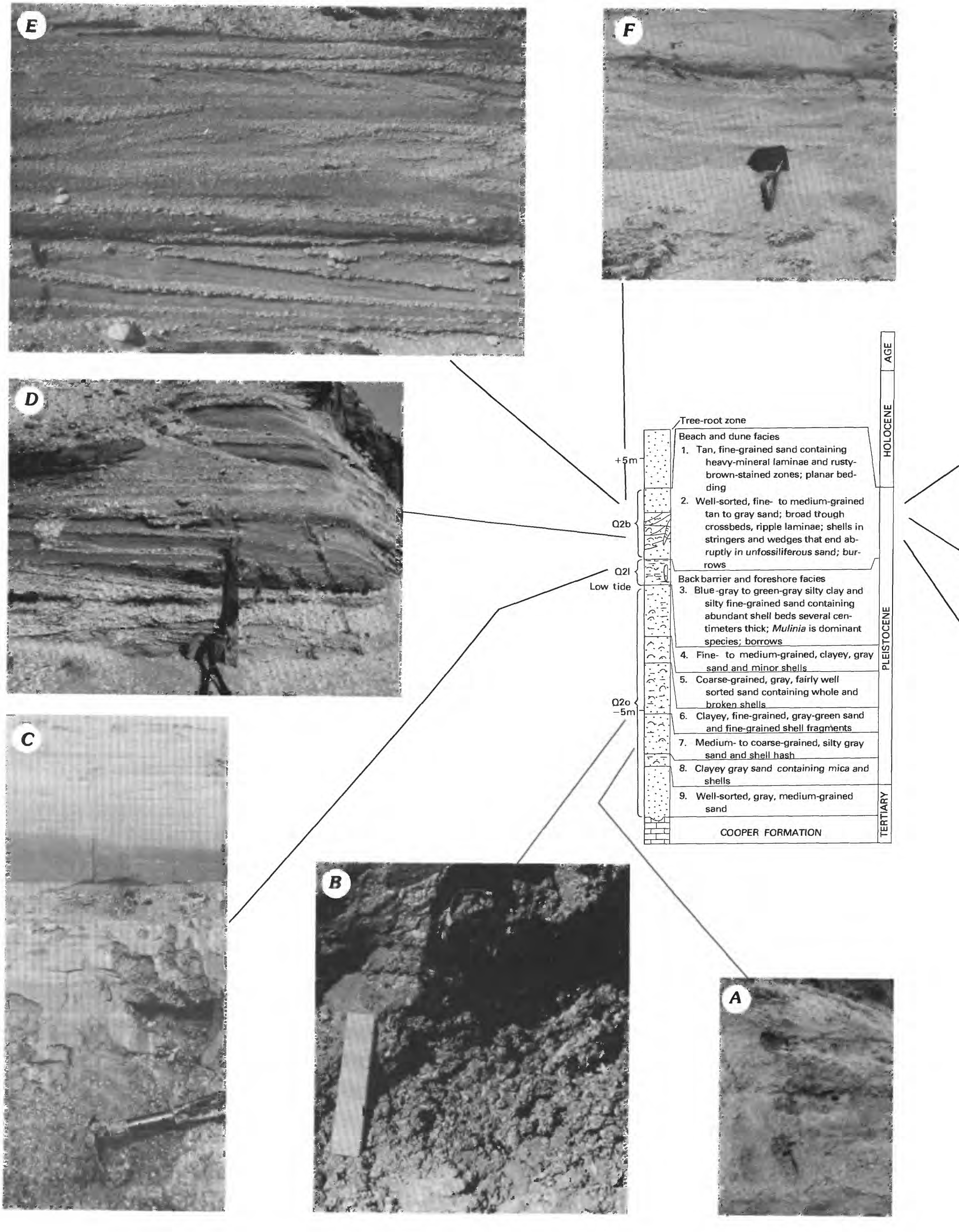


FIGURE 15.—Quaternary lithostratigraphic units Q1–Q6 in the Charleston, S.C., area. The modern shoreline and the seaward edge of the Tertiary outcrop belt are lines of reference. *A*, Unit Q1, <8 ka; *B*, unit Q2, about 100 ka; *C*, unit Q3, about 200 ka; *D*, unit Q4, about 450 ka; *E*, unit Q5, >730 ka; *F*, unit Q6, >1 Ma. Dashed line in *D* indicates approximate seaward edge of unit Q4 outcrop belt.



Beach and dune facies

1. Tan, fine-grained sand containing heavy-mineral laminae and rusty-brown-stained zones; planar bedding
2. Well-sorted, fine- to medium-grained tan to gray sand; broad trough crossbeds, ripple laminae; shells in stringers and wedges that end abruptly in unfossiliferous sand; burrows

Backbarrier and foreshore facies

3. Blue-gray to green-gray silty clay and silty fine-grained sand containing abundant shell beds several centimeters thick; *Mulinia* is dominant species; borrows
4. Fine- to medium-grained, clayey, gray sand and minor shells
5. Coarse-grained, gray, fairly well sorted sand containing whole and broken shells
6. Clayey, fine-grained, gray-green sand and fine-grained shell fragments
7. Medium- to coarse-grained, silty gray sand and shell hash
8. Clayey gray sand containing mica and shells
9. Well-sorted, gray, medium-grained sand

COOPER FORMATION

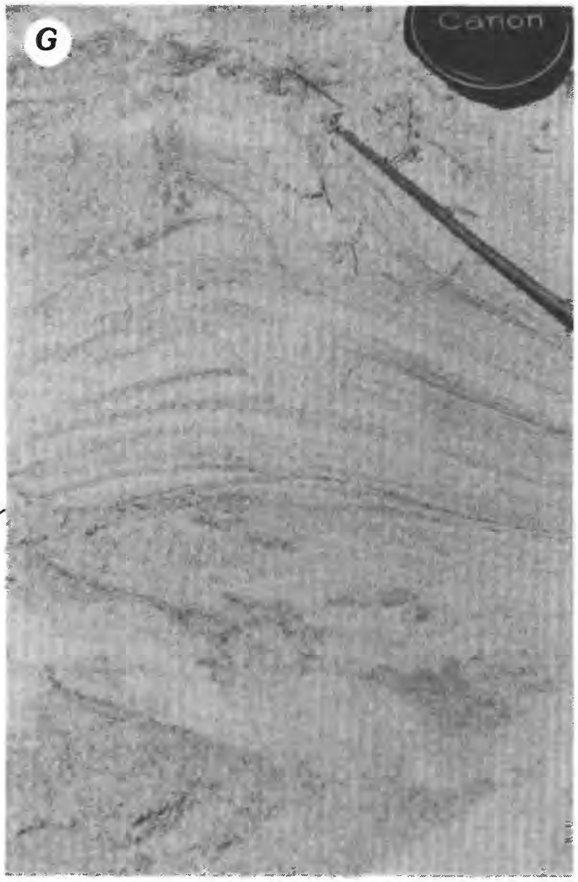
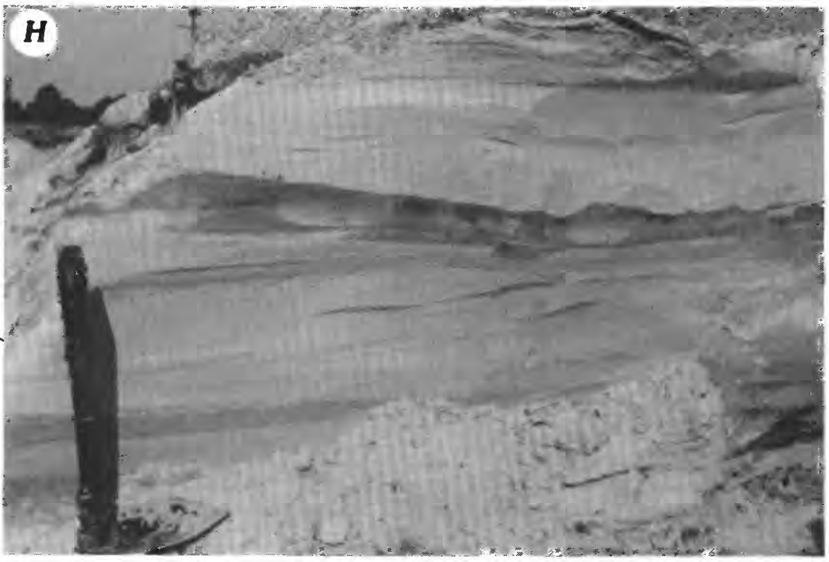
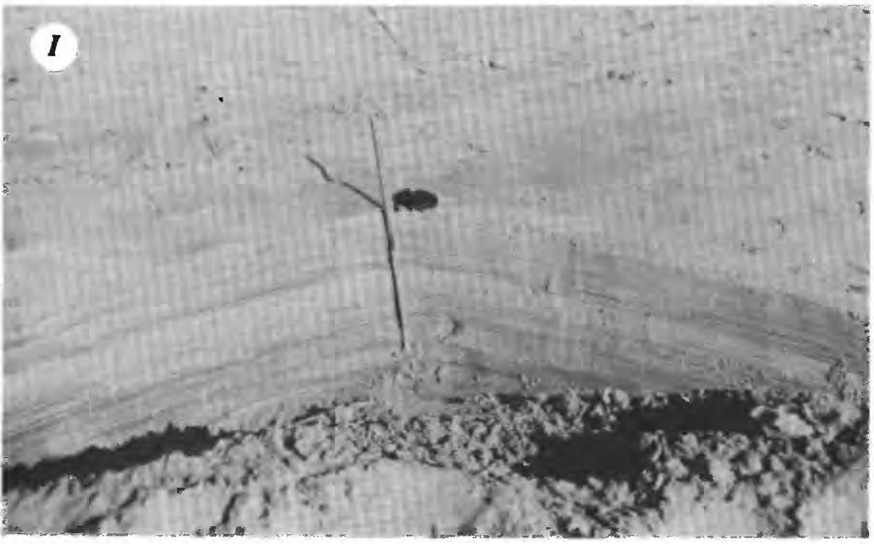


FIGURE 16.—Typical Quaternary lithostratigraphic unit in the Charleston, S.C., area. Stratigraphic column for unit Q2 at Mount Pleasant (modified from McCartan and others, 1980) includes, from the top, lithofacies Q2b (beach), Q2l (backbarrier), and Q2o (shelf). Uppermost 1.5 m of section is not shown because it is eolian sand derived from lithofacies Q2b and was redeposited during the Holocene (^{14}C date no. 10 on stumps of forest trees engulfed by sand; see table 2). This section records transgression during sea-level rise, as shown by the thick section of shelf deposits at the base, and regression accompanying a sea-level drop, as shown by the superposition of shallower water facies over slightly deeper water facies—beach and backbarrier over shelf. A stillstand or slight rise in sea level is indicated by the superposition of beach deposits over backbarrier deposits (see text for further discussion). Section below sea level is known from drill-hole samples; photographs *A* and *B* are from shallow-shelf deposits elsewhere. *A*, Lithofacies Q2o, shelly sand, poorly sorted, crudely bedded; head of shovel is 20 cm long. *B*, Lithofacies Q2o, muddy shelly sand; divisions on rule are centimeters. *C*, Backbarrier, lithofacies Q2l; interbedded mud and sand containing shells, overlain by beach sand in which shells are dissolving; shovel head is 20 cm. *D*, *E*, and *F*, Foreshore and shore facies, lithofacies Q2b; long, low-angle crossbeds in shelly sand; megaripples; lined burrows; landward is to the right in *D* and behind the viewer in *E* and *F*; shovel head is 20 cm, and large shell in *E* is 7 cm across. *G*, Dune, lithofacies Q2b; crossbedding marked by heavy minerals; lens cover is about 5 cm across; photograph is from a modern dune elsewhere because dunes in units Q2–Q6 appear massive due to loss of heavy minerals by weathering. *H*, Beach, lithofacies Q2b; well-sorted, medium- to fine-grained sand; dark patches are oxidized heavy-mineral layers; landward is to the right; shovel head is 20 cm long. *I*, Trench through beach facies; rod is at a 90° bend in face; dark laminae are heavy minerals; seaward is toward the right; lens cover is about 5 cm across.





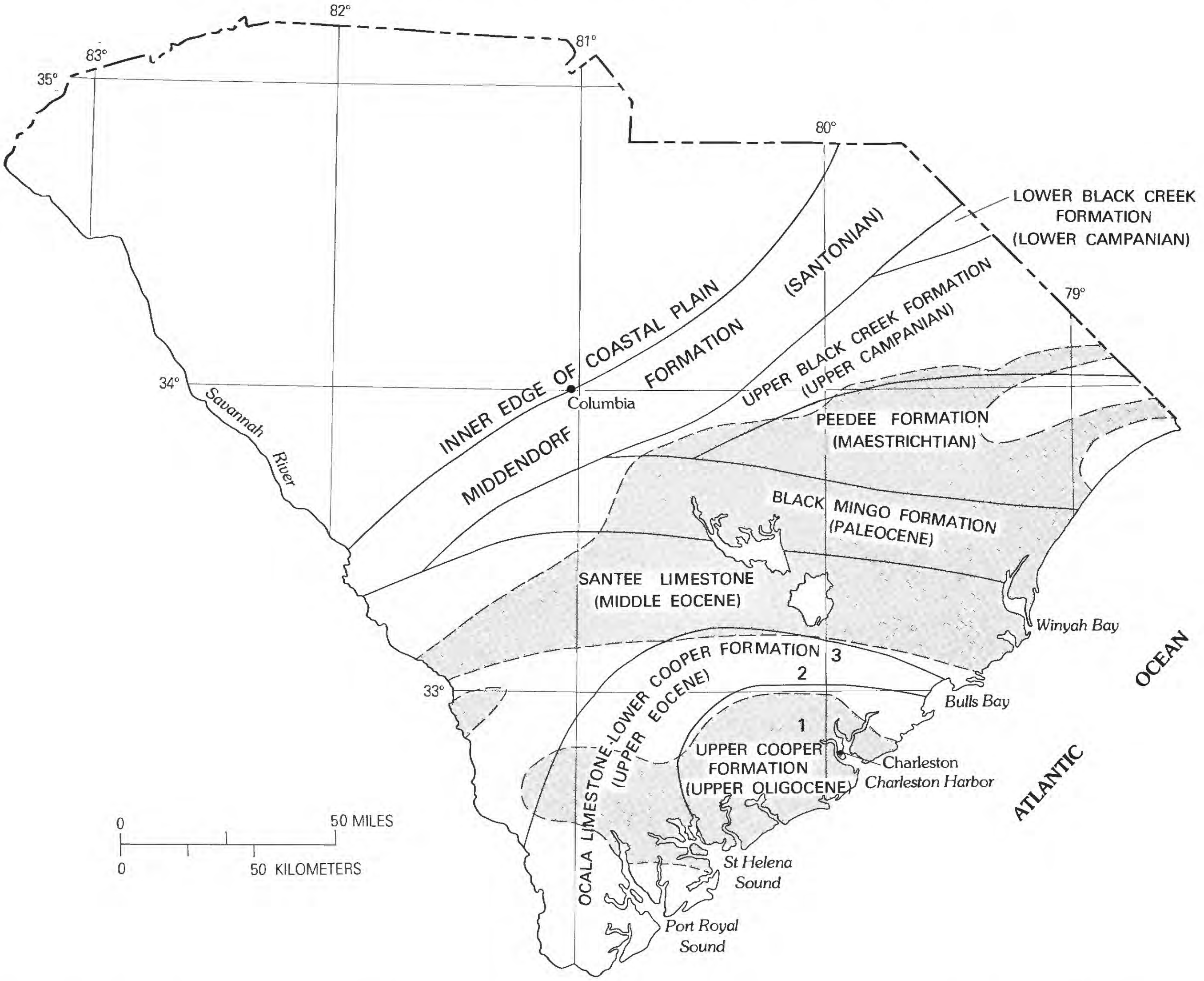


FIGURE 17.—Generalized pre-Miocene geology of the South Carolina Coastal Plain (J.P. Owens, written commun., 1981). The lower part of the Cooper Group (upper Eocene) grades southwestward into the Ocala Limestone. In this area, the orientation of contacts is controlled by tectonism expressed as the Cape Fear Arch (North Carolina) and the southeast Georgia embayment (see fig. 18). Shaded areas are regional aeromagnetic highs (over 11,000 gammas total magnetic intensity; Zietz and others, 1982). Local aeromagnetic highs (labeled 1, 2, and 3 where residual magnetic intensity is greater than 0 gammas; Phillips and others, 1978) coincide approximately with areas in which Eocene deposits of the Cooper Group and Santee Limestone are at unusually high altitudes.

appears to be related to continual or sporadic uplift, as the depositional strikes of successively younger units become progressively more east of north. If this tectonic style continued into the Quaternary, it probably influenced Quaternary deposition as well. In addition, other factors, such as changes in ocean currents, may have affected the pattern of Quaternary deposits.

To the southwest, downwarping of the southeast Georgia embayment during the Quaternary is suggested by the extensive erosion of each Quaternary unit by the sea during each succeeding depositional cycle. For example, in the southwest quarter of the maps in figures 2 and 6, backbarrier sediment of each unit younger than unit Q6 is found in a relatively narrow outcrop belt near or adjacent to lithofacies Q6b. By contrast, north of Charleston, broad outcrop belts of units Q5 and Q3 were preserved, probably by Quaternary uplift of the Cape Fear Arch.

Weems and others (1982) have inferred from the superposition of three Quaternary (units Q1, Q2, and Q5, fig. 2) and at least three pre-Quaternary units that the Cooper River (fig. 1*A*) is a tectonically controlled drainage within the downwarped southeast Georgia embayment. This inference is further supported by the disequilibrium bottom profile of the Back River, which drains eastward into the Cooper River (Force, 1979). The main

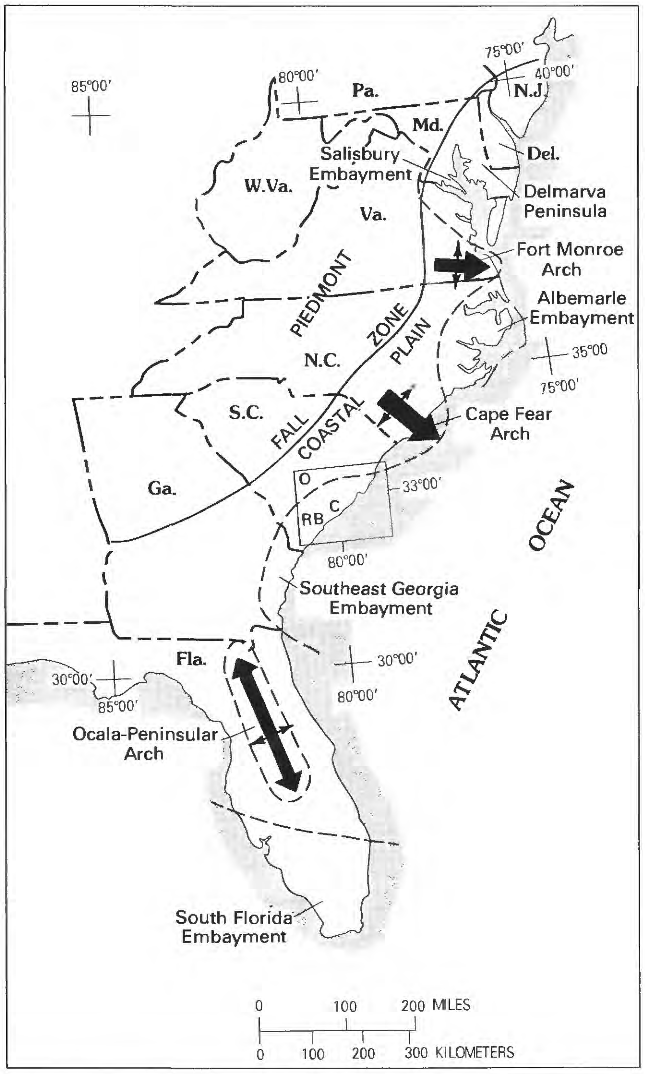


FIGURE 18.—Structural framework of the Atlantic Coastal Plain of the Southeastern United States (modified from Owens, 1983). Area of this report is outlined at lat 33° N., long 80° W. Dashed lines outline the named arches and basins; arrows indicate the axial trend and plunge of each arch through time. Abbreviations: C, Charleston; O, Orangeburg; B, Beaufort high; R, Ridgeland basin (see fig. 1*A*).

channel of the upper reaches of the Back River is steeper than neighboring streams and cannot be explained by harder bedrock. Recent uplift of the headwaters region could account for the steep profile.

On the basis of the distribution of Eocene and Miocene units, Heron and Johnson (1966) established the presence of a high at Beaufort and a trough extending westward into Georgia from the Ridgeland area (B and R in fig. 18). Preservation of a notable high as an erosional remnant during a succeeding marine incursion is unlikely, as is confinement of sediment containing minerals suggestive of restricted water conditions within an erosional trough. These features are more likely to have been controlled structurally during at least part of their depositional history. The Savannah River flood of 1929 deposited sediment in the Ridgeland basin (lithofacies Q1r, southwest corner of fig. 2). Therefore, the concentration of flood deposits in this area suggests continued downwarping here.

Drilling studies of the Tertiary section over three of the aeromagnetic highs near Charleston (1, 2, and 3 in fig. 17) suggest that the highs coincide approximately with unusually high areas of Eocene deposits. These areas of unconsolidated to semilithified deposits are interpreted as structural domes rather than erosional remnants, because they have been, since deposition, under at least 10 m of seawater five to nine times during the Tertiary and early Pleistocene.

Modern small-magnitude earthquakes coincide with an area 5 km south of Summerville (fig. 1*A*) near the "Cooke Fault" of Behrendt and others (1981). No causal relationship has been shown between the minor northeast-trending disruption of seismic lines there and modern seismicity.

SMALL DEFORMATIONAL FEATURES

A series of spectacular small faults, sand dikes, and contorted sand and clay beds are associated with pre-Quaternary deposits at the surface in the upper Coastal Plain (Colquhoun and others, 1969) in the Orangeburg area and farther west (fig. 1*A*) (Owens and others, 1976; McDowell and Houser, 1983). The features appear to be the result of rapid earth movements or pore pressure changes and thus could have accompanied an earthquake. This zone of disruption lies east and northeast of the high-angle faults proposed by Faye and Prowell (1982) and appears to be on strike with one of them. On the basis of the probable age of the disrupted deposits, some of the structures may be as old as early Tertiary. Whether or not earth movements have occurred during the Quaternary is unknown, as there are no recognizable Quaternary units in the disrupted zone.

Sand blows and other surface dislocations were photographed immediately after the 1886 earthquake (Dutton, 1889), but most of these have not been relocated in the field for examination despite an extensive search. Many probably occurred in swampy ground, and the action of ground water and tree roots has thoroughly masked them. However, three of the 1886 sand blows have been relocated (fig. 3) (Weems and others, 1986). Trenches through two of them reveal ejection dikes in marine deposits. Fresh sand that geysered up from below during the earthquake fills large cracks in yellow to deep-orange soil at the top of the trenches. Two of the three sand blows are in unit Q3 and one is in unit Q2.

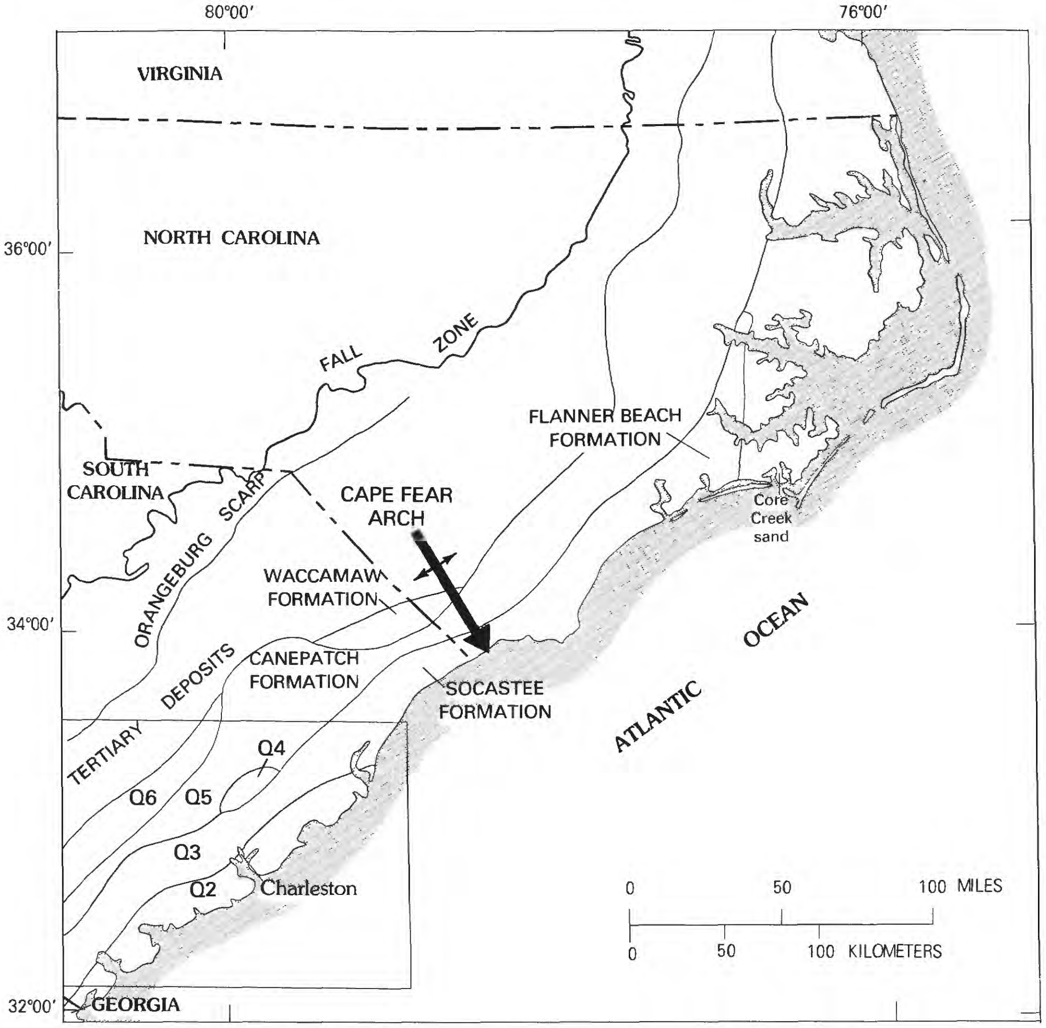


FIGURE 19.—Time-stratigraphic map of generalized geologic units of Quaternary age in South Carolina and North Carolina (North Carolina and northern South Carolina modified from Mixon and Pilkey, 1976; DuBar, 1971; DuBar, Johnson, and others, 1974; and Owens, 1982). Units Q6 and Q2 and their correlatives, such as the Waccamaw Formation and Core Creek sand, respectively, are missing for over 150 km north of the Cape Fear Arch; unit Q1 is included in unit Q2 in this map. The area outlined is shown in more detail in figure 2 and coincides with the outlined area in figure 18 at lat 33° N., long 80° W. Ages are discussed throughout the text, and generalized lithologic units are shown in figure 6.

A 1-m-wide "chaotic dike" was discovered in a railroad embankment west of Goose Creek Reservoir, S.C. (fig. 20) (W. L. Newell and D. C. Prowell, written commun., 1980). The clay and sand probably were deposited in the backbarrier environment about 200 ka (lithofacies Q31) (McCartan and others, 1984). The disruption took place after dewatering of the clay,[3] as the material is in small, angular clasts and therefore did not flow, but was fractured. However, the disruption took place prior to the deposition of the well-sorted sand that unconformably overlies the disrupted zone, which is probably from unit Q2 (McCartan and others, 1984). The disruption, therefore, occurred between 200 and 100 ka and was a rapid event that may have accompanied an earthquake.

CRUSTAL MOVEMENT AFFECTING CRETACEOUS AND CENOZOIC COASTAL PLAIN DEPOSITS BETWEEN NEW JERSEY AND SOUTH CAROLINA

Comparison of detailed stratigraphy in New Jersey, the Delmarva Peninsula, North Carolina, and South Carolina indicates that the North American continental margin has not subsided uniformly during its history (Owens, 1983). Cretaceous and Tertiary units outline

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[3] Pleistocene clay is dewatered; Holocene is not. The maximum time for dewatering is thus <86,000 years, the age of the youngest of the dated Pleistocene deposits.

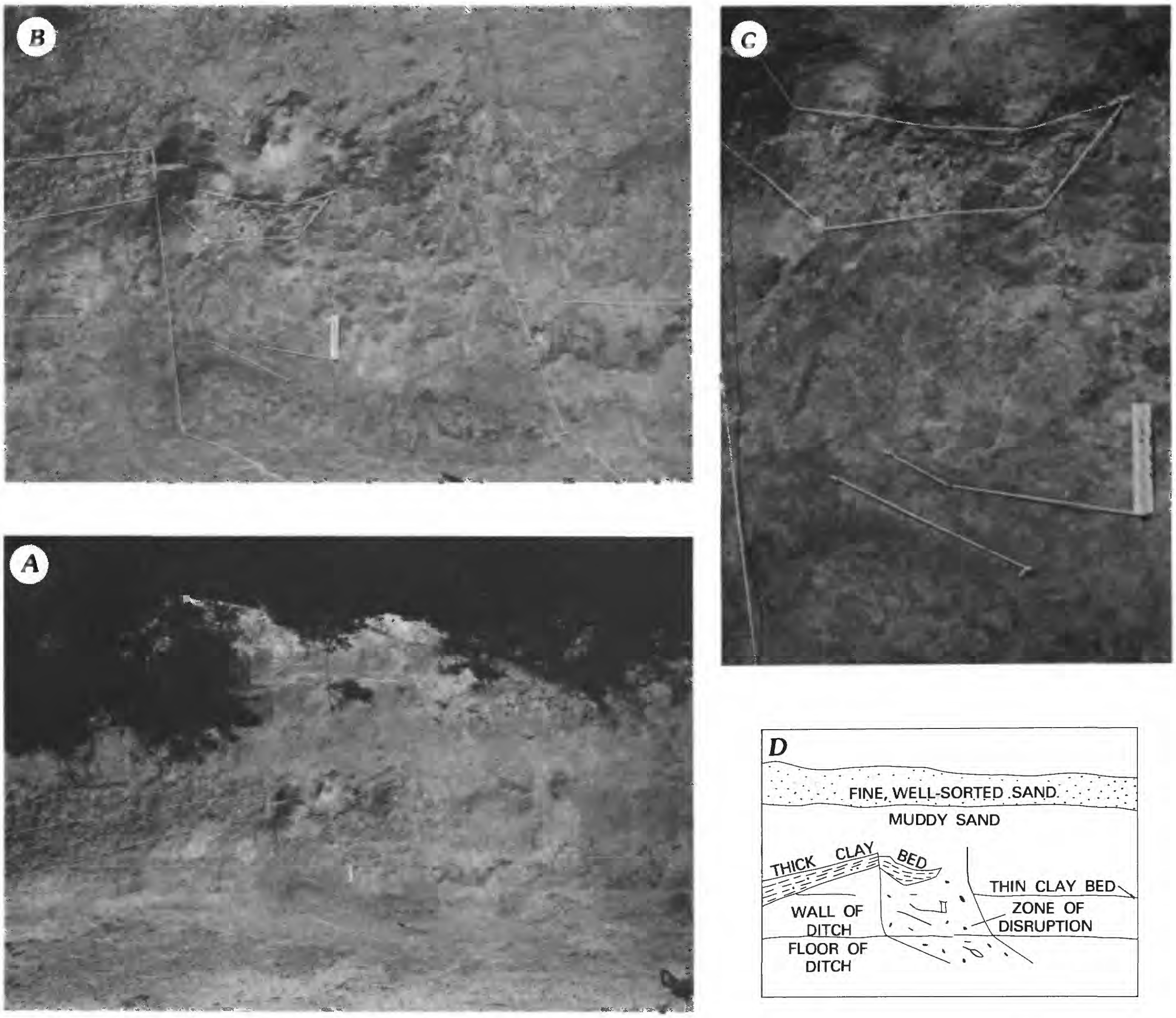

FIGURE 20.—Disrupted Pleistocene unit in railroad embankment west of Goose Creek Reservoir, S.C. (fig. 1*A*). *A*, *B*, and *C* are successively closer views of the disruption zone; ruler is about 18 cm long. *D* is a sketch of *A*. Compare photographs with sketch to determine the nature of the features outlined by the string pinned to the outcrop: a clay bed that was deposited in a backbarrier tidal channel, deeper to the south (left), incised into muddy backbarrier sand; a thin clay bed beveled on its southern end by the tidal channel; and the nearly vertical disruption zone. Mottling is due to weathering; light-colored material at top of bank is a spoil pile, about 0.75 m high, overlying a fine-grained sand unit, about 0.5 m thick, that overlies and postdates the disruption.

major long-term basins (Raritan, Salisbury, Albemarle, southeast Georgia) and arches (South Jersey, Fort Monroe, Cape Fear) (all but New Jersey features are shown in fig. 18). Neither the rate nor the direction of movement of these major structures is constant. Understanding the tectonic style of the Coastal Plain is essential to the correct correlation of Quaternary and older units. Although one or more units can be correlated between adjacent areas on the basis of radiometric dates, fossils, lithology, or a combination of these, the details of the stratigraphic sequence in each area are unique. Sea-level histories, which are based on lithologic sequences, may differ even in nearby areas. This clearly illustrates the local tectonic complication of the theoretical eustatic depositional patterns.

Differential movement of regional arches and basins is evident in the distribution of Mesozoic and Cenozoic sediment of the Atlantic Coastal Plain. Reversals of thickness (Gohn, Bybell, and others, 1978; Gohn, Christopher, and others, 1978) and the absence of certain units

(Owens, 1983) show that these regional structures sometimes moved in the direction opposite to the general trend (that is, arches moving downward with respect to basins and adjacent basins moving at different rates).

SUMMARY

In the Charleston area, 5–25 m of marine and fluvial Quaternary deposits blanket Paleocene to Pliocene units between about 35 m altitude and the sea. There are at least six Quaternary lithostratigraphic units, including the Holocene deposits of unit Q1: unit Q6 has corals older than 1 Ma and backbarrier deposits, which mark approximately the position of sea level, up to 26 m; on the basis of reversed magnetic polarity, unit Q5 is between 1 Ma and 730 ka, and it has backbarrier deposits up to 23 m; unit Q4 is biostratigraphically correlated with a unit at Myrtle Beach, S.C., that contains corals about 500 ka, and it has backbarrier deposits up to 15 m; unit Q3 has corals about 200 ka and backbarrier deposits up to 11 m; and unit Q2 has corals about 100 ka and backbarrier deposits up to 8 m.

Each lithostratigraphic unit has several depositional lithofacies, including (1) beach deposits contained in one or more linear, generally well-sorted sand bodies that parallel the modern coast (these beaches may lie adjacent to older deposits at the inner edge of a bay or on the seaward edge of a barrier); (2) shelf and open-bay deposits consisting of shelly, clean to muddy sand sheets adjacent to and seaward of the beaches; (3) backbarrier deposits consisting of muddy sand bodies landward of the barriers; and (4) fluvial deposits consisting of sinuous, muddy sand belts oriented typically 45 to 90° to the coastline. Younger units bevel older units and lie at progressively lower altitudes. The resulting pattern is complex: “islands” of older material surrounded by younger intertidal deposits; younger sand bodies over older shelf deposits; younger fluvial facies cutting across older marine facies.

One characteristic used to distinguish adjacent or juxtaposed units of different ages is the weathering profile. Weathering is more distinct in older units: the soil profile is thicker, certain primary minerals are selectively dissolved, and secondary minerals become notable.

The oldest Pleistocene deposits, unit Q6, consist of a discontinuous, long, low belt of fine- to medium-grained quartz sand having surface altitudes up to 32 m; muddy sand flats extending northwest (inland) of the sand belt, but at slightly lower altitudes; and shelly, gritty, medium-grained sand extending southeast (seaward of the sand belt) at altitudes of 10 to 15 m beneath younger deposits. We interpret these lithofacies as having been deposited in the beach (Q6b), backbarrier (Q6l), and shelf (Q6o) environments. The biostratigraphic age of the fossils is judged to be early Pleistocene on the basis of fossils from remnants of lithofacies Q6o deposits preserved in channels beneath younger sediment and on the basis of fossils presumably reworked from unit Q6 and found at the base of some unit Q5 deposits. Radiometric dates on corals from the reworked material are older than 1 Ma. The unit is probably a correlative of the Waccamaw Formation of northern South Carolina and southern North Carolina. The weathered sand has little hornblende, epidote, and garnet; the clay fraction of the weathered sand contains abundant kaolinite; and dioctahedral vermiculite, gibbsite, and goethite are present in many samples.

In the area between Summerville and Pinopolis, a large, southward-prograded, intertidal spit system accumulated as unit Q5. It consists of a series of long, slightly muddy sand ridges (lithofacies Q5b) and associated muddy sand flats (lithofacies Q5l) between 28 m and 15 m above sea level. Beneath these lithofacies lies a transgressive shelf deposit (lithofacies Q5o) containing abundant fossils.

In the Bethera area between 19 m and 12 m is a single large, low, clean quartz sand body (lithofacies Q4b) and associated gritty, muddy, medium-grained sand (lithofacies Q4l) deposited after the Summerville spits but before the later Pleistocene units (units Q3 and Q2). Fossils are sparse in unit Q4, and radiometric dates are not available from the Charleston area for this unit. However, on the basis of its position between units Q5 and Q3, we tentatively correlate unit Q4 with the Canepatch Formation of Myrtle Beach 100 km to the north. Mineralogy also suggests significant age differences among most lithofacies of units Q5, Q4, and Q3. The Canepatch Formation in Myrtle Beach has yielded several corals that have an average radiometric age of 450 ka. Some of the deposits labeled unit Q5 at lower altitudes in the western part of the map area may actually be unit Q4.

Undifferentiated fluvial deposits of units Q4 and Q5 (lithofacies Q4–5r) consist of well-sorted to muddy, medium- to coarse-grained sand with or without gravel or a mud matrix and are found mainly along the Salkehatchie-Combahee, Edisto, and Cooper Rivers. The presence of lithofacies Q4–5r deposits in the upper part of the Santee valley and their absence southeast of Lake Moultrie in the Santee valley suggest that the Santee previously occupied the present Cooper River course.

The older of two later Pleistocene units (unit Q3) is exposed as low sand ridges (lithofacies Q3b) below surface altitudes of 16 m and associated muddy sand flats (lithofacies Q3l) below 11 m. Notable amounts of hornblende and epidote are preserved in the weathered part of the sand facies; vermiculite is poorly developed in the clay fraction, and shells are present near the surface. Shelly, fine-grained sand, muddy in places (lithofacies Q3o), is present discontinuously beneath lithofacies Q3b. Corals from two sites yielded radiometric dates of about 200 ka, and this date and fossil faunas support correlation with upper Pleistocene units. Medium- to coarse-grained, poorly sorted fluvial deposits (lithofacies Q3r) are found in the valleys of the Edisto, Cooper, and Santee Rivers.

The youngest Pleistocene unit, exposed in lithofacies Q2b and Q2l, occupies the first beach and backbarrier system, 11 m to 8 m in altitude, behind the Holocene beaches. Alignment of some unit Q2 deposits (lithofacies Q2l) along Holocene rivers indicates reoccupation of older channels. Shelly, muddy sand of lithofacies Q2o is found widely beneath deposits of lithofacies Q2l and Q2b. The fluvial lithofacies (Q2r) is limited, probably by Holocene river erosion, to narrow terraces along the Santee, Stono, and Broad Rivers. Unit Q2 deposits are characterized by a very thin weathering profile and by fresh-looking shells and unweathered heavy minerals near the surface. Unit Q2 has a modern fauna and has yielded corals about 120 to 90 ka.

Holocene deposits (unit Q1) consist of well-sorted sand (lithofacies Q1b) in modern beaches that reach an altitude of 5 m; muddy sand (lithofacies Q1l) in the backbarrier environment below 2 m; subtidal shelly, fine- to medium-grained sand containing muddy layers (lithofacies Q1o) in open bays and on the shelf; poorly sorted, fine- to coarse-grained fluvial deposits (lithofacies Q1r) in modern river channels and flood plains; and swamp deposits (lithofacies Q1s) consisting mainly of fine-grained sand and, rarely, mud and plant fragments. Holocene mud generally is not dewatered, unlike Pleistocene mud.

Delineation of Quaternary stratigraphic units is a prerequisite to determining whether or not tectonism has affected Quaternary sedimentation. If seismicity is a short-term manifestation of tectonism, inferences about the relationship between tectonism and the pattern of Quaternary deposits may help achieve the original goal of the Charleston Project, which was to determine the cause of the 1886 earthquake and the subsequent high level of seismicity in the area. No faults offsetting Quaternary sediment have yet been found in the Charleston area, but within the modern seismic zone and elsewhere in the Charleston area are structures that appear to affect the pattern of some Quaternary deposits. Regional basins and arches also have affected Quaternary sedimentation, but the relationship among these larger structures, the smaller ones, and seismicity is not yet clear.

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Calcareous Nannofossils from Pliocene and Pleistocene Deposits in South Carolina

By LAUREL M. BYBELL

STUDIES RELATED TO THE CHARLESTON, SOUTH CAROLINA,
EARTHQUAKE OF 1886—NEOGENE AND QUATERNARY
LITHOSTRATIGRAPHY AND BIOSTRATIGRAPHY

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1367-B

CONTENTS

ILLUSTRATIONS

[Plate 1 follows references cited]

STUDIES RELATED TO THE CHARLESTON, SOUTH CAROLINA, EARTHQUAKE OF 1886— NEOGENE AND QUATERNARY LITHOSTRATIGRAPHY AND BIOSTRATIGRAPHY

CALCAREOUS NANNOFOSSILS FROM PLIOCENE AND PLEISTOCENE DEPOSITS IN SOUTH CAROLINA

By Laurel M. Bybell

ABSTRACT

Marine Pliocene and Pleistocene units from the South Carolina Coastal Plain yield low-diversity, poorly preserved calcareous nannofossils. Because standard zonations often cannot be applied directly, we substituted other calcareous nannofossil horizons. Nannofossil data used in conjunction with magnetic polarity, uranium-disequilibrium-series dating, and planktonic foraminiferal data result in fairly precise ages for each lithostratigraphic unit: Wando Formation—late Pleistocene, 129,000–87,000 years ago; Ten Mile Hill beds—Pleistocene, 240,000–200,000 years ago; Canepatch Formation—Pleistocene, about 450,000 years ago; Penholoway Formation—Pleistocene, 925,000–700,000 years ago; Waccamaw(?) Formation—early Pleistocene, 1.7–1.25 million years ago; Bear Bluff Formation—late Pliocene, 3.0–1.75 million years ago; Goose Creek Limestone and associated beds—middle Pliocene, 3.9–3.2 million years ago; and Raysor Formation and associated beds—early Pliocene, 5.2–3.9 million years ago.

INTRODUCTION

Pliocene and Pleistocene sediments of the South Carolina Coastal Plain accumulated in a wide variety of marine to nonmarine environments. The resulting mosaic of sedimentary units, combined with the complexity of the existing lithostratigraphic nomenclature, often makes it difficult to assign a formation name to a particular outcrop. Calcareous nannofossils were studied from all the marine Pliocene and Pleistocene units in the Charleston area in order to define the ages of the units, so that some of the lithologic complexities might be resolved. Unfortunately, most of the many samples examined contained no calcareous nannofossils or contained only rare, poorly preserved specimens, and calcareous nannofossils were never abundant. This is probably the result of deposition in shallow-water environments, where the species never were abundant, or the result of postdepositional alteration. Many specimens are poorly preserved as a result of both dissolution and recrystallization. Because of the poor abundance of floras, additional samples were examined from similar units farther north in South Carolina. These samples frequently contained somewhat better, but never diverse, assemblages.

Species occurrences for all the best South Carolina samples are given in this paper, although not all the barren and extremely sparse samples are included. Individual sedimentary units sometimes could be differentiated by calcareous nannofossils, but not always. In this paper, sediments of similar ages are grouped together whenever the terminology for the units is unresolved and they cannot be separated paleontologically. At some later date, these units may be identified lithostratigraphically, but for the present, it seems best to describe the calcareous nannofossils at specific localities.

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MATERIALS AND METHODS

Members of the U.S. Geological Survey (USGS) conducted studies of South Carolina Coastal Plain sediments

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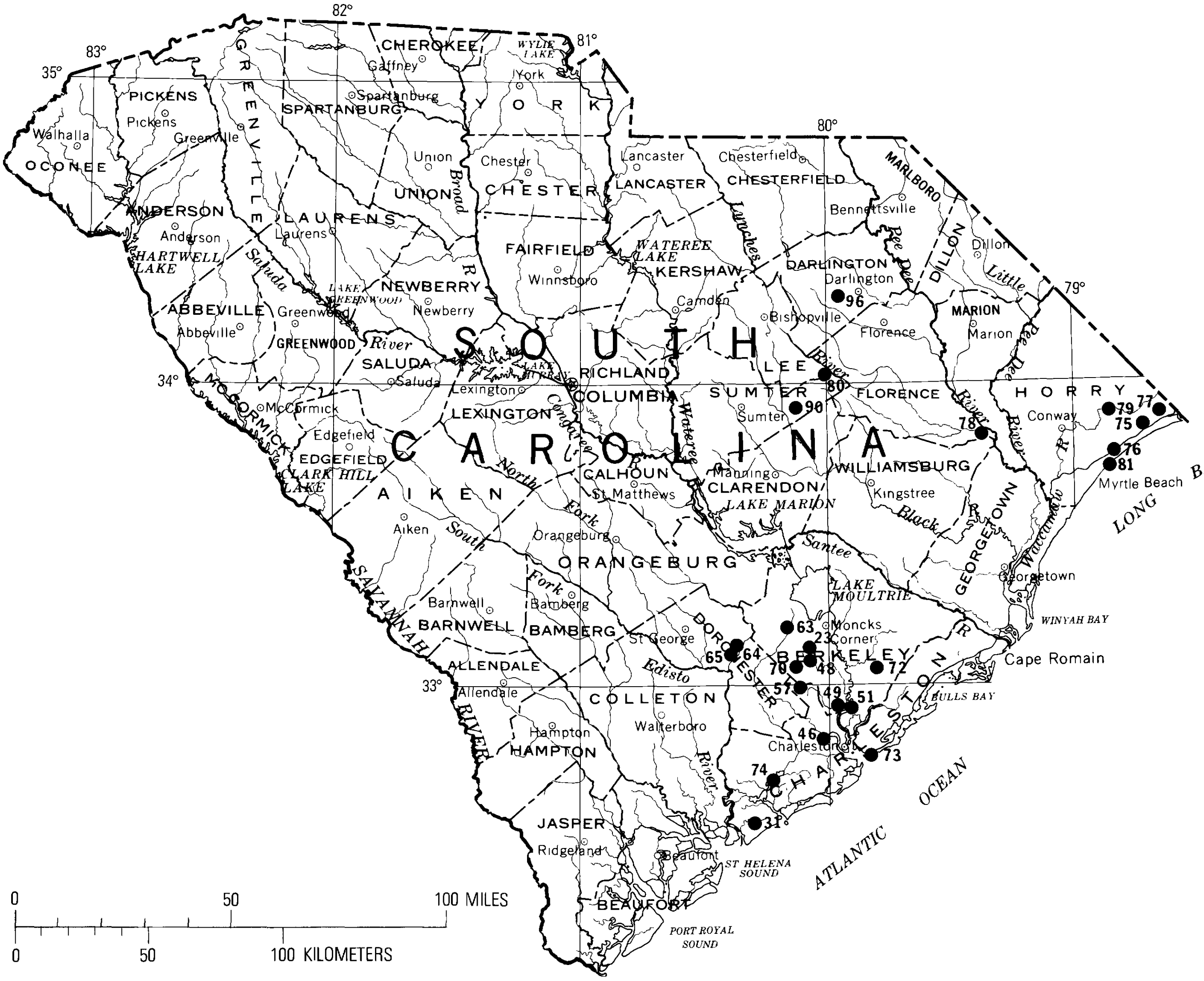

FIGURE 1.—South Carolina sample localities discussed in text and listed in figure 3. Base from U.S. Geological Survey, 1972, scale 1:2,500,000.

from 1973 to 1984. Many samples were collected in the Charleston area, as well as in other parts of the State. Because calcareous nannofossils are found in most marine sediments throughout the world, samples from all of the Pliocene and Pleistocene marine units in South Carolina were processed and examined for their nannofossil content. These samples come from three general areas in South Carolina: near Charleston, farther north near Myrtle Beach, and inland from Myrtle Beach (fig. 1). Most of the samples for this study were collected from outcrops, coreholes, and auger holes by Robert E. Weems, Thomas M. Cronin, and Lucy McCartan of the USGS. Each locality and its specific geographic data are listed by the locality number in the "Locality register" of Weems and McCartan (this volume). The marine sedimentary units that were examined include the Pliocene Raysor Formation, Givhans beds, Goose Creek Limestone, and Bear Bluff Formation and the Pleistocene Waccamaw Formation (unit Q6 of McCartan and others, this volume), Penholoway Formation (unit Q5), Canepatch Formation (unit Q4), Ten Mile Hill beds (unit Q3), and Wando Formation (unit Q2). Table 1 in the introduction to this volume shows these marine units, as well as other Neogene and Quaternary formations in the Charleston area.

Samples were processed as soon as possible after they were collected because of the high organic content of many of these units. If samples are allowed to remain wet in airtight plastic sample bags, the water rapidly becomes very acidic and dissolves the calcareous nannofossils. If samples could not be processed immediately, they were dried in an oven at 60 °C to prevent dissolution. Oven drying at this temperature appears to have no adverse effects on the calcareous nannofossil specimens.

Calcareous nannofossil slides routinely were examined under a light microscope. Because of the poor preservation and low abundance of calcareous nannofossils, routine use of the scanning electron microscope (SEM) was judged to be impractical. Only a few of the better samples were examined by using the SEM.

CALCAREOUS NANNOFOSSIL ZONATION

Martini (1971) and Bukry (1973, 1978) presented detailed calcareous nannofossil zonations for Pliocene sediments (fig. 2), zonations that rely mainly on the occurrences of discoasters and ceratoliths. Unfortunately, only an occasional *Discoaster brouweri*, along with a few discoasters that were unidentifiable as a result of recrystallization, were encountered in this study; there were no ceratoliths in any of the samples. Only one specimen of *Reticulofenestra pseudoumbilica* was observed (pl. 1, fig. 9). Following Backman and Shackleton (1983) and Haq and Berggren (1978), we consider this species to include only large forms at least 5 micrometers in size.

Because the standard zonations cannot be used in South Carolina, we substituted other horizons (fig. 2). The first appearance datum (FAD) of *Pseudoemiliania lacunosa* has been reported to occur well below the last appearance datum (LAD) of *R. pseudoumbilica* in some areas (Gartner and others, 1983; Mazzei and others, 1979; Steinmetz and Stradner, 1984). More commonly, the FAD of *P. lacunosa* is assumed to occur at or slightly above the LAD of *R. pseudoumbilica* (Berggren and others, 1985; Haq and Takayama, 1984; Percival, 1984; Poore and others, 1983; Rio and others, 1984). It is now generally agreed that the LAD of *R. pseudoumbilica* occurs at about 3.5 Mega-annum (Ma, 10^6 years), very near the Gauss-Gilbert magnetic epoch boundary (Backman and Shackleton, 1983; Berggren and others, 1985; Gartner and others, 1983; Haq and Takayama, 1984; Hsu and others, 1984). The FAD of *P. lacunosa* has been reported as old as about 3.9 Ma (Gartner and others, 1983) or as young as 3.4 Ma (Haq and Takayama, 1984), depending upon whether or not an overlap is observed for the ranges of these two species. *R. pseudoumbilica* was found only questionably in South Carolina Pliocene sediments (the one scanning electron micrograph could be the result of contamination), so the overlap with *P. lacunosa* in this region is a moot point. For the purposes of this study, the FAD of *P. lacunosa* at 3.9 Ma is utilized. Cronin and others (1984) used a date of 3.4 Ma for the FAD of *P. lacunosa* in the Atlantic Coastal Plain. However, this was before the LAD of *R. pseudoumbilica* was moved down to 3.5 Ma as a result of redefining this species to include only the larger forms. In addition, Cronin and others (1984) made the assumption that the ranges of these two species probably do overlap.

The LAD of all *Sphenolithus* species, particularly *S. abies* (pl. 1, fig. 8), occurs somewhat above the LAD of *R. pseudoumbilica* (Gartner and others, 1983; Berggren and others, 1985). The LAD of *Discoaster brouweri* occurs somewhere between 1.9 Ma (Berggren and others, 1985) and 1.68 Ma (Haq and Takayama, 1984). Any samples containing *D. brouweri* were assumed to be no younger than 1.68 Ma, as long as reworking was assumed not to occur.

The first appearance of *Gephyrocapsa caribbeanica* (pl. 1, fig. 4) has been placed at 1.68 Ma (Haq and Takayama, 1984) and 1.65 Ma (Rio and others, 1984), and the first appearance of *G. oceanica* (pl. 1, fig. 1) is at 1.65 Ma (Haq and Takayama, 1984) or 1.62 Ma (Rio and others, 1984). This is very near the extinction of *D. brouweri*, and as mentioned by Haq and Takayama (1984), the first appearance of these two *Gephyrocapsa* species is often a good indicator of the Pliocene-Pleistocene boundary if discoasters are sparse. Other small species in the genus *Gephyrocapsa* have been found well down into the Pliocene (Gartner and others, 1983; Rio and others, 1984; Samtleben, 1980; Akers and Koeppel, 1973), and they cannot be used to indicate this boundary. There is considerable confusion in the taxonomy of the small species of *Gephyrocapsa* other than *G. caribbeanica*. Only small species that have a definite crossbar are included in the genus in this study. *G. reticulata*, which lacks a crossbar, is not considered to belong to this genus. The light microscope cannot resolve individual small species that have a crossbar; a scanning electron microscope is essential. In the study area, *G. caribbeanica*, which under optimum conditions can be separated from other small species in this genus, cannot be differentiated by using only the light microscope because of poor preservation of most of the specimens examined. Frequently the crossbars have obvious overgrowths, in many instances almost completely filling the central area. Separation of *G. caribbeanica* is not necessary, however, because no small forms of the genus *Gephyrocapsa* were found to occur in sedimentary units that did not also contain *G. oceanica*. Due to its large size, *G. oceanica* is very easy to identify, and its FAD is used in this study to approximate the Pliocene-Pleistocene boundary. *G. oceanica* has never been reported in Pliocene sediments.

For the Pleistocene units in South Carolina, Gartner's (1977) modification of Martini's (1971) zones can be used with no significant alteration (fig. 2). *Emiliania huxleyi* has not been observed to date in South Carolina, North Carolina, or Virginia (Cronin and others, 1984). As discussed in Cronin and others (1984), this species appears to be absent in lower Zone NN 21 in this area

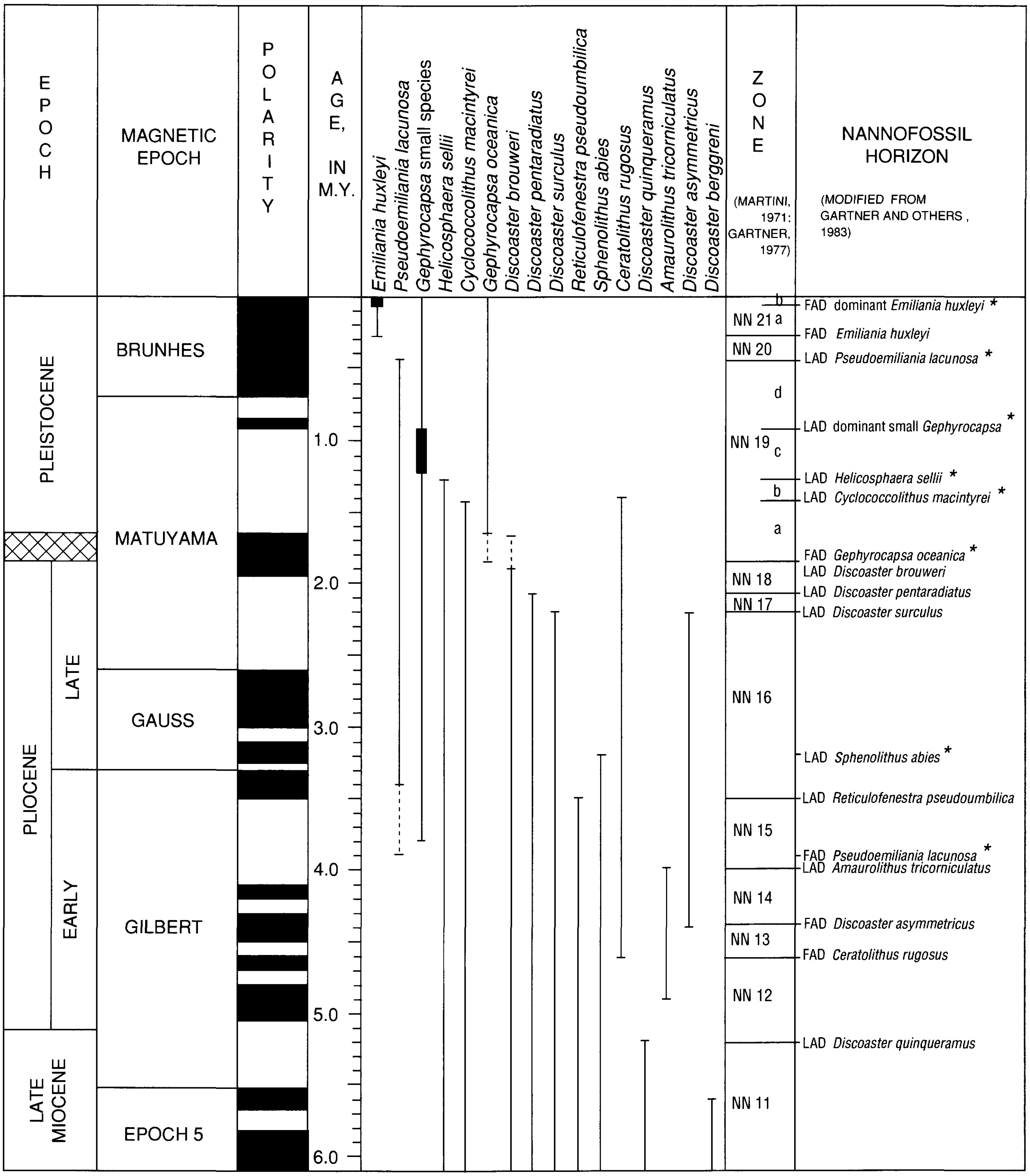

FIGURE 2.—Ranges of key Pliocene and Pleistocene calcareous nannofossil taxa modified from Gartner and others, 1983. Asterisks indicate calcareous nannofossil horizons that were used in South Carolina. Dotted range indicates disputed occurrence interval, and heavy bar indicates the interval when the species was dominant. FAD, first appearance datum; LAD, last appearance datum.

because of the shallow-water environment of deposition. Any sediments younger than the FAD of dominant *E. huxleyi* (upper Zone NN 21) would be expected to contain this species.

In summary, the useful calcareous nannofossil datums for the Pliocene and Pleistocene of the Atlantic Coastal Plain include (1) FAD of dominant *Emiliania huxleyi*—0.075 Ma, (2) LAD of *Pseudoemiliania lacunosa*—0.44 to 0.47 Ma, (3) LAD of dominant small *Gephyrocapsa*—0.925 Ma, (4) LAD of *Helicosphaera sellii*—1.2 to 1.37 Ma, (5) LAD of *Cyclococcolithus macintyrei* (*C. tropicus* of Gartner and others, 1983)—1.42 to 1.5 Ma, (6) FAD of *Gephyrocapsa oceanica*—1.65 to 1.85 Ma, (7) LAD of *Discoaster brouweri*—1.68 to 1.9 Ma, (8) LAD of *Sphenolithus abies*—3.2 to 3.47 Ma, and (9) FAD of *Pseudoemiliania lacunosa*—3.4 to 3.9 Ma.

RESULTS

The marine sedimentary units examined in the study area will be discussed from presumed oldest to youngest units. See the introduction to this volume (table 1) for a list of all the Pliocene and Pleistocene units in the Charleston, S.C., area, and see figure 3 for the occurrences of calcareous nannofossils in South Carolina.

RAYSOR FORMATION AND RELATED BEDS

These sediments cannot be differentiated by using calcareous nannofossils, and their exact lithologic interrelationships are unknown. Included in this category are Raysor Formation samples from the Charleston area (only auger sample PR6 from locality 65 (fig. 1) contained enough species to list in fig. 3), samples of unnamed sediments from outcrop 78TC281 along the Pee Dee River (locality 78) and corehole LB173 (locality 80) southwest of Florence, and auger samples SN12 and PR19 assigned to the Givhans beds (localities 63 and 64 in the Charleston area). Calcareous nannofossil diversity is uniformly low in these samples, and preservation is normally poor. Samples from these beds contain *Cyclococcolithus macintyrei* (pl. 1, figs. 3, 7) and *Helicosphaera sellii* (pl. 1, figs. 5, 6). *Pseudoemiliania lacunosa* has not been observed. It is possible that the absence of *P. lacunosa* may be a result of environmental or preservational factors. A similar situation may occur also in the Yorktown Formation in North Carolina and Virginia. *P. lacunosa* is present both in the basal sediments of and throughout the Yorktown at Lee Creek mine, Aurora, N.C.; however, it is absent from some lower Yorktown samples in Virginia. We do not know whether this indicates older pre-*P. lacunosa* deposits in Virginia or just the absence of the species here due to shallower water conditions.

Several *Reticulofenestra* species occur in the Raysor and related beds, but they are too small to be included with *R. pseudoumbilica*. However, one *R. pseudoumbilica* specimen was observed by using the SEM (pl. 1, fig. 9). This species may be sporadically, but not consistently, present in this area, or conversely, the one specimen may be a result of reworking. Solely on the basis of calcareous nannofossils, these units could be dated only as being late Miocene to early Pliocene in age. However, samples from corehole LB173 and outcrop 78TC281 were examined for planktonic foraminifers, and according to R.Z. Poore (oral commun., 1985), they contain *Globorotalia puncticulata*, which has a FAD somewhat above the base of the Pliocene, and *Globoquadrina altispira*, which has its LAD at 3.9 Ma (Berggren and others, 1985). Combining the foraminiferal data with the calcareous nannofossil data would limit the age of the units from upper Zone NN 12 to Zone NN 15 or from about 5.2 to 3.9 Ma in the Pliocene.

GOOSE CREEK LIMESTONE, BEAR BLUFF FORMATION, AND ASSOCIATED BEDS

This category includes outcrop samples NC2 and NC4 assigned to the Goose Creek Limestone in the Charleston area (localities 49 and 51), outcrop samples 78TC205, 78TC208, 78TC209, and 78TC210 assigned to the Bear Bluff Formation in the Myrtle Beach area (locality 79), and unnamed sediments from corehole LB179 (locality 96) near Darlington and corehole LB173 (locality 80) southwest of Florence. These three units cannot be easily differentiated by using calcareous nannofossils; they normally contain *Pseudoemiliania lacunosa*, *Helicosphaera sellii*, *Cyclococcolithus macintyrei*, and rare *Discoaster brouweri*. All *Gephyrocapsa* species are conspicuously absent. Although preservation is never very good and assemblages are limited, these units contain somewhat better calcareous nannofossil assemblages than the presumably underlying Raysor Formation and related sediments. On the basis of calcareous nannofossil content, these units could range in age from 3.9 to 1.75 Ma or Zone NN 15 to NN 18.

A preliminary study of the Goose Creek Limestone did not find any specimens of *P. lacunosa*, which explains a placement no younger than Zone NN 15 for this unit in Weems and others (1982). Since then, examination of additional material has confirmed the presence of *P. lacunosa* in this unit, as well as a few specimens of *Sphenolithus abies*. If the *S. abies* is not reworked, the

ABUNDANCE	PRESERVATION	*Braarudosphaera bigelowi*	*Coccolithus pelagicus*	*Cruciplacolithus* sp.	*Cyclococcolithus leptoporus*	*Cyclococcolithus macintyrei*	*Cyclococcolithus* sp.	*Discoaster brouweri*	*Discoaster* sp.	*Discolithina multipora*	*Discolithina* sp.	*Gephyrocapsa oceanica*	*Gephyrocapsa* small species	*Helicosphaera carteri*	*Helicosphaera sellii*	*Helicosphaera* sp.	*Pseudoemiliania lacunosa*	*Reticulofenestra pseudoumbilica*	*Sphenolithus abies*	*Thoracosphaera* sp.	Nannofossil number	Sample number	Locality number	Formation (lithostratigraphic unit)	Nannofossil zone	Epoch
F	F	X										X									N1280	MJI7	46	(Q2) WANDO FORMATION	NN 20	PLEISTOCENE
F	P											X	X								N1284	XFM4	73			
A	F	X	X				X					X								X	N1340	78TC72	74C			
F	F	X	X								X	X								X	N1341	78TC73	74B			
F	P	X	X								X	X									N1339	78TC71	74A			
F	F											X								X	N1338	78TC68	31D			
R	P	X										X									N1038	78TC67	31C			
C	P	X	X									X									N1337	78TC66	31B			
F	P	X										X	X								N1039	78TC65	31A			
A	F											X	X								N1283B	XHU1	72	Ten Mile Hill beds (Q3)	NN 21a	
C	P											X	X	X							N1320	78TC19	75C	(Q4) CANEPATCH FORMATION		
F												X	X	X							N1045	78TC91	76H			
R			X									X	X								N1343	78TC90	76G			
R		X										X	X								N1047	NCSC68	76A			
R	P	X	X									X									N1044	78TC89	76F			
R	P		X									X	X								N1043	78TC88	76E			
F		X	X									X									N1042	78TC87	76D			
F	F	X										X	X								N1041	78TC86	76C			
C	G	X										X	X	X							N1342	78TC85	76B			
F	P		X									X	X								N2505	ST24	57	(Q5) PENHOLOWAY FORMATION	NN 19d	
C	P											X	X							X	N2504	MH86	48			
F	F											X	X							X	N2503	CMH9	23			
F	F											X	X				X				N1274	XSU1	70			
F	P	X	X									X	X		X		X				N1034	NCSC70	81	(Q6) WACCAMAW(?) FORMATION	NN 19 a, b	
C	P	X	X									X	X	X	X						N1035	NCSC72	81			
C	F	X	X			X						X	X	X	X						N1319	78TC18	75A			
F	P	X	X			X							X		X		X				N1416	NCSC66	75B			
C	P	X	X				X						X		X		X				N1048	78TC94	77B			
F	F	X	X			X						X	X	X	X		X				N1344	78TC93	77A			
C		X	X				X							X			X				N1054	78TC210	79D	BEAR BLUFF FORMATION	Lower NN 15-NN 18	LATE PLIOCENE
C	P		X				X										X				N1377	78TC209	79C			
F			X												X		X				N1053	78TC208	79B			
C	T		X														X				N1375	78TC205	79A			
			X			X								X	X		X		X	X	N1311	NC4	51	GOOSE CREEK LIMESTONE		
			X			X									X				X		N1289	NC2	49			
C		X	X	X				X						X	X		X				N1069	LB179 (47.5')	96	Unnamed sediments		
C		X	X			X		X						X	X		X				N1071	LB179 (49.5')	96			
C	P	X	X						X		X			X	X		X				N1073	LB179 (51.5')	96			
C	P	X	X			X								X	X		X			X	N1075	LB179 (53.5')	96			
C	P	X	X			X											X				N1082	LB173 (44.5')	80			
C	P	X	X			X									X				X		N1084	LB173 (46.5')	80	Unnamed sediments	Upper NN 12-NN 15	EARLY PLIOCENE
A		X	X			X								X	X					X	N1085	LB173 (47.5')	80			
		X	X			X				X						X					N1086	LB173 (48.5')	80			
C	P	X	X			X									X						N1089	LB173 (51.5')	80			
C	P	X	X			X					X				X			X	X		N1090	LB173 (52.5')	80			
A		X	X												X						N4293	838	90			
C			X												X						N1066	78TC281	78			
C	P		X			X			X						X						N4598	PR6	65	RAYSOR FM		
C	F		X			X					X				X				X	X	N4595	SN12	63	Givhans beds		
C	F		X		X										X						N4597	PR19	64			

FIGURE 3.—Occurrences of calcareous nannofossils in South Carolina. Preservation: G, good; F, fair; P, poor; T, terrible. Abundance: A, abundant (10–100 specimens per field of view at ×600); C, common (1–10 specimens per field of view at ×600); F, frequent (1 specimen per 1–10 fields of view at ×600); R, rare (1 specimen per 10–100 fields of view at ×600).

Goose Creek Limestone age is between 3.9 and 3.2 Ma or Zone NN 15 to mid-Zone NN 16. The unnamed sediments from corehole LB179 at 14.5 m (47.5 ft) contain the planktonic foraminifer *Globorotalia puncticulata*, which occurs no higher than about 3.0 Ma (R.Z. Poore, oral commun., 1985). This confines the age of these unnamed sediments to 3.9 to 3.0 Ma or from Zone NN 15 to mid-Zone NN 16. *G. puncticulata* was not found in the Bear Bluff sample 78TC208 (R.Z. Poore, oral commun., 1985), which may place this formation younger than 3.0 Ma or from 3.0 to 1.75 Ma in the late Pliocene Zones NN 16 to NN 18.

The exact stratigraphic and lithologic relationships among these three units currently are unknown. It is probable that the unnamed sediments from inland South Carolina and the Goose Creek Limestone are older than the Bear Bluff. The stratigraphic relationship between the unnamed sediments and the Goose Creek is unknown at this time.

WACCAMAW(?) FORMATION (UNIT Q6)

The Waccamaw(?) Formation or Quaternary lithostratigraphic unit Q6 of McCartan and others (this volume) contained no calcareous nannofossils in the Charleston area. This unit is believed to correlate with the Waccamaw in northern South Carolina in the Myrtle Beach area (McCartan and others, this volume), where there are six fossiliferous samples. Outcrop samples NCSC66 and 78TC18 from locality 75 contain *Gephyrocapsa oceanica*, *Cyclococcolithus macintyrei*, *Helicosphaera sellii*, and *Pseudoemiliania lacunosa*. This indicates that these samples are from the earliest part of the Pleistocene, Zone NN 19a, and have an age between 1.85 and 1.42 Ma. These samples appear to be from the lower part of the Waccamaw. At locality 77, outcrop sample 78TC93 is also in Zone NN 19a. Outcrop sample 78TC94, which is from the same locality but is 1.4 m (4.5 ft) higher, does not contain *C. macintyrei*. However, it does contain *H. sellii*, which presumably places this sample within Zone NN 19b or about 1.37 to 1.2 Ma. Outcrop samples NCSC70 and NCSC72 from locality 81 also were identified as being from the upper part of the Waccamaw, and both appear to be in Zone NN 19b. The separation of the Waccamaw into two subzones based on the presence or absence of *C. macintyrei* is not recommended, because this may be only an artificial division of the unit due to preservational bias. In either case, the Waccamaw in the Myrtle Beach area is confined to Zone NN 19a or NN 19b or 1.85 to 1.2 Ma. Because this unit has a reversed polarity in that area (Liddicoat and others, 1981; McCartan and others, this volume), the age can probably be more closely limited to 1.7 to 1.2 Ma.

PENHOLOWAY FORMATION (UNIT Q5)

There are four fossiliferous Penholoway samples from four localities in the Charleston area. They are presumed to be equivalent to unit Q5 of McCartan and others (this volume). All four samples are Pleistocene in age on the basis of the presence of *Gephyrocapsa oceanica* and *Gephyrocapsa* small species. The abundance of *Gephyrocapsa* small species does not dominate over that of *G. oceanica*. *Pseudoemiliania lacunosa* was identified in outcrop sample XSU1 (locality 70); it was absent from the other three samples, ST24 (locality 57, auger sample), MH86 (locality 48, corehole sample), and CMH9 (locality 23, auger sample). *P. lacunosa* is never common in any of the South Carolina deposits studied, and its absence from these three samples is believed to be a result of preservational bias. If we assume that sample XSU1, which contains *P. lacunosa*, is representative of the formation, then the Penholoway is in Zone NN 19d and has an age between 925 kilo-annum (ka, 10^3 years) and about 450 ka. A reversed magnetic polarity for this unit (McCartan and others, this volume) supports placement of the formation in Zone NN 19d, because all of the overlying Zone NN 20 falls in a period of normal polarity. One uranium-disequilibrium-series coral date for the Penholoway makes it older than 700 ka (Weems and Lemon, 1984). Combining these data gives an age of 925 to 700 ka for the Penholoway.

CANEPATCH FORMATION (UNIT Q4)

The nine fossiliferous Canepatch samples examined are all from outcrops in the Myrtle Beach area: 78TC85, 78TC86, 78TC87, 78TC88, 78TC89, NCSC68, 78TC90, 78TC91 (all locality 76), and 78TC19 (locality 75). This unit is represented by unit Q4 of McCartan and others (this volume) in the Charleston area. *Pseudoemiliania lacunosa* and *Emiliania huxleyi* are absent from this formation. As discussed in the zonation section of this paper, *Emiliania huxleyi* has never been observed in South Carolina. Because it appears that this species is present only sparsely or is totally absent in the Atlantic Coastal Plain until its acme zone at 75 ka, we would not expect to identify this species in any sediments older than 75 ka. On the basis of this evidence and the fact that the Canepatch has normal magnetic polarity (Liddicoat and others, 1981; McCartan and others, this volume), as well as coral dates clustering about 460 ka (Szabo, 1985), the age of this unit can be placed in the Pleistocene at about 450 ka or in Zone NN 20.

TEN MILE HILL BEDS (OLDER PART OF UNIT Q3)

There is only one fossiliferous sample from this unit; it is from an auger hole in the Charleston area (sample XHU1 from locality 72). This sample contains essentially the same calcareous nannofossil flora as the presumably underlying Canepatch Formation, which places it within Pleistocene Zones NN 20 to NN 21a or 450 to 75 ka. These two units, as well as the overlying Wando Formation, cannot be differentiated by using calcareous nannofossils. All three formations also have normal magnetic polarity (Liddicoat and others, 1981; McCartan and others, this volume). Coral dates for the Ten Mile Hill beds provide much more refinement than is possible using calcareous nannofossils and have placed the formation of this unit between 240 and 200 ka (Weems and Lemon, 1984) or more probably between 230 and 202 ka (Szabo, 1985).

WANDO FORMATION (UNIT Q2)

There are nine fossiliferous Wando Formation samples in the Charleston area: outcrop samples 78TC65, 78TC66, 78TC67, 78TC68 (locality 31); outcrop samples 78TC71, 78TC73, 78TC72 (locality 74); auger sample XFM4 (locality 73); and outcrop sample MJI7 (locality 46). As for the Ten Mile Hill beds, this unit is confined to Pleistocene Zones NN 20 to NN 21a or from 450 to 75 ka on the basis of calcareous nannofossil content only, and it has normal polarity (Liddicoat and others, 1981; McCartan and others, this volume). However, uranium dating of corals within the unit places the probable age of most of the Wando between 129 and 87 ka (Szabo, 1985).

CONCLUSIONS

In spite of usually poor preservation, low diversity, and low abundance, calcareous nannofossils can be used to date Pliocene and Pleistocene South Carolina Coastal Plain marine sediments. When nannofossil data are used in conjunction with magnetic polarity, uranium dating, and planktonic foraminiferal information, fairly precise results are obtained for most units.

The following ages were determined for the marine units examined in South Carolina. The Raysor Formation and associated beds are early Pliocene in age in Zones NN 12–NN 15, 5.2 to 3.9 Ma. The Goose Creek Limestone and associated beds may span the early-late Pliocene boundary in Zones NN 15–NN 16, 3.9 to 3.2 Ma. The Bear Bluff Formation is a late Pliocene unit occurring somewhere within Zones NN 16–NN 18, 3.0 to 1.75 Ma. The Waccamaw(?) Formation occurs in early Pleistocene Zones NN 19a and (or) NN 19b, 1.7 to 1.2 Ma. The Penholoway Formation is in Pleistocene Zone NN 19d, 925 to 700 ka. The Pleistocene Canepatch Formation occurs in Zone NN 20 or about 450 ka. The Ten Mile Hill beds are also of Pleistocene age in Zones NN 20–NN 21a, 240 to 200 ka. And finally, the Wando Formation was deposited in the late Pleistocene in Zones NN 20–NN 21a or from 129 to 87 ka.

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PLATE

A contact photograph of the plate in this report is available,
at cost, from the U.S. Geological Survey Photographic Library, Federal Center,
Denver, CO 80225.

PLATE 1

FIGURE 1. *Gephyrocapsa oceanica* Kamptner, 1943.
  Specimen (×10,000) from auger-hole sample XHU1.

2. *Coccolithus pelagicus* (Wallich, 1877) Schiller, 1930.
  Specimen (×7,800) from corehole sample LB173 at a depth of 16 m (52.5 ft).

3, 7. *Cyclococcolithus macintyrei* Bukry & Bramlette, 1969.
  3. Distal view (×7,200) from corehole sample LB173 at a depth of 16 m (52.5 ft).
  7. Proximal view (×5,000) from corehole sample LB173 at a depth of 16 m (52.5 ft).

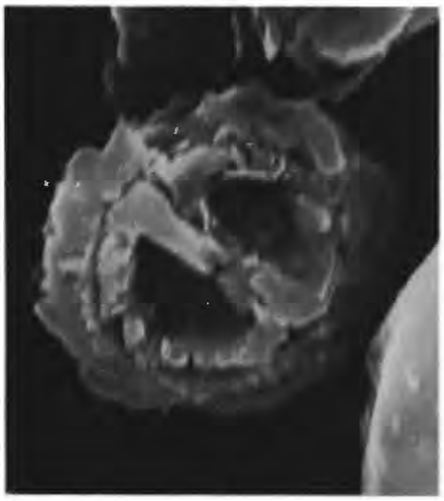
4. *Gephyrocapsa caribbeanica* Boudreaux & Hay, 1967.
  Specimen (×10,000) from auger-hole sample XHU1.

5, 6. *Helicosphaera sellii* (Bukry & Bramlette, 1969) Jafar & Martini, 1975.
  5. Distal view (×4,800) from corehole sample LB173 at a depth of 16 m (52.5 ft).
  6. Proximal view (×5,500) from corehole sample LB173 at a depth of 16 m (52.5 ft).

8. *Sphenolithus abies* Deflandre, 1954.
  Specimen (×12,000) from outcrop sample NC4.

9. *Reticulofenestra pseudoumbilica* (Gartner, 1967) Gartner, 1969.
  Specimen (×5,300) from corehole sample LB173 at a depth of 16 m (52.5 ft).

10, 11. *Braarudosphaera bigelowi* (Gran & Braarud, 1935) Deflandre, 1947.
  10. Specimen (×4,500) from corehole sample LB173 at a depth of 16 m (52.5 ft).
  11. Specimen (×2,200) from corehole sample LB173 at a depth of 16 m (52.5 ft).



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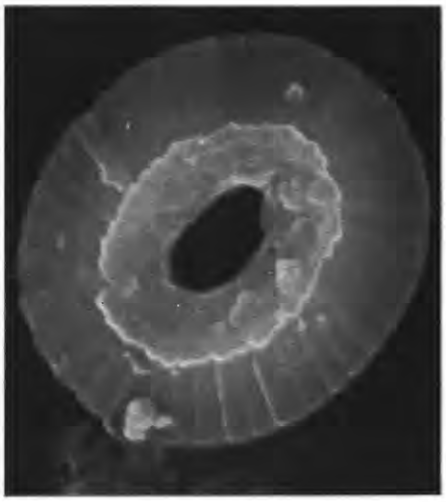

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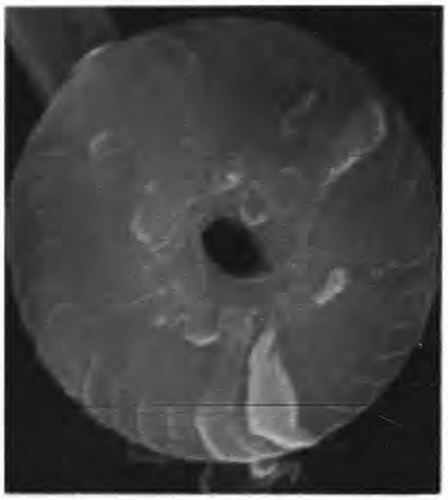

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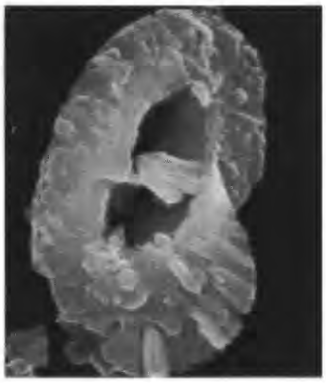

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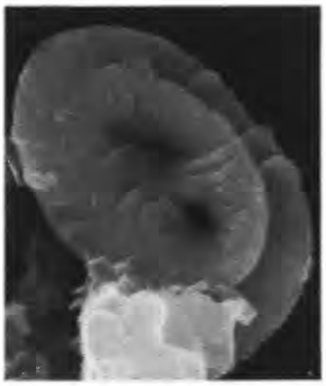

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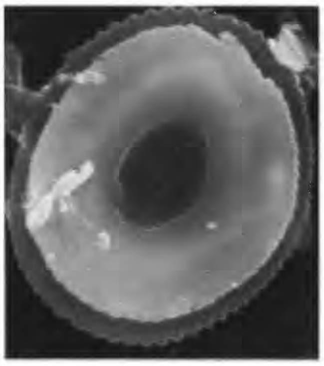

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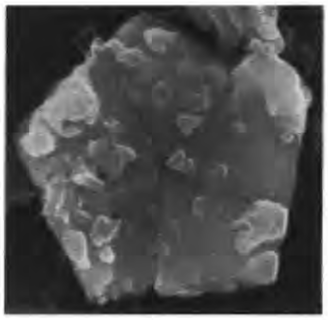

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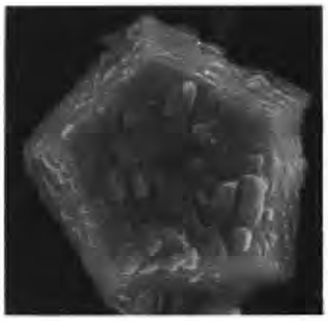

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GEPHYROCAPSA, *COCCOLITHUS*, *CYCLOCOCCOLITHUS*, *HELICOSPHAERA*, *SPHENOLITHUS*, *RETICULOFENESTRA*, AND *BRAARUDOSPHAERA*

Evolution of Neogene and Quaternary Marine Ostracoda, United States Atlantic Coastal Plain: Evolution and Speciation in Ostracoda, IV

By THOMAS M. CRONIN

STUDIES RELATED TO THE CHARLESTON, SOUTH CAROLINA,
EARTHQUAKE OF 1886—NEOGENE AND QUATERNARY
LITHOSTRATIGRAPHY AND BIOSTRATIGRAPHY

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1367-C

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TABLES

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EVOLUTION OF NEOGENE AND QUATERNARY MARINE OSTRACODA, UNITED STATES ATLANTIC COASTAL PLAIN: EVOLUTION AND SPECIATION IN OSTRACODA, IV

By Thomas M. Cronin

ABSTRACT

The evolution of Pliocene and Pleistocene marine Ostracoda from the U.S. Atlantic Coastal Plain suggests a relationship between rates of speciation and climatic and associated oceanographic change. On the basis of evolutionary first appearances of 127 species endemic to the region between Delaware and central Florida, most ostracode species evolved in the early Pliocene (65 species) and the middle Pliocene (29 species) at rates of 40.6 and 48.3 new species per million years, respectively. Only 23 species have evolved in the last 2.8 million years. Oceanographic changes related to the intensification and shifting position of the Gulf Stream during a period of high sea level in the early and middle Pliocene are believed to have been partly responsible for the high rate of species origination. Conversely, frequent, high-amplitude glacial-interglacial cycles of the last 2.8 million years have had little effect on the evolution of new ostracode species. Eleven new species are described, and 71 are illustrated by scanning electron photomicrographs.

INTRODUCTION

Marine Ostracoda are abundant and well preserved in Atlantic Coastal Plain Neogene and Quaternary deposits. They have contributed greatly to our understanding the region's geologic and climatic history (Hazel, 1971a, b; Hazel and others, 1977; Cronin, 1981a, 1988a; Cronin and others, 1981). Ostracodes from the Eastern United States also have shown potential for helping us understand the relationship between climatic events and evolutionary processes such as speciation (Cronin, 1985). Changes in the Earth's climate during the last 5 million years (m.y.), reflected in water-temperature and sea-level changes, have had substantial effects on the zoogeography of organisms living in temperate and subtropical regions along the Eastern United States. Consequently, the region provides a natural laboratory for examining the response of temperature-sensitive species to these environmental events.

This paper is part IV in a series of studies designed to investigate evolution and speciation in Ostracoda. The strategy in this research has been to examine the relationship between patterns of ostracode evolution and possible causes of disruption in the habitat of species ultimately leading to geographic isolation of populations. Three possible causes, summarized in table 1, are being studied.

One of these causes of isolation can be a tectonic event that can result in the formation of a land barrier. An example of a land barrier is the Isthmus of Panama, which formed 3.5 to 3.0 Mega-annum (Ma, 10^6 years) and caused the separation of ostracode populations on either side. This separation, in theory, might have led to evolutionary divergence. Cronin (1987, 1988b) and Cronin and Schmidt (1988) discuss the effects of this event on ostracode species evolving independently on either side of the isthmus since it formed.

A second possible cause of isolation occurs when populations are dispersed by currents from one area to another across a preexisting barrier (table 1). This process represents a fundamentally distinct process from the splitting of a population by the later formation of a barrier, such as the Isthmus of Panama. The relative importance of dispersalist and vicariant processes in explaining the distribution and diversity of organisms is an actively disputed topic in zoogeography. When there is inadequate geologic or paleontologic evidence, it is often difficult to determine if the present zoogeographic

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TABLE 1.—*Possible extrinsic events influencing ostracode evolution*

Extrinsic event	Type of barrier	Degree of isolation	Example	Reference
I. Tectonism	Land	Complete	Isthmus of Panama	Cronin, 1987; Cronin and Schmidt, 1988; and Cronin, 1988b.
II. Rafting by currents	Deep-water	High	Pacific atolls; islands	Cronin, 1988b.
III. Climate:				
a. Shallow- to deep-water transition at continental shelf-slope boundary	Thermocline, O_2 minimum	High	Quaternary sea-level drops	Unpublished.
b. Arctic	Thermal temperature gradient	Variable, low to high	Quaternary glacial periods	Cronin and Ikeya, 1987; and Cronin, 1988c.
c. Temperate-subtropical	do.	do.	North-south continental shelves	This paper.
d. Tropical	do.	do.	North-south continental shelves	Unpublished.

distribution of species reflects dispersal or vicariant splitting by a barrier. However, when paleontologic evidence is available and the tectonic history of the area is known, one alternative may be more likely than the other. In the Cenozoic, several species of shallow-water ostracodes were rafted across tropical regions, most likely on drifting marine algae (Teeter, 1973). The major barrier among populations isolated in this way is the deep-water environment, which most shallow-water species can neither inhabit nor, because they lack planktonic larvae, cross by means of dispersal. Passive dispersal by currents, sometimes over great distances, has been suggested in Cronin (1988b) and Weissleader and others (1989) for some tropical ostracode species recently discovered living on Pacific atolls.

A third possible cause of isolation is a climatic change that would cause sea-level and water-temperature fluctuations (table 1). Sea-level fluctuations result not only in shifts in shoreline position, but also in significant oscillations between shallow and deep water at the transition from the Outer Continental Shelf to the upper slope. In this transition zone, the thermocline, oxygen minimum zone, and lower limit of the euphotic zone form a significant faunal boundary. These last three factors vary in concert with drops in sea level, which reached as much as 100 m during glacial periods.

A climatic change that causes variation in bottom-water temperature results in latitudinal shifts in the zoogeographic distribution of species, and this could lead to varying degrees of isolation among populations. Patterns of ostracode evolution are under study in climatic zones that correspond to marine faunal provinces existing along north-trending continental shelves (fig. 1). Climate affects circumpolar arctic species living in frigid and subfrigid zones so that they migrate south during glacial periods and then retreat north again during subsequent interglacial periods (table 1) (Cronin, 1988c; Cronin and Ikeya, 1987). The converse situation occurs in low latitudes where tropical species migrate north during climatically warm intervals and then retreat south during cool intervals. Cronin (1985, 1987) described such a situation in which speciation patterns in the ostracode genus *Puriana* indicated that new species evolve when populations migrate north from the Caribbean to the Atlantic Coast region.

The present paper describes the evolution of the ostracode fauna inhabiting the mild-temperate to subtropical zones from Delaware to central Florida off the Eastern United States, zones that comprise the Virginian and Carolinian benthic marine faunal provinces of the western North Atlantic (fig. 1). The primary objectives of this paper are (1) to standardize ostracode taxonomy for the Neogene and Quaternary of the region, (2) to use these data to determine the evolutionary first appearances of species endemic to the region, and (3) to examine rates of species origination within the context of climatic and oceanographic events in mild-temperate and subtropical zones.

ACKNOWLEDGMENTS

I want to give special thanks to J.E. Hazel (Louisiana State University) for helpful taxonomic comments and discussions of Coastal Plain ostracodes. R.M. Forester, R.Z. Poore, and Graham Coles provided helpful reviews of early drafts of this manuscript. Lucy McCartan provided samples from the Charleston, S.C., area and a helpful review of the stratigraphy. I also thank S.K. Lyon for information on the Pleistocene ostracodes, E.E.

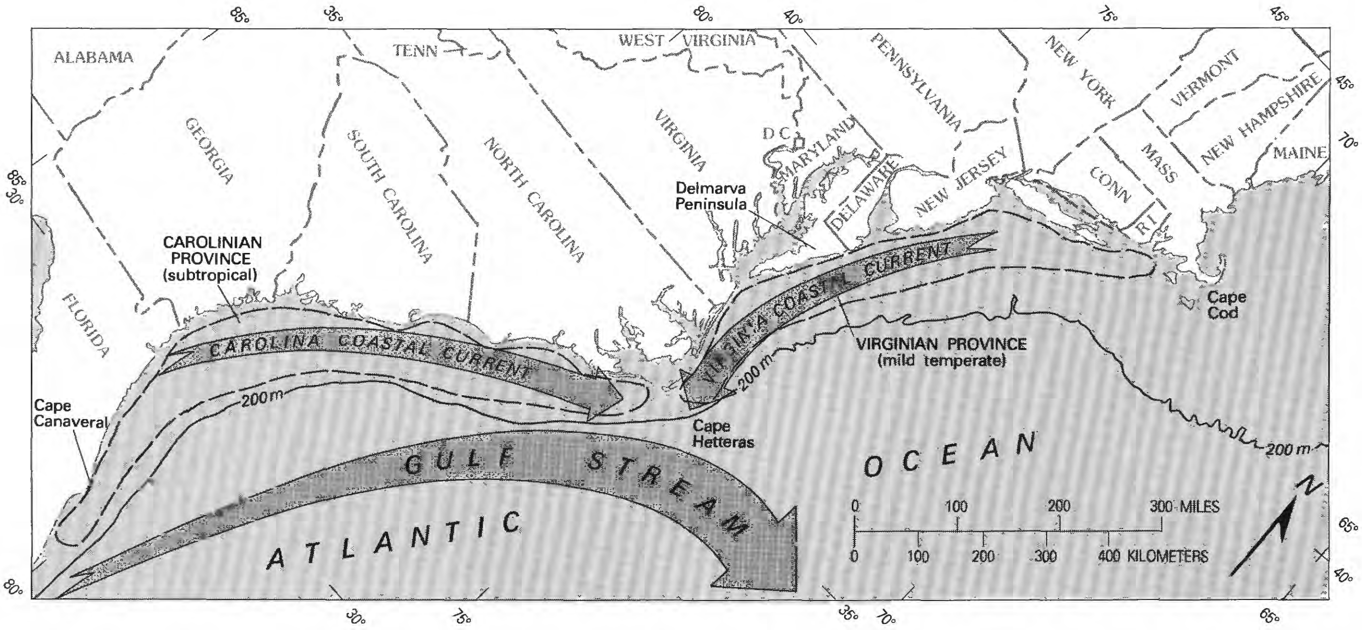

FIGURE 1.—Ostracode marine faunal provinces, associated marine climatic zones (in parentheses), and major ocean currents off the Eastern United States. Provinces for the Atlantic Ocean are taken from Valentine (1971) and Hazel (1970); oceanographic data are taken from Bumpus and Lauzier (1965).

Compton-Gooding for considerable help with the U.S. Geological Survey ostracode collection, and E.G. Shaw for scanning electron photomicroscopy. This work was supported in part by the U.S. Nuclear Regulatory Commission, Office of Nuclear Research, under Agreement No. AT(49–25)–1000.

MATERIAL AND METHODS

In order to study the evolution of ostracodes along the U.S. Atlantic Coast, data from many published Pliocene, Pleistocene, and Holocene ostracode studies were organized taxonomically and stratigraphically. To do this, several hundred ostracode samples were studied from the Coastal Plain collection assembled by the U.S. Geological Survey (USGS) during the past 25 years. Many of these samples came from the early ostracode studies of J.E. Hazel (Hazel, 1968, 1970, 1971a, b, 1975, 1977, 1983; Hazel and Cronin, 1988). Additional material came from studies by Valentine (1971), Cronin (1979), Cronin and Hazel (1980), and Forester (1980). The majority of samples from these earlier studies came from outcrops and cores in Virginia, Maryland, North Carolina, and northeastern South Carolina. To fill the gap for southeastern South Carolina, a newly acquired set of samples from the Charleston, S.C., area (Weems and McCartan, this volume) was studied and is described in the "Systematic paleontology" section below. A related study by Lyon (this volume) also provided information on late Pleistocene ostracodes from the Charleston area. Finally, an extensive collection of modern ostracodes from approximately 500 samples taken on the continental shelf and slope between Maine and Florida during a joint USGS and Woods Hole Oceanographic Institution program between 1963 and 1970 complements the fossil material by providing a comprehensive picture of the modern ostracode fauna. The distribution data of modern species from these collections are given in Hazel (1970) for the northern region between Nova Scotia (just north of Maine in fig. 1) and Cape Cod, Mass., in Valentine (1971) and Hazel (1975) for the central region between New Jersey and northeastern South Carolina, and in Cronin (1983; unpub. data) and Lyon (this volume) for the southern region between South Carolina and the Florida Keys (just south of fig. 1).

The published literature on Neogene and Quaternary marine ostracodes from the Eastern United States is extensive, and in addition to those papers mentioned above, the reader is referred to the bibliography in Garbett and Maddocks (1979) for additional papers about Atlantic and Gulf Coast ostracodes. Modern and fossil ostracodes from backbarrier brackish-water environments also have been the subject of many papers (Tressler and Smith, 1948; Puri, 1960; Darby, 1965; Grossman, 1967; Hall, 1965; Cronin, 1979; Garbett and Maddocks, 1979). Every attempt has been made to make consistent the species-level taxonomy of the USGS collections housed in Reston, Va., with the taxonomy of collections elsewhere, many of which are housed in the U.S. National Museum (USNM) in Washington, D.C.

A standard processing technique was applied to most samples of Coastal Plain sediments. Approximately 50–200 grams of sediment per sample was washed through U.S. standard sieves of no. 230 mesh (63 micrometers) and no. 20 mesh (850 micrometers). When needed, the additives sodium carbonate ($NaCO_3$), hydrogen peroxide, varsol, or a detergent (Quaternary O) were used to break down semiconsolidated sediments. In cases when ostracodes were rare, carapaces and disarticulated valves were concentrated by flotation using soap in water. After drying, the sediment was sieved again, and ostracode specimens were picked from each size fraction by using a fine brush. Specimens were placed on a standard micropaleontological slide and then sorted and identified. No standard quantity of sediment or number of individual ostracode specimens was picked because of the extreme variation in abundance; however, most samples contained between 200 and 300 specimens.

Specimens for most species were coated with a gold and palladium alloy and photographed by using a scanning electron microscope. Most specimens illustrated in this paper are from North and South Carolina and are deposited in the Department of Paleobiology, USNM.

GEOLOGIC AND CLIMATIC FRAMEWORK

The Atlantic Coastal Plain, including the emerged part and the submerged shelf, represents the inner edge of a passive continental margin that has been relatively stable during the Cenozoic. The geologic history and stratigraphy of the Atlantic margin have been studied intensely in the last decade, and a summary can be found in Poag (1985). The history of the area involves the formation of a series of sedimentary basins that have been influenced strongly by eustatic sea-level changes. The stratigraphic correlations among geologic formations of the emerged Atlantic Coastal Plain have been collated by Carter (1984), and they provide a useful framework for this study. In addition, Cronin and others (1984), by using several geochronological techniques, have estimated the ages and correlations of the fossiliferous marine units that yielded the ostracodes studied here. For the purposes of calculating rates of speciation, the last 10 Ma are divided here into the following nine intervals of time on the basis of geochronological data summarized in Blackwelder (1981) and in Cronin and others (1984) (geologic formations are given in parentheses): late Miocene, 10.0–5.0 Ma (Eastover Formation); early Pliocene, 5.0–3.4 Ma (Yorktown Formation, zone 1); middle Pliocene, 3.4–2.8 Ma (Duplin Formation, Goose Creek Limestone; Yorktown Formation, zone 2); late Pliocene, 2.8–2.0 Ma (Bear Bluff, Chowan River Formations); early Pleistocene, 2.0–0.7 Ma (Waccamaw, Wicomico, Penholoway, James City Formations); early middle Pleistocene, 0.7–0.4 Ma (Omar Formation at Dirickson Creek, Del., of Cronin and others, 1984; Canepatch, Talbot Formations); late middle Pleistocene, 0.4–0.18 Ma (Flanner Beach, Pamlico Formations; Great Bridge Formation of Oaks and Coch, 1973); late Pleistocene, 0.18–0.07 Ma (Core Creek sand; Norfolk Formation of Clark and Miller, 1906; Kempsville Formation of Oaks and Coch, 1973; Wando, Socastee, Sinepuxent Formations); and Wisconsinan-Holocene, 0.07 Ma to present.

Several factors that are related to the regional tectonic setting of the study area have implications for benthic organisms living along the continental margin. First, because the continental shelf is wide, a large habitable area existed during periods of high sea level, but most of the shelf habitat for benthic organisms was eliminated during a typical late Pleistocene sea-level drop of 100 m. Second, the primary mechanism affecting paleogeography over the last 5 m.y. has been the repeated glacioeustatic sea-level changes, which were frequent and rapid compared with tectonic movements (Cronin, 1981b). Climatic and sea-level oscillations that occurred approximately every 10^3 to 10^6 years constituted major abiotic events that affected the habitats of benthic marine organisms living on the shelf. Third, the region is characterized by a variety of coastal habitats found in lagoons, bays, and estuaries. These environments, which shifted back and forth across the shelf during glacioeustatic transgressive-regressive cycles provided, at least in theory, opportunities for varying degrees of isolation among populations living in shelf and marginal-marine environments.

Bottom-water temperatures are known to influence the broad zoogeographic distribution of ostracodes because the survival and (or) reproduction of many species are limited by temperature (Hazel, 1970). The following brief summary of the oceanography of the region (fig. 1) is taken from Bumpus and Lauzier (1965) and Hazel (1975). The region between Cape Cod, Mass., and Cape Hatteras, N.C., has been referred to as the mild-temperate marine climatic zone. The Virginia coastal current is a primary current influencing the oceanography of the region. It flows southward along the Delmarva Peninsula, southeastern Virginia, and northeastern North Carolina. The area is characterized by bottom-water temperatures in winter between about 4 and 10 °C and in summer between about 20 and 26 °C (Hazel, 1970; Valentine, 1971). The region south of Cape Hatteras to Cape Canaveral, Fla., is considered to be a subtropical marine climatic zone having winter temperatures never below 10 °C and summer temperatures between about 25 and 30 °C. The oceanography of the outer shelf and upper slope is dominated by the flow of the Gulf Stream and the underlying Carolina slope water. Nearshore, the Carolina coastal current flows northward toward Cape Hatteras, where it meets the southward-flowing Virginia coastal current and creates a region of strong isothermal convergence (Hazel, 1975).

The modern climatic conditions represent a relatively warm interval that is similar to interglacial periods of the Pleistocene. Significantly, the strength and position of the Gulf Stream have varied greatly during the last 5 m.y. of climatic change. The following summary briefly outlines the climatic history of the region based on studies by Hazel (1971a), Blackwelder (1981), Riggs (1984), Cronin and others (1984), and Cronin (1988a). The most relevant climatic factors for the present paper are (1) the frequency of climatic oscillations, the understanding of which requires accurate geochronology, and (2) the intensity or amplitude of climatic oscillations that can be documented by extremes of cold and warmth during glacial and interglacial periods.

The frequency of climatic oscillations has varied during the last few million years. During the early Pliocene, a relatively cool climate existed between Virginia and South Carolina (Hazel, 1971a). In the middle Pliocene, about 3.2 Ma or slightly earlier, a significant climatic warming occurred in this region, and simultaneously, faunal provinces became more distinct as temperate faunas north of Cape Hatteras became differentiated from subtropical to tropical faunas to the south. This faunal dichotomy is evident in the faunal dissimilarity between assemblages from the contemporaneous upper part of the Yorktown (zone 2) and the Duplin Formations. One hypothesis proposed by Hazel (1971a) postulates that the relatively sudden influx of tropical ostracodes and other marine organisms reflects the increased influence of the Gulf Stream. This idea is supported by other evidence that the Gulf Stream intensified between about 3.5 and 3.0 Ma (Cronin and others, 1984; Cronin, 1988a). The frequency of climatic oscillations during this extended period of warmth and high sea level is difficult to determine at present, and the oscillations may have been of an amplitude too low to detect. Recent data from North Carolina suggest that cyclic climatic fluctuations are indeed difficult to recognize by using paleontologic data from the early and middle Pliocene (Snyder and others, 1986).

The late Pliocene record between about 2.8 and 2.0 Ma is poorly represented by datable marine sediments in the Coastal Plain. This depositional hiatus signifies a substantial drop in eustatic sea level that corresponded with the beginning of major Pleistocene-like glaciations in the Northern Hemisphere (Cronin, 1988a). Shackleton and others (1984) provide evidence from deep-sea cores for glacial buildup 2.5 to 2.4 Ma.

During the early Pleistocene, another extended period of warm climate, similar to that in the early and middle Pliocene, is represented by the Waccamaw Formation in North and South Carolina. If climatic oscillations occurred during the early Pleistocene, their amplitudes were not great enough to be recorded in the sediments and faunas of the Waccamaw.

During the last several hundred thousand years, the climatic record has been predominated by glacial-interglacial oscillations, of which only the warm intervals, representing eustatic high stands of sea level, are known from the emerged Coastal Plain. A good correspondence exists between periods of high sea level, warm climates in the Coastal Plain (Cronin and others, 1981; Cronin, 1983, 1988a), and the timing of warm periods of Milankovitch climatic cycles documented in deep-sea cores (Hays and others, 1976). Many interglacial deposits have been dated by using uranium-disequilibrium-series techniques (Szabo, 1985), and many contain pollen assemblages indicating interglacial terrestrial floras.

Glacial conditions during the middle and late Pleistocene also have been determined from paleontologic evidence such as the southward shifts of arctic and subarctic ostracodes found in isostatically uplifted marine deposits in the Northeastern United States and eastern Canada (Brady and Crosskey, 1871; Cronin, 1981a, 1988c). Hazel (1968) documented cooler water faunas representing glacial periods in samples from submarine canyons between Massachusetts and North Carolina. Bernhard and Cronin (1982) and Cronin (1988a) also found similar faunas in cores off the coast of New Jersey. These data provide evidence that cooling during glacial periods caused cold-water species to migrate as much as several degrees of latitude south of their present range.

In summary, high-frequency, high-amplitude climatic oscillations characterize the Pleistocene. This mode of climatic change is distinct from periods of extended warmth in the Pliocene when oscillations, if present, were of relatively low amplitude.

PALEONTOLOGIC DATA

The need for paleontologic data to test evolutionary models has been emphasized by Vrba (1984) and Maynard Smith (1982). For example, the fossil record has been cited as the testing ground for comparing the Red Queen model of biotic diversity (Van Valen, 1973), which states that evolution is driven by biotic interactions, with the Stationary model (Stenseth and Maynard Smith, 1984), which calls for extrinsic events as the force behind evolutionary trends (see Hoffman, 1984). However, some authors (Schopf, 1982; Levinton and others, 1986)

TABLE 2.—*Ostracode taxa excluded from evolutionary computations in this study*

Predominantly bathyal genera	Rare genera	Cryophilic taxa	Thermophilic taxa
Argilloecia	*Basslerites*	*Baffinicythere emarginata* (sars, 1865)	*Acuticythereis laevissima* Edwards, 1944.
Cytherella	*Bythocythere*	*Cythere lutea* (Müller, 1785)	*Bairdoppilata* sp.
Henryhowella	*Hirschmannia*	*Elofsonella concinna* (Jones, 1857)	*Cativella navis* Coryell and Fields, 1937.
Jonesia	*Paradoxostoma*	*Finmarchinella finmarchica* (Sars, 1865)	*Caudites paraasymmetricus* Hazel, 1983.
Macrocypris	*Pontocythere*	*Hemicythere villosa* (Sars, 1865)	*Cytherelloidea umbonata* Edwards, 1944.
Paracypris	*Propontocypris*	*Heterocyprideis fascis* (Brady and Norman, 1889)	*Hemicytherura cranekeyensis* Puri, 1953.
	Sahnicythere	*Leptocythere angusta* (Blake, 1933)	*Hermanites ascitus* Hazel, 1983.
	Sclerochilus	*Palmenella limicola* (Norman, 1865)	*Neonesidea gerda* (Benson and Coleman, 1963).
			Orionina vaughani (Ulrich and Bassler, 1904).
			Palaciosa minuta (Edwards, 1944).
			Paranesidea sp.
			Pellucistoma magniventra Edwards, 1944.
			Phlyctocythere sp.
			Radimella confragosa (Edwards, 1944).
			Reticulocythereis sp.
			Triebelina sp.
			Xestoleberis sp.

have criticized the use of the paleontologic record for evolutionary study because paleontologists do not deal with real "biological" species and because rare or stratigraphically short-ranging taxa are omitted. Other studies have been equivocal as to whether the fossil record could be used to test evolutionary models (Hoffman and Kitchell, 1984). Consequently, we should state clearly the exact nature and the limitations of the ostracode data used here.

The data used in this paper meet several prerequisites for evolutionary study for three main reasons. First, occurrences of species were determined from direct examination of fossil and recent populations, rather than compiled from the literature. This approach is preferred over taxonomic compilation because judgment can be used in selecting species to be included or excluded (see below). It ensures a taxonomically up-to-date set of data having an internal consistency that is difficult to achieve by using taxonomy taken from monographs. Additionally, the data have the advantage of broad geographic sample coverage that includes not only the immediate study area but also adjacent regions. Second, ostracodes have biological characteristics that enhance our confidence that we are dealing with real biological species. Their ontogeny involves growth through molting, and the distinction between adult individuals and juvenile instars can be accomplished easily by using carapace features. Most species reproduce sexually, and sexual dimorphism is expressed in the size and shape of the adult carapace, so that males and females can be discriminated from each other. Further, the carapace contains many species-specific morphologic features (such as eye tubercles, muscle scars, and normal pore canals) that represent homologous reference points that are useful in phylogenetic analysis (Cronin, 1987). Third, a large percentage of the species used in this study live along the Atlantic Coast today, so that collections of these are available for comparison. Firsthand knowledge of the ecology, zoogeography, and morphology of a species is an advantage in the study of fossil populations.

An important requirement of paleontological studies of speciation is the need to distinguish between true evolutionary appearances and migration from other areas. To accomplish this objective, only well-known species indigenous to the continental shelf from the Delmarva Peninsula to Florida (fig. 1) were analyzed in the computations below. Species that belong to bathyal genera that live on the continental slope, species that were rare (one or two specimens in a single sample), and species that evolved in other climatic zones (cryophilic and thermophilic species from arctic and tropical climatic zones, respectively) were culled from the data set (see table 2). By eliminating selected species, we introduce a certain degree of subjectivity into the analysis, but these species are not numerically important constituents of shelf-ostracode assemblages. Further, although the study area cannot be considered a closed system, knowledge of ostracodes from its margins (the continental slope and regions to the north and south) increases the probability that first appearances of fossils in the Coastal Plain are true evolutionary appearances and not migrations from other areas. The well-studied genus *Neocaudites* illustrates this point. Tropical and subtropical in habitat, species of *Neocaudites* that occur in the study area are believed to have evolved there during the Pliocene; Coastal Plain occurrences predate first appearances in the Caribbean.

In such cases where phylogenetic and biogeographic evidence shows that a species evolved in the study area, that species is included in the analysis. This contrasts with the species that are widespread outside the study area (*Finmarchinella finmarchica*, for example, see Neale, 1974) and that evolved elsewhere. It is, of course, not possible to identify the exact location of the population giving rise to a new species, but the data generally allow the identification of the zoogeographic province in which most species evolved.

The major factor limiting the accuracy of the age of each evolutionary first appearance of ostracode species is the incomplete stratigraphic record that lacks marine deposits corresponding to periods of eustatic low sea level. Thus, to estimate the time interval during which each new species evolved, a range of age estimates was used for the geologic formation in which the species first occurs.

RESULTS

Table 3 lists 127 species endemic to mild-temperate and subtropical climatic zones of the western Atlantic Ocean. It also lists the names used by earlier workers to provide a convenient synonym chart. Table 4 shows the last 5 m.y. divided into distinct intervals, and it separates the regions north and south of Cape Hatteras, N.C., into the Virginian and Carolinian faunal provinces, respectively, in order to show the diachrony of stratigraphic ranges for species in the two areas. This list forms the basis of the computations below. In table 4, the biostratigraphic range is given for each species that evolved in the Virginian (Cape Cod to Cape Hatteras) and Carolinian (Cape Hatteras to Cape Canaveral) faunal provinces (fig. 1).

Table 5 summarizes the data in table 4 by treating the Eastern United States as a single region. I combined the Virginian and Carolinian endemic species and then subtracted species common to both. For convenience, calculated variables are labeled *A* through *K*. *A* is the total number of species for a given time interval for the entire region. *B* is the number of those species still extant, and *C* is the percent of total species extant. *D* is the total number of endemic (sensu latu) species living in mild- and warm-temperate and subtropical regions (Cape Cod to Cape Canaveral), but this excludes cold-temperate and tropical species, which are included in the value *E*. *F* is the number of endemic species (*D*) that are extant, and *G* is the percent of endemic species extant. *H* is the number of species first appearing in the region during each time interval. Because migration from regions north of Cape Cod and south of Cape Canaveral has been eliminated as an explanation for the first stratigraphic occurrence of an endemic species, the value *H* represents real evolutionary first appearances. *I* divides the evolutionary first appearances, *H*, by the duration of each time interval, *J*, to give a rate of speciation. *K* is the midpoint of the time interval used to plot the data. Because the study was limited to the Pliocene and Pleistocene, a late Miocene total for diversity was not calculated. However, examination of material from the study of Miocene ostracodes by Forester (1980) shows that 10 species out of the 127 total species first appeared in the late Miocene (table 5).

The values for the Wisconsinan-Holocene represent a special case because of the great number of modern samples available. Of the 127 total endemic species, 67 are living on the shelf today; three of these (*Finmarchinella finmarchica*, *Leptocythere angusta*, *Hemicythere emarginata*) are considered to have evolved elsewhere. Hazel (1975) found 126 total species of modern ostracodes in 38 samples from the Virginian and Carolinian provinces in the Cape Hatteras region. Of this total, Hazel judged 76 species to be common (occurring in 4 or more samples). From Hazel's complete list of 126 species, I omitted the same types of species listed in table 2 that were omitted from the fossil data, which left a total of 78 species, roughly the same as Hazel's independently derived estimate of common species. Thus, about 75–80 ostracode species are considered to be common in the modern Virginian and Carolinian regions.

SPECIES DIVERSITY

The pattern of ostracode species diversity shown in figure 2 is characterized by high diversity in the early and middle Pliocene and the early Pleistocene (about 90–110 species) and generally by lower diversities during the late Pliocene, middle and late Pleistocene, and Holocene (about 60–80 species). The pattern for endemic species (fig. 2*B*) roughly parallels that for total species (fig. 2*A*) because the number of thermophilic and cryophilic species does not change much. High diversity during the Pliocene reflects the species-rich faunas of the Yorktown and Duplin Formations. In an early study of Yorktown ostracodes, Hazel (1971b) found 230 species, 80 of which occurred in 5 or more of his 46 samples. Although this number might appear to be anomalously high, Hazel's total includes ostracodes from several stratigraphic units subdivided here into the lower and upper Yorktown and the Chowan River Formations. These are represented by the early, middle, and late Pliocene and early Pleistocene categories in tables 4 and 5. Further, Hazel's total does not exclude those species omitted from my analysis (table 2).

TABLE 3.—*Synonyms for 127 Neogene and Quaternary ostracode*

[Names used by earlier workers are shown below. Biostratigraphic occurrence data are summarized in table 4 for nine time intervals for the Virginian and Carolinian faunal

Species name	Hazel, 1971a	Valentine, 1971	Hazel, 1977	Cronin, 1979
Actinocythereis captionis Hazel, 1983	*A.* sp. B	*A.* aff. *A. gomillionensis*	*A. captionis*	*A.* sp. A
A. dawsoni (Brady, 1870)	*A. dawsoni*	*A. dawsoni*	*A. dawsoni*	—
A. marylandica (Howe and Hough, 1935)	*A.* cf. *A. marylandica*	—	—	—
A. mundorfi Swain, 1951	*A. mundorfi*	—	*A. mundorfi*	—
A. aff. *A. bahamaensis* (Brady, 1868)	—	—	—	—
Aurila laevicula Edwards, 1944	*A. laevicula*	—	*A. laevicula*	*A. laevicula*
Bensonocythere americana Hazel, 1967	*B. americana*	*B. americana*	—	*B. americana*
B. arenicola (Cushman, 1906)	—	—	—	—
B. blackwelderi Hazel, 1983	*B.* spp. J and K	*B.* sp. G	—	—
B. bradyi Hazel, 1983	*B.* sp. R	—	*B. bradyi*	—
B. calverti (Ulrich and Bassler, 1904)	—	—	*B. calverti*	—
B. florencensis Cronin n. sp.	—	—	—	—
B. gouldensis Hazel, 1983	*B.* sp. B	—	*B. gouldensis*	—
B. hazeli Cronin n. sp.	—	*B.* sp. E	*B.* sp. M	—
B. hollyensis Cronin n. sp.	—	—	—	—
B. ricespitensis Hazel, 1983	*B.* sp. N	—	*B. ricespitensis*	—
B. rugosa Hazel, 1983	*B.* sp. O	—	*B. rugosa*	—
B. sapeloensis (Hall, 1965)	—	*B. sapeloensis*	—	*B. sapeloensis*
B. trapezoidalis (Swain, 1974)	—	—	*B. trapezoidalis*	—
B. valentinei Cronin n. sp.	—	*B.* sp. D	—	*B.* spp. B and O
B. whitei (Swain, 1951)	*B. whitei*	*B. whitei*	*B. whitei*	*B. whitei*
B. aff. *B. americana* Hazel, 1967	—	*B.* sp. A	—	—
B. aff. *B. blackwelderi* Hazel, 1983	—	*B.* sp. B	—	—
B. sp. D	*B.* sp. D.	—	—	—
Campylocythere laeva Edwards, 1944	*C. laeva*	*C. laeva*	—	*C. laeva*
Climacoidea gigantica (Edwards, 1944)	—	*Proteoconcha gigantica*	—	*P. gigantica*
C. jamesensis (Hazel, 1983)	*Proteoconcha* sp. E	—	—	—
C. mimica (Plusquellec and Sandberg, 1969)	—	—	—	—
C. multipunctata (Edwards, 1944)	*Proteoconcha multipunctata*	—	—	—
C. nelsonensis (Grossman, 1967)	—	*Proteoconcha nelsonensis*	—	*P. nelsonensis*
C. tuberculata (Puri, 1960)	—	*Proteoconcha tuberculata*	—	*P. tuberculata*
Cushmanidea seminuda (Cushman, 1906)	*C.* sp. I	*C. seminuda*	—	*C. seminuda*
Cytheridea campwallacensis Hazel, 1983	*C.* sp. B	—	*C. campwallacensis*	—
C. carolinensis Hazel, 1983	*C.* sp. G	—	*C. carolinensis*	—
C. virginiensis (Malkin, 1953)	*C. virginiensis*	—	*C. virginiensis*	—
C. sp. A	—	—	—	—
Cytheromorpha curta Edwards, 1944	—	—	—	*C. curta*
C. fuscata (Brady, 1870)	—	*C.* sp. A	—	*C. fuscata*
C. incisa Hazel, 1983	*C.* sp. D	—	*C. incisa*	—
C. macroincisa Hazel, 1983	—	—	*C. macroincisa*	—
C. newportensis Williams, 1966	—	*C. warneri newportensis*	—	*C. newportensis*
C. suffolkensis Hazel, 1983	*C.* sp. C	—	*C. suffolkensis*	—
C. warneri Howe and Spurgeon, 1935	*C. warneri*	—	—	—
Cytheropteron talquinensis Puri, 1953	*C. talquinensis*	*C. talquinensis*	—	—
C. yorktownensis (Malkin, 1953)	*C. yorktownensis*	—	*C. yorktownensis*	—

species from the Atlantic Coastal Plain

provinces. Data are given for 127 mild-temperate and subtropical species. See text for discussion. —,species did not occur]

Cronin and Hazel, 1980	Forester, 1980	Cronin, 1981b	Hazel, 1983	Lyon, this volume
A. captionis	—	—	*A. captionis*	*A. captionis*
—	—	*A. dawsoni*	*A. dawsoni*	—
—	—	*A. marylandica*	*A. marylandica*	—
—	—	—	*A. mundorfi*	—
—	—	*A.* sp. H	—	—
—	—	—	*A. laevicula*	*A. laevicula*
—	—	—	—	—
—	—	—	—	—
—	—	—	*B. blackwelderi*	—
—	—	—	*B. bradyi*	—
—	*B. calverti*	—	*B. calverti*	—
B. aff. *B. bradyi*	—	*B.* sp. E	*B.* sp. PP	—
B. gouldensis	—	*B.* spp. B and C	*B. gouldensis*	—
—	—	*B.* sp. A	*B.* sp. M	—
—	—	*B.* sp. EE	*B.* sp. OO	—
B. ricespitensis	—	*B.* sp. AA	*B. ricespitensis*	—
B. rugosa	—	*B.* sp. R	*B. rugosa*	—
—	—	*B.* sp. B	—	*B. sapeloensis*
—	—	—	*B. trapezoidalis*	—
B. sp. D	—	*B.* sp. D	—	*B. valentinei*
B. whitei	—	*B. whitei*	*B. whitei*	*B. whitei*
—	—	—	—	—
—	—	—	—	—
—	—	—	—	—
—	—	*C. laeva*	*C. laeva*	*C. laeva*
—	—	—	*P. gigantica*	*P. gigantica*
—	—	—	*P. jamesensis*	—
—	—	—	*P. mimica*	—
—	—	—	*P. multipunctata*	—
—	—	—	—	*P. nelsonensis*
—	—	—	*P. tuberculata*	*P. tuberculata*
—	—	—	*C. seminuda*	*C. seminuda*
—	—	—	*P. campwallacensis*	—
—	—	—	*C. carolinensis*	—
—	*C. virginiensis*	*C. virginiensis*	*C. virginiensis*	—
—	—	—	*C.* aff. *C. virginiensis*	—
—	—	—	*C. curta*	*C. curta*
—	—	—	—	—
—	—	—	*C. incisa*	—
—	—	—	*C. macroincisa*	—
—	—	—	—	*C. newportensis*
—	—	—	*C. suffolkensis*	—
—	—	—	*C. warneri*	—
—	—	—	—	—
—	*C.? yorktownensis*	—	—	—

TABLE 3.—*Synonyms for 127 Neogene and Quaternary ostracode*

[Names used by earlier workers are shown below. Biostratigraphic occurrence data are summarized in table 4 for nine time intervals for the Virginian and Carolinian faunal

Species name	Hazel, 1971a	Valentine, 1971	Hazel, 1977	Cronin, 1979
Cytherura carolinensis Cronin n. sp.	—	—	—	—
C. elongata Edwards, 1944	—	—	—	—
C. fiscina Garbett and Maddocks, 1979	—	*C. forulata*	—	—
C. forulata Edwards, 1944	—	—	—	*C. forulata*
C. howei Puri, 1953	*C. howei*	*C. howei*	—	*C. howei*
C. neusensis Cronin n. sp.	—	*C.* sp. D	—	*C.* sp. B
C. nucis Garbett and Maddocks, 1979	—	—	—	*C. nucis*
C. pseudostriata Hulings, 1966	—	*C. pseudostriata*	—	*C. pseudostriata*
C. reticulata Edwards, 1944	—	*C. reticulata*	—	*C. reticulata*
C. sablensis Benson and Coleman, 1963	—	—	—	*C. sablensis*
C. valentini Garbett and Maddocks, 1979	—	*C.* sp. A	—	*C.* sp. A
C. wardensis Howe and Brown, 1935	—	*C. wardensis*	—	—
C. sp. A	—	—	—	—
C. sp. B	—	—	—	—
Echinocythereis leecreekensis Hazel, 1983	—	*E.* sp. A	*E. leecreekensis*	—
E. planibasalis (Ulrich and Bassler, 1904)	*E. planibasalis*	—	—	—
Eucythere declivis (Norman, 1865)	*E. declivis*	*E. declivis*	—	—
E. gibba Edwards, 1944	*E. gibba*	*E. gibba*	—	*E. gibba*
E. triangulata Puri, 1953	—	*E. triangulata*	—	*E. triangulata*
Hulingsina americana (Cushman, 1906)	*H. americana*	*H.* sp. A	—	—
H.? cylindrica (Ulrich and Bassler, 1904)	—	—	—	—
H. glabra (Hall, 1965)	—	*H. glabra*	—	*H. glabra*
H. rugipustulosa (Edwards, 1944)	*H. rugipustulosa*	*H. rugipustulosa*	—	*H. rugipustulosa*
H. sp. A	—	*H.* sp. B	—	*H.* sp. A
H. sp. B	—	*H. americana*	—	*H.* sp. B
H. sp. C	—	*H.* sp. D	—	*H.* sp. D
H. sp. D	*H. ashermani*	*H.* sp. C	—	*H.* sp. C
Loxoconcha carolinensis Cronin n. sp.	—	—	—	—
L. edentonensis Swain, 1951	*L. edentonensis*	—	*L. edentonensis*	—
L. florencensis Cronin n. sp.	*L.* spp. M and H	—	—	—
L. matagordensis Swain, 1955	—	*L. matagordensis*	—	*L. matagordensis*
L. purisubrhomboidea Edwards, 1953	—	—	—	—
L. reticularis Edwards, 1944	*L. reticularis*	*L. reticularis*	—	*L. reticularis*
L. sperata Williams, 1966	—	*L. sperata*	—	*L. sperata*
L. aff. *L. florencensis* Cronin n. sp.	—	*L.* aff. *L. granulata*	—	*L.* sp.
L. cf. *L. impressa*	*L. impressa*	—	—	—
L. sp. A	—	—	*L.* sp. A	—
Malzella conradi (Howe and McGuirt, 1935)	*Radimella conradi*	—	*M. conradi*	—
M. evexa Hazel, 1983	—	—	*M. evexa*	—
M. floridana (Benson and Coleman, 1963)	*Radimella floridana*	*Aurila floridana*	—	"*A.*" *floridana*
M. aff. *M. evexa* Hazel, 1983	—	—	—	—
Muellerina bassiounii Hazel, 1983	*M.* sp. D	—	*M. bassiounii*	—
M. blowi Hazel, 1983	*M.* sp. F	—	*M. blowi*	—
M. canadensis (Brady, 1870)	*M.* aff. *M. canadensis*	*M. canadensis*	—	
M. ohmerti Hazel, 1983	*M.* sp. A	*M.* aff. *M. lienenklausi*	—	*M.* sp. A

species from the Atlantic Coastal Plain—Continued

provinces. Data are given for 127 mild-temperate and subtropical species. See text for discussion. —,species did not occur]

Cronin and Hazel, 1980	Forester, 1980	Cronin, 1981b	Hazel, 1983	Lyon, this volume
—	—	*C.* sp. HH	—	—
—	—	—	*C. elongata*	—
—	—	—	*C.* sp. BB	—
—	—	—	*C. forulata*	*C. forulata*
—	—	—	*C. howei*	—
—	—	—	—	—
—	—	*C. nucis*	—	*C. nucis*
—	—	*C. pseudostriata*	—	—
—	—	—	*C. reticulata*	—
—	—	*C. sablensis*	—	—
—	—	—	—	*C. valentini*
—	—	—	*C. wardensis*	*C. wardensis*
—	—	—	*C.* sp. AA	—
—	—	*C.* sp. II	—	—
E. leecreekensis	—	—	*E. leecreekensis*	—
—	—	—	*E. planibasalis*	—
—	—	—	*E. declivis*	—
—	—	—	*E. gibba*	—
—	—	—	*E. triangulata*	—
—	—	—	*H. americana*	*H. americana*
—	*H. cylindrica*	*H.* sp. CC	—	—
—	—	—	*H. glabra*	*H. glabra*
—	*H. rugipustulosa*	*H.* sp. EE	*H. rugipustulosa*	*H. rugipustulosa*
—	—	—	—	*H.* aff. *H. rugipustulosa*
—	—	*H.* sp. I	*H.* sp. C	*H.* aff. *H. semicircularis*
H. sp. N	—	—	—	*H.* sp.
—	—	—	*H.* sp. F	—
—	—	*L.* sp. R	—	—
L. edentonensis	—	*L. edentonensis*	*L. edentonensis*	—
L. sp. B	—	*L.* spp. P and S	*L.* sp. H	—
L. matagordensis	—	—	*L. matagordensis*	*L. matagordensis*
—	—	—	*L. purisubrhomboidea*	—
—	—	—	*L. reticularis*	*L. reticularis*
—	—	—	—	—
—	—	*L.* sp. B	—	*L. florencensis*
—	—	—	*L.* sp. C	—
L. sp. A	—	*L.* sp. A	—	—
M. conradi	—	*M. conradi*	*M. conradi angulata*	—
M. evexa	—	"*A.*" sp. A	*M. evexa*	—
M. floridana	—	"*A.*" *floridana*	—	—
—	—	—	*M. evexa* (part)	*M. evexa*
M. bassiounii	—	*M.* sp. D	*M. bassiounii*	—
—	—	—	*M. blowi*	—
—	—	—	*M. ohmerti*	*M. ohmerti*

TABLE 3.—*Synonyms for 127 Neogene and Quaternary ostracode*

[Names used by earlier workers are shown below. Biostratigraphic occurrence data are summarized in table 4 for nine time intervals for the Virginian and Carolinian faunal

Species name	Hazel, 1971a	Valentine, 1971	Hazel, 1977	Cronin, 1979
M. petersburgensis Hazel, 1983	—	—	*M. canadensis petersburgensis*	—
M. wardi Hazel, 1983	*M.* sp. E	—	*M. wardi*	—
M. aff. *M. ohmerti* Hazel, 1983	—	—	—	—
Murrayina barclayi McLean, 1957	*M. barclayi*	—	*M. barclayi*	—
M. macleani Swain, 1974	—	—	—	—
Neocaudites angulata Hazel, 1983	—	—	—	—
N. atlantica Cronin, 1979	—	*N.* sp. A	—	*N. atlantica*
N. subimpressa (Edwards, 1944)	—	—	—	—
N. triplistriata (Edwards, 1944)	—	—	*N. triplistriatus*	—
N. variabilis Hazel, 1983	—	—	—	—
Neolophocythere subquadrata Grossman, 1967	—	*N. subquadrata* and *N.* sp. A	—	*N. subquadrata*
Paracytheridea altila Edwards, 1944	*P. altila*	*P. altila*	—	*P. altila*
P. cronini Hazel, 1983	—	—	*P. edwardsi*	—
P. hazeli Cronin n. sp.	—	*P.* sp. A	—	*P.* sp. A
P. mucra Edwards, 1944	*P. mucra*	—	*P. mucra*	—
P. rugosa Edwards, 1944	—	*P. rugosa*	—	*P.* cf. *P. rugosa*
P. washingtonensis Puri, 1953	—	—	—	—
Protocytheretta reticulata (Edwards, 1944)	*P.* sp. D	—	—	—
P. sahnii (Puri, 1952)	—	*P.* aff. *P. sahnii*	—	*P.* aff. *P. sahnii*
Pseudocytheretta cf. *P. burnsi* (Ulrich and Bassler, 1904)	—	—	—	—
P. edwardsi Cushman, 1906	—	*P. edwardsi*	—	—
Pterygocythereis alophia Hazel, 1983	—	*P.* sp. A	—	*P.* sp. A
P. inexpectata (Blake, 1929)	*P. inexpectata*	*P. americana inexpectata*	*P. inexpectata*	—
Puriana carolinensis Hazel, 1983	*P.* sp. D	*P.* sp. A	*P. carolinensis*	*P.* sp.
P. convoluta Teeter, 1975	—	—	*P. convoluta*	*P. convoluta*
P. floridana Puri, 1960	—	*P. floridana*	—	*P. floridana*
P. mesacostalis (Edwards, 1944)	*P. mesacostalis*	—	*P. mesacostalis*	—
P. rugipunctata (Ulrich and Bassler, 1904)	*P. rugipunctata*	*P. rugipunctata*	—	—
Tetracytherura choctawhatcheensis (Puri, 1953)	*M. choctawhatcheensis*	*M. choctawhatcheensis*	*M. choctawhatcheensis*	*M. choctawhatcheensis*
T. expanda (Hazel, 1983)	*Microcytherura* sp. A	—	*M. expanda*	—
T. *mccartanae* Cronin n. sp.	—	*M.* sp. A	—	*M.* sp. A
T. minuta (Hazel, 1983)	*M.* sp. O	—	*M. minuta*	—
T. norfolkensis (Cronin, 1979)	—	*M.* sp. B	—	*M. norfolkensis*
T. owensi Cronin n. sp.	—	—	—	—
T. similis (Malkin, 1953)	*M. similis*	—	*M. similis*	—
Thaerocythere carolinensis Hazel, 1983	—	—	*T. carolinensis*	—
T. schmidtae (Malkin, 1953)	*T. schmidtae*	—	*T. schmidtae*	—

species from the Atlantic Coastal Plain—Continued

provinces. Data are given for 127 mild-temperate and subtropical species. See text for discussion. —, species did not occur]

Cronin and Hazel, 1980	Forester, 1980	Cronin, 1981b	Hazel, 1983	Lyon, this volume
—	—	*M.* sp. A	*M. canadensis petersburgensis*	—
M. wardi	—	*M.* sp. C	*M. wardi*	—
M. sp. B	—	*M.* sp. B	—	—
—	—	—	*M. barclayi*	—
—	—	—	*M. macleani*	—
—	—	—	*N. angulatus*	—
N. triplistriatus	—	*N. atlantica*	—	*N. atlantica*
—	—	*N. subimpressus*	*N. subimpressus*	—
—	—	—	*N. triplistriatus*	—
N. variabilis	—	—	*N. variabilis*	—
—	—	—	—	—
P. altila	*P. altila*	—	*P. altila*	*P. altila*
P. edwardsi	—	*P.* sp. B	*P. cronini*	—
P. sp. A	—	*P.* sp. A	—	*P. hazeli*
P. mucra	—	*P. mucra*	*P. mucra*	—
P. rugosa	—	—	*P. rugosa*	*P. rugosa*
—	—	—	—	—
—	—	—	—	—
—	—	—	—	*P.* cf. *P. sahnii*
—	*P. burnsi*	—	*P. burnsi*	—
—	—	—	—	—
—	—	—	*P. alophia*	*P. alophia*
—	—	*P. inexpectata*	*P. inexpectata*	—
P. carolinensis	—	*P.* sp. A	*P. carolinensis*	*P. carolinensis*
P. convoluta	—	—	*P. convoluta*	—
—	—	—	—	*P. floridana*
P. mesacostalis	—	*P. mesacostalis*	*P. mesacostalis*	—
—	*P. rugipunctata*	—	*P. rugipunctata*	—
M. choctawhatcheensis	—	—	*M. choctawhatcheensis*	—
M. expanda	—	*M.* sp. M	*M. expanda*	—
M. sp. C	—	*M.* sp. D	*M.* sp. R	*M. mccartanae*
M. minuta	—	*M. minuta*	*M. minuta*	—
—	—	—	—	—
M. sp. B	—	*M.* sp. B	—	—
M. similis	*M. similis*	*M. similis*	*M. similis*	—
—	—	—	*T. carolinensis*	—
—	*T. schmidtae*	—	*T. schmidtae*	—

TABLE 4.—*Biostratigraphic ranges for 127 Neogene and Quaternary ostracode species from the Atlantic Coastal Plain*

[Data for 127 mild-temperate and subtropical species are summarized for nine time intervals for the Virginian and Carolinian faunal provinces. —, not present; X, present]

Species name	Virginian province									Carolinian province								
	Late Miocene	Early Pliocene	Middle Pliocene	Late Pliocene	Early Pleistocene	Early-middle Pleistocene	Late-middle Pleistocene	Late Pleistocene	Holocene	Late Miocene	Early Pliocene	Middle Pliocene	Late Pliocene	Early Pleistocene	Early-middle Pleistocene	Late-middle Pleistocene	Late Pleistocene	Holocene
Actinocythereis captionis Hazel, 1983	—	X	X	X	X	—	X	X	X	—	X	X	X	X	X	—	X	X
A. dawsoni (Brady, 1870)	X	X	X	—	X	—	—	—	X	—	X	X	—	—	—	—	—	—
A. marylandica (Howe and Hough, 1935)	X	X	X	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—
A. mundorfi Swain, 1951	—	X	X	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—
A. aff. *A. bahamaensis* (Brady, 1868)	—	—	—	—	—	—	—	—	—	—	X	X	—	—	—	—	—	—
Aurila laevicula Edwards, 1944	—	X	X	—	X	—	—	—	X	—	X	X	X	X	X	—	X	X
Bensonocythere americana Hazel, 1967	—	X	X	X	—	—	X	X	X	—	—	—	—	—	—	—	—	—
B. arenicola (Cushman, 1906)	—	X	—	—	—	—	—	X	X	—	—	—	—	—	—	—	—	—
B. blackwelderi Hazel, 1983	—	X	X	X	—	—	—	X	—	—	—	—	—	—	—	—	—	—
B. bradyi Hazel, 1983	—	—	X	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—
B. calverti (Ulrich and Bassler, 1904)	X	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
B. florencensis Cronin n. sp.	—	—	—	X	—	—	—	—	—	—	X	X	X	—	—	—	—	—
B. gouldensis Hazel, 1983	—	X	X	X	—	—	—	—	—	—	X	X	X	X	—	—	—	—
B. hazeli Cronin n. sp.	—	—	—	—	X	—	—	—	—	—	—	—	X	X	X	X	X	X
B. hollyensis Cronin n. sp.	—	—	—	X	—	—	—	—	—	—	—	X	—	X	X	—	—	—
B. ricespitensis Hazel, 1983	—	—	—	X	X	—	—	—	—	—	—	X	X	X	—	—	—	—
B. rugosa Hazel, 1983	—	X	X	X	—	—	—	—	—	—	X	X	X	X	—	—	—	—
B. sapeloensis (Hall, 1965)	—	—	—	—	—	—	X	X	X	—	—	—	—	X	X	—	X	X
B. trapezoidalis (Swain, 1974)	—	X	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
B. valentinei Cronin n. sp.	—	—	—	—	—	—	X	X	X	—	—	—	X	X	X	X	X	X
B. whitei (Swain, 1951)	—	—	—	X	X	—	X	X	X	—	—	X	X	X	X	X	X	X
B. aff. *B. americana* Hazel, 1967	—	—	—	—	—	—	—	X	X	—	—	—	—	—	—	—	—	—
B. aff. *B. blackwelderi* Hazel, 1983	—	X	—	—	—	—	—	X	X	—	—	—	—	—	—	—	—	—
B. sp. D	—	X	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Campylocythere laeva Edwards, 1944	—	X	X	X	X	—	X	X	X	—	X	X	X	X	X	X	X	X
Climacoidea gigantica (Edwards, 1944)	—	—	—	X	X	—	X	X	X	X	X	X	—	X	X	X	X	X
C. jamesensis (Hazel, 1983)	—	X	X	X	—	—	—	—	—	—	—	—	—	X	—	—	—	—
C. mimica (Plusquellec and Sandberg, 1969)	—	—	X	—	—	—	—	—	—	—	—	X	—	X	—	—	—	—
C. multipunctata (Edwards, 1944)	—	X	X	X	X	—	X	—	—	—	X	X	X	X	X	X	—	X
C. nelsonensis (Grossman, 1967)	—	—	—	—	—	—	X	X	X	—	—	X	—	X	X	—	X	X
C. tuberculata (Puri, 1960)	—	—	—	X	—	—	X	X	X	—	—	X	X	X	X	X	X	X
Cushmanidea seminuda (Cushman, 1906)	—	—	—	—	X	—	X	X	X	—	—	—	—	X	—	—	—	X
Cytheridea campwallacensis Hazel, 1983	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
C. carolinensis Hazel, 1983	—	—	—	X	X	—	—	—	—	—	—	—	—	—	—	—	—	—
C. virginiensis (Malkin, 1953)	—	X	X	X	X	—	—	—	—	—	X	X	—	—	—	—	—	—
C. sp. A	—	—	—	—	—	—	X	X	—	—	—	—	—	—	—	—	—	—
Cytheromorpha curta Edwards, 1944	—	—	—	X	—	—	—	—	—	—	—	X	—	X	X	—	X	X
C. fuscata (Brady, 1870)	—	—	—	—	—	—	X	X	X	—	—	—	—	—	—	—	—	—
C. incisa Hazel, 1983	X	—	X	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—
C. macroincisa Hazel, 1983	—	—	—	X	X	—	—	—	—	—	—	—	—	—	—	—	—	—
C. newportensis Williams, 1966	—	—	—	—	—	—	X	X	X	—	—	X	—	X	X	—	X	X
C. suffolkensis Hazel, 1983	—	—	X	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—
C. warneri Howe and Spurgeon, 1935	X	X	X	X	—	—	—	—	—	—	X	X	—	—	—	—	—	—
Cytheropteron talquinensis Puri, 1953	—	X	X	X	X	—	—	—	—	—	X	X	X	X	X	—	—	—
C. yorktownensis (Malkin, 1953)	—	X	X	X	X	—	—	—	—	—	X	X	X	X	X	—	—	—

TABLE 4.—*Biostratigraphic ranges for 127 Neogene and Quaternary ostracode species from the Atlantic Coastal Plain*—Continued

[Data for 127 mild-temperate and subtropical species are summarized for nine time intervals for the Virginian and Carolinian faunal provinces. —, not present; X, present]

Species name	Virginian province									Carolinian province								
	Late Miocene	Early Pliocene	Middle Pliocene	Late Pliocene	Early Pleistocene	Early-middle Pleistocene	Late-middle Pleistocene	Late Pleistocene	Holocene	Late Miocene	Early Pliocene	Middle Pliocene	Late Pliocene	Early Pleistocene	Early-middle Pleistocene	Late-middle Pleistocene	Late Pleistocene	Holocene
Cytherura carolinensis Cronin n. sp.	—	—	—	—	—	—	—	—	—	—	X	X	—	—	—	—	—	—
C. elongata Edwards, 1944	—	X	X	—	X	—	—	—	X	—	X	X	X	X	X	—	X	X
C. fiscina Garbett and Maddocks, 1979	—	—	—	X	X	—	—	X	X	—	X	X	X	X	X	—	X	X
C. forulata Edwards, 1944	—	X	X	X	X	—	X	X	X	—	X	X	—	X	X	—	X	X
C. howei Puri, 1953	—	X	X	X	X	—	X	X	X	—	—	X	X	X	X	—	X	X
C. neusensis Cronin n. sp.	—	—	—	—	X	—	X	X	X	—	—	X	X	X	X	X	X	X
C. nucis Garbett and Maddocks, 1979	—	—	—	—	—	—	—	—	—	—	—	X	—	X	X	—	X	X
C. pseudostriata Hulings, 1966	—	—	—	—	—	—	—	X	X	—	—	X	—	X	X	—	X	X
C. reticulata Edwards, 1944	—	—	X	X	X	—	X	X	X	—	—	X	X	X	X	—	X	X
C. sablensis Benson and Coleman, 1963	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	X
C. valentini Garbett and Maddocks, 1979	—	—	—	—	—	—	X	X	X	—	—	—	—	—	—	—	X	X
C. wardensis Howe and Brown, 1935	—	X	X	X	X	—	X	X	X	—	—	X	—	—	—	X	—	—
C. sp. A	—	—	—	X	X	—	—	—	—	—	—	—	—	—	—	—	—	—
C. sp. B	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—
Echinocythereis leecreekensis Hazel, 1983	—	—	—	X	—	—	—	—	—	—	—	X	X	X	X	—	X	X
E. planibasalis (Ulrich and Bassler, 1904)	—	X	X	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—
Eucythere declivis (Norman, 1865)	—	X	—	X	X	—	X	X	X	—	—	—	—	—	—	—	—	X
E. gibba Edwards, 1944	—	X	X	X	X	—	—	X	X	—	X	X	X	X	X	X	X	X
E. triangulata Puri, 1953	—	—	—	X	—	—	—	—	—	—	X	X	X	X	X	X	X	X
Hulingsina americana (Cushman, 1906)	—	X	X	X	X	—	X	X	X	—	X	X	X	X	X	X	X	X
H.? cylindrica (Ulrich and Bassler, 1904)	X	—	X	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—
H. glabra (Hall, 1965)	X	—	—	X	X	—	X	X	—	—	—	X	X	X	X	—	X	X
H. rugipustulosa (Edwards, 1944)	—	X	X	X	X	—	X	X	X	—	X	X	X	X	X	X	X	X
H. sp. A	—	—	—	—	X	—	X	X	X	—	X	X	X	X	X	X	X	X
H. sp. B	—	X	X	X	X	—	X	X	X	—	X	X	X	X	X	X	X	X
H. sp. C	—	—	—	—	—	—	X	X	X	—	—	X	—	X	X	—	X	X
H. sp. D	—	—	—	X	X	—	X	X	X	—	—	X	X	X	X	X	X	X
Loxoconcha carolinensis Cronin n. sp.	—	—	—	—	—	—	—	—	—	—	X	X	—	—	—	—	—	—
L. edentonensis Swain, 1951	—	—	—	X	X	—	—	—	—	—	X	X	X	X	X	—	—	—
L. florencensis Cronin n. sp.	—	X	—	X	X	—	—	—	—	—	X	X	—	—	—	—	—	—
L. matagordensis Swain, 1955	—	—	—	X	X	—	X	X	—	—	—	X	X	X	X	—	X	X
L. purisubrhomboidea Edwards, 1953	—	—	—	X	—	—	—	—	—	—	X	X	X	X	—	—	—	—
L. reticularis Edwards, 1944	—	X	X	X	—	—	—	—	—	—	X	X	X	X	X	X	X	X
L. sperata Williams, 1966	—	X	X	X	—	—	X	X	X	—	—	—	—	—	—	—	—	—
L. aff. *L. florencensis* Cronin n. sp.	—	—	—	—	X	—	X	X	X	—	—	—	—	—	X	X	X	X
L. cf. *L. impressa*	—	X	X	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—
L. sp. A	—	—	—	—	—	—	—	—	—	—	X	X	—	—	—	—	—	—
Malzella conradi (Howe and McGuirt, 1935)	—	X	X	X	—	—	—	—	—	—	X	X	X	—	—	—	—	—
M. evexa Hazel, 1983	—	X	X	X	X	—	—	—	—	—	—	—	X	X	—	—	—	—
M. floridana (Benson and Coleman, 1963)	—	—	—	—	—	—	X	X	—	—	—	—	—	—	X	X	X	X
M. aff. *M. evexa* Hazel, 1983	—	—	X	—	—	—	—	—	—	—	—	X	—	—	—	—	X	—
Muellerina bassiounii Hazel, 1983	—	—	—	X	X	—	—	—	—	—	—	X	X	X	X	—	—	—
M. blowi Hazel, 1983	—	—	X	X	—	—	—	—	—	—	X	—	—	—	—	—	—	—
M. canadensis (Brady, 1870)	—	—	—	—	—	—	—	X	X	—	—	—	—	—	—	—	—	—
M. ohmerti Hazel, 1983	X	X	X	X	X	—	X	X	X	—	X	X	X	X	X	—	X	X

TABLE 4.—*Biostratigraphic ranges for 127 Neogene and Quaternary ostracode species from the Atlantic Coastal Plain*—Continued

[Data for 127 mild-temperate and subtropical species are summarized for nine time intervals for the Virginian and Carolinian faunal provinces. —, not present; X, present]

Species name	Virginian province									Carolinian province								
	Late Miocene	Early Pliocene	Middle Pliocene	Late Pliocene	Early Pleistocene	Early-middle Pleistocene	Late-middle Pleistocene	Late Pleistocene	Holocene	Late Miocene	Early Pliocene	Middle Pliocene	Late Pliocene	Early Pleistocene	Early-middle Pleistocene	Late-middle Pleistocene	Late Pleistocene	Holocene
M. petersburgensis Hazel, 1983	—	X	X	X	X	—	—	—	—	—	X	—	X	—	—	—	—	—
M. wardi Hazel, 1983	—	X	X	X	X	—	—	—	—	—	X	X	X	X	—	—	—	—
M. aff. *M. ohmerti* Hazel, 1983	—	—	—	—	—	—	—	—	—	—	—	X	—	X	X	—	—	—
Murrayina barclayi McLean, 1957	—	X	X	—	—	—	—	—	—	—	X	X	—	—	—	—	—	—
M. macleani Swain, 1974	—	X	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—
Neocaudites angulata Hazel, 1983	—	—	X	—	X	—	—	—	—	—	X	—	—	X	—	—	—	—
N. atlantica Cronin, 1979	—	—	—	—	—	—	X	X	—	—	X	X	X	X	X	—	X	X
N. subimpressa (Edwards, 1944)	—	—	X	—	—	—	—	—	—	—	—	X	—	X	—	—	—	—
N. triplistriata (Edwards, 1944)	—	X	X	—	—	—	—	—	—	—	—	X	X	X	X	—	—	—
N. variabilis Hazel, 1983	—	—	—	X	—	—	—	—	—	—	X	X	—	X	—	—	—	—
Neolophocythere subquadrata Grossman, 1967	—	X	—	—	—	—	X	X	X	—	—	—	—	—	—	—	—	—
Paracytheridea altila Edwards, 1944	—	X	X	X	X	X	X	X	—	—	X	X	X	X	X	X	X	X
P. cronini Hazel, 1983	—	X	X	X	X	—	X	—	—	—	—	X	X	X	—	—	—	—
P. hazeli Cronin n. sp.	—	—	—	—	—	—	X	X	—	—	—	X	—	X	X	—	X	X
P. mucra Edwards, 1944	—	—	—	X	—	—	X	—	—	—	—	X	X	—	—	—	—	—
P. rugosa Edwards, 1944	—	—	—	X	X	—	—	—	—	—	X	X	X	X	X	X	—	—
P. washingtonensis Puri, 1953	—	—	—	—	—	—	—	—	—	—	X	X	—	X	—	—	—	—
Protocytheretta reticulata (Edwards, 1944)	—	—	X	X	—	—	—	—	—	—	X	X	—	X	—	—	—	—
P. sahnii (Puri, 1952)	—	—	—	—	X	—	X	X	X	—	—	—	—	—	—	—	X	X
Pseudocytheretta cf. *P. burnsi* (Ulrich and Bassler, 1904)	X	X	X	X	X	—	X	—	—	—	X	X	X	X	—	—	—	—
P. edwardsi Cushman, 1906	—	—	—	—	—	—	X	X	X	—	—	—	—	—	—	—	—	X
Pterygocythereis alophia Hazel, 1983	—	—	—	—	—	—	—	—	X	—	X	X	X	X	—	—	X	X
P. inexpectata (Blake, 1929)	—	X	—	—	—	—	—	—	X	—	X	—	—	—	—	—	—	—
Puriana carolinensis Hazel, 1983	—	X	X	X	X	—	—	—	—	—	—	X	X	X	—	—	X	X
P. convoluta Teeter, 1975	—	—	—	X	X	—	X	—	—	—	—	X	X	X	—	—	—	—
P. floridana Puri, 1960	—	—	—	—	—	—	X	X	X	—	—	X	—	X	X	X	X	X
P. mesacostalis (Edwards, 1944)	—	—	—	X	X	—	X	X	X	—	—	X	X	X	X	—	—	—
P. rugipunctata (Ulrich and Bassler, 1904)	X	X	X	X	—	—	X	X	X	—	X	X	X	—	—	—	—	—
Tetracytherura choctawhatcheensis (Puri, 1953)	—	X	X	X	X	—	X	X	X	—	X	X	X	X	X	X	—	X
T. expanda (Hazel, 1983)	—	—	—	X	X	—	—	—	—	—	—	X	X	X	—	—	—	—
T. mccartanae Cronin n. sp.	—	—	—	X	X	—	X	X	X	—	—	X	X	X	X	—	X	X
T. minuta (Hazel, 1983)	—	X	—	X	—	—	—	—	—	—	—	X	—	X	—	—	—	—
T. norfolkensis (Cronin, 1979)	—	—	—	—	—	—	X	X	X	—	—	—	—	—	—	—	—	—
T. owensi Cronin n. sp.	—	—	—	—	—	—	—	—	—	—	—	—	—	X	X	—	—	—
T. similis (Malkin, 1953)	—	—	X	X	X	—	—	—	—	—	X	X	X	X	—	—	—	—
Thaerocythere carolinensis Hazel, 1983	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—
T. schmidtae (Malkin, 1953)	—	—	—	X	X	—	—	—	—	—	—	—	—	—	—	—	—	—

TABLE 5.—*Summary of ostracode evolutionary data from the Atlantic Coastal Plain*

	Variable	Age								
		Late Miocene	Early Pliocene	Middle Pliocene	Late Pliocene	Early Pleistocene	Early middle Pleistocene	Late middle Pleistocene	Late Pleistocene	Wisconsinan-Holocene
A.	Total species	—	83	109	92	94	60	63	76	67
B.	Number extant species	—	33	52	48	59	49	52	73	67
C.	Percent extant species	—	39.8	47.7	52.2	62.8	81.7	82.5	96.0	100
D.	Total endemic temperate and subtropical species	—	75	97	80	83	53	55	64	64
E.	Total endemic cold-temperate and tropical species	—	8	12	12	11	7	8	12	3
F.	Number endemic species extant	—	26	43	39	49	42	44	61	—
G.	Percent endemic species extant	—	34.7	44.3	48.8	59.0	72.2	80.0	95.3	100
H.	Evolutionary first appearances per time interval	10	65	29	7	5	2	6	3	—
I. (=*H*÷*J*)	Evolutionary first appearances per million years	2.0	40.6	48.3	8.8	3.9	6.7	27.3	27.3	—
J.	Duration of time (interval), in millions of years	5.0 (10–5)	1.6 (5–3.4)	.6 (3.4–2.8)	.8 (2.8–2.0)	1.3 (2.0–0.7)	.3 (0.7–0.4)	.22 (0.4–0.18)	.11 (0.18–0.07)	.07 (0.07–0.0)
K.	Midpoint of time interval, in millions of years	7.5	4.2	3.1	2.4	1.35	.55	.29	.125	.035

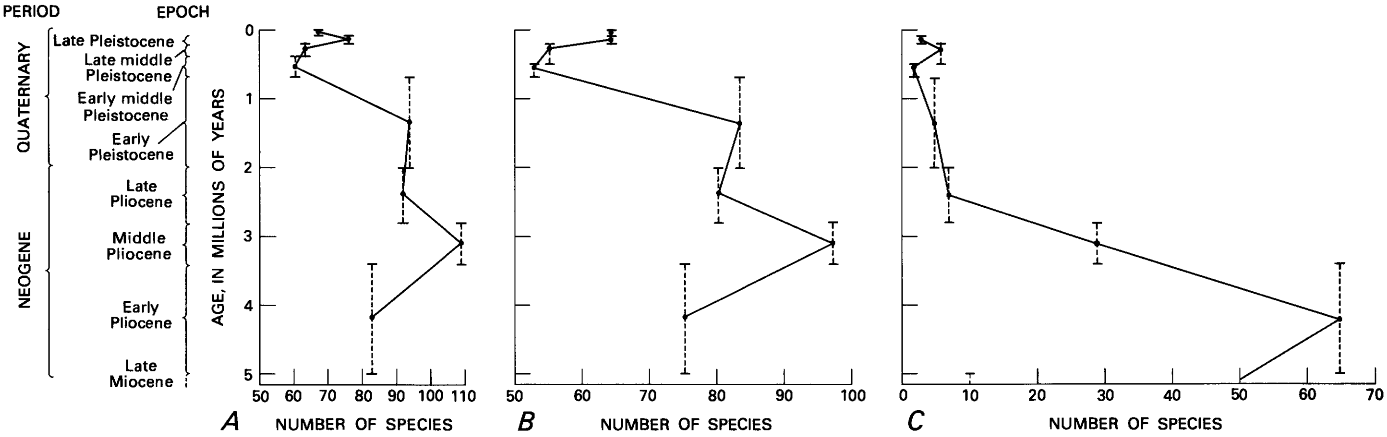

FIGURE 2.—Species diversity of Atlantic Coastal Plain Ostracoda during the Neogene and Quaternary. *A*, Total number of species per time interval (duration of interval shown by vertical bar). *B*, Total number of endemic species per time interval. *C*, Total number of evolutionary first appearances per time interval. See text for discussion.

EVOLUTIONARY FIRST APPEARANCES

The value *H* in table 5 represents the number of evolutionary first appearances in the study area for an interval of time. Figure 2*C* shows that, of the total 127 endemic species, 10 species evolved during the late Miocene, 65 during the early Pliocene, 29 during the middle Pliocene, and a total of 23 since the middle Pliocene about 2.8 Ma. Normalizing these data (*I* in table 5) for the duration of each time interval (*J* in table 5), I found that early and middle Pliocene rates of origination were 40.6 and 48.3 species per million years, respectively (fig. 3). This is equivalent to about one new species every 20,000 to 25,000 years. Rates ranged between about three and nine species per million years during the interval between 2.8 and 0.4 Ma, which is equivalent to a rate of one new species every 100,000 to 300,000 years. An intermediate rate of about 27 species per

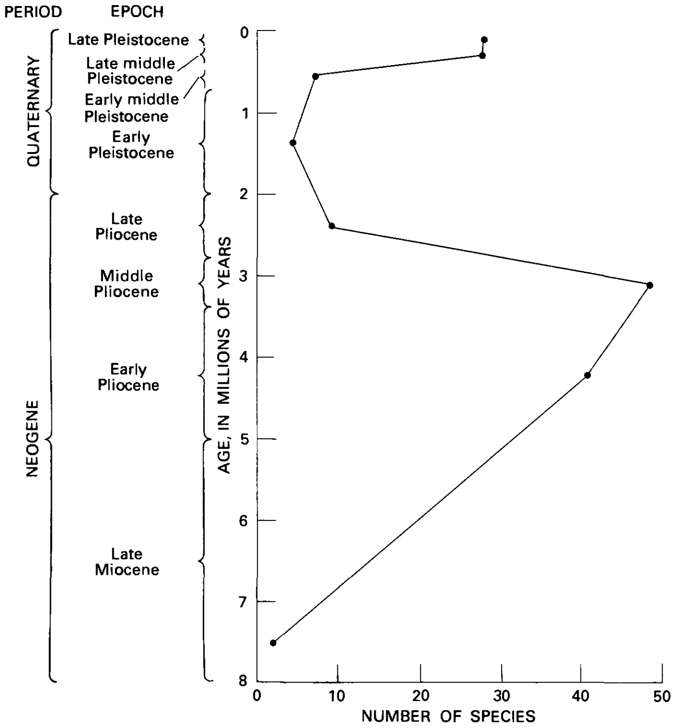

FIGURE 3.—Number of ostracode species originations per million years for the Atlantic Coastal Plain for each of eight intervals of time during the Neogene and Quaternary.

million years characterized the last 400,000 years, but these apparently high rates of species origination may be overestimates, reflecting the "pull of the Recent" and a larger number of samples for the late Pleistocene and Holocene.

ASSOCIATION OF SPECIES ORIGINATIONS AND CLIMATIC CHANGE

Vrba (1984) and Cracraft (1982) postulated a direct link between evolutionary patterns and climatic change. Indeed, case studies associating evolutionary events with climatic events are common (for example, see Brenchley, 1984). However, a simple correspondence in age between climatically induced environmental changes and an observed species diversification (or extinction) does not prove a direct link. In this vein, Schopf (1984) has urged that density-independent factors, such as climate, be distinguished from density-dependent factors, such as population size, in evolutionary studies. He stressed the need for consideration of internal genetic processes to explain evolutionary patterns and suggested regional climatic studies, such as this study, be undertaken to assess the faunal diversity and species-area effects.

The period of high rates of species origination shown in figure 3 corresponds to (1) a period of high sea level and increasing ocean-water temperatures between 4.0 and 3.2 Ma and (2) an intensified pulse of warm water between 3.2 and 2.8 Ma. This warmer water along the Eastern United States reflects enhanced flow of the Gulf Stream due to the closure of the Isthmus of Panama (Keigwin, 1978; Jones and Hasson, 1985). The drop in ostracode species originations since the early and middle Pliocene corresponds with a rapid drop in sea level, which reflects a glacioeustatic event corresponding to northern hemispheric glaciation. Evidence for these glaciations is discussed in Backman (1979), Shackleton and others (1984), and Cronin (1988a).

The observed association between ostracode diversification and local, hemispheric, and global oceanographic changes constitutes a working hypothesis that can be tested in two distinct ways. The Pliocene diversification can be compared, albeit qualitatively, to (1) contemporaneous ostracode patterns from other zoogeographic provinces and (2) noncontemporaneous patterns from the same area. There is evidence that Pliocene shallow-water ostracodes of the northeastern North Atlantic experienced a similar diversification. For example, Maybury and Whatley (1988) have reported 387 ostracode species from the Pliocene St. Erth beds of Cornwall, southwest England and 384 species from equivalent strata in northwest France. Therefore, the oceanographic effects of the intensification of the Gulf Stream and North Atlantic Current may have influenced ostracode rates of speciation in shallow-water environments on both sides of the North Atlantic. Further comparison between trends of shallow-water and deep-sea ostracodes is instructive. Benson and others (1984), studying Cenozoic ostracode generic diversity in faunas from deep-sea cores, identified a Pliocene event about 3.5 Ma when ostracode diversity was reduced greatly. They infer a possible link between reduced diversity and the closing of the Isthmus of Panama and the inception of northern hemispheric glaciation. Unfortunately, species-level data are not available for deep-sea ostracodes.

The low rate of species origination during the Pleistocene in the Atlantic Coastal Plain contrasts with the rate during the Pliocene and further supports the hypothesis that the unique oceanographic changes of the Pliocene caused more species to evolve then. If this were not the case, one would expect a similar rate of species origination throughout the last 5 m.y. and one would not expect a decrease during the Pleistocene. This change in rate of origination corresponds with the fundamental change to high-amplitude Milankovitch climatic cycles that occurred at about 100,000-, 40,000-, and 20,000-year periodicities during the last 2.4 m.y. and intensified during the last 700,000 years. Although these climatic cycles altered the zoogeographic distributions of the temperature-sensitive species, they were not sufficient, for unknown reasons, to cause significant numbers of new species to evolve. Cronin (1985, 1987) found a similar pattern in a phylogenetic study of the ostracode genus *Puriana* from both the Eastern United States and the Caribbean.

COMPARISON OF COASTAL PLAIN OSTRACODE AND MOLLUSK PATTERNS

The most intensely studied marine invertebrate group from the Atlantic Coastal Plain is mollusks. Stanley (1982, 1984, 1986a, b) compiled occurrence data on mollusks, primarily from the published literature, and postulated that a regional mass extinction occurred that began in the late Pliocene and continued into the early Pleistocene. Stanley suggested (1) that as many as 65 percent of early Pliocene mollusk species became extinct; (2) that extinction was selective and eliminated primarily tropical species, whereas species capable of living in nontropical areas survived; (3) that stenothermal species became extinct first and eurythermal species, somewhat later; and (4) that by comparison with Pacific Ocean patterns, the extinction in the Atlantic Ocean did not result from a drop in sea level but from the combined effects of global cooling and the formation of a hypothetical zone of cool-upwelling water between Florida and the Bahamas and the Caribbean. Although the present study has been concerned with species origination and not extinction per se, the molluscan data of Stanley are derived mostly from the same stratigraphic units as the ostracodes and a comparison is worthwhile.

The most obvious similarity in the ostracode and mollusk data is the diversity pattern—high diversity in the Pliocene followed by lower diversity in the Pleistocene. Climate is assigned a strong role in influencing evolutionary patterns both in this paper and in Stanley's work on mollusks, but the interpretations of the causal effects of climate are distinct. When closely examined, however, the interpretation of the Coastal Plain molluscan record that led Stanley to propose the theory of a regional mass extinction has several ambiguities with respect to the stratigraphy, paleoclimatology, and zoogeography.

In relation to the regional stratigraphy, the age estimates given by Stanley (1986a) for several formations are equivocal. For example, in the discussion of the Waccamaw Formation of South and North Carolina and Caloosahatchee Formation of Florida, Stanley (1986a, p. 20) assigned a late Pliocene age to these deposits; yet it is known from planktonic foraminifers and nannofossils (Akers, 1972; Cronin and others, 1984) that the Waccamaw and Caloosahatchee Formations are early Pleistocene in age, no older than the Olduvai event 1.8 to 1.6 Ma, near the Pliocene-Pleistocene boundary. Stanley (1986a, p. 26) mentioned the possibility of a younger age for these units when he contrasted the Atlantic data with data from the Pacific San Diego Formation. However, he suggested (Stanley, 1982, p. 186) that the difference between a late Pliocene or early Pleistocene age matters little because "the crucial point for the present analysis is that both faunas lived before major glacial episodes and accompanying sea level depressions." The main thesis of Stanley's extinction hypothesis was that climatic cooling that began before the late Pliocene initiated a regional extinction event, and he cited ample evidence for the initiation of glaciation in the Northern Hemisphere. The Waccamaw and Caloosahatchee molluscan faunas do not predate the first hemispheric glaciation.

In reference to the paleoclimatic history of the Pliocene and Pleistocene outlined in the important paper by Shackleton and others (1984), Stanley stated (1986a, p. 26), "Continental glaciers expanded in the Northern Hemisphere about 3.2 m.y. ago (Shackleton et al., 1984)." However, two other points were emphasized by Shackleton and others (1984). First, they concluded that a major northern hemispheric glaciation began at 2.4 Ma when "the first glacial maximum at 2.37 Myr * * * represents a truly glacial interval, with an ice volume similar to maxima during the middle Pleistocene" (Shackleton and others, 1984, p. 622). Second, they concluded that the present-day North Atlantic deep water has existed since at least about 3.5 Ma. Although Shackleton and others (1984) mentioned the work of McDougall and Wensink (1966) documenting glaciation in Iceland at about 3.1 Ma, this does not necessarily constitute the continental glaciation invoked by Stanley as an agent of extinction. Shackleton and others (1984) pointed out that the Iceland glaciers did not reach sea level until about 2.0 Ma, and the most significant oceanographic events occurring between 3.4 and 2.4 Ma involved an increase in formation of deep water in the North Atlantic (Backman, 1979), which was related to intensification of Gulf Stream flow. Brunner (1979) documented a change in sedimentary regime at 3.4 Ma in the Straits of Florida, when an increase in winnowed sediments, turbidites, and sedimentary hiatuses in piston cores was recorded. Brunner attributed these events to the closing of the Isthmus of Panama.

The distinction between 3.2 and 2.4 Ma as the age for major climatic cooling is important for the extinction model that implies that an ice sheet and periglacial environment similar to those of the last glacial maximum about 18 kilo-annum (ka, 10^3 years) existed in eastern North America during the Pliocene. At present, little direct paleontologic or isotopic evidence exists for reconstructing continental climatic conditions that existed in the Southeastern United States at that time. Instead, the intensified flow of the Gulf Stream mentioned above actually increased warm-water influx along southeastern North America and was directly responsible for the northward migration of tropical-water species into the region. It may not, therefore, be justified to extrapolate the well-known late Wisconsinan (about 18,000 ka) glacial conditions in eastern North America to the Pliocene because water temperatures along the Southeastern United States south of the Cape Hatteras region remained relatively warm due to the continued flow of the Gulf Stream. No evidence exists in marine deposits for colder climates along the coast south of Cape Hatteras even during the Pleistocene (Hazel, 1968; Cronin, 1981b, 1988a).

To support the model that climate caused a regional mass extinction, Stanley (1982) compared the molluscan record of the Eastern United States to records from Japan and from California. He postulated that a major extinction did not occur in the Japanese and Californian molluscan faunas because they were not subjected to extreme temperature changes (1982, p. 184). However, Neogene (Ingle, 1981) and Quaternary (Lajoie and others, 1979) climatic cycles are well documented from southern California. Further, the specific localities from Japan that were selected for their molluscan fauna (Stanley, 1986b, table 1) were only a small subsample of the Omma-Manganjian faunas that occur from Hokkaido, Japan, to Korea and include a heterogeneous array of molluscan (Chinzei, 1978) and ostracode (Cronin and Ikeya, 1987) assemblages. In fact, well-documented regional Neogene oceanographic changes come from studies of the Omma-Manganjian faunas in northern Honshu, Japan (Okada, 1979; Cronin and Ikeya, 1987), and there is abundant published evidence from terrestrial and marine microfossils (Heusser and Morley, 1985; Sancetta and Silvestri, 1986, and references therein) for significant climatic changes during the Pliocene and Pleistocene Omma-Manganjian period. Japanese and Californian faunas were subjected to climatic extremes, and thus, the discordant extinction patterns in the eastern and western Pacific versus the Atlantic do not necessarily support the interpretation that paleotemperatures were the primary influence on molluscan extinction.

The concept that a region of upwelling existed and served as a major barrier between molluscan faunas (Stanley, 1986a) is based on indirect evidence from the region between Florida and North Carolina. Riggs (1984) carefully documented intermittent periods of upwelling along the Southeastern United States in studies of phosphorite deposition. Rigg's most detailed documentation was the Miocene Pungo River Formation of North Carolina and the Hawthorn Formation of Florida and South Carolina. With respect to the early Pliocene Yorktown Formation, Riggs (1984, p. 125) stated that the lower Yorktown represents a phosphogenic episode, which means that the period of upwelling predated the extinction event later in the Pliocene and could not have acted as a barrier to southward dispersal of mollusks. Riggs described two types of Pliocene phosphates in Florida, one being the Bone Valley Formation, which he considered to be reworked largely from the underlying Hawthorn Formation, and the other being a "Pliocene phosphate in shallow marine facies scattered through eastern and southern Florida," which he considered to be "probably primary" (Riggs, 1984, p. 126). Thus, although areas of upwelling certainly occurred in the region during parts of the Pliocene and Pleistocene, the evidence does not indicate unique circumstances during the late Pliocene and Pleistocene that would have formed an environmental barrier to dispersal.

How is one to interpret the change from high diversity during the Pliocene to lower diversity during the Pleistocene that has been recorded for both ostracodes (fig. 2) and mollusks? First, some of the change may be attributed simply to the southward migration of tropical species back to regions in the Caribbean. Second, one could partly explain the drop in the number of mollusk species as a drop in the rate of species origination, as was postulated above for the ostracodes. Only by distinguishing true evolutionary first and last appearances from migration events can one recognize an anomalously high rate of species origination or extinction during the Pliocene for the Southeastern United States. Interestingly, there was no great corresponding extinction in benthic Foraminifera, according to M.A. Buzas (quoted in Stanley, 1986a, p. 28), nor in ostracodes. Therefore, the role of climate as an agent of speciation and extinction needs further investigation.

CONCLUSIONS

Evolutionary patterns in Pliocene and Quaternary marine ostracodes from the Atlantic Coastal Plain suggest that climatic and oceanographic changes, including sea-level and water-temperature fluctuations, exert an important influence on rates of speciation. A high diversity of ostracode species (about 90–110 species) and a high rate of species origination (1 new species per 20,000–25,000 years) characterized the early and middle Pliocene and early Pleistocene of the Atlantic Coastal Plain. In contrast, late Pliocene, middle and late Pleistocene, and Holocene diversity (60–80 species) and rate of species origination (1 new species per 100,000–300,000 years) are lower. The difference in evolutionary patterns is attributed, in part, to climatic change. The early to middle Pliocene was characterized by high sea level and sustained oceanographic change reflecting intensification of the Gulf Stream and gradually warmer water. If climatic cycles occurred, they were of low amplitude. Middle and late Pleistocene climatic changes were related primarily to high-amplitude, high-frequency Milankovitch climatic cycles, during which relatively few new ostracode species evolved.

SYSTEMATIC PALEONTOLOGY

This section emphasizes the taxonomy of ostracodes from South Carolina because published taxonomic studies on ostracodes from Virginia, Maryland, and North Carolina provide adequate description and illustration of northern faunas (Swain, 1974; Valentine, 1971; Cronin, 1979; Forester, 1980; Hazel, 1983, and references therein). A total of 67 samples was examined from the Charleston, S.C., area, and locality and stratigraphic data for these are given in Weems and McCartan (this volume) and in McCartan and others (this volume). A total of 113 taxa was identified from these samples; 71 species are illustrated by scanning electron photomicrographs in plates 1–17. For species not illustrated in this paper, a reference to a published paper is provided in this section. Table 6 shows ostracode presence-absence occurrence data arranged by geologic formation for the 67 samples examined.

The most common genera in Pliocene and Pleistocene marine deposits near Charleston are *Actinocythereis*, *Bensonocythere*, *Cytherura*, *Hulingsina*, *Muellerina*, *Paracytheridea*, *Climacoidea*, and *Tetracytherura*. Some species are restricted in their occurrence to one or several geologic formations, which makes them useful for correlating within the region. However, the stratigraphic ranges of species in South Carolina apply only locally and should not be used in regions south and north.

Most ostracode assemblages from the Pliocene and Pleistocene of South Carolina signify an inner shelf environment and normal marine salinities. However, there are important exceptions. For example, a few samples of the Raysor Formation contain middle to outer shelf assemblages, which include *Pterygocythereis inexpectata* and *Echinocythereis planibasalis*. Samples 22 and 23 of the Penholoway Formation and samples 48 and 49 of the Wando Formation contain brackish-water, backbarrier taxa such as *Cyprideis*, *Leptocythere*, *Perissocytheridea*, and *Cytheromorpha curta* (see Lyon, this volume).

Specimens illustrated in plates 1–17 are deposited in the Department of Paleobiology, USNM in Washington, D.C.; the faunal slides are in the USGS ostracode collections in Reston, Va.

Family CYTHERELLIDAE Sars, 1866

Genus CYTHERELLOIDEA Alexander, 1929

Remarks.—Most specimens are referred to *C. umbonata* Edwards, 1944; however, *Cytherelloidea* occurs in very low numbers. Its occurrence typically signifies warm water, and *C. umbonata* also occurs in the Caribbean (Teeter, 1975).

Distribution.—Duplin, Raysor, Bear Bluff, Waccamaw, and Wando Formations, Goose Creek Limestone, and Ten Mile Hill beds.

Illustration.—Teeter (1975), figures 23n-o.

Family BAIRDIIDAE Sars, 1888

Genus PARANESIDEA Maddocks, 1969

Distribution.—Duplin, Raysor, Bear Bluff, Penholoway, Waccamaw, and Wando Formations and Ten Mile Hill beds.

Family PONTOCYPRIDIDAE G.W. Müller, 1894

Genus PROPONTOCYPRIS Sylvester-Bradley, 1947

Remarks.—This genus is rare in most Coastal Plain deposits; when present, it often occurs only as juveniles. Valentine (1971) found *P. edwardsi* (Cushman, 1906) common in the Norfolk Formation of Virginia.

Distribution.—Goose Creek Limestone.

Family PARADOXOSTOMATIDAE Brady and Norman, 1889

Genus PARADOXOSTOMA Fischer, 1855

Remarks.—This genus occurs sporadically in Coastal Plain deposits, but its taxonomy is poorly understood. The most commonly encountered species is *P. delicata* Puri, 1953.

Genus PELLUCISTOMA Coryell and Fields, 1937

Pellucistoma magniventra Edwards, 1944

Plate 6, figure 8

Remarks.—This species has a variable shape and low, elongate forms (such as that in plate 6, figure 8) differing from the typical slipper-shaped form; may be a distinct species.

Distribution.—Duplin, Raysor, Waccamaw, and Wando Formations and Ten Mile Hill beds.

Genus PARACYTHEROMA Juday, 1907

Paracytheroma stephensoni (Puri, 1953)

Distribution.—Duplin, Penholoway, Waccamaw, and Wando Formations.

Illustration.—Cronin (1979), plate 19, figures 2, 4; Lyon (this volume), plate 6, figure 5.

TABLE 6.—*Ostracode occurrence data for Neogene and Quaternary*

[Locality numbers: top row, numbers used in Weems and McCartan (this volume,

Species	Raysor Formation (including "Givhans beds")									Bear Bluff Formation and Goose Creek Limestone										Penholoway Formation								
	94	91	85	95	63	63	63	66	65	88	64	93	49	50	50	89	89	20	51	56	57	60	60	86	87	87	83	83
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Actinocythereis captionis	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	X
A. dawsoni	—	—	X	X	—	X	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
A. marylandica	—	—	X	X	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
A. subquadrata	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—
Acuticythereis laevissima	—	X	—	—	—	—	—	—	—	—	X	—	—	—	—	—	X	—	—	—	—	—	X	—	—	—	X	—
Aurila laevicula	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—
Basslerites sp.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—
Bensonocythere florencensis	—	X	X	X	—	X	—	—	X	—	—	—	—	X	—	X	—	—	X	—	—	—	—	—	—	—	—	—
B. gouldensis	—	X	X	X	X	—	—	X	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
B. hazeli	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—
B. ricespitensis	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—
B. rugosa	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—
B. sapeloensis	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	X	X	X	—	—	—
B. valentinei	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—
B. whitei	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	X	—	—	X	X	X	—	X	X	X	—	X	—
B. spp.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—
Campylocythere laeva	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	X	—	—	—	X	—	—	—	—	—	—	—	—
Climacoidea gigantica	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	X	—	—	X	X	X	—	X	—
C. jamesensis	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	X	—	—	—	X	—	—	—	—	—	—	—	—
C. multipunctata	—	—	—	—	—	—	—	—	—	—	X	X	—	X	—	—	—	X	—	—	—	—	X	—	X	—	—	—
C. nelsonensis	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	X	—	—	X	—
C. tuberculata	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	X	—	—	X	X
C. spp.	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Cushmanidea seminuda	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Cyprideis margarita	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	X	—	—	—	—	—
C. mexicana	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	X	X	—	—	—	—	—
C. salebrosa	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	X	—	—	—	—	—
C. spp.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	X	X	X	X	X
Cytherelloidea sp.	—	X	X	—	—	—	—	—	—	X	—	X	—	X	—	—	X	—	—	—	—	—	—	—	—	—	—	—
Cytheridea virginiensis	—	X	X	X	—	X	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Cytheromorpha curta	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	X	—	X	—	—	—
C. newportensis	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	X	—	—	—
C. warneri	—	X	X	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Cytheropteron talquinensis	—	X	X	X	X	X	X	X	X	X	X	—	—	X	X	X	X	—	—	—	—	—	—	—	—	—	—	—
C. yorktownensis	—	X	—	X	—	X	X	X	X	—	X	—	—	X	—	—	X	—	—	—	X	—	—	—	—	—	—	—

deposits of the Atlantic Coastal Plain in the Charleston, S.C., area

fig. 2); bottom row, numbers used in this paper. —, not present; X, present]

					Ladson Formation	Ten Mile Hill beds				Wando Formation																												
54	84	23	23	48	4	29	59	44	11	31	31	31	31	60	60	60	14	14	14	92	10	30	30	30	46	46	46	78	82	21	21	43	19	19	19	69	60	13
29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67
—	—	—	—	X	—	—	—	X	—	X	—	X	X	X	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	X	—	—	—	—	X	—	X	X	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	X	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
X	—	X	—	—	—	X	—	—	X	—	—	X	X	X	—	X	—	—	—	—	—	—	—	X	—	—	—	—	X	—	X	X	—	—	—	—	—	—
—	—	X	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
X	—	—	—	X	—	—	—	—	—	X	—	X	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	X	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—
—	—	X	X	X	—	—	—	—	X	—	X	X	X	X	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	X	—	—	—	—	—	—	—
X	—	X	—	X	—	—	—	—	X	X	X	—	X	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	X	—
X	—	X	—	X	—	—	X	X	X	X	X	X	X	X	—	X	—	—	—	—	X	—	X	X	—	X	—	—	X	X	X	X	—	—	—	X	X	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
X	—	—	—	—	—	—	X	X	—	—	X	X	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	X	X	—
—	—	X	X	X	—	—	—	X	X	X	X	X	X	X	—	—	—	—	X	—	X	—	X	—	—	—	—	—	X	—	—	—	—	—	—	X	X	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—
—	—	—	—	—	—	—	—	—	—	X	X	X	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	X	—	—	X	X	X	X	—	—	—	—	—	—	X	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—
—	—	—	—	—	—	—	—	—	—	—	X	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—
—	X	—	X	X	X	—	—	X	—	—	—	—	—	X	X	—	—	—	—	—	—	X	X	X	—	—	—	X	—	—	X	—	—	—	—	—	X	—
—	—	—	—	—	—	—	—	—	X	—	—	X	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	X	X	X	—	—	—	—	—	X	—	X	X	X	X	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—
—	—	—	—	—	—	—	—	—	—	X	—	X	—	X	—	—	—	—	X	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	X	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

TABLE 6.—*Ostracode occurrence data for Neogene and Quaternary*

[Locality numbers: top row, numbers used in Weems and McCartan (this volume,

Species	Raysor Formation (including "Givhans beds")									Bear Bluff Formation and Goose Creek Limestone										Penholoway Formation								
	94	91	85	95	63	63	63	66	65	88	64	93	49	50	50	89	89	20	51	56	57	60	60	86	87	87	83	83
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Cytherura carolinensis	—	—	—	—	X	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—
C. elongata	—	X	—	—	—	—	—	—	—	—	X	X	—	—	—	X	X	—	—	X	—	—	—	—	—	—	X	—
C. fiscina	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
C. forulata	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	X	—	—	X	—	X	—	X	—
C. howei	—	X	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	X	—	—	—	—	X	—	—	—
C. neusensis	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	X	—	X	X	X	—	X	X
C. nucis	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
C. pseudostriata	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—
C. reticulata	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	X	—	—	X	—	X	—	—	X
C. wardensis	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
C. spp.	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—
Echinocythereis leecreekensis	—	—	X	X	—	—	—	—	—	—	X	—	—	—	—	—	X	—	—	X	—	—	—	—	—	—	—	—
E. planibasalis	—	—	—	X	—	X	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Eucythere gibba	—	—	—	—	X	—	—	X	—	—	X	—	—	—	—	—	—	—	—	—	—	—	X	—	X	—	—	—
E. triangulata	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	X	—	—	—	—	—	—	—	X	—	—	—	—
Hermanites ascitus	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—
Hulingsina americana	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	X	X	—	—	—	X	—	—	—
H.? cylindrica	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	X	—	—	—
H. glabra	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	X	—	—	—	—	X
H. rugipustulosa	—	X	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	X	—	X	X	X	X	X	—
H. cf. *H. sulcata*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	X	—	—	—	—	—
H. sp. A	—	X	X	X	—	X	—	X	X	X	X	X	—	X	—	—	X	X	X	X	X	X	X	X	X	X	X	—
H. sp. B	—	—	—	—	—	—	—	—	—	X	X	X	—	—	—	X	X	—	X	—	X	—	X	X	—	—	—	—
H. sp. C	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	X	X	—	—	—	—
H. spp.	—	—	—	—	X	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Leptocythere nikraveshae	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	X	—	—	—
Loxoconcha carolinensis	—	—	X	—	X	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
L. florencensis	—	X	X	—	—	X	—	—	—	—	X	—	X	X	—	X	—	X	—	—	—	—	—	—	—	—	—	—
L. matagordensis	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	X	—	—	—
L. reticularis	—	—	—	—	—	—	—	X	—	X	X	—	—	X	—	X	X	—	—	—	X	—	X	—	—	—	X	X
L. spp.	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—
Malzella conradi	—	X	X	X	X	X	X	X	X	X	X	X	—	X	X	X	X	X	—	—	—	—	—	—	—	—	—	—
M. evexa	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—
M. floridana	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Megacythere sp.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

deposits of the Atlantic Coastal Plain in the Charleston, S.C., area—Continued

fig. 2); bottom row, numbers used in this paper. —, not present; X, present]

					Ladson Formation	Ten Mile Hill beds				Wando Formation																												
54	84	23	23	48	4	29	59	44	11	31	31	31	31	60	60	60	14	14	14	92	10	30	30	30	46	46	46	78	82	21	21	43	19	19	19	69	60	13
29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
X	X	—	—	—	—	—	—	—	X	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—
—	—	X	—	X	—	—	—	—	X	X	X	X	X	X	—	—	X	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	X	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—
X	—	—	—	X	—	—	X	—	X	X	X	X	X	X	—	—	—	—	X	—	—	—	—	—	X	X	X	—	X	X	X	X	—	—	—	X	X	X
X	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	X	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	X	—	—	X	—	X	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
X	—	—	—	—	—	—	—	X	X	X	—	X	X	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—
—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	X	—	X	X	—	—	—	—	—	—	—	X	—	—	—	—	—	X	—	—	—	—	X	—	—	—	—	—	—
—	—	—	—	—	—	—	X	—	X	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
X	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	X	—	X	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	X	—	—	—	—	—	—	X	—	—	X	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—
X	—	X	—	—	—	—	X	X	X	X	X	X	X	X	X	X	—	X	X	—	X	—	—	—	X	X	X	X	—	X	—	X	—	X	—	X	X	X
—	—	X	—	X	—	—	—	X	X	—	X	X	X	X	—	—	—	—	—	—	—	—	—	X	—	—	X	—	X	—	—	—	—	—	—	—	X	—
—	X	X	—	X	—	X	X	X	X	—	X	X	X	X	—	—	—	—	—	—	X	—	—	X	—	X	X	—	X	X	X	X	X	—	—	X	X	—
X	—	X	—	—	—	—	—	—	X	—	X	—	X	—	—	—	—	—	—	—	—	—	X	—	X	X	—	—	X	X	—	X	—	—	—	—	X	—
X	—	X	—	X	—	—	—	X	X	—	—	X	X	—	—	X	—	—	—	—	—	—	—	—	X	—	—	—	—	X	X	X	—	—	—	—	—	—
—	—	—	—	X	—	—	—	—	—	X	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	X	—	—	—	—	—	—	X	—	X	X	X	—	—	—	—	X	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	X	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	X	—	—	X	X	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	X	—	X	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	X	—	X	X	X	X	X	X	—	—	—	—	X	—	—	—	—	X	—	—	—	—	X	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	X	—	—	—	—	—	—	—	—	X	—	—	—	X	—	—	—	X	X	—

TABLE 6.—*Ostracode occurrence data for Neogene and Quaternary*

[Locality numbers: top row, numbers used in Weems and McCartan (this volume,

	Raysor Formation (including "Givhans beds")									Bear Bluff Formation and Goose Creek Limestone										Penholoway Formation								
Species	94	91	85	95	63	63	63	66	65	88	64	93	49	50	50	89	89	20	51	56	57	60	60	86	87	87	83	83
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Muellerina bassiounii	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	X	—	—	X	—	X	—	X	—	X	—
M. ohmerti	—	—	—	—	—	X	—	—	—	—	—	—	—	X	—	X	X	X	—	X	—	—	X	—	—	—	—	—
M. petersburgensis	—	X	X	X	X	—	—	X	X	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
M. wardi	—	X	X	—	X	—	—	—	—	—	—	X	—	X	X	—	X	—	—	X	X	—	X	—	X	—	X	—
M. spp.	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Murrayina macleani	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Neocaudites atlantica	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
N. subimpressa	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—
N. variabilis	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	X	—	—	—
Orionina vaughani	—	X	—	X	X	X	—	X	X	—	X	—	—	X	—	X	—	X	—	X	X	—	—	—	—	—	X	—
Palaciosa minuta	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	X	—	X	—	—	—
Paracytheridea altila	—	—	—	—	—	—	—	—	—	—	X	X	—	X	—	—	—	—	—	X	X	—	X	X	X	—	X	X
P. hazeli	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—
P. rugosa	—	X	X	—	—	X	—	X	—	—	X	—	—	X	—	X	X	—	—	—	—	—	X	—	—	—	X	—
Paracytheroma stephensoni	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	X	—	X	X	X	—	—	—
P. texana	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Paradoxostoma sp.	—	—	X	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Paranesidea sp.	—	—	X	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Pellucistoma magniventra	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Peratocytheridea bradyi	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	X	—	X	—	X	—	—	X
P. setipunctata	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—
P. sp.	—	—	—	X	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	X	—	X	—	X	—	—	—
Perissocytheridea brachyforma	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—
Phlyctocythere sp.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Pontocythere spp.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—
Propontocypris sp.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—
Protocytheretta reticulata	—	—	X	X	—	X	—	—	—	—	X	—	—	X	—	X	—	X	X	—	—	—	—	—	—	—	—	—
P. cf. *P. sahnii*	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	X	—	—	—
Pseudocytheretta cf. *P.burnsi*	—	—	X	X	—	—	—	—	—	X	—	—	—	—	—	X	X	—	—	—	—	—	—	—	—	—	—	—
Pterygocythereis alophia	—	X	X	—	X	—	—	—	X	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—
P. inexpectata	—	—	X	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Puriana carolinensis	—	—	X	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	X	—	X	X	X	—	—	X
P. convoluta	—	—	—	—	—	—	—	—	—	—	—	—	—	X	X	—	—	—	—	—	—	—	X	—	—	—	—	—
P. mesacostalis	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—
P. rugipunctata	X	X	X	X	—	—	—	—	—	X	—	—	—	X	—	—	—	X	—	—	—	—	—	—	—	—	—	X

deposits of the Atlantic Coastal Plain in the Charleston, S.C., area—Continued

fig. 2); bottom row, numbers used in this paper. —, not present; X, present]

					Ladson Formation	Ten Mile Hill beds				Wando Formation																												
54	84	23	23	48	4	29	59	44	11	31	31	31	31	60	60	60	14	14	14	92	10	30	30	30	46	46	46	78	82	21	21	43	19	19	19	69	60	13
29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67
X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	X	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	X	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
X	—	X	—	—	—	—	X	—	X	—	X	X	X	—	—	X	—	—	X	—	—	—	—	X	X	X	X	—	—	—	—	X	—	—	—	—	—	X
—	—	—	X	X	—	—	—	X	X	—	X	X	X	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
X	—	X	—	X	—	—	—	—	—	X	—	X	—	X	—	—	—	—	X	—	—	—	—	—	X	X	X	—	—	—	—	X	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	X	—	X	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	X	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	X	X	X	X	—	X	X	—	—	—	—	—	—	—	—	—	—	X	X	—	—	—	X	—	X	—	—	—	—	—	—
X	—	X	X	X	—	—	X	X	X	X	X	X	X	X	X	X	—	X	—	—	X	—	—	X	X	X	X	—	X	X	X	X	—	X	X	X	—	—
—	—	X	X	X	—	—	X	—	—	X	X	—	—	—	—	—	—	—	—	—	—	—	—	—	X	X	X	—	—	—	—	X	—	—	—	X	—	—
—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	X	—	—	—	—	X	—	X	—	—	—	—	—	—	X	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—
—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	X	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	X	X	—	X	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	X	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	X	—	—	—	—	—	X	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	X	—	X	—	—	—	—	—	—	X	—	—	X	—	—	—	—	—	—	—	—	X	X	—	—	X	—	—	—	—	—	—	—	—	—	—	—
—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

TABLE 6.—*Ostracode occurrence data for Neogene and Quaternary*

[Locality numbers: top row, numbers used in Weems and McCartan (this volume,

Species	Raysor Formation (including "Givhans beds")									Bear Bluff Formation and Goose Creek Limestone										Penholoway Formation								
	94	91	85	95	63	63	63	66	65	88	64	93	49	50	50	89	89	20	51	56	57	60	60	86	87	87	83	83
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Radimella confragosa	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	X	X	—	X	—	X	—	—	—
Sahnicythere spp.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	X	—	—	—
Tetracytherura choctawhatcheensis	—	X	X	X	X	X	X	X	X	—	X	X	—	X	X	X	X	—	—	X	X	—	X	—	—	—	X	—
T. mccartanae	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—
T. minuta	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	X	—	—	—
T. similis	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	X	—	—	—
T. spp.	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	X	—	—	—	—	X	—	—	—
Xestoleberis sp.	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	X	—	—	—	X	—	—	X	—	X	—	—	X
Other	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—

Paracytheroma texana Garbett and Maddocks, 1979

Remarks.—This species apparently migrated into the Charleston area from the Gulf of Mexico only during the last interglacial period.

Distribution.—Wando Formation.

Illustration.—Cronin (1979), plate 19, figures 3, 5, 6, 8.

Genus MEGACYTHERE Puri, 1960

Remarks.—Rare specimens resembling *M. johnsoni* Mincher occur in the Waccamaw and Wando Formations. The distinctive species *M. repexa* Garbett and Maddocks, 1979, occurs in Pleistocene deposits of the Omar Formation of Delaware (Cronin and others, 1984).

Family CYTHERIDAE Baird, 1850

Genus CYTHEROMORPHA Hirschmann, 1909

Cytheromorpha curta Edwards, 1944

Remarks.—This species is atypical of the genus *Cytheromorpha*, as it lacks strong sexual dimorphism.

Distribution.—Common in brackish-water facies of the Duplin, Penholoway, Waccamaw, and Wando Formations.

Illustration.—Cronin (1979), plate 12, figures 6–9.

Cytheromorpha newportensis Williams, 1966

Remarks.—Originally described as a subspecies of *C. warneri*, this species is distinguished by its finely pitted surface in males, by fine pitting anteriorly and coarse pitting posteriorly in females, and by a smooth posteroventral depression.

Distribution.—Wando Formation.

Illustration.—Cronin (1979), plate 13, figures 5–8.

Cytheromorpha warneri Howe and Spurgeon, 1935

Plate 2, figure 1

Remarks.—This species is widespread in upper Miocene and Pliocene deposits of the Atlantic Coastal Plain (see Swain, 1974). It is characterized by regular, polygonal-shaped fossae and by a lack of posteroventral indentation.

Distribution.—Raysor and Bear Bluff Formations.

Genus MUNSEYELLA van den Bold, 1957

Munseyella subminuta (Puri, 1953)

Plate 2, figure 2

Remarks.—*Munseyella* is always found in very low numbers in the Coastal Plain.

Distribution.—Duplin, Raysor, and Waccamaw Formations.

Family CYTHERIDEIDAE Sars, 1925

Genus CYTHERIDEA Bosquet, 1852

Cytheridea virginiensis (Malkin, 1953)

Plate 1, figures 1, 2

Remarks.—Hazel (1983) identified three species of *Cytheridea* in the Pliocene and early Pleistocene deposits of central North Carolina. Only *C. virginiensis* reaches the Charleston, S.C., area.

Distribution.—Raysor and Bear Bluff Formations.

Genus CYPRIDEIS Jones, 1857

Remarks.—In Coastal Plain deposits *Cyprideis* is a genus of moderate diversity. At least six species occur in the Charleston, S.C., area, and Cronin (1986) found five species in the Quaternary of the Corpus Christi, Tex.,

deposits of the Atlantic Coastal Plain in the Charleston, S.C., area—Continued

fig. 2); bottom row, numbers used in this paper. —, not present; X, present]

					Ladson Formation	Ten Mile Hill beds				Wando Formation																												
54	84	23	23	48	4	29	59	44	11	31	31	31	31	60	60	60	14	14	14	92	10	30	30	30	46	46	46	78	82	21	21	43	19	19	19	69	60	13
29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	X	—	X	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	X	X	—	—	X	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	X	X	X	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	X	—	X	—	X	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—
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—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
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—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	X	—	—	—	—	—	X	X	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

area. A detailed study of the genus is warrented, particularly to determine affinities with Caribbean *Cyprideis*.

Cyprideis curta Edwards, 1944

Plate 1, figures 3, 4

Distribution.—Brackish-water facies of the Duplin, Waccamaw, and Wando Formations.

Cyprideis floridana Howe and Hough, 1935

Plate 1, figures 5–7

Distribution.—Duplin, Raysor, and Waccamaw Formations.

Cyprideis margarita Cronin, 1979

Distribution.—Brackish-water facies of the Penholoway and Wando Formations.

Illustration.—Cronin (1979), plate 1, figures 9, 10; plate 2, figures 7, 8; plate 3, figures 5, 6.

Cyprideis mexicana Sandberg, 1964

Distribution.—Brackish-water facies of the Waccamaw and Wando Formations.

Illustration.—Cronin (1979), plate 1, figures 1–4; plate 3, figures 1, 2.

Cyprideis salebrosa van den Bold, 1963

Distribution.—Duplin, Waccamaw, and Wando Formations.

Illustration.—Cronin (1979), plate 1, figures 5–8; plate 2, figures 5, 6; plate 3, figures 3, 4.

Cyprideis sp. A

Plate 1, figure 8

Remarks.—One of several morphotypes of *Cyprideis* that cannot as yet be assigned to a described species.

Distribution.—Penholoway and Wando Formations and Ten Mile Hill beds.

Genus PERATOCYTHERIDEA Hazel, 1983

Peratocytheridea bradyi (Stephenson, 1938)

Distribution.—Waccamaw and Wando Formations.

Illustration.—Cronin (1979), plate 2, figures 3, 4.

Peratocytheridea setipunctata (Brady, 1869)

Distribution.—Duplin, Waccamaw, and Wando Formations.

Illustration.—Cronin (1979), plate 2, figures 1, 2.

Genus PERISSOCYTHERIDEA Stephenson, 1938

Remarks.—Several species of *Perissocytheridea* that are common in the Gulf of Mexico do not reach the South Carolina coast in their distribution (Cronin, 1986). One undescribed species (*Perissocytheridea* sp. of Kontrovitz and Bitter, 1976) occurs in the Pleistocene of North Carolina (Cronin and others, 1981) and as far north as Nova Scotia in the Holocene, but it has not been found in South Carolina.

Perissocytheridea brachyforma Swain, 1955

Remarks.—Throughout Pliocene and Pleistocene deposits of the Atlantic Coastal Plain, this species varies in the development of ridges and pits on the lateral surface (see illustrations in references below).

Distribution.—Common in brackish-water facies of the Duplin, Raysor, Waccamaw, and Wando Formations.

Illustration.—Cronin (1979), plate 4, figures 7–10; Cronin and Hazel (1980), figure 9g.

Perissocytheridea subpyriformis Edwards, 1944

Remarks.—This species is characterized by an extremely inflated posterodorsal area, a subpyriform shape, and an irregularly reticulated surface.
Distribution.—Duplin Formation.
Illustration—Cronin and Hazel (1980), figure 9e.

Genus PONTOCYTHERE Dubowsky, 1939

Pontocythere sp. A

Plate 3, figures 1, 2

Distribution.—Canepatch and Wando Formations.

Pontocythere? sp. B

Plate 3, figure 3

Remarks.—This species occurs with *Pontocythere* sp. A, but it is smaller and less arched dorsally. Not enough specimens were available to determine its relation to *Pontocythere.*
Distribution.—Ladson and Canepatch Formations.

Pontocythere? sp. I

Plate 3, figures 4–6

Remarks.—This species was referred to as *Hulingsina* sp. I in Cronin (1981a), but its lack of a sulcus and its similarity in shape and hinge to other *Pontocythere* species suggest that it may belong in the latter genus.
Distribution.—Duplin and Raysor Formations.

Family CUSHMANIDEIDAE Puri, 1973
Genus CUSHMANIDEA Blake, 1933

Cushmanidea seminuda (Cushman, 1906)

Distribution.—Wando Formation.
Illustration.—Cronin (1979), plate 5, figures 1, 3, 5, 7.

Genus HULINGSINA Puri, 1958

Remarks.—Puri (1958) described *Hulingsina* as a tuberculate or coarsely pitted neocytherideid genus that has a subacute posterior. In a review of some ostracodes of the family Cytherideidae Sars, Athersuch (1982) placed *Hulingsina* in synonymy with *Pontocythere* Dubowsky, 1939. However, *Hulingsina* is very common in modern and fossil sublittoral sediments of the Atlantic and Gulf Coastal Plains, and its species consistently show the following features that distinguish it from *Pontocythere. Hulingsina* has a moderately to heavily ornamented surface, usually consisting of coarse pits, low ridges, or tubercles, the presence of an oblique, dorsomedian sulcus, a relatively thick shell, and an elongate shape. In contrast, *Pontocythere* from the Atlantic Coast are smooth to very faintly ribbed anteriorly, lack a sulcus, and are more arched dorsally. Both occur in deposits in the Coastal Plain of South Carolina. Swain (1974) considered *Hulingsina* to be a subgenus of *Pontocythere. Cushmanidea* Blake, 1933, is distinguished from these genera by its centrally located hinge area, differences in hinge details (Athersuch, 1982), a lack of strong sexual dimorphism, and its distinctive shape, in which anterior and posterior ends are both evenly rounded. *Cushmanidea* occurred in only one sample in the Charleston area but is common in fossil and modern sediments from North Carolina to Massachusetts.

Hulingsina americana (Cushman, 1906)

Distribution.—Duplin, Raysor, Penholoway, Waccamaw, and Canepatch Formations and Goose Creek Limestone.
Illustration.—Valentine (1971), plate 3, figures 11, 15, 16 (not pl. 3, figs. 8, 12, 13, 14=*H.* sp. A below).

Hulingsina glabra (Hall, 1965)

Distribution.—Penholoway, Waccamaw, and Wando Formations, Goose Creek Limestone, and Ten Mile Hill beds.
Illustration.—Cronin (1979), plate 6, figure 2.

Hulingsina cf. H. sulcata Puri, 1960

Distribution.—Penholoway and Wando Formations and Ten Mile Hill beds.
Illustration.—Puri (1960), plate 2, figure 7.

Hulingsina? cylindrica (Ulrich and Bassler, 1904)

Plate 3, figures 7, 8

Remarks.—Specimens from the Duplin Formation appear to be similar in ornament and shape to that illustrated by Forester (1980, pl. 2, fig. 2) from the Calvert Formation. The specimens from South Carolina also resemble *Cushmanidea*, hence the uncertain generic assignment.
Distribution.—Penholoway Formation.

Hulingsina aff. H. semicircularis (Ulrich and Bassler, 1904)

Plate 2, figures 3–5

Remarks.—The specimens illustrated in this paper from the Duplin Formation may be the same species as that identified as *Cytherideis ashermani* Ulrich and Bassler, 1904, by Edwards (1944). Forester (1980) discussed the taxonomy of Ulrich and Bassler's species of *Hulingsina* in detail.
Distribution.—Duplin and Raysor Formations.

Hulingsina rugipustulosa (Edwards, 1944)

Plate 2, figures 6–8

Remarks.—The specimens illustrated in this paper represent a distinct Pliocene morphotype of *H. rugipus-*

tulosa characterized by broad, low fossae and a lack of ridges. It was referred to as *H.* sp. EE in Cronin (1981a). However, in Pleistocene and modern sediments, ridges are usually absent, especially in the posterior half of the carapace, and tubercles are usually present (see Valentine, 1971; Cronin, 1979).

Distribution.—This morphotype occurs only in the Duplin and Raysor Formations, but the species is found commonly in younger formations as well.

Hulingsina sp. A

Distribution.—Duplin, Raysor, Bear Bluff, Penholoway, and Waccamaw Formations and Goose Creek Limestone.

Illustration.—Cronin (1979), plate 6, figures 1, 3, 5.

Hulingsina sp. C

Distribution.—Penholoway, Waccamaw, and Wando Formations and Ten Mile Hill beds.

Illustration.—Cronin (1979), plate 7, figures 2, 4.

Hulingsina spp.

Remarks.—Rare specimens of *Hulingsina* that occur in some formations cannot be assigned to any of the above species.

Family NEOCYTHERIDEIDAE Puri, 1957

Genus NEOCYTHERIDEIS Puri, 1952, and genus SAHNICYTHERE Athersuch, 1982

Remarks.—Athersuch (1982) provided a useful revision of *Neocytherideis* Puri, its synonym *Sahnia* Puri, 1952, and *Sahnicythere* Athersuch, 1982. The criteria by which Athersuch distinguishes *Neocytherideis* and *Sahnicythere* are consistent in specimens in the western North Atlantic Cenozoic assemblages and are summarized as follows. *Neocytherideis* is larger and has short, widely spaced radial pore canals, a broad anterior vestibule, and no median sulcus. *Sahnicythere* is smaller and has long, sinuous radial pore canals, a narrow anterior vestibule, a wide inner lamella, and a distinct sulcus. In contrast to European species, American *Sahnicythere* specimens have a faint surface ornament (Lyon, this volume, pl. 8, fig. 4; Cronin, 1979, pl. 6, fig. 7), whereas specimens tentatively assigned to *Neocytherideis* have an evenly pitted surface (Cronin, 1979, pl. 9, fig. 8).

Distribution.—These two genera occur together in very low numbers in the Canepatch, Ladson, and Wando Formations.

Family CYTHERURIDAE G.W. Müller, 1894

Genus CYTHERURA Sars, 1866

Cytherura carolinensis Cronin n. sp.

Plate 4, figures 3, 4

Diagnosis.—Relatively thick-shelled *Cytherura* that has a large oval posteroventral depression, reticulate ornamentation consisting of longitudinal rows of fossae, and a blunt caudal process. Fossae are square to subrectangular in shape, longitudinally arranged over most of the surface but concentrically arranged in the posteroventral depression. Fine pits visible within the fossae. Small anterior vestibule and posteroventral vestibule present. Carapace is highest in the posterior half.

Holotype.—Female left valve (pl. 4, fig. 3), USNM 413859; length, 325 μm; height, 180 μm.

Type locality.—Duplin Formation, Darlington West 7½-minute quadrangle, South Carolina, lat 34°19′45″ N., long 79°58′00″ W.; surface altitude, 182 ft; depth, 38.5–48.5 ft below surface altitude.

Etymology.—Named for South Carolina.

Remarks.—This extinct species is distinguished from other *Cytherura* found in Coastal Plain deposits by its characteristic ornament and heavily calcified carapace.

Distribution.—Duplin, Raysor, and Penholoway Formations.

Cytherura elongata Edwards, 1944

Distribution.—Duplin, Raysor, Bear Bluff, Penholoway, Waccamaw, and Wando Formations, Goose Creek Limestone, and Ten Mile Hill beds.

Illustration.—Garbett and Maddocks (1979), plate 5, figure 2.

Cytherura fiscina Garbett and Maddocks, 1979

Remarks.—Some specimens are difficult to distinguish from the closely related *C. forulata.*

Distribution.—Ten Mile Hill beds and Wando Formation.

Illustration.—Garbett and Maddocks (1979), plate 5, figures 7–10.

Cytherura forulata Edwards, 1944

Distribution.—Duplin, Bear Bluff, Penholoway, and Wando Formations and Ten Mile Hill beds.

Illustration.—Cronin (1979), plate 8, figures 1–3.

Cytherura howei Puri, 1953

Distribution.—Duplin, Raysor, Bear Bluff, Penholoway, and Waccamaw Formations and Ten Mile Hill beds.

Illustration.—Cronin (1979), plate 14, figure 7.

Cytherura neusensis Cronin n. sp.

Plate 17, figures 1–4

Diagnosis.—*Cytherura* characterized by a subovate shape, convex dorsum in females, longitudinal rows of fossae that grade into smaller pits posteriorly in males, a posterior caudal process, and strong sexual dimorphism. Females are subovate and higher than males. Males have a swollen posterior, so the fossae become faint and the pits within the reticulum, more prominent. Sometimes the swollen area appears to be smooth. The eye spot is prominent.

Holotype.—Female left valve (pl. 17, fig. 1), USNM 413963; length, 435 µm; height, 225 µm.

Type locality.—Wando Formation, Wadmalaw Island 7½-minute quadrangle, South Carolina, lat 32°39′30″ N., long 80°10′15″ W.; surface altitude, 15 ft; depth, 10–15 ft below surface altitude.

Etymology.—Named for Neuse River, N.C., where this species was found in abundance in Pleistocene deposits (species B of Cronin, 1979).

Remarks.—Differs from *C. elongata* in the position and shape of the caudal process, the overall carapace shape, and the presence of pitting in the fossae.

Distribution.—Penholoway, Waccamaw, Canepatch, and Wando Formations and Ten Mile Hill beds.

Cytherura nucis Garbett and Maddocks, 1979

Distribution.—Penholoway and Wando Formations.

Illustration.—Cronin (1979), plate 10, figures 3–5; Lyon (this volume), plate 10, figure 3.

Cytherura pseudostriata Hulings, 1966

Distribution.—Penholoway and Wando Formations and Ten Mile Hill beds.

Illustration.—Cronin (1979), plate 9, figure 6.

Cytherura reticulata Edwards, 1944

Distribution.—Duplin, Bear Bluff, Penholoway, Waccamaw, and Wando Formations and Ten Mile Hill beds.

Illustration.—Cronin (1979), plate 8, figures 5, 6.

Cytherura wardensis Howe and Brown, 1935

Plate 4, figure 1

Remarks.—Specimens from the Waccamaw (species C of Cronin, 1981a) have more subdued reticulation than those described by Howe and Brown (in Howe and others, 1935) from the Arca Zone of the Choctawhatchee Formation of Florida.

Distribution.—Penholoway and Waccamaw Formations.

Cytherura cf. C. radialirata Swain, 1955

Plate 4, figure 2

Remarks.—Specimens from the Canepatch Formation resemble this species from the Gulf of Mexico in size, shape, and the distinctive pattern of ornament; however, the distribution of fossae in *C. radialirata* is more concentric posteriorly.

Distribution.—Canepatch and Wando Formations.

Cytherura spp.

Remarks.—*Cytherura* is represented by other rare species in the Atlantic and Gulf Coastal Plains, such as *C. sablensis* Benson and Coleman, 1963 (see Cronin, 1979), and *C.* aff. *C. swaini* van den Bold, 1963 (see Lyon, this volume). In some cases, these occurrences represent brief northward migrations from southern Florida, the Gulf of Mexico, or the Caribbean.

Genus CYTHEROPTERON Sars, 1866

Cytheropteron talquinensis Puri, 1953

Distribution.—Duplin, Raysor, Bear Bluff, Penholoway, and Waccamaw Formations and Goose Creek Limestone.

Illustration.—Puri (1953), plate 5, figures 5–7.

Cytheropteron yorktownensis (Malkin, 1953)

Distribution.—Duplin, Raysor, Bear Bluff, Penholoway, and Waccamaw Formations and Goose Creek Limestone.

Illustration.—Swain (1974), plate 3, figures 9–15.

Genus TETRACYTHERURA Ruggieri, 1952

Tetracytherura choctawhatcheensis (Puri, 1953)

Distribution.—Duplin, Raysor, Bear Bluff, Waccamaw, Canepatch, Ladson, and Wando Formations and Goose Creek Limestone.

Illustration.—Cronin and Hazel (1980), figure 7c; Hazel (1983), plate 29, figure 3.

Tetracytherura expanda (Hazel, 1983)

Distribution.—Waccamaw and Canepatch Formations.

Illustration.—Cronin and Hazel (1980), figure 7f; Hazel (1983), plate 30, figures 1–3.

Tetracytherura minuta (Hazel, 1983)

Plate 5, figure 7

Remarks.—This species is smaller and more convex dorsally than *T. norfolkensis* (Cronin, 1979), and female specimens from the two species are difficult to distinguish from one another.

Distribution.—Duplin and Bear Bluff Formations.

Tetracytherura norfolkensis (Cronin, 1979)

Remarks.—This species probably descended from *T. minuta*. Males of *T. norfolkensis* characteristically are rectangular in shape. *T. norfolkensis* was found only in the Canepatch Formation in South Carolina, but it is more common in Pleistocene deposits of North Carolina and Virginia.

Distribution.—Canepatch Formation.

Illustration.—Cronin (1979), plate 10, figures 8–10.

Tetracytherura similis (Malkin, 1953)

Plate 5, figures 3, 4

Remarks.—*T. similis* shows great variability in size, but all specimens are finely and evenly pitted and have very faint to absent reticulum.

Distribution.—Duplin, Raysor, Bear Bluff, Penholoway, and Waccamaw Formations.

Tetracytherura owensi Cronin n. sp.

Plate 5, figures 1, 2, 8

Diagnosis.—*Tetracytherura* that has a thick subquadrate carapace and angular margins; females highest in posterior half near posterodorsal margin. Large, evenly spaced, deep pits on the surface. Carapace has strong sexual dimorphism; females have faint vertical sulcus; both sexes have a conspicuous indentation at the anterior margin.

Holotype.—Female left valve (pl. 5, fig. 1), USNM 413865; length, 665 μm; height, 290 μm.

Type locality.—Bear Bluff Formation, Conway 7½-minute quadrangle, South Carolina, lat 33°50′ N., long 79°00′ W.; surface altitude, 50 ft; depth, 63–68 ft below surface altitude.

Etymology.—Named for J.P. Owens (USGS), who provided material from South Carolina.

Remarks.—Specimens of *T. owensi* are consistently more coarsely pitted than *T. similis*. The specimens illustrated in this paper have fewer and smaller pits than the specimens illustrated in Cronin and Hazel (1980, fig. 7b) from the Waccamaw Formation.

Distribution.—Bear Bluff and Waccamaw Formations.

Tetracytherura mccartanae Cronin n. sp.

Plate 5, figures 5, 6

Diagnosis.—Small *Tetracytherura* characterized by a subovate shape, gently rounded margins, and surface ornament that consists of a mesh of very faint polygonal fossae. Evenly spaced, fine pitting within the polygons. Males taper significantly toward the posterior end.

Holotype.—Female left valve (pl. 5, fig. 5), USNM 413870; length, 560 μm; height, 260 μm.

Type locality.—Ten Mile Hill beds, Beaufort 7½-minute quadrangle, South Carolina, lat 32°25′30″ N., long 80°44′00″ W.; surface altitude, 15 ft; depth, 10 ft below surface altitude.

Etymology.—Named for Lucy McCartan (USGS), who mapped the Quaternary geology of the Charleston area.

Remarks.—This species is larger, is more ovate, and has larger pits than *T. minuta* (Hazel, 1983). It differs from *T. similis* in that its pitting is not as dense as in *T. similis* and its margins are rounded, not sharp.

Distribution.—Waccamaw, Canepatch, and Wando Formations and Ten Mile Hill beds.

Family LOXOCONCHIDAE Sars, 1925
Genus LOXOCONCHA Sars, 1866

Loxoconcha edentonensis Swain, 1951

Remarks.—Some specimens of this species have weak longitudinal ridges; others, a more reticulating pattern. There is gradation between the two morphotypes.

Distribution.—Bear Bluff, Waccamaw, and Canepatch Formations.

Illustration.—Cronin and Hazel (1980), figure 9d; Hazel (1983), plate 24, figures 2, 4.

Loxoconcha matagordensis Swain, 1955

Distribution.—Common especially in brackish-water facies of the Penholoway, Waccamaw, Canepatch, and Wando Formations.

Illustration.—Cronin and Hazel (1980), figure 9c.

Loxoconcha purisubrhomboidea Edwards, 1953

Plate 6, figure 1

Distribution.—Duplin, Bear Bluff, and Waccamaw Formations and Goose Creek Limestone.

Loxoconcha reticularis Edwards, 1944

Distribution.—Duplin, Raysor, Bear Bluff, Waccamaw, Wando, and Canepatch Formations and Ten Mile Hill beds.

Illustration.—Lyon (this volume), plate 2, figure 1.

Loxoconcha sp. A

Plate 6, figure 2

Remarks.—This small, finely pitted form has a straight dorsal margin and evenly spaced pitting on its surface. It has a different shape from *L. purisubrhomboidea* and lacks an eye spot.

Distribution.—Duplin Formation.

Loxoconcha florencensis Cronin n. sp.

Plate 6, figures 3–5

Diagnosis.—*Loxoconcha* that has a smooth to coarsely pitted surface, often forming concentric patterns, a sharp posterodorsal angle, and a straight dorsal margin. A straight posterodorsal region leads to a pointed posterior. Female specimens are usually convex along the ventral margin.

Holotype.—Female left valve (pl. 6, fig. 3), USNM 413875; length, 690 μm; height, 380 μm.

Type locality.—Duplin Formation, Florence East 15-minute quadrangle, South Carolina, lat 34°01′ N., long 79°41′ W.; surface altitude, 90 ft; depth, 38.5–48.5 ft below surface altitude.

Etymology.—Named for its type locality near Florence, S.C.

Remarks.—This species differs from other Coastal Plain *Loxoconcha* in its concentric pitting and subquadrate shape. It is relatively large for the genus *Loxoconcha.*

Distribution.—Duplin, Raysor, and Bear Bluff Formations and Goose Creek Limestone.

Loxoconcha carolinensis Cronin n. sp.

Plate 6, figures 6, 7; plate 17, figure 5

Diagnosis.—*Loxoconcha* characterized by its small size, coarsely pitted surface, and thick murae. Surface has very few large pits compared to most *Loxoconcha*, and this species also has compressed peripheries at anterior and posterior ends.

Holotype.—Female left valve (pl. 6, fig. 6), USNM 413878; length, 390 μm; height, 260 μm.

Type locality.—Duplin Formation, Florence East 15-minute quadrangle, South Carolina, lat 34°01′ N., long 79°41′ W.; surface altitude, 90 ft; depth, 38.5–48.5 ft below surface altitude.

Etymology.—Named for South Carolina.

Remarks.—This species is somewhat similar to *Loxoconcha* sp. B of Cronin (1983), a modern bathyal species off the coast of Florida, but differs in its more rounded outline and less compressed periphery.

Distribution.—Raysor and Duplin Formations.

Family LEPTOCYTHERIDAE Hanai, 1957

Genus LEPTOCYTHERE Sars, 1925

Leptocythere nikraveshae Morales, 1966

Remarks.—Small *Leptocythere* occur commonly in brackish-water facies of Quaternary deposits of the Coastal Plain and show great variation in surface ornament. Cronin (1979) illustrates late Pleistocene specimens showing morphotypes gradational from finely pitted to rugose, probably representing variations that result from environmental factors, such as fluctuating salinity and water temperature.

Distribution.—Canepatch and Wando Formations and Ten Mile Hill beds.

Illustration.—Cronin (1979), plate 14, figures 1–6.

Family PARACYTHERIDEIDAE Puri, 1957

Genus PARACYTHERIDEA G.W. Müller, 1894

Paracytheridea altila Edwards, 1944

Distribution.—Duplin, Raysor, Penholoway, Waccamaw, Canepatch, and Wando Formations and Ten Mile Hill beds.

Illustration.—Cronin and Hazel (1980), figure 8f; Hazel (1983), plate 28, figure 4.

Paracytheridea cronini Hazel, 1983

Plate 4, figure 6

Distribution.—Duplin, Bear Bluff, Penholoway, Waccamaw, and Canepatch Formations.

Paracytheridea mucra Edwards, 1944

Plate 4, figure 5

Remarks.—Although previously believed extinct since the early Pleistocene, *P. mucra* occurs in deposits dated about 200 ka in central North Carolina (Cronin and others, 1981).

Distribution.—Duplin, Bear Bluff, and Waccamaw Formations.

Paracytheridea rugosa Edwards, 1944

Distribution.—Duplin, Raysor, Bear Bluff, Penholoway, and Waccamaw Formations and Goose Creek Limestone.

Illustration.—Cronin and Hazel (1980), figure 8b.

Paracytheridea hazeli Cronin n. sp.

Plate 4, figures 7, 8; plate 17, figure 6

Diagnosis.—*Paracytheridea* that has a pointed posterior and prominent longitudinal ridges and tubercles in posterior region. The ventral longitudinal ridge can be bladelike but not as long or pointed as in *P. rugosa* Edwards. One posteroventral tubercle always projects beyond margin behind ventral ridge. Three ridges converge anteriorly from the subcentral tubercle, from just above the tubercle, and from the eye region.

Holotype.—Female left valve (pl. 4, fig. 8), USNM 413864; length, 570 μm; height, 315 μm.

Type locality.—Ten Mile Hill beds, Beaufort 7½-minute quadrangle, South Carolina, lat 32°25′30″ N., long 80°44′00″ W.; surface altitude, 15 ft; depth, 10 ft below surface altitude.

Etymology.—Named for J.E. Hazel (Louisiana State University), who first recognized this species.

Remarks.—This species occurs in low numbers in modern sediments along the Atlantic Coast (referred to *Paracytheridea* sp. A by Valentine, 1971) and in Pleistocene deposits. The complex of short ridges and tubercles in the posterior region is developed to different degrees in different populations.

Distribution.—Canepatch and Wando Formations and Ten Mile Hill beds.

Family EUCYTHERIDAE Puri, 1953
Genus EUCYTHERE Brady, 1868

Eucythere gibba Edwards, 1944

Distribution.—Duplin, Raysor, Bear Bluff, Penholoway, and Waccamaw Formations and Ten Mile Hill beds.

Illustration.—Cronin (1979), plate 15, figure 7.

Eucythere triangulata Puri, 1953

Distribution.—Bear Bluff, Penholoway, Waccamaw, and Wando Formations, Goose Creek Limestone, and Ten Mile Hill beds.

Illustration.—Cronin (1979), plate 15, figure 8.

Family TRACHYLEBERIDIDAE Sylvester-Bradley, 1948
Subfamily TRACHYLEBERIDINAE Sylvester-Bradley, 1948
Genus ACTINOCYTHEREIS Puri, 1960

Actinocythereis captionis Hazel, 1983

Plate 7, figures 5, 6

Remarks.—This is one of the more common species in the Atlantic Coastal Plain, where it is abundant in nearshore deposits.

Distribution.—Duplin, Raysor, Bear Bluff, Penholoway, Waccamaw, Wando, and Socastee Formations, Goose Creek Limestone, and Ten Mile Hill beds.

Illustration.—Hazel (1983), plate 8, figures 1, 2, 4.

Actinocythereis dawsoni (Brady, 1870)

Plate 7, figures 1, 2

Remarks.—Specimens from the Pliocene deposits of South Carolina have a more rounded anterodorsal ridge than those illustrated by Hazel (1977, 1983) from the Yorktown Formation.

Distribution.—Duplin and Raysor Formations.

Actinocythereis marylandica (Howe and Hough, 1935)

Plate 7, figures 3, 4

Remarks.—Forester (1980) stated that *A. marylandica* (Howe and Hough) was larger and more robust than *A. exanthemata* (Ulrich and Bassler) and that the two species differed in the positioning of the surface spines. The Raysor material more closely resembles *A. marylandica* in its very large size. The degree of variability in the spines precludes separation of *A. marylandica* from *A. exanthemata* on the basis of this characteristic.

Distribution.—Raysor and Bear Bluff Formations.

Actinocythereis aff. A. bahamaensis (Brady, 1868)

Plate 7, figures 7, 8

Remarks.—This distinctive species has circularly shaped bullate spines over much of its surface and a series of four bullate spines occurring along the anterodorsal margin, in contrast to the ridge found in most other species. It most closely resembles *A. bahamaensis*, which is larger and has a smoother surface containing fewer spines.

Distribution.—Raysor and Duplin Formations.

Actinocythereis cf. A. subquadrata Puri, 1960

Remarks.—A few distinct specimens resembling this species were found at a single locality in lower Pleistocene deposits believed to represent the Penholoway Formation near Charleston, S.C. If correct, this occurrence signifies a brief northward migration from the Florida region during a warm, early Pleistocene interval.

Genus NEOCAUDITES Puri, 1960

Neocaudites angulata Hazel, 1983

Plate 8, figure 3

Remarks.—This species is similar to *N. atlantica* Cronin, 1979, but it has much stronger ridges, a less compressed carapace, and prominent lateral, posterodorsal, and posteroventral projections at the ends of longitudinal ridges.

Distribution.—Duplin, Raysor, and Waccamaw Formations.

Neocaudites atlantica Cronin, 1979

Distribution.—Canepatch, Socastee, and Wando Formations.

Illustration.—Cronin (1979), plate 16, figures 4–7.

Neocaudites subimpressa (Edwards, 1944)

Plate 8, figures 1, 2, 4

Remarks.—The species *Neocaudites scottae* Teeter, 1975, strongly resembles Edwards' species.

Distribution.—Duplin, Penholoway, and Waccamaw Formations.

Neocaudites triplistriata (Edwards, 1944)

Remarks.—This species lives off Florida today, but its range does not extend as far north as the South Carolina coast.

Distribution.—Duplin, Bear Bluff, Penholoway, and Waccamaw Formations.

Illustration.—Hazel (1983), plate 6, figure 1.

Neocaudites variabilis Hazel, 1983

Plate 8, figure 5

Remarks.—*Neocaudites pulchra* Teeter, 1975, differs from *N. variabilis* only slightly in the posteroventral area and in details of the surface reticulation.

Distribution.—Penholoway and Waccamaw Formations.

Genus HENRYHOWELLA Puri, 1957

Henryhowella cf. H. evax (Ulrich and Bassler, 1904)

Plate 8, figures 7, 8

Remarks.—This species is extremely variable in morphology and requires detailed study to understand the taxonomic relationships between deep- and shallow-water populations.

Distribution.—Duplin and Raysor Formations.

Genus MURRAYINA Puri, 1953

Murrayina barclayi McLean, 1957

Plate 9, figure 3

Remarks.—This species is restricted to lower Pliocene deposits of South Carolina, but it occurs in slightly younger deposits in North Carolina (Hazel, 1983).

Distribution.—Raysor Formation.

Murrayina macleani Swain, 1974

Plate 9, figures 1, 2

Remarks.—This species is restricted to lower Pliocene deposits of South Carolina, but it occurs in slightly younger deposits in North Carolina (Hazel, 1983).

Distribution.—Raysor Formation.

Genus ECHINOCYTHEREIS Puri, 1953

Echinocythereis leecreekensis Hazel, 1983

Distribution.—Duplin, Raysor, Bear Bluff, Penholoway, Waccamaw, and Wando Formations, Goose Creek Limestone, and Ten Mile Hill beds.

Illustration.—Hazel (1983), plate 36, figures 1–3; plate 38, figure 3.

Echinocythereis planibasalis (Ulrich and Bassler, 1904)

Plate 11, figures 1, 2

Distribution.—Raysor and Bear Bluff Formations.

Genus PURIANA Coryell and Fields, 1937

Remarks.—A detailed evolutionary and taxonomic study of *Puriana* can be found in Cronin (1987).

Puriana carolinensis Hazel, 1983

Plate 11, figure 8

Remarks.—This species is extremely common in the Coastal Plain deposits that represent warm-water conditions. In these deposits, specimens typically have thick but distinctly separated carinae. Pliocene and early Pleistocene forms are considered conspecific with the form discussed by Hazel (1983, p. 111) as an undescribed species and illustrated as *Puriana* sp. A by Cronin and Hazel (1980, fig. 4a). This latter form, which ranges from the middle Pleistocene to the Holocene, has a variably smooth surface in which the carinae are joined, especially in the middle of the valve surface. The similarity in size, shape, and primary pattern of carinae suggests that these species are conspecific and are ecophenotypic variants of the same species. Water temperature probably partly affects the secretion of the test in *Puriana*, so that narrow carinae are formed in warm waters and thick carinae, in cool waters (Cronin, 1987).

Distribution.—Carinate form: Duplin, Raysor, Bear Bluff, Penholoway, and Waccamaw Formations and Goose Creek Limestone. Smooth form: Canepatch, Wando, Ladson, and Socastee Formations.

Puriana convoluta Teeter, 1975

Remarks.—Coastal Plain species are larger than those from the type area off the coast of Belize and are larger than those from other modern Caribbean environments as well.

Distribution.—Duplin, Bear Bluff, Penholoway, Canepatch(?), and Waccamaw Formations.

Illustration.—Cronin and Hazel (1980), figure 4d.

Puriana floridana Puri, 1960

Remarks.—This species is variable in surface ornament, as specimens from warmer water deposits are more spinose and specimens from cooler water deposits are more smooth.

Distribution.—Waccamaw, Canepatch, Wando(?), and Socastee Formations.

Illustration.—Cronin (1979), plate 16, figure 10.

Puriana mesacostalis (Edwards, 1944)

Plate 11, figures 5, 6

Remarks.—The form illustrated in plate 11, figure 5, has narrow ridges and a smooth surface and is typical of the Bear Bluff and Duplin Formations, whereas the one shown in plate 11, figure 6, has stronger ridges and is typical of the Penholoway and Waccamaw Formations.

Distribution.—Duplin, Bear Bluff, Penholoway, Waccamaw, and Wando Formations.

Puriana rugipunctata (Ulrich and Bassler, 1904)

Plate 11, figure 7

Distribution.—Duplin, Raysor, and Canepatch Formations.

Subfamily CYTHERETTINAE Triebel, 1950
Genus PSEUDOCYTHERETTA Cushman, 1906

Pseudocytheretta cf. P. burnsi (Ulrich and Bassler, 1904)

Plate 9, figures 5–7

Remarks.—Raysor Formation specimens have more prominent eye spots compared to specimens from the Yorktown, Calvert, and Choptank Formations (Forester, 1980; Hazel, 1983). Swain (1974) referred to very similar specimens as *P. burnsi.*

Distribution.—Duplin, Raysor, and Bear Bluff Formations and Goose Creek Limestone.

Pseudocytheretta edwardsi Cushman, 1906

Plate 9, figure 8

Distribution.—Raysor, Penholoway, and Wando Formations.

Genus PROTOCYTHERETTA Puri, 1958

Protocytheretta reticulata (Edwards, 1944)

Plate 9, figure 4

Remarks.—These specimens resemble *P. karlana* (Howe and Pyeatt, 1935) illustrated by Puri (1958) from the Chipola and Shoal River Formations of Florida, and it is possible that the two forms are conspecific.

Distribution.—Duplin, Raysor, and Waccamaw Formations.

Subfamily PTERYGOCYTHEREIDINAE Puri, 1957
Genus PTERYGOCYTHEREIS Blake, 1933

Pterygocythereis alophia Hazel, 1983

Distribution.—Duplin, Bear Bluff, Penholoway, Waccamaw, Canepatch, Wando, and Socastee Formations.

Illustration.—Hazel (1983), plate 7, figures 3, 4.

Pterygocythereis inexpectata (Blake, 1929)

Plate 8, figure 6

Remarks.—This species occurs with *Echinocythereis planibasalis*, *Henryhowella*, and *Murrayina* in a typical early Pliocene assemblage in the Raysor Formation, but none of these occurs in younger sediments in this region.

Distribution.—Raysor Formation.

Family HEMICYTHERIDAE Puri, 1953
Subfamily HEMICYTHERINAE Puri, 1953
Genus AURILA Pokorny, 1955

Aurila laevicula Edwards, 1944

Distribution.—Duplin, Bear Bluff, Penholoway, Waccamaw, Wando, Canepatch, and Socastee Formations.

Illustration.—Cronin (1979), plate 15, figures 1–4.

Genus CAUDITES Coryell and Fields, 1937

Caudites paraasymmetricus Hazel, 1983

Plate 13, figures 5, 6

Remarks.—Hazel (1983) described *C. paraasymmetricus* from the early Pleistocene of North Carolina and Florida. He noted that it differed from *C. asymmetricus* Pokorny, 1970, from the Galapagos Islands because *C. paraasymmetricus* has a longer ventral carina and a more centrally located caudal process. The two forms are closely related and signify faunal interchange before the formation of the Isthmus of Panama.

Distribution.—Penholoway and Waccamaw Formations.

Genus HERMANITES Puri, 1955

Hermanites ascitus Hazel, 1983

Plate 11, figures 3, 4

Remarks.—This species is very rare in Coastal Plain deposits and shows significant variability in the development of pitting between the longitudinal ridges.

Distribution.—Duplin and Raysor Formations and Goose Creek Limestone.

Genus MALZELLA Hazel, 1983

Malzella conradi (Howe and McGuirt, 1935)

Plate 10, figures 1, 2

Distribution.—Raysor, Bear Bluff, and Duplin Formations and Goose Creek Limestone.

Malzella evexa Hazel, 1983

Plate 10, figures 3, 4

Distribution.—Penholoway, Waccamaw, and Canepatch Formations.

Malzella floridana (Benson and Coleman, 1963)

Plate 10, figure 5

Distribution.—Canepatch, Wando, and Socastee Formations and Ten Mile Hill beds.

Genus MUELLERINA Bassiouni, 1965

Muellerina bassiounii Hazel, 1983

Plate 12, figures 7, 8

Remarks.—This species is relatively small for the genus and has two characteristic vertical ridges in the posterior region.

Distribution.—Duplin, Raysor, Bear Bluff, Penholoway, and Waccamaw Formations.

Muellerina ohmerti Hazel, 1983

Plate 12, figures 1, 2

Remarks.—Specimens from South Carolina are concave dorsally and have a very prominent eye spot.

Distribution.—Duplin, Raysor, Bear Bluff, Waccamaw, Canepatch, Wando, and Socastee Formations and Goose Creek Limestone.

Muellerina aff. M. ohmerti Hazel, 1983

Plate 12, figures 3, 4, 9

Remarks.—This species is characterized by three well-developed longitudinal ridges in the posterodorsal region, the most dorsal of which forms the dorsal margin. These ridges are curved in females (pl. 12, fig. 3) and straight in males (pl. 12, fig. 4). A nearly vertical ridge connects the posterior end of these two ridges with a well-developed ventral longitudinal ridge. This species is closely related to *M. ohmerti*, but it differs in having a less prominent eye spot, in having much stronger ridges, and in the detail of the surface pitting.

Distribution.—Bear Bluff and Waccamaw Formations.

Muellerina wardi Hazel, 1983

Plate 12, figures 5, 6, 10

Remarks.—This species is larger and has a straighter dorsum than *M. bassiounii.*

Distribution.—Duplin, Raysor, Bear Bluff, Penholoway, and Waccamaw Formations and Goose Creek Limestone.

Muellerina petersburgensis Hazel, 1983

Remarks.—This form is considered here to be a distinct species from *M. canadensis* Brady.

Distribution.—Raysor Formation and Goose Creek Limestone.

Illustration.—Hazel (1983), plate 16, figure 2; plate 18, figures 1, 3.

Genus ORIONINA Puri, 1953

Orionina vaughani (Ulrich and Bassler, 1904)

Plate 13, figure 8

Remarks.—Cronin and Schmidt (1988) compared specimens from the Coastal Plain with specimens of *O. pseudovaughani* Swain from the Pacific Coast off Central America and concluded that these two forms were conspecific, as originally implied by Swain and others (1964) in their initial study of ostracodes of the Gulf of California. The distinction between *O. vaughani* and *O. serrulata* van den Bold, two species distinguished only in some populations on the basis of the number of radial pore canals (van den Bold, 1963), is also minor, and Cronin and Schmidt (1988) consider these two forms probably to be conspecific as well.

Distribution.—Duplin, Raysor, Bear Bluff, Penholoway, and Canepatch Formations and Goose Creek Limestone.

Genus PALACIOSA Hartmann, 1959

Palaciosa minuta (Edwards, 1944)

Plate 13, figures 1–4

Distribution.—Duplin, Penholoway, and Waccamaw Formations.

Genus RADIMELLA Pokorny, 1968

Radimella confragosa (Edwards, 1944)

Plate 10, figures 6–8

Distribution.—Duplin, Bear Bluff, Penholoway, Waccamaw, and Canepatch(?) Formations and Goose Creek Limestone.

Subfamily CAMPYLOCYTHERINAE Puri, 1960
Genus ACUTICYTHEREIS Edwards, 1944

Acuticythereis laevissima Edwards, 1944

Plate 14, figures 1, 2

Remarks.—The specimen in plate 14, figure 2, is assigned tentatively to the species, but it differs from the typical form in having more rounded margins.

Distribution.—Duplin, Raysor, Bear Bluff, and Penholoway Formations and Goose Creek Limestone.

Genus BASSLERITES Howe, 1937

Basslerites cf. B. miocenica Howe, 1937

Plate 14, figure 8

Remarks.—*Basslerites* is very rare in Coastal Plain sediments, perhaps because it prefers an outer shelf-upper slope environment.

Distribution.—Raysor, Penholoway, and Canepatch Formations.

Genus BENSONOCYTHERE Hazel, 1967

Remarks.—*Bensonocythere* is a diverse genus that occurs frequently in temperate and subtropical climatic zones along the Atlantic Coastal Plain (Hazel, 1983). The size, shape, primary surface ornament, and distribution of normal pores are characteristics used to distinguish the species.

Bensonocythere florencensis Cronin n. sp.

Plate 15, figures 3, 4; plate 16, figure 4

Diagnosis.—*Bensonocythere* characterized by a large, thick carapace, a subrectangular shape, and broad ridges that form a distinctive surface pattern. The surface ridges are always very wide and rounded, and the surface is never reticulated or pitted.

Holotype.—Female left valve (pl. 15, fig. 3), USNM 413949; length, 770 µm; height, 415 µm.

Type locality.—Duplin Formation, Florence East 15-minute quadrangle, South Carolina, lat 34°01′ N., long 79°41′ W.; surface altitude, 90 ft; depth, 38.5–48.5 ft below surface altitude.

Etymology.—Named for Florence, S.C.

Remarks.—This large species has very broad ridges and lacks the numerous fossae of many other *Bensonocythere*. It differs from *B. rugosa* in having parallel dorsal and ventral margins, whereas *B. rugosa* is concave along the dorsal margin. *B. florencensis* also has thicker ridges than *B. rugosa* and differs in the pattern of ridges anteriorly and posteroventrally.

Distribution.—Duplin, Raysor, and Bear Bluff Formations and Goose Creek Limestone.

Bensonocythere gouldensis Hazel, 1983

Plate 15, figures 1, 2

Remarks.—This species exhibits variation in the size of the fossae and the thickness of the muri for both the material studied here and that studied from the Yorktown Formation by Hazel (1983).

Distribution.—Duplin, Raysor, Bear Bluff, and Waccamaw Formations.

Bensonocythere hazeli Cronin n. sp.

Plate 16, figures 5, 6

Diagnosis.—*Bensonocythere* that has an anterior margin truncated dorsally and a sharply rounded ventral surface. The surface has very broad ridges oriented vertically posterodorsally, obliquely anterodorsally.

Holotype.—Female right valve (pl. 16, fig. 6), USNM 413960; length, 590 µm; height, 295 µm.

Type locality.—Ten Mile Hill beds, Beaufort 7½-minute quadrangle, South Carolina, lat 32°25′30″ N., long 80°44′00″ W.; surface altitude, 15 ft; depth, 10 ft below surface altitude.

Etymology.—Named for J.E. Hazel (Louisiana State University), who described the genus *Bensonocythere*.

Remarks.—*B. hazeli* differs from *B. rugosa* in its straight dorsal margin, less prominent anterior marginal rim, and wider ridges.

Distribution.—Penholoway, Canepatch, and Wando Formations and Ten Mile Hill beds.

Bensonocythere hollyensis Cronin n. sp.

Plate 15, figures 5–8

Diagnosis.—Rectangular *Bensonocythere* characterized by an even pattern of circular to polygonal fossae and no apparent longitudinal or vertical ridges. The walls of the fossae are of even thickness throughout the surface.

Holotype.—Female left valve (pl. 15, fig. 7), USNM 413953; length, 660 µm; height, 305 µm.

Type locality.—Penholoway Formation, Mount Holly 7½-minute quadrangle, South Carolina, lat 33°04′30″ N., long 80°06′15″ W.; surface altitude, 83 ft; depth, 32–34 ft below surface altitude.

Etymology.—Named for Mount Holly, S.C.

Remarks.—This species has thinner fossae walls and a more rounded posterior than *B. ricespitensis* Hazel, 1983. Some forms of *B. hollyensis* are similar, but differ mainly in the finer ornament, straight dorsal margin, and less heavily calcified shell of *B.* ricespitensis.

Distribution.—Duplin, Bear Bluff, Penholoway, Waccamaw, and Canepatch Formations.

Bensonocythere ricespitensis Hazel, 1983

Plate 16, figure 3

Distribution.—Bear Bluff, Penholoway, and Waccamaw Formations.

Bensonocythere rugosa Hazel, 1983

Plate 16, figure 1

Distribution.—Duplin and Waccamaw Formations.

Bensonocythere sapeloensis (Hall, 1965)

Distribution.—Penholoway, Canepatch, Socastee, and Wando Formations.

Illustration.—Cronin (1979), plate 18, figure 1.

Bensonocythere valentinei Cronin n. sp.

Plate 16, figures 7, 8

Diagnosis.—*Bensonocythere* characterized by both an evenly rounded anterior and posterior, as well as by a surface showing a regular pattern of ovate to subcircular fossae, most of which are approximately the same size and form a pattern that has no longitudinal or vertical ridges.

Holotype.—Female right valve (pl. 16, fig. 8), USNM 413962; length, 590 µm; height, 300 µm.

Type locality.—Wando Formation, Wadmalaw Island 7½-minute quadrangle, South Carolina, lat 32°39′30″ N., long 80°10′15″ W.; surface altitude, 15 ft; depth, 10–15 ft below surface altitude.

Etymology.—Named for P.C. Valentine (USGS), who first illustrated this species (Valentine, 1971, pl. 1, figs. 28, 29).

Remarks.—*B. valentinei* has a distinctive shape and a regular pattern of surface ornament. The fossae are larger and more ovate than those in *B. americana* Hazel, 1967.

Distribution.—Penholoway, Canepatch, and Wando Formations and Ten Mile Hill beds.

Bensonocythere whitei (Swain, 1951)

Plate 16, figure 2

Distribution.—Old form: Duplin, Bear Bluff, Penholoway, and Waccamaw Formations and Goose Creek Limestone. Young form: Canepatch and Wando Formations.

Genus CAMPYLOCYTHERE Edwards, 1944

Campylocythere laeva Edwards, 1944

Plate 14, figures 3–5

Remarks.—The illustrated specimens show the wide range of variability in surface ornament that characterizes this species.

Distribution.—Duplin, Bear Bluff, Penholoway, Waccamaw, Canepatch, and Wando Formations, Goose Creek Limestone, and Ten Mile Hill beds.

Genus CLIMACOIDEA Puri 1956
Subgenus PROTEOCONCHA Plusquellec and Sandberg, 1969

Climacoidea (Proteoconcha) gigantica (Edwards, 1944)

Plate 14, figure 7

Distribution.—Duplin, Penholoway, Waccamaw, Canepatch, and Wando Formations, Goose Creek Limestone, and Ten Mile Hill beds.

Climacoidea (Proteoconcha) jamesensis (Hazel, 1983)

Plate 14, figure 6

Remarks.—Pitting occurs only rarely on the posterior half of the surface.

Distribution.—Raysor and Penholoway Formations and Goose Creek Limestone.

Climacoidea (Proteoconcha) multipunctata (Edwards, 1944)

Distribution.—Duplin, Bear Bluff, Penholoway, Waccamaw, and Wando Formations and Goose Creek Limestone.

Illustration.—Plusquellec and Sandberg (1969), plate 2, figures 1–11; plate 5, figure 9; plate 6, figures 12, 13; plate 8, figure 5; plate 9, figures 6, 12–16.

Climacoidea (Proteoconcha) nelsonensis (Grossman, 1967)

Remarks.—Some reticulated specimens of this species can be confused with specimens of *P. multipunctata.*

Distribution.—Penholoway and Wando Formations and Ten Mile Hill beds.

Illustration.—Cronin (1979), plate 17, figure 1.

Climacoidea (Proteoconcha) tuberculata (Puri, 1960)

Distribution.—Bear Bluff, Penholoway, Waccamaw, and Wando Formations and Ten Mile Hill beds.

Illustration.—Cronin (1979), plate 18, figure 10.

Family XESTOLEBERIDIDAE Sars, 1928
Genus XESTOLEBERIS Sars, 1866

Remarks.—*Xestoleberis* occurs occasionally in low numbers in Coastal Plain deposits, especially in deposits that formed during relatively warm early Pleistocene climates.

Other taxa

Phlyctocythere sp.

Remarks.—This species is very rare in Coastal Plain deposits and modern shelf sediments.

Distribution.—Ten Mile Hill beds.

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PLATES 1–17

USNM, U.S. National Museum, Washington, D.C.
Contact photographs of plates 1–17 are available,
at cost, from the U.S. Geological Survey Photographic Library, Federal Center,
Denver, CO 80225.

PLATE 1

FIGURES 1, 2. *Cytheridea virginiensis* (Malkin, 1953) (p. C28).
  1. Left valve female, sample 4, Raysor, USNM 413833, ×100.
  2. Right valve male, sample 4, Raysor, USNM 413834, ×94.

3, 4. *Cyprideis curta* Edwards, 1944 (p. C29).
  3. Left valve female, Waccamaw, USNM 413835, ×86.
  4. Left valve female, internal view, Duplin, USNM 413836, ×86.

5–7. *Cyprideis floridana* Howe and Hough, 1935 (p. C29).
  5. Left valve female, Waccamaw, USNM 413837, ×86.
  6. Right valve male, internal view, Waccamaw, USNM 413838, ×86.
  7. Right valve male, Waccamaw, USNM 413839, ×78.

8. *Cyprideis* sp. A (p. C29).
  Left valve female, sample 32, Penholoway, USNM 413840, ×78.


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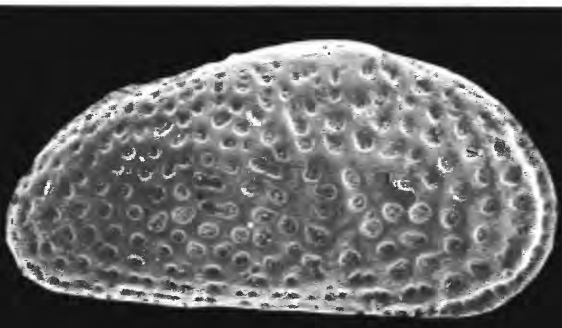
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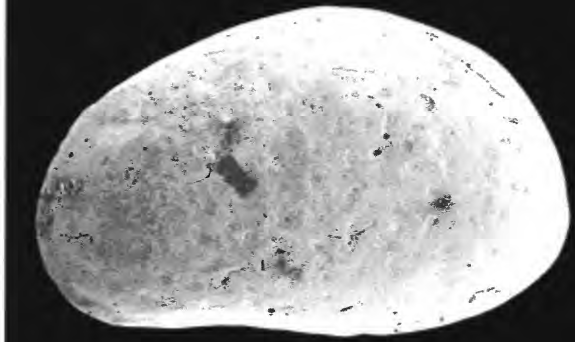
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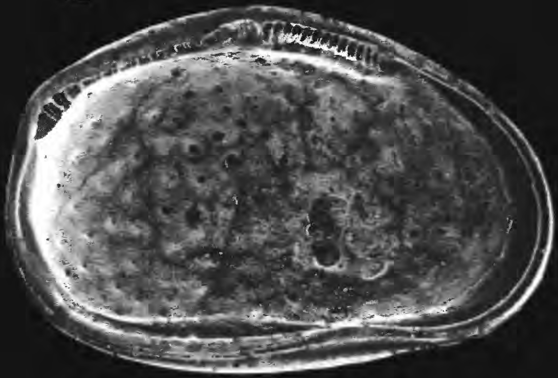
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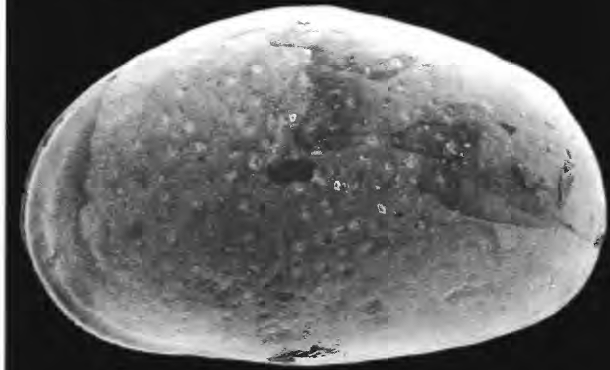
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CYTHERIDEA AND *CYPRIDEIS*

PLATE 2

FIGURE 1. *Cytheromorpha warneri* Howe and Spurgeon, 1935 (p. C28).
  Left valve female, Raysor, USNM 413841, ×100.
2. *Munseyella subminuta* (Puri, 1953) (p. C28).
  Left valve carapace, lateral view, Raysor, USNM 413842, ×220.
3–5. *Hulingsina* aff. *H. semicircularis* (Ulrich and Bassler, 1904) (p. C30).
  3. Left valve female, Duplin, USNM 413843, ×110.
  4. Left valve male, Duplin, USNM 413844, ×100.
  5. Left valve female, internal view, Duplin, USNM 413845, ×100.
6–8. *Hulingsina rugipustulosa* (Edwards, 1944) (p. C30).
  6. Left valve female, Raysor, USNM 413846, ×100.
  7. Right valve male, internal view, Raysor, USNM 413847, ×100.
  8. Right valve male, Raysor, USNM 413848, ×100.

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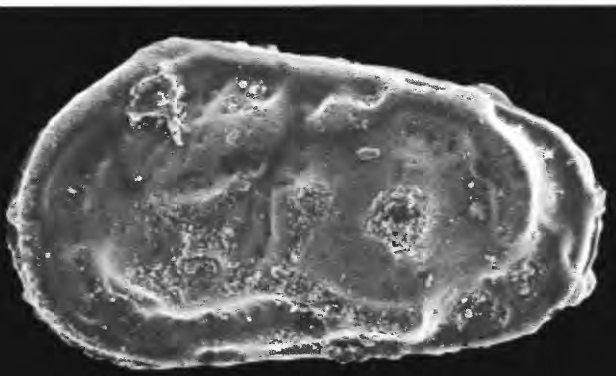

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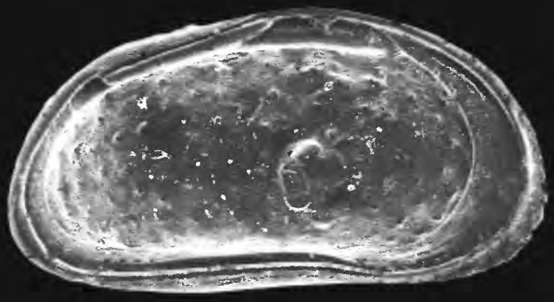

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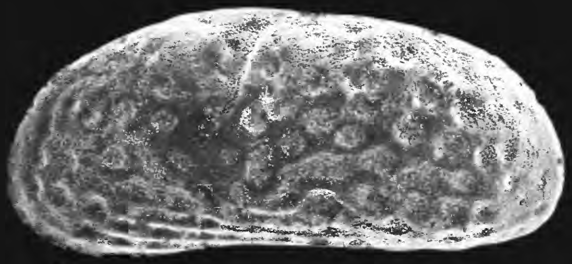

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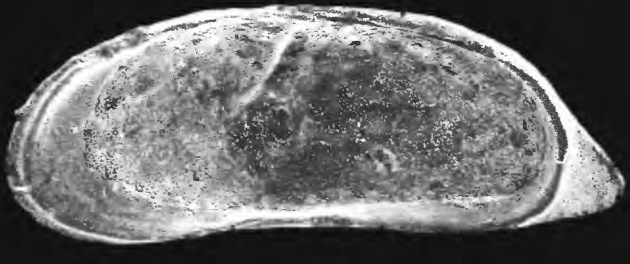

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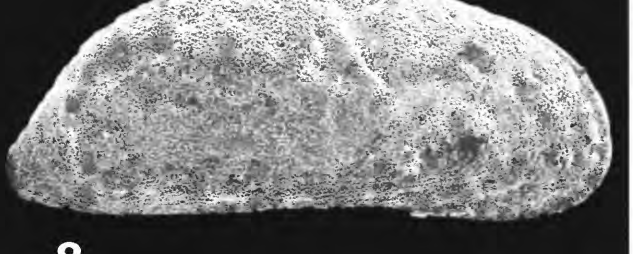

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CYTHEROMORPHA, MUNSEYELLA, AND *HULINGSINA*

PLATE 3

FIGURES 1, 2. *Pontocythere* sp. A (p. C30).

- 1. Left valve female, Canepatch, USNM 413849, ×130.
- 2. Right valve female, internal view, Canepatch, USNM 413850, ×130.

3. *Pontocythere*? sp. B (p. C30).

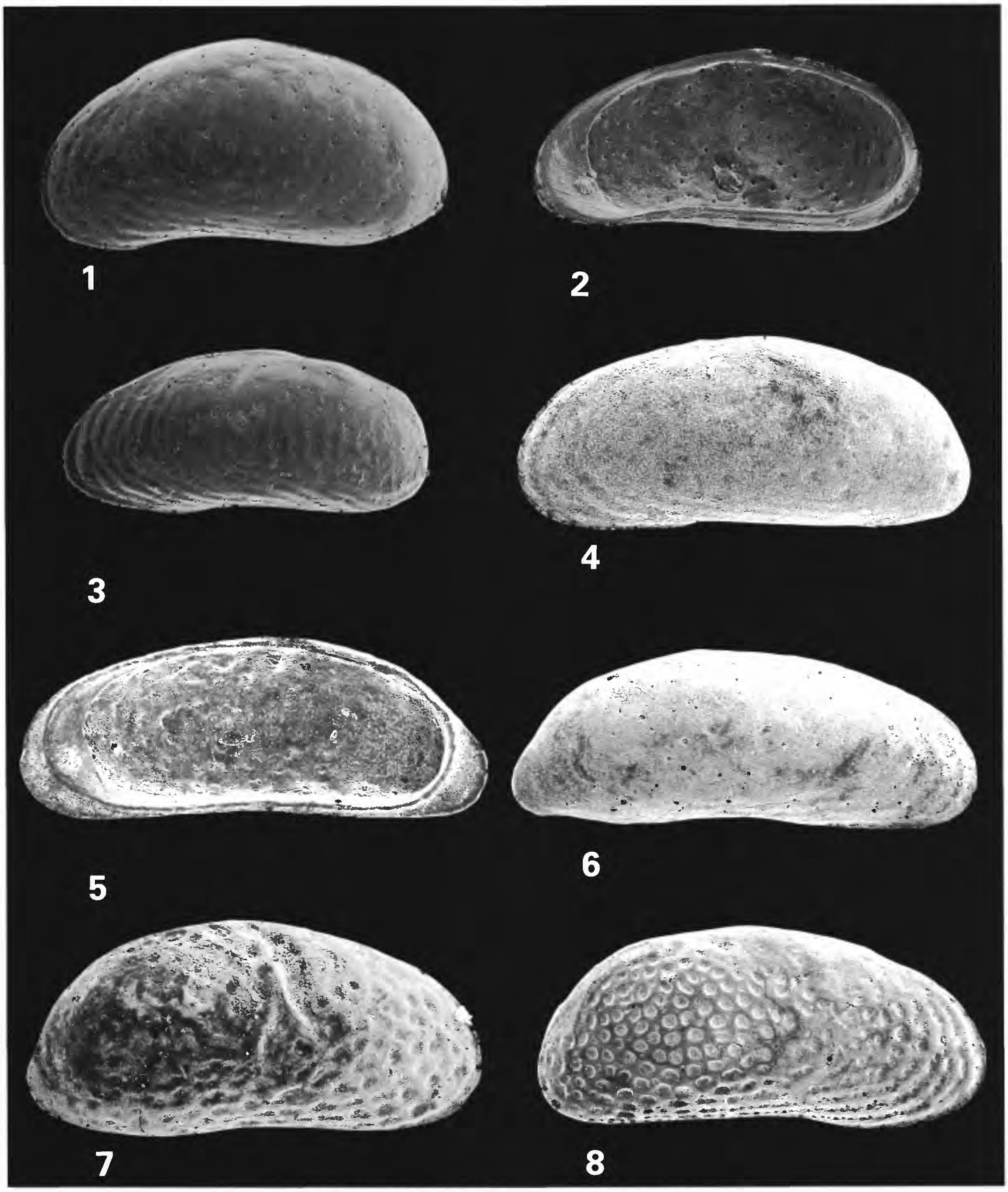
Left valve female?, Canepatch, USNM 413851, ×160.

4–6. *Pontocythere*? sp. I (p. C30).

- 4. Left valve female, Raysor, USNM 413852, ×100.
- 5. Right valve male, internal view, Raysor, USNM 413853, ×100.
- 6. Right valve male, Duplin, USNM 413854, ×100.

7, 8. *Hulingsina*? *cylindrica* (Ulrich and Bassler, 1904) (p. C30).

- 7. Left valve female, Duplin, USNM 413855, ×110.
- 8. Left valve female, Duplin, USNM 413856, ×94.



PONTOCYTHERE, PONTOCYTHERE?, AND *HULINGSINA?*

PLATE 4

FIGURE 1. *Cytherura wardensis* Howe and Brown, 1935 (p. C32).
Left valve female, Waccamaw, USNM 413857, ×150.
2. *Cytherura* cf. *C. radialirata* Swain, 1955 (p. C32).
Left valve male, Canepatch, USNM 413858, ×150.
3, 4. *Cytherura carolinensis* Cronin n. sp. (p. C31).
3. Left valve female, Duplin, USNM 413859, ×240, holotype.
4. Right valve female, internal view, Duplin, USNM 413860, ×200.
5. *Paracytheridea mucra* Edwards, 1944 (p. C34).
Left valve female, Bear Bluff, USNM 413861, ×100.
6. *Paracytheridea cronini* Hazel, 1983 (p. C34).
Left valve male, Duplin, USNM 413862, ×130.
7, 8. *Paracytheridea hazeli* Cronin n. sp. (p. C34).
7. Right valve male, sample 38, Ten Mile Hill beds, USNM 413863, ×100.
8. Left valve female, sample 38, Ten Mile Hill beds, USNM 413864, ×100, holotype.

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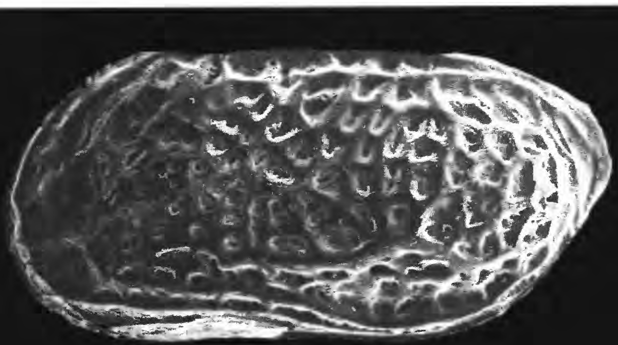

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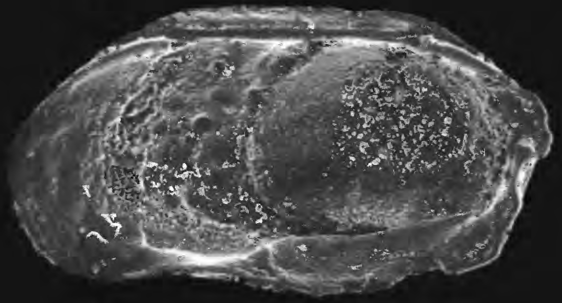

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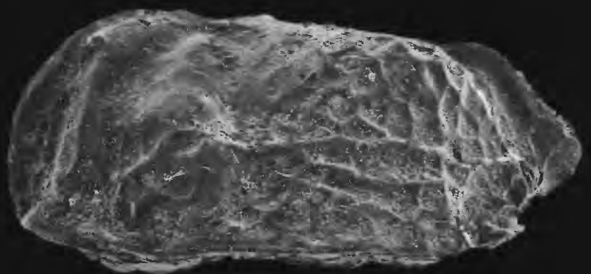

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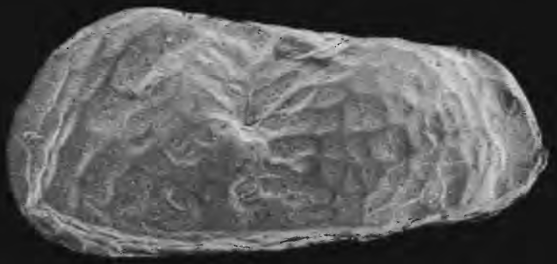

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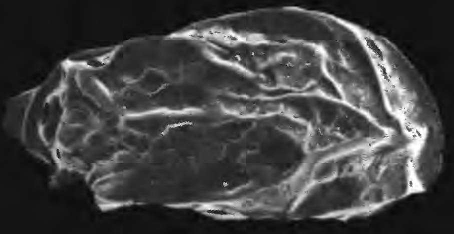

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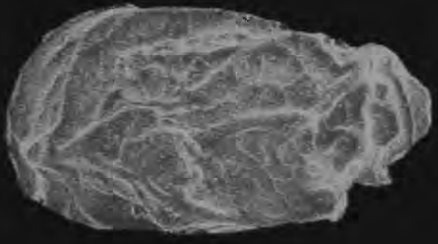

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CYTHERURA AND *PARACYTHERIDEA*

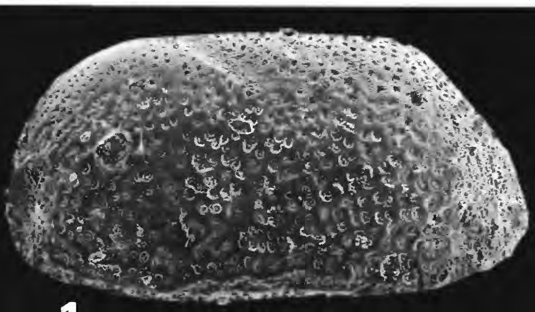
PLATE 5

FIGURES 1, 2, 8. *Tetracytherura owensi* Cronin n. sp. (p. C33).
1. Left valve female, Bear Bluff, USNM 413865, ×120, holotype.
2. Left valve male, Bear Bluff, USNM 413866, ×120.
8. Right valve male, internal view, Bear Bluff, USNM 413867, ×120.

3, 4. *Tetracytherura similis* (Malkin, 1953) (p. C33).
3. Right valve female, Waccamaw, USNM 413868, ×160.
4. Right valve male, Waccamaw, USNM 413869, ×160.

5, 6. *Tetracytherura mccartanae* Cronin n. sp. (p. C33).
5. Left valve female, sample 38, Ten Mile Hill beds, USNM 413870, ×160, holotype.
6. Left valve male, sample 38, Ten Mile Hill beds, USNM 413871, ×160.

7. *Tetracytherura minuta* (Hazel, 1983) (p. C32).
Left valve female, Duplin, USNM 413872, ×180.



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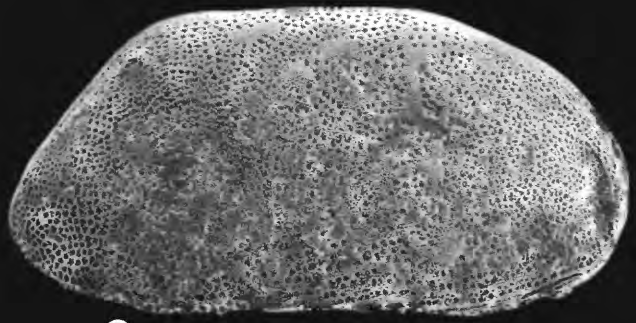

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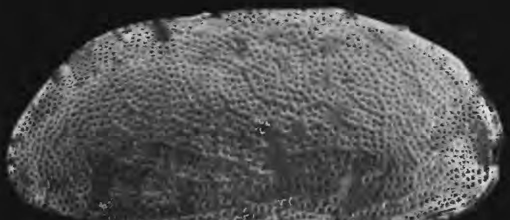

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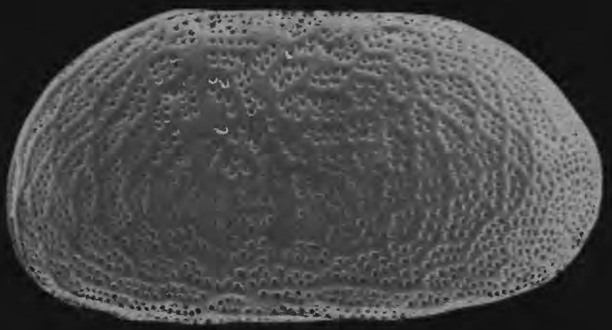

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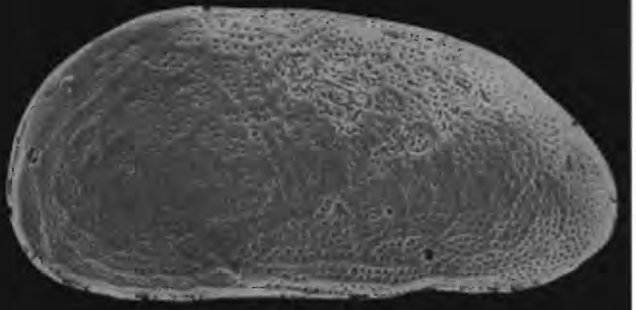

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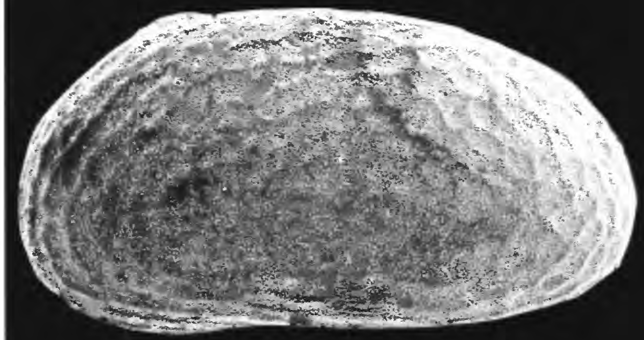

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TETRACYTHERURA

PLATE 6

FIGURE 1. *Loxoconcha purisubrhomboidea* Edwards, 1953 (p. C33).
  Left valve female, Waccamaw, USNM 413873, ×150.

2. *Loxoconcha* sp. A (p. C33).
  Left valve female, Duplin, USNM 413874, ×150.

3–5. *Loxoconcha florencensis* Cronin n. sp. (p. C33).
  3. Left valve female, Duplin, USNM 413875, ×120, holotype.
  4. Left valve male, Duplin, USNM 413876, ×120.
  5. Left valve female, Duplin, USNM 413877, ×120.

6, 7. *Loxoconcha carolinensis* Cronin n. sp. (p. C34).
  6. Left valve female, Duplin, USNM 413878, ×180, holotype.
  7. Left valve male carapace, lateral view, Duplin, USNM 413879, ×180.

8. *Pellucistoma magniventra* Edwards, 1944 (p. C21).
  Right valve male, Raysor, USNM 413880, ×130.


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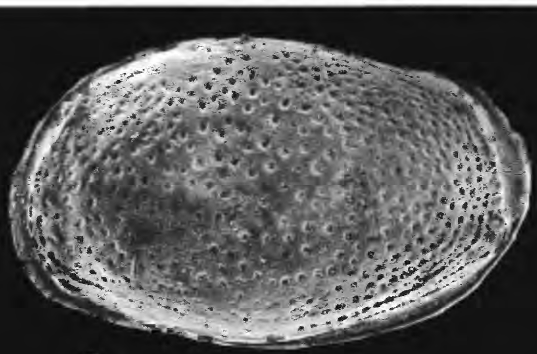
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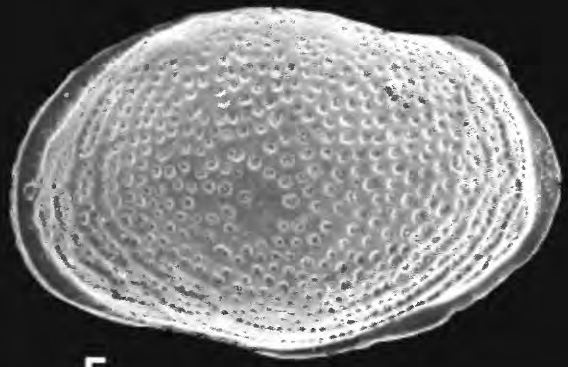
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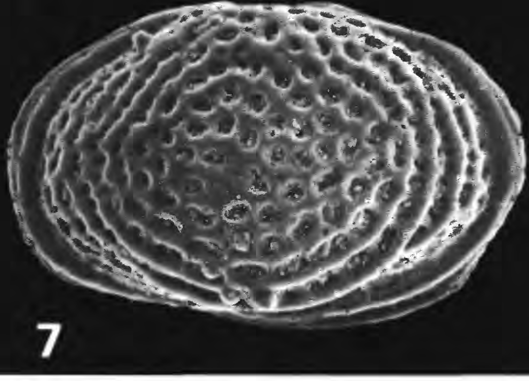
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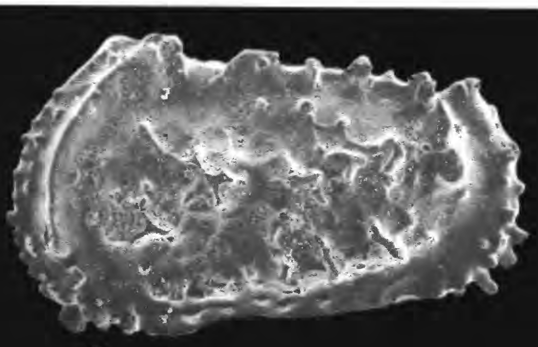
8

LOXOCONCHA AND *PELLUCISTOMA*

PLATE 7

FIGURES 1, 2. *Actinocythereis dawsoni* (Brady, 1870) (p. C35).
    1. Left valve female, Raysor, USNM 413881, ×86.
    2. Left valve male, Raysor, USNM 413882, ×86.
3, 4. *Actinocythereis marylandica* (Howe and Hough, 1935) (p. C35).
    3. Left valve female, Raysor, USNM 413883, ×72.
    4. Left valve male, Raysor, USNM 413884, ×72.
5, 6. *Actinocythereis captionis* Hazel, 1983 (p. C35).
    5. Left valve female, Raysor, USNM 413885, ×100.
    6. Left valve male, Raysor, USNM 413886, ×100.
7, 8. *Actinocythereis* aff. *A. bahamaensis* (Brady, 1868) (p. C35).
    7. Left valve female, Raysor, USNM 413887, ×94.
    8. Left valve male, Raysor, USNM 413888, ×100.



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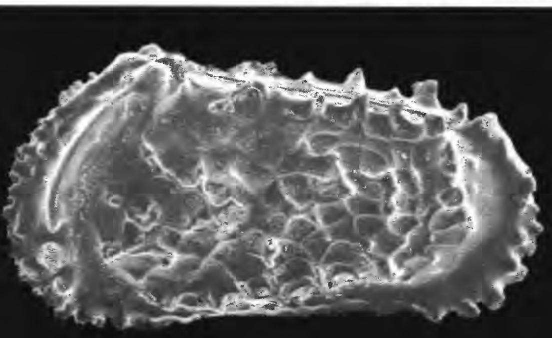

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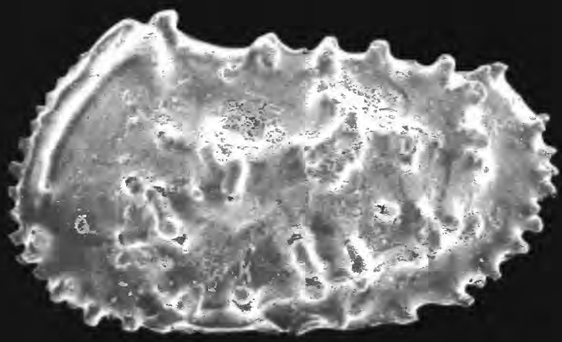

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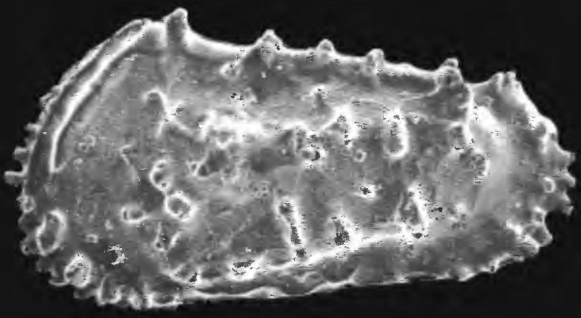

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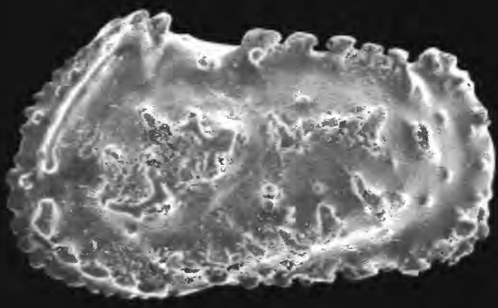

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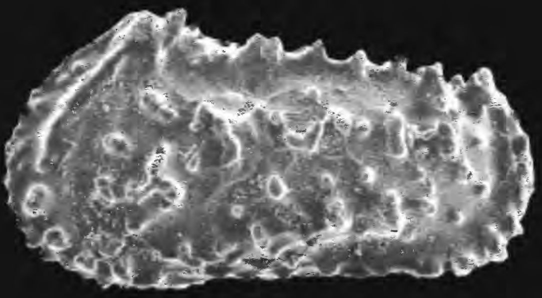

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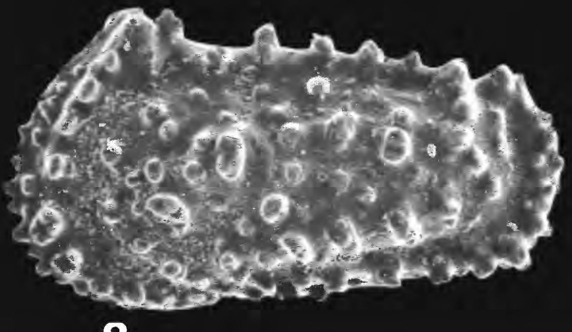

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ACTINOCYTHEREIS

PLATE 8

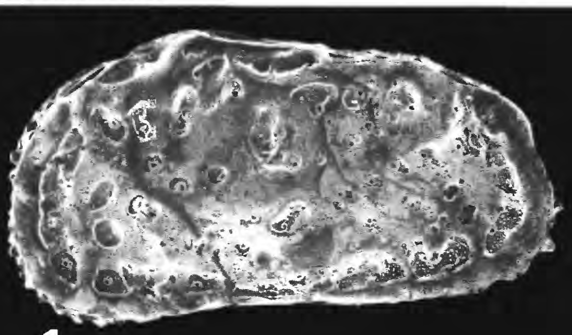
FIGURES 1, 2, 4. *Neocaudites subimpressa* (Edwards, 1944) (p. C35).
1. Left valve female, Waccamaw, USNM 413889, ×120.
2. Left valve male, Waccamaw, USNM 413890, ×110.
4. Right valve male, internal view, Waccamaw, USNM 413891, ×120.

3. *Neocaudites angulata* Hazel, 1983 (p. C35).
Left valve female, sample 3, Raysor, USNM 413892, ×120.

5. *Neocaudites variabilis* Hazel, 1983 (p. C36).
Left valve female, sample 24, Penholoway, USNM 413893, ×120.

6. *Pterygocythereis inexpectata* (Blake, 1929) (p. C37).
Left valve male, sample 4, Raysor, USNM 413894, ×78.

7, 8. *Henryhowella* cf. *H. evax* (Ulrich and Bassler, 1904) (p. C36).
7. Left valve male, Raysor, USNM 413895, ×94.
8. Right valve juvenile, Raysor, USNM 413896, ×100.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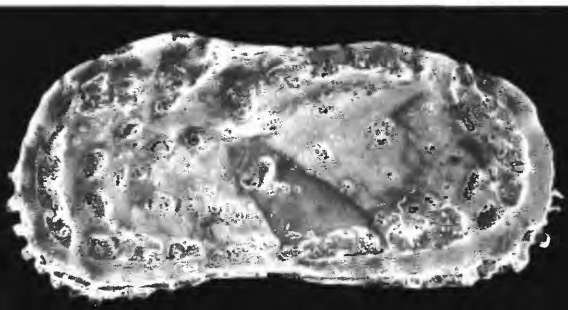
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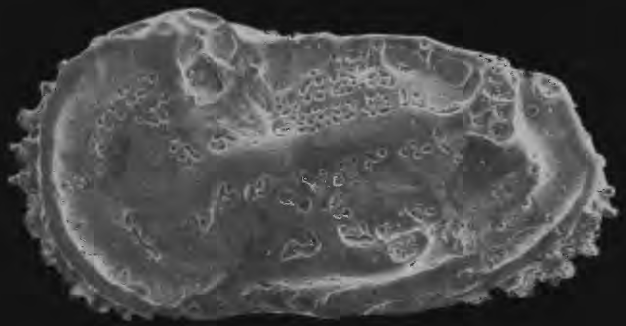
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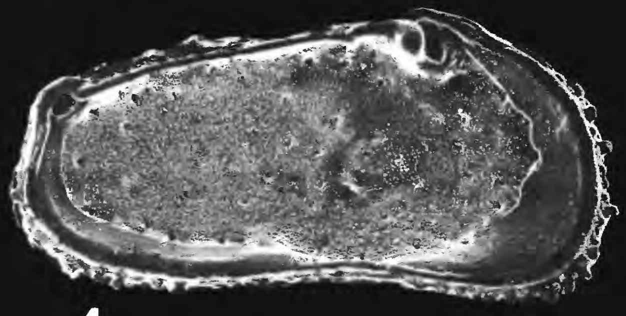
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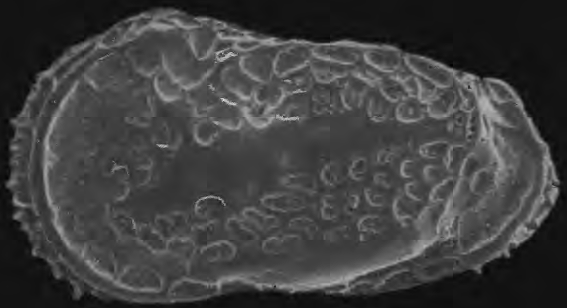
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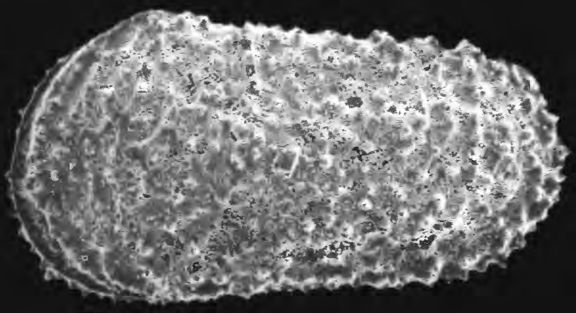
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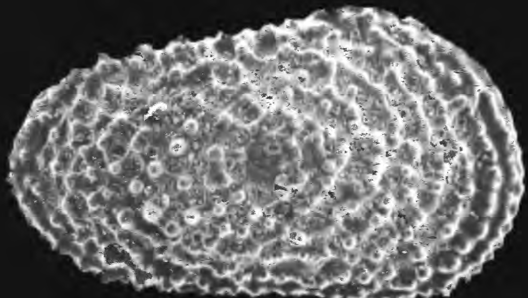
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NEOCAUDITES, PTERYGOCYTHEREIS, AND *HENRYHOWELLA*

PLATE 9

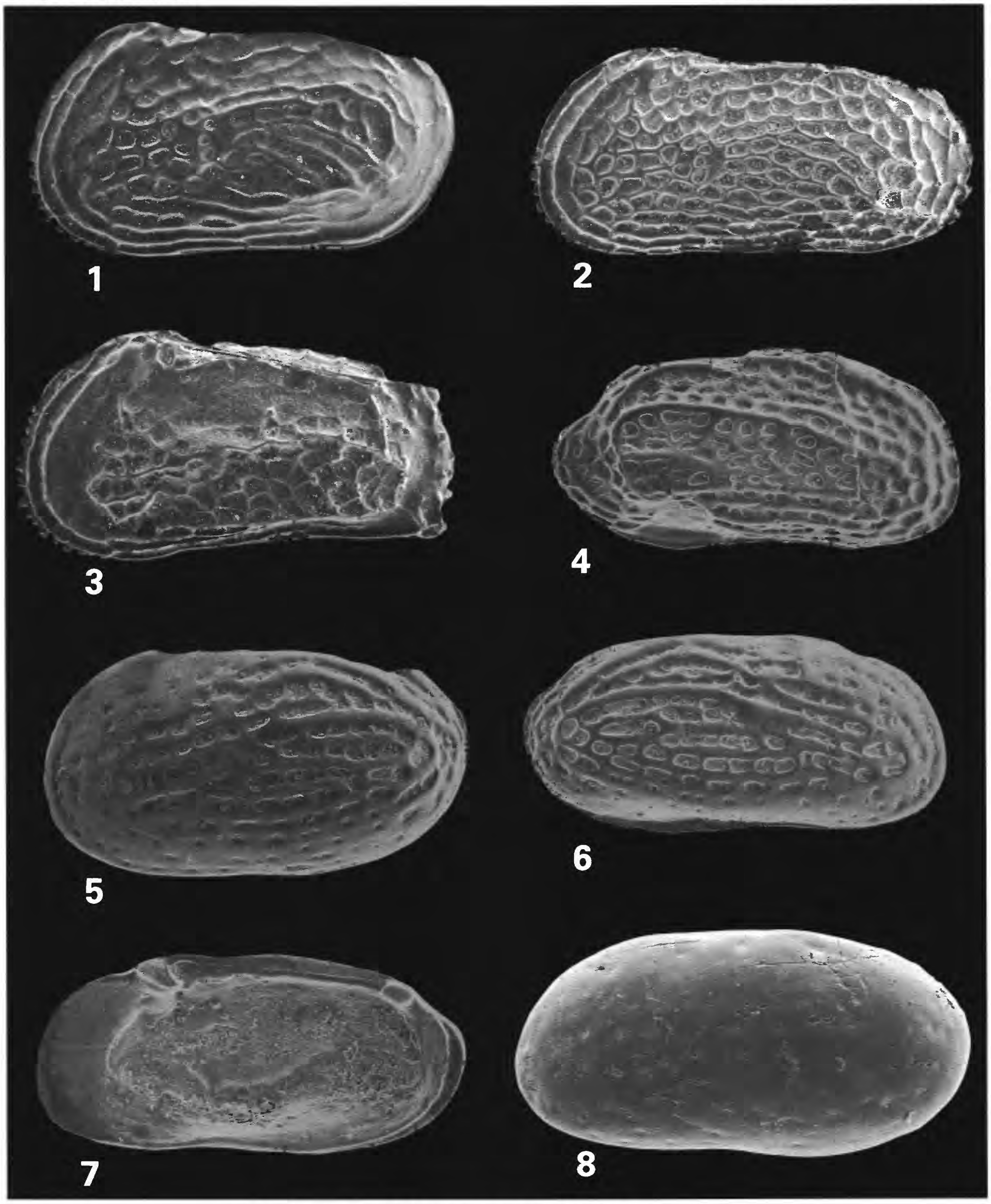
FIGURES 1, 2. *Murrayina macleani* Swain, 1974 (p. C36).
- 1. Left valve female, Raysor, USNM 413897, ×94.
- 2. Left valve male, Raysor, USNM 413898, ×86.

3. *Murrayina barclayi* McLean, 1957 (p. C36).
Left valve male?, Raysor, USNM 413899, ×110.

4. *Protocytheretta reticulata* (Edwards, 1944) (p. C37).
Right valve female, sample 4, Raysor, USNM 413900, ×72.

5–7. *Pseudocytheretta* cf. *P. burnsi* (Ulrich and Bassler, 1904) (p. C37).
- 5. Left valve female, sample 4, Raysor, USNM 413901, ×72.
- 6. Right valve male, sample 4, Raysor, USNM 413902, ×72.
- 7. Right valve male, internal view, sample 4, Raysor, USNM 413903, ×72.

8. *Pseudocytheretta edwardsi* Cushman, 1906 (p. C37).
Left valve female, Miocene-Pliocene, Marthas Vineyard, Mass., USNM 413904, ×72.



MURRAYINA, PROTOCYTHERETTA, AND *PSEUDOCYTHERETTA*

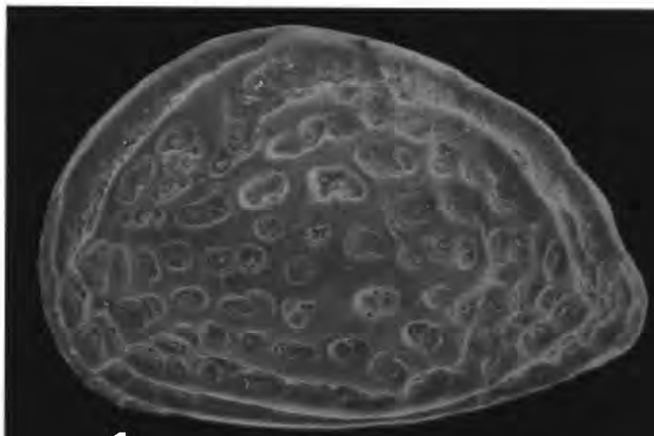
PLATE 10

Figures 1, 2. *Malzella conradi* (Howe and McGuirt, 1935) (p. C37).
  1. Left valve female, sample 4, Raysor, USNM 413905, ×130.
  2. Left valve male, sample 4, Raysor, USNM 413906, ×150.

3, 4. *Malzella evexa* Hazel, 1983 (p. C37).
  3. Left valve female, Waccamaw, USNM 413907, ×110.
  4. Left valve male, Waccamaw, USNM 413908, ×120.

5. *Malzella floridana* (Benson and Coleman, 1963) (p. C37).
  Left valve female, sample 38, Ten Mile Hill beds, USNM 413909, ×110.

6–8. *Radimella confragosa* (Edwards, 1944) (p. C38).
  6. Left valve female, Waccamaw, USNM 413910, ×150.
  7. Left valve female, internal view, Waccamaw, USNM 413911, ×130.
  8. Right valve female juvenile, Waccamaw, USNM 413912, ×160.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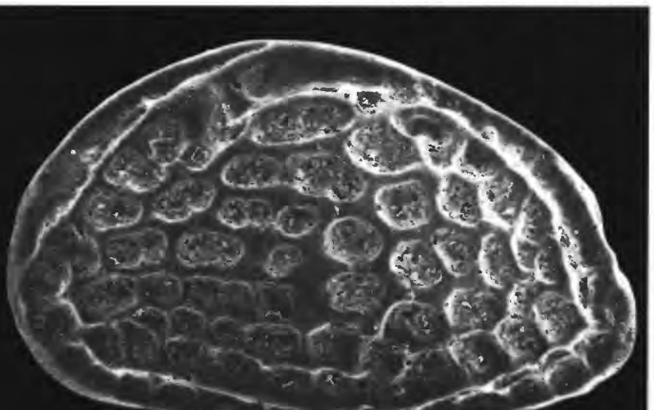
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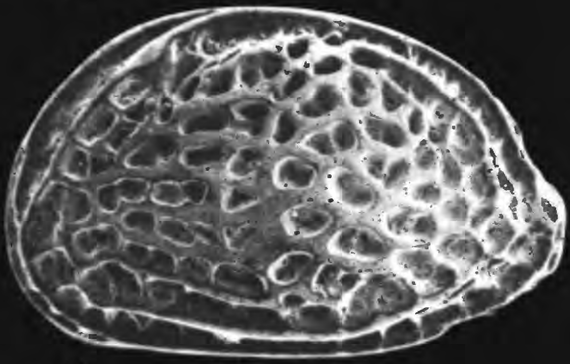
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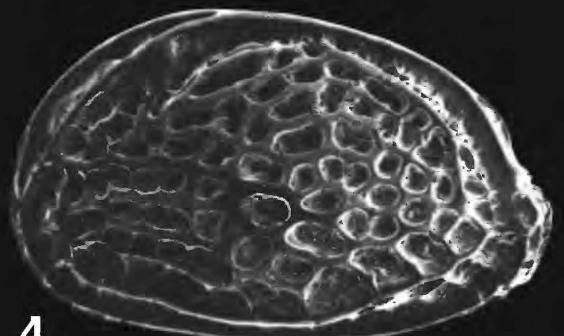
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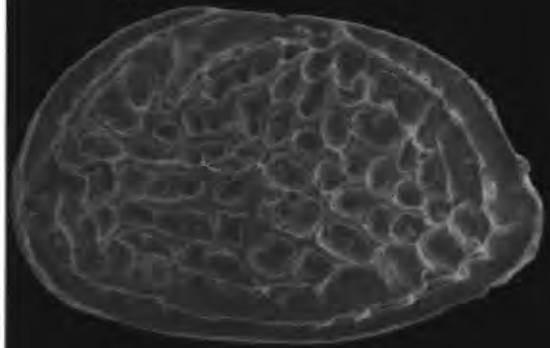
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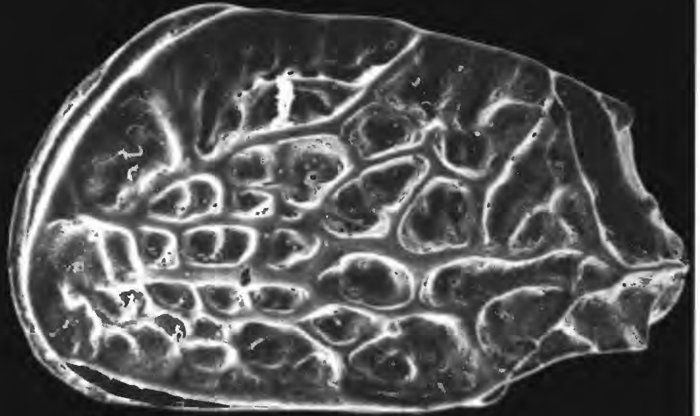
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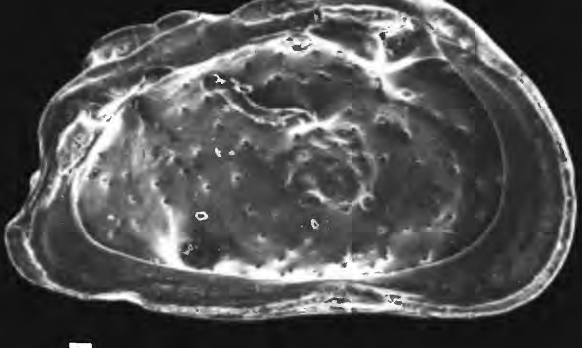
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MALZELLA AND *RADIMELLA*

PLATE 11

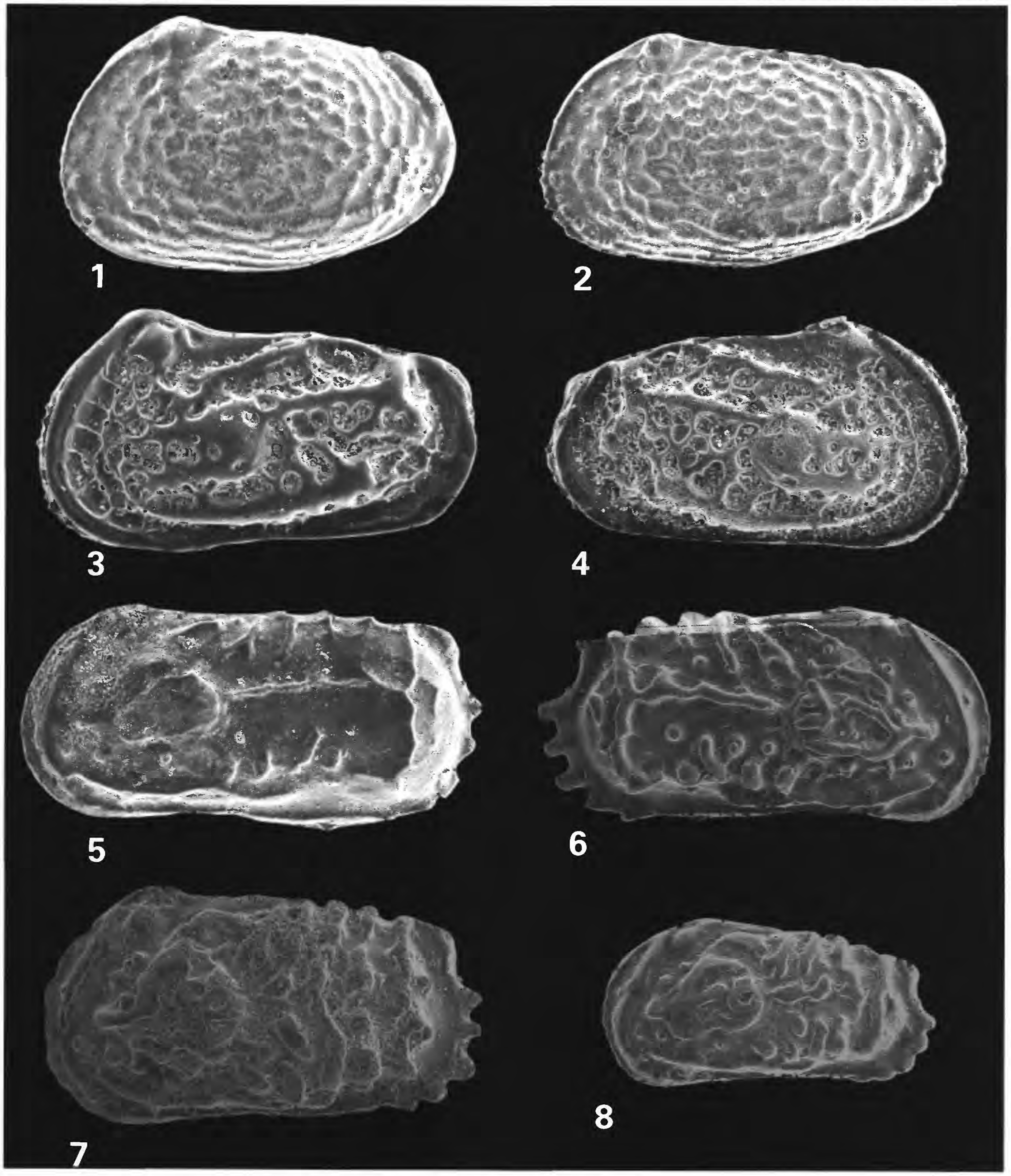
FIGURES 1, 2. *Echinocythereis planibasalis* (Ulrich and Bassler, 1904) (p. C36).
  1. Left valve female, Raysor, USNM 413913, ×86.
  2. Left valve male, Raysor, USNM 413914, ×86.

3, 4. *Hermanites ascitus* Hazel, 1983 (p. C37).
  3. Left valve female, Raysor, USNM 413915, ×150.
  4. Right valve female, Raysor, USNM 413916, ×130.

5, 6. *Puriana mesacostalis* (Edwards, 1944) (p. C36)
  5. Left valve male, Bear Bluff, USNM 413917, ×120.
  6. Right valve female, sample 24, Penholoway, USNM 413918, ×120.

7. *Puriana rugipunctata* (Ulrich and Bassler, 1904) (p. C37).
  Left valve female, sample 3, Raysor, USNM 413919, ×120.

8. *Puriana carolinensis* Hazel, 1983 (p. C36).
  Left valve female, sample 21, Penholoway, USNM 413920, ×120.



ECHINOCYTHEREIS, HERMANITES, AND *PURIANA*

PLATE 12

FIGURES 1, 2. *Muellerina ohmerti* Hazel, 1983 (p. C38).
  1. Left valve female, Raysor, USNM 413921, ×130.
  2. Right valve male, Raysor, USNM 413922, ×130.

3, 4, 9. *Muellerina* aff. *M. ohmerti* Hazel, 1983 (p. C38).
  3. Left valve female, Waccamaw, USNM 413923, ×110.
  4. Left valve male, Waccamaw, USNM 413924, ×110.
  9. Left valve female, internal view, Waccamaw, USNM 413925, ×110.

5, 6, 10. *Muellerina wardi* Hazel, 1983 (p. C38).
  5. Left valve female, Waccamaw, USNM 413926, ×110.
  6. Left valve male, Waccamaw, USNM 413927, ×110.
  10. Right valve female, internal view, Waccamaw, USNM 413928, ×110.

7. *Muellerina bassiounii* Hazel, 1983 (p. C38).
  Left valve female, Waccamaw, USNM 413929, ×150.

8. *Muellerina* cf. *M. bassiounii* Hazel, 1983 (p. C38).
  Left valve male, Raysor, USNM 413930, ×150.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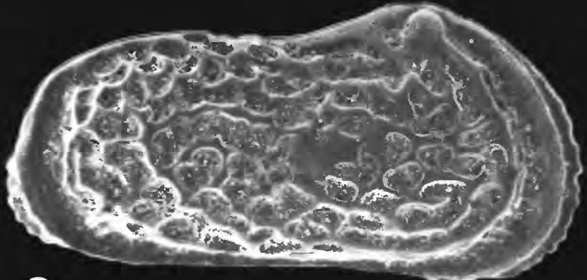
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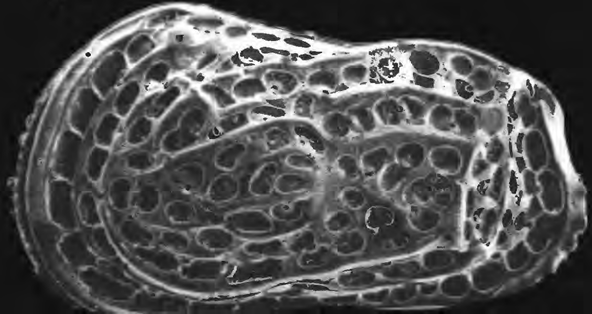
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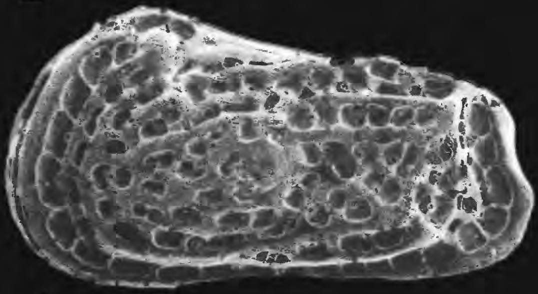
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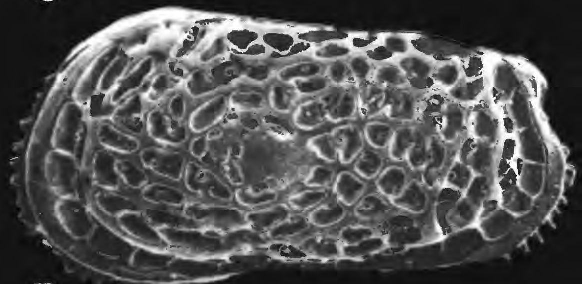
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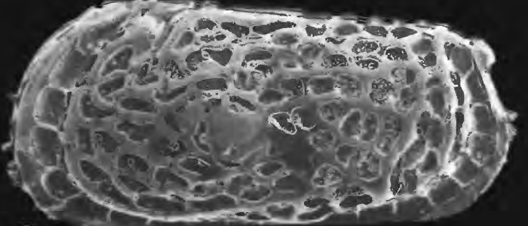
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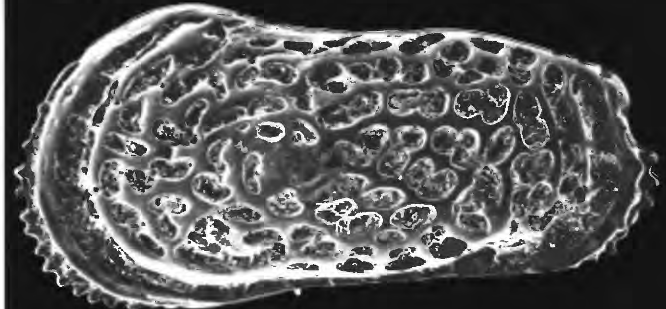
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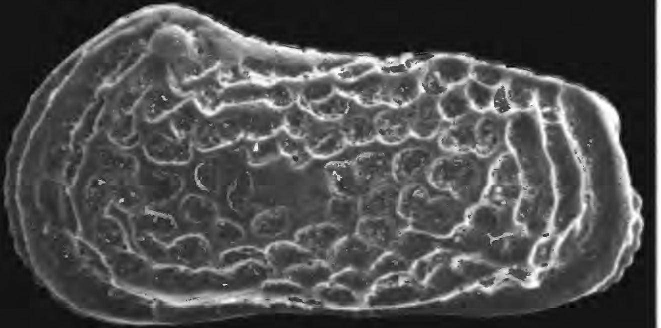
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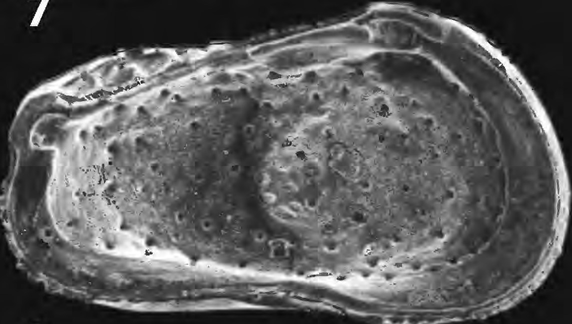
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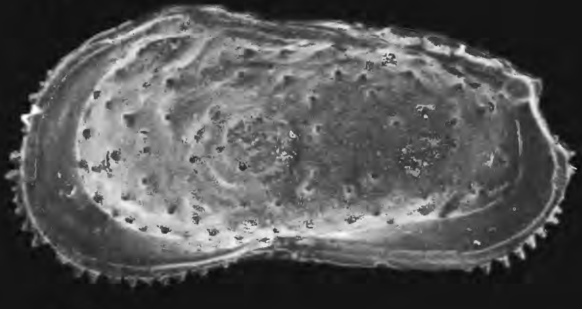
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MUELLERINA

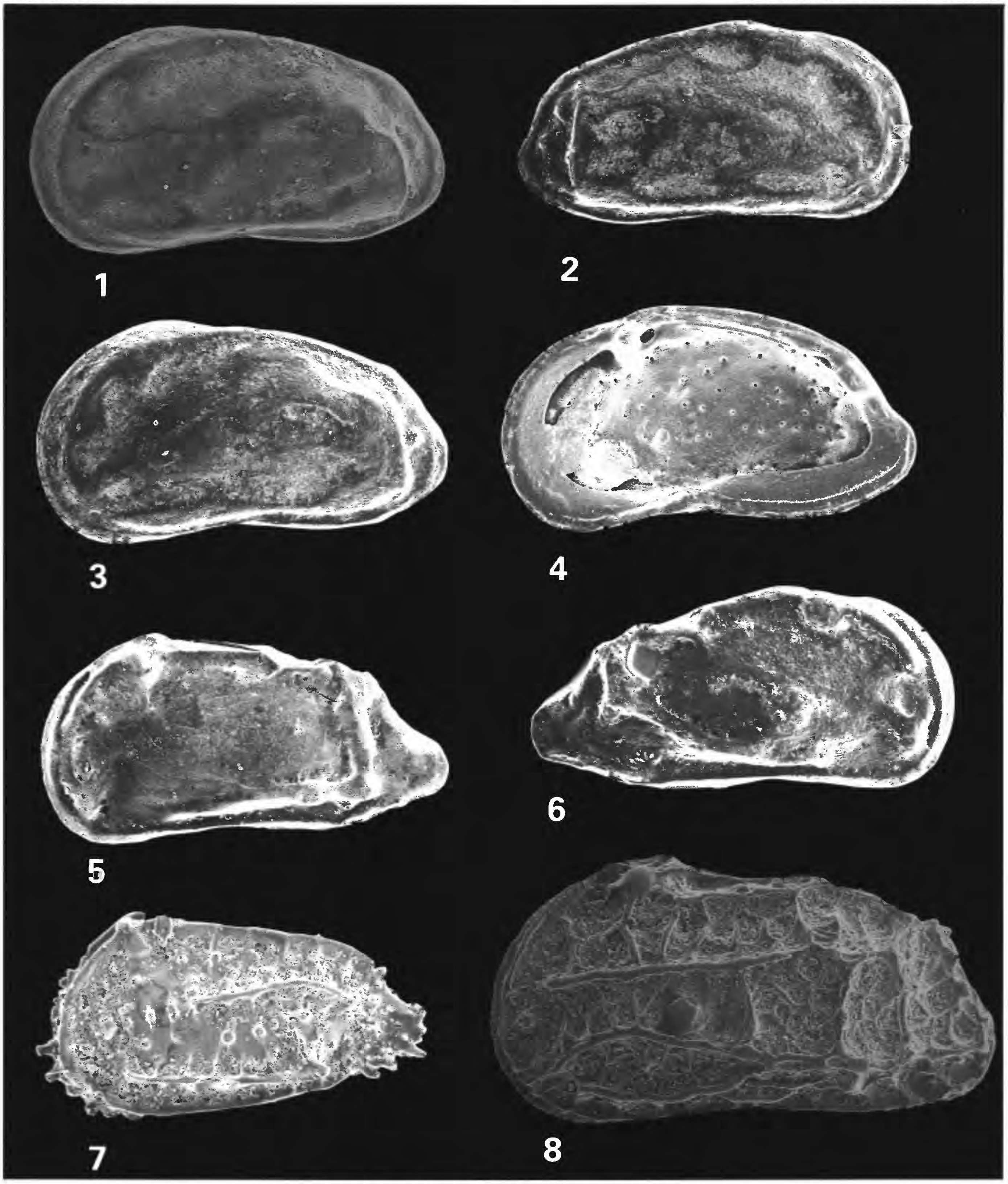
PLATE 13

FIGURES 1–4. *Palaciosa minuta* (Edwards, 1944) (p. C38).
- 1. Left valve female, sample 20, Penholoway, USNM 413931, ×160.
- 2. Right valve female, Waccamaw, USNM 413932, ×160.
- 3. Left valve male?, Waccamaw, USNM 413933, ×160.
- 4. Right valve female, internal view, Waccamaw, USNM 413934, ×160.

5, 6. *Caudites paraasymmetricus* Hazel, 1983 (p. C37).
- 5. Left valve female, Waccamaw, USNM 413935, ×130.
- 6. Right valve male?, Waccamaw, USNM 413936, ×130.

7. *Cativella navis* Coryell and Fields, 1937.
Left valve female, Raysor, USNM 413937, ×120.

8. *Orionina vaughani* (Ulrich and Bassler, 1904) (p. C38).
Left valve female, sample 3, Raysor, USNM 413938, ×130.



PALACIOSA, CAUDITES, CATIVELLA, AND *ORIONINA*

PLATE 14

FIGURES 1, 2. *Acuticythereis laevissima* Edwards, 1944 (p. C38).
- 1. Left valve female, Raysor, USNM 413939, ×78.
- 2. Left valve female, internal view, Duplin, USNM 413940, ×78.

3–5. *Campylocythere laeva* Edwards, 1944 (p. C40).
- 3. Right valve female, Waccamaw, USNM 413941, ×86.
- 4. Right valve male, Waccamaw, USNM 413942, ×86.
- 5. Right valve female, Waccamaw, USNM 413943, ×86.

6. *Climacoidea* (*Proteoconcha*) *jamesensis* (Hazel, 1983) (p. C40).
Left valve female?, Raysor, USNM 413944, ×86.

7. *Climacoidea* (*Proteoconcha*) *gigantica* (Edwards, 1944) (p. C40).
Left valve female, sample 24, Penholoway, USNM 413945, ×86.

8. *Basslerites* cf. *B. miocenica* Howe, 1937 (p. C38).
Left valve female, Raysor, USNM 413946, ×120.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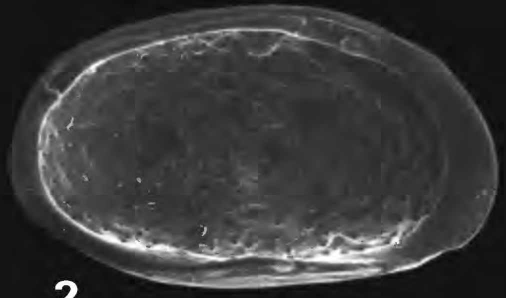
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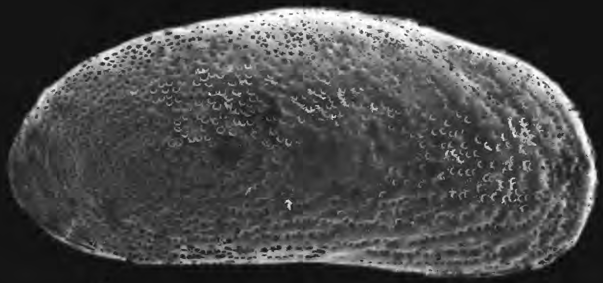
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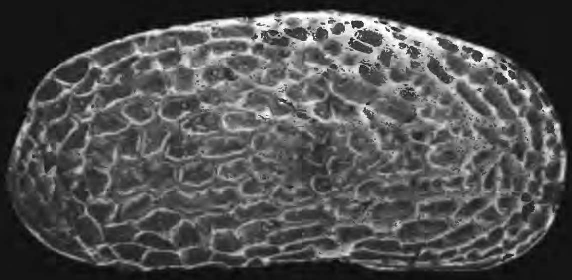
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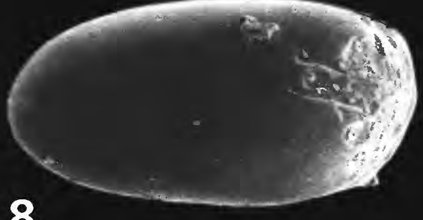
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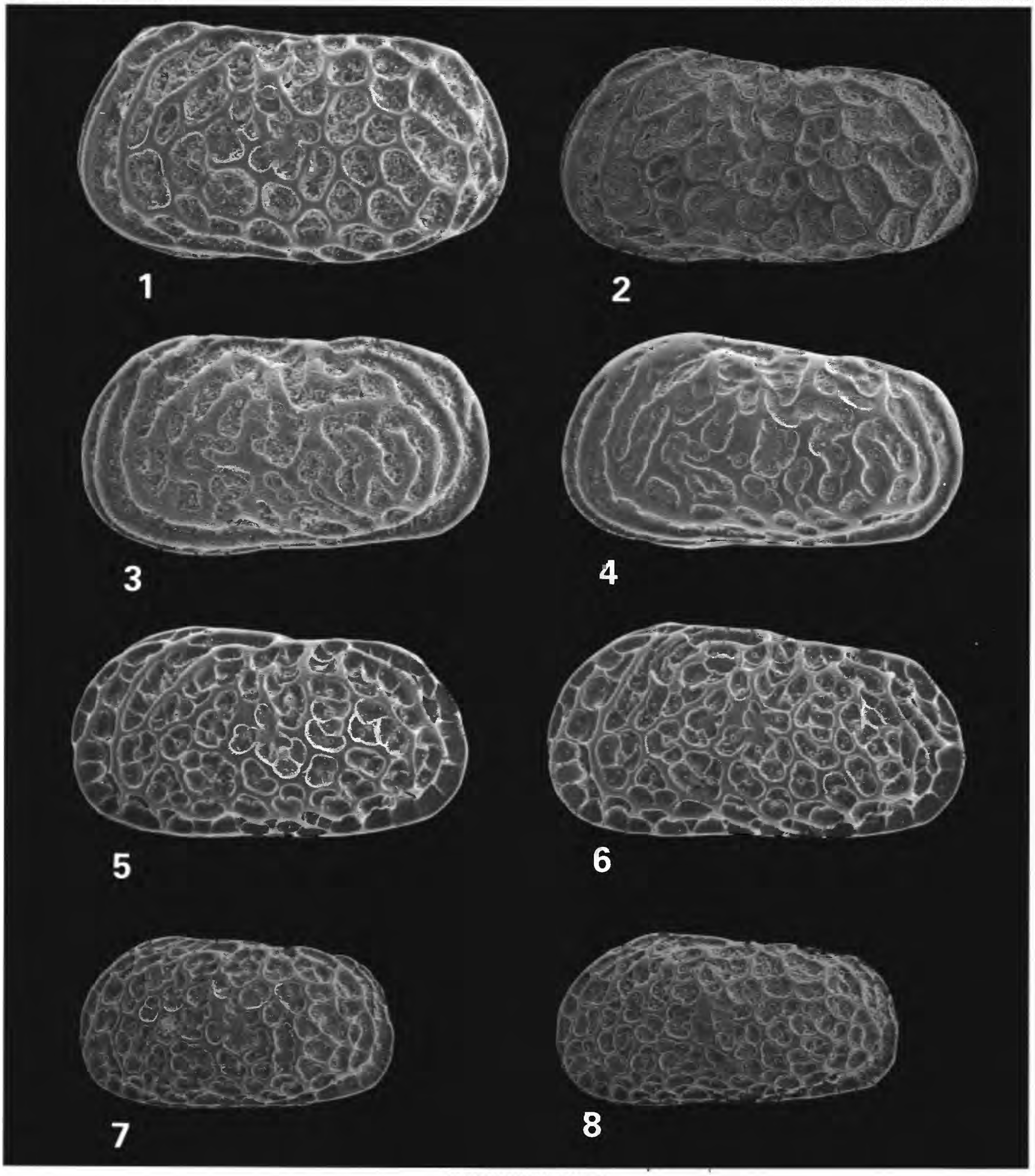
ACUTICYTHEREIS, CAMPYLOCYTHERE, PROTEOCONCHA, AND *BASSLERITES*

PLATE 15

FIGURES 1, 2. *Bensonocythere gouldensis* Hazel, 1983 (p. C39).
- 1. Left valve female, Duplin, USNM 413947, ×110.
- 2. Left valve male, Raysor, USNM 413948, ×100.

3, 4. *Bensonocythere florencensis* Cronin n. sp. (p. C39).
- 3. Left valve female, Duplin, USNM 413949, ×94, holotype.
- 4. Left valve male, Duplin, USNM 413950, ×100.

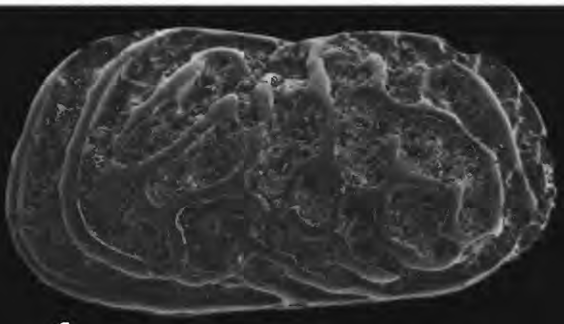
5–8. *Bensonocythere hollyensis* Cronin n. sp. (p. C39).
- 5. Left valve female, Duplin, USNM 413951, ×120.
- 6. Left valve male, Duplin, USNM 413952, ×120.
- 7. Left valve female, sample 29, Penholoway, USNM 413953, ×100, holotype.
- 8. Left valve male, sample 20, Penholoway, USNM 413954, ×100.



BENSONOCYTHERE

PLATE 16

FIGURE 1. *Bensonocythere rugosa* Hazel, 1983 (p. C39).
Left valve female, Waccamaw, USNM 413955, ×110.
2. *Bensonocythere whitei* (Swain, 1951) (p. C40).
Left valve female, Waccamaw, USNM 413956, ×100.
3. *Bensonocythere ricespitensis* Hazel, 1983 (p. C39).
Right valve female, Waccamaw, USNM 413957, ×110.
4. *Bensonocythere florencensis* Cronin n. sp. (p. C39).
Right valve female, Duplin, USNM 413958, ×94.
5, 6. *Bensonocythere hazeli* Cronin n. sp. (p. C39).
  5. Right valve male, sample 38, Ten Mile Hill beds, USNM 413959, ×110.
  6. Right valve female, sample 38, Ten Mile Hill beds, USNM 413960, ×110, holotype.
7, 8. *Bensonocythere valentinei* Cronin n. sp. (p. C39).
  7. Left valve male, sample 59, Wando, USNM 413961, ×110.
  8. Right valve female, sample 43, Wando, USNM 413962, ×110, holotype.



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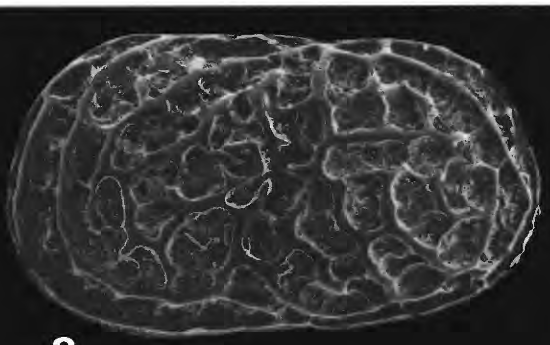

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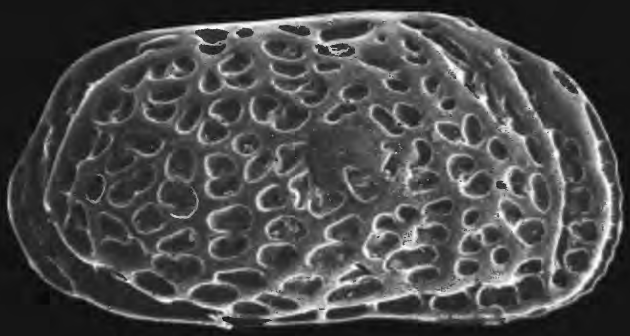

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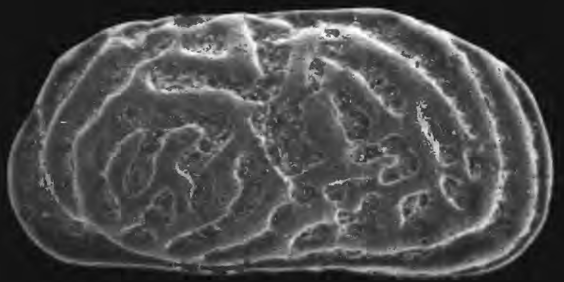

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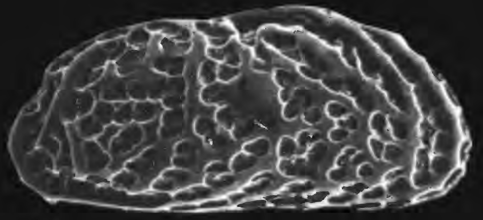

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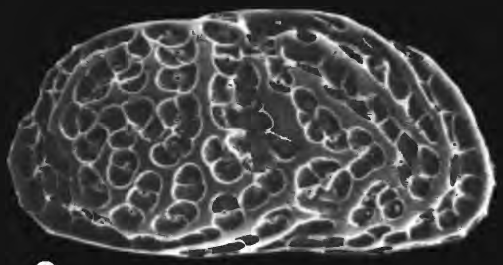

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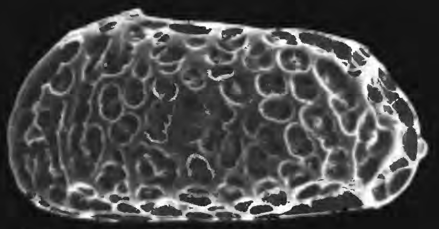

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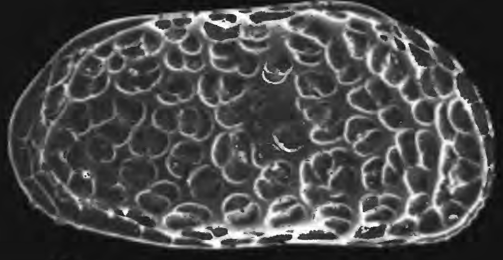

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BENSONOCYTHERE

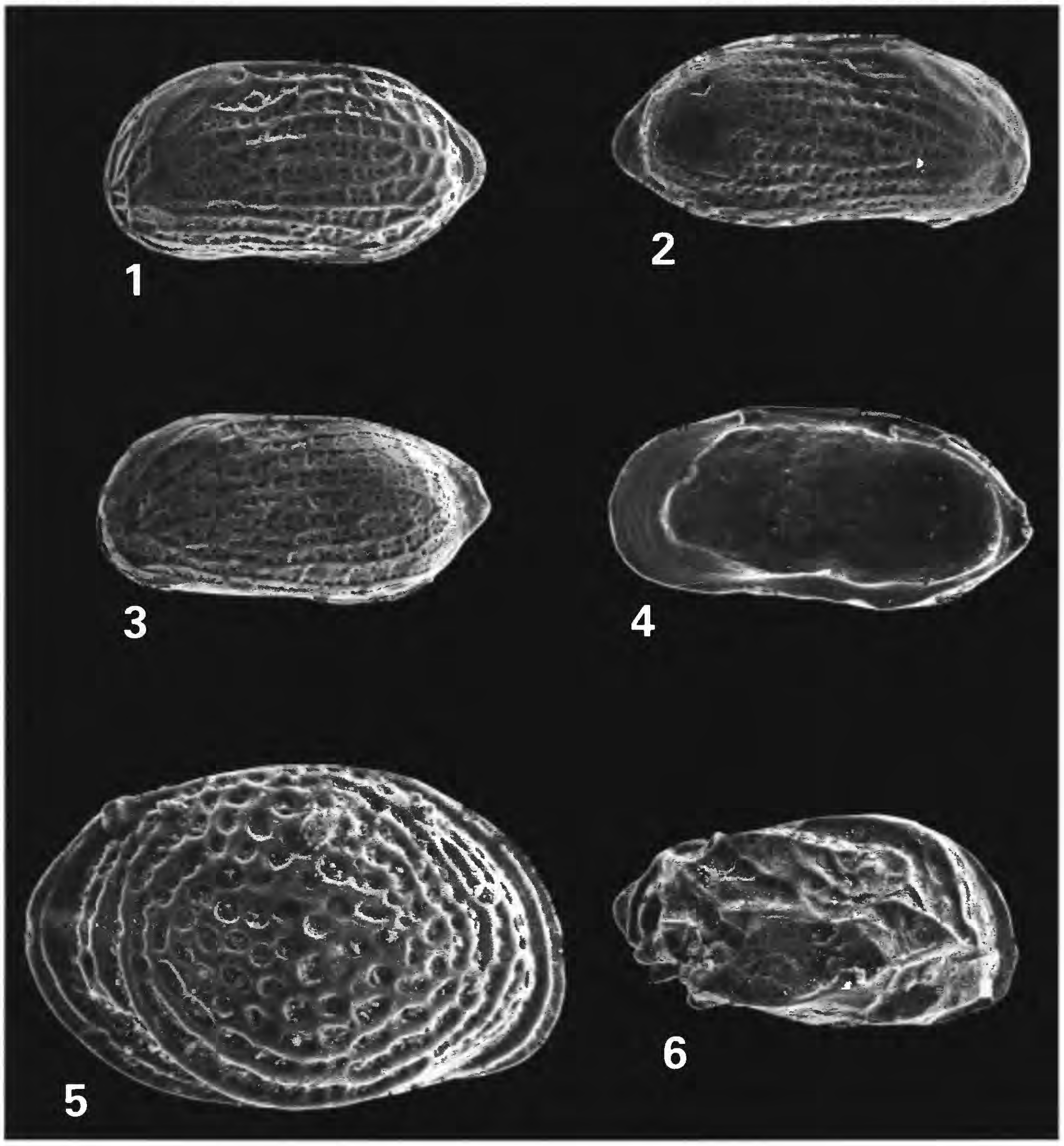
PLATE 17

FIGURES 1–4. *Cytherura neusensis* Cronin n. sp. (p. C31).

1. Left valve female, sample 23, Penholoway, USNM 413963, ×120, holotype.
2. Right valve male, sample 23, Penholoway, USNM 413964, ×120.
3. Left valve male, sample 23, Penholoway, USNM 413965, ×120.
4. Right valve male, internal view, sample 23, Penholoway, USNM 413966, ×120.

5. *Loxoconcha carolinensis* Cronin n. sp. (p. C34).
Right valve female carapace, lateral view, Raysor, USNM 413967, ×180.

6. *Paracytheridea hazeli* Cronin n. sp. (p. C34).
Right valve female, sample 38, Ten Mile Hill beds, USNM 413968, ×100.



CYTHERURA, *LOXOCONCHA*, AND *PARACYTHERIDEA*

Biostratigraphic and Paleoenvironmental Interpretations from Late Pleistocene Ostracoda, Charleston, South Carolina

By SHARON KING LYON

STUDIES RELATED TO THE CHARLESTON, SOUTH CAROLINA,
EARTHQUAKE OF 1886—NEOGENE AND QUATERNARY
LITHOSTRATIGRAPHY AND BIOSTRATIGRAPHY

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1367–D

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STUDIES RELATED TO THE CHARLESTON, SOUTH CAROLINA, EARTHQUAKE OF 1886—
NEOGENE AND QUATERNARY LITHOSTRATIGRAPHY AND BIOSTRATIGRAPHY

BIOSTRATIGRAPHIC AND PALEOENVIRONMENTAL INTERPRETATIONS FROM LATE PLEISTOCENE OSTRACODA, CHARLESTON, SOUTH CAROLINA

By SHARON KING LYON[1]

ABSTRACT

Pleistocene ostracode assemblages from 16 auger holes in the vicinity of Charleston, S.C., are used here as biostratigraphic and paleoenvironmental indicators. Ostracode taxa representing the early Pleistocene *Puriana convoluta* Assemblage Zone were found in two auger holes. Taxa from the late Pleistocene *Bensonocythere sapeloensis* Assemblage Zone represent three separate transgressive-regressive events. Three biofacies are recognized in the study area: oyster-bank and open-sound backbarrier biofacies and inner sublittoral marine biofacies. Comparison of the late Pleistocene inner sublittoral marine assemblages with species distributions from Holocene assemblages shows that a majority of late Pleistocene species are still extant. Although some late Pleistocene species presently extend into the Nova Scotian, Virginian, and (or) Caribbean faunal provinces, all but one are living currently within the subtropical Carolinian faunal province. This distribution is interpreted to indicate a late Pleistocene subtropical paleoclimate similar to the climate found in the area today. On the basis of ecostratigraphy, uranium-disequilibrium-series coral dates, and amino-acid ratios on mollusks, the three transgressive-regressive events are dated at approximately 120,000, 94,000, and 72,000 years ago.

INTRODUCTION

PURPOSE

The purpose of this study is threefold: (1) to describe late Pleistocene Ostracoda from the Charleston, S.C., area, (2) to determine paleoenvironments by using Pleistocene ostracodes in biofacies analysis and in comparisons of fossil marine assemblages to modern marine assemblages, and (3) to use biofacies changes and ostracode assemblage zones as biostratigraphic markers in order to date the marine sediments in the study area. Further, these data were integrated with parallel studies involving uranium-disequilibrium-series dating of corals and amino-acid-ratio dating of mollusks.

STUDY AREA

The study area is located in the Atlantic Coastal Plain physiographic province of Eastern North America (fig. 1). Samples of Pleistocene sediments were taken from auger holes drilled in three 7½-minute quadrangles, Johns Island, Charleston, and Fort Moultrie, near Charleston, S.C., and material from 16 of these holes was selected for micropaleontological analysis (table 1).

Micropaleontological analyses were made on 35 samples from 16 power-auger holes in the Charleston area. These samples were taken from stratigraphic intervals that contained calcareous material. Of these 16 power-auger holes, 11 were bored into the part of the Wando Formation (McCartan and others, 1980) that underlies the Pamlico-Princess Anne terrace (Colquhoun, 1974). The 11 holes are designated as C5, C7, C9, C10, C11, C17, C21, C22, C23, C24, and JI18 (fig. 1). Four holes were drilled into the Wando Formation underlying the Silver Bluff terrace (Colquhoun, 1974); these holes are designated as C14, FM1, FM2, and FM3 (fig. 1). One hole, FM4, was drilled on the modern coastal barrier (fig. 1). All auger holes were drilled through the entire Pleistocene sequence and into the underlying Tertiary strata.

Ocean-bottom samples of Holocene marine sediments also were studied for ostracodes. These samples were collected from the continental shelf, continental slope, and Blake Plateau between the latitudes of Charleston

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TABLE 1.—*Location of auger holes near Charleston, S.C. (see also fig. 1)*

[Letters in front of auger-hole number indicate the 7½-minute quadrangle in which the holes are located: C, Charleston; FM, Fort Moultrie; and JI, Johns Island. Latitude and longitude are approximate]

Auger hole	Latitude (north)	Longitude (west)
C5	32°47′00″	79°53′00″
C7	32°47′00″	79°58′30″
C9	32°50′00″	79°56′30″
C10	32°50′00″	79°53′45″
C11	32°48′30″	79°53′45″
C14	32°45′30″	79°53′30″
C17	32°48′00″	79°59′30″
C21	32°51′30″	79°55′30″
C22	32°51′30″	79°54′00″
C23	32°52′00″	79°53′30″
C24	32°52′30″	79°54′30″
FM1	32°47′30″	70°51′00″
FM2	32°50′00″	79°49′00″
FM3	32°46′00″	79°51′00″
FM4	32°45′30″	79°51′30″
JI18	32°47′00″	80°01′00″

(lat 32°49′30″ N., long 79°14′24″ W.) and the Florida Keys (lat 24°10′00″ N., long 81°22′00″ W.) (fig. 2) between 1963 and 1970 by the U.S. Geological Survey (USGS) and Woods Hole Oceanographic Institution (Hathaway, 1971). In that work, 55 samples were taken in water depths ranging from 9 to 1,097 m.

STRATIGRAPHIC SETTING

In the Charleston area, there are at least 11 Neogene and Quaternary lithostratigraphic units. For more detailed discussions about the Quaternary units, see the introduction to this volume, McCartan and others (this volume), and McCartan and others (1984).

The Quaternary sequence in the Charleston area unconformably overlies either the Parkers Ferry Formation of the Cooper Group, a pale-greenish-gray limestone (Gohn and others, 1977); the Ashley Formation of the Cooper Group, a yellowish-gray to olive-brown impure limestone (Gohn and others, 1977); the Chandler Bridge Formation, a light-gray quartz-phosphate sand (Sanders and others, 1982); the Goose Creek Limestone, a pale-yellow limestone (Weems and others, 1982); or a unit of uncertain correlation that is a dark-green drab noncalcareous clay to sand (McCartan and others, 1984; McCartan and others, this volume). The Parkers Ferry Formation is Eocene (Hazel and others, 1977), the Ashley Formation is Oligocene (Hazel and others, 1977), the Chandler Bridge Formation is Oligocene (Sanders and others, 1982), the Goose Creek Limestone is Pliocene (Weems and others, 1982), and the uncorrelated unit is early or middle Miocene in age (L.E. Edwards, USGS, oral commun., 1982).

PREVIOUS OSTRACODE STUDIES

In the identification of Pleistocene ostracode species, studies of Neogene ostracodes have to be considered as well. This is because many of the Pleistocene species range upward from the Miocene and Pliocene and were described originally from Neogene deposits. Edwards (1944) described ostracode taxa from the Duplin Formation in North Carolina, now considered Pliocene in age (DuBar and others, 1974). Pooser (1965) used ostracodes as biostratigraphic markers for Tertiary strata from wells in South Carolina. Miocene ostracodes from Florida were studied by Puri (1953c). Ostracode assemblage zones for the Yorktown Formation of Virginia and North Carolina have been delineated by Hazel (1971), and these ostracodes have been compared to ostracodes from the Pliocene and Pleistocene Croatan Formation (Hazel, 1983). Swain (1974) identified ostracodes from the Yorktown and Duplin Formations of Virginia and North Carolina. Malkin (1953) studied Miocene ostracodes from New Jersey, Maryland, and Virginia. Pliocene and early Pleistocene ostracodes of the Atlantic seaboard are discussed further by Cronin (this volume).

Pleistocene ostracodes from North and South Carolina have been identified by Hazel (1977), Cronin and Hazel (1980), and Cronin (1979, 1980). Valentine (1971) compared Pleistocene ostracodes from Virginia with Holocene ostracodes from the mid-Atlantic shelf. Ostracodes from the lower Pleistocene Waccamaw Formation of North and South Carolina were identified by Swain (1968). Kontrovitz (1978) studied Pleistocene ostracodes from south Florida, Hall (1965) studied late Pleistocene ostracodes from Sapelo Island, Ga., and Cronin (1986) identified Quaternary ostracodes from the South Texas Gulf Coast.

Most species found in South Carolina Pleistocene sediments are living presently off the east coast of North America and in the Gulf of Mexico. Studies of modern faunas that were helpful in species identification include Benda and Puri (1962), Benson and Coleman (1963), van den Bold (1971, 1977), Cushman (1906), Darby (1965), Garbett and Maddocks (1979), Grossman (1967), Hazel (1975), Hulings (1958, 1959, 1967), Keyser (1975), Kontrovitz (1976), Maddocks (1969), Morales (1966), Puri (1960), Puri and Hulings (1957), Teeter (1975), and Williams (1966). Previous studies that were especially helpful in determining the geographic distribution of modern taxa include Cronin (1979), Hazel (1970b, 1975), Hulings (1967), and Valentine (1971).

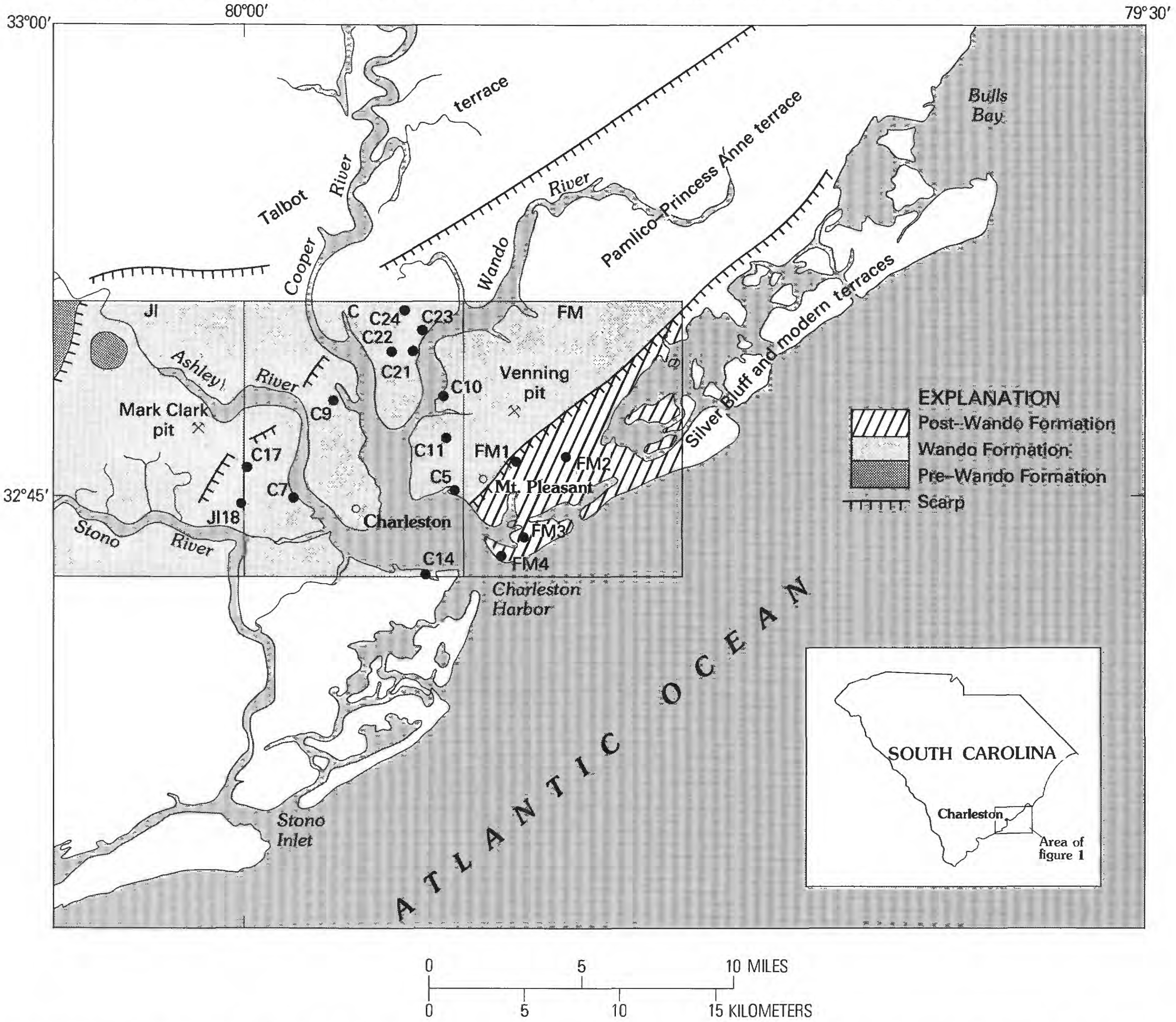


FIGURE 1.—Atlantic Coastal Plain in the vicinity of Charleston, S.C., showing generalized geology in the study area and auger-hole locations. Letter in front of auger-hole number indicates the 7½-minute quadrangle in which the auger hole is located (C, Charleston; FM, Fort Moultrie; and JI, Johns Island). Terraces are taken from Colquhoun (1974); generalized geology is taken from McCartan and others (1984).

Four papers have been published on the Pleistocene ostracode biostratigraphy of South Carolina. Hazel (1977) reviewed his ostracode assemblage zones for the Pliocene and established an assemblage zone for the lower Pleistocene Waccamaw Formation. Cronin and Hazel (1980) and Cronin (1980) composed an ostracode range chart for Pliocene to late Pleistocene species from North and South Carolina. Cronin (1981) summarized data from the three previous publications and defined assemblage zones within the Pleistocene.

TECHNIQUES

Figured ostracode specimens were attached to scanning electron microscope sample stubs and were coated with gold-palladium alloy. The specimens were then photographed by using a JEOL, JSM-35C scanning electron microscope at the USGS, Reston, Va. Settings of 10 kilovolts (kV) and 100 microamperes (μA) were used. Photographs were taken by using Polaroid 665 positive/negative film.

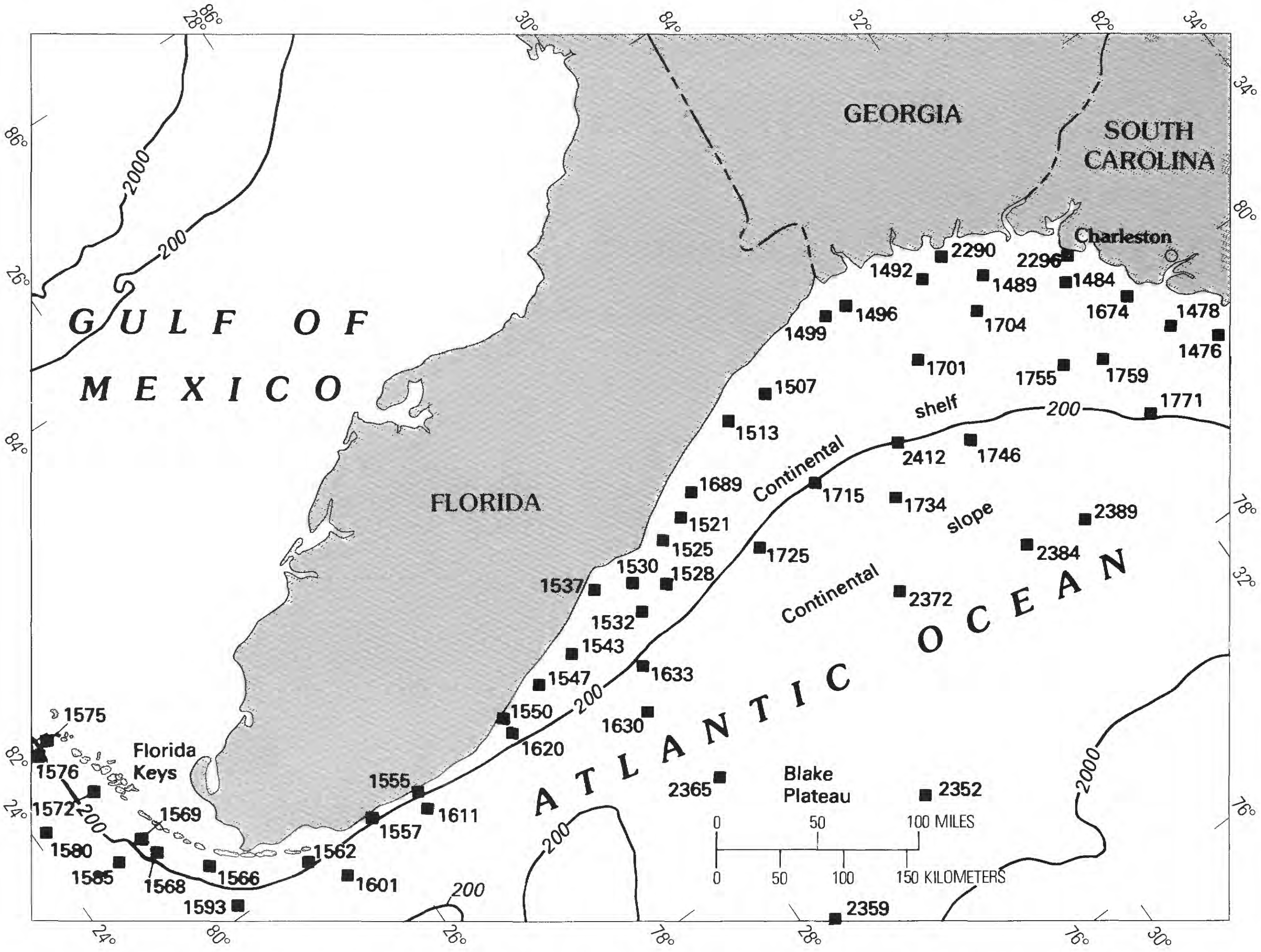


FIGURE 2.—Continental shelf, continental slope, and Blake Plateau between Charleston, S.C., and the Florida Keys showing the sample number and location of each ocean-bottom sample used for Holocene ostracode data. Depth contours are in meters.

ACKNOWLEDGMENTS

I thank Thomas M. Cronin, USGS, for his help in defining this project, checking ostracode identifications, and critically reviewing the text of this paper. Gregory S. Gohn, USGS, originally suggested that this project be undertaken. Robert E. Weems, USGS, and Earl M. Lemon, Jr., assisted me in the field and provided their interpretation of the lithologic data. Lucy McCartan, USGS, provided information on the Pleistocene stratigraphy of the study area. Joseph St. Jean, Jr., the late Walter H. Wheeler, and Joseph G. Carter of the University of North Carolina at Chapel Hill, N.C., reviewed the manuscript. Dr. Wheeler offered suggestions on stratigraphic problems, and Dr. St. Jean also checked the ostracode identifications. Effie G. Shaw, USGS, assisted with scanning electron microscope (SEM) and darkroom procedures for the production of the plates. Stratigraphic studies and related investigations by the USGS near Charleston, S.C., were supported by the U.S. Nuclear Regulatory Commission, Office of Nuclear Research, under Agreement No. AT(49–25)–1000.

PLEISTOCENE OSTRACODE BIOSTRATIGRAPHY

The ostracode biostratigraphy of Pliocene and Pleistocene deposits from North and South Carolina has been studied previously by Pooser (1965), Hazel (1971, 1977), Cronin and Hazel (1980), and Cronin (1980, 1981). Hazel (1971, 1977) defined assemblage zones for Pliocene and lower Pleistocene deposits from Virginia to southern Florida. The lower Pleistocene Waccamaw Formation of Dall (1892) has a characteristic ostracode fauna that has been defined as the upper *Puriana mesacostalis* Assemblage Zone (Hazel, 1977). Although Cronin and Hazel (1980) listed the ostracode taxa of the middle Pleistocene Canepatch Formation on a range chart, they did not propose a formal assemblage zonation. Cronin (1979) illustrated late Pleistocene ostracodes both from the Socastee Formation of DuBar and others (1974) and from deposits underlying the Princess Anne and Silver Bluff terraces of Colquhoun (1974) (equals the Wando Formation of McCartan and others, 1980).

Cronin (1980, 1981) summarized the early, middle, and late Pleistocene occurrences of ostracodes and defined three assemblage zones. The absolute age assignments of these zones are based on independent absolute age data and are subject to refinement. Cronin's (1979) *Puriana convoluta* Assemblage Zone is equivalent to the upper *Puriana mesacostalis* Assemblage Zone of Hazel (1977) and is characterized by the extinct forms of *Puriana mesacostalis* (Edwards, 1944) and at least eight extinct species: *Puriana carolinensis* Hazel, 1983; *Neocaudites variabilis* Hazel, 1983; *Bensonocythere* sp. (=*Bensonocythere* sp. A, Cronin and Hazel, 1980, p. B17, fig. 5d); *Tetracytherura* sp. (=*Microcytherura* sp. B, Cronin and Hazel, 1980, p. B21, fig. 7b); *Muellerina bassiounii* Hazel, 1983; *Muellerina* sp. (=*Muellerina* sp. B, Cronin and Hazel, 1980, p. B19, fig. 6b); *Malzella evexa* Hazel, 1983; and *Tetracytherura* sp. (=*Microcytherura* sp. D, Cronin and Hazel, 1980, p. B21, fig. 7e). Cronin (1981) places the top of the *Puriana convoluta* Assemblage Zone at approximately 700 kilo-annum (ka, 10^3 years).

Cronin's (1981) *Neocaudites atlantica* Assemblage Zone is diagnostic of the middle Pleistocene Canepatch Formation of DuBar and others (1974). Five species that are present in older deposits became extinct after the Canepatch transgression: *Muellerina wardi* Hazel, 1983; *Orionina vaughani* (Ulrich and Bassler, 1904); *Radimella confragosa* (Edwards, 1944); *Paracytheridea cronini* Hazel, 1983; and *Loxoconcha edentonensis* Swain, 1951. Six extant species appear for the first time during Canepatch time in this region: *Puriana floridana* Puri, 1960; *Paracytheridea hazeli* Cronin, this volume (=*Paracytheridea* sp. A, Cronin and Hazel, 1980, p. B23, fig. 8e); *Puriana carolinensis* Hazel, 1983 (=*Puriana* sp. A, Cronin and Hazel, 1980, p. B15, fig. 4a); *Malzella floridana* (Benson and Coleman, 1963); *Neocaudites atlantica* Cronin, 1979; and *Bensonocythere hazeli* Cronin, this volume (=*Bensonocythere* sp. A, Cronin, 1979, p. 148, pl. 18, fig. 3). Thus, the *Neocaudites atlantica* Assemblage Zone can be recognized by the overlap of these extinct and extant species. Cronin (1981) estimated the top of this assemblage zone to be at 300 ka, which places the Canepatch Formation in the middle Pleistocene. Several corals from the Canepatch Formation have dates of about 450 ka (B.J. Szabo *in* McCartan and others, 1982) and support Cronin's estimate.

The late Pleistocene ostracodes of the Socastee Formation of DuBar and others (1974) are grouped into the *Bensonocythere sapeloensis* Assemblage Zone (Cronin, 1981). In addition to the six extant species listed above for the *Neocaudites atlantica* Assemblage Zone, nine other Holocene species typify the *Bensonocythere sapeloensis* Assemblage Zone: *Cytherura sablensis* (Benson and Coleman, 1963); *Cytherura nucis* Garbett and Maddocks, 1979; *Paracytheroma texana* Garbett and Maddocks, 1979; *Cytheromorpha fuscata* (Brady, 1869a); *Cyprideis margarita* Cronin, 1979; *Cytherura valentini* Garbett and Maddocks, 1979; *Neolophocythere subquadrata* Grossman, 1967; *Pontocythere* sp. (=*Pontocythere* sp. A, Cronin, 1979, p. 143, pl. 5, figs. 2, 4); and *Tetracytherura norfolkensis* Cronin, 1979. All these species are probably living today, although *Cytherura sablensis*, *Cytherura nucis*, and *Paracytheroma texana* are found today only in the Gulf of Mexico, and *Cyprideis margarita* is rarely found in the Holocene. Cronin (1981) considers the *Bensonocythere sapeloensis* Assemblage Zone to represent the late Pleistocene from 300 to 10 ka.

The ostracode faunas near the bottom of auger holes C21 and C24 (figs. 1, 3) are quite distinct from faunas found in holes drilled to the south. Diagnostic species from holes C21 and C24 include *Muellerina bassiounii* Hazel, 1983; *Orionina vaughani* (Ulrich and Bassler, 1904); *Puriana carolinensis* Hazel, 1983; *Malzella evexa* Hazel, 1983; *Muellerina wardi* Hazel, 1983; *Neocaudites variabilis* Hazel, 1983; and *Bensonocythere whitei* (Swain, 1951). The concurrent ranges of these species overlap in the *Puriana convoluta* Assemblage Zone of Cronin (1981). Therefore, it can be concluded that the age of these samples is early Pleistocene (approximately 1.8 to 0.7 Mega-annum (Ma, 10^6 years)) and that they represent a buried outlier of lower Pleistocene sediments beneath upper Pleistocene deposits. Ostracodes from nearby auger holes C22 and C23 belong to the oyster-bank biofacies, rather than the inner sublittoral biofacies of holes C21 and C24, and thus are not characteristic of a particular assemblage zone. From regional mapping, the deposits containing these ostracodes correlate with upper Pleistocene deposits to the southwest and northeast (R.E. Weems, oral commun., 1983).

Auger holes drilled farther south in the Wando Formation, C5, C7, C9, C10, C11, C14, and JI18 (figs. 1, 3), yield ostracode assemblages that are similar to one another but differ in several respects from the assemblages in holes C21, C22, C23, and C24. The fauna in the southern holes is composed predominantly of extant species whose ranges overlap in the late Pleistocene *Bensonocythere sapeloensis* Assemblage Zone of Cronin (1981). Species that are diagnostic of this assemblage zone and are found in the southern holes listed above are *Puriana floridana* Puri, 1960; *Paracytheridea hazeli*

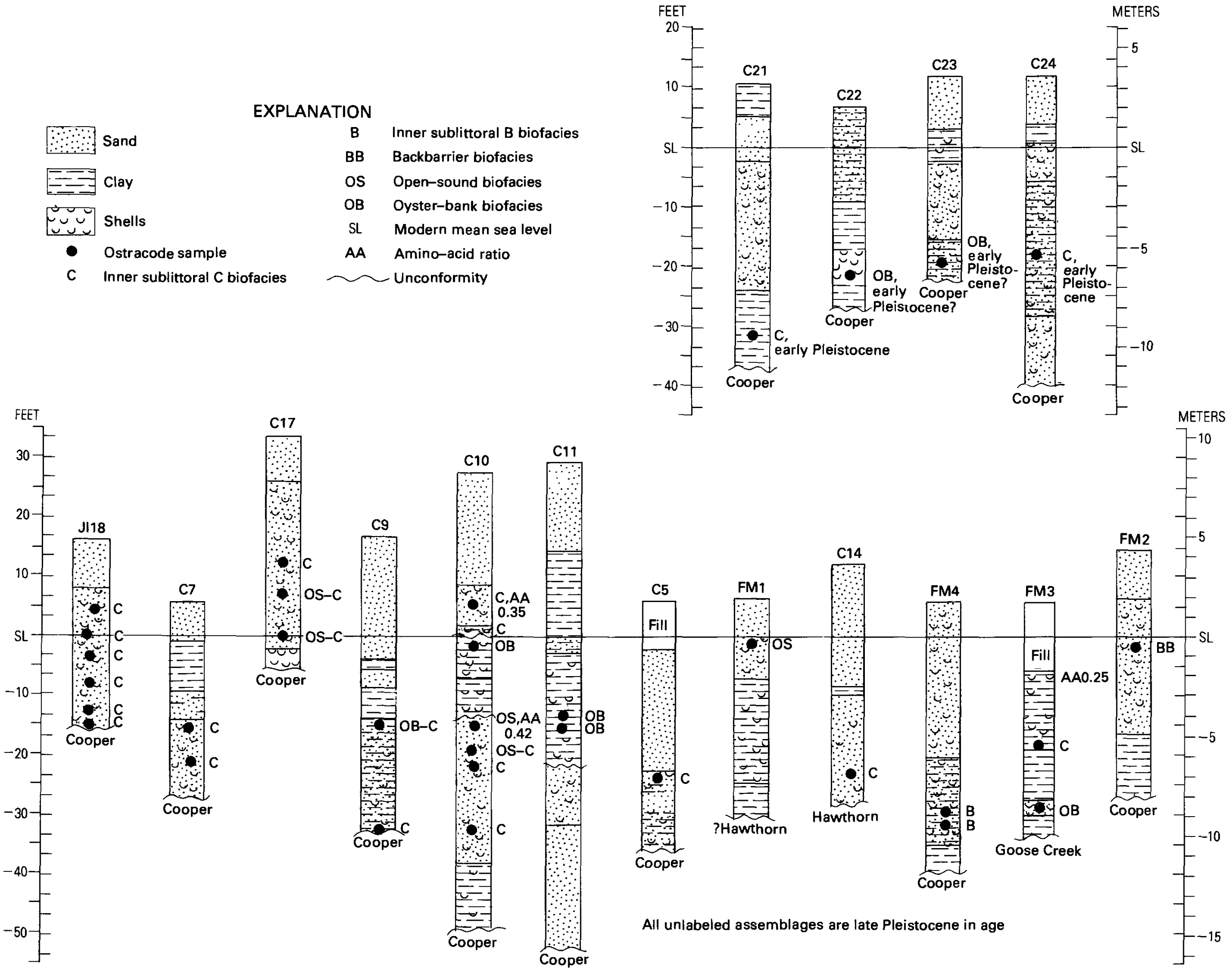


FIGURE 3.—Stratigraphic columns constructed from auger-hole logs and samples of Pleistocene deposits in the Charleston, S.C., area. Lithologies, biofacies, ages, and amino-acid ratios are shown. Auger-hole locations are shown in figure 1.

Cronin, this volume (=*Paracytheridea* sp. A, Cronin and Hazel, 1980, p. B23, fig. 8e); *Puriana carolinensis* Hazel, 1983 (=*Puriana* sp. A, Cronin and Hazel, 1980, p. B15, fig. 4a); *Neocaudites atlantica* Cronin, 1979; *Bensonocythere valentinei* Cronin, this volume (=*Bensonocythere* sp. B, Cronin, 1979, p. 149, pl. 18, fig. 5); *Cytherura nucis* Garbett and Maddocks, 1979; *Cyprideis margarita* Cronin, 1979; and *Cytherura valentini* Garbett and Maddocks, 1979. In addition, Cronin (1979) illustrates many other species that are common in upper Pleistocene deposits in the Carolinas and that also occur in these holes. Thus, the Pamlico-Princess Anne terrace part of the Wando Formation is late Pleistocene in age in the vicinity of Charleston, S.C., and south of auger holes C21 and C22 (fig. 1).

Distinguishing late Pleistocene assemblages from Holocene assemblages is difficult because most species still live off the coast today. *Cytherura nucis* Garbett and Maddocks, 1979, which is known in Holocene sediments only from Texas bays and lagoons, is an exception. Auger hole FM2 (figs. 1, 3) is in an area surrounded by Holocene lagoonal sediments. However, a late Pleistocene date for the samples taken from this core is substantiated by the abundance of *Cytherura nucis* at a depth of 2.1 m below modern mean sea level. Auger hole FM3, situated directly behind the modern barrier, and auger hole FM4 (figs. 1, 3), located on the modern barrier, are both in areas of Holocene sedimentation. These samples contain ostracode faunas that could be either late Pleistocene or Holocene in age.

BIOFACIES ANALYSIS

The term "biofacies" has been defined in various ways by different authors. Buzas (1970) defines a biofacies as "the zonation of multispecies assemblages living in a specified area." Therefore, many different biofacies may be defined within one community. Raup and Stanley (1971) define a biofacies as "fossils which show lateral changes in aspect." By Raup and Stanley's definition, groups of samples that constitute biofacies can be distinguished from one another by the presence of certain species in the samples. Biofacies may change vertically in a stratigraphic section, as well as laterally, and thus, biofacies have thickness. Therefore, biofacies, like lithofacies, should be mappable units (Hazel, 1975).

The method of Q-mode principal coordinates analysis has been used successfully to delineate biofacies (Hazel, 1970a, 1975; Cronin, 1979, 1980, 1981). Cronin (1979) used this method to determine five biofacies of late Pleistocene ostracodes for the southern Atlantic Coastal Plain. These are lagoonal, oyster-bank, estuarine, open-sound, and inner sublittoral biofacies (table 2). The first four biofacies all occur behind a seaward barrier in fluctuating, brackish-water, backbarrier systems. Few species can tolerate these brackish conditions, and thus, species diversity is low in all of these biofacies. In contrast, the inner sublittoral biofacies occurs in the open ocean, and species diversity is much greater. Cronin's (1979) biofacies can be applied to the ostracode assemblages found within this study area.

A total of 62 species of Ostracoda are recognized in the upper Pleistocene deposits of the Charleston area (fig. 4). Two of the backbarrier biofacies, the oyster-bank and the open-sound biofacies, are represented. Oyster banks are scattered throughout lagoons but are most common in peripheral areas, and many of the same species are found in both the oyster-bank and lagoonal biofacies. *Cyprideis mexicana* Sandberg, 1964, *Perissocytheridea brachyforma* Swain, 1955, and *Loxoconcha matagordensis* Swain, 1955, are found in both biofacies, although they vary in abundance. For example, *C. mexicana* is abundant in oyster-bank assemblages and is less common in lagoonal assemblages, and the dominant lagoonal species, *L. matagordensis*, can also be found in very low numbers in oyster-bank assemblages (table 2). Salinities in both oyster banks and lagoons range from 15 to 30 parts per thousand; salinities in open sounds range from 15 to 35 parts per thousand, where the lower part of the range reflects proximity to an estuary or river mouth (Cronin, 1979).

The inner sublittoral marine biofacies that is represented in the study area has a more diverse fauna, including *Peratocytheridea bradyi* (Stephenson, 1938), *Hulingsina rugipustulosa* (Edwards, 1944), and *Proteoconcha gigantica* (Edwards, 1944) as common species (table 2). Along the Atlantic Coastal Plain, the inner sublittoral environment occurs, by definition, seaward of a barrier and is characterized by normal marine salinities of 34–36 parts per thousand (Cronin, 1979). Holocene occurrence data from both the literature and the Holocene assemblages studied here were plotted to infer the ranges in water depth for the Pleistocene inner sublittoral species (fig. 5). None of the Holocene samples was taken at a depth less than 9 m; therefore, data for shallower depths are not given. The overlap of the depth ranges of the Holocene species suggests a paleodepth of less than 20 m for all Pleistocene inner sublittoral samples in this study. Cronin (1980), using the percentage of backbarrier species washed into the inner sublittoral environment from adjacent backbarrier environments, has more closely estimated the paleodepth (table 2). Because backbarrier ostracode species seldom are found today on the Atlantic Continental Shelf (Cronin, 1979), a

TABLE 2.—*Depositional environments, paleodepth ranges, and diagnostic ostracode taxa of late Pleistocene biofacies for the southern Atlantic Coastal Plain*

[Modified from Cronin, 1980]

Depositional environment	Estimated depth range (in meters)	Diagnostic ostracodes (in order of decreasing abundance)
Brackish-water		
Lagoonal	1–3	*Loxoconcha matagordensis* *Cyprideis mexicana* *Perissocytheridea brachyforma* *Cytheromorpha newportensis*
Oyster-bank	2–4	*Cyprideis mexicana* *Loxoconcha matagordensis* *Perissocytheridea brachyforma*
Estuarine	1–5	*Cyprideis salebrosa* *Cytheromorpha curta* *Cytheromorpha fuscata*
Open-sound	2–5	*Peratocytheridea setipunctata* *Proteoconcha nelsonensis* *Cytheromorpha newportensis* *Hulingsina rugipustulosa*
Marine		
Inner sublittoral A	5–25	*Peratocytheridea bradyi* *Hulingsina rugipustulosa* *Proteoconcha gigantica* *Cytherura* aff. *C. elongata*
Inner sublittoral B	5–20	*Peratocytheridea bradyi* *Hulingsina rugipustulosa* *Proteoconcha gigantica* *Cytherura* aff. *C. elongata* (Containing as much as 10 percent brackish-water species)
Inner sublittoral C	2–8	*Peratocytheridea bradyi* *Hulingsina rugipustulosa* *Proteoconcha gigantica* *Cytherura* aff. *C. elongata* (Containing 10–50 percent brackish-water species)

Biofacies (taken from Cronin, 1979)	TOTAL	*Cytherelloidea* sp.	*Pterygocythereis alophia*	*Paracytheridea hazeli*	*Paracytheridea rugosa*	*Paracytheridea altila*	*Tetracytherura mccartanae*	*Cytherura* aff. *C. elongata*	*Cytherura valentini*	*Cytherura* aff. *C. pseudostriata*	*Cytherura pseudostriata*	*Cytherura* aff. *C. swaini*	*Cytherura nucis*	*Cytherura wardensis*	*Cytherura forulata*	*Sahnicythere* sp.	*Hulingsina americana*	*Hulingsina* aff. *H. semicircularis*	*Hulingsina* aff. *H. rugipustulosa*	*Hulingsina* sp.	*Hulingsina* aff. *H. glabra*	*Hulingsina glabra*	*Hulingsina rugipustulosa*	*Cushmanidea seminuda*	*Eucythere triangulata*	*Eucythere declivis*	*Perissocytheridea brachyforma*	*Cyprideis margarita*	*Cyprideis mexicana*
Inner sublittoral C	34	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	5	—	—	—	—	—	7
Inner sublittoral C	224	—	1	1	1	6	—	26	—	—	—	—	—	—	7	—	—	—	—	2	—	—	60	—	—	—	—	10	20
Oyster-bank	226	—	—	—	—	—	—	—	—	—	—	—	—	3	1	—	—	—	—	—	—	—	12	—	—	—	3	—	200
Open-sound	103	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	14	—	—	—	15	—	—	—	—	—	—
Open-sound to inner sublittoral C	180	—	—	2	—	3	1	2	2	—	—	—	—	—	3	—	—	—	15	—	—	—	34	—	—	1	—	—	3
Inner sublittoral C	109	—	—	—	—	1	—	4	—	—	—	—	—	1	3	—	—	—	11	—	—	—	22	—	—	—	—	6	14,2
Inner sublittoral C	140	—	—	—	2,4j	1,1j	—	1	—	—	—	—	—	2	9	—	—	—	2	—	—	—	49	—	—	—	—	—	—
Too sparse to determine	9	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	3	—	—	—	2	—	—	—	—	—	1
Inner sublittoral C	431	—	—	1	3	9	—	7	—	—	1	—	—	1	3	—	—	4	30	5	—	—	74	—	—	—	—	—	—
Inner sublittoral C	348	—	1	2	3	3	—	15	—	—	1	—	—	1	12	1	—	4	32	1	6	1	51	—	—	—	—	—	1,2
Inner sublittoral C	311	—	—	—	1	5	1	11	—	3	2	—	—	—	5	—	—	—	22	—	9	2	32	—	—	—	—	—	—
Inner sublittoral C	311	—	—	—	3	3j	2	17	2	1	1	—	—	—	10	—	—	7	21	4	2	1	20	—	1,1j	—	—	—	1
Inner sublittoral C	284	—	—	2	1	4	—	9	2	1	—	—	—	—	2	—	—	19	21	—	2	—	35	—	1	—	—	—	—
Inner sublittoral C	86	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	3	10	1	—	1	14	—	—	—	—	—	—
Inner sublittoral C	94	—	—	2	4	3	—	—	1	3	—	—	—	1	—	—	—	—	2	—	—	1	10	—	—	—	—	—	—
Inner sublittoral C	81	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	4	—	—	1	9	—	—	—	—	—	—
Inner sublittoral C	173	1	—	—	—	—	—	6	—	—	—	—	—	2	3	—	—	—	7	4	—	2	11	—	—	—	—	—	28
Inner sublittoral C	94	—	—	—	1	—	—	3	—	—	—	—	—	—	—	—	—	—	6	—	—	—	26	—	—	—	—	—	—
Open-sound to inner sublittoral C	174	—	—	2	2	11	1	52	—	—	2	—	—	—	7	—	—	—	5	—	—	—	31	—	—	—	—	—	—
Open-sound to inner sublittoral C	217	—	—	1,1j	3.6j	1	—	14	6	4	2	—	2	2	21	—	—	—	11	—	1	—	23	—	1	—	—	—	—
Inner sublittoral C	49	—	—	—	—	1	—	1	1	—	—	—	—	—	—	—	—	—	1	1	—	1	9	—	—	—	—	—	—
Inner sublittoral C	83	—	—	—	1j	1j	—	12	2	—	—	—	4	—	3	—	—	—	15	—	—	—	4	—	—	—	2j	—	4,
Oyster-bank	31	—	—	—	—	—	—	1j	—	—	—	—	—	—	—	—	—	—	—	—	—	—	10	—	—	—	—	—	17
Oyster-bank	224	—	—	—	—	2	—	44	3	1	—	—	—	1	13	—	—	—	—	—	—	—	85	—	1	—	—	6	25
Oyster-bank to inner sublittoral C	62	—	—	—	2j	—	—	4,7j	2	—	—	—	—	1	2	1j	—	—	8	—	—	—	13	—	—	—	—	—	10
Inner sublittoral C	24	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	2	—	—	6	—	—	—	—	—	1j
Open-sound	17	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	—	5	—	—	—	—	—	—
Backbarrier bay	265	—	—	—	1,4j	—	—	2,10j	—	—	—	4	45	2	—	—	—	—	—	—	—	—	9	—	—	—	—	—	—
Inner sublittoral C	151	—	—	—	—	2	—	15	1	—	—	—	—	3	—	—	1	—	19	—	—	2	23	2	—	—	—	—	7,
Oyster-bank	118	—	—	—	—	—	—	6	2	—	—	—	—	3	5	—	—	1	—	—	—	1	68	—	—	—	—	10	12
Inner sublittoral B	32	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	7	4	—	—	—	—	—	—	—	—	—	—
Inner sublittoral B	80	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	2	11	—	3	6	6	—	—	—	—	—	1
GRAND TOTAL	4765																												

FIGURE 4.—Occurrences of late Pleistocene ostracode species found in the Charleston, S.C., area and interpreted biofacies of each sample. For more information on each biofacies, see table 2. Lowercase "j" indicates juvenile forms; —, not present.

high percentage of backbarrier species in any given sample indicates its close association with a backbarrier environment. Therefore, the high percentage of backbarrier species in most of the Pleistocene inner sublittoral samples (between 10 and 50 percent in most samples) indicates that deposition was very near shore, probably in no more than 2–8 m of water (inner sublittoral C, table 2; B is rare; A is never found).

Peratocytheridea bradyi	*Pellucistoma magniventra*	*Paracytheroma stephensoni*	*Paradoxostoma* sp.	*Paradoxostoma delicata*	*Protocytheretta* cf. *P. sahnii*	*Actinocythereis captionis*	*Neocaudites atlantica*	*Echinocythereis* sp.	*Puriana floridana*	*Puriana carolinensis*	*Muellerina ohmeri*	*Aurila laevicula*	*Malzella evexa*	*Bensonocythere hazeli*	*Bensonocythere valentinei*	*Bensonocythere sapeloensis*	*Bensonocythere whitei*	*Proteoconcha nelsonensis*	*Proteoconcha tuberculata*	*Proteoconcha gigantica*	*Campylocythere laeva*	*Leptocythere nikraveshae*	*Cytheromorpha newportensis*	*Cytheromorpha curta*	*Loxoconcha* cf. *L. florencensis*	*Loxoconcha matagordensis*	*Loxoconcha reticularis*	*Propontocypris edwardsi*	*Bairdoppilata* sp.	*Bairdoppilata* sp.	*Neonesidea gerda*	Auger-hole number and depth, in meters above or below sea level	
8	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	—	8	2	—	1	—	—	—	—	—	—	—	—	—	C10	1.5
50	—	—	—	—	—	—	—	—	—	—	—	—	—	10	—	—	—	—	5	23	1	—	—	1	—	—	—	—	—	—	—	C10	0.3
—	—	4	—	—	—	—	—	—	—	—	—	—	1j	—	—	—	—	—	—	—	—	—	—	1j	—	1	—	—	—	—	—	C10	- 0.3
9	2	—	—	—	—	—	—	—	1j	—	1	—	3j	1	—	—	—	—	—	2,2j	—	—	—	—	—	—	—	—	—	—	—	C10	- 4.0
35	1	1	—	—	2	—	—	—	2	1j	—	—	1j	2	—	1	—	1	4	8	1	—	—	—	—	—	—	—	—	—	—	C10	- 5.3
21	—	—	—	—	—	—	—	—	1j	—	—	—	1	—	—	—	—	—	4	7	—	—	—	—	—	—	—	—	—	—	—	C10	- 6.1
18	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3	31	—	—	—	1	—	—	1	—	—	—	—	C10	- 8.9
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—	—	C10	-10.1
200	2	1	—	—	—	2,1j	3	—	2j	—	—	—	3j	1	1	5	1	5	9	19	4	3	1	—	—	17	1	—	—	—	—	JI18	1.2
106	1	1	1	—	—	—	—	1j	2j	—	—	1	2j	1	5	2	1j	7	30	15	1	1	1	—	—	19	4	—	—	—	—	JI18	0.0
100	2	2	1	—	—	—	2,1j	—	19j	2	1	—	3j	2	—	2	2	2	28	5	16	—	—	—	—	11,1j	1	—	2	2	1	JI18	- 1.2
120	—	—	—	1	4j	—	—	—	2j	—	—	—	6j	—	—	—	—	4	15	5	—	1	—	—	—	—	1	1	—	1	—	JI18	- 2.4
125	2	3	—	—	1j	—	1	—	1j	1	—	—	1j	—	—	1	—	2,2j	9	15	—	1	—	—	—	2	1	—	—	—	—	JI18	- 3.7
34	1	1	—	—	—	—	—	—	1j	1	—	—	1j	—	1	1	—	—	4	4	—	1	—	—	—	—	—	—	—	—	—	JI18	- 4.3
33	—	—	—	—	1	—	—	—	—	1j	—	—	3j	—	—	—	—	—	3	6	—	—	—	—	—	—	—	—	—	—	—	C7	- 4.3
20	6	—	—	—	18j	—	—	—	—	2	—	—	2j	—	—	—	—	—	—	3	—	—	—	—	—	1	—	—	—	—	—	C7	- 5.8
58	—	2	—	—	5	—	—	1j	—	4j	1,2j	—	—	—	—	6	4	—	16	5	1j	—	—	—	1,2j	—	2	1	—	—	—	C7	- 7.6
30	—	—	—	—	—	—	—	—	—	—	—	—	1j	—	—	—	—	—	2,1j	1	1	—	—	—	—	—	—	—	—	—	—	C17	1.2
—	3	—	1	—	—	—	—	—	4j	—	—	—	—	—	—	5	2	—	—	—	1	2	—	—	—	4	3	—	2	4	1	C17	- 1.5
—	12	10	1	—	2	2	1j	—	7j	—	—	1	10j	—	—	—	—	4	8	5	1	2	1,2j	—	—	5	1,1j	—	2	—	1	C17	- 4.0
22	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	4	2	1	2	—	—	—	—	—	1	—	—	—	—	—	C14	- 6.4
11	—	—	—	—	—	—	—	—	1j	—	—	—	1	—	1	—	1	2	—	—	—	2	5	4	—	—	—	—	—	—	1j	C5	- 6.7
2j	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	C11	- 3.7
—	—	—	—	—	—	—	34	—	1	—	—	—	—	—	—	1	—	—	4	2	—	—	—	—	—	—	—	—	—	—	—	C11	- 4.3
—	—	4	—	—	—	—	2	—	2j	—	—	1	—	1	—	1	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	C9	- 4.0
10	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	1j	—	—	—	—	—	—	—	—	—	—	C9	- 8.9
3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3	—	—	—	—	2	—	—	—	—	—	—	—	FM1	- 0.6
3	45	—	—	6	—	—	—	—	—	—	—	—	—	1	—	1	—	—	70	15	—	41	—	4	—	—	—	—	—	—	—	FM2	- 2.1
37	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	9	12	18	—	—	—	—	—	—	—	—	—	—	—	FM3	- 5.2
7	—	—	—	—	—	—	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	—	—	—	—	—	—	—	FM3	- 7.6
11	—	—	—	—	—	2	—	—	—	—	—	—	—	—	—	—	2	—	—	4	—	—	—	—	—	—	—	—	—	—	—	FM4	- 8.2
33	—	—	—	—	—	—	—	—	—	—	—	—	1	—	—	1	—	—	4	9	—	—	—	—	—	—	—	—	1	1	—	FM4	- 8.9

THE RELATIONSHIP BETWEEN PLEISTOCENE AND HOLOCENE SPECIES DISTRIBUTION

The Atlantic Continental Shelf of the United States has been subdivided by several authors into faunal provinces and climatic zones on the basis of different groups of benthic organisms (see review by Hazel, 1970b). Faunal provinces are established according to the geographic distribution of assemblages of marine organisms, and climatic zones are inferred from these provinces. Factors that influence the distribution of these organisms include annual range of water temperature, substrate composition, rate of sediment influx, water depth, and salinity. Ostracodes of the continental shelf are temperature-sensitive organisms; their species distribution is influenced not only by winter and summer temperatures that affect their survival, but by winter

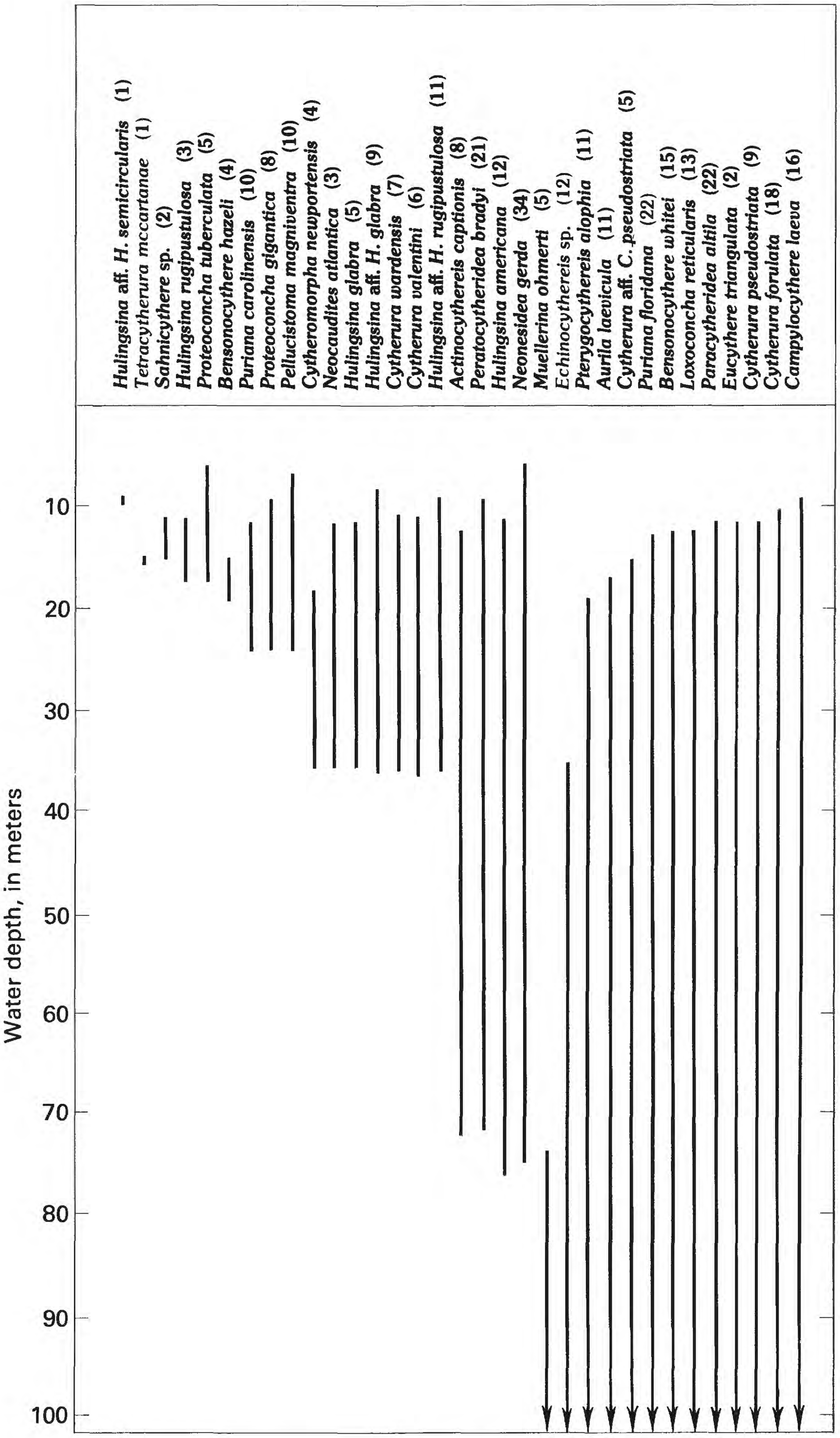


FIGURE 5.—Depth ranges for Holocene ostracode species that are found also in South Carolina inner sublittoral Pleistocene deposits. Number of Holocene samples used for each depth determination is in parentheses.

and summer temperatures that affect their reproduction as well.

This study of ostracode zoogeography follows the faunal-province classification of Hazel (1970b). From north to south, six marine faunal provinces and climatic zones have been established along the east coast of North America: Arctic (frigid), Labrador (subfrigid), Nova Scotian (cold temperate), Virginian (mild temperate), Carolinian (subtropical), and Caribbean (tropical). Some authors (Dana, 1853; Hedgpeth, 1957; and Stephenson and Stephenson, 1954) recognize a separate warm-temperate climatic zone within the Virginian faunal province. Valentine (1971) doubts that the latter climatic zone occurs today, although he found evidence that it existed during the late Pleistocene in the Virginia area. Climatic zones are based by most authors not on temperature but, rather, on the distribution of organisms, because the boundaries of climatic zones have been defined for convenience as equivalent to those of the faunal provinces. As water temperature is one of the major factors controlling the distribution of organisms of the continental shelf (Hazel, 1970b), water-temperature ranges are reflected in the established climatic zones. Ocean-bottom temperatures in the Virginian faunal province range from 0 to 17.5 °C in February and from 17.5 to 25 °C in August. In contrast, bottom temperatures in the Carolinian faunal province vary between 10 and 20 °C in February and between 25 and 30 °C in August, while bottom temperatures on the south Florida shelf fluctuate between 17.5 and 25 °C in February and between about 25 and 32.5 °C in August (Walford and Wicklund, 1968). In addition, many climatic-zone boundaries reflect regions of strong isothermal convergence (Walford and Wicklund, 1968).

The Pleistocene samples in this study are located within the modern Carolinian faunal province (Cape Hatteras, N.C., south to Cape Canaveral, Fla.; fig. 6). The ocean-bottom temperatures at Charleston, S.C., are known to range from 10 to 15 °C in February and from 27.5 to 30 °C in August (Walford and Wicklund, 1968).

The distribution of Holocene ostracodes along the east coast of North America has been studied in detail. The distribution from the southern part of the Nova Scotian faunal province (Gulf of St. Lawrence, Canada, south to Cape Cod, Mass.) to the northern part of the Virginian faunal province (Cape Cod south to Cape Hatteras, N.C.) has been determined by Hazel (1970b) (fig. 6). Valentine (1971) has studied the Holocene ostracode distribution from the southern Virginian and northern Carolinian faunal provinces. Ostracodes from Cape Hatteras, N.C., to Jupiter Inlet, Fla., have been identified by Hulings (1967). In addition, van den Bold (1977) has reported on the modern distribution of ostracodes in the Gulf of Mexico and the Caribbean region. He defined a "transition zone" between the two regions, a zone encompassing the shallow carbonate platforms of Yucatan, Cuba, Florida, and the Bahamas.

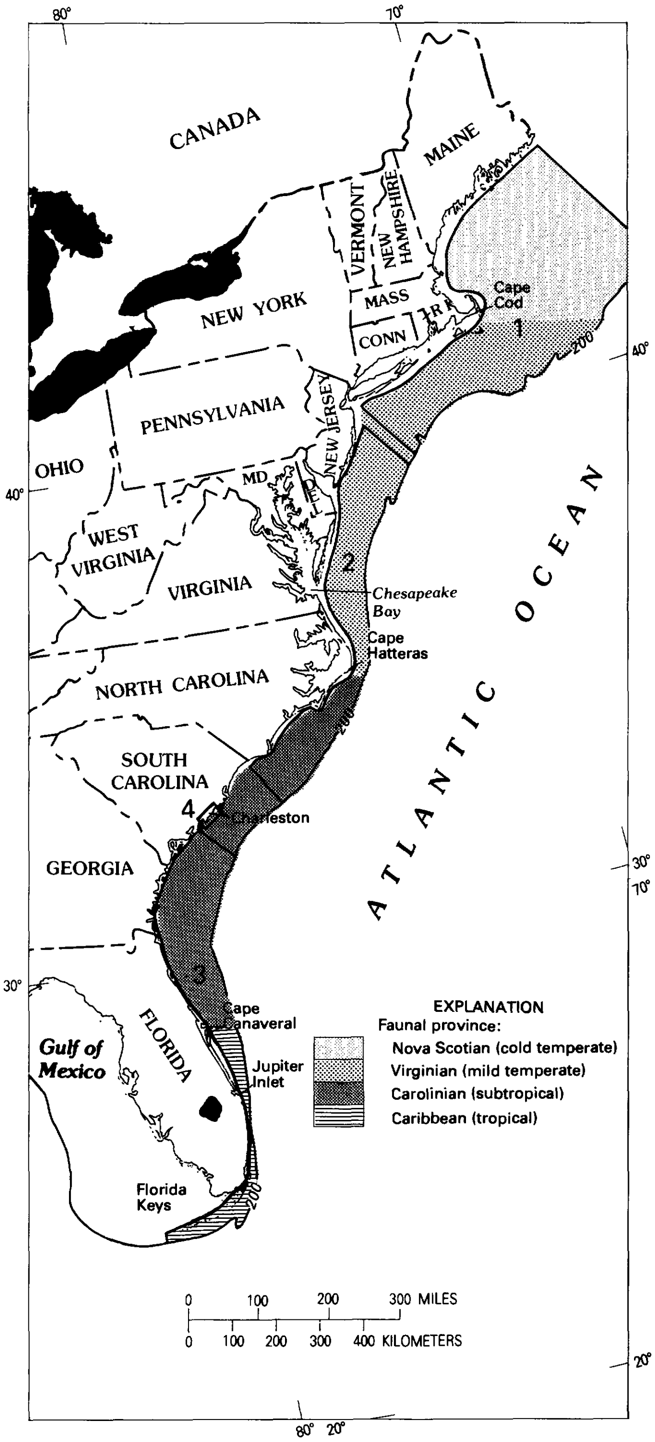


FIGURE 6.—Ostracode study areas along the East Coast of the United States. Holocene study areas offshore include those of (1) Hazel (1970b), (2) Valentine (1971) and Hazel (1975), and (3) Lyon (this paper). The Pleistocene study area onshore of Lyon (this paper) is also shown (4). Depth contours are in meters.

Because the Holocene ostracode distribution within the Carolinian and Caribbean faunal provinces is important for paleoclimatic interpretation of the Pleistocene assemblages, further study of this area was undertaken. I studied 55 Holocene samples from South Carolina to the Florida Keys in order to ascertain the ostracode distribution. This work concentrated primarily on the clastic-shelf assemblages between South Carolina and Florida because of their marked similarity to the Charleston Pleistocene assemblages. In contrast, samples from the carbonate shelf off southern Florida, the continental slope, and the Blake Plateau yielded taxa that are wholly different from the Pleistocene assemblages at Charleston. Of the 62 ostracode species found in the upper Pleistocene deposits of South Carolina, 44 are still living off the east coast of North America (fig. 7); most of the others are still alive in other areas. A study of the present distribution, and thus the climatic ranges, of the 44 species locally extant was undertaken in order to infer the Pleistocene paleoclimate of the Charleston area.

Within the Holocene ostracode assemblages, articulated, finely ornamented ostracode valves are common, and some chitinous parts are preserved. Juvenile and adult forms, as well as carapaces and valves of the same species, occur together. This evidence shows that little postmortem transport has occurred (Kontrovitz and Nicolich, 1979).

The distribution of the ostracode species common to both the late Pleistocene of the Charleston area and the Holocene continental shelf off the Southeastern United States within the Carolinian and Caribbean faunal provinces is summarized in figure 8. Individual maps showing the distribution of the species in the bottom sediments of these two faunal provinces are given in taxonomic order in the "Systematic paleontology" section.

Of the 44 species found in both the upper Pleistocene deposits of the Charleston area and the Holocene deposits on the continental shelf, 43 species are living presently in the Carolinian faunal province (fig. 7). Of these species, 39 extend north into the Virginian faunal province as well, and 2 of these, *Muellerina ohmerti* Hazel, 1983, and *Propontocypris edwardsi* (Cushman, 1906), extend even farther north into the Nova Scotian faunal province today. Only 1 of the 39 species living in the Virginian faunal province, *Cushmanidea seminuda* (Cushman, 1906), does not extend today south of Cape Hatteras into the Carolinian faunal province. To the south of Cape Canaveral, 27 of the species are found also in the Caribbean faunal province. Although no distinct faunal break occurs at Cape Canaveral, a break seems to be indicated farther south at approximately lat 27°00′00″ N. This break appears primarily to reflect a change from a clastic to a carbonate regime (Hathaway, 1972).

Several of the late Pleistocene species in the Charleston area are characteristic of the Gulf of Mexico. Twelve species have been reported by Garbett and Maddocks (1979) as living in Texas bays. Benson and Coleman (1963) have identified *Neonesidea gerda* (Benson and Coleman, 1963), *Campylocythere laeva* Edwards, 1944, and *Pellucistoma magniventra* Edwards, 1944, in the eastern Gulf of Mexico. And nine of the late Pleistocene species from Charleston are still living today along the west coast of Florida (Puri, 1960).

A Pleistocene paleoclimate much like the climate found in the Carolinian faunal province today can be interpreted from the distribution of modern shelf species common to both the upper Pleistocene deposits of Charleston and the Holocene deposits of the continental shelf. Therefore, it appears likely that a subtropical paleoclimate existed in the Charleston area during the periods in the late Pleistocene when ostracode-bearing sediments were deposited. The ocean-bottom temperatures then probably ranged from 10 to 15 °C in the winter and from 27.5 to 30 °C in the summer, and they must have occurred during interglacial intervals.

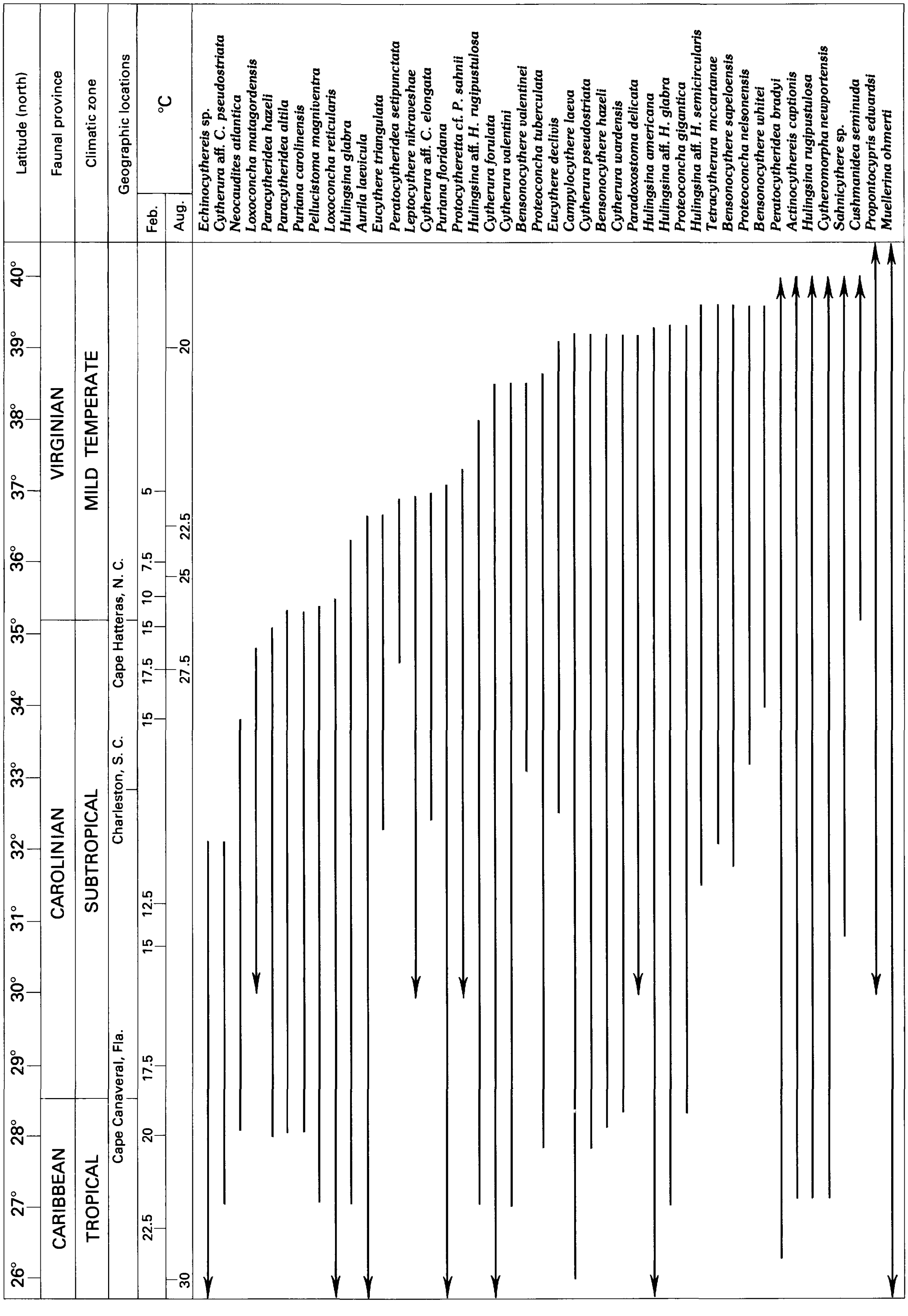
DISCUSSION

BIOSTRATIGRAPHIC INTERPRETATION

One method of dating Pleistocene marine sediments is by the use of ostracode assemblage zones to distinguish among early, middle, and late Pleistocene deposits (Cronin, 1980). Two assemblage zones are recognizable among the ostracode assemblages in the Charleston area. The first is the *Puriana convoluta* Assemblage Zone of Cronin (1981), which is found in two auger holes (C21 and C24) north of Charleston and indicates that a sedimentary depositional event occurred somewhere between 1.8 and 0.7 Ma during the early Pleistocene. These deposits are the approximate age equivalent of the Waccamaw Formation of Dall (1892) and are overlain unconformably by deposits whose age could not be determined by biostratigraphic analysis. However, the lateral relationships of the overlying deposits indicate that they correlate with fossiliferous upper Pleistocene beds to the southeast (R.E. Weems, USGS, oral commun., 1981).

The second recognizable assemblage zone is the *Bensonocythere sapeloensis* Assemblage Zone of Cronin (1981), which is found in all the remaining auger holes

FIGURE 7.—Geographic range, faunal province, climatic zone, and temperature range of Holocene ostracode species that also occur in the upper Pleistocene deposits of the Charleston, S.C., area. Arrow indicates a species range that extends farther north or south, but extent is unknown. ▶


Latitude (north)
26°
27°
28°
29°
30°
31°
32°
33°
34°
35°
36°
37°
38°
39°
40°
Faunal province
CARIBBEAN
CAROLINIAN
VIRGINIAN
Climatic zone
TROPICAL
SUBTROPICAL
MILD TEMPERATE
Geographic locations
Cape Canaveral, Fla.
Charleston, S. C.
Cape Hatteras, N. C.
°C
Feb.
22.5
20
17.5
15
12.5
15
17.5
15
10
7.5
5
Aug.
30
27.5
25
22.5
20
Echinocythereis sp.
Cytherura aff. C. pseudostriata
Neocaudites atlantica
Loxoconcha matagordensis
Paracytheridea hazeli
Paracytheridea altila
Puriana carolinensis
Pellucistoma magniventra
Loxoconcha reticularis
Hulingsina glabra
Aurila laevicula
Eucythere triangulata
Peratocytheridea setipunctata
Leptocythere nikraveshae
Cytherura aff. C. elongata
Puriana floridana
Protocytheretta cf. P. sahnii
Hulingsina aff. H. rugipustulosa
Cytherura forulata
Cytherura valentini
Bensonocythere valentinei
Proteoconcha tuberculata
Eucythere declivis
Campylocythere laeva
Cytherura pseudostriata
Bensonocythere hazeli
Cytherura wardensis
Paradoxostoma delicata
Hulingsina americana
Hulingsina aff. H. glabra
Proteoconcha gigantica
Hulingsina aff. H. semicircularis
Tetracytherura mccartanae
Bensonocythere sapeloensis
Proteoconcha nelsonensis
Bensonocythere whitei
Peratocytheridea bradyi
Actinocythereis captionis
Hulingsina rugipustulosa
Cytheromorpha newportensis
Sahnicythere sp.
Cushmanidea seminuda
Propontocypris edwardsi
Muellerina ohmerti

landward of the modern barrier. This zone was deposited between 300 and 10 ka during the late Pleistocene, when three separate transgressive-regressive sedimentary events took place according to ecostratigraphy and age dating.

ECOSTRATIGRAPHY

The ostracode assemblages in the study area are considered to be untransported death assemblages on the basis of the presence of many unworn, articulated specimens and the abundance of juveniles. Changes through time in the species within a local group result in biofacies changes within sedimentary deposits. These biofacies changes reflect significant changes in environmental processes, such as sediment deposition, water depth, and salinity changes. Although they do not reflect major evolutionary events, they denote significant environmental fluctuations. Therefore, ecostratigraphy, the study and classification of stratified rocks according to their environment of deposition (Hedberg, 1958), provides an approach that may be used to delineate separate depositional events, regardless of evolutionary change in the constituent fauna.

Biofacies changes can be seen in auger holes in the late Pleistocene sediments around Charleston. For example, the vertical biofacies change seen in the auger hole C10 (fig. 3) reflects an apparent transgressive-regressive-transgressive sequence. Inner sublittoral ostracodes are found between 6.1 and 8.9 m below modern mean sea level in the basal, fine-grained, shelly sand of a first high stand of sea level. A change in the ostracodes begins at 6.1 m below modern mean sea level from ostracodes characteristic of an inner sublittoral biofacies to those characteristic of an open-sound biofacies. The change is complete at 5.3 m below modern mean sea level. At this point the environment became slightly restricted and the salinity was lower, although the lithology remained the same. Above this unit (ostracode sample at 4 m below modern mean sea level) is a shelly clay unit containing wood and grass fragments, which in turn is overlain by the oyster-bank biofacies (ostracode sample at 0.3 m below modern mean sea level). The environment of this facies was very restricted, the water was brackish, and the dominant sediment was a dark-blue, shelly clay. Above the oyster-bank biofacies, the sediment grades from gray, shelly clay to yellow, fine-grained, shelly sand of a second high stand of sea level; here, inner sublittoral assemblages (ostracode sample at 1.5 m above modern mean sea level) are again apparent. An unconformity is inferred at about modern sea level.

Ostracode assemblages found in the samples from auger hole FM2 (figs. 1, 3) belong to the same assemblage zone as the ostracodes from auger holes in the Wando Formation. However, the assemblages from auger hole FM2 most resemble assemblages found today in Texas bays, rather than the inner sublittoral assemblages found today in the Atlantic Ocean. The large numbers of *Pellucistoma magniventra* Edwards, 1944, *Cytherura nucis* Garbett and Maddocks, 1979, *Leptocythere nikraveshae* Morales, 1966, and *Paradoxostoma delicata* Puri, 1953c (fig. 4), indicate a slightly warmer climate during the deposition of these sediments than during the deposition of other late Pleistocene sediments in the study area (Garbett and Maddocks, 1979). Thus, using an ecostratigraphic approach, these sediments can be shown to have been deposited probably during a third high stand of sea level, when a different mixture of ostracode species lived in slightly warmer climatic conditions than those existing during the previous two late Pleistocene transgressions.

AMINO-ACID RATIOS AND URANIUM-DISEQUILIBRIUM-SERIES DATES

In addition to biostratigraphy and ecostratigraphy, amino-acid ratios from mollusks and the uranium-disequilibrium-series dating of corals can be used to date depositional events. Amino-acid (alloisoleucine:isoleucine) ratios have been determined from the mollusk *Mulinia lateralis* (Say) for late Pleistocene samples in the Charleston study area (Corrado and others, 1986). Valves of this small mollusk, found below the unconformity within the Pleistocene section of auger hole C10, yield an amino-acid ratio of 0.42 (fig. 3). Above this unconformity, an amino-acid ratio of 0.35 was obtained. An average amino-acid ratio of 0.42 also has been found in *M. lateralis* shells within Pleistocene deposits at the Mark Clark pit, a sand pit near auger hole C7 (fig. 1). A uranium-disequilibrium-series date derived from a coral, *Astrangia* sp., found within Pleistocene deposits in the pit, indicates an age of 120±6 ka (Cronin and others, 1981; Szabo, 1985). Because of the equivalence of amino-acid ratios for mollusks in the Mark Clark pit and in auger hole C10 below the unconformity, the age of the lower C10 sediments is considered to be 120±6 ka.

Uranium-disequilibrium-series ratios from corals found in Pleistocene deposits from two auger holes near Mt. Pleasant, S.C. (fig. 1), indicate an age of 94±6 ka and 96±6 ka (Cronin and others, 1981; McCartan and others, 1982; Szabo, 1985). The Pleistocene deposits near Mt. Pleasant may be traced lithologically to auger hole C10, where they correlate with the section above the unconformity (R.E. Weems and E.M. Lemon, Jr., USGS, oral commun., 1981). Amino-acid ratios from mollusks at Mt. Pleasant average approximately 0.35 and match ratios determined for the upper part of the section of auger hole

C10 as well (Corrado and others, 1986). Therefore, the age of the upper part of the section can be estimated at approximately 94±6 ka.

An amino-acid ratio of approximately 0.25 has been determined from mollusks in auger hole FM2, which suggests an age of approximately 70 ka (Corrado and others, 1986) if the previous amino-acid ratios and uranium-disequilibrium-series coral dates are used as guidelines. Corals from the Norfolk Formation in Virginia and North Carolina have been dated from 75 to 72 ka as well (Cronin and others, 1981; Szabo, 1985). These deposits may be approximately equivalent in age to those in auger hole FM2.

In summary, ostracode ecostratigraphy indicates that three separate high stands of sea level (transgressive-regressive events) are represented in the upper Pleistocene deposits in the vicinity of Charleston. The sediments in the vicinity of, and within, auger hole C10 were deposited during the two older events, which occurred at approximately 120 ka and 94 ka. The sediments in auger hole FM2 may have been deposited during a third transgressive event at approximately 72 ka. Further uranium-disequilibrium-series dating of this latest marine unit in the Charleston area is required, however, before a firm age is established. Nonetheless, all of these events can be recognized by using ostracode ecostratigraphy.

CONCLUSIONS

Pleistocene Coastal Plain sediments can be correlated and dated by multiple methods. On the basis of biostratigraphy, ostracode assemblage zones alone serve to distinguish only early, middle, and late Pleistocene deposition. Taxa representing the early Pleistocene *Puriana convoluta* Assemblage Zone are found near the bottom of two auger holes in the Charleston area. All other marine sediments in the study area near Charleston, S.C., contain taxa diagnostic of the late Pleistocene *Bensonocythere sapeloensis* Assemblage Zone.

On the basis of biofacies analysis and a Holocene distribution study, many of the late Pleistocene inner sublittoral marine ostracode species are still living off the east coast of North America in the Nova Scotian, Virginian, Carolinian, and Caribbean marine zoogeographic faunal provinces, as well as in the Gulf of Mexico. Although these modern ostracode species are distributed in the four faunal provinces east of North America, all but one species coexist in the Carolinian faunal province. This distribution indicates a subtropical paleoclimate for the study area in the late Pleistocene.

On the basis of the ecostratigraphy, uranium-disequilibrium-series dating of corals, and amino-acid ratios from mollusks, three separate depositional events can be recognized within the late Pleistocene ostracode assemblage zone in deposits in South Carolina. The events, dated at approximately 120, 94, and 72 ka, reflect high stands of sea level. These events must have occurred during warm climatic (interglacial) intervals, because the ostracode assemblages studied here are not compatible with a cold climate regime.

SYSTEMATIC PALEONTOLOGY

The classification used in this study is modified from the "Treatise on Invertebrate Paleontology" (Benson and others, 1961). I depart from this classification in recognizing the families Paracytherideidae Puri, 1957, Cushmanideidae Puri, 1973, and Neocytherideidae Puri, 1957, and the subfamilies Hemicytherinae Puri, 1953b, and Trachyleberidinae Sylvester-Bradley, 1948. Following Hartmann and Puri (1974), I place the genera *Cushmanidea* and *Hulingsina* in the family Cushmanideidae and the genus *Sahnicythere* in the family Neocytherideidae. Also, I place the genus *Campylocythere* Edwards, 1944, in the family Hemicytheridae Puri, 1953b, as outlined by Hazel (1967). In addition, the following genera are recognized: *Neonesidea* Maddocks, 1969; *Muellerina* Bassiouni, 1965; *Bensonocythere* Hazel, 1967; *Proteoconcha* Plusquellec and Sandberg, 1969; *Neocaudites* Puri, 1960; *Sahnicythere* Athersuch, 1982; *Malzella* Hazel, 1983; *Peratocytheridea* Hazel, 1983; and *Tetracytherura* Müller, 1894. The criteria of Van Morkhoven (1962) were used as guidelines for classification below the subordinal level.

Synonomies are abbreviated and list only the name changes of which the author is certain. References for names of genus level and above, including type species of genera, are not listed in the bibliography but may be found in King (1981). No new names are proposed. Pleistocene occurrence data for each species are given in figure 4. Holocene distribution data for each species are summarized in figure 8. The following abundance scale is used: less than 10 percent, rare; 10–50 percent, common; and greater than 50 percent, abundant.

Figured specimens have been deposited in the U.S. National Museum (USNM), Washington, D.C. Additional specimens are kept at the University of North Carolina at Chapel Hill, N.C. Faunal slides are stored at the USGS, Reston, Va.

Order PODOCOPIDA Müller, 1894
Suborder PODOCOPINA Sars, 1866
Superfamily BAIRDIACEA Sars, 1888
Family BAIRDIIDAE Sars, 1888
Genus NEONESIDEA Maddocks, 1969

Neonesidea Maddocks, 1969.

Type species.—Triebelina schulzi Hartmann, 1962.

Sample number	Latitude (north)	Longitude (west)	*Loxoconcha reticularis*	*Cytheromorpha newportensis*	*Campylocythere laeva*	*Proteoconcha gigantica*	*Proteoconcha tuberculata*	*Proteoconcha nelsonensis*	*Bensonocythere whitei*	*Bensonocythere hazeli*	*Aurila laevicula*	*Muellerina ohmeri*	*Puriana carolinensis*	*Puriana floridana*	*Echinocythereis* sp.	*Neocaudites atlantica*	*Actinocythereis captionis*	*Pellucistoma magniventra*	*Peratocytheridea bradyi*	*Eucythere triangulata*	*Hulingsina rugipustulosa*	*Hulingsina glabra*	*Hulingsina* aff. *H. glabra*	*Hulingsina* aff. *H. rugipustulosa*	*Hulingsina* aff. *H. semicircularis*	*Hulingsina americana*	*Sahnicythere* sp.	*Cytherura forulata*	*Cytherura wardensis*	*Cytherura pseudostriata*	*Cytherura* aff. *C. pseudostriata*	*Cytherura valentini*	*Paracytheridea altila*	*Paracytheridea hazeli*	*Pterygocythereis alophia*
1476	32°49′18″	79°14′24″																						●		●		●							
1478	32°38′30″	79°29′24″				●																													
1771	32°09′42″	79°00′42″	●		●				●					●	●													●		●	●		●		●
1674	32°27′36″	79°58′48″			●				●	●			●	●				●	●														●	●	
1759	32°04′54″	79°38′18″	●						●						●											●		●	●	●				●	
2296	32°15′42″	80°27′00″			●	●							●					●	●	●	●	●	●	●		●	●	●	●	●		●	●	●	
1484	32°09′36″	80°16′06″			●		●		●	●			●	●					●														●	●	
1755	31°49′54″	79°45′24″												●																			●		
1489	31°41′00″	80°45′00″									●		●																						●
1704	31°30′48″	80°30′00″																								●		●							
1746	31°00′00″	79°44′30″													●																				
2290	31°31′12″	81°03′54″			●	●													●					●	●			●							
1492	31°20′24″	81°01′00″				●																													
1701	31°00′12″	80°29′30″			●				●										●														●		
1496	30°50′06″	81°13′24″	●		●	●							●	●				●	●		●		●	●		●	●	●	●		●	●	●	●	
1499	30°39′36″	81°13′42″			●		●		●				●	●				●	●														●		●
2412	30°31′00″	80°07′00″							●		●				●																		●		
1734	30°20′24″	79°44′00″																																	
1507	29°59′00″	81°02′18″	●		●	●							●	●				●	●				●	●		●		●	●		●	●	●		
1715	29°50′18″	80°15′30″	●		●				●		●			●												●		●		●			●	●	●
1513	29°39′30″	81°00′00″											●	●				●	●														●		
1689	29°09′24″	80°44′06″	●			●	●						●	●				●	●				●			●		●		●	●		●	●	
1521	29°00′00″	80°39′00″			●					●				●			●		●													●	●		
1525	28°50′00″	80°29′30″	●	●	●				●					●			●	●	●				●	●					●				●		
1725	29°20′24″	80°01′18″	●																																
1528	28°39′48″	80°14′30″			●			●	●					●			●		●													●	●	●	●
1530	28°29′30″	80°23′06″	●		●	●	●		●					●		●	●		●				●	●				●		●			●	●	
1537	28°10′18″	80°28′36″		●				●		●			●	●			●	●	●				●	●		●		●	●	●			●		
1532	28°20′18″	80°09′36″	●	●				●	●		●			●		●	●		●			●	●	●		●		●	●	●		●			●
1543	27°49′30″	80°10′48″	●				●		●		●								●			●				●				●			●		
1633	28°10′24″	79°48′54″																																	
1547	27°29′30″	80°08′24″			●				●		●			●			●		●			●											●	●	
1630	28°02′12″	79°31′06″																																	
1550	27°09′54″	80°07′00″	●	●					●					●		●		●	●		●	●	●	●		●		●			●	●	●	●	
1620	27°10′00″	80°00′00″															●		●																●
1611	26°22′30″	79°53′30″									●	●			●									●				●							
1555	26°21′06″	80°03′12″									●								●																
1557	25°59′54″	80°05′00″			●						●				●													●							●
1601	25°38′24″	79°50′00″																																	
1562	25°29′30″	80°03′30″												●	●													●							
1566	24°54′00″	80°26′30″													●																				
1593	24°50′12″	80°09′30″																																	
1568	24°42′12″	80°45′30″												●	●													●							
1569	24°37′36″	80°56′00″										●		●	●																				●
1585	24°24′18″	80°52′00″												●																					
1572	24°29′18″	81°27′42″									●	●			●																		●		●
1580	24°10′00″	81°22′00″																																	
1575	24°25′06″	82°00′06″	●								●	●																							●
1576	24°20′06″	81°55′18″										●																							
2389	31°23′00″	78°40′00″																																	
2384	30°54′30″	78°43′00″																																	
2372	30°01′00″	79°00′00″																																	
2365	28°16′00″	78°45′24″																																	
2352	29°16′00″	77°35′18″																																	
2359	28°14′30″	77°14′48″																																	

FIGURE 8.—Summary of the distribution of ostracode species common to both the upper Pleistocene deposits of Charleston, S.C., and the Holocene continental shelf deposits off the Southeastern United States within the Carolinian and Caribbean faunal provinces.

Remarks.—This genus was defined by Maddocks (1969) in the establishment of a new classification for the Bairdiidae. She restricted *Bairdia* McCoy, 1844, to forms from the upper Paleozoic that are closely comparable to its Carboniferous type species *Bairdia curta* McCoy, 1844. The other closely allied Paleozoic species are listed in Maddocks (1969, p. 1). *Neonesidea* Maddocks, 1969, is characterized by a smooth or finely punctate, thin carapace, which is elongately subtriangular in outline, and has a finely serrate hinge bar, a muscle scar pattern consisting of wedge-shaped scars in four zigzag rows, no denticles or few on the anterior right valve, a smooth anterior left valve margin, and a denticulate posterior margin. It is closely related to *Paranesidea* Maddocks, 1969, which has a coarsely punctate, robust, rotund carapace, a smooth hinge bar, subcircular muscle scars arranged in a tight spiral pattern, frilled right valve margins, and denticulate left valve margins. *Triebelina* van den Bold, 1946, has a very robust, coarsely punctate, nodose, or ridged carapace, which is subquadrate in lateral outline, and it has a smooth hinge bar, irregular oblong muscle scars arranged in four diagonal rows, and stout spines along the margins of both valves.

Neonesidea gerda (Benson and Coleman, 1963)

Plate 1, figure 1

Bairdia gerda Benson and Coleman, 1963, p. 19, pl. 1, figs. 14–16, text fig. 8.

Neonesidea gerda (Benson and Coleman). Maddocks, 1969, p. 24, fig. 7.

Description.—Carapace pyriform in lateral view; dorsal margin gently arched anterodorsally, strongly arched posterodorsally, and converging with ventral margin, forming a pointed posterior; ventral margin straight; anterior bluntly rounded; surface smooth, but has minute scattered pores; hinge adont.

Dimensions.—Left valve: length, 0.63 mm; height, 0.38 mm.

Figured specimen.—USNM 316437.

Remarks.—*Neonesidea gerda* (Benson and Coleman) may be distinguished from *Neonesidea crosskeiana* (Brady, 1866) by its subequal valves and by its faceted dorsum.

Stratigraphic range.—Late Pleistocene-Holocene.

Biofacies.—Rare in inner sublittoral biofacies.

Modern occurrence.—Found off the East Coast of the United States between lat 24°59′00″ N. and lat 28°17′24″ N.; abundant at depths less than 15 m; salinity range 34.86 to 39.92 parts per thousand; substrate predominantly fine-grained calcareous fragments (Benson and Coleman, 1963, p. 20).

Genus BAIRDOPPILATA Coryell, Sample, and Jennings, 1935

Bairdoppilata Coryell, Sample, and Jennings, 1935.

Type species.—*Bairdoppilata martyni* Coryell, Sample, and Jennings, 1935.

Remarks.—This genus is characterized by a thin, smooth, or finely punctate carapace (subhexagonal in lateral outline), a smooth hinge bar, oblong muscle scars arranged in a loose spiral, a smooth or frilled right valve margin, and a frilled or denticulate left valve margin. *Glyptobairdia* Stephenson, 1946, is distinguished from *Bairdoppilata* by a very robust, punctate carapace, which is also subhexagonal in lateral outline, a serrate hinge bar, subquadrate muscle scars in three horizontal rows, and stout spines on both valve margins. *Triebelina* van den Bold, 1946, is similar to *Bairdoppilata*, but the former may be distinguished by the characteristics listed previously.

Bairdoppilata sp.

Plate 1, figures 2, 3

Description.—Carapace rounded pyriform in lateral view; dorsal margin arched, ventral margin slightly concave; posterior obliquely rounded and denticulate, anterior bluntly rounded and denticulate; smooth surface containing minute pores; hinge characterized by smooth bar and fine auxiliary dentition.

Dimensions.—Left valve: length, 0.56 mm; height, 0.32 mm.

Figured specimens.—USNM 316438, USNM 316439.

Stratigraphic range.—Late Pleistocene.

Biofacies.—Rare in inner sublittoral biofacies.

Bairdoppilata sp.

Plate 1, figures 4, 5

Description.—Carapace subhexagonal in lateral view; dorsal margin arched, highest anterior to center, anterodorsal angle flatly sloping, posterior margin slightly concave; anterior rounded and frilled, posterior sharply produced and slightly frilled; smooth surface containing minute pores; hinge characterized by smooth bar and auxiliary dentition.

Dimensions.—Right valve: length, 0.69 mm; height, 0.37 mm.

Figured specimens.—USNM 316440, USNM 316441.

Remarks.—This form may be distinguished from the previously described *Bairdoppilata* sp. by its sloping anterodorsal margin and its produced posterior.

Stratigraphic range.—Late Pleistocene.

Biofacies.—Rare in inner sublittoral biofacies.

Superfamily CYPRIDACEA Baird, 1845
Family PONTOCYPRIDIDAE Müller, 1894
Genus PROPONTOCYPRIS Sylvester-Bradley, 1947

Propontocypris Sylvester-Bradley, 1947.

Type species.—*Pontocypris trigonella* Sars, 1866.

Remarks.—*Propontocypris* differs from *Pontocypris* Sars, 1866, in that the former's left valve is higher than the right, and it lacks posteroventral margin spines on the right valve. *Propontocypris* is characterized by a cluster of five muscle scars, whereas *Pontocypris* is characterized by a few elongate scars.

Propontocypris edwardsi (Cushman, 1906)

Plate 1, figure 6

Pontocypris edwardsi Cushman, 1906, p. 368, pl. 30, figs. 26–34.
Propontocypris edwardsi (Cushman). Valentine, 1971, p. D8, pl. 4, figs. 42, 47.

Description.—Carapace small and subtriangular in lateral view; dorsal margin highly arched (highest in center), ventral margin concave centrally; anterior bluntly rounded, posterior pointed; surface smooth; hinge adont.

Dimensions.—Right valve: length, 0.54 mm; height, 0.25 mm.

Figured specimen.—USNM 316442.

Stratigraphic range.—Late Pleistocene-Holocene.

Biofacies.—Rare in inner sublittoral biofacies.

Modern occurrence.—Found off the Eastern United States between lat 32°59′00″ N. and lat 41°55′00″ N. at 17–87 m depth.

Superfamily CYTHERACEA Baird, 1850
Family LOXOCONCHIDAE Sars, 1925
Genus LOXOCONCHA Sars, 1866

Loxoconcha Sars, 1866.
Normania Brady, 1866.
Loxoleberis Sars, 1866.

Type species.—*Cythere rhomboidea* Fischer, 1855.

Remarks.—This genus differs from *Loxoconchella* Triebel, 1954, in its more complex hinge and its nonbranching marginal pore canals. *Phlyctocythere* Keij, 1958, unlike *Loxoconcha*, is smooth, is very thin shelled, and has a nondifferentiated hinge. Van Morkhoven (1963, p. 388) has suggested that a revision of this genus may result in a division into several subgenera or even separate genera.

Loxoconcha reticularis Edwards, 1944

Plate 2, figure 1

Loxoconcha reticularis Edwards, 1944, p. 527, pl. 88, figs. 26, 27.

Description.—Carapace subovate in lateral view; dorsal margin straight to slightly sinuate, ventral margin convex; anterior and posterior rounded, having marginal flattened keels; large, oval pits arranged concentrically, forming almost a reticulate surface; hinge gongylodont.

Dimensions.—Left valve: length, 0.46 mm; height, 0.29 mm.

Figured specimen.—USNM 316456.

Remarks.—This species may be distinguished from *Loxoconcha jacksonensis* Howe and Chambers, 1935, by its reticulate carapace.

Stratigraphic range.—Late Miocene-Holocene.

Biofacies.—Rare in inner sublittoral biofacies.

Modern occurrence.—Found off the Eastern United States between lat 24°25′06″ N. and lat 35°29′00″ N. (fig. 9) at 12–460 m depth.

Loxoconcha matagordensis Swain, 1955

Plate 2, figure 2

Loxoconcha matagordensis Swain, 1955, p. 629, pl. 63, figs. 9a, b, pl. 64, figs. 1a, b, text figs. 7a, b, 36b, 39.

Description.—Carapace subrhomboidal in lateral view; dorsal margin straight to slightly convex, ventral margin sinuous, concave anterior to center; sloped anterodorsally, anterior rounded and extended, posterior broadly rounded with bordering keel, concavity posterodorsally producing what appears to be a caudal process; eye tubercle visible anterodorsally; posterodorsal tubercle distinct; surface ornamented by tiny pits arranged concentrically and vaguely reticulate anteriorly and posteriorly; hinge gongylodont.

Dimensions.—Left valve: length, 0.49 mm; height, 0.33 mm.

Figured specimen.—USNM 316457.

Remarks.—This species may be distinguished from *Loxoconcha purisubrhomboidea* Edwards, 1953 (*in* Puri, 1953a), by its reticulation along the anterior and posterior margins. It differs from *Loxoconcha postdorsoalata* Puri, 1960, in that the latter is much more elongate and more coarsely reticulate.

Stratigraphic range.—Pliocene-Holocene.

Biofacies.—Rare in inner sublittoral and oyster-bank biofacies.

Modern occurrence.—Along the Atlantic Coast from North Carolina to New Jersey; also found in Texas bays crawling on plants in silty substrates (Garbett and Maddocks, 1979, p. 875).

Loxoconcha cf. L. florencensis Cronin, this volume

Plate 2, figure 3

Description.—Carapace subovate in lateral view; dorsal margin slightly convex, ventral margin highly convex

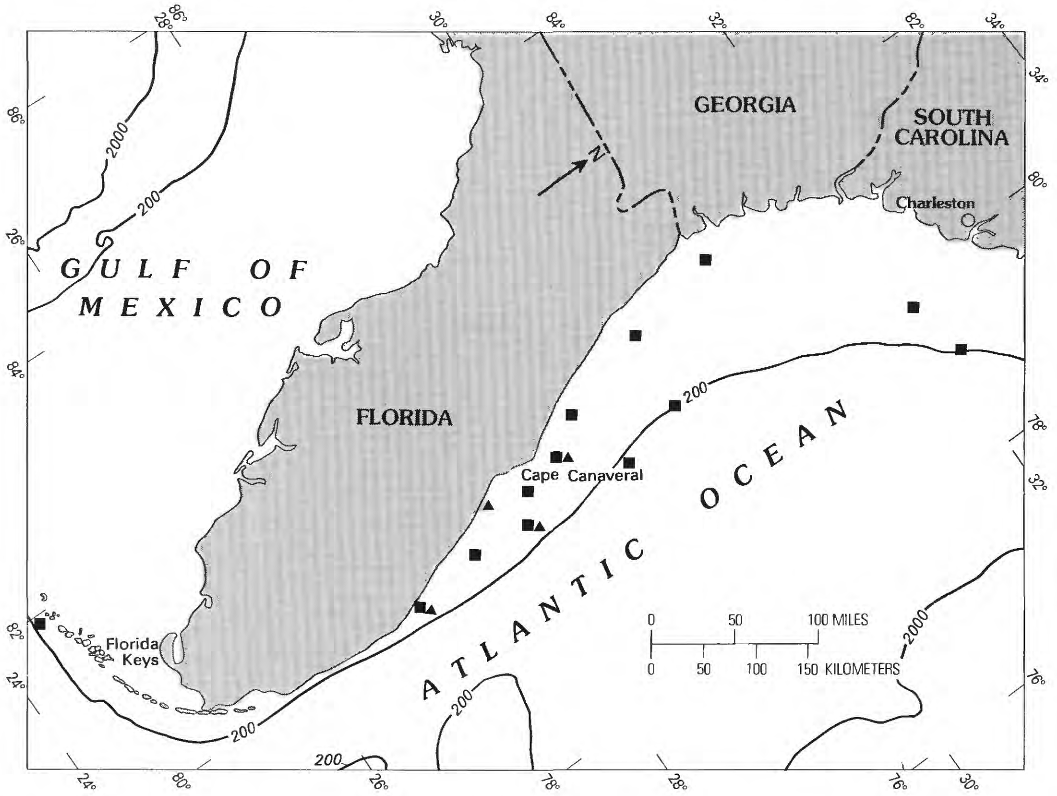


FIGURE 9.—Distribution of *Loxoconcha reticularis* Edwards, 1944 (solid squares), and *Cytheromorpha newportensis* Williams, 1966 (solid triangles). In the Holocene study area, *L. reticularis* (pl. 2, fig. 1) occurs on the continental shelf and slope between South Carolina and the Florida Keys, and *C. newportensis* (pl. 2, fig. 5) occurs on the shallow continental shelf off Cape Canaveral, Fla., and central Florida. Depth contours are in meters.

and slopes posteroventrally; anterior rounded, posterior blunt; entire margin surrounded by a low keel; surface smooth centrally, but has rows of tiny pits posteriorly and ridges and pits anteriorly paralleling margin; hinge gongylodont.

Dimensions.—Left valve: length, 0.59 mm; height, 0.38 mm.

Figured specimen.—USNM 316458.

Remarks.—This form may be distinguished from *Loxoconcha edentonensis* Swain, 1951, by its lack of strong ridges across the carapace.

Stratigraphic range.—Late Pleistocene.

Biofacies.—Rare in inner sublittoral biofacies.

Genus CYTHEROMORPHA Hirschmann, 1909

Cytheromorpha Hirschmann, 1909.

Type species.—*Cythere fuscata* Brady, 1869a.

Remarks.—This genus differs from *Leptocythere* Sars, 1922–28, in its gongylodont hinge and its unbranched pore canals.

Cytheromorpha curta Edwards, 1944

Plate 2, figure 4

Cytheromorpha curta Edwards, 1944, p. 516, pl. 86, figs. 19–22.

Description.—Carapace minute, short, and compressed in lateral view; dorsal and ventral margins straight; rounded anteriorly, bluntly rounded posteriorly; surface pitted; eye spot distinct; hinge has narrow bar and U-shaped teeth and sockets.

Dimensions.—Left valve: length, 0.32 mm; height, 0.21 mm.

Figured specimen.—USNM 316459.

Remarks.—This species is much shorter than both *Cytheromorpha fuscata* (Brady, 1869a) and *Cytheromorpha newportensis* Williams, 1966, and it lacks the strong sexual dimorphism of these two species.

Stratigraphic range.—Pliocene-late Pleistocene.

Biofacies.—Rare in inner sublittoral, oyster-bank, and open-sound biofacies.

Cytheromorpha newportensis Williams, 1966

Plate 2, figure 5

Cytheromorpha warneri newportensis Williams, 1966, p. 17, figs. 1, 6, 11a-c.

Cytheromorpha newportensis Williams. Cronin, 1979, p. 142, pl. 13, figs. 5–8.

Description.—Carapace subrectangular in lateral view; anterior and posterior rounded; ventral and dorsal margins subparallel and straight; sulcus indistinct; smooth, low anterior and anteroventral keel; surface reticulate, but has a small, smooth, subtriangular posteroventral area; hinge gongylodont.

Dimensions.—Right valve: length, 0.55 mm; height, 0.25 mm.

Figured specimen.—USNM 316460.

Remarks.—This species is distinguished from *Cytheromorpha warneri* Howe and Spurgeon, 1935 (*in* Howe and others, 1935), by its delicate reticulate network and sulcus. It is distinguished from *Cytheromorpha warneri okaloosaensis* Howe and Chambers, 1935, by its smooth posteroventral area.

Stratigraphic range.—Late Pleistocene-Holocene.

Biofacies.—Rare in inner sublittoral biofacies.

Modern occurrence.—Found off the Eastern United States between lat 27°09′54″ N. and lat 36°20′00″ N. (fig. 9) at 17–36 m depth.

Family LEPTOCYTHERIDAE Hanai, 1957
Genus LEPTOCYTHERE Sars, 1922–28

Leptocythere Sars, 1922–28.

Type species.—*Cythere pellucida* Baird, 1850.

Remarks.—This genus resembles *Cytheromorpha* Hirschmann, 1909, in shape and ornament but differs in its amphidont hinge and its branching pore canals.

Leptocythere nikraveshae Morales, 1966

Plate 2, figure 7

Leptocythere nikraveshae Morales, 1966, p. 62, pl. 5, figs. 2a, b.

Description.—Carapace elongate in lateral view; dorsal margin slightly arched, ventral margin concave centrally; anterior rounded, posterior bluntly rounded; subacute posterodorsally; surface finely reticulate along the margins, but becomes coarser centrally; one deep, central sulcus present; posteroventral depression distinct; inner lamella narrow; hinge amphidont.

Dimensions.—Left valve: length, 0.45 mm; height, 0.23 mm.

Figured specimen.—USNM 316462.

Remarks.—This species is distinguished by its small size, reticulate surface, single sulcus, and posteroventral depression.

Stratigraphic range.—Late Pleistocene-Holocene.

Biofacies.—Rare in inner sublittoral biofacies; common in backbarrier biofacies.

Modern occurrence.—Found in Laguna de Terminos, Campeche, Mexico.

Family HEMICYTHERIDAE Puri, 1953b
Subfamily CAMPYLOCYTHERINAE Puri, 1960
Genus CAMPYLOCYTHERE Edwards, 1944

Campylocythere Edwards, 1944.

Acuticythereis Edwards, 1944 (part).

Type species.—*Campylocythere laeva* Edwards, 1944.

Remarks.—Hazel (1967, p. 26) places this genus in the Hemicytheridae instead of the Leguminocythereididae because of the presence of two frontal scars, its sieve-type normal pores, and its shape. Malkin (1953, p. 784) and Swain (1955, p. 636) regard *Acuticythereis* Edwards, 1944, as a synonym of *Campylocythere* Edwards, 1944. However, Plusquellec and Sandberg (1969, p. 445) consider only part of the original description of *Acuticythereis* to be in synonymy with *Campylocythere* and, therefore, uphold *Acuticythereis* as a valid genus.

Campylocythere laeva Edwards, 1944

Plate 2, figure 6

Campylocythere laeva Edwards, 1944, p. 515, pl. 86, figs. 8–14.

Campylocythere laeva posteropunctata Edwards, 1944, p. 515, pl. 86, figs. 15, 16 (see also Plusquellec and Sandberg, 1969, p. 443).

Description.—Carapace elongate in lateral view; dorsal margin slightly arched, ventral margin straight; anterior rounded, posterior bluntly rounded in males and rounded in females; surface smooth to pitted and containing numerous normal pores; inner lamella well developed; anterior vestibule deep; hinge holamphidont.

Dimensions.—Right valve: length, 0.73 mm; height, 0.31 mm.

Figured specimen.—USNM 316461.

Stratigraphic range.—Late Miocene-Holocene.

Biofacies.—Rare in inner sublittoral biofacies.

Modern occurrence.—Found off the Eastern United States between lat 32°59′00″ N. and lat 41°55′00″ N. (fig. 10) at 9–181 m depth. Restricted to sand substrates (Hulings and Puri, 1964, p. 321).

Genus PROTEOCONCHA Plusquellec and Sandberg, 1969

Proteoconcha Plusquellec and Sandberg, 1969.

Type species.—*Proteoconcha nelsonensis* (Grossman, 1967).

Remarks.—*Proteoconcha* Plusquellec and Sandberg, 1969, is very similar to *Acuticythereis* Edwards sensu stricto, 1944, and *Campylocythere* Edwards, 1944. All three genera exhibit an amphidont hinge and four paral-

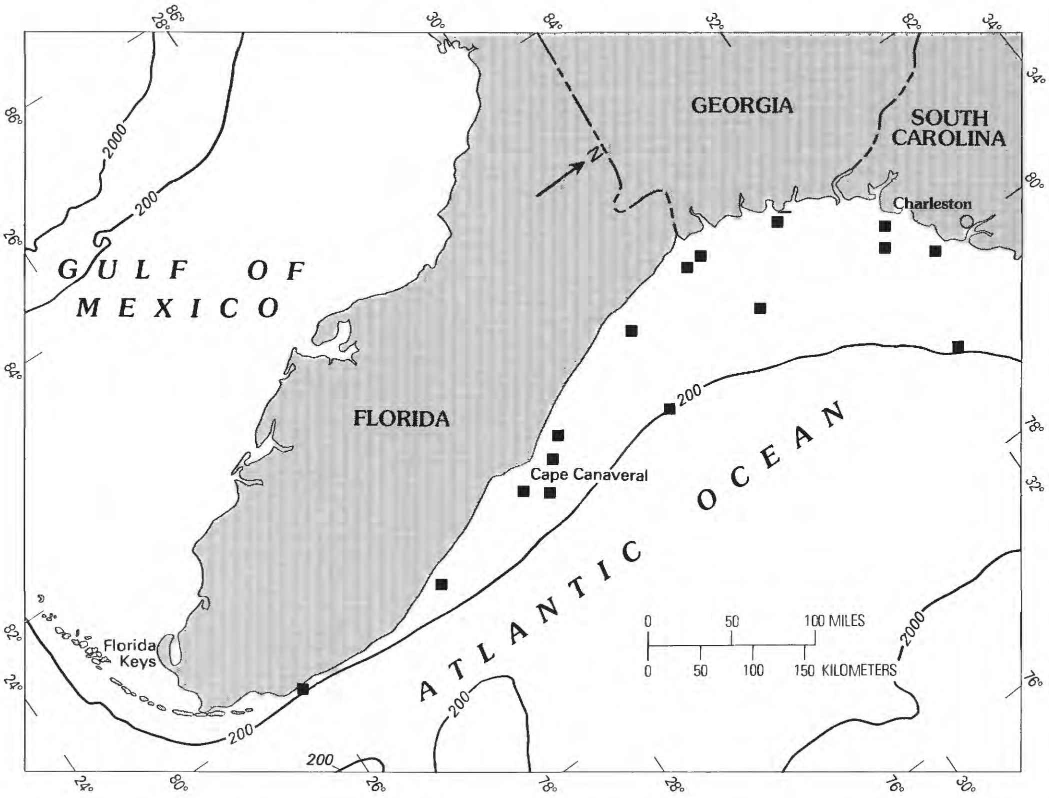


FIGURE 10.—Distribution of *Campylocythere laeva* Edwards, 1944 (solid squares). This species (pl. 2, fig. 6) occurs in the Holocene study area on the shallow and deep continental shelf between Charleston, S.C., and southern Florida. Depth contours are in meters.

lel, elongate adductor scars. *Proteoconcha* may be smooth, pitted, or reticulate, and it displays pronounced sexual dimorphism, the males being lower, less broad, and more pointed posteriorly. Its inner lamella is not as wide as that of *Acuticythereis* and *Campylocythere*. *Proteoconcha* has half as many normal pore canals as *Acuticythereis*, although they are scattered over the entire carapace. In contrast, *Acuticythereis* is smooth to finely pitted and has the greatest number of normal pore canals. It has a wider fused zone than *Campylocythere* and also displays sexual dimorphism, as does *Proteoconcha*. *Campylocythere* is smooth to finely pitted and possesses the fewest number of normal pores, which have a relatively large diameter. Plusquellec and Sandberg (1969, p. 427–480) discuss these genera further.

Proteoconcha gigantica (Edwards, 1944)

Plate 3, figures 1, 2

Basslerites giganticus Edwards, 1944, p. 521, pl. 87, figs. 19–23.
Proteoconcha gigantica (Edwards). Plusquellec and Sandberg, 1969, p. 455, pl. 4, figs. 1, 2, pl. 5, fig. 3, pl. 7, figs. 2, 3, 8, pl. 10, fig. 32, text figs. 2c, 3f, 4, 10.

Description.—Carapace large and elongate to subquadrate in lateral view; dorsal margin nearly straight and slightly arched anteriorly, ventral margin nearly straight; anterior obliquely rounded, posterior margin rounded or slightly pointed in right valve and rounded in left valve; left valve larger than right valve; females more bulbous than males; surface smooth, but has minute pits restricted to ventral margin in some specimens and covering carapace in others; anterior vestibule wide; hinge holamphidont.

Dimensions.—Left valve: length, 0.80 mm; height, 0.38 mm; right valve: length, 0.74 mm; height, 0.37 mm.

Figured specimens.—USNM 316450, USNM 316451.

Remarks.—This species may be distinguished from *Proteoconcha mimica* Plusquellec and Sandberg, 1969, by its minute pits and its larger size. It differs from *Proteoconcha redbayensis* (Puri, 1953c), as *Proteoconcha gigantica* is larger and also has a wider anterior vestibule.

Stratigraphic range.—Middle Miocene-Holocene.

Biofacies.—Common to rare in inner sublittoral biofacies; rare in oyster-bank and open-sound biofacies.

Modern occurrence.—Found off the Eastern United States between lat 28°29′30″ N. and lat 39°21′00″ N. (fig. 11) at 9–24 m depth.

Proteoconcha tuberculata (Puri, 1960)

Plate 3, figures 3, 4

Acuticythereis tuberculata Puri, 1960, p. 129, text figs. 16, 17.

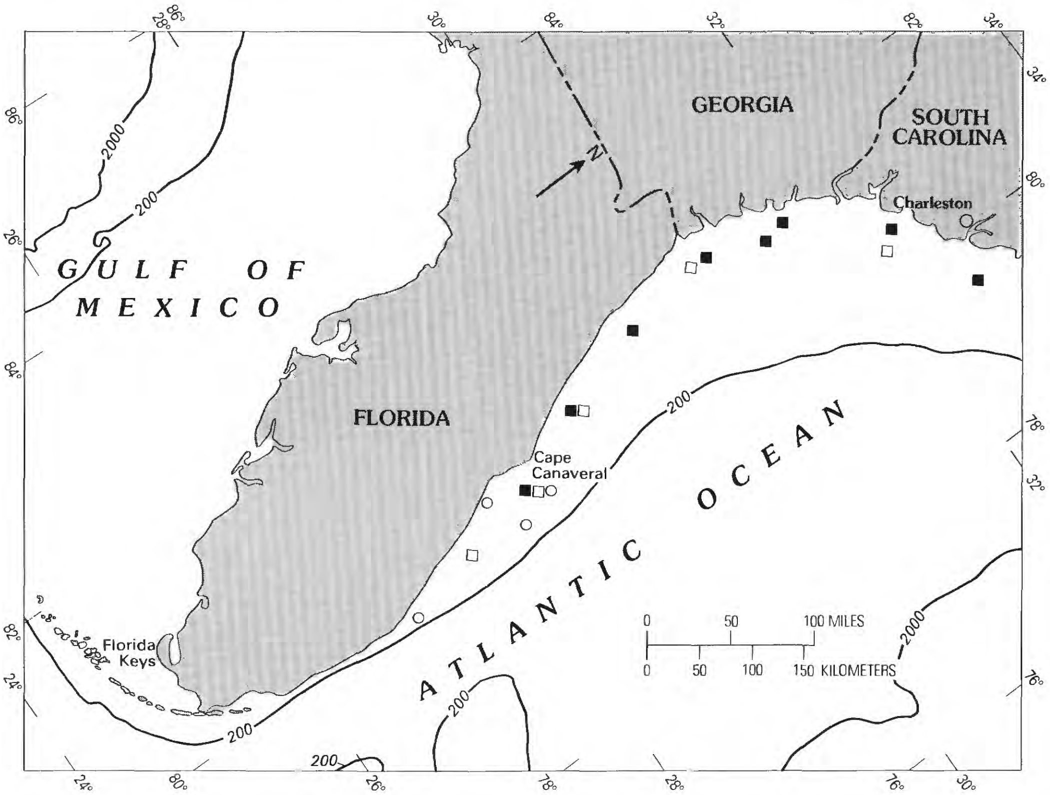


FIGURE 11.—Distribution of *Proteoconcha gigantica* (Edwards, 1944) (solid squares), *Proteoconcha tuberculata* (Puri, 1960) (open squares), and *Proteoconcha nelsonensis* (Grossman, 1967) (open circles). In the Holocene study area, *P. gigantica* (pl. 3, figs. 1, 2) and *P. tuberculata* (pl. 3, figs. 3, 4) occur on the shallow continental shelf between South Carolina and central Florida, and *P. nelsonensis* (pl. 3, figs. 5–7) occurs on the shallow continental shelf off central Florida. Depth contours are in meters.

Proteoconcha tuberculata (Puri). Plusquellec and Sandberg, 1969, p. 464, pl. 3, figs. 7–10, pl. 5, fig. 10, pl. 7, figs. 9, 10, pl. 8, fig. 12, pl. 10, figs. 2a-f, text figs. 2j, k, 4, 14.

Description.—Carapace elongate in lateral view; dorsal margin highest one-third back from anterior, sloped posteriorly, ventral margin slightly concave centrally; anterior rounded, posterior subtriangular; females more inflated than males; surface smooth or has minute pits; inner lamella well developed; anterior vestibule wide; hinge holamphidont.

Dimensions.—Left valve: length, 0.61 mm; height, 0.29 mm; right valve: length, 0.62 mm; height, 0.27 mm.

Figured specimens.—USNM 316452, USNM 316453.

Remarks.—The specimens in this study lack the short, clear tubercles that Puri's (1960) specimens exhibit. However, Plusquellec and Sandberg (1969, p. 468) note that the tubercles are a weathering phenomenon observed in numerous species. This species may be distinguished from *Proteoconcha gigantica* (Edwards, 1944) by its smaller size and more elongate carapace. It differs from *Proteoconcha multipunctata* (Edwards, 1944) and from *Proteoconcha concinnoidea* (Swain, 1955) in its lack of reticulation. *Proteoconcha edwardsi* Plusquellec and Sandberg, 1969, is smaller than this species and has a subdued diamond-shaped ornamentation as well.

Stratigraphic range.—Late Miocene-Holocene.

Biofacies.—Common in open-sound biofacies; common to rare in inner sublittoral biofacies; rare in oyster-bank biofacies.

Modern occurrence.—Found off the Eastern United States between lat 27°49′30″ N. and lat 38°50′00″ N. (fig. 11) at 12–24 m depth.

Proteoconcha nelsonensis (Grossman, 1967)

Plate 3, figures 5–7

Acuticythereis nelsonensis Grossman, 1967, p. 72, pl. 12, fig. 4, pl. 17, figs. 6, 8, 9.

Proteoconcha proteus Plusquellec and Sandberg, 1969, p. 450, pl. 1, figs. 1–18, pl. 3, figs. 5, 6, pl. 5, fig. 4, pl. 6, figs. 1–7, 17–19, pl. 7, fig. 7, pl. 8, figs. 1, 3, 4, 6, 9, 11, pl. 10, figs. 1a-h, text figs. 1, 2l, m, 4, 7 (see also Hazel, 1983).

Proteoconcha nelsonensis (Grossman). Valentine, 1971, p. D20, pl. 4, figs. 50, 55.

Description.—Carapace ovate, elongate in lateral view; dorsal margin slightly arched, ventral margin straight in left valves and slightly concave in right valves; anterior obliquely rounded, posterior more sharply rounded; ornamentation highly variable, ranging from smooth to finely or coarsely pitted only in the posterior region to finely or coarsely pitted overall to reticulate overall; inner lamella wide and mostly fused; hinge holamphidont.

Dimensions.—Left valve: length, 0.51 mm; height, 0.27 mm.

Figured specimens.—USNM 316454, USNM 316455, USNM 316506.

Remarks.—*Proteoconcha nelsonensis* may be distinguished from *Proteoconcha multipunctata* (Edwards, 1944) by its smaller, shorter carapace and its more rounded posterior margin. *Proteoconcha nelsonensis* is smaller than *Proteoconcha tuberculata* (Puri, 1960), its valves are less elongate, and its radial pore canals are distributed unevenly.

Stratigraphic range.—Late Miocene-Holocene.

Biofacies.—Rare in inner sublittoral biofacies.

Modern occurrence.—Found in the Gulf of Mexico from Texas to Florida and along the Atlantic Coast north to Delaware (fig. 11) at 12–36 m depth. Rare to common in lower bay biofacies of Texas bays (Garbett and Maddocks, 1979, p. 914).

Genus BENSONOCYTHERE Hazel, 1967

Bensonocythere Hazel, 1967.

Type species.—*Leguminocythereis whitei* Swain, 1951.

Remarks.—This genus differs from *Leguminocythereis* Howe and Law, 1936, in its more quadrate shape and its weakly developed hinge. It differs from *Triginglymus* Blake, 1950, in its weaker hinge and lack of an ocular sinus.

Bensonocythere whitei (Swain, 1951)

Plate 4, figure 1

Leguminocythereis whitei Swain, 1951, p. 43, pl. 3, figs. 14, 16–18, pl. 4, fig. 1.

Triginglymus whitei (Swain). Pooser, 1965, p. 36, pl. 15, figs. 2, 5, 6, 8, 9.

Bensonocythere whitei (Swain). Hazel, 1967, p. 27, pl. 5, figs. 2, 3, 8–10, pl. 10, figs. 1–8, pl. 11, figs. 1, 2.

Description.—Carapace quadrate in lateral view; dorsal margin nearly straight, ventral margin slightly sinuous; anterior and posterior margins rounded; sexual dimorphism strong, females being larger and more quadrate; two ridges surround free margin and form a deep anterior furrow; surface coarsely reticulate with extremely deep pits; inner lamella wide; hinge modified lophodont.

Dimensions.—For female, right valve: length, 0.65 mm; height, 0.36 mm.

Figured specimen.—USNM 316478.

Remarks.—This species differs from *Bensonocythere sapeloensis* (Hall, 1965) and *Bensonocythere americana* Hazel, 1967, in its deep reticulation and deep anterior furrow.

Stratigraphic range.—Early Pleistocene-Holocene.

Biofacies.—Rare in inner sublittoral biofacies.

Modern occurrence.—Found off the Eastern United States between lat 27°09′54″ N. and lat 36°09′00″ N. (fig. 12) at 12–181 m depth.

Bensonocythere sapeloensis (Hall, 1965)

Plate 4, figures 2, 3

Triginglymus sapeloensis Hall, 1965, p. 37, pl. 9, figs. 20–27.

Bensonocythere sapeloensis (Hall). Valentine, 1971, p. D19, pl. 1, figs. 1, 6, 11, 12.

Description.—Carapace elongate in lateral view; dorsal and ventral margins straight; anterior rounded, but has blunt marginal spines, posterior sloped dorsally and rounded to slightly denticulate below; surface ornamented by large, shallow pits; small, smooth subcentral area; anterior ridge and the ridge slightly behind the center are particularly prominent; inner lamella wide, lacking vestibules; hinge lophodont.

Dimensions.—For male, right valve: length, 0.52 mm; height, 0.24 mm; for female, right valve: length, 0.58 mm; height, 0.29 mm.

Figured specimens.—USNM 316479, USNM 316480.

Remarks.—This species may be distinguished from *Bensonocythere whitei* (Swain, 1951) by its shallower ridge and pit pattern and its smaller size. It differs from *Bensonocythere americana* Hazel, 1967, by its elongate shape and lack of vestibules.

Stratigraphic range.—Late Pleistocene-Holocene.

Biofacies.—Rare in inner sublittoral and oyster-bank biofacies.

Modern occurrence.—Found off the East Coast of the United States between lat 31°25′00″ N. and lat 35°29′00″ N.

Bensonocythere valentinei Cronin, this volume

Plate 4, figures 4, 5

Bensonocythere cf. *B. sapeloensis* (Hall, 1965). Valentine, 1971, p. D19, pl. 1, figs. 28, 29.

Bensonocythere sp. B, Cronin, 1979, p. 149, pl. 18, fig. 5.

Bensonocythere sp. D, Cronin and Hazel, 1980, p. B16, fig. 5f.

Bensonocythere valentinei Cronin, this volume, p. C39, pl. 16, figs. 7, 8.

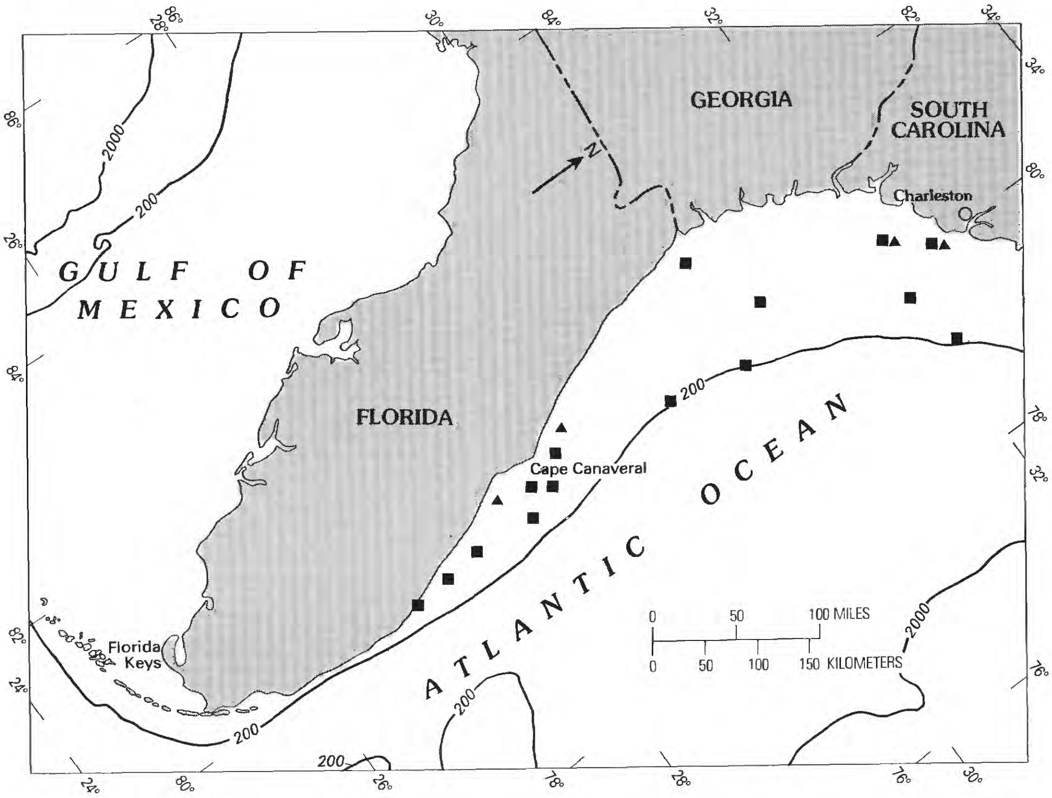


FIGURE 12.—Distribution of *Bensonocythere whitei* (Swain, 1951) (solid squares) and *Bensonocythere hazeli* Cronin, this volume (solid triangles). In the Holocene study area, *B. whitei* (pl. 4, fig. 1) occurs on the shallow to deep continental shelf between Charleston, S.C., and central Florida, and *B. hazeli* (pl. 4, figs. 6, 7) occurs on the shallow continental shelf off South Carolina and central Florida. Depth contours are in meters.

Description.—Carapace subquadrate in lateral view; dorsal and ventral margins straight; anterior obliquely rounded, posterior rounded in females and obliquely rounded in males; sexual dimorphism strong, females being wider and more quadrate; surface ornamented by large, shallow, circular pits and thick ridges; deep furrow of connected pits parallels posterior margin; central area smooth; inner lamella wide with small anterior vestibule.

Dimensions.—For male, left valve: length, 0.51 mm; height, 0.25 mm; for female, left valve: length, 0.55 mm; height, 0.29 mm.

Figured specimens.—USNM 316481, USNM 316482.

Remarks.—This form may be distinguished from *Bensonocythere americana* Hazel, 1967, by its larger, more circular pits and its deep furrow along the posterior margin.

Stratigraphic range.—Middle Pleistocene-Holocene.

Biofacies.—Rare in inner sublittoral biofacies.

Modern occurrence.—Found off the East Coast of the United States between lat 32°59′00″ N. and lat 36°20′00″ N.

Bensonocythere hazeli Cronin, this volume

Plate 4, figures 6, 7

Bensonocythere sp. E, Valentine, 1971, p. D19, pl. 1, figs. 4, 9, 15, 20.
Bensonocythere sp. A, Cronin, 1979, p. 148, pl. 18, fig. 3.
Bensonocythere sp. C, Cronin and Hazel, 1980, p. B17, fig. 5e.
Bensonocythere hazeli Cronin, this volume, p. C39, pl. 16, figs. 5, 6.

Description.—Carapace large, subquadrate to elongate in lateral view; dorsal and ventral margins straight; anterior obliquely rounded, posterior rounded in females and sloped dorsally and rounded below in males; sexual dimorphism strong, females being larger and more quadrate; surface ornamented by deep pits and strong, narrow, mostly vertical ridges; two ridges parallel posterior margin, creating deep furrow; two strong posterodorsal ridges form characteristic slanted furrow; small subcentral region smooth; inner lamella wide anteriorly with narrow vestibule; hinge lophodont.

Dimensions.—For male, right valve: length, 0.55 mm; height, 0.24 mm; for female, left valve: length, 0.55 mm; height, 0.30 mm.

Figured specimens.—USNM 316483, USNM 316484.

Remarks.—This form may be distinguished from *Bensonocythere rugosa* Hazel, 1983, by its straighter dorsal margin and thinner ribbing.

Stratigraphic range.—Late Pleistocene-Holocene.

Biofacies.—Rare in inner sublittoral and open-sound biofacies.

Modern occurrence.—Found off the East Coast of the United States between lat 28°10′18″ N. and lat 36°20′00″ N. (fig. 12) at 15–19 m depth.

Subfamily HEMICYTHERINAE Puri, 1953b

Genus MALZELLA Hazel, 1983

Malzella Hazel, 1983.

Type species.—*Malzella evexa* Hazel, 1983.

Remarks.—This genus differs from *Aurila* Pokorny, 1955, by its more ribbed and coarsely pitted surface. *Malzella* consistently exhibits a denticulate caudal process, which is variable in *Aurila*.

Malzella evexa Hazel, 1983

Plate 5, figure 1

Malzella evexa Hazel nomen nudum. Hazel, 1977, figs. 3, 6d, table 1.
Malzella evexa Hazel nomen nudum. Cronin and Hazel, 1980, fig. 4g.
Malzella evexa Hazel, 1983, p. 105, pl. 14, fig. 3, pl. 15, figs. 1–3, 5.

Description.—Carapace almond shaped in lateral view; dorsal margin arched, ventral margin rounded; anterior rounded, posterior pointed; surface coarsely reticulate, having high ridges and large, circular to elliptical pits that coalesce in places; strong ridge parallels the periphery of the carapace; eye tubercle prominent; hinge holamphidont.

Dimensions.—Right valve: length, 0.55 mm; height, 0.35 mm.

Figured specimen.—USNM 316464.

Remarks.—Only juveniles were found. This form may be distinguished from *Malzella floridana* (Benson and Coleman, 1963) by its lack of a strong ventrolateral keel. Hazel (1983, p. 105) lists a complete synonymy for this species.

Stratigraphic range.—Pliocene-late Pleistocene.

Biofacies.—Rare in inner sublittoral biofacies.

Genus AURILA Pokorny, 1955

Aurila Pokorny, 1955.

Type species.—*Aurila punctata* (Munster, 1830).

Remarks.—This genus is characterized by its rounded caudal process and its shallow surface pitting.

Aurila laevicula (Edwards, 1944)

Plate 5, figure 2

Hemicythere laevicula Edwards, 1944, p. 518, pl. 86, figs. 27–30.
Aurila laevicula (Edwards). Hazel, 1967, p. 23.

Description.—Carapace small and almond shaped in lateral view; dorsal margin arched, ventral margin concave one-third distance back from anterior; anterior rounded; posterior of right valve concave above middle and pointed below; posterior of left valve blunt; surface finely pitted centrally, becoming medium reticulate around margins; hinge holamphidont.

Dimensions.—Right valve: length, 0.52 mm; height, 0.30 mm.

Figured specimen.—USNM 316465.

Remarks.—This species may be distinguished from *Aurila amygdala* (Stephenson, 1944) by its finer surface pitting and its more elongate shape.

Stratigraphic range.—Pliocene-Holocene.

Biofacies.—Rare in inner sublittoral biofacies.

Modern occurrence.—Found off the Eastern United States between lat 24°25′06″ N. and lat 35°09′00″ N. (fig. 13) at 17–307 m depth.

Genus MUELLERINA Bassiouni, 1965

Muellerina Bassiouni, 1965.

Type species.—*Cythere latimarginata* Speyer, 1863.

Remarks.—This genus resembles *Urocythereis* Ruggieri, 1950, in its shape and hingement but differs in its finer ornament and its smaller carapace, which is less produced posteroventrally. Also, *Muellerina* displays two frontal muscle scars, whereas *Urocythereis* displays three.

Muellerina ohmerti Hazel, 1983

Plate 2, figure 8

Muellerina ohmerti Hazel, 1983, p. 107, pl. 16, fig. 3; Cronin, 1979, p. 147, pl. 17, fig. 3.

Description.—Carapace subquadrate in lateral view; dorsal margin sloped posteriorly, highest just in front of center, ventral margin nearly straight; anterior rounded, posterior rounded dorsally and denticulate below; surface reticulate; strong ridges parallel anterior, causing deep furrow; eye spot distinct, subcentral tubercle large; normal pores scattered over carapace; hinge modified amphidont.

Dimensions.—Left valve: length, 0.53 mm; height, 0.25 mm.

Figured specimen.—USNM 316463.

Remarks.—This form differs from *Muellerina lienenklausi* (Ulrich and Bassler, 1904) in its lack of two prominent posterior ridges.

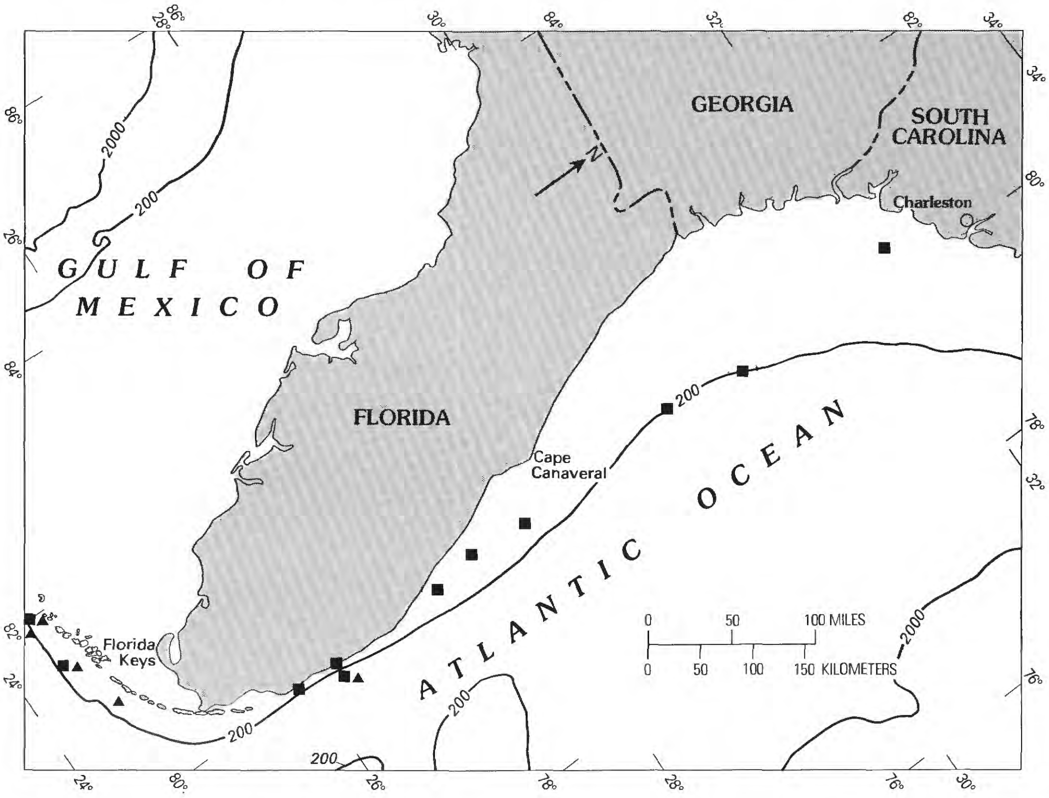


FIGURE 13.—Distribution of *Aurila laevicula* (Edwards, 1944) (solid squares) and *Muellerina ohmerti* Hazel, 1983 (solid triangles). In the Holocene study area, *A. laevicula* (pl. 5, fig. 2) occurs on the shallow and deep continental shelf and on the continental slope between South Carolina and the Florida Keys, and *M. ohmerti* (pl. 2, fig. 8) occurs on the deep continental shelf and continental slope off southern Florida and the Florida Keys. Depth contours are in meters.

Stratigraphic range.—Late Pleistocene-Holocene.

Biofacies.—Rare in inner sublittoral and open-sound biofacies.

Modern occurrence.—Found off the Eastern United States between lat 24°20′06″ N. and lat 44°41′00″ N. (fig. 13) at 74–307 m depth.

Family TRACHYLEBERIDIDAE Sylvester-Bradley, 1948
Subfamily TRACHYLEBERIDINAE Sylvester-Bradley, 1948
Genus PURIANA Coryell and Fields, 1937

Favella Coryell and Fields, 1937, preoccupied by *Favella* Jorgensen, 1925 (Protozoa).

Puriana Coryell and Fields, *in* Puri, 1953a.

Type species.—*Favella puella* Coryell and Fields, 1937.

Remarks.—The type species of this genus may be synonymous with *Puriana rugipunctata* (Ulrich and Bassler, 1904).

Puriana carolinensis Hazel, 1983

Plate 5, figure 4

Puriana carolinensis Hazel nomen nudum. Hazel, 1977, p. 376, figs. 3, 8b.

Puriana carolinensis Hazel nomen nudum. Cronin and Hazel, 1980, p. B15, fig. 4b.

Puriana carolinensis Hazel, 1983, p. 111–112, pl. 27, figs. 1, 3, 4.

Description.—Carapace subquadrate in lateral view; dorsal margin straight, ventral margin slightly concave; anterior rounded, posterior rounded above and denticulate below; surface nearly smooth, but has a few rounded pits; ridge parallels anterior margin; median groove present; posterior slightly inflated; inner lamella wide; hinge modified lophodont.

Dimensions.—Left valve: length, 0.53 mm; height, 0.27 mm.

Figured specimen.—USNM 316477.

Remarks.—This form represents a cool-water morphotype of *Puriana carolinensis* Hazel, 1983.

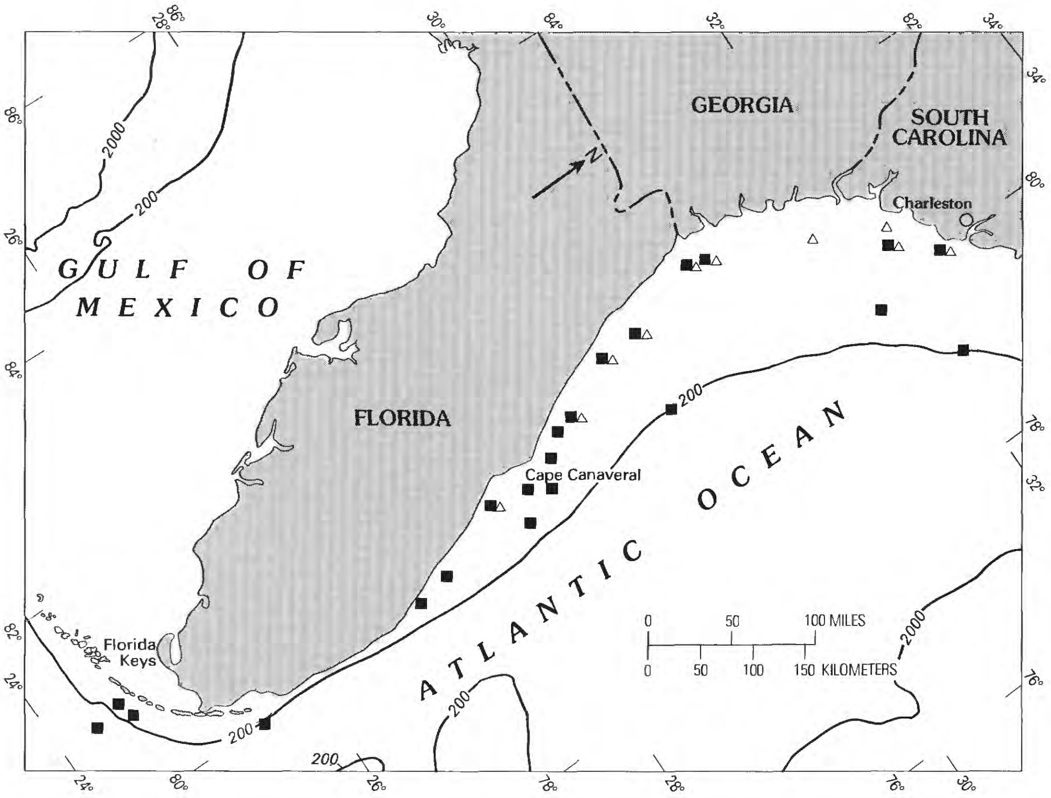


FIGURE 14.—Distribution of *Puriana carolinensis* Hazel, 1983 (open triangles), and *Puriana floridana* Puri, 1960 (solid squares). In the Holocene study area, *P. carolinensis* (pl. 5, fig. 4) occurs on the shallow continental shelf between South Carolina and central Florida, and *P. floridana* (pl. 5, fig. 3) occurs on the shallow and deep continental shelf and continental slope between Charleston, S.C., and the Florida Keys. Depth contours are in meters.

Stratigraphic range.—Pliocene-Holocene.

Biofacies.—Rare in inner sublittoral biofacies.

Modern occurrence.—Found off the Eastern United States between lat 28°10′18″ N. and lat 35°20′00″ N. (fig. 14) at 11–24 m depth.

Puriana floridana Puri, 1960

Plate 5, figure 3

Puriana floridana Puri, 1960, p. 127, pl. 1, figs. 7, 8, text figs. 20, 21.

Description.—Carapace subquadrate in lateral view; dorsal margin straight, ventral margin nearly straight; anterior rounded, posterior coarsely denticulate; surface tuberculate; tubercles arranged in a T-shaped ridge; ventral ridge well developed; inner lamella wide; radial pore canals numerous; hinge holamphidont.

Dimensions.—Right valve: length, 0.61 mm; height, 0.31 mm.

Figured specimen.—USNM 316476.

Remarks.—This species may be distinguished from *Puriana rugipunctata* (Ulrich and Bassler, 1904) and *Puriana convoluta* Teeter, 1975, by its lack of convoluted ridges along the posterodorsal margin. After this paper was completed, this species was recognized as an extant morphotype of *Puriana mesacostalis* (Edwards, 1944) (Cronin, 1987). Therefore, the modern occurrence map includes both this species and the more spinose *Puriana floridana.*

Stratigraphic range.—Pliocene-Holocene.

Biofacies.—Rare in inner sublittoral, open-sound, and oyster-bank biofacies.

Modern occurrence.—Found off the East Coast of the United States between lat 24°24′18″ N. and lat 37°05′00″ N. (fig. 14) at 12–216 m depth.

Genus ECHINOCYTHEREIS Puri, 1953c

Echinocythereis Puri, 1953c.

Type species.—*Cythereis garretti* Howe and McGuirt, 1935, *in* Howe and others, 1935.

Remarks.—This genus is similar to *Henryhowella* Puri, 1957, but differs in that it lacks a V-shaped frontal scar and the broad longitudinal plications that are in the posterior of the latter.

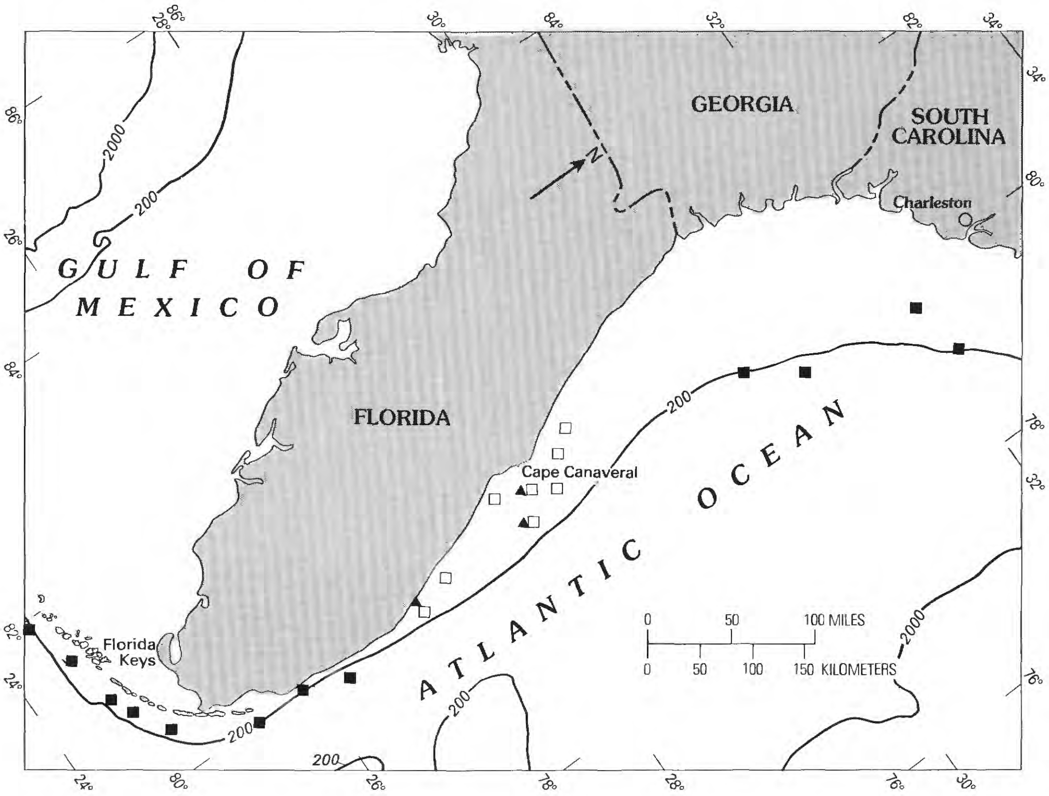


FIGURE 15.—Distribution of *Echinocythereis* sp. (solid squares), *Neocaudites atlantica* Cronin, 1979 (solid triangles), and *Actinocythereis captionis* Hazel, 1983 (open squares). In the Holocene study area, *E.* sp. (pl. 5, fig. 5) occurs on the deep continental shelf and continental slope between Charleston, S.C., and the Florida Keys, and *N. atlantica* (pl. 5, fig. 6) and *A. captionis* (pl. 6, fig. 1) occur on the shallow continental shelf off central Florida. Depth contours are in meters.

Echinocythereis sp.

Plate 5, figure 5

?*Echinocythereis* sp. A, Cronin, 1979, p. 147, pl. 17, fig. 10.
?*Echinocythereis leecreekensis* Hazel, 1983, p. 106, pl. 36, figs. 1–3, pl. 38, fig. 3.

Description.—Carapace subtriangular in lateral view; dorsal and ventral margins straight, forming an obtuse angle; anterior and posterior rounded; surface covered by rounded tubercles arranged vaguely in rows; margins spinose; hinge amphidont.

Dimensions.—Left valve, juvenile: length, 0.48 mm; height, 0.32 mm.

Figured specimen.—USNM 316475.

Remarks.—Only juveniles of this form were found.

Stratigraphic range.—Middle Pleistocene-Holocene.

Biofacies.—Rare in inner sublittoral biofacies.

Modern occurrence.—Found off the Eastern United States between lat 24°29′18″ N. and lat 39°09′42″ N. (fig. 15) at 35–347 m depth.

Genus NEOCAUDITES Puri, 1960

Neocaudites Puri, 1960.

Type species.—*Neocaudites nevianii* Puri, 1960.

Remarks.—This genus may be distinguished from *Caudites* Coryell and Fields, 1937, by its thin shell and elongate shape. In contrast, the carapace in *Caudites* also shows an anterior thickened rim and additional longitudinal and dorsal ridges (Puri, 1960, p. 127).

Neocaudites atlantica Cronin, 1979

Plate 5, figure 6

Neocaudites atlantica Cronin, 1979, p. 147, pl. 16, figs. 4–7.

Description.—Carapace large and subrectangular in lateral view; dorsal margin nearly straight, but has a small hinge ear, ventral margin straight; anterior rounded and denticulate, posterior subrounded and denticulate posteroventrally; surface ornamented by three strong longitudinal ridges (median, ventral, and dorsal) and pits flanking the ridges; the median and dorsal ridges converge posteriorly; hinge holamphidont.

Dimensions.—Right valve: length, 0.67 mm; height, 0.34 mm.

Figured specimen.—USNM 316474.

Remarks.—This species differs from *Neocaudites nevianii* Puri, 1960, in lacking anterior convergence of the median and ventral ridges and in the presence of pits. It differs from *Neocaudites triplistriatus* (Edwards, 1944) in the presence of pits and its much larger size.

Stratigraphic range.—Middle Pleistocene-Holocene.

Biofacies.—Common to rare in oyster-bank biofacies; rare in inner sublittoral biofacies.

Modern occurrence.—Found off the Eastern United States between lat 27°09′54″ N. and lat 33°41′00″ N. (fig. 15) at 12–36 m depth.

Genus ACTINOCYTHEREIS Puri, 1953b

Actinocythereis Puri, 1953b.

Type species.—*Cythere exanthemata* Ulrich and Bassler, 1904.

Remarks.—The ridged ornamentation of this genus resembles that of *Costa* Neviani, 1928, but differs in that the ridges of this genus are broken up into spines.

Actinocythereis captionis Hazel, 1983

Plate 6, figure 1

Actinocythereis captionis Hazel nomen nudum. Hazel, 1977, figs. 3, 8c, table 1.
Actinocythereis sp. A, Cronin, 1979, p. 146, pl. 16, figs. 1, 2.
Actinocythereis captionis Hazel nomen nudum. Cronin and Hazel, 1980, figs. 6g, h.
Actinocythereis captionis Hazel, 1983, p. 103, pl. 8, figs. 1, 2, 4.

Description.—Carapace large and subrectangular in lateral view; dorsal and ventral margins straight and coarsely denticulate; anterior and posterior margins rounded, having robust but less coarse denticules than those on the dorsal and ventral margins; surface has three longitudinal ridges broken into spines and a short vertical posterodorsal ridge of five spines; anterodorsal ridge smooth; subcentral tubercle of well-defined spines; large hyaline eye tubercle; smooth ridge extends from eye tubercle and parallels anterior margin; hinge holamphidont.

Dimensions.—Right valve: length, 0.63 mm; height, 0.33 mm.

Figured specimen.—USNM 316471.

Remarks.—This species may be distinguished from *Actinocythereis gomillionensis* (Howe and Ellis, 1935) (*in* Howe and others, 1935) by its lack of fine pustules between the spines and its smooth anterodorsal ridge. It differs from *Actinocythereis vandenboldi* Kontrovitz, 1976, and *Actinocythereis triangularis* Morales, 1966, in its subrectangular shape.

Stratigraphic range.—Pliocene-Holocene.

Biofacies.—Rare in inner sublittoral biofacies.

Modern occurrence.—Found off the East Coast of the United States between Cape Cod and Florida (Hazel, 1983) (fig. 15).

Family CYTHERETTIDAE Triebel, 1952
Genus PROTOCYTHERETTA Puri, 1958b

Paracytheretta Puri, 1952; Swain, 1955.
Protocytheretta Puri, 1958b.

Type species.—*Cythere danaiana* Brady, 1869b.

Remarks.—*Protocytheretta* Puri, 1958b, may be distinguished from *Cytheretta* Müller, 1894, by its three longitudinal surface ribs. *Paracytheretta* Triebel, 1941, displays a rounded posterior process that is lacking in other Cytherettidae. *Paracytheretta* possesses a paramphidont hinge, whereas that in *Protocytheretta* is holamphidont. See Puri (1958b, p. 183–189) for a complete discussion of these genera.

Protocytheretta cf. P. sahnii (Puri, 1952)

Plate 6, figure 2

Protocytheretta cf. *P. sahnii* (Puri). Valentine, 1971, p. D20, pl. 2, figs. 43, 47.

Description.—Carapace large and elongate, ovate in lateral view; valves thick; left valve strongly overlaps right valve; dorsal margin straight, ventral margin concave centrally; anterior rounded, posterior acutely rounded; distinct notch on either side of dorsal margin; surface ornamented by three strong longitudinal ridges having depressions between them; ventral surface covered by slender longitudinal ribs; inner lamella very wide; hinge holamphidont.

Dimensions.—Right valve: length, 0.98 mm; height, 0.55 mm.

Figured specimen.—USNM 316473.

Remarks.—This form may be distinguished from *Protocytheretta karlana* (Howe and Pyeatt, 1935) (*in* Howe and others, 1935) and from *Protocytheretta daniana* (Brady, 1869b) by its lack of reticulation. This form is distinguished from *Protocytheretta sahnii* (Puri, 1952) by its dorsal longitudinal ridge, which disappears posteriorly rather than bending sharply downward as in the holotype.

Stratigraphic range.—Late Pleistocene-Holocene.

Biofacies.—Common to rare in inner sublittoral biofacies.

Modern occurrence.—Found off the East Coast of the United States in the Virginian and Carolinian faunal provinces.

Family PARADOXOSTOMATIDAE Brady and Norman, 1889

Subfamily PARADOXOSTOMATINAE Brady and Norman, 1889

Genus PARADOXOSTOMA Fischer, 1855

Paradoxostoma Fischer, 1855.

Type species.—*Paradoxostoma dispar* Fischer, 1855.

Remarks.—This genus is characterized by a blunt caudal process, lophodont hinge, and three or four adductor muscle scars.

Paradoxostoma delicata Puri, 1953c

Plate 6, figure 3

Paradoxostoma(?) *delicata* Puri, 1953c, p. 288, pl. 15, fig. 3, text fig. 12f.

Paradoxostoma delicata Puri. Valentine, 1971, p. D20, pl. 4, fig. 4.

Description.—Carapace small and subtriangular in lateral view; dorsal margin slopes downward anteriorly, ventral margin sinuous and concave anteroventrally; anterior produced, posterior broadly rounded; surface smooth, containing a few small normal pores; inner lamella wide, having numerous marginal pore canals; hinge lophodont.

Dimensions.—Right valve: length, 0.42 mm; height, 0.20 mm.

Figured specimen.—USNM 316466.

Remarks.—This species may be distinguished from *Paradoxostoma robusta* Puri, 1953c, and *Paradoxostoma elongata* Puri, 1953c, by its small size and its compact shape.

Stratigraphic range.—Late Pleistocene-Holocene.

Biofacies.—Rare in inner sublittoral biofacies and in backbarrier biofacies.

Modern occurrence.—Found off the East Coast of the United States between lat 32°59′00″ N. and lat 39°09′00″ N.

Paradoxostoma sp.

Plate 6, figure 4

Paradoxostoma sp. A, Cronin, 1979, p. 149, pl. 6, fig. 6.

Description.—Carapace subtriangular in lateral view; dorsal margin arched, ventral margin concave just forward of center; anterior produced and rounded, posterior obliquely rounded; surface smooth, but containing scattered, minute normal pores; inner lamella wide, having a well-developed anterior vestibule; hinge lophodont.

Dimensions.—Left valve: length, 0.64 mm; height, 0.29 mm.

Figured specimen.—USNM 316467.

Remarks.—This form may be distinguished from *Paradoxostoma delicata* Puri, 1953c (see above), by its more elongate shape. It differs from *Paradoxostoma robusta* Puri, 1953c, in its rounded posterior.

Stratigraphic range.—Late Pleistocene.

Biofacies.—Rare in inner sublittoral biofacies.

Subfamily CYTHEROMATINAE Elofson, 1939

Genus PARACYTHEROMA Juday, 1907

Paracytheroma Juday, 1907.

Type species.—*Paracytheroma pedrensis* Juday, 1907.

Remarks.—The original description of this genus is concerned almost entirely with soft-part anatomy. Study of the carapaces of paradoxostomatids reveals that *Paracytheroma* Juday, 1907, has a hinge showing distinctly developed terminal teeth, whereas *Cytheroma* Müller, 1894, has a more specialized hinge, approaching a pentodont type. Also, *Cytheroma* has a prominent frontal scar, whereas that of *Paracytheroma* is faint (McKenzie, 1969, p. 52).

Paracytheroma stephensoni (Puri, 1953c)

Plate 6, figure 5

Microcythere stephensoni Puri, 1953c, p. 291, pl. 16, figs. 11, 12, text figs. 12g, h.

Megacythere stephensoni (Puri). Puri, 1960, p. 122.

Paracytheroma stephensoni (Puri). Keyser, 1976, p. 65, pl. 2, figs. 15–17.

Description.—Carapace small and elongate in lateral view; dorsal margin straight, ventral margin slightly concave anteroventrally; anterior rounded, posterior subangular and arched posterodorsally; surface smooth; inner lamella wide with numerous marginal pore canals; anterior vestibule wide; hinge lophodont.

Dimensions.—Right valve: length, 0.53 mm; height, 0.28 mm.

Figured specimen.—USNM 316468.

Remarks.—This species may be distinguished from *Paracytheroma texana* Garbett and Maddocks, 1979, by its gently sloped posterodorsal margin.

Stratigraphic range.—Late Miocene-Holocene.

Biofacies.—Rare in oyster-bank and inner sublittoral biofacies.

Modern occurrence.—Found in estuarine and nearshore environments throughout the Gulf of Mexico and off the East Coast of the United States, at least as far north as Sapelo Island, Ga. (Garbett and Maddocks, 1979, p. 871). Teeter (1975, p. 484) also has reported this species as far south as Belize.

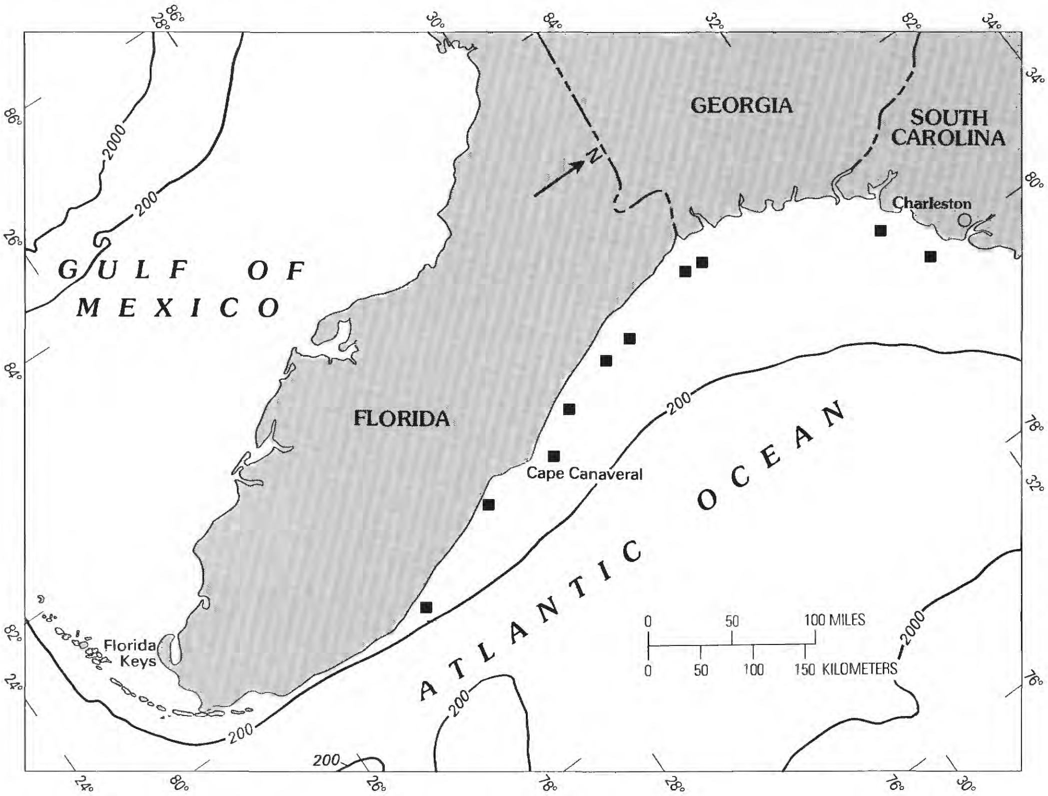


FIGURE 16.—Distribution of *Pellucistoma magniventra* Edwards, 1944 (solid squares). This species (pl. 6, fig. 6) occurs in the Holocene study area on the shallow continental shelf between South Carolina and central Florida. Depth contours are in meters.

Genus PELLUCISTOMA Coryell and Fields, 1937

Pellucistoma Coryell and Fields, 1937.

Type species.—*Pellucistoma howei* Coryell and Fields, 1937.

Remarks.—This genus is distinguished by its prominent caudal process, widely spaced radial pores, and merodont hinge.

Pellucistoma magniventra Edwards, 1944

Plate 6, figure 6

Pellucistoma magniventra Edwards, 1944, p. 528, pl. 88, figs. 33–35.

Description.—Carapace small and elongate in lateral view; dorsal margin convex anteriorly, abruptly concave posterior to the caudal process and highest centrally; ventral margin strongly sinuous and concave anteroventrally; anterior bluntly rounded, posterior extended by a caudal process; surface smooth; inner lamella wide with widely spaced, frequently bifurcating radial and false radial pore canals; anterior vestibule narrow; hinge merodont.

Dimensions.—Right valve: length, 0.50 mm; height, 0.27 mm.

Figured specimen.—USNM 316469.

Remarks.—This species is distinguished from *Pellucistoma howei* Coryell and Fields, 1937, by its narrow anterior vestibule, its larger size, and its “slipper” shape.

Stratigraphic range.—Miocene-Holocene.

Biofacies.—Rare in inner sublittoral biofacies.

Modern occurrence.—Rare in lower bay biofacies in Texas bays; reported from Mexico to Florida and up the Atlantic Coast at least as far north as North Carolina (lat 35°29′00″ N.) (Garbett and Maddocks, 1979, p. 870) (fig. 16). Abundant at depths between 7 and 10 m; salinity 35.01–39.92 parts per thousand (Benson and Coleman, 1963, p. 42).

Family CYTHERIDEIDAE Sars, 1925
Subfamily CYTHERIDEINAE Sars, 1925
Genus PERATOCYTHERIDEA Hazel, 1983

Peratocytheridea Hazel, 1977 (nomen nudum).
Peratocytheridea Hazel, 1983.

Type species.—*Cytheridea setipunctata* Brady, 1869b.

Remarks.—This genus may be distinguished from *Haplocytheridea* by its wide, more rounded posterior and its posteriorly concave ventral margin.

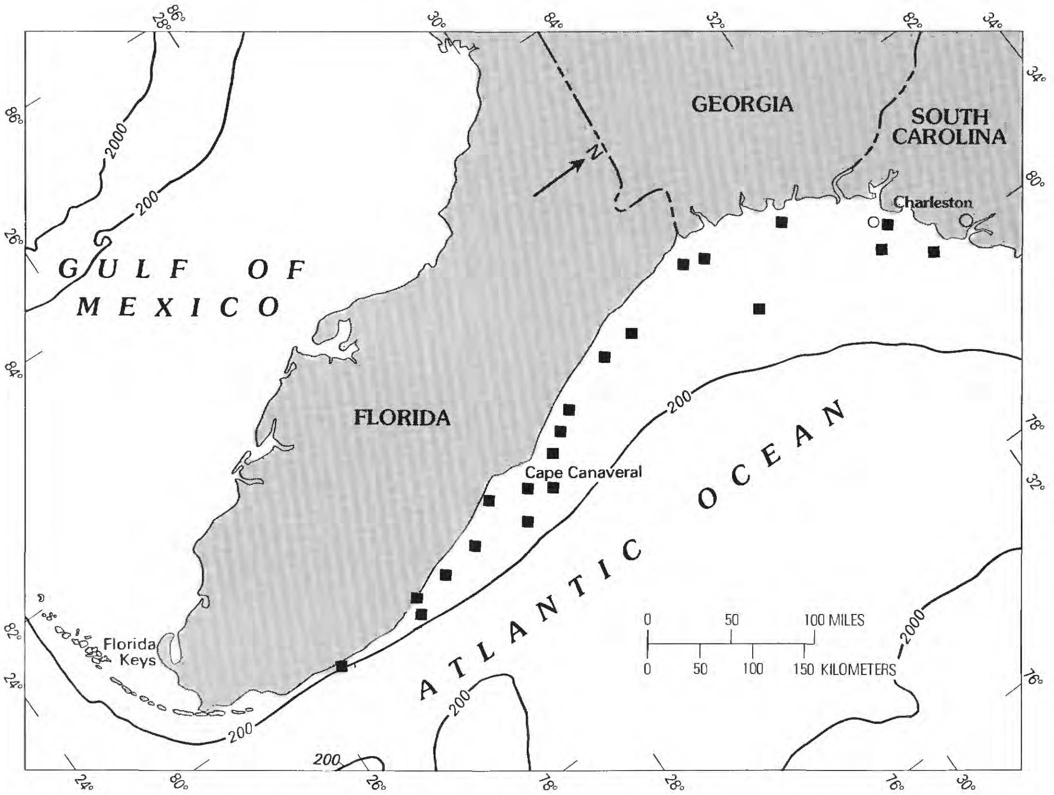


FIGURE 17.—Distribution of *Peratocytheridea bradyi* (Stephenson, 1938) (solid squares) and *Eucythere triangulata* Puri, 1953c (open circle). In the Holocene study area, *P. bradyi* (pl. 7, fig. 2) occurs on the shallow continental shelf between South Carolina and southern Florida, and *E. triangulata* (pl. 8, fig. 1) was found at one locality on the shallow shelf off South Carolina. Depth contours are in meters.

Peratocytheridea bradyi (Stephenson, 1938)

Plate 7, figure 2

Cytheridea (*Haplocytheridea*) *bradyi* Stephenson, 1938, p. 129, pl. 23, fig. 22, pl. 24, figs. 5, 6, text fig. 10.
Haplocytheridea bradyi (Stephenson). Swain, 1955, p. 618, pl. 59, figs. 12a, b.
"Haplocytheridea" bradyi (Stephenson). Garbett and Maddocks, 1979, p. 898, pl. 11, figs. 3–6.
Peratocytheridea bradyi (Stephenson). Hazel, 1983, p. 101.

Description.—Carapace elongate and ovate in lateral view; dorsal margin arched, highest point being slightly anterior to middle, ventral margin straight; anterior rounded, posterior narrowly rounded; left valve smaller than right valve; surface has moderately deep, circular pits at irregular intervals; hinge holomerodont and reversed.

Dimensions.—Left valve: length, 0.74 mm; height, 0.57 mm.

Figured specimen.—USNM 316444.

Remarks.—Reversal of valve size and hinge structure occurs in this species, as well as in other species within the genus. This species is similar to *Haplocytheridea* proboscidiala Edwards, 1944, which also displays valve and hinge reversal, but displays a much stronger hinge.

Stratigraphic range.—Pliocene-Holocene.

Biofacies.—Common in inner sublittoral biofacies; rare in oyster-bank biofacies; rare to common in open-sound biofacies.

Modern occurrence.—Found off the Eastern United States between lat 26°21′06″ N. and lat 39°00′00″ N. (fig. 17) at 9–72 m depth.

Peratocytheridea setipunctata (Brady, 1869b)

Plate 7, figure 1

Cytheridea setipunctata Brady, 1869b, p. 124, pl. 14, figs. 15, 16.
Haplocytheridea setipunctata (Brady). Grossman, 1967, p. 64, pl. 11, figs. 4, 7, pl. 16, figs. 13–18.
"Haplocytheridea" setipunctata (Brady). Garbett and Maddocks, 1979, p. 901–902, pl. 11, figs. 7–10.
Peratocytheridea setipunctata (Brady). Hazel, 1983, p. 101, pl. 4, fig. 4.

Description.—Carapace large and ovate in lateral view; dorsal margin arched, highest point being slightly anterior to middle, ventral margin slightly convex; anterior broadly rounded, posterior bluntly rounded; left valve larger than right valve; surface dotted with large, circular to oval pits at irregular intervals; hinge holomerodont and reversed.

Dimensions.—Left valve: length, 0.94 mm; height, 0.56 mm.

Figured specimen.—USNM 316443.

Remarks.—This species may be distinguished from *Peratocytheridea bradyi* (Stephenson, 1938) by its larger size and more ovate shape. It differs from *Haplocytheridea gigantea* Benson and Coleman, 1963, in its hinge reversal and its lack of denticles at the anteroventral margin.

Stratigraphic range.—Pliocene-Holocene.

Biofacies.—Abundant to common in open-sound biofacies; common to rare in inner sublittoral biofacies.

Modern occurrence.—Found from the Chesapeake Bay (fig. 6) to Mexico, Puerto Rico, and the Bahamas, primarily in estuaries and lagoons (Hazel, 1983). Most abundant in sandy substrates (Cronin, 1979, p. 129).

Genus CYPRIDEIS Jones, 1857

Cyprideis Jones, 1857.
Anomocytheridea Stephenson, 1938.
Anomocythere Sohn, 1951.

Type species.—*Candona torosa* Jones, 1857.

Remarks.—*Cyprideis* species are important markers for the correlation of Cenozoic brackish-water deposits.

Cyprideis salebrosa van den Bold, 1963

Plate 7, figure 3

Cyprideis salebrosa van den Bold, 1963, p. 377, pl. 7, figs. 9a-d, pl. 11, figs. 1a-c.

Description.—Carapace large and quadrate in lateral view; dorsal margin arched, ventral margin slightly concave anteroventrally; anterior rounded, posterior blunt; coarsely punctate surface having an obscure submedian sulcus; hinge entomodont.

Dimensions.—Right valve: length, 1.10 mm; height, 0.62 mm.

Figured specimen.—USNM 316445.

Remarks.—*Cyprideis salebrosa* van den Bold, 1963, may be distinguished from *Cyprideis margarita* Cronin, 1979, and from *Cyprideis mexicana* Sandberg, 1964, by its large size and its coarsely punctate surface.

Stratigraphic range.—Miocene-Holocene.

Biofacies.—Rare in oyster-bank biofacies.

Modern occurrence.—Common to abundant in Texas bays, where it thrives in areas where water bodies mix; found along the entire U.S. Gulf Coast and in the Caribbean, as well as off the coasts of New York, New Jersey, Brazil, and Argentina (Garbett and Maddocks, 1979, p. 902).

Cyprideis mexicana Sandberg, 1964

Plate 7, figures 4, 5

Cyprideis mexicana Sandberg, 1964, v. 12, p. 125, pl. 10, figs. 1, 2, pl. 11, figs. 11-14, pl. 12, figs. 1-5, pl. 17, fig. 1, pl. 22, figs. 2, 9a, b.

Description.—Carapace subrectangular in lateral view; anterior rounded, posterior bluntly rounded; ventral margin straight, dorsal margin slightly arched; inner lamella narrow; surface slightly pitted and has a shallow sulcus; rounded mandibular muscle scar; hinge entomodont.

Dimensions.—Right valve: length, 0.75 mm; height, 0.40 mm.

Figured specimens.—USNM 316446, USNM 316447.

Remarks.—*Cyprideis mexicana* may be distinguished from *Cyprideis margarita* Cronin, 1979, by its slightly pitted surface and its rounded mandibular muscle scar. It differs from *Cyprideis salebrosa* van den Bold, 1963, in its smaller size and its rounded mandibular muscle scar.

Stratigraphic range.—Late Pleistocene-Holocene.

Biofacies.—Abundant to common in oyster-bank biofacies; common in inner sublittoral biofacies.

Modern occurrence.—Found off Veracruz and Campeche, Mexico, in lower salinity, brackish-water environments (Sandberg, 1964).

Cyprideis margarita Cronin, 1979

Plate 7, figures 6, 7

Cyprideis margarita Cronin, 1979, p. 142, pl. 1, figs. 9, 10, pl. 2, figs. 7, 8, pl. 3, figs. 5, 6.

Description.—Carapace ovate-subtriangular to ovate-elongate in lateral view; anterior rounded, posterior sloping; surface smooth and has an indistinct, very narrow sulcus; narrow inner lamella; elongated mandibular muscle scar; hinge entomodont.

Dimensions.—Right valve: length, 0.57 mm; height, 0.30 mm.

Figured specimens.—USNM 316448, USNM 316449.

Remarks.—*Cyprideis margarita* may be distinguished from *Cyprideis shrewsburyensis* Kontrovitz and Bitter, 1976, by its smaller size, smooth carapace, and more elongate mandibular muscle scar. It is distinguished from *Cyprideis stephensoni* Sandberg, 1964, and from *Cyprideis mexicana* Sandberg, 1964 (see above), by its smooth carapace and more elongate mandibular muscle scar.

Stratigraphic range.—Late Pleistocene-Holocene.

Biofacies.—Rare in oyster-bank and inner sublittoral biofacies.

Modern occurrence.—Known only from the Eastern United States off the coasts of South Carolina and Georgia (Cronin, 1979, p. 143).

Genus PERISSOCYTHERIDEA Stephenson, 1938

Perissocytheridea Stephenson, 1938.
?*Ilyocythere* Klie, 1939.

Type species.—*Cytheridea matsoni* Stephenson, 1935.

Remarks.—Van Morkhoven (1963, p. 108) placed *Ilyocythere* Klie, 1939, questionably in synonomy with *Perissocytheridea* Stephenson, 1938, because the type material was unavailable to him for study.

Perissocytheridea brachyforma Swain, 1955

Plate 6, figure 7

Perissocytheridea brachyforma Swain, 1955, p. 619, pl. 61, figs. 1, 2, 5, text figs. 33a, 39, 6a-c.

Description.—Carapace subquadrate in lateral view; dorsal margin sinuous in right valve, straight in left; ventral margin slightly convex in right valve, straight in left; anterior rounded, posterior produced into a caudal process; left valve larger than right valve; anterocentral sulcus deep; surface ornamented by four sinuous, longitudinal ridges, two of which rim the periphery and two of which are particularly visible posteriorly; inner lamella wide; hinge antimerodont.

Dimensions.—Right valve: length, 0.53 mm; height, 0.28 mm.

Figured specimen.—USNM 316502.

Remarks.—This species may be distinguished from *Perissocytheridea rugata* Swain, 1955, by its lack of coarse reticulation, and it may be distinguished from *Perissocytheridea excavata* Swain, 1955, by its larger size and weaker longitudinal ridges.

Stratigraphic range.—Late Pleistocene-Holocene.

Biofacies.—Rare in oyster-bank and inner sublittoral biofacies.

Modern occurrence.—Found in brackish-water environments of the U.S. Gulf Coast and in tidal bays of Delaware (Garbett and Maddocks, 1979, p. 894), where they forage through very fine sand (Krutak, 1972, p. 158).

Subfamily EUCYTHERINAE Puri, 1953c
Genus EUCYTHERE Brady, 1868a

Cytheropsis Sars, 1866, preoccupied by *Cytheropsis* McCoy, 1849.
Eucythere Brady, 1868a.

Type species.—*Cythere declivis* Norman, 1865.

Eucythere triangulata Puri, 1953c

Plate 8, figure 1

Eucythere triangulata Puri, 1953c, p. 300, pl. 16, figs. 7, 8, text fig. 13j.

Description.—Carapace subtriangular in lateral view; dorsal margin arched, ventral margin concave centrally; anterior broadly rounded, posterior narrowly rounded; surface ornamented by rugae and faint reticulate pattern; inner lamella wide; hinge lophodont.

Dimensions.—Right valve: length, 0.68 mm; height, 0.29 mm.

Figured specimen.—USNM 316486.

Remarks.—This species may be distinguished from *Eucythere chickasawhayensis* Howe, 1936, by its rounded posterior and its lack of strong reticulation. It differs from *Eucythere gibba* Edwards, 1944, in its smaller size, its more elongate shape, and its lack of ventral swelling.

Stratigraphic range.—Late Pleistocene-Holocene.

Biofacies.—Rare in inner sublittoral and oyster-bank biofacies.

Modern occurrence.—Found off the East Coast of the United States between lat 32°15′42″ N. and lat 35°21′00″ N. (fig. 17) at approximately 11 m depth.

Eucythere declivis (Norman, 1865)

Plate 8, figure 2

Cythere declivis Norman, 1865, p. 16, pl. 5, figs. 9–12.
Eucythere declivis (Norman). Brady, 1868a, p. 429.

Description.—Carapace subtriangular in lateral view; dorsal margin arched, ventral margin straight and slightly inflated; anterior broadly rounded, posterior pointed; surface has a very faint reticulate pattern around anterior and posterior margins; surface slightly pitted; hinge lophodont.

Dimensions.—Right valve: length, 0.50 mm; height, 0.23 mm.

Figured specimen.—USNM 316485.

Remarks.—This species differs from *Eucythere triangulata* Puri, 1953c, in its smaller size and faintly reticulate margins. It differs from *Eucythere gibba* Edwards, 1944, in its smaller size and more elongate shape.

Stratigraphic range.—Late Pleistocene-Holocene.

Biofacies.—Rare in inner sublittoral biofacies.

Modern occurrence.—Found off the East Coast of the United States between lat 32°43′00″ N. and lat 39°09′00″ N.

Family CUSHMANIDEIDAE Puri, 1973
Genus CUSHMANIDEA Blake, 1933

Cytherideis Jones, 1857 (part).
?*Sacculus* Neviani, 1928.
Cushmanidea Blake, 1933.
Pontocythere Dubowsky, 1939.
Hemicytherideis Ruggieri, 1952.

Type species.—*Cytheridea seminuda* Cushman, 1906.

Remarks.—Puri (1958a, p. 171–173) offers a complete discussion of this genus and its synonomy. This genus is characterized by its elongate carapace, nondenticulate hinge, and valves that are articulated by three pairs of flanges.

Cushmanidea seminuda (Cushman, 1906)

Plate 8, figure 3

Cytheridea seminuda Cushman, 1906, p. 374, pl. 33, figs. 62–64, pl. 34, figs. 76, 77.

Cushmanidea seminuda (Cushman). Blake, 1933, p. 233.

Description.—Carapace large and elongate in lateral view; dorsal margin arched, ventral margin concave; anterior and posterior rounded; smooth in dorsal region, pitted elsewhere, pits becoming arranged into rows paralleling the anterior and ventral margins; faintly raised ridges occur between rows of pits; hinge lophodont.

Dimensions.—Left valve: length, 0.98 mm; height, 0.36 mm.

Figured specimen.—USNM 316491.

Remarks.—This species may be distinguished from *Cushmanidea elongata* (Brady, 1868a) by its pitted carapace.

Stratigraphic range.—Pliocene-Holocene.

Biofacies.—Rare in inner sublittoral biofacies.

Modern occurrence.—Found along the gulf coast of Texas and Florida, as well as along the Atlantic Coast north to Woods Hole, Mass. (Garbett and Maddocks, 1979, p. 903). Not found in this study south of the Virginian faunal province.

Genus HULINGSINA Puri, 1958a

Hulingsina Puri, 1958a.

Type species.—*Hulingsina tuberculata* Puri, 1958a.

Remarks.—This genus is similar to *Cushmanidea* Blake, 1933, but may be distinguished from it by its heavier shell, its stronger selvage development, and its oblique posterior margin, which is subacute.

Hulingsina rugipustulosa (Edwards, 1944)

Plate 9, figures 1, 2

Cytherideis rugipustulosa Edwards, 1944, p. 514, pl. 86, figs. 5–7.

Pontocythere rugipustulosa (Edwards). Swain, 1968, p. 9, pl. 1, fig. 10.

Hulingsina rugipustulosa (Edwards). Valentine, 1971, p. D19, pl. 3, figs. 17, 18, 21, 22, 25, 26, 29, 30.

Pontocythere (*Hulingsina*) *rugipustulosa* (Edwards). Swain, 1974, p. 17, pl. 1, fig. 18, pl. 2, figs. 4–7.

Hulingsina rugipustulosa (Edwards). Cronin, 1979, p. 144, pl. 5, figs. 6, 8, pl. 7, figs. 5, 7.

Description.—Carapace elongate in lateral view; dorsal margin slightly convex, ventral margin centrally concave; anterior rounded, posterior narrowly rounded; posterodorsal sulcus distinct and comma shaped; surface ornamented by low ridges paralleling margins; in some specimens, ridges bear short, rounded pustules, and in others, surface is pitted; hinge lophodont.

Dimensions.—Right valve: length, 0.57 mm; height, 0.26 mm; left valve: length, 0.67 mm; height, 0.28 mm.

Figured specimens.—USNM 316493, USNM 316494.

Remarks.—Cronin (1979, p. 144) noted two ecophenotypes of this species, the pustulose variety, which is more common in warmer subtropical waters, and the pitted variety, which is more common in mild-temperate waters. *Hulingsina rugipustulosa* may be distinguished from *Hulingsina ashermani* (Ulrich and Bassler, 1904) by its slightly convex dorsal margin and, in some specimens, by its pustulose surface.

Stratigraphic range.—Late Miocene-Holocene.

Biofacies.—Common to rare in inner sublittoral, oyster-bank, and open-sound biofacies.

Modern occurrence.—Common in the subtropical Carolinian faunal province (11–17 m) (fig. 18). However, only the nonpustulose form occurs north of Cape Hatteras (Forester, 1980, p. 7) in the Virginian faunal province.

Hulingsina glabra (Hall, 1965)

Plate 9, figure 3

Cushmanidea glabra Hall, 1965, p. 40, pl. 14, figs. 9–21.

Hulingsina glabra (Hall). Valentine, 1971, p. D19, pl. 3, fig. 3.

Description.—Carapace elongate in lateral view; dorsal margin convex, ventral margin slightly concave; anterior rounded, posterior bluntly rounded; surface smooth, having faint anterior ridges; inner lamella wide; hinge lophodont.

Dimensions.—Left valve: length, 0.57 mm; height, 0.25 mm.

Figured specimen.—USNM 316495.

Remarks.—This species may be distinguished from other species of *Hulingsina* by its blunt posterior margin.

Stratigraphic range.—Late Pleistocene-Holocene.

Biofacies.—Rare in inner sublittoral and oyster-bank biofacies.

Modern occurrence.—Found off the East Coast of the United States between lat 27°09′54″ N. and lat 35°21′00″ N. (fig. 18) at 11–36 m depth.

Hulingsina sp.

Plate 9, figure 4

Hulingsina sp. C, Valentine, 1971, p. D19, pl. 3, figs. 19, 20, 23, 24.

Description.—Carapace elongate in lateral view; dorsal margin arched (highest centrally), ventral margin slightly concave centrally; anterior obliquely rounded,

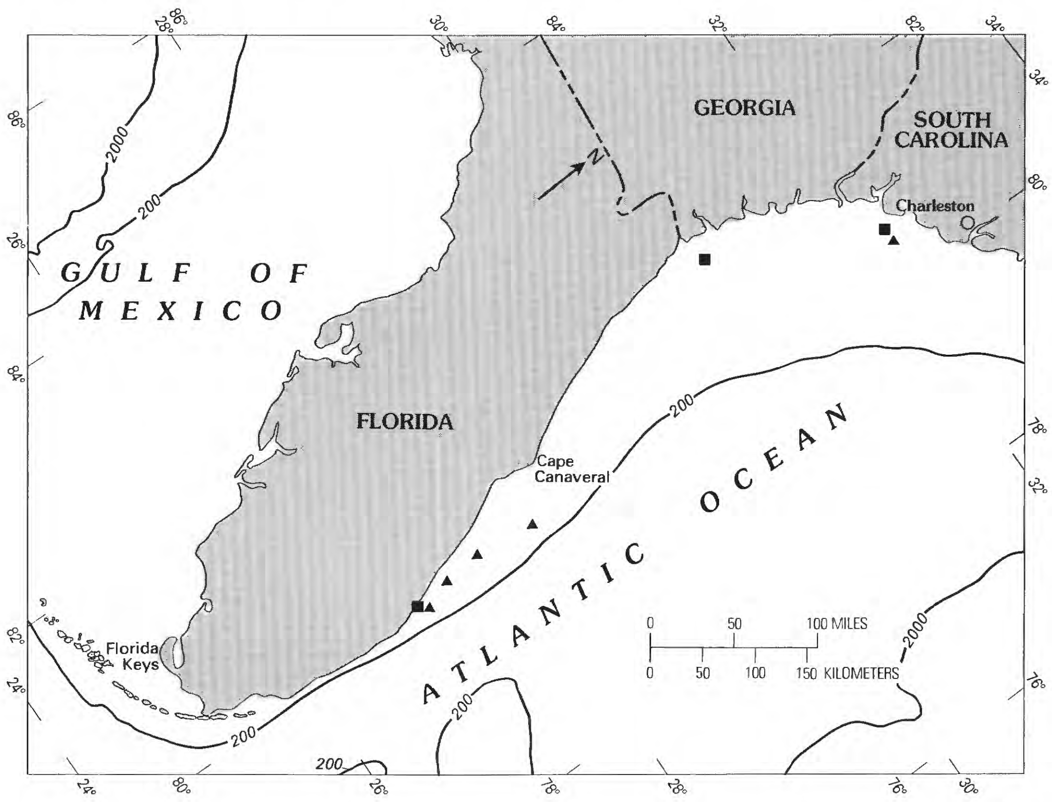


FIGURE 18.—Distribution of *Hulingsina rugipustulosa* (Edwards, 1944) (solid squares) (pl. 9, figs. 1, 2) and *Hulingsina glabra* (Hall, 1965) (solid triangles) (pl. 9, fig. 3). These species occur in the Holocene study area on the shallow continental shelf between South Carolina and central Florida. Depth contours are in meters.

posterior sloped steeply upward and narrowly rounded below; surface smooth, but has many minute normal pores; weak ridges parallel anterior margin; hinge lophodont.

Dimensions.—Right valve: length, 0.64 mm; height, 0.28 mm.

Figured specimen.—USNM 316496.

Remarks.—This form may be distinguished from *Hulingsina glabra* (Hall, 1965) by its arched dorsal margin.

Stratigraphic range.—Late Pleistocene-Holocene.

Biofacies.—Rare in inner sublittoral biofacies.

Modern occurrence.—Found off the East Coast of the United States between lat 32°43′00″ N. and lat 39°21′00″ N.

Hulingsina aff. H. glabra (Hall, 1965)

Plate 9, figure 5

Description.—Carapace elongate in lateral view; dorsal margin slightly arched (highest in the center), ventral margin slightly concave; anterior and posterior narrowly rounded; surface mostly smooth, but has faint ridges paralleling anterior margin and scattered normal pits; sulcus distinct; hinge lophodont.

Dimensions.—Right valve: length, 0.74 mm; height, 0.27 mm.

Figured specimen.—USNM 316497.

Remarks.—This form may be distinguished from *Hulingsina glabra* (Hall, 1965) by its narrowly rounded posterior margin.

Stratigraphic range.—Late Pleistocene-Holocene.

Biofacies.—Rare in inner sublittoral biofacies.

Modern occurrence.—Found off the Eastern United States between lat 27°09′54″ N. and lat 32°15′42″ N. (fig. 19) at 11–36 m depth.

Hulingsina aff. H. rugipustulosa (Edwards, 1944)

Plate 9, figure 6

Hulingsina sp. B, Valentine, 1971, p. D19, pl. 3, figs. 4, 5.
Hulingsina sp. A, Cronin, 1979, p. 144, pl. 6, figs. 1, 3, 5.

Description.—Carapace small and elongate in lateral view; dorsal margin uniformly arched from anterior to posterior, ventral margin concave anterior to middle; anterior rounded, posterior bluntly rounded; surface ornamented by rugae, which form parallel ridges anteriorly; normal pores abundant; hinge lophodont.

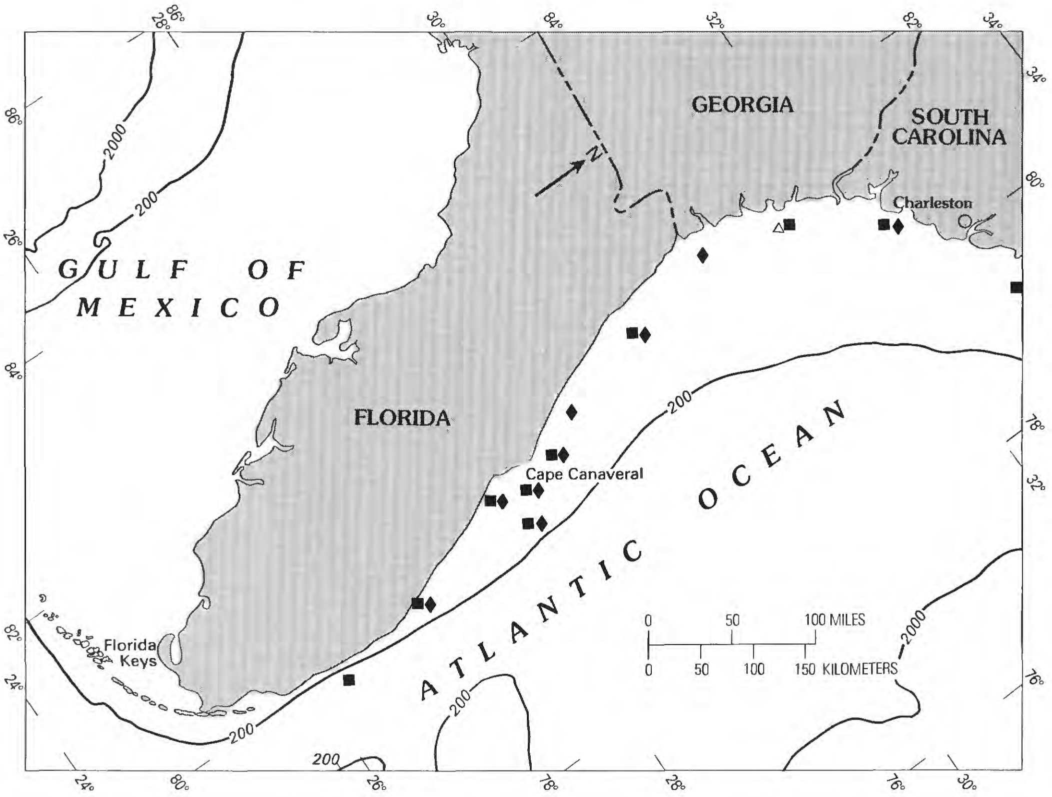


FIGURE 19.—Distribution of *Hulingsina* aff. *H. glabra* (Hall, 1965) (solid diamonds) (pl. 9, fig. 5), *Hulingsina* aff. *H. rugipustulosa* (Edwards, 1944) (solid squares) (pl. 9, fig. 6), and *Hulingsina* aff. *H. semicircularis* (Ulrich and Bassler, 1904) (open triangle) (pl. 8, fig. 6). In the Holocene study area, *Hulingsina* aff. *H. glabra* occurs on the shallow continental shelf between South Carolina and central Florida; *Hulingsina* aff. *H. rugipustulosa* is distributed between the shallow continental shelf off South Carolina and the shallow to deep continental shelf and continental slope off southern Florida; and *Hulingsina* aff. *H. semicircularis* occurs at one locality on the shallow continental shelf off Georgia. Depth contours are in meters.

Dimensions.—Left valve: length, 0.46 mm; height, 0.25 mm.

Figured specimen.—USNM 316498.

Remarks.—This form may be distinguished from *Hulingsina rugipustulosa* (Edwards, 1944) by its smaller size, the presence of rugae, and its nonpustulose surface.

Stratigraphic range.—Late Pleistocene-Holocene.

Biofacies.—Common to rare in inner sublittoral biofacies.

Modern occurrence.—Found off the Eastern United States between lat 26°22′30″ N. and lat 37°59′00″ N. (fig. 19) at 11–307 m depth.

Hulingsina aff. H. semicircularis (Ulrich and Bassler, 1904)

Plate 8, figure 6

Hulingsina sp. B, Cronin, 1979, p. 144, pl. 7, figs. 1, 3.

Description.—Carapace elongate in lateral view; dorsal margin uniformly convex, ventral margin slightly concave; anterior rounded, posterior narrowly rounded; surface ornamented by shallow, circular pits that become aligned ventrally; hinge lophodont.

Dimensions.—Right valve: length, 0.83 mm; height, 0.33 mm.

Figured specimen.—USNM 316504.

Remarks.—This form may be distinguished from *Hulingsina semicircularis* (Ulrich and Bassler, 1904), from *Hulingsina americana* (Cushman, 1906) (see below), and from *Hulingsina ashermani* (Ulrich and Bassler, 1904) by its shallow pitting.

Stratigraphic range.—Late Pleistocene-Holocene.

Biofacies.—Common to rare in inner sublittoral biofacies; rare in oyster-bank biofacies.

Modern occurrence.—Found off the Eastern United States between lat 31°31′12″ N. and lat 39°21′00″ N. (fig. 19) at around 9 m depth.

Hulingsina americana (Cushman, 1906)

Plate 8, figure 7

Cytheridea americana Cushman, 1906, p. 375, pl. 33, fig. 67, pl. 34, figs. 68–75.

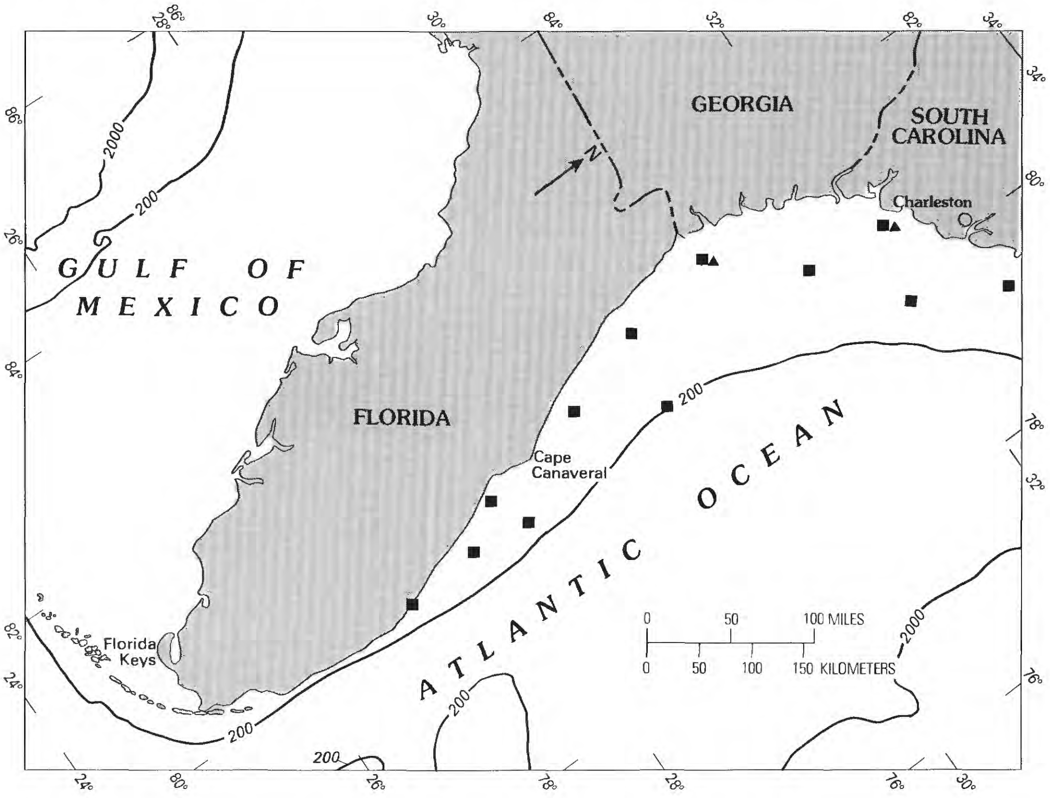


FIGURE 20.—Distribution of *Hulingsina americana* (Cushman, 1906) (solid squares) and *Sahnicythere* sp. (solid triangles). In the Holocene study area, *H. americana* (pl. 8, fig. 7) occurs on the shallow continental shelf between South Carolina and central Florida, and *S.* sp. (pl. 8, fig. 4) was found at two localities on the shallow continental shelf off Georgia and South Carolina. Depth contours are in meters.

Hulingsina americana (Cushman). Puri, 1958a, p. 173, pl. 1, figs. 6–10.

Description.—Carapace large and elongate in lateral view; dorsal margin slightly convex, ventral margin slightly concave; anterior and posterior rounded; posterodorsal margin curved; surface ornamented entirely by large pits; inner lamella well developed; hinge lophodont.

Dimensions.—Left valve: length, 1.00 mm; height, 0.40 mm.

Figured specimen.—USNM 316503.

Remarks.—*Hulingsina americana* (Cushman, 1906) may be distinguished from *Hulingsina ashermani* (Ulrich and Bassler, 1904) by its lack of a sulcus and its curved posterodorsal margin.

Stratigraphic range.—Late Pleistocene-Holocene.

Biofacies.—Rare in inner sublittoral biofacies.

Modern occurrence.—Distributed off the Eastern United States between Cape Cod, Mass., and central Florida (lat 27°09′54″ N.) (fig. 20) at 11–77 m depth.

Family NEOCYTHERIDEIDAE Puri, 1957

Genus SAHNICYTHERE Athersuch, 1982

Sahnicythere Athersuch, 1982.

Type species.—*Sahnicythere retroflexa* (Klie, 1936).

Remarks.—Athersuch (1982) reviewed the genera in the family Cytherideidae and placed *Sahnicythere* in the family Neocytherideidae. *Sahnicythere* may be distinguished from *Neocytherideis* by its smaller size, narrow anterior vestibule, long radial pore canals, wide inner lamella, and median sulcus.

Sahnicythere sp.

Plate 8, figure 4

Sahnia sp. Hall, 1965, p. 44, pl. 3, figs. 1–9.
Sahnia sp. A, Cronin, 1979, p. 143, pl. 6, fig. 7.

Description.—Carapace very elongate in lateral view; dorsal margin slightly convex, ventral margin nearly straight; posterior rounded, anterior narrowly rounded; carapace tapers to anterior; surface nearly smooth, but has faint ridges subparallel to margins and scattered, small normal pores; inner lamella having many marginal pore canals anteriorly; hinge lophodont.

Dimensions.—Left valve: length, 0.57 mm; height, 0.20 mm.

Figured specimen.—USNM 316492.

Stratigraphic range.—Late Pleistocene-Holocene.

Biofacies.—Rare in inner sublittoral biofacies.

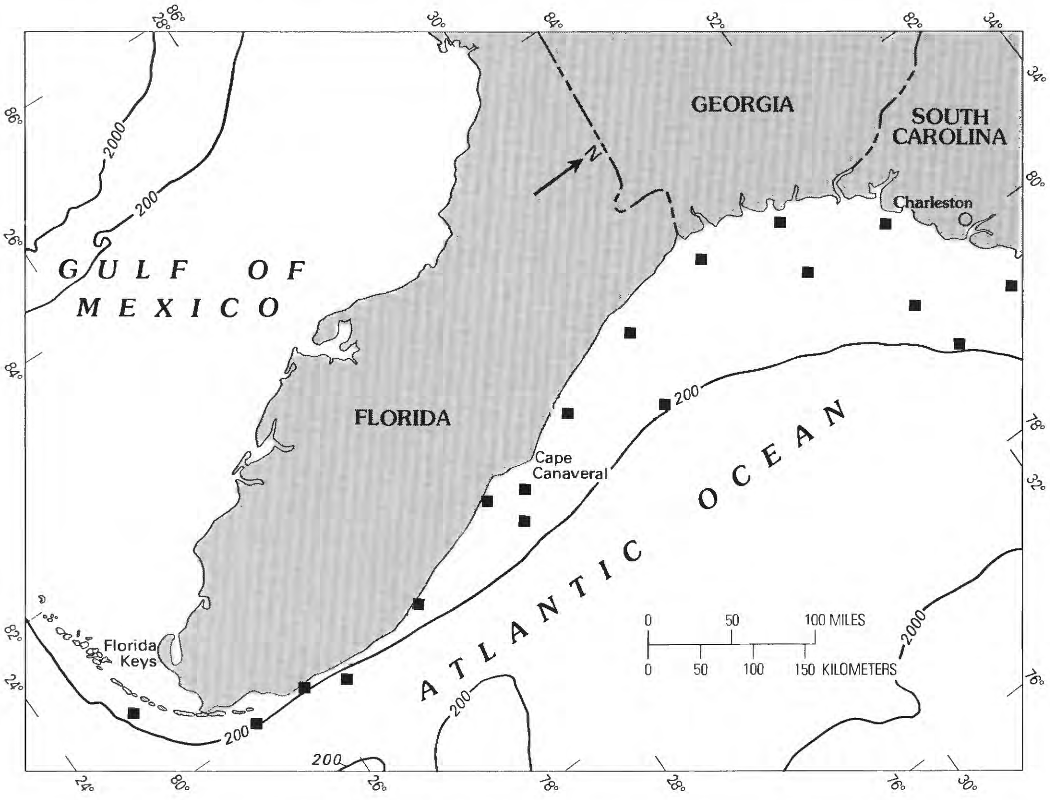


FIGURE 21.—Distribution of *Cytherura forulata* Edwards, 1944 (solid squares). This species (pl. 10, fig. 1) occurs in the Holocene study area on the shallow to deep continental shelf and continental slope between South Carolina and the Florida Keys. Depth contours are in meters.

Modern occurrence.—Found off the Eastern United States between lat 30°50′06″ N. and lat 32°15′42″ N. (fig. 20) at 11–15 m depth.

Family CYTHERURIDAE Müller, 1894
Genus CYTHERURA Sars, 1866

Cytherura Sars, 1866.

Type species.—*Cythere gibba* Müller, 1785.

Cytherura forulata Edwards, 1944

Plate 10, figure 1

Cytherura forulata Edwards, 1944, p. 526, pl. 88, figs. 17–20.

Description.—Carapace small and elongate in lateral view; dorsal margin straight, ventral margin slightly concave anteroventrally; anterior rounded, posterior has a very short caudal process; posterior slightly higher than anterior; surface ornamented by low, thin, delicate longitudinal ribs having faint crossbars at irregular intervals; Y-shaped posterior radial pore canals; hinge entomodont.

Dimensions.—Left valve: length, 0.49 mm; height, 0.26 mm.

Figured specimen.—USNM 316507.

Remarks.—*Cytherura forulata* Edwards, 1944, may be distinguished from *Cytherura fiscina* Garbett and Maddocks, 1979, by its short caudal process, straighter dorsal margin, and Y-shaped posterior radial pore canals.

Stratigraphic range.—Pliocene-Holocene.

Biofacies.—Common to rare in inner sublittoral biofacies; rare in oyster-bank biofacies.

Modern occurrence.—Found off the East Coast of the United States between lat 24°42′12″ N. and lat 36°20′00″ N. (fig. 21) at 9–307 m depth. Also found in Florida mangroves (Keyser, 1975, p. 489) and in San Antonio Bay, Tex. (Swain, 1955, p. 628). Abundant in sand and mud mixtures (Hulings and Puri, 1964, p. 336).

Cytherura wardensis Howe and Brown, 1935

Plate 10, figure 2

Cytherura wardensis Howe and Brown, 1935, *in* Howe and others, 1935, p. 36, pl. 1, figs. 23, 27, pl. 4, fig. 19.

Description.—Carapace subquadrate in lateral view; dorsal margin straight, parallel with ventral margin, and sloped anterodorsally; anterior bluntly rounded, caudal process developed posterodorsally; eye tubercle distinct; surface strongly reticulate; hinge entomodont.

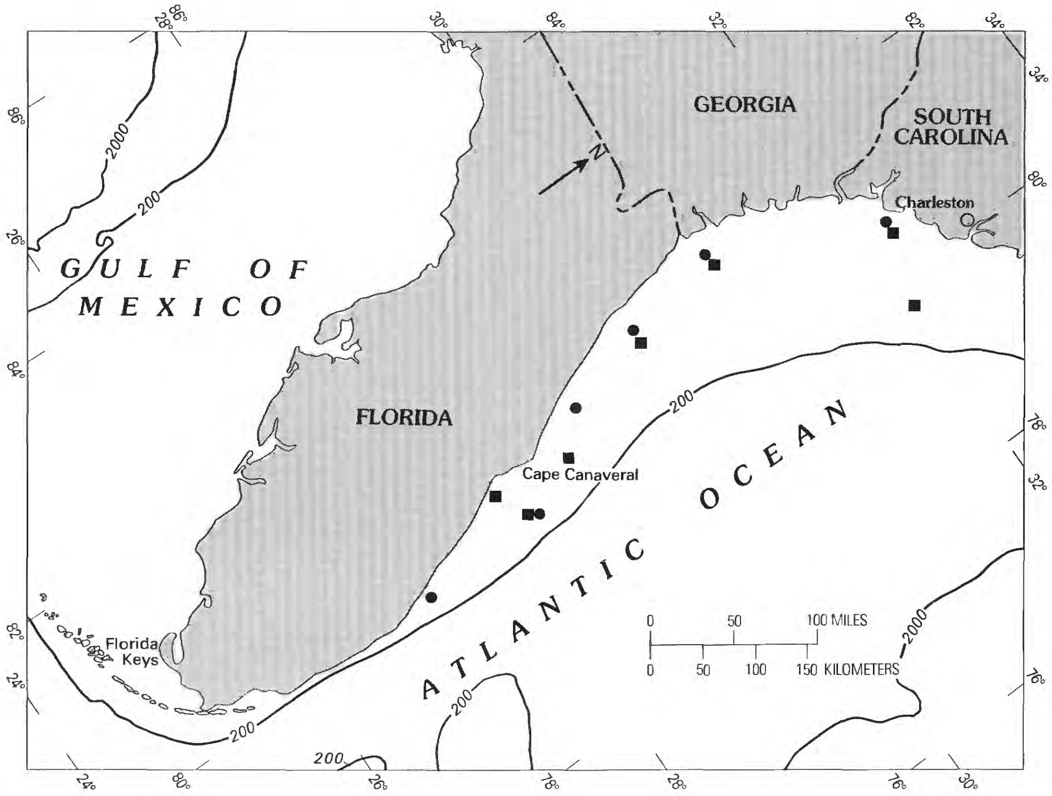


FIGURE 22.—Distribution of *Cytherura wardensis* Howe and Brown, 1935 (solid squares) (pl. 10, fig. 2), and *Cytherura valentini* Garbett and Maddocks, 1979 (solid circles) (pl. 10, figs. 5, 6). In the Holocene study area, these species occur on the shallow continental shelf between South Carolina and central Florida. Depth contours are in meters.

Dimensions.—Right valve: length, 0.44 mm; height, 0.21 mm.

Figured specimen.—USNM 316508.

Remarks.—This species may be distinguished from *Cytherura pseudostriata* Hulings, 1966, by its strong, reticulate ornamentation and its weaker crossribs.

Stratigraphic range.—Miocene-Holocene.

Biofacies.—Rare in inner sublittoral and oyster-bank biofacies.

Modern occurrence.—Found off the East Coast of the United States between lat 28°20′18″ N. and lat 36°20′00″ N. (fig. 22) at 11–36 m depth. Abundant in sand and mud mixtures associated with marine grasses (Hulings and Puri, 1964, p. 336).

Cytherura nucis Garbett and Maddocks, 1979

Plate 10, figure 3

Cytherura nucis Garbett and Maddocks, 1979, p. 884, pl. 6, figs. 1–6, text fig. 36.

Description.—Carapace small and subquadrate in lateral view; dorsal margin straight, ventral margin concave in front of center; sloped anterodorsally; anterior rounded, posterior has centrally located caudal process; males reticulate, females reticulate to smooth; surface covered by abundant, medium-sized pores; eye tubercle visible; hinge entomodont.

Dimensions.—Right valve: length, 0.32 mm; height, 0.18 mm.

Figured specimen.—USNM 316509.

Remarks.—All specimens found in this study are smaller than the holotype and appear smooth under a binocular microscope, although SEM photographs show the faint, characteristic reticulate pattern. Garbett and Maddocks (1979, p. 885) note that smooth females were shown with the SEM to have faint reticulation.

Stratigraphic range.—Late Pleistocene-Holocene.

Biofacies.—Common in backbarrier biofacies; rare in inner sublittoral biofacies.

Modern occurrence.—Rare to common in upper bay and midbay biofacies of Texas bays (Garbett and Maddocks, 1979, p. 885).

Cytherura aff. C. swaini van den Bold, 1963

Plate 10, figure 4

Description.—Carapace minute and elongate in lateral view; dorsal margin straight (sloping anterodorsally), ventral margin sinuate; anterior rounded, posterior pro-

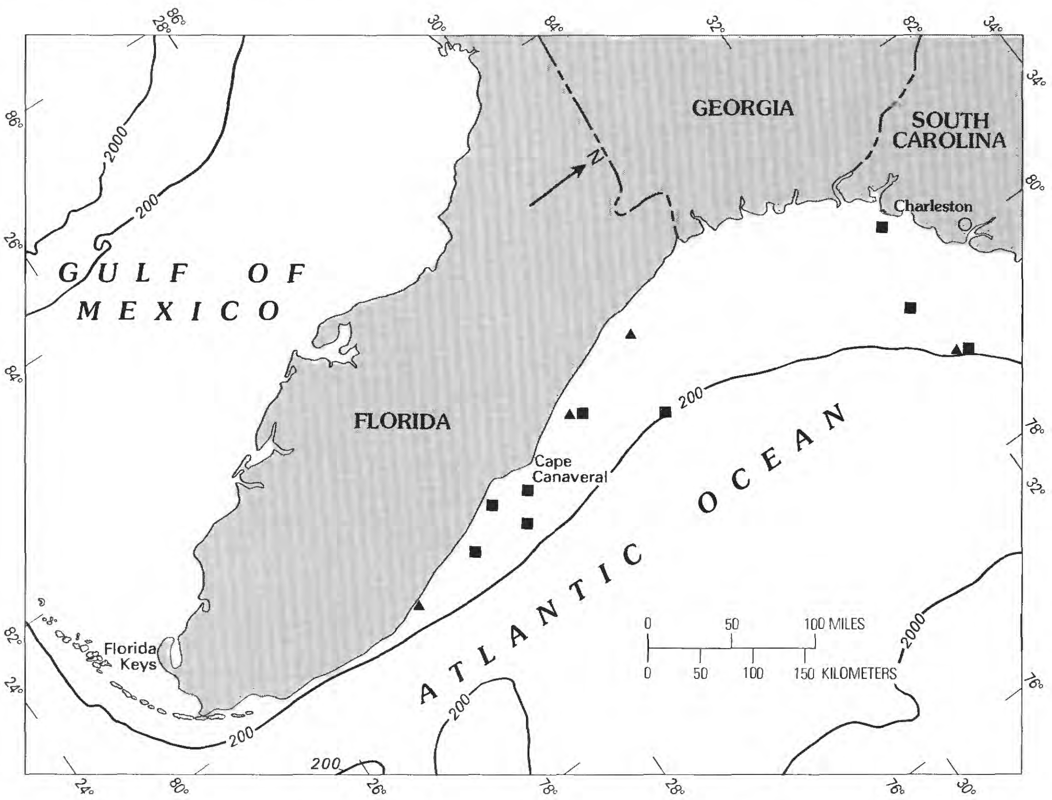


FIGURE 23.—Distribution of *Cytherura pseudostriata* Hulings, 1966 (solid squares) (pl. 10, fig. 7), and *Cytherura* aff. *C. pseudostriata* Hulings, 1966 (solid triangles) (pl. 10, fig. 8). In the Holocene study area, these species occur on the shallow to deep continental shelf between Charleston, S.C., and central Florida. Depth contours are in meters.

duced into a long caudal process; surface ornamented by longitudinal ridges, four of which are prominent, and by numerous, medium-sized, prominent pits between the ridges; hinge entomodont.

Dimensions.—Right valve: length, 0.36 mm; height, 0.16 mm.

Figured specimen.—USNM 316510.

Remarks.—The specimens found in this study differ from the holotype of *Cytherura swaini* van den Bold, 1963 (p. 395, pl. 9, figs. 4a, b), in that they possess pits, rather than transverse ridges, between the longitudinal ridges.

Stratigraphic range.—Late Pleistocene.

Biofacies.—Rare in backbarrier biofacies.

Cytherura pseudostriata Hulings, 1966

Plate 10, figure 7

Cytherura pseudostriata Hulings, 1966, p. 52, fig. 7d.

Description.—Carapace subquadrate in lateral view; dorsal margin straight, ventral margin sinuous; anterior rounded, caudal process extends posterodorsally; surface ornamented by 8–10 longitudinal ribs and faint crossribs, crossribs becoming more distinct in posterior region; dorsal and ventral ribs join anteriorly; eye tubercle prominent; hinge entomodont.

Dimensions.—Left valve: length, 0.45 mm; height, 0.26 mm.

Figured specimen.—USNM 316513.

Remarks.—This species may be distinguished from *Cytherura* aff. *C. pseudostriata* Hulings, 1966 (see below), by its anterior rib arrangement, where the dorsal and ventral ribs join.

Stratigraphic range.—Late Pleistocene-Holocene.

Biofacies.—Rare in inner sublittoral biofacies.

Modern occurrence.—Found off the Eastern United States between lat 27°39′40″ N. and lat 36°09′00″ N. (fig. 23) at 11–181 m depth.

Cytherura aff. C. pseudostriata Hulings, 1966

Plate 10, figure 8

Description.—Carapace subquadrate in lateral view; dorsal and ventral margins straight; anterior rounded, caudal process extends posterodorsally; surface ornamented by 8–10 faint longitudinal ribs; dorsal and ventral ribs do not join anteriorly; eye tubercle prominent; hinge entomodont.

Dimensions.—Right valve: length, 0.50 mm; height, 0.27 mm.

Figured specimen.—USNM 316505.

Remarks.—This form may be distinguished from *Cytherura pseudostriata* Hulings, 1966, by its lack of crossribs and its anterior rib arrangement, in which the dorsal and ventral ribs do not join.

Stratigraphic range.—Late Pleistocene-Holocene.

Biofacies.—Rare in oyster-bank and inner sublittoral biofacies.

Modern occurrence.—Found off the Eastern United States between lat 27°09′54″ N. and lat 32°09′42″ N. (fig. 23) at 15–181 m depth.

Cytherura valentini Garbett and Maddocks, 1979

Plate 10, figures 5, 6

Cytherura valentini Garbett and Maddocks, 1979, p. 890, pl. 8, figs. 1–6, text fig. 39.

Description.—Carapace small, males elongate and subrectangular in lateral view, females subquadrate in lateral view; dorsal margin straight, paralleling ventral margin; anterodorsum sloped in females, rounded in males; anterior rounded, caudal process extends posterodorsally; surface strongly reticulate and faintly pitted and has two particularly heavy ventral ridges; eye tubercle prominent; hinge entomodont.

Dimensions.—Left valve: length, 0.43 mm; height, 0.22 mm; right valve: length, 0.41 mm; height, 0.21 mm.

Figured specimens.—USNM 316511, USNM 316512.

Remarks.—This species is distinguished by its rectangular shape, its strong reticulation, and its two heavy ventral ridges.

Stratigraphic range.—Late Pleistocene-Holocene.

Biofacies.—Rare in inner sublittoral and oyster-bank biofacies.

Modern occurrence.—Found in lower bay biofacies of Texas bays and found between lat 27°09′54″ N. and lat 38°40′00″ N. off eastern North America (fig. 22) at 11–36 m depth.

Cytherura aff. C. elongata Edwards, 1944

Plate 11, figures 1, 2

Cytherura sp. D, Valentine, 1971, p. D19, pl. 2, figs. 17, 18, 23, 24.
Cytherura sp. B, Cronin, 1979, p. 144, pl. 9, figs. 1–5.

Description.—Carapace small, males elongate in lateral view, females subquadrate in lateral view; dorsal margin straight, paralleling ventral margin; anterodorsum sloped in females, straight in males; anterior rounded, posterior produced by a rounded central caudal process; surface ornamented by longitudinal ribs and well-developed crossribs centrally, grading into pitted surfaces anteriorly and posteriorly; posterior inflated; normal pores abundant; eye tubercle distinct; hinge entomodont.

Dimensions.—Left valve: length, 0.48 mm; height, 0.23 mm.

Figured specimens.—USNM 316499, USNM 316500.

Remarks.—This form may be distinguished from *Cytherura elongata* Edwards, 1944, by its lack of ventral swelling and its pitted surface. It may be distinguished from *Cytherura reticulata* Edwards, 1944, by its heavier ornamentation.

Stratigraphic range.—Late Pleistocene-Holocene.

Biofacies.—Common to rare in inner sublittoral and oyster-bank biofacies; rare in open-sound biofacies.

Modern occurrence.—Found off the East Coast of the United States between lat 33°10′00″ N. and lat 39°00′00″ N.

Genus TETRACYTHERURA Müller, 1894

Tetracytherura Müller, 1894.

Type species.—*Cytheridea angulosa* Seguenza, 1880.

Tetracytherura mccartanae Cronin, this volume

Plate 8, figure 5

Microcytherura sp. A, Valentine, 1971, p. D19, pl. 4, figs. 13, 14, 19, 20.
Microcytherura sp. C, Cronin and Hazel, 1980, p. B20, fig. 7a.
Tetracytherura mccartanae Cronin, this volume, p. C33, pl. 5, figs. 5, 6.

Description.—Carapace trapezoidal to elongate in lateral view; dorsal and ventral margins nearly straight; anterior rounded, posterior obliquely rounded; surface faintly reticulate and covered by abundant minute pits; hinge merodont.

Dimensions.—Left valve: length, 0.46 mm; height, 0.24 mm.

Figured specimen.—USNM 316501.

Remarks.—This form may be distinguished from *Tetracytherura norfolkensis* (Cronin, 1979) by its weaker reticulation and its abundant pits. It differs from *Tetracytherura choctawhatcheensis* (Puri, 1953c) in its more gently sloped posterior margin and its weaker reticulation.

Stratigraphic range.—Late Pleistocene-Holocene.

Biofacies.—Rare in inner sublittoral biofacies.

Modern occurrence.—Found off the East Coast of the United States between lat 32°59′00″ N. and lat 39°21′00″ N.

Family PARACYTHERIDEIDAE Puri, 1957
Genus PARACYTHERIDEA Müller, 1894

Paracytheridea Müller, 1894.

Type species.—*Paracytheridea depressa* Müller, 1894.

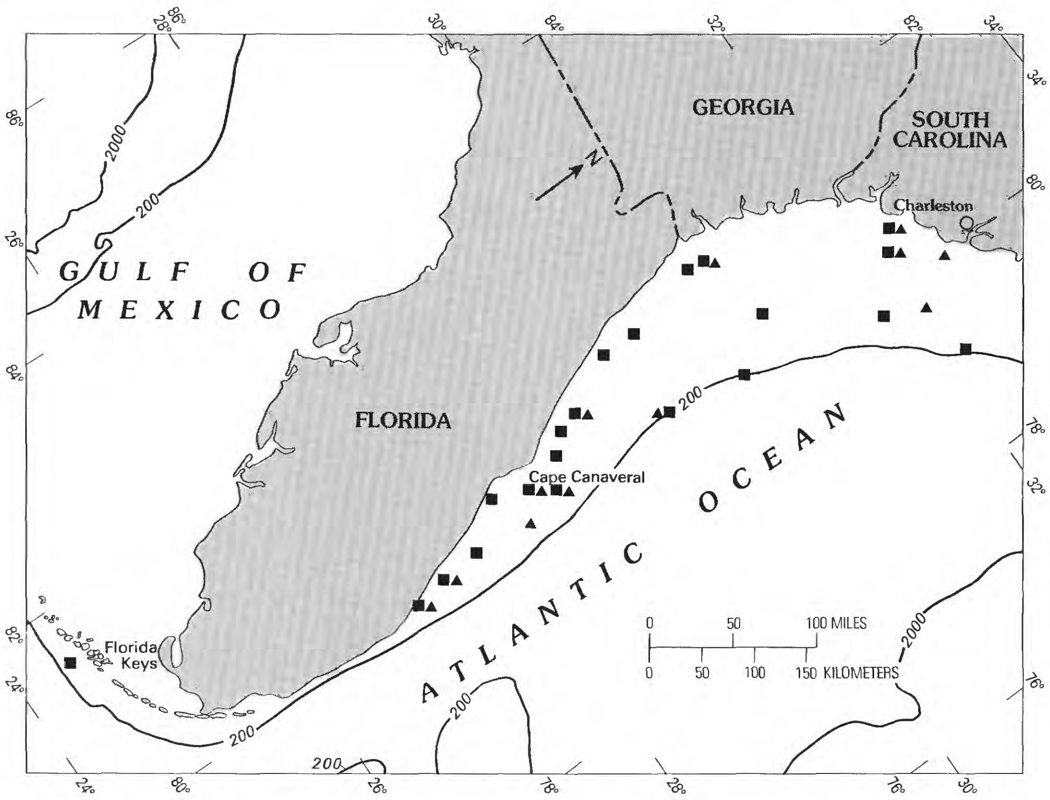


FIGURE 24.—Distribution of *Paracytheridea altila* Edwards, 1944 (solid squares), and *Paracytheridea hazeli* Cronin, this volume (solid triangles). In the Holocene study area, *P. altila* (pl. 11, figs. 3, 4) occurs on the shallow to deep continental shelf between Charleston, S.C., and the Florida Keys, and *P. hazeli* (pl. 11, fig. 6) occurs on the shallow to deep continental shelf between South Carolina and central Florida. Depth contours are in meters.

Remarks.—The type species may be synonymous with *Paracytheridea bovettensis* (Seguenza, 1880), although Van Morkhoven (1963, p. 379) questions this synonymy.

Paracytheridea altila Edwards, 1944

Plate 11, figures 3, 4

Paracytheridea altila Edwards, 1944, p. 512, pl. 85, figs. 20, 21.

Description.—Carapace elongate, quadrate in lateral view, and alate; dorsal margin straight, ventral margin straight with alar process directed posteriorly; anterior rounded, posterior extended by a pointed subdorsal caudal process; carapace posterodorsally inflated, especially in females; surface ornamented by two longitudinal ribs, which are more highly developed in males than females, one rib forming a ventral ridge and the other crossing the carapace centrally; subvertical sulcus distinct; surface covered by a reticulate pit pattern; large eye tubercle distinct anterodorsally behind a shallow depression; hinge paleomerodont.

Dimensions.—Left valve: length, 0.59 mm; height, 0.29 mm.

Figured specimens.—USNM 316488, USNM 316489.

Remarks.—This species may be distinguished from *Paracytheridea chipolensis* Howe and Stephenson, 1935 (*in* Howe and others, 1935), by its lack of a strong spine at the posterior end of the alar process and by its strong dorsal node and medial depression. This species is very similar to *Paracytheridea vandenboldi* Puri, 1953a, but differs from that species in its stronger alae and distinct subvertical sulcus.

Stratigraphic range.—Late Miocene-Holocene.

Biofacies.—Rare in inner sublittoral and oyster-bank biofacies.

Modern occurrence.—Found off the Eastern United States between lat 24°29′18″ N. and lat 35°21′00″ N. (fig. 24) at 11–181 m depth.

Paracytheridea rugosa Edwards, 1944

Plate 11, figure 5

Paracytheridea rugosa Edwards. Cronin, 1979, p. 146, pl. 4, fig. 5.

Description.—Carapace elongate, quadrate in lateral view, and highly alate; dorsal margin straight, ventral margin straight with pointed alar process posteriorly; anterior rounded, posterior extended by a sharp caudal process; surface ornamented by three irregular ribs, of which the dorsal rib dies out anteriorly, the ventral rib extends to a sharp spine posteroventrally, and the central rib bifurcates anteriorly, one branch joining the ventral rib and the other reaching to the posterocardinal angle; posterior region has a weak, irregular reticulate pattern; hinge paleomerodont.

Dimensions.—Left valve: length, 0.50 mm; height, 0.26 mm.

Figured specimen.—USNM 316487.

Remarks.—This form differs from *Paracytheridea rugosa* Edwards, 1944, as it lacks the latter's distinctive triangular ridge arrangement from anterior to middle. It may be distinguished from *Paracytheridea altila* Edwards, 1944 (see above), by its stronger, more pointed alar process, its lack of posterodorsal inflation, and its lack of strong reticulation. It differs from *Paracytheridea chipolensis* Howe and Stephenson, 1935 (*in* Howe and others, 1935), by its lack of strong reticulation and its lack of posterodorsal inflation.

Stratigraphic range.—Late Pleistocene.

Biofacies.—Rare in inner sublittoral biofacies.

Paracytheridea hazeli Cronin, this volume

Plate 11, figure 6

Paracytheridea sp. A, Cronin, 1979, p. 146, pl. 4, fig. 6.
Paracytheridea hazeli Cronin, this volume, p. C34, pl. 4, figs. 7, 8, pl. 17, fig. 6.

Description.—Carapace elongate in lateral view; dorsal margin convex (anteriorly arched), ventral margin straight; dorsal and ventral margins taper posteriorly; anterior rounded, posterior pointed; surface ornamented by many irregular, longitudinal ribs, of which two prominent ribs cross the carapace and coalesce anteriorly; strong ridge present that parallels the dorsal margin; small alar process posteroventrally; surface appears "wrinkled"; hinge paleomerodont.

Dimensions.—Left valve: length, 0.45 mm; height, 0.25 mm.

Figured specimen.—USNM 316490.

Remarks.—This form may be distinguished from *Paracytheridea tschoppi* van den Bold, 1946, by its lack of swelling in front of the posterior cardinal angle and its smaller posteroventral alar process.

Stratigraphic range.—Middle Pleistocene-Holocene.

Biofacies.—Rare in inner sublittoral biofacies.

Modern occurrence.—Found off the Eastern United States between lat 27°09′54″ N. and lat 35°09′00″ N. (fig. 24) at 11–77 m depth.

Family BRACHYCYTHERIDAE Puri, 1953c
Genus PTERYGOCYTHEREIS Blake, 1933

Fimbria Neviani, 1928, preoccupied by *Fimbria* Bohadsch 1761 (Mollusca), Rosso 1826 (Tunicata).
Pterygocythereis Blake, 1933.
Diogmopteron Hill, 1954.
Alatacythere Murray and Hussey, 1942.

Type species.—*Cythereis jonesii* Baird, 1850.

Remarks.—This genus is characterized by strong, pointed alae and a bladelike dorsal ridge.

Pterygocythereis alophia Hazel, 1983

Plate 11, figure 7

Pterygocythereis sp. A, Cronin, 1979, p. 147 (oral commun., 1981).
Pterygocythereis alophia Hazel, 1983, p. 104, pl. 7, figs. 2, 4.

Description.—Carapace large and subquadrate; dorsal and ventral margins straight; anterior rounded, posterior sloped downward and pointed; margins denticulate, and posterior denticles are larger and fewer than along anterior and ventral margins; a denticulate ala extends posteroventrally; dorsal ridge pointed; surface smooth; inner lamella narrow; hinge holamphidont.

Dimensions.—Left valve: length, 0.88 mm; height, 0.41 mm.

Figured specimen.—USNM 316472.

Remarks.—This species differs from *Pterygocythereis americana* (Ulrich and Bassler, 1904) in its lack of a fluted dorsal crest and in its denticulate, rather than spinose, ala. It may be distinguished from *Pterygocythereis cornuta* (Roemer, 1838) by its smooth surface. It differs from *Pterygocythereis miocenica* van den Bold, 1967, in its smaller size, its less sloping dorsal margin, and its denticulate ala.

Stratigraphic range.—Pliocene-Holocene.

Biofacies.—Rare in inner sublittoral biofacies.

Modern occurrence.—Found off the East Coast of the United States between lat 24°25′06″ N. and lat 36°09′00″ N. (fig. 25) at 17–181 m depth.

Suborder PLATYCOPINA Sars, 1866
Family CYTHERELLIDAE Sars, 1866
Genus CYTHERELLOIDEA Alexander, 1929

Cytherelloidea Alexander, 1929.

Type species.—*Cythere* (*Cytherella*) *williamsoniana* Jones, 1849.

Remarks.—This genus differs from *Cytherella* Jones, 1849, in its ornamented carapace and, for females, its two posterior, internal brood cavities.

Cytherelloidea sp.

Plate 11, figure 8

Description.—Carapace subrectangular in lateral view; dorsal and ventral margins slightly concave in center; anterior broadly rounded, posterior rounded; surface smooth, except for scattered normal pores and a

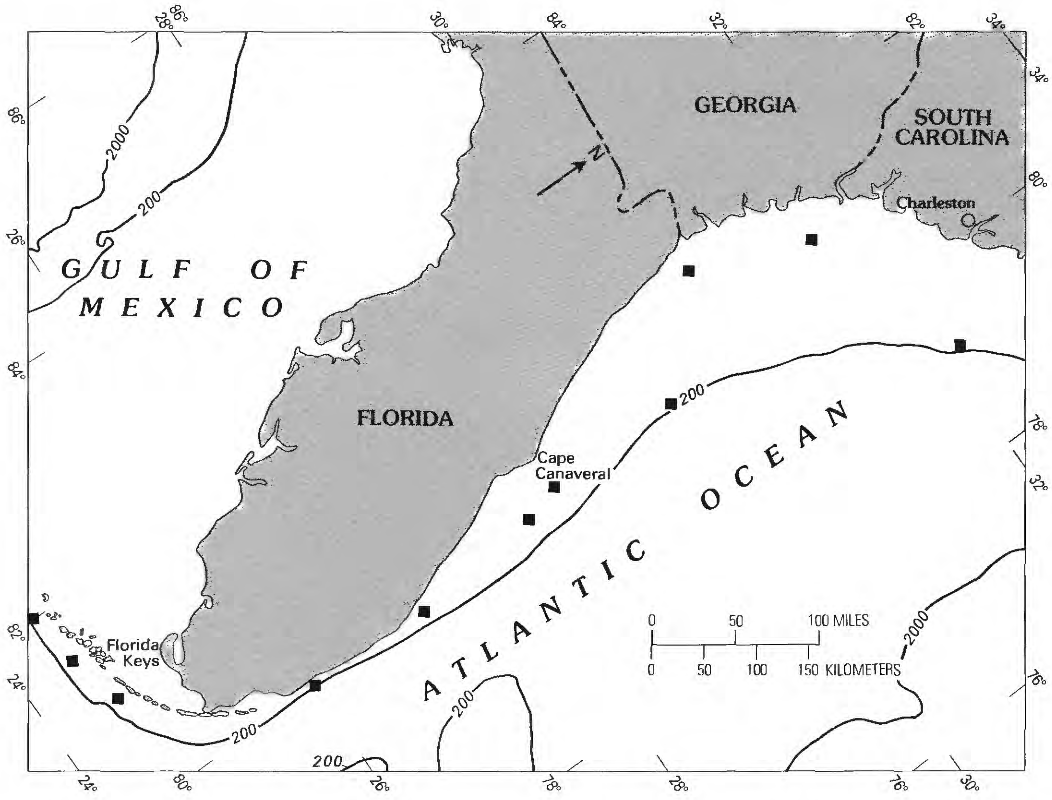


FIGURE 25.—Distribution of *Pterygocythereis alophia* Hazel, 1983 (solid squares). This species (pl. 11, fig. 7) occurs in the Holocene study area on the shallow to deep continental shelf between Charleston, S.C., and the Florida Keys. Depth contours are in meters.

large, circular, central depression; a faint ridge parallels posterior margin; in females, internal brood cavity shallow; hinge has a groove in the right valve and a flange in the left valve.

Dimensions.—Left valve: length, 0.61 mm; height, 0.33 mm.

Figured specimen.—USNM 316470.

Remarks.—This form may be distinguished from *Cytherelloidea sarsi* Puri, 1960, *Cytherelloidea umbonata* Edwards, 1944, and *Cytherelloidea cavernosa* (Brady, 1868b) by its nonreticulate, smooth surface, its absence of longitudinal ridges, and its relatively large, circular, central depression.

Stratigraphic range.—Late Pleistocene.

Biofacies.—Rare in inner sublittoral biofacies.

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PLATES 1–11

USNM, U.S. National Museum, Washington, D.C.
Contact photographs of plates 1–11 are available,
at cost, from the U.S. Geological Survey Photographic Library, Federal Center,
Denver, CO 80225.

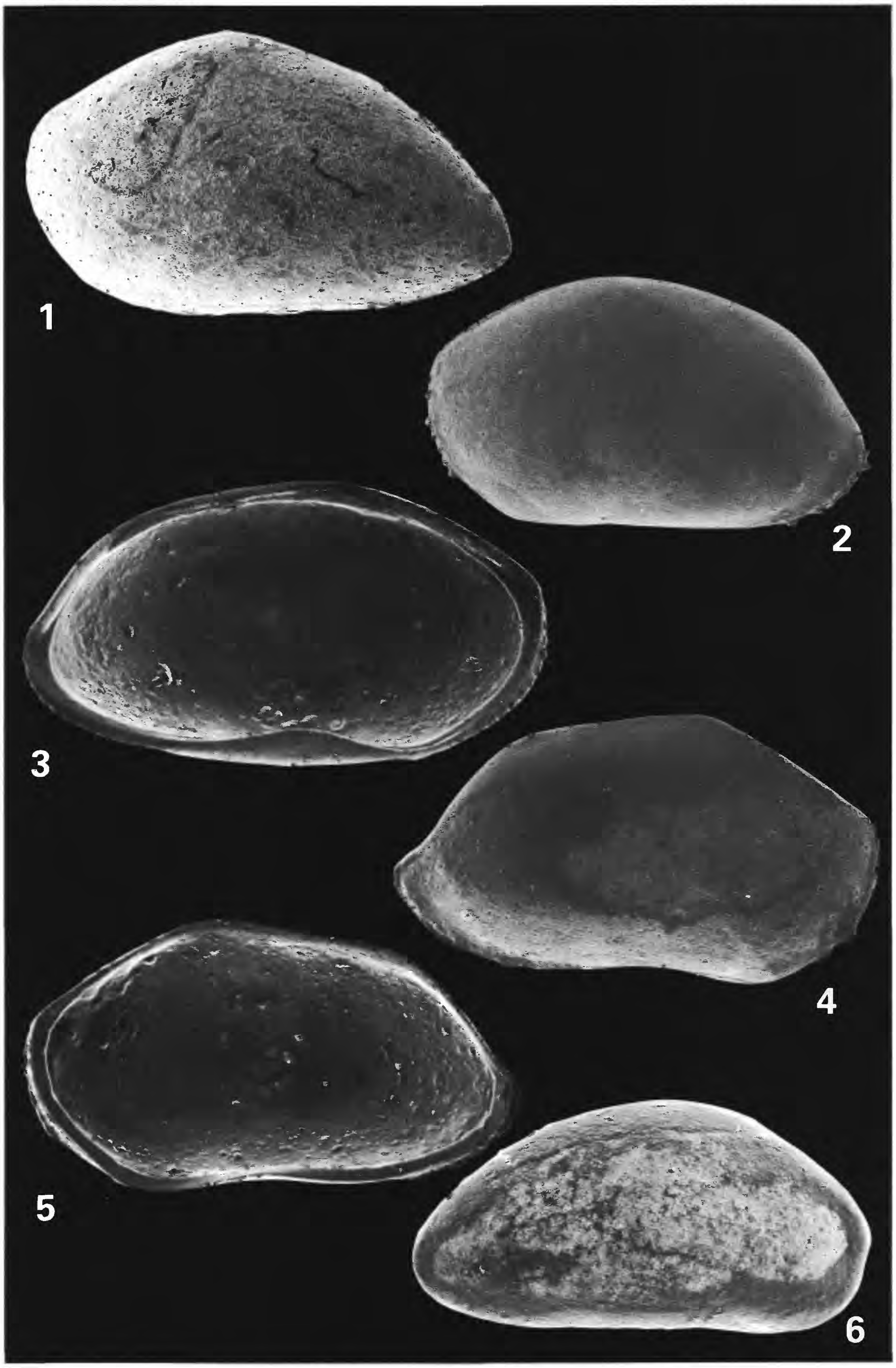
PLATE 1

FIGURE 1. *Neonesidea gerda* (Benson and Coleman, 1963) (p. D17).
    Lateral view, left valve (×150), USNM 316437, from auger hole C17 at 4.0 m below sea level.

2, 3. *Bairdoppilata* sp. (p. D17).
    2. Lateral view, left valve (×130), USNM 316438, from auger hole JI18 at 1.2 m below sea level.
    3. Internal view, left valve (×150), USNM 316439, from auger hole C17 at 1.5 m below sea level.

4, 5. *Bairdoppilata* sp. (p. D17).
    4. Lateral view, right valve (×120), USNM 316440, from auger hole FM4 at 8.9 m below sea level.
    5. Internal view, right valve (×120), USNM 316441, from auger hole C17 at 1.5 m below sea level.

6. *Propontocypris edwardsi* (Cushman, 1906) (p. D18).
    Lateral view, right valve (×150), USNM 316442, from auger hole JI18 at 2.4 m below sea level.



NEONESIDEA, *BAIRDOPPILATA*, AND *PROPONTOCYPRIS*

PLATE 2

FIGURE 1. *Loxoconcha reticularis* Edwards, 1944 (p. D18).
Lateral view, left valve (×160), USNM 316456, from auger hole JI18 at 1.2 m above sea level.

2. *Loxoconcha matagordensis* Swain, 1955 (p. D18).
Lateral view, left valve (×150), USNM 316457, from auger hole C10 at 8.9 m below sea level.

3. *Loxoconcha* cf. *L. florencensis* Cronin, this volume (p. D18).
Lateral view, left valve (×120), USNM 316458, from auger hole C7 at 7.6 m below sea level.

4. *Cytheromorpha curta* Edwards, 1944 (p. D19).
Lateral view, left valve, juvenile (×180), USNM 316459, from auger hole FM2 at 2.1 m below sea level.

5. *Cytheromorpha newportensis* Williams, 1966 (p. D20).
Lateral view, right valve (×130), USNM 316460, from auger hole JI18 at 1.2 m above sea level.

6. *Campylocythere laeva* Edwards, 1944 (p. D20).
Lateral view, left valve, female? (×100), USNM 316461, from auger hole JI18 at sea level.

7. *Leptocythere nikraveshae* Morales, 1966 (p. D20).
Lateral view, left valve (×150), USNM 316462, from auger hole FM2 at 2.1 m below sea level.

8. *Muellerina ohmerti* Hazel, 1983 (p. D25).
Lateral view, left valve (×130), USNM 316463, from auger hole C7 at 7.6 m below sea level.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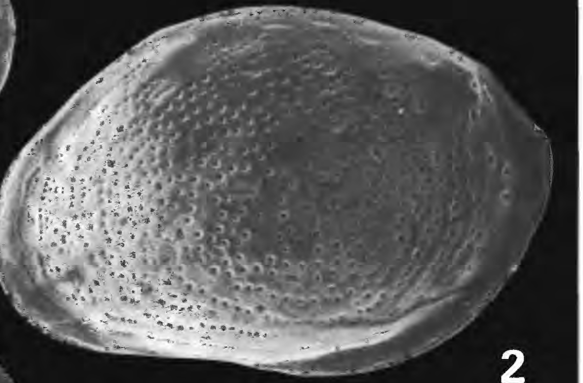
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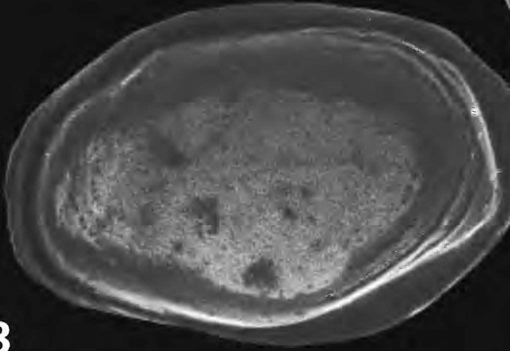
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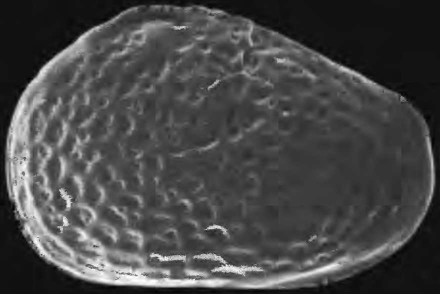
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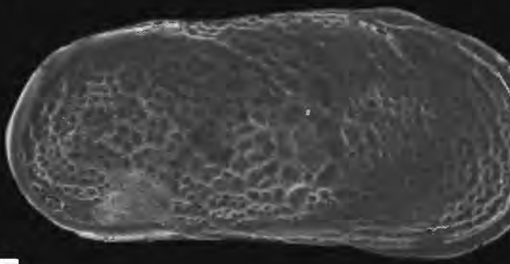
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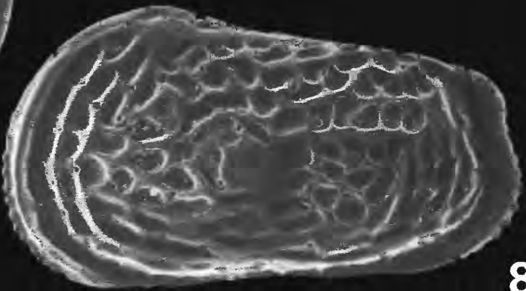
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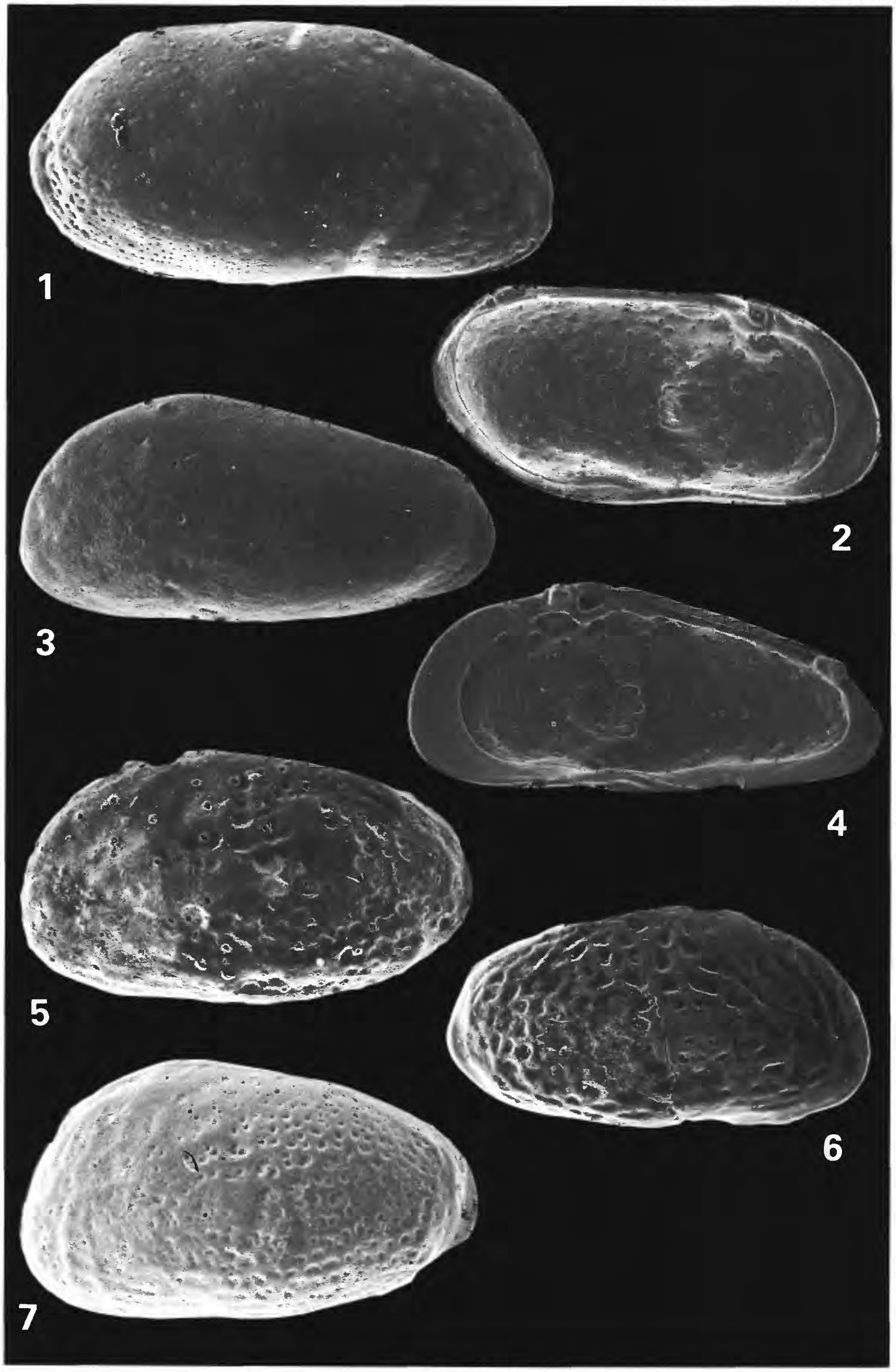
LOXOCONCHA, CYTHEROMORPHA, CAMPYLOCYTHERE, LEPTOCYTHERE, AND *MUELLERINA*

PLATE 3

FIGURES 1, 2. *Proteoconcha gigantica* (Edwards, 1944) (p. D21).
- 1. Lateral view, right valve (×120), USNM 316450, from auger hole C10 at 6.1 m below sea level.
- 2. Internal view, left valve (×94), USNM 316451, from auger hole C10 at 6.1 m below sea level.

3, 4. *Proteoconcha tuberculata* (Puri, 1960) (p. D21).
- 3. Lateral view, left valve (×130), USNM 316452, from auger hole C10 at 5.3 m below sea level.
- 4. Internal view, right valve (×130), USNM 316453, from auger hole C10 at 5.3 m below sea level.

5–7. *Proteoconcha nelsonensis* (Grossman, 1967) (p. D22).
- 5. Lateral view, left valve (×150), USNM 316455, from auger hole JI18 at 1.2 m above sea level.
- 6. Lateral view, right valve (×130), USNM 316506, from auger hole JI18 at 1.2 m above sea level.
- 7. Lateral view, left valve (×150), USNM 316454, from auger hole C10 at 5.3 m below sea level.



PROTEOCONCHA

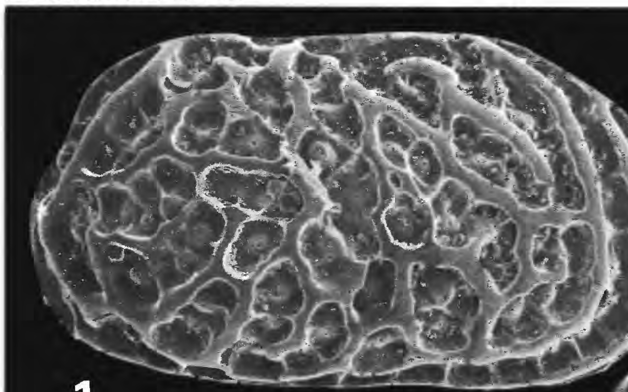
PLATE 4

FIGURE 1. *Bensonocythere whitei* (Swain, 1951) (p. D23).
Lateral view, right valve, female (×130), USNM 316478, from auger hole C10 at 1.5 m above sea level.

2, 3. *Bensonocythere sapeloensis* (Hall, 1965) (p. D23).
2. Lateral view, right valve, female (×120), USNM 316479, from auger hole JI18 at sea level.
3. Lateral view, right valve, male (×150), USNM 316480, from auger hole JI18 at sea level.

4, 5. *Bensonocythere valentinei* Cronin, this volume (p. D23).
4. Lateral view, left valve, female (×130), USNM 316481, from auger hole JI18 at sea level.
5. Lateral view, left valve, male (×150), USNM 316482, from auger hole JI18 at sea level.

6, 7. *Bensonocythere hazeli* Cronin, this volume (p. D24).
6. Lateral view, right valve, male (×160), USNM 316483, from auger hole C10 at 5.3 m below sea level.
7. Lateral view, left valve, female (×150), USNM 316484, from auger hole C10 at 5.3 m below sea level.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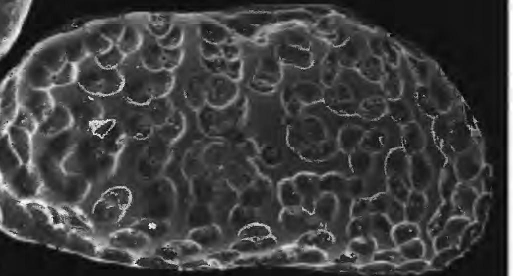
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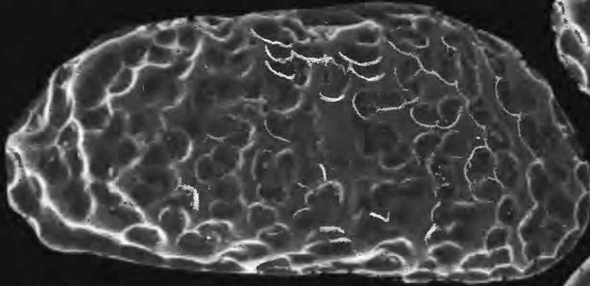
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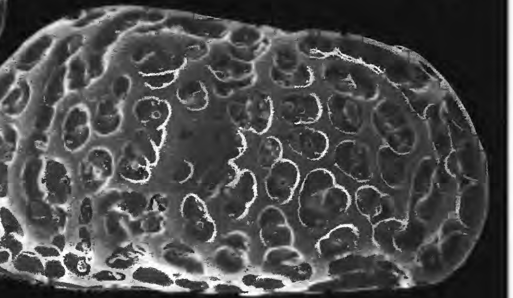
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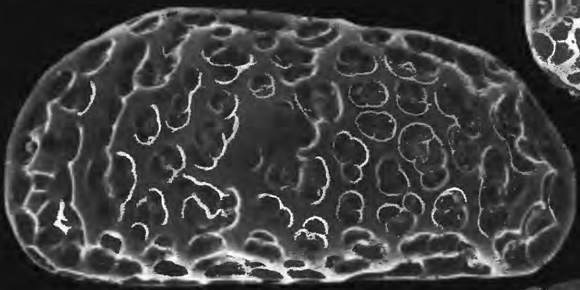
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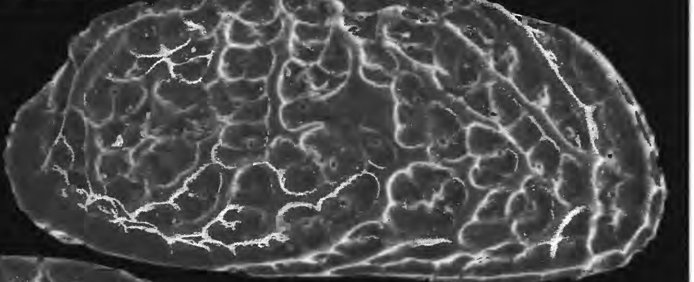
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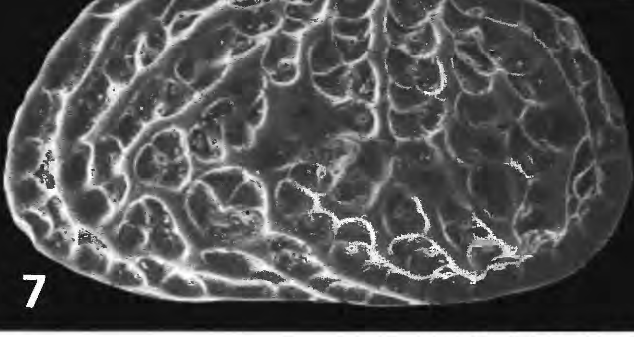
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BENSONOCYTHERE

PLATE 5

FIGURE 1. *Malzella evexa* Hazel, 1983 (p. D25).
Lateral view, right valve, juvenile (×150), USNM 316464, from auger hole C17 at 1.5 m below sea level.

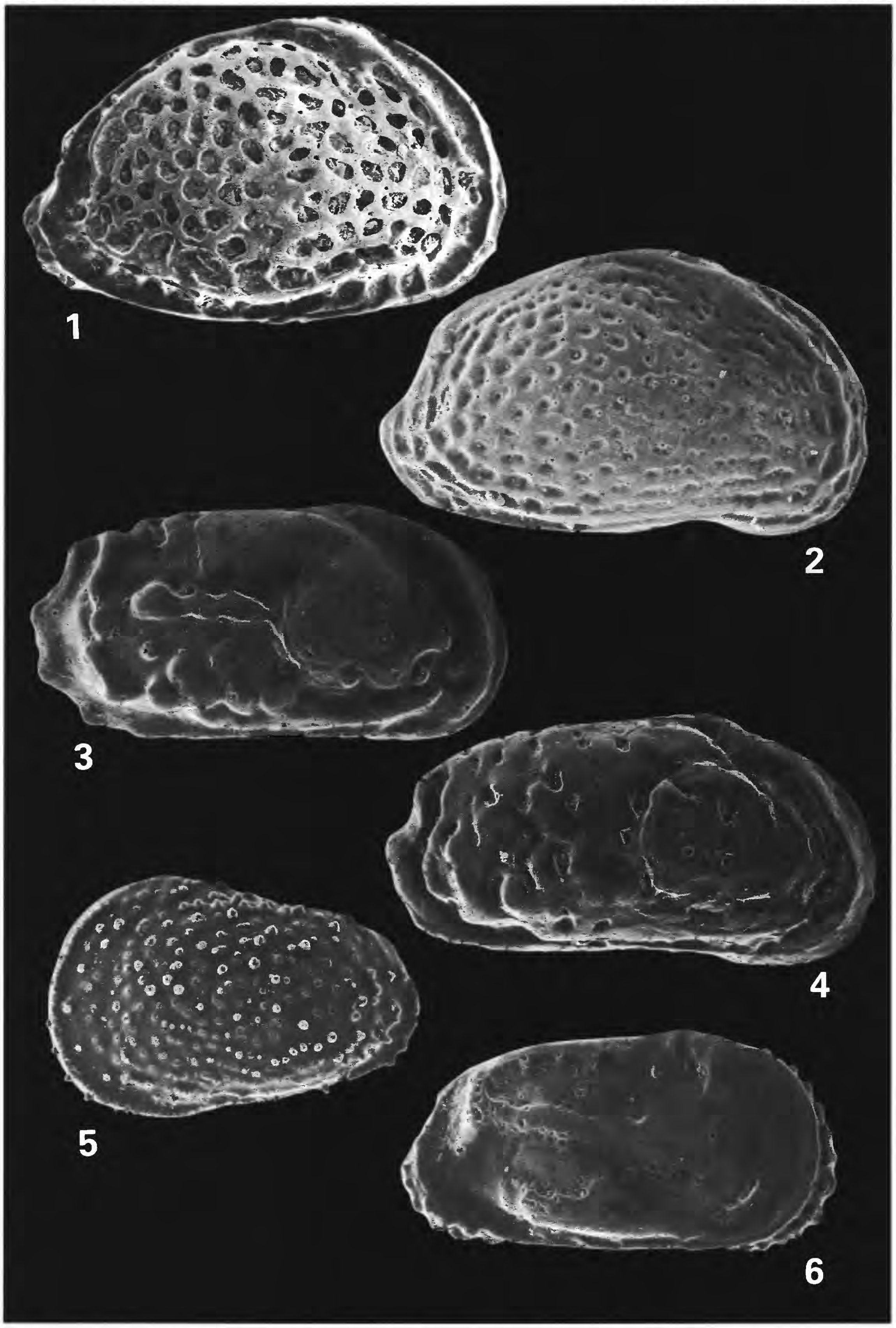
2. *Aurila laevicula* (Edwards, 1944) (p. D25).
Lateral view, right valve (×160), USNM 316465, from auger hole JI18 at sea level.

3. *Puriana floridana* Puri, 1960 (p. D27).
Lateral view, right valve (×130), USNM 316476, from auger hole JI18 at 1.2 m below sea level.

4. *Puriana carolinensis* Hazel, 1983 (p. D26).
Lateral view, right valve (×150), USNM 316477, from auger hole JI18 at 1.2 m below sea level.

5. *Echinocythereis* sp. (p. D28).
Lateral view, left valve, juvenile (×130), USNM 316475, from auger hole C7 at 7.6 m below sea level.

6. *Neocaudites atlantica* Cronin, 1979 (p. D28).
Lateral view, right valve, female (×110), USNM 316474, from auger hole C11 at 3.7 m below sea level.



MALZELLA, AURILA, PURIANA, ECHINOCYTHEREIS, AND *NEOCAUDITES*

PLATE 6

FIGURE 1. *Actinocythereis captionis* Hazel, 1983 (p. D29).
Lateral view, left valve (×110), USNM 316471, from auger hole C17 at 1.5 m below sea level.

2. *Protocytheretta* cf. *P. sahnii* (Puri, 1952) (p. D29).
Lateral view, right valve (×86), USNM 316473, from auger hole C17 at 1.5 m below sea level.

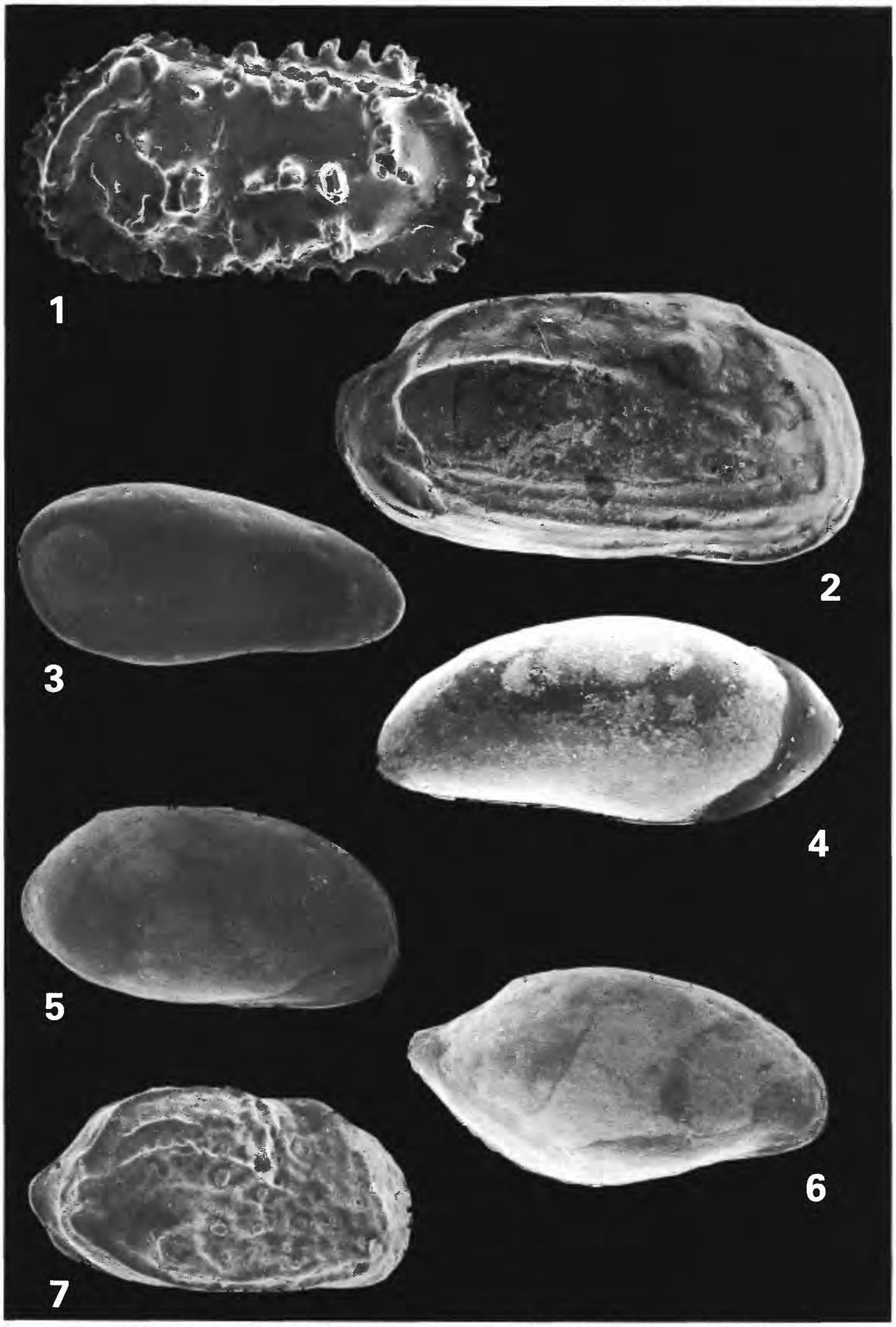
3. *Paradoxostoma delicata* Puri, 1953c (p. D30).
Lateral view, right valve (×150), USNM 316466, from auger hole FM2 at 2.1 m below sea level.

4. *Paradoxostoma* sp. (p. D30).
Lateral view, left valve (×130), USNM 316467, from auger hole JI18 at sea level.

5. *Paracytheroma stephensoni* (Puri, 1953c) (p. D30).
Lateral view, right valve (×120), USNM 316468, from auger hole C17 at 4.0 m below sea level.

6. *Pellucistoma magniventra* Edwards, 1944 (p. D31).
Lateral view, right valve (×110), USNM 316469, from auger hole JI18 at 2.4 m below sea level.

7. *Perissocytheridea brachyforma* Swain, 1955 (p. D34).
Lateral view, right valve (×120), USNM 316502, from auger hole C10 at 0.3 m below sea level.



ACTINOCYTHEREIS, *PROTOCYTHERETTA*, *PARADOXOSTOMA*, *PARACYTHEROMA*, *PELLUCISTOMA*, AND *PERISSOCYTHERIDEA*

PLATE 7

FIGURE 1. *Peratocytheridea setipunctata* (Brady, 1869b) (p. D32).
  Lateral view, left valve (×86), USNM 316443, from auger hole C10 at 5.3 m below sea level.

2. *Peratocytheridea bradyi* (Stephenson, 1938) (p. D31).
  Lateral view, left valve (×100), USNM 316444, from auger hole C10 at 6.1 m below sea level.

3. *Cyprideis salebrosa* van den Bold, 1963 (p. D33).
  Lateral view, right valve (×78), USNM 316445, from auger hole C11 at 4.3 m below sea level.

4, 5. *Cyprideis mexicana* Sandberg, 1964 (p. D33).
  4. Lateral view, right valve (×94), USNM 316446, from auger hole C10 at 0.3 m above sea level.
  5. Internal view, right valve (×94), USNM 316447, from auger hole C10 at 0.3 m above sea level.

6, 7. *Cyprideis margarita* Cronin, 1979 (p. D33).
  6. Lateral view, right valve (×120), USNM 316448, from auger hole C10 at 0.3 m above sea level.
  7. Internal view, right valve (×100), USNM 316449, from auger hole C10 at 0.3 m above sea level.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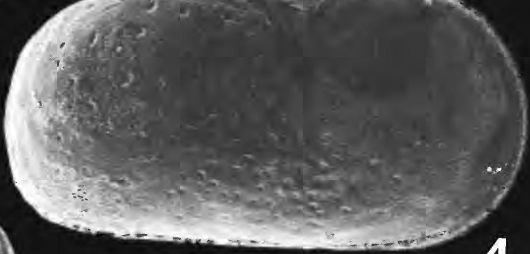
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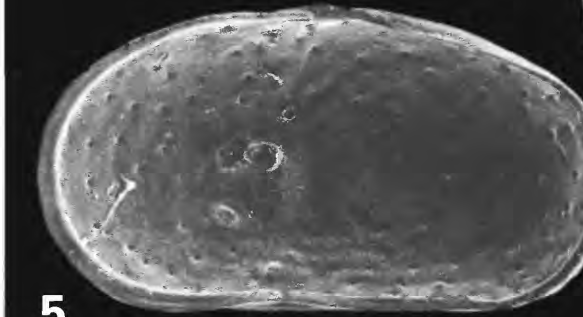
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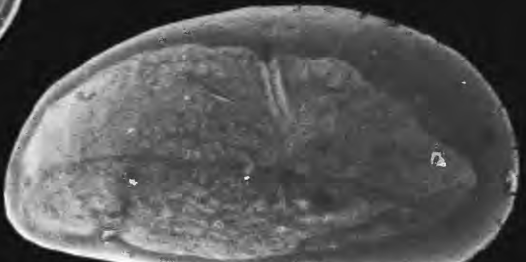
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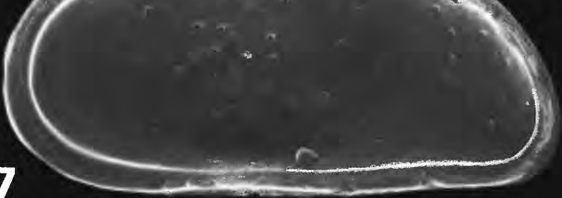
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PERATOCYTHERIDEA AND *CYPRIDEIS*

PLATE 8

FIGURE 1. *Eucythere triangulata* Puri, 1953c (p. D34).
Lateral view, right valve (×120), USNM 316486, from auger hole JI18 at 2.4 m below sea level.

2. *Eucythere declivis* (Norman, 1865) (p. D34).
Lateral view, right valve (×150), USNM 316485, from auger hole C10 at 5.3 m below sea level.

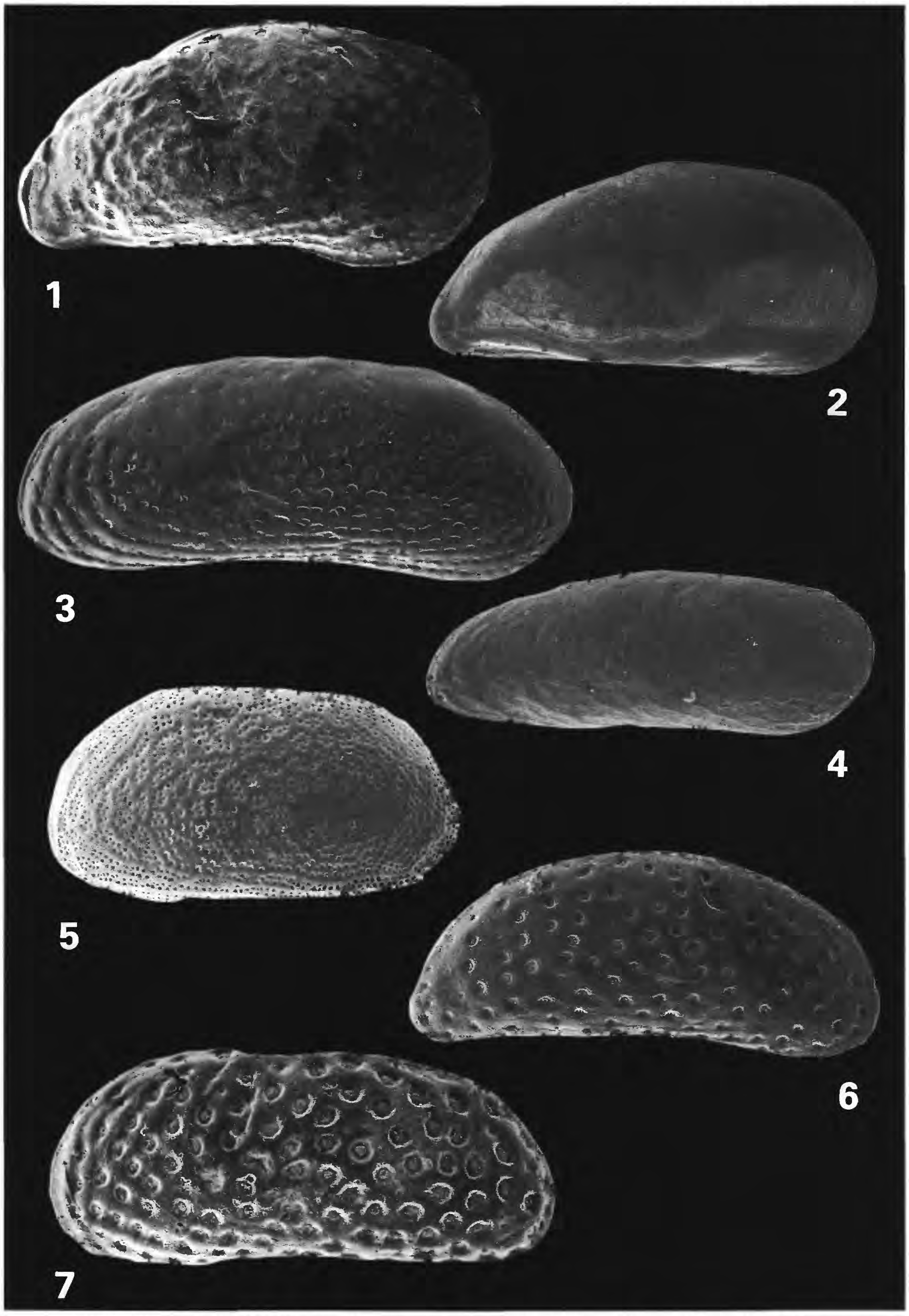
3. *Cushmanidea seminuda* (Cushman, 1906) (p. D35).
Lateral view, left valve (×94), USNM 316491, from auger hole FM3 at 5.2 m below sea level.

4. *Sahnicythere* sp. (p. D38).
Lateral view, left valve (×130), USNM 316492, from auger hole JI18 at sea level.

5. *Tetracytherura mccartanae* Cronin, this volume (p. D42).
Lateral view, left valve (×150), USNM 316501, from auger hole C10 at 5.3 m below sea level.

6. *Hulingsina* aff. *H. semicircularis* (Ulrich and Bassler, 1904) (p. D37).
Lateral view, right valve (×94), USNM 316504, from auger hole JI18 at sea level.

7. *Hulingsina americana* (Cushman, 1906) (p. D37).
Lateral view, left valve (×86), USNM 316503, from auger hole FM3 at 5.2 m below sea level.



EUCYTHERE, CUSHMANIDEA, SAHNICYTHERE, TETRACYTHERURA, AND *HULINGSINA*

PLATE 9

FIGURES 1, 2. *Hulingsina rugipustulosa* (Edwards, 1944) (p. D35).

1. Lateral view, left valve (×130), USNM 316493, from auger hole C7 at 4.3 m below sea level.
2. Lateral view, right valve (×150), USNM 316494, from auger hole C10 at 6.1 m below sea level.

3. *Hulingsina glabra* (Hall, 1965) (p. D35).

Lateral view, left valve (×130), USNM 316495, from auger hole C7 at 7.6 m below sea level.

4. *Hulingsina* sp. (p. D35).

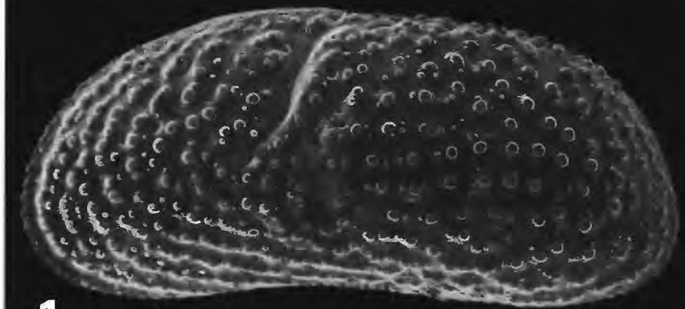
Lateral view, right valve (×120), USNM 316496, from auger hole JI18 at sea level.

5. *Hulingsina* aff. *H. glabra* (Hall, 1965) (p. D36).

Lateral view, right valve (×110), USNM 316497, from auger hole JI18 at 1.2 m below sea level.

6. *Hulingsina* aff. *H. rugipustulosa* (Edwards, 1944) (p. D36).

Lateral view, right valve (×160), USNM 316498, from auger hole C10 at 8.9 m below sea level.



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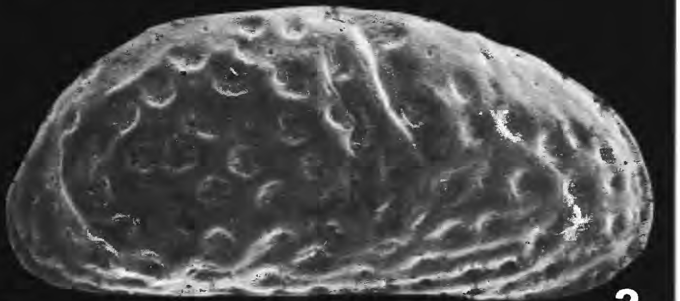

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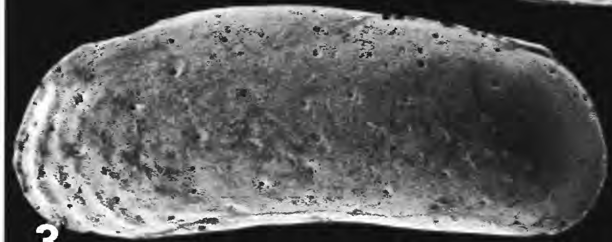

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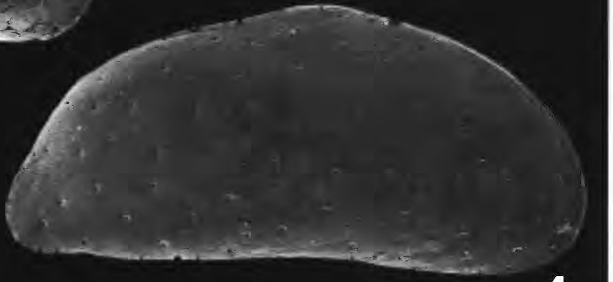

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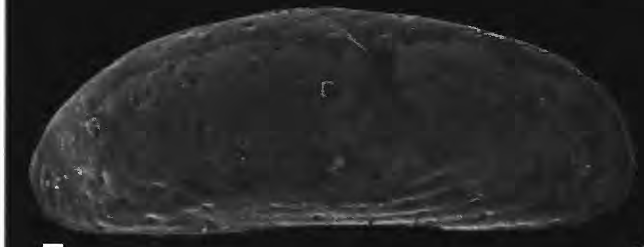

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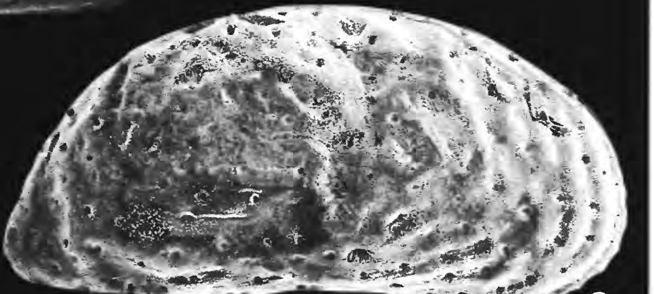

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HULINGSINA

PLATE 10

FIGURE 1. *Cytherura forulata* Edwards, 1944 (p. D39).
Lateral view, left valve (×160), USNM 316507, from auger hole JI18 at 2.4 m below sea level.

2. *Cytherura wardensis* Howe and Brown, 1935 (p. D39).
Lateral view, right valve, male (×160), USNM 316508, from auger hole C7 at 4.3 m below sea level.

3. *Cytherura nucis* Garbett and Maddocks, 1979 (p. D40).
Lateral view, right valve (×220), USNM 316509, from auger hole FM2 at 2.1 m below sea level.

4. *Cytherura* aff. *C. swaini* van den Bold, 1963 (p. D40).
Lateral view, right valve (×220), USNM 316510, from auger hole FM2 at 2.1 m below sea level.

5, 6. *Cytherura valentini* Garbett and Maddocks, 1979 (p. D42).
5. Lateral view, left valve, female (×160), USNM 316512, from auger hole C7 at 4.3 m below sea level.
6. Lateral view, right valve, female (×160), USNM 316511, from auger hole JI18 at 2.4 m below sea level.

7. *Cytherura pseudostriata* Hulings, 1966 (p. D41).
Lateral view, left valve, female? (×150), USNM 316513, from auger hole FM4 at 8.9 m below sea level.

8. *Cytherura* aff. *C. pseudostriata* Hulings, 1966 (p. D41).
Lateral view, right valve (×150), USNM 316505, from auger hole C7 at 4.3 m below sea level.

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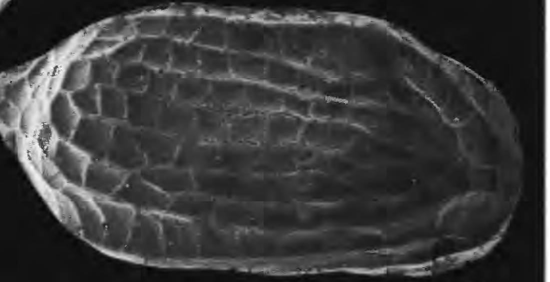

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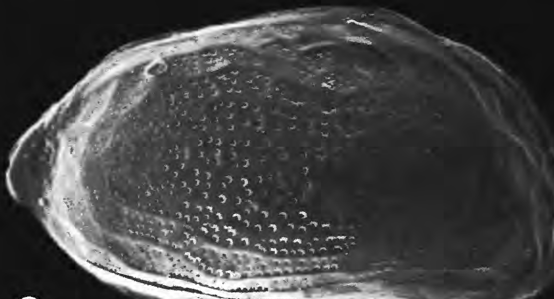

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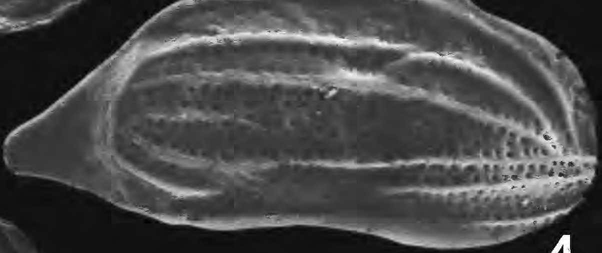

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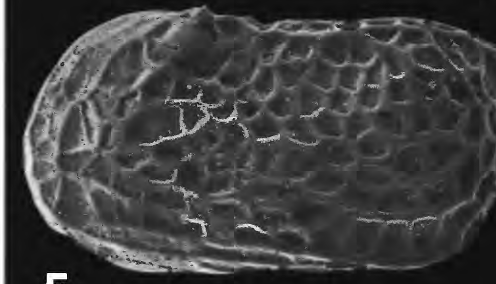

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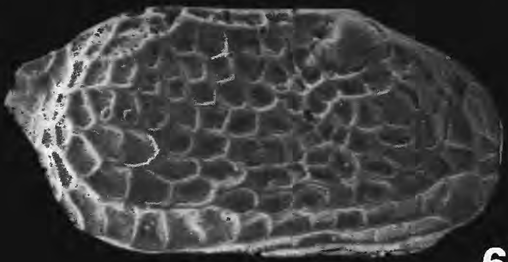

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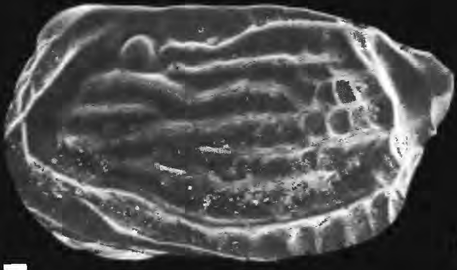

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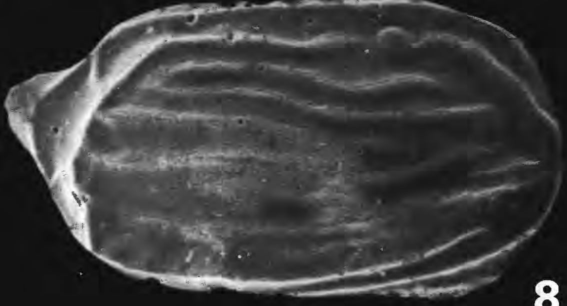

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CYTHERURA

PLATE 11

FIGURES 1, 2. *Cytherura* aff. *C. elongata* Edwards, 1944 (p. D42).
  1. Lateral view, left valve, male (×160), USNM 316500, from auger hole C5 at 6.7 m below sea level.
  2. Lateral view, right valve, female (×160), USNM 316499, from auger hole C10 at 0.3 m above sea level.

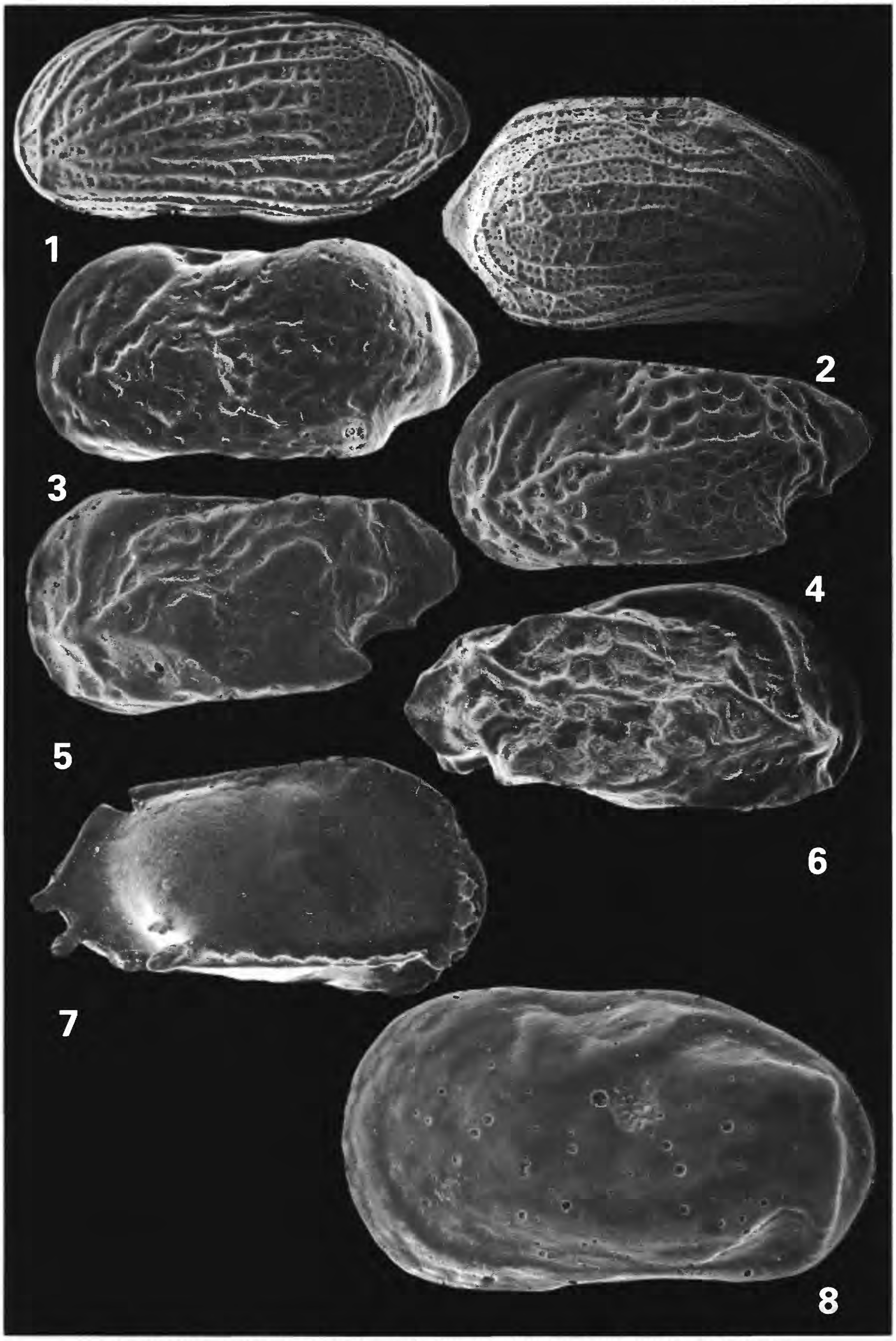
3, 4. *Paracytheridea altila* Edwards, 1944 (p. D43).
  3. Lateral view, left valve, female (×130), USNM 316488, from auger hole JI18 at 1.2 m above sea level.
  4. Lateral view, left valve, male (×120), USNM 316489, from auger hole C7 at 5.8 m below sea level.

5. *Paracytheridea rugosa* Edwards, 1944 (p. D43).
  Lateral view, left valve (×150), USNM 316487, from auger hole JI18 at 2.4 m below sea level.

6. *Paracytheridea hazeli* Cronin, this volume (p. D44).
  Lateral view, left valve (×150), USNM 316490, from auger hole JI18 at 1.2 m above sea level.

7. *Pterygocythereis alophia* Hazel, 1983 (p. D44).
  Lateral view, right valve (×120), USNM 316472, from auger hole JI18 at sea level.

8. *Cytherelloidea* sp. (p. D44).
  Lateral view, left valve (×150), USNM 316470, from auger hole C7 at 7.6 m below sea level.



CYTHERURA, PARACYTHERIDEA , PTERYGOCYTHEREIS, AND *CYTHERELLOIDEA*

Neogene and Pleistocene Dinocysts of the Charleston, South Carolina, Region

By LUCY E. EDWARDS

STUDIES RELATED TO THE CHARLESTON, SOUTH CAROLINA,
EARTHQUAKE OF 1886—NEOGENE AND QUATERNARY
LITHOSTRATIGRAPHY AND BIOSTRATIGRAPHY

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1367–E

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NEOGENE AND PLEISTOCENE DINOCYSTS OF THE CHARLESTON, SOUTH CAROLINA, REGION

By Lucy E. Edwards

ABSTRACT

The distribution and ranges of dinoflagellate cysts were recorded for 17 samples from the Charleston and Beaufort, S.C., areas in order to examine the biostratigraphic potential of the dinocysts. The emphasis of the study is placed on the Miocene formations: Edisto, Marks Head, and Coosawhatchie. However, the study also includes one sample each from the Oligocene Chandler Bridge Formation and the Pleistocene Penholoway and Canepatch(?) Formations. The observed dinocyst ranges are given for the Charleston and Beaufort areas, and biostratigraphically important forms are illustrated.

Dinocyst preservation varies from poor to good, and species diversity often varies correspondingly. The Oligocene assemblage is dominated by *Homotryblium plectilum*. Potentially useful dinocyst datums in the Miocene include the highest occurrences of *Membranophoridium aspinatum* and vermicular forms of *Pentadinium laticinctum* and the lowest occurrences of *Batiacasphaera sphaerica*, *Pentadinium* sp. I, and *Labyrinthodinium truncatum*. Pleistocene assemblages contain few dinocysts relative to the amount of pollen but are dominated by *Spiniferites* spp.

Dinocysts offer considerable promise for biostratigraphic correlation within the Miocene deposits of the Coastal Plain of South Carolina, and some correlations can be made between the present study and previously published dinocyst zonation schemes. However, no single zonation is applicable.

INTRODUCTION

Dinoflagellates are unicellular algae that may inhabit marine, fresh, or brackish water. The life cycle of some dinoflagellates includes an encysted stage, the dinocyst, that is composed of an organic wall. As part of the Charleston Project, the Miocene formations in the area were examined for dinocysts. A small number of older and younger samples also were included in the study.

Relatively few detailed stratigraphic studies have been made of Miocene dinoflagellate cysts. Maier (1959) and Gerlach (1961) documented the occurrences of selected dinocysts in Germany, and these occurrences included Miocene material. Habib (1971) reported the occurrences of dinoflagellates across the Miocene-Pliocene boundary in northern Italy. Later, Habib (1972) included Miocene dinoflagellate cysts in his report on the Mesozoic and Cenozoic deposits off the coast of Southeastern North America. Williams (1975) and Williams and Brideaux (1975) included Miocene, as well as older and younger, dinoflagellate material in their studies of the Grand Banks and Scotian Shelf. In his later work, Williams (1977) presented a zonation of the Triassic to Pliocene that included three zones in the Miocene. Manum (1976) studied the Tertiary dinocysts from the Norwegian-Greenland Sea sediments and devised a provisional zonation. Stover (1977) documented the recovery of dinocysts from the Oligocene to early Miocene deposits off the shore of South Carolina (Blake Plateau), and he divided the section into four informal intervals. Costa and Downie (1979) reported on the Cenozoic dinocysts from the North Atlantic Ocean (Rockall Plateau) and established nine informal partial-range zones. Harland (1979) erected a different, tentative fourfold informal zonation for the Neogene and Quaternary units of the Bay of Biscay. Piasecki (1980) set up four formal biozones based on the successive first occurrences of dinoflagellates from the Miocene deposits of Denmark. Parts of these formal and informal dinocyst zonations are summarized in figure 1, which focuses on the Miocene.

Because there is no widely accepted dinoflagellate zonation for the Neogene and Quaternary and because very little is known of the dinoflagellates of this age in the Eastern United States, the present study was undertaken. The purpose of it was to record the distribution and ranges of dinocysts in the Charleston and Beaufort areas of South Carolina and Georgia and to examine the

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biostratigraphic potential of dinocysts. The study is based on the recovery of dinocysts from 17 reconnaissance samples of both outcrop and auger-hole material. The observed dinocyst ranges are reported and important taxa are illustrated, but no formal or informal zonation is introduced.

ACKNOWLEDGMENTS

Field work and sampling for this study were performed by E.M. Lemon, Jr., Lucy McCartan, and R.E. Weems, all of the U.S. Geological Survey (USGS). Lithologic descriptions are by R.E. Weems, and locality compilation is by C.M. Crampsey (USGS). I thank R.E. Weems and T.M. Cronin (USGS) and B.L. Whitney and R.J. Witmer (both of Union Oil Co., Brea, Calif.) for helpful comments.

METHOD OF STUDY

Material for this study comes from 17 localities, as shown in figure 2. With the exception of sample R2373, which comes from a construction-site excavation, all samples are from auger holes. Detailed locality information, including depth of the sample in the auger hole and its altitude relative to mean sea level, is given in table 1. A total of 13 samples (fig. 3) are from the Charleston area and represent the Chandler Bridge (Oligocene), Edisto and Marks Head (Miocene), and Penholoway (Pleistocene) Formations. Four samples (fig. 4) are from the Beaufort area and are from the Marks Head and Coosawhatchie (Miocene) and Canepatch(?) (Pleistocene) Formations. Lithostratigraphic details and details on age assignments are given in McCartan (this volume), McCartan and others (this volume), and Weems and McCartan (this volume).

Samples were treated with hydrochloric and hydrofluoric acids, oxidized with nitric acid, separated by floating in heavy liquid ($ZnCl_2$), and stained with Bismark brown. All samples were observed by using light microscope using Nomarski interference contrast. Three samples also were examined by using the scanning electron microscope (SEM). All processed and bulk material is part of the USGS paleobotanical collection in Reston, Va. Slide coordinates are given in plates 1–3 for the mechanical stage on Olympus microscope 201526; microscope slides are held by a specially milled metal insert.

RESULTS

CHANDLER BRIDGE FORMATION

Although the Oligocene is mostly outside the scope of the present study, a single sample was examined from the youngest Oligocene unit in the area, the Chandler Bridge Formation in Berkeley County, S.C. (R2793) (table 1, fig. 3). Here, the Chandler Bridge is a sand that is medium grained, dark greenish gray, and silty and contains abundant sand-sized phosphate. The dinocyst preservation is good, the flora is diverse, and the assemblage is dominated by *Homotryblium plectilum* Drugg & Loeblich. Forms such as *Deflandrea* sp. cf. *D. heterophlycta* Deflandre & Cookson (pl. 1, fig. 1), *Wetzeliella symmetrica* Weiler (pl. 1, fig. 8), and *Samlandia chlamydophora* Eisenack are found here, but not in younger samples. Other forms present include *Membranophoridium aspinatum* Gerlach (pl. 1, fig. 4), *Batiacasphaera hirsuta* Stover, *Emslandia spiridoides* (Benedek) Benedek & Sarjeant, *Tuberculodinium vancampoae* (Rossignol) Wall, vermicular forms of *Pentadinium laticinctum* Gerlach, and *Chiropteridium* spp.

The Chandler Bridge flora indicates assignment to Williams' (1977) *Chiropteridium dispersum-Samlandia chlamydophora* Zone (fig. 1). Williams equated this zone with the Oligocene. Although Williams recognized two subzones within this zone, these subzones cannot be recognized in the South Carolina material of this study.

The Chandler Bridge falls within Stover's (1977) *Pentadinium* Interval, in the Oligocene part, below the lowest occurrence of *Batiacasphaera sphaerica* Stover. It should be noted that *E. spiridoides* and *T. vancampoae* were not found by Stover until the Miocene part of his *Pentadinium* Interval. Costa and Downie (1979), however, show the lowest occurrence of *E. spiridoides* in the late Eocene and the lowest occurrence of *T. vancampoae* in their late Oligocene Zone VIIa.

EDISTO FORMATION

Two samples (R2794 and R2795) are from sediments assigned to the Miocene Edisto Formation in the Charleston area. Both samples are calcarenites that are fine grained and white to pale brown and contain shell fragments. The preservation of dinocysts is good, but the species diversity is lower than in the underlying Chandler Bridge. Sample R2794 appears to be older than R2795 because it contains *Pentadinium laticinctum* having vermicular surface ornament (pl. 1, figs. 5, 6) and *Membranophoridium aspinatum*, but it lacks *Batiacasphaera sphaerica*. This lower sample also contains abundant sand-sized phosphate (R.E. Weems, written commun., 1984). Both samples contain specimens of *Pentadinium* sp. cf. *P. laticinctum granulatum* Gocht, abundant *Chiropteridium* spp. (pl. 1, figs. 2, 3), *Homotryblium plectilum*, and *Homotryblium vallum* Stover (pl. 1, fig. 14).

The Edisto Formation falls within Williams' (1977) *Cordosphaeridium cantharellum* Zone, which he

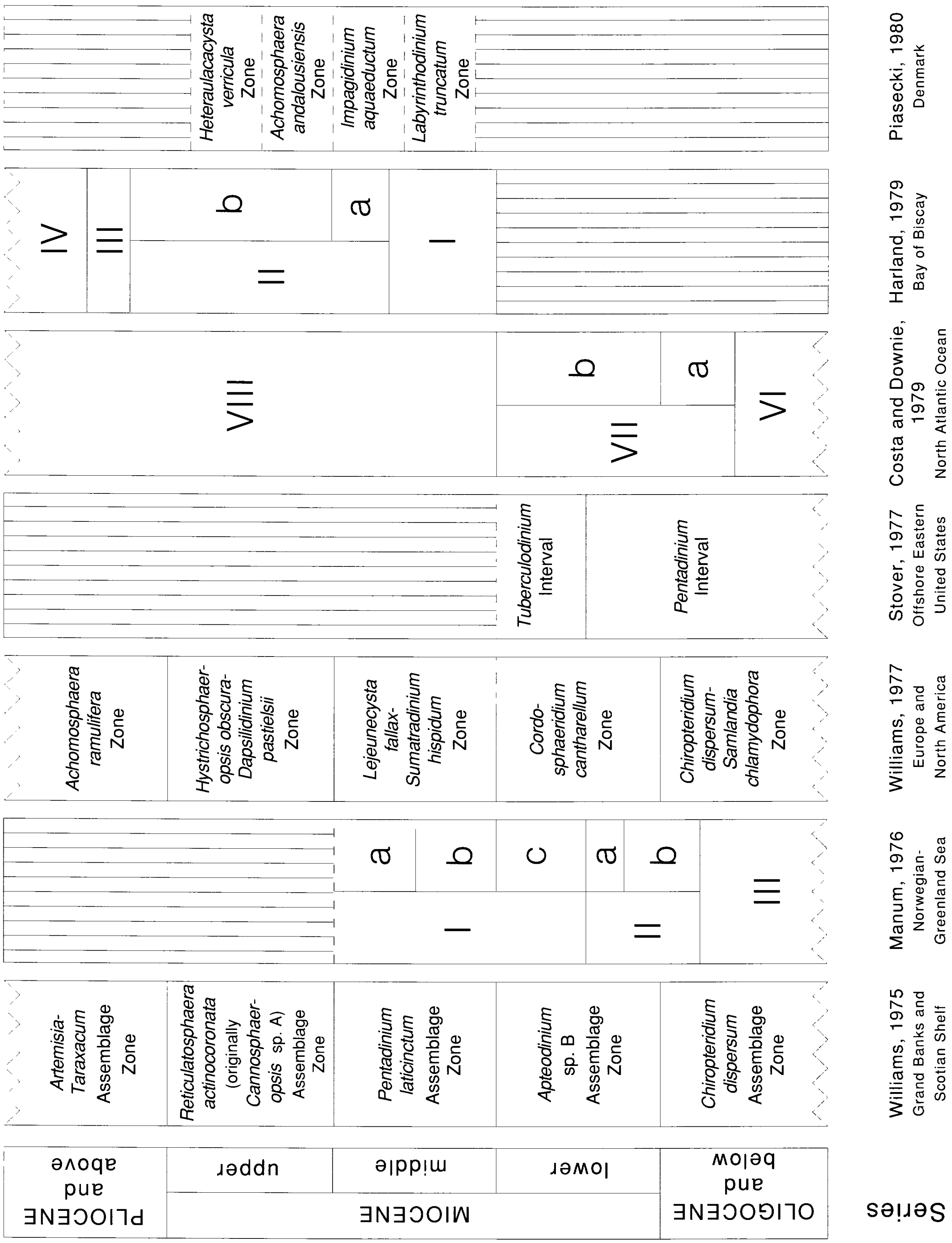


FIGURE 1.—Formal and informal dinocyst zonations that include Miocene material. Correlations to series are as given by the original authors, dashed where approximate. Correlations among the various zonations are, therefore, somewhat imprecise. Vertical lines indicate section that is not present or that is unzoned.

FIGURE 2.—Index map of South Carolina showing counties and the locations of samples used in this study. Base from U.S. Geological Survey, 1972, scale 1:2,500,000.

equated with the lower Miocene. Sample R2794 falls within Stover's (1977) *Pentadinium* Interval, and sample R2795, which is above the highest occurrence of *M. aspinatum*, is within his *Tuberculodinium* Interval.

MARKS HEAD FORMATION

A total of 11 samples were collected from the Marks Head Formation—9 samples from the Charleston area and 2 from the Beaufort area. As noted in the introduction to this volume, there are two lithofacies within the Marks Head: one is phosphatic quartz sand, and the other is cheese-textured clay. Eight of the samples (R2172B, R2172C, R2172D, R2798, R2799, R2971, R3066, and R3067, figs. 3 and 4) come from the sand lithofacies of the Marks Head, which is fine grained, sometimes silty, and brownish to grayish olive. Preservation of the dinocysts varies from poor to good, and species diversity varies correspondingly. Several of the samples from this lithofacies are dominated by *Hystrichokolpoma rigaudiae* Deflandre & Cookson (pl. 2, fig. 1). Three of the samples are from the clay lithofacies, a dense, brownish- to grayish-olive clay. Again, preservation varies from poor to good, and species diversity varies accordingly. No single species appears to dominate the clay facies.

Important species in the Marks Head include *Pentadinium* sp. cf. *P. laticinctum granulatum*, which has high septa and varying surface ornamentation (dotted surface texture, pl. 2, figs. 11–14; rough surface texture,

TABLE 1.—*Locality information for samples from the Charleston, S.C., region that contain dinocysts*

[All samples are from auger holes except sample R2373, which is from a construction-site excavation. Altitude is given relative to mean sea level]

Paleobotanical number	Field number	Depth, in m	Altitude, in m	State	County	Quadrangle	Latitude	Longitude
R2172A	CH–14	12–17	−9 to −14	S.C.	Charleston	Charleston 7½′	32°45′10″ N.	79°53′59″ W.
R2172B	CH–5	12–16	−10 to −15	S.C.	Charleston	Charleston 7½′	32°47′17″ N.	79°53′05″ W.
R2172C	RA–3	15–18	−3 to −6	S.C.	Charleston	Ravenel 7½′	32°45′28″ N.	80°14′37″ W.
R2172D	FM–5	18–21	−16 to −20	S.C.	Charleston	Fort Moultrie 7½′	32°45′59″ N.	79°49′04″ W.
R2373	SU–1	—	+15	S.C.	Berkeley	Summerville 7½′	33°02′09″ N.	80°08′40″ W.
R2793	PR–5	6	+19	S.C.	Berkeley	Pringletown 7½′	33°14′31″ N.	80°19′34″ W.
R2794	CC–6	9–10	+8	S.C.	Dorchester	Clubhouse Crossroads 7½′	32°58′23″ N.	80°19′32″ W.
R2795	CC–1	6–7	+9	S.C.	Dorchester	Clubhouse Crossroads 7½′	32°59′31″ N.	80°16′17″ W.
R2797	CH–32	13	−10	S.C.	Charleston	Charleston 7½′	32°45′06″ N.	79°55′56″ W.
R2798	FM–16	10	−8	S.C.	Charleston	Fort Moultrie 7½′	32°46′41″ N.	79°51′45″ W.
R2799	FM–17	9	−6	S.C.	Charleston	Fort Moultrie 7½′	32°48′44″ N.	79°49′04″ W.
R2800	FM–24	15	−13	S.C.	Charleston	Fort Moultrie 7½′	32°49′42″ N.	79°48′05″ W.
R2971	CC–3	11–12	+4	S.C.	Dorchester	Clubhouse Crossroads 7½′	32°56′48″ N.	80°17′31″ W.
R3053	C83–9	10	−7	S.C.	Beaufort	Green Pond 15′	32°31′43″ N.	80°44′53″ W.
R3054	C83–19	14	−13	Ga.	Chatham	Tybee Island North 7½′	32°01′17″ N.	80°50′40″ W.
R3066	C83–1	20	−18	S.C.	Beaufort	Fripps Inlet 7½′	32°20′33″ N.	80°27′46″ W.
R3067	C83–12	20	−18	S.C.	Beaufort	Parris Island 7½′	32°18′38″ N.	80°40′41″ W.

pl. 2, figs. 9, 10), *Polysphaeridium zoharyi* (Rossignol) Bujak et al. (pl. 3, fig. 2), *Homotryblium plectilum* (pl. 1, fig. 13), and *Batiacasphaera sphaerica* (pl. 1, figs. 9, 10). A small, distinctive new form, *Pentadinium* sp. I (pl. 2, figs. 4–6, 8), is restricted to the Marks Head in this study. It is interesting to note that, although *H. plectilum* is present in most of the Marks Head samples from the Charleston area, it is absent in the Beaufort area samples. In both areas, *P. zoharyi* is present in all Marks Head samples that lack *H. plectilum*. Williams (1977, p. 1275–1276) suggested that both species are subtropical to tropical forms. Although some workers have used the highest occurrence of *H. plectilum* as a biostratigraphic datum, its disappearance is more likely to have paleoecological significance.

The Marks Head flora falls within Williams' (1977) *Cordosphaeridium cantharellum* Zone. *Sumatradinium hispidum* (Drugg) Lentin & Williams (pl. 3, fig. 6) has its lowest occurrence in this zone. Williams (1977) noted that *Reticulatosphaera actinocoronata* (Benedek) Bujak & Matsuoka (pl. 1, fig. 11; junior synonyms are *Cannosphaeropsis* sp. A of Williams and Brideaux, 1975, and *Impletosphaeridium* sp. I of Manum, 1976) also has its lowest appearance in this zone, although Manum (1976) and Costa and Downie (1979) reported this species' first occurrence within the Oligocene. The Marks Head flora falls within Stover's (1977) *Tuberculodinium* Interval; the top of this interval is, however, undefined.

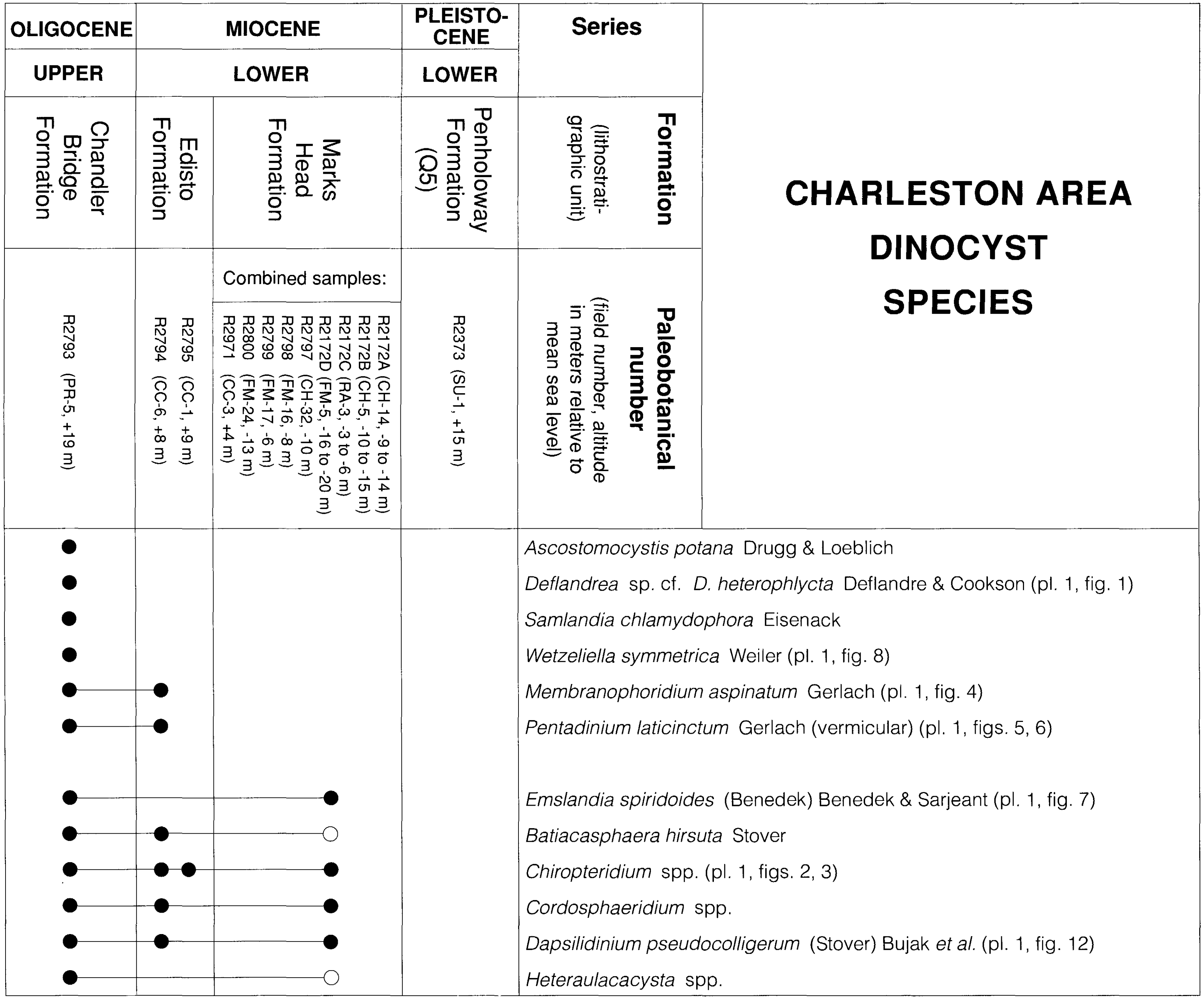
COOSAWHATCHIE FORMATION

A single sample (R3053) comes from the Coosawhatchie Formation in the Beaufort area and is from a silty, grayish-olive clay. Preservation is fair; the assemblage is dominated by *Spiniferites pseudofurcatus* (Klumpp) Sarjeant. This sample contains specimens of *Labyrinthodinium truncatum* Piasecki (pl. 3, figs. 9, 10), *Reticulatosphaera actinocoronata*, *Batiacasphaera sphaerica*, *Spiniferites mirabilis* (Rossignol) Sarjeant, and other species as shown in figure 4.

According to Piasecki (1980), *L. truncatum* is restricted to the middle Miocene. The presence of *L. truncatum* below the first occurrence of *Impagidinium aquaeductum* (Piasecki) Lentin & Williams places the Coosawhatchie sample within Piasecki's *L. truncatum* Zone. Manum (1976), however, has the first occurrence of *L. truncatum* (as *Cordosphaeridium* sp. II) at the same level as *I. aquaeductum* (as *Leptodinium* sp. V) at the base of his Zone Ia. More samples would be needed to determine whether the absences of species such as *Pentadinium laticinctum*, *Palaeocystodinium golzowense* Alberti, and *I. aquaeductum* in the Coosawhatchie are real and are of biostratigraphic significance.

PENHOLOWAY FORMATION (UNIT Q5)

A single sample (R2373) comes from the Pleistocene Penholoway Formation northwest of Charleston and is



CHARLESTON AREA DINOCYST SPECIES

OLIGOCENE	MIOCENE			PLEISTO-CENE	**Series**
UPPER	LOWER			LOWER	
Chandler Bridge Formation	Edisto Formation		Marks Head Formation	Penholoway Formation (Q5)	**Formation** (lithostratigraphic unit)
R2793 (PR-5, +19 m)	R2794 (CC-6, +8 m)	R2795 (CC-1, +9 m)	Combined samples: R2172A (CH-14, -9 to -14 m) R2172B (CH-5, -10 to -15 m) R2172C (RA-3, -3 to -6 m) R2172D (FM-5, -16 to -20 m) R2797 (CH-32, -10 m) R2798 (FM-16, -8 m) R2799 (FM-17, -6 m) R2800 (FM-24, -13 m) R2971 (CC-3, +4 m)	R2373 (SU-1, +15 m)	**Paleobotanical number** (field number, altitude in meters relative to mean sea level)
●					*Ascostomocystis potana* Drugg & Loeblich
●					*Deflandrea* sp. cf. *D. heterophlycta* Deflandre & Cookson (pl. 1, fig. 1)
●					*Samlandia chlamydophora* Eisenack
●					*Wetzeliella symmetrica* Weiler (pl. 1, fig. 8)
●	●				*Membranophoridium aspinatum* Gerlach (pl. 1, fig. 4)
●	●				*Pentadinium laticinctum* Gerlach (vermicular) (pl. 1, figs. 5, 6)
●			●		*Emslandia spiridoides* (Benedek) Benedek & Sarjeant (pl. 1, fig. 7)
●	●		○		*Batiacasphaera hirsuta* Stover
●	●	●	●		*Chiropteridium* spp. (pl. 1, figs. 2, 3)
●	●		●		*Cordosphaeridium* spp.
●	●		●		*Dapsilidinium pseudocolligerum* (Stover) Bujak *et al.* (pl. 1, fig. 12)
●			○		*Heteraulacacysta* spp.

FIGURE 3.—Distribution and ranges of dinocysts recovered from samples in the Charleston, S.C., region. Series and formation assignments are from McCartan (this volume), McCartan and others (this volume), and Weems and McCartan (this volume). The subdivision of each series is informal. Within the Marks Head Formation, open circles represent taxa that occur in one-third or fewer of the samples; solid circles indicate taxa found in greater than one-third of the samples. Figure gives plate and figure references for illustrated species.

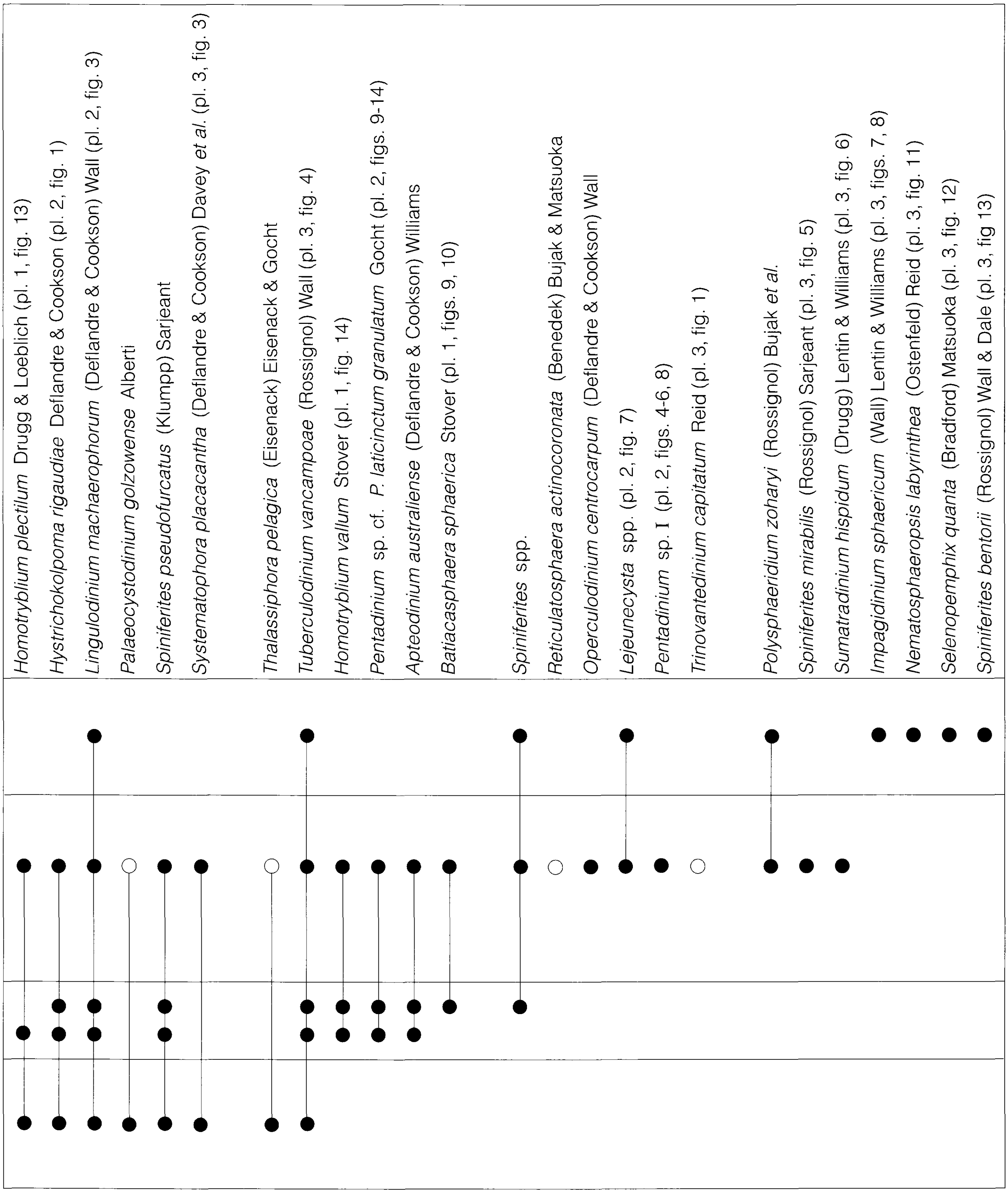


FIGURE 3.—Continued.

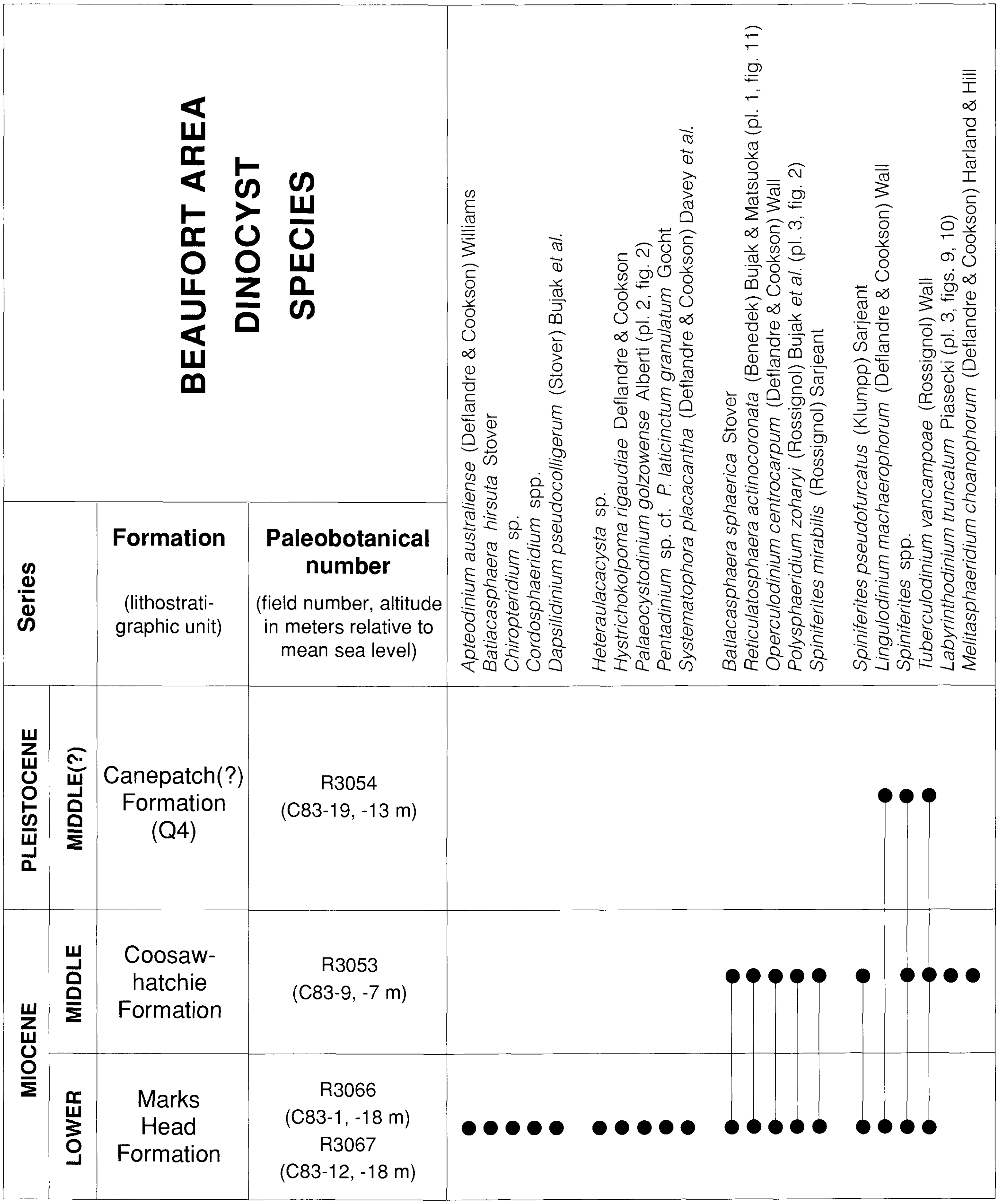


FIGURE 4.—Distribution and ranges of dinocysts recovered from samples in the Beaufort, S.C., region. Series and formation assignments are from McCartan (this volume), McCartan and others (this volume), and Weems and McCartan (this volume). The subdivision of each series is informal. Figure gives plate and figure references for illustrated species.

presumed to be equivalent to lithostratigraphic unit Q5 of McCartan and others (this volume). The sample consists of gray, laminated clay, and pollen is much more abundant than the dinocysts. The preservation of dinocysts is fair, and the assemblage is dominated by several species of *Spiniferites*. Other forms found are given in figure 3.

Selenopemphix quanta (Bradford) Matsuoka (pl. 3, fig. 12) first appears in the uppermost part of Harland's (1979) Zone III; thus, the Penholoway correlates with his uppermost Zone III or his Zone IV. Harland's figure 1 places this interval in the Pleistocene, correlative to the nannofossil zone NN 19.

CANEPATCH(?) FORMATION (UNIT Q4)

One sample (R3054) is questionably from the Canepatch Formation southwest of Beaufort in a deposit represented by unit Q4 of McCartan and others (this volume). The lithology is sand that is very fine, silty, micaceous, shelly, and grayish olive. The preservation of dinocysts is fair, and only a few nondiagnostic dinocysts were encountered (see fig. 4). The assemblage is dominated by gymnosperm pollen.

CONCLUSIONS

This reconnaissance study indicates that dinoflagellate cysts offer considerable promise for biostratigraphic correlation within the Miocene deposits of the Coastal Plain of South Carolina. Potentially useful dinocyst datums include the highest occurrence of *Membranophoridium aspinatum*, the highest occurrence of vermicular forms of *Pentadinium laticinctum*, the lowest occurrence of *Batiacasphaera sphaerica*, and the lowest occurrence of *Pentadinium* sp. I. *Labyrinthodinium truncatum*, a middle Miocene marker in Denmark, is also found in the middle Miocene Coosawhatchie Formation in South Carolina. Some correlations can be made with difficulty between the present study and previously published formal and informal dinocyst zonations. However, no single zonation is applicable.

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PLATES 1–3

Contact photographs of plates 1–3 are available,
at cost, from the U.S. Geological Survey Photographic Library, Federal Center,
Denver, CO 80225.

PLATE 1

FIGURE 1. *Deflandrea* sp. cf. *D. heterophlycta* Deflandre & Cookson, 1955.

Oblique ventral view (×660), sample R2793, from Chandler Bridge Formation (Oligocene), Berkeley County, S.C. Note small raised bumps on periphragm and larger bumps on endophragm, where periphragm is broken at apex. Scanning electron micrograph (SEM).

2. *Chiropteridium lobospinosum* (Gocht, 1956) Gocht, 1960.

Ventral view of optical section (×475), R2794, slide 2, from Edisto Formation (Miocene), Dorchester County, S.C. Slide coordinates: 27.3, 106.4.

3. *Chiropteridium dispersum* Gocht, 1960.

Ventral view of optical section (×475), R2795, slide 2, from Edisto Formation (Miocene), Dorchester County, S.C. 18.0, 79.9.

4. *Membranophoridium aspinatum* Gerlach, 1961.

Dorsal view (×660), R2793, from Chandler Bridge Formation (Oligocene), Berkeley County, S.C. SEM.

5, 6. *Pentadinium laticinctum* Gerlach, 1961 (vermicular surface ornament).

Oblique apical views of apex and optical section (×475), R2794, slide 2, from Edisto Formation (Miocene), Dorchester County, S.C. Compare this surface texture with that in plate 2, figures 9–14. Note lack of parasutural features, except at cingular and sulcal regions. 30.0, 82.5.

7. *Emslandia spiridoides* (Benedek, 1972) Benedek & Sarjeant, 1981.

Right lateral view of right lateral surface (×475), R2800, slide 2, from Marks Head Formation (Miocene), Charleston County, S.C. Note distinctive surface texture. 33.8, 87.7.

8. *Wetzeliella symmetrica* Weiler, 1956.

Dorsal view of optical section (×475), R2793, slide 2, from Chandler Bridge Formation (Oligocene), Berkeley County, S.C. Note that the archeopyle is soleiform. 26.4, 91.6.

9, 10. *Batiacasphaera sphaerica* Stover, 1977.

9. Apical view of apex(?) (×720), R2798, slide 2, from Marks Head Formation (Miocene), Charleston County, S.C. 28.2, 108.3.

10. Orientation uncertain (×1,200), R2800, from Marks Head Formation (Miocene), Charleston County, S.C. SEM.

11. *Reticulatosphaera actinocoronata* (Benedek, 1972) Bujak & Matsuoka, 1986.

Orientation uncertain (×475), R3066, slide 2, from Marks Head Formation (Miocene), Beaufort County, S.C. 29.2, 85.6.

12. *Dapsilidinium pseudocolligerum* (Stover, 1977) Bujak et al., 1980.

Orientation uncertain (×475), R2172B, slide 1, from Marks Head Formation (Miocene), Charleston County, S.C. Note amorphous material adhering to and obscuring the specimen. This is typical of samples that are poorly preserved in the Charleston area. 16.9, 79.0.

13. *Homotryblium plectilum* Drugg & Loeblich, 1967.

Interior view of hypocyst (×475), R2797, slide 2, from Marks Head Formation (Miocene), Charleston County, S.C. 31.9, 92.8.

14. *Homotryblium vallum* Stover, 1977.

Interior view of hypocyst (×475), R2794, slide 2, from Edisto Formation (Miocene), Dorchester County, S.C. 20.7, 97.8.


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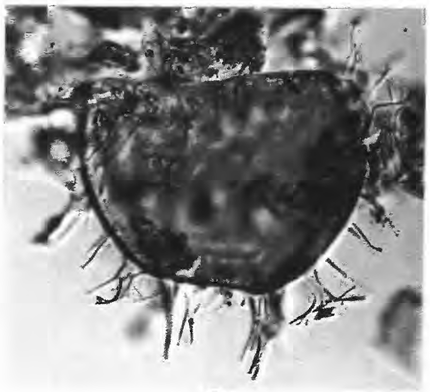
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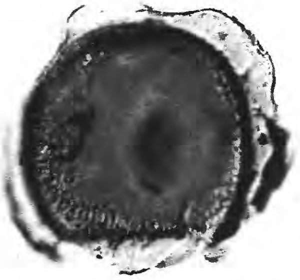
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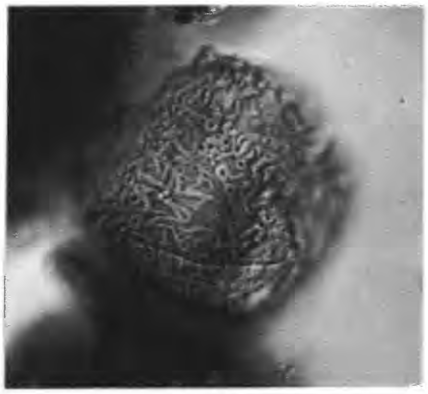
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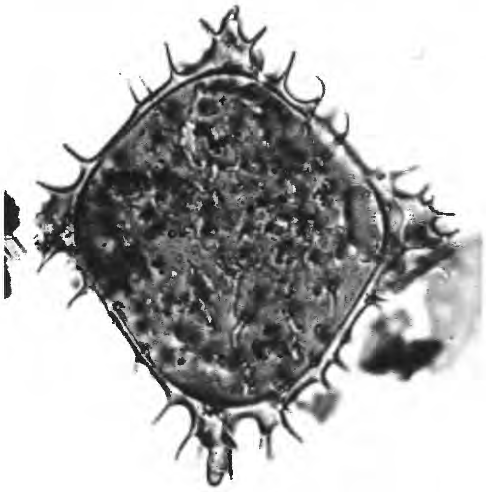
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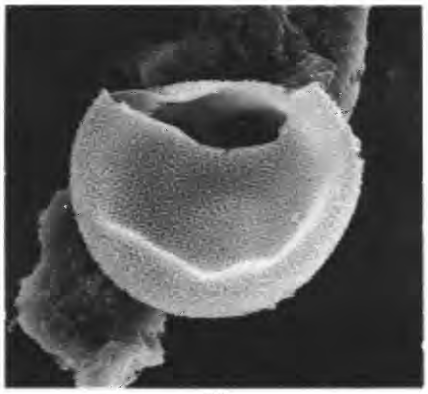
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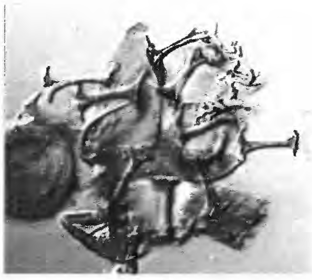
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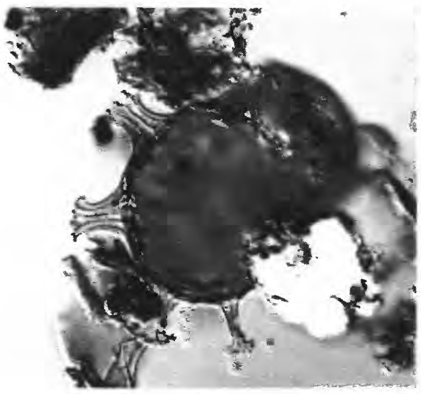
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DEFLANDREA, CHIROPTERIDIUM, MEMBRANOPHORIDIUM, PENTADINIUM, EMSLANDIA, WETZELIELLA, BATIACASPHAERA, RETICULATOSPHAERA, DAPSILIDINIUM, AND *HOMOTRYBLIUM*

PLATE 2

FIGURE 1. *Hystrichokolpoma rigaudiae* Deflandre & Cookson, 1955.
Dorsal view of dorsal surface (×440), R2172C, slide 1, from Marks Head Formation (Miocene), Charleston County, S.C. 17.2, 99.0.

2. *Palaeocystodinium golzowense* Alberti, 1961.
Ventrolateral view of dorsolateral surface (×475), R3067, slide 2, from Marks Head Formation (Miocene), Beaufort County, S.C. 26.1, 111.0.

3. *Lingulodinium machaerophorum* (Deflandre & Cookson, 1955) Wall, 1967.
Ventral view of ventral surface (×475), R2172D, slide 1, from Marks Head Formation (Miocene), Charleston County, S.C. This specimen shows the 5P archeopyle; specimens having 3P and (tAtP) archeopyles are also present. 20.2, 93.6.

4–6, 8. *Pentadinium* sp. I.
4–6. Ventral views (×580) of ventral surface, optical section, and dorsal surface are shown in figures 4–6, respectively. R2798, slide 2, from Marks Head Formation (Miocene), Charleston County, S.C. 32.0, 90.3.
8. Dorsal view (×1,100), R2799, from Marks Head Formation (Miocene), Charleston County, S.C. SEM.

7. *Lejeunecysta* sp.
Ventral view of ventral surface (×475), R2172D, slide 1, from Marks Head Formation (Miocene), Charleston County, S.C. 33.2, 95.7.

9–14. *Pentadinium* sp. cf. *P. laticinctum granulatum* Gocht, 1969.
9, 10. Ventral view (×600), R2800, from Marks Head Formation (Miocene), Charleston County, S.C. Note rough surface texture. Stereopair, SEM.
11. Left lateral view (×720), R2800, from Marks Head Formation (Miocene), Charleston County, S.C. Note the "dotted" surface texture. SEM.
12–14. Dorsal views (×475) of dorsal surface, optical section, and ventral surface are shown in figures 12–14, respectively. R2800, slide 2, from Marks Head Formation (Miocene), Charleston County, S.C. This particular specimen has "dotted" surface texture. Using light microscopy, it becomes difficult to distinguish between the end-member textures that are shown in SEM in figures 9–11 above. 37.0, 89.8.

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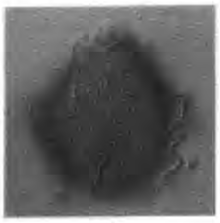

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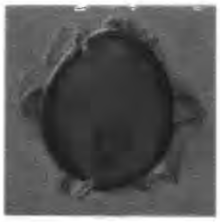

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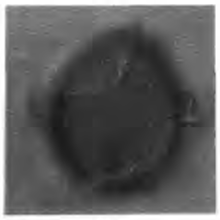

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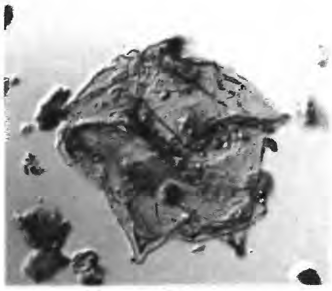

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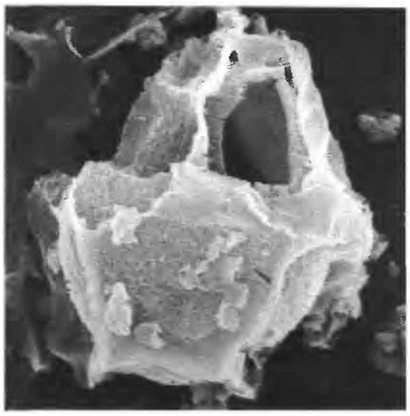

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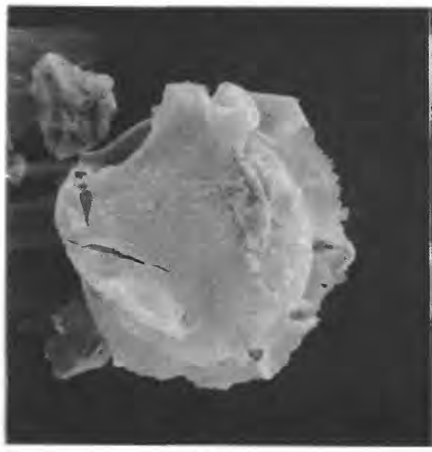

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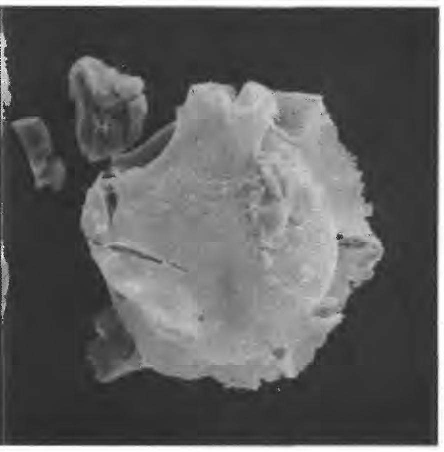

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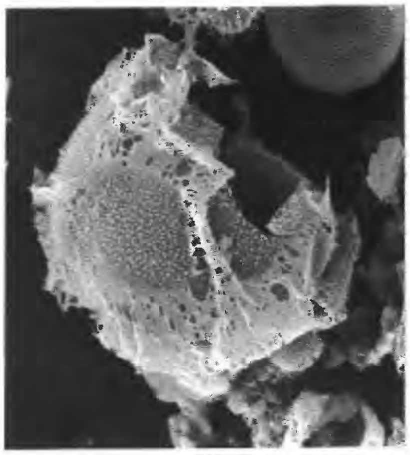

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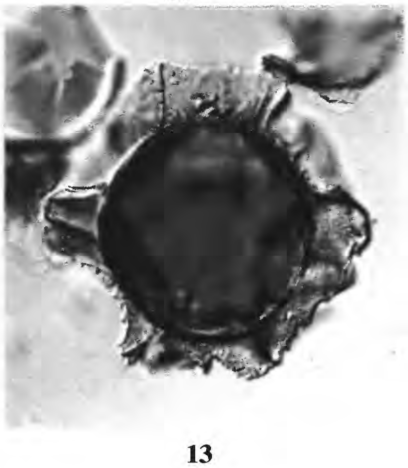

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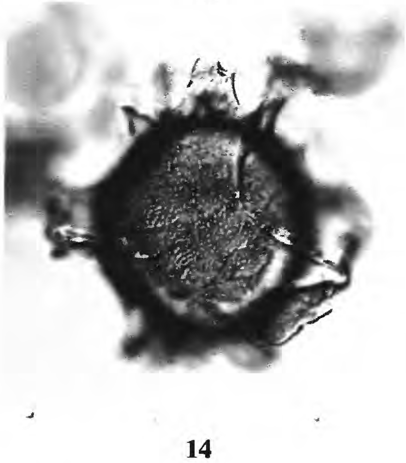

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HYSTRICHOKOLPOMA, PALAEOCYSTODINIUM, LINGULODINIUM, PENTADINIUM, AND *LEJEUNECYSTA*

PLATE 3

FIGURE 1. *Trinovantedinium capitatum* Reid, 1977.
Ventral view of dorsal surface (×440), R2800, slide 2, from Marks Head Formation (Miocene), Charleston County, S.C. 22.0, 85.6.

2. *Polysphaeridium zoharyi* (Rossignol, 1962) Bujak et al., 1980.
Antapical view focused on paracingulum (×475), R3067, slide 2, from Marks Head Formation (Miocene), Beaufort County, S.C. 22.8, 85.2.

3. *Systematophora placacantha* (Deflandre & Cookson, 1955) Davey et al., 1969.
Oblique antapical view of antapex (×475), R2800, slide 2, from Marks Head Formation (Miocene), Charleston County, S.C. 36.2, 79.2.

4. *Tuberculodinium vancampoae* (Rossignol, 1962) Wall, 1967.
Antapical view of antapex (×475), R2172C, slide 1, from Marks Head Formation (Miocene), Charleston County, S.C. 32.0, 105.8.

5. *Spiniferites mirabilis* (Rossignol, 1963) Sarjeant, 1970.
Ventral view of optical section (×475), R2800, slide 2, from Marks Head Formation (Miocene), Charleston County, S.C. 26.5, 95.7.

6. *Sumatradinium hispidum* (Drugg, 1970) Lentin & Williams, 1976.
Ventral view of ventral surface (×475), R2799, slide 2, from Marks Head Formation (Miocene), Charleston County, S.C. 20.5, 92.8.

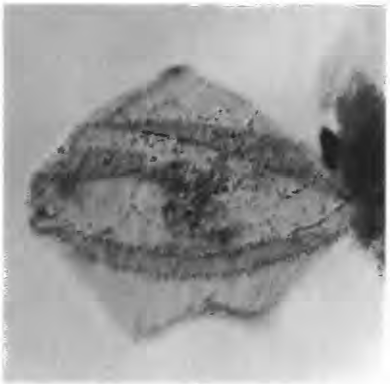
7, 8. *Impagidinium sphaericum* (Wall, 1967) Lentin & Williams, 1981.
Dorsal views of dorsal surface and ventral surface (×720), R2373, slide 2, from Penholoway Formation (Pleistocene), Berkeley County, S.C. 26.9, 98.8.

9, 10. *Labyrinthodinium truncatum* Piasecki, 1980.
Antapical views of antapex and optical section (×720), R3053, slide 1, from Coosawhatchie Formation (Miocene), Beaufort County, S.C. 18.9, 94.9.

11. *Nematosphaeropsis labyrinthea* (Ostenfeld, 1903) Reid, 1974.
Left lateral(?) view of optical section (×660), R2373, slide 2, from Penholoway Formation (Pleistocene), Berkeley County, S.C. 28.2, 98.7.

12. *Selenopemphix quanta* (Bradford, 1977) Matsuoka, 1985.
Apical view at midfocus (×475), R2373, slide 2, from Penholoway Formation (Pleistocene), Berkeley County, S.C. 36.6, 86.8.

13. *Spiniferites bentorii* (Rossignol, 1964) Wall & Dale, 1970.
Dorsolateral view of dorsolateral surface (×660), R2373, slide 2, from Penholoway Formation (Pleistocene), Berkeley County, S.C. 25.1, 81.5.



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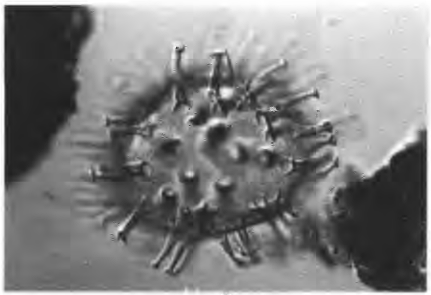

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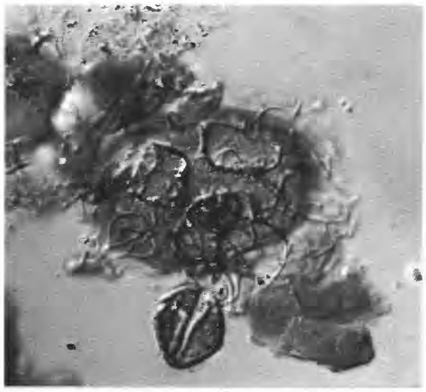

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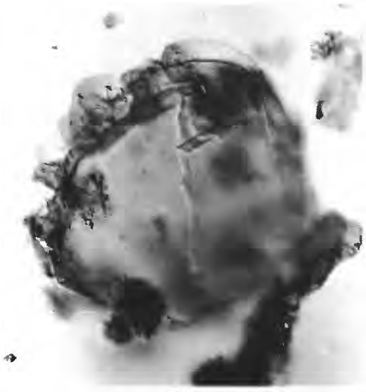

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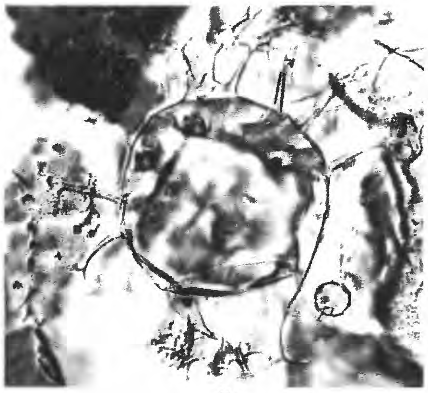

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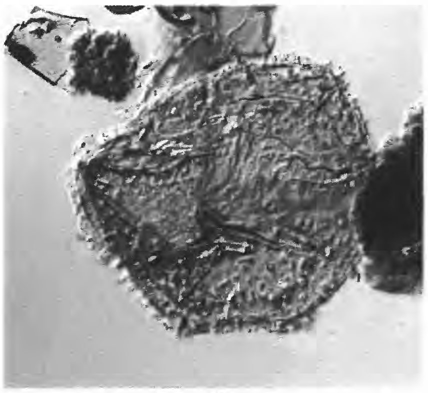

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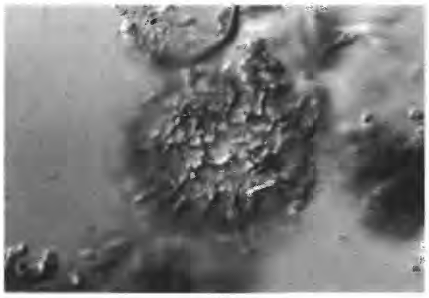

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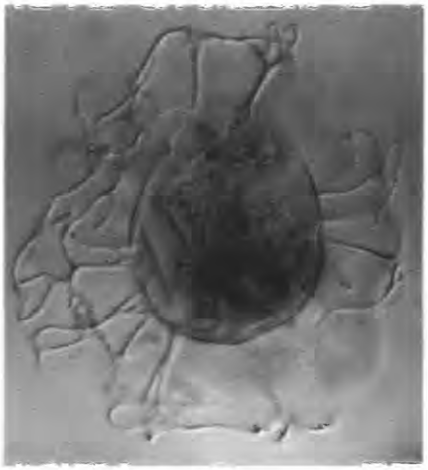

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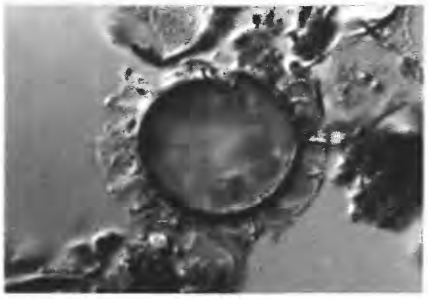

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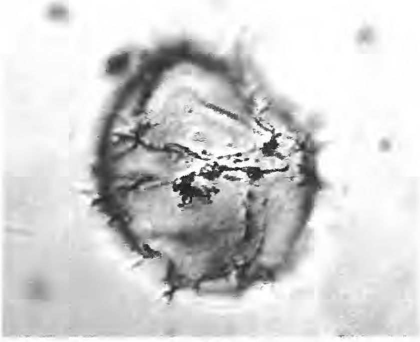

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TRINOVANTEDINIUM, POLYSPHAERIDIUM, SYSTEMATOPHORA, TUBERCULODINIUM, SPINIFERITES,
SUMATRADINIUM, IMPAGIDINIUM, LABYRINTHODINIUM, NEMATOSPHAEROPSIS,
AND *SELENOPEMPHIX*

Mollusks from the Edisto Formation (Lower Miocene) of South Carolina

By LAUCK W. WARD *and* BLAKE W. BLACKWELDER

STUDIES RELATED TO THE CHARLESTON, SOUTH CAROLINA,
EARTHQUAKE OF 1886—NEOGENE AND QUATERNARY
LITHOSTRATIGRAPHY AND BIOSTRATIGRAPHY

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1367–F

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ILLUSTRATIONS

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TABLE

STUDIES RELATED TO THE CHARLESTON, SOUTH CAROLINA, EARTHQUAKE OF 1886—NEOGENE AND QUATERNARY LITHOSTRATIGRAPHY AND BIOSTRATIGRAPHY

MOLLUSKS FROM THE EDISTO FORMATION (LOWER MIOCENE) OF SOUTH CAROLINA

By Lauck W. Ward[1] and Blake W. Blackwelder[2]

ABSTRACT

The lower Miocene Edisto Formation in South Carolina is correlated with the Tampa Limestone in southern Florida, with the Belgrade Formation in North Carolina, and with the Old Church Formation in Virginia on the basis of their contained molluscan assemblages. The genera present in the Edisto are indicative of a subtropical or tropical marine climate and water depths of approximately 10–30 meters. In these deposits is the last known appearance of the genus *Glyptoactis* on the Atlantic Coastal Plain.

INTRODUCTION

The Edisto Formation (lower Miocene) crops out along the Edisto River near Givhans Ferry, Dorchester County, S.C. (type locality, Ward and others, 1979) (see fig. 1). These deposits also have been encountered in the subsurface downriver from Givhans Ferry. One such occurrence, found in the shallow excavations at the northeast corner of the intersection of the U.S. Route 17 bridge and the Edisto River at Ponpon, Charleston County, S.C. (see fig. 1), yielded an assemblage of mollusks that was sampled from spoil piles. Because the lower Miocene deposits in the Eastern United States are thin and discontinuous, paleontologic data are generally lacking on deposits of that age. The mollusks present in the Edisto Formation provide an important record of the early Miocene assemblages from the middle Atlantic Coastal Plain.

ACKNOWLEDGMENTS

The authors wish to thank C.M. Mason of Morehead State University, J.R. DuBar of the Texas Geological Survey, and G.S. Gohn of the U.S. Geological Survey (USGS) for providing locality information. D.T. Dockery III (Mississippi Geological Survey) commented on the taxonomy, and J.E. Hazel (Louisiana State University) and N.F. Sohl (USGS) provided assistance in all phases of this study. R.E. Weems (USGS) reviewed the manuscript.

SETTING AND PRESERVATION

The Edisto Formation was restricted by Ward and others (1979) to lower Miocene deposits that occur along the Edisto River in South Carolina. The Edisto Formation, as originally mapped by Sloan (1908), included beds of Oligocene and Pliocene age that have no relationship to the Edisto at its type locality. Along the Edisto River, the Edisto Formation unconformably overlies the Ashley Formation (upper Oligocene) of the Cooper Group and is, in turn, unconformably overlain by the upper Pliocene Raysor Formation (of Blackwelder and Ward, 1979). The Edisto is present in South Carolina largely as thin erosional remnants on the top of the Cooper. The Edisto pinches out northeast of the Edisto River and is absent in the northern part of South Carolina. The upper surface of the Edisto was bored by mollusks during a period of submarine erosion, probably during the Pliocene. Southwest of the Edisto River area, the formation apparently persists as a thin erosional remnant; however, it is absent in southern South Carolina in the vicinity of Beaufort County (80 km southwest of Charleston, S.C.), where Eocene beds are near the surface.

The mollusk specimens used in this study were collected from float that was dredged to make shallow ponds at Ponpon. The ponds lie on indurated, calcareous, quartz sandstone of the Edisto Formation. Sometime

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Manuscript approved for publication September 27, 1988.

[1] U.S. Geological Survey.

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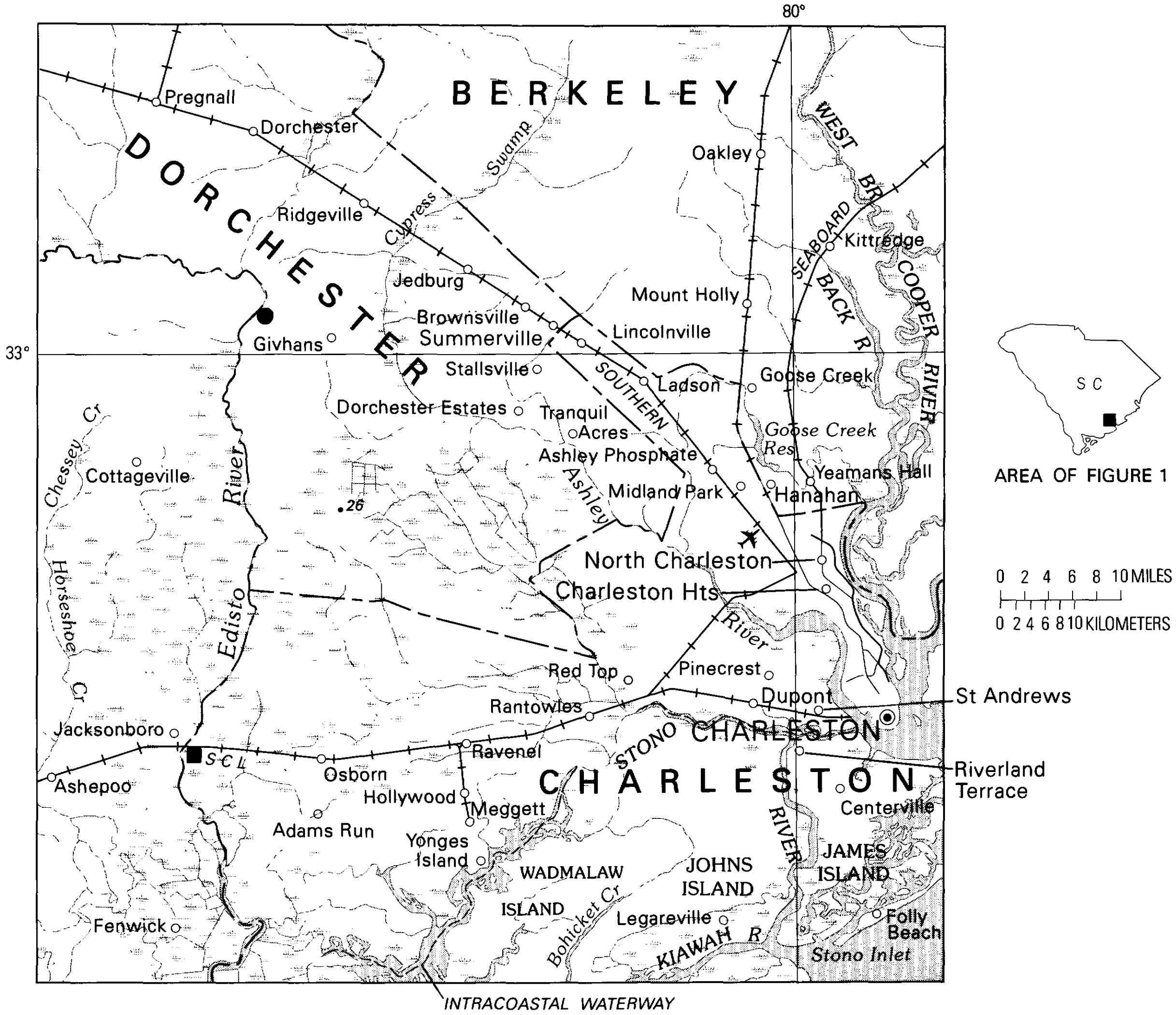

FIGURE 1.—Charleston, S.C., and vicinity showing position of Givhans Ferry, Dorchester County (solid dot), and Ponpon, Charleston County (solid square). Base from U.S. Geological Survey, 1970, 1:500,000-scale State base map.

after this unit was lithified, aragonitic mollusks were dissolved by leaching, which left only molds. The upper surface of this sandstone subsequently was exposed as a submarine outcrop. Some of the exposed molds were occupied by polychaetes and were filled with their fecal pellets and other detrital material. Some of the fecal pellets that filled a mold and subsequently were lithified are visible in plate 1, figure 7. The upper Pliocene deposits that rest on the irregular, bored surface of the Edisto Formation at Givhans Ferry are evidence that the submarine exposure took place during, and possibly before, Pliocene time. The polychaete? fecal pellets that filled the molds subsequently were dolomitized, as were the molds, and weathering of the upper surface of the Edisto has freed many of the dolomitic casts from the enclosing matrix. The dolomite is a drab brown color due to the presence of clay and other impurities. The original color of the enclosing rock matrix appears, from some apparently fresh fragments, to be light gray.

PALEOECOLOGY AND BIOSTRATIGRAPHY

Table 1 is a list of the taxa collected from float of the Edisto Formation from dug ponds near the U.S. Route 17 bridge and the Edisto River at Ponpon, S.C. Occurrences of these taxa in the Tampa Limestone of southern Florida, Belgrade Formation of North Carolina, and Old Church Formation (of Ward, 1985) of Virginia are noted. The presence of subtropical and tropical genera, such as *Chicoreus* and *Serpulorbis*, indicates that water temperatures were at least as warm as today on the shelf off South Carolina. In addition, the following genera found in the Edisto Formation are subtropical to tropical genera that live presently off the Atlantic Coast of the

TABLE 1.—*List of species collected from float of the Edisto Formation near the intersection of the U.S. Route 17 bridge and the Edisto River at Ponpon, S.C., showing additional occurrences of these species in the Tampa Limestone, Belgrade Formation, and Old Church Formation*

Edisto Formation mollusks	Tampa Limestone	Belgrade Formation	Old Church Formation
Glycymeris anteparilis Kellum, 1926	—	X	—
"Pecten" crocus (Cooke, 1919)	X	X	—
"Pecten" sp.	—	—	—
Plicatula sp.	—	X	X
Hyotissa antiguensis (Brown, 1914)	X	—	—
Glyptoactis nodifera (Kellum, 1926)	—	X	—
Mactromeris (?) sp.	—	—	—
Mercenaria gardnerae (Kellum, 1926)	—	X	X
Bicorbula idonea (Conrad, 1833)	—	X	X
Turritella pagodaeformis Heilprin, 1887	X	—	—
Serpulorbis ballistae Dall, 1892	X	—	—
Calyptraea trochiformis Lamarck, 1804	X	X	X
Cypraea sp.	—	—	—
Chicoreus (Phyllonotus) davisi (Richards, 1943)	—	X	—
Scaphella sp.	—	—	—

United States: *Plicatula*, *Glycymeris*, *Cypraea*, and *Calyptraea*. Several of the Edisto species also occur in the Tampa Limestone, which was deposited under tropical conditions. The species *Hyotissa antiguensis* (Brown, 1914) and *"Pecten" crocus* (Cooke, 1919) were far-ranging Caribbean forms, as was *Serpulorbis*.

Today, large specimens of *Glycymeris* are typical of shallow-marine environments on the present continental shelf of the United States. The presence of other shallow-marine genera in the Edisto, such as *Mercenaria*, indicates that this unit probably formed on the inner part of the shallow shelf at depths between 10 and 30 m.

The species *"Pecten" crocus* (Cooke, 1919) is a useful guide fossil for regional correlation of the Edisto and its stratigraphic equivalents. This taxon occurs in deposits in the Caribbean, in the Tampa Limestone in Florida, and in the Haywood Landing Member of the Belgrade Formation in North Carolina. Therefore, on the basis of the presence of *"Pecten" crocus*, as well as the presence of *Glycymeris anteparilis* Kellum, 1926, the Edisto can be correlated with the Belgrade Formation in North Carolina. *Mercenaria gardnerae* (Kellum, 1926) occurs in the Edisto Formation, the Belgrade Formation, and the Old Church Formation (of Ward, 1985) in Virginia. The Tampa, Belgrade, and Edisto Formations have been considered to be early Miocene in age (Ward and others, 1979). However, there is some controversy over the placement of the Oligocene-Miocene boundary on the Atlantic Coast, and it is possible that these deposits are of very late Oligocene (Chattian) age. The same equivocal age assignment is indicated for the correlative Old Church Formation in Virginia (Ward, 1985).

SYSTEMATIC PALEONTOLOGY

Class BIVALVIA
Subclass PTERIOMORPHIA
Order ARCOIDA
Superfamily LIMOPSACEA
Family GLYCYMERIDIDAE
Genus GLYCYMERIS Da Costa, 1778

Glycymeris anteparilis Kellum, 1926

Plate 1, figures 7, 8

Glycymeris anteparilis Kellum, 1926, p. 35, pl. VIII, figs. 4–6; Richards, 1943, p. 519; Bird, 1965, p. 38–39, pl. 5, figs. 1a, b, 2.

The type specimen of *Glycymeris anteparilis* is from the Haywood Landing Member of the Belgrade Formation in Onslow County, N.C. *Glycymeris anteparilis* apparently gave rise to the species *Glycymeris parilis* (Conrad, 1843a), which is present in the lower middle Miocene part of the Calvert Formation in Maryland. *Glycymeris anteparilis* differs from *G. parilis* in having more elongate hinge teeth, a more pronounced umbonal area, a more convex shell, and a more curved and more elongate hinge line. Also, *G. parilis* has weaker internal marginal crenulations and a thinner shell. *Glycymeris anteparilis* is common in the Edisto Formation at Ponpon, S.C.

Order PTERIOIDA
Suborder PTERIINA
Superfamily PECTINACEA
Family PECTINIDAE
Subfamily CHLAMYDINAE
Genus "PECTEN"

"Pecten" crocus (Cooke, 1919)

Plate 1, figure 2

Pecten crocus Cooke, 1919, p. 135, pl. 9, figs. 2a, b, pl. 11, fig. 9(?).
Chlamys (Chlamys) crocus Cooke. Tucker, 1934, p. 614, pl. 25, fig. 3; Mansfield, 1937, p. 205–206, pl. 13, fig. 3; Rowland, 1936, p. 1006, pl. 6, figs. 9, 11; Mansfield, 1937, p. 205, pl. 13, fig. 3.

The type specimen is from Crocus Bay, Anguilla, West Indies. This species is a guide fossil to lower Miocene deposits in the Southeastern United States. The species is rather common in lower Miocene deposits in Florida (Tampa Limestone), in South Carolina (Edisto Formation), and in North Carolina (Haywood Landing Member of the Belgrade Formation). The taxon's prominent scales, its higher than long dimensions, and its tendency to develop a small riblet between the primary ribs make its identification certain.

"Pecten" sp.

Plate 1, figure 1

This taxon has a distinctive sculptured pattern that consists of very fine, raised, concentric lamellae on the ribs. It is similar to *"Pecten" vaughani* Cooke, 1919, and it may be that species, but comparative material is scant. Broken specimens also come from the Edisto Formation type locality at Givhans Ferry, S.C.

Family PLICATULIDAE
Genus PLICATULA Lamarck, 1801

Plicatula sp.

Plate 2, figure 2

Plicatula densata Cooke, 1919, p. 145, pl. 1, figs. 12a, b (not *Plicatula densata* of Conrad, 1843a, 1845).
Plicatula densata Kellum, 1926, p. 36 (not *Plicatula densata* of Conrad, 1843a, 1845).
Plicatula densata Richards, 1943, p. 519, pl. 84, fig. 5 (not *Plicatula densata* of Conrad, 1843a, 1845).
Plicatula densata Richards, 1950, p. 77, fig. 67e (not *Plicatula densata* of Conrad, 1843a, 1845).
Plicatula sp. Ward, 1985, pl. 6, figs. 14, 15.

This taxon has been assigned repeatedly to *Plicatula densata* Conrad, 1843a, but it differs in its more numerous, smaller ribs and in its prominent scales, which are formed where growth lamellae intersect the ribs. This produces broad, raised scales that, in many specimens, are hyote in form. This scaling pattern can be found in specimens of *Plicatula guppyi* Woodring, 1925, but that species has fewer ribs. Because the specimens from the Edisto Formation are all broken, we hesitate to name this distinct species. This taxon is present in the Edisto Formation, and fragments in the Ashley Formation of the Cooper Group may also belong to the species. It is present in the Haywood Landing Member of the Belgrade Formation in North Carolina and the Old Church Formation in Virginia (Ward, 1985) as well.

Suborder OSTREINA
Superfamily OSTREACEA
Family OSTREIDAE
Genus HYOTISSA Stenzel, 1971

Hyotissa antiguensis (Brown, 1914)

Plate 1, figures 5, 6

Ostrea antiguensis Brown, 1914, pl. XIX, fig. 7, pl. XX, figs. 5, 6; Cooke, 1919, p. 128, pl. 6, figs. 1, 2.

Hyotissa antiguensis is used here as the name of this taxon, even though many workers have referred to this species as *Ostrea haitensis* Sowerby, 1849. The original description of *Ostrea haitensis* is vague, and there is no figure. The earliest description of a taxon that can be identified with Edisto specimens is Brown's (1914) description of *Ostrea antiguensis.* Brown stated that *O. antiguensis* has about five ridges separated from two other ridges by a broad fold. This description and Brown's figures agree well with specimens from the Edisto. *Hyotissa antiguensis* is, therefore, used as the specific name for these lower Miocene oysters, which were named for specimens from the island of Antigua, West Indies, in the Carribean. The species is extremely abundant in the Edisto Formation at Givhans State Park, S.C., although most of the exposure at that locality is now obscured. The species also is common in the Tampa Limestone and in stratigraphically equivalent formations in Florida. Specimens of a similar, if not identical, species occur in "zone" 10 (of Shattuck, 1904) of the Calvert Formation (lower middle Miocene) in Maryland.

Subclass HETERODONTA
Order VENEROIDA
Superfamily CARDITACEA
Family CARDITIDAE
Subfamily CARDITESINAE
Genus GLYPTOACTIS Stewart, 1930

Glyptoactis nodifera (Kellum, 1926)

Plate 1, figures 3, 4

Venericardia nodifera Kellum, 1926, p. 36–37, pl. IX, figs. 1–3; Mansfield, 1937, p. 236; Richards, 1943, p. 520; Richards, 1950, figs. 66d, e (p. 76).
Venericardia (Glyptoactis) nodifera nodifera Kellum. Heaslip, 1968, p. 111–112, pl. 27, figs. 5a–c, 6.

The type specimen of *Glyptoactis nodifera* is from the Belgrade Formation near Silverdale, Onslow County, N.C. This is the highest known stratigraphic occurrence of this genus on the Atlantic Coastal Plain.

Superfamily MACTRACEA
Family MACTRIDAE
Genus MACTROMERIS (?) Conrad, 1868

Mactromeris (?) sp.

Plate 2, figure 8

This small specimen is very close morphologically to *Mactromeris polynyma* (Stimpson, 1860) from the Holocene off the northeast coast of North America. The single specimen is an internal mold, so that definite generic or specific placement is difficult. The specimen is also similar in form to the species found in Miocene and

Pliocene deposits known as *Spisula* (*Hemimactra*) *delumbis* (Conrad, 1832) (see Glenn, 1904).

Superfamily VENERACEA
Family VENERIDAE
Subfamily CHIONINAE
Genus MERCENARIA Schumacher, 1817

Mercenaria gardnerae (Kellum, 1926)

Plate 2, figure 1

Venus gardnerae Kellum, 1926, p. 37, pl. 9, figs. 8, 9; Richards, 1943, p. 522; Richards, 1948, p. 5, pl. 4, fig. 25; Richards, 1950, fig. 65c; Ward, 1985, pl. 6, fig. 8.

Mercenaria gardnerae (Kellum, 1926) has pronounced, raised, concentric sculpture over the entire exterior surface of the disk. It is variable in form because, within a single population, the length of some specimens is nearly equal to the height, whereas other specimens are more elongate. The taxon makes its first known appearance in the upper part of the River Bend Formation (upper Oligocene, Chickasawhayan Stage) in North Carolina. That occurrence is also the first known for the genus *Mercenaria* on the Atlantic Coastal Plain. *Mercenaria gardnerae* is also found in the Haywood Landing Member of the Belgrade Formation of early Miocene age in North Carolina and the Old Church Formation of latest Oligocene and early Miocene age in Virginia. *Venus halidona* Dall, 1915, from the Tampa Limestone in Florida, is similar to *M. gardnerae* and may be closely related. *Venus capax* Conrad, 1843b, 1845, found in [New] Kent County, Va., may be the same species as *M. gardnerae*, but the specific locality from which it came is unknown, and only the type is available for comparison. We suspect that *Mercenaria capax* (Conrad, 1843b) came from the unit now known as the Old Church Formation (Ward, 1985). If true, that name may take priority over *M. gardnerae*.

Order MYOIDA
Suborder MYINA
Superfamily MYACEA
Family CORBULIDAE
Subfamily CORBULININAE
Genus BICORBULA Fischer, 1887

Bicorbula idonea (Conrad, 1833)

Plate 2, figures 4, 5

Corbula idonea Conrad, 1833, p. 341; Conrad, 1938, p. 6–7, pl. X, fig. 6; Richards, 1943, p. 522, pl. 84, figs. 13, 14.

This species ranges through the entire Miocene. Its first known appearance is in the Haywood Landing Member of the Belgrade Formation, the Edisto Formation, and the Old Church Formation (all lower Miocene). It is common in the Calvert and Choptank Formations in Maryland but is rare in the St. Marys Formation in Maryland and in the Claremont Manor Member of the Eastover Formation in Virginia.

Class GASTROPODA
Order MESOGASTROPODA
Superfamily CERITHIACEA
Family TURRITELLIDAE
Genus TURRITELLA Lamarck, 1799

Turritella pagodaeformis Heilprin, 1887

Plate 2, figure 9

Turritella pagodaeformis Heilprin, 1887, p. 112, pl. 8, fig. 52.
Turritella tampae var. *pagodaeformis* Heilprin. Dall, 1892, p. 310, pl. 17, fig. 9; Dall, 1915, p. 98, pl. 14, fig. 8.

Specimens from the Edisto Formation in South Carolina compare quite favorably with Dall's (1892) specimens of this species and with a suite of specimens of this species in collections at the U.S. National Museum. The figured specimen appears to have been flattened slightly during compaction and diagenesis and, therefore, appears a little broader than the specimen was originally. Also, the spiral bands bounding the sutures are not as raised as in Heilprin's (1887) figured specimen. The type specimen is from the Tampa Limestone, Tampa Bay, Fla.

Family VERMETIDAE
Genus SERPULORBIS Sassi, 1827

Serpulorbis ballistae Dall, 1892

Plate 2, figures 10, 11

Serpulorbis (*granifera* var.?) *ballistae* Dall, 1892, p. 304, pl. 22, fig. 21.
Serpulorbis ballistae Dall, 1915, p. 95, pl. 14, fig. 4.

The type specimen, which consists of only the early growth stages, is from the Tampa Limestone, Tampa Bay, Fla. The specimens from the Edisto Formation are much larger in size than the type specimen, but the exterior sculpture patterns are very similar. Woodring (1959, p. 161, pl. 29, fig. 13) illustrated a morphologically similar species and stated that this form was widespread in the Caribbean during the early Miocene.

Superfamily CALYPTRAEACEA
Family CALYPTRAEIDAE
Subfamily Calyptraeinae
Genus CALYPTRAEA Lamarck, 1799

Calyptraea trochiformis Lamarck, 1804

Plate 2, figure 7

Calyptraea trochiformis Lamarck, 1804, p. 385; Kellum, 1926, p. 39; Richards, 1943, p. 523, pl. 86, figs. 6, 7.

Calyptraea is a common taxon in Tertiary Atlantic Coastal Plain deposits. It is, therefore, of little stratigraphic value. A closely related species, *Calyptraea aperta* (Solander), occurs throughout the Miocene in Maryland. *Calyptraea trochiformis* is common in the Tampa Limestone in southern Florida and the River Bend and Belgrade Formations in North Carolina, and it is present in the Old Church Formation in Virginia.

Superfamily CYPRAEACEA
Family CYPRAEIDAE
Genus CYPRAEA Linné, 1758

Cypraea sp.

Plate 2, figure 3

Cypraea is known from the Edisto Formation only as internal molds that are not specifically determinable. The presence of the genus indicates subtropical to tropical, marine conditions.

Order NEOGASTROPODA
Suborder STENOGLOSSA
Superfamily MURICACEA
Family MURICIDAE
Subfamily MURICINAE
Genus CHICOREUS Montfort, 1810
Subgenus PHYLLONOTUS Swainson, 1833

Chicoreus (Phyllonotus) davisi (Richards, 1943)

Plate 2, figure 6

Murex davisi Richards, 1943, p. 524, pl. 85, figs. 1, 2; Richards, 1950, p. 77, fig. 67j.

Chicoreus (Phyllonotus) davisi (Richards). Vokes, 1967, p. 140, pl. 2, figs. 2a, b.

The type specimen is from the Belgrade Formation near Silverdale, N.C. The presence of this genus indicates subtropical to tropical conditions on the Atlantic Continental Shelf as far north as North Carolina.

Superfamily VOLUTACEA
Family VOLUTIDAE
Subfamily SCAPHELLINAE
Genus SCAPHELLA Swainson, 1832

Scaphella sp.

Plate 2, figure 12

This specimen of *Scaphella* is much more slender than specimens of *Scaphella stromboidella* Kellum, 1926, and it lacks the shoulder of that species. The material from the Edisto Formation consists only of steinkerns, but it is evident that the taxon is related to the *Scaphella mutabilis* (Conrad) lineage.

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PLATES 1–2

USNM, U.S. National Museum, Washington, D.C.
Contact photographs of plates 1–2 are available,
at cost, from the U.S. Geological Survey Photographic Library, Federal Center,
Denver, CO 80225.

PLATE 1

FIGURE 1. *"Pecten"* sp. (p. F4).

Right valve of an immature specimen, USNM 379659. Length, 20.0 mm; height, 20.3 mm.

2. *"Pecten" crocus* (Cooke, 1919) (p. F3).

Right valve of an immature specimen, USNM 379660. Length, 23.1 mm; height, 27.5 mm.

3, 4. *Glyptoactis nodifera* (Kellum, 1926) (p. F4).

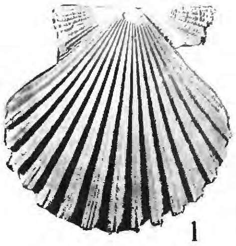
3. Left valve, USNM 379661. Length, 52.5 mm; height, 43.0 mm.
4. Right valve, USNM 379662. Length, 44.8 mm; height, 59.9 mm.

5, 6. *Hyotissa antiguensis* (Brown, 1914) (p. F4).

5. Left valve, USNM 379663. Length, 74.3 mm; height, 85.6 mm.
6. Right valve, USNM 379664. Length, 78.6 mm; height, 92.9 mm.

7, 8. *Glycymeris anteparilis* Kellum, 1926 (p. F3).

7. Left valve, USNM 379665. Length, 43.2 mm; height, 43.3 mm.
8. Left valve, USNM 379666. Length, 39.7 mm; height, 38.0 mm.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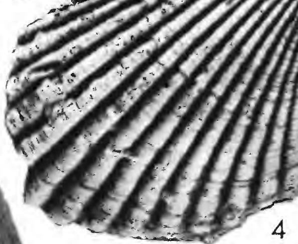
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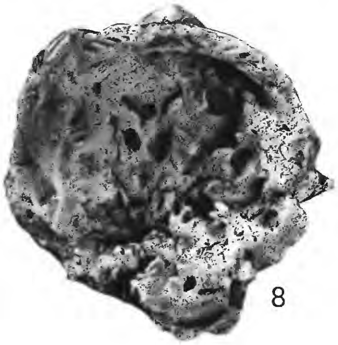
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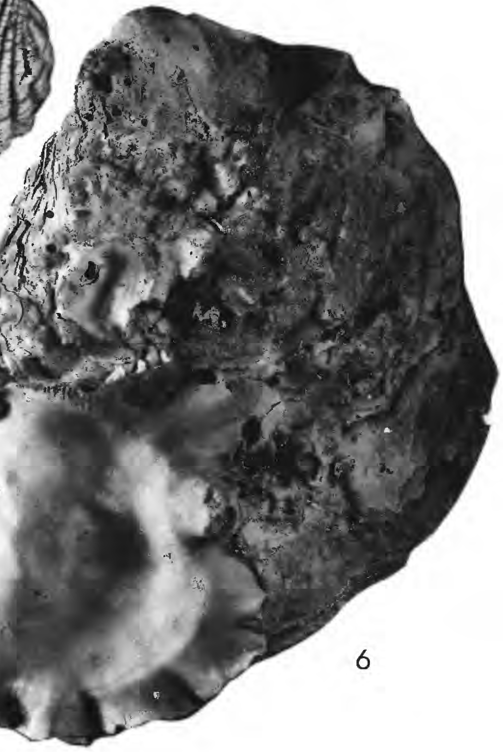
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"PECTEN," GLYPTOACTIS, HYOTISSA, AND *GLYCYMERIS*

PLATE 2

FIGURE 1. *Mercenaria gardnerae* (Kellum, 1926) (p. F5).
Right valve, USNM 379667. Length, 54.0 mm; height, 45.6 mm.

2. *Plicatula* sp. (p. F4).
Left valve of an incomplete specimen, USNM 379668. Length of fragment, 30 mm.

3. *Cypraea* sp. (p. F6).
Apertural view of steinkern, USNM 379669. Height, 25.9 mm.

4, 5. *Bicorbula idonea* (Conrad, 1833) (p. F5).
4. Right valve, USNM 379670. Length, 20.0 mm; height, 19.7 mm.
5. Right valve, USNM 379671. Length, 17.8 mm; height, 14.6 mm.

6. *Chicoreus (Phyllonotus) davisi* (Richards, 1943) (p. F6).
Dorsal view, USNM 379672. Height, 58.0 mm.

7. *Calyptraea trochiformis* Lamarck, 1804 (p. F5).
Dorsal view of an incomplete specimen, USNM 379673. Maximum length of specimen as viewed, 41.7 mm.

8. *Mactromeris* (?) sp. (p. F4).
Internal mold of a left valve, USNM 379674. Length, 38.2 mm; height, 27.3 mm.

9. *Turritella pagodaeformis* Heilprin, 1887 (p. F5).
Dorsal view of an incomplete specimen, USNM 379675. Length, 31.5 mm.

10, 11. *Serpulorbis ballistae* Dall, 1892 (p. F5).
10. Fragment of a large specimen, USNM 379676. Length, 40.9 mm.
11. Fragment of a large specimen, USNM 379677. Length, 67.5 mm.

12. *Scaphella* sp. (p. F6).
Apertural view of a broken specimen, USNM 379678. Height, 39.0 mm.


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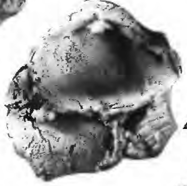
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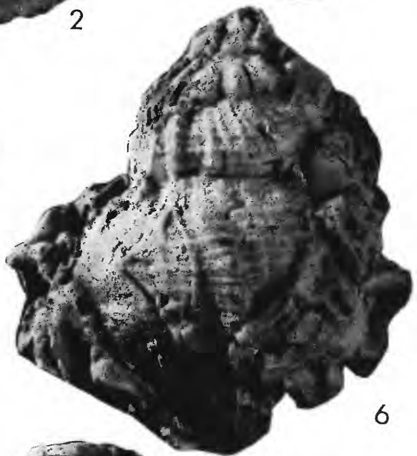
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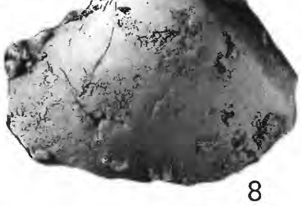
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MERCENARIA, PLICATULA, CYPRAEA, BICORBULA, CHICOREUS (PHYLLONOTUS), CALYPTRAEA, MACTROMERIS (?), TURRITELLA, SERPULORBIS, AND *SCAPHELLA*

A Summary of Selected Stratigraphic Occurrences of Neogene and Quaternary Invertebrate Faunas and Microfloras in the Charleston, South Carolina, Area

By R.E. WEEMS *and* LUCY McCARTAN

STUDIES RELATED TO THE CHARLESTON, SOUTH CAROLINA,
EARTHQUAKE OF 1886—NEOGENE AND QUATERNARY
LITHOSTRATIGRAPHY AND BIOSTRATIGRAPHY

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1367–G

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NEOGENE AND QUATERNARY LITHOSTRATIGRAPHY AND BIOSTRATIGRAPHY

A SUMMARY OF SELECTED STRATIGRAPHIC OCCURRENCES OF NEOGENE AND QUATERNARY INVERTEBRATE FAUNAS AND MICROFLORAS IN THE CHARLESTON, SOUTH CAROLINA, AREA

By R.E. Weems and Lucy McCartan

ABSTRACT

The stratigraphic occurrences are summarized for selected invertebrate faunas and microfloras, specifically diatoms, foraminifers, mollusks, and sporomorphs, from the lower Coastal Plain deposits of South Carolina. The fossil collections reported on here, made during the U.S. Geological Survey study of the Charleston 1886 earthquake, provide a much better basis for biostratigraphy and for paleoecology than do the less extensive and less carefully cataloged older collections. Because the occurrences of richly fossiliferous deposits are related strongly to both the conditions of deposition and diagenesis of the sediments, the abundance and preservation of each fossil group vary widely from geologic unit to geologic unit.

INTRODUCTION

This paper presents a summary of the stratigraphic occurrences of Neogene and Quaternary invertebrate faunas and microfloras in the Charleston, S.C., area that are not discussed in more detail in preceding chapters (see other chapters in this volume by Bybell, Cronin, Lyon, Edwards, and Ward and Blackwelder). This summary was achieved by integrating unpublished paleontologic reports of the U.S. Geological Survey (USGS) that were produced during the years 1973–84 with the late Cenozoic lithostratigraphy of the Charleston area that evolved over the same years during the USGS study of the Charleston 1886 earthquake. The fossil data presented in this chapter and other chapters in this volume aided significantly in dating lithostratigraphic units in the Charleston area, as well as in interpreting the environments of deposition and the facies relationships of the units (McCartan and others, this volume; McCartan and others, 1984; Weems and Lemon, 1984a, b).

The area around Charleston, S.C., has been known for a long time to yield fossils of Tertiary and Quaternary age. As early as the 1820's, Vanuxem (1829) recognized the existence of Tertiary and Pleistocene beds in the Charleston area by their fossil faunas. Papers by Conrad (1832), Ruffin (1843), Lyell (1845), Tuomey (1848), Tuomey and Holmes (1857), Holmes (1860), and Pugh (1905) steadily expanded knowledge of the species and, through biostratigraphic correlation, ascertained the approximate ages of fossils from the Charleston area. For the most part, however, the lithostratigraphic framework of the deposits containing the fossils remained incompletely understood because the few richly fossiliferous outcrops are too widely separated. In addition, many of the middle to upper Tertiary and lower Pleistocene units are found preserved only in small, local patches located between upper Oligocene and upper Pleistocene beds. However, during this century, auger drilling, coring, and examination of ditches dug during urban expansion, combined with correlation of some Charleston-area fossils with those from deep sea cores and an increased knowledge of Coastal Plain sections to the north and south, have permitted the synthesis of a new upper Cenozoic lithostratigraphic section for the Charleston area. This synthesis, presented in figure 1, has been erected from a large body of work, principally Sloan (1908), Cooke (1936), Malde (1959), DuBar (1971), Colquhoun (1974), Gohn and others (1977), Hazel and others (1977), Ward and others (1979), Blackwelder and Ward (1979), McCartan and others (1980, 1982, 1984, and this volume), Sanders and others (1982), Weems and others (1982), and Weems and Lemon (1984a, b).

Fossil localities in the Charleston area are given in the "Locality register" section and are plotted in a general-

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Age[1]	Symbols for correlative Quaternary units	Geologic units	Series	System
8–0 ka	Qh, Q1	Modern beach and marsh	Holocene	QUATERNARY
130–70 ka	Qw, Q2	Wando Formation	Pleistocene	
240–200 ka	Qtm, Q3	Ten Mile Hill beds, Socastee Formation		
450–400 ka	Ql, Q4	Ladson Formation, Canepatch Formation		
1.25? Ma–730 ka	Qp, Q5	Penholoway Formation		
1.6?–1.25? Ma	Qww, Q6	Waccamaw(?) Formation		
		Bear Bluff Formation, Goose Creek Limestone	Pliocene	NEOGENE
		Givhans beds, Raysor Formation		
		Coosawhatchie Formation	Miocene	
		Marks Head Formation		
		Edisto Formation		

[1] Based on uranium-disequilibrium-series coral age estimates (Szabo, 1985; McCartan and others, 1980, 1982; Cronin and others, 1981) and ^{14}C dates (McCartan and others, this volume), magnetostratigraphy (Liddicoat and others, 1981), and calcareous nannofossils (Gartner and others, 1983).

FIGURE 1.—Quaternary geologic units present in South Carolina and Neogene and Quaternary geologic units present at the ground surface throughout the area. All the units and symbols listed on one line are probably wholly or largely correlative. Units Q1–Q6 are informal stratigraphic designations used in McCartan and others (1984) and in McCartan and others (this volume). Abbreviations: ka, kilo-annum (10^3 years); Ma, Mega-annum (10^6 years).

ized map (fig. 2) that shows the surficial geology of the Charleston area (modified from McCartan and others, this volume). These fossil localities are referred to in the tables and in other chapters in this volume by Bybell and by Cronin.

ACKNOWLEDGMENTS

The compilation of fossil occurrences and the interpretations of age and depositional environment are based almost entirely on extensive paleontologic reports prepared for the Charleston Project between 1973 and 1984 by T.A. Ager (Pliocene and Quaternary sporomorphs), G.W. Andrews (diatoms), B.W. Blackwelder (Pliocene and Quaternary mollusks), L.M. Bybell (calcareous nannofossils), N.O. Frederiksen (Miocene and Pliocene sporomorphs), T.G. Gibson (foraminifers), R.Z. Poore (foraminifers), and L.W. Ward (Miocene and Pliocene mollusks). This work was supported by the U.S. Nuclear Regulatory Commission, Office of Nuclear Research, under Agreement No. AT(49–25)–1000.

STRATIGRAPHIC OCCURRENCE OF FOSSILS AS A FUNCTION OF DEPOSITION AND DIAGENESIS

In any local stratigraphic setting, the conditions of deposition and diagenesis strongly bias the content of the fossil record. To help put these depositional and diagenetic biases into perspective, the stratigraphic units of the Charleston area are shown in table 1 in the context of their environments of deposition and the diagenetic alterations and cementation that they have undergone since deposition.

An example of strong depositional control can be shown by the Pleistocene Ladson Formation, which in the Charleston area includes mostly fluvial to estuarine facies and, therefore, lacks diagnostic fossils, which are mainly shelf taxa. Conversely, both the older Pleistocene Penholoway Formation and the younger Pleistocene Ten Mile Hill beds and Wando Formation have relatively rich molluscan faunas because their shelf facies are preserved.

An example of diagenetic bias is provided by the Pliocene Goose Creek Limestone. In this highly calcareous unit, aragonite has been entirely removed by leaching and only calcite remains. As a result, only calcitic mollusks have been recorded in our faunal lists. Although aragonitic forms are seen occasionally in the form of poorly preserved molds and casts, they have not been studied yet in detail, except possibly in Malde (1959). In contrast, the older Pliocene Raysor Formation still contains well-preserved aragonitic shells (Blackwelder, 1967; Blackwelder and Ward, 1979), as leaching has been slight. Thus, the much more extensive faunal list of the

TABLE 1.—*Environment of deposition and postdepositional diagenetic factors that influence preservation of fossils in Neogene and Quaternary geologic units in the Charleston, S.C., area*

[Abbreviations: Environment of deposition: X, present; —, not present. Diagenetic effects: O, none; S, slight; E, extensive; P, pervasive; ?, questionable]

	Environment of deposition						Diagenesis							
							Alteration				Cementation			
Unit	Unit symbol[1]	Fluvial	Estuarine	Backbarrier	Shoreface	Shallow shelf	Compaction	Oxidation	Recrystallization[2]	Leaching	Phosphatization	Silicification	Calcification	Dolomitization
Holocene	Q1	X	X	X	X	X	S	S	O	O	O	O	O	O
Wando Formation	Q2	X	X	X	X	X	S	S	O	S	O	O	O	O
Ten Mile Hill beds	Q3	X	X	X	X	X	S	E	O	E	O	O	O	O
Ladson Formation	Q4	X	X	X	X	—	E	E	O	E	O	O	O	O
Penholoway Formation	Q5	X	X	X	X	X	E	E	O	E	O	O	O	O
Waccamaw(?) Formation	Q6	X	X	X	X	—	E	P	?	P	O	O	O	O
Bear Bluff Formation	—	—	—	—	—	X	E	S	E	E	O	O	S	O
Goose Creek Limestone	—	—	—	—	—	X	E	S	E	E	O	O	S	O
Givhans beds	—	—	—	—	—	X	E	S	E	E	O	O	S	O
Raysor Formation	—	—	—	—	—	X	E	S	S	S	O	O	O	O
Coosawhatchie Formation	—	—	—	?	—	—	P	S	S	E	S	S	O	O
Marks Head Formation	—	—	—	?	—	X	P	S	E	E	S	O	O	S
Edisto Formation	—	—	—	—	—	X	P	S	E	E	E[3]	O	E	E

[1] As in McCartan and others, 1984, and in McCartan and others, this volume.

[2] Principally aragonite to calcite.

[3] Includes blocks of phosphate rock reworked into Pleistocene units; remnants in places are only slightly phosphatized.

Raysor, compared to that of the Goose Creek, does not necessarily reflect an equally large difference in the original content of the molluscan faunas.

DISTRIBUTION OF FOSSILS BY GROUP

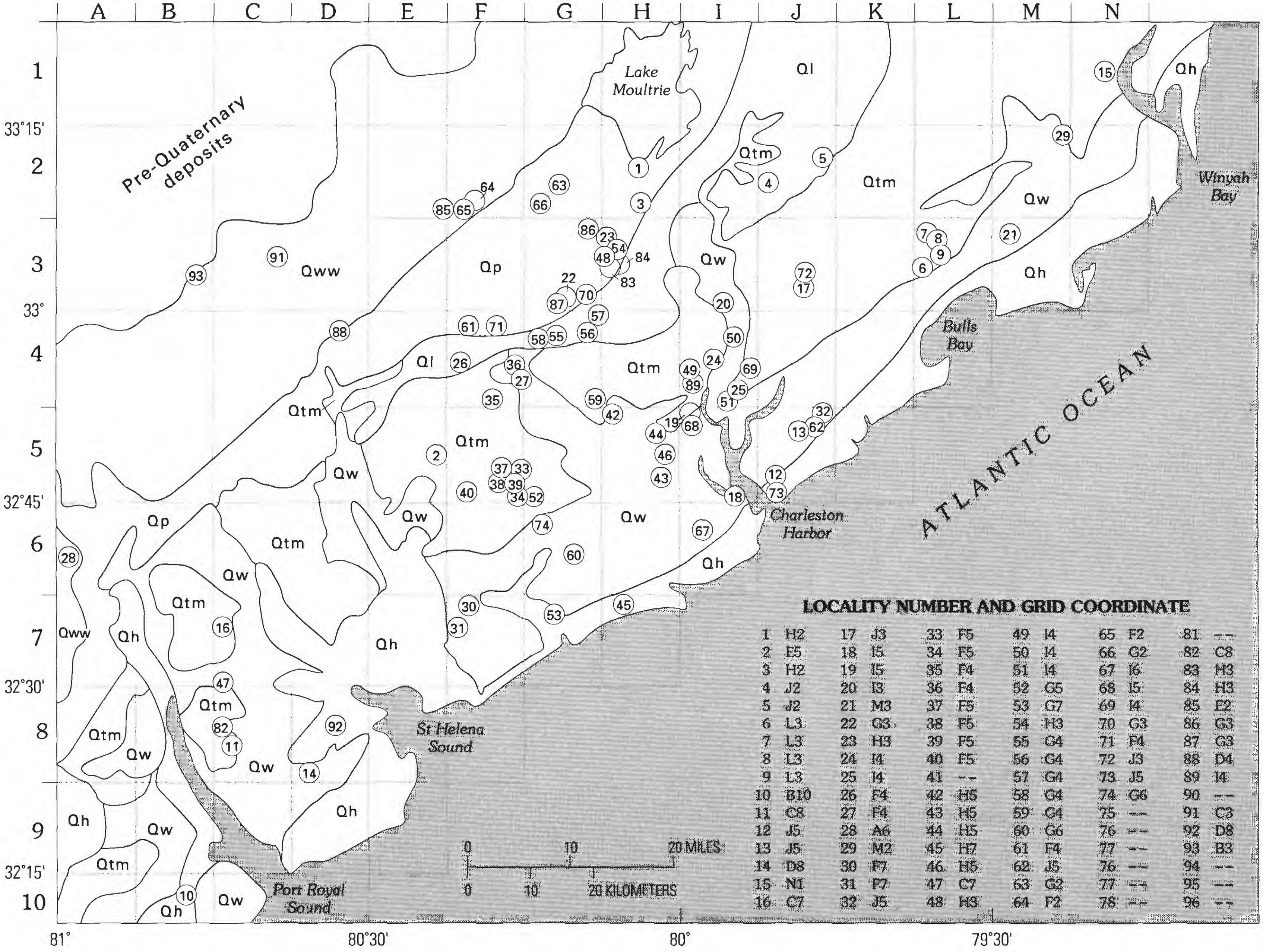
DIATOMS

Only one occurrence of diatoms has been reported in the Charleston area in sediments older than Pleistocene (table 2). This sample is from the Miocene Coosawhatchie Formation (fig. 1) and is similar to other Coosawhatchie samples from southern South Carolina (Abbott and Andrews, 1979; Abbott, 1978). The lack of diatoms in other Neogene samples may be due partly to spotty collecting, but a number of samples were examined from the Miocene Marks Head Formation, and none of them was found to contain diatoms. This is consistent with Abbott and Huddlestun's (1980) observation that siliceous microfossils have been leached from the Marks Head.

All of the diatomaceous samples of Quaternary age come from the middle to upper Pleistocene Ten Mile Hill beds and Wando Formation and from Holocene beds. These deposits are too young to be dated biostratigraphically by diatoms. Only three possibly extinct diatom species were observed, *Actinoptychus australis*, *Coscinodiscus kurzii*, and *Rhaphoneis angularis*, and the ranges of these taxa are too imperfectly known to make them useful as biostratigraphic markers. The diatoms do, however, provide information on the paleoecology of these deposits. All of the assemblages studied were dominated by shallow-marine diatom taxa, and *Paralia sulcata* (a common shallow-shelf diatom in both fossil and modern marine sediments) occurred in varying degrees of abundance in all samples. There are a few freshwater diatoms in some of the samples, but they suggest little more than the influence of occasional freshwater runoff from the nearby land. Thus, the environment of deposition of these beds can be characterized as a predominantly shallow-marine environment plus occasional brackish episodes that were caused by an inflow of freshwater.

FORAMINIFERS

Foraminifers are found in the Neogene Edisto Formation and Goose Creek Limestone and in the middle to upper Pleistocene Ten Mile Hill beds and Wando Formation (table 3, fig. 1). In all cases, the faunas are sparse and poorly preserved. The foraminifers reported here



LOCALITY NUMBER AND GRID COORDINATE

1	H2	17	J3	33	F5	49	I4	65	F2	81	--
2	E5	18	I5	34	F5	50	I4	66	G2	82	C8
3	H2	19	I5	35	F4	51	I4	67	I6	83	H3
4	J2	20	I3	36	F4	52	G5	68	I5	84	H3
5	J2	21	M3	37	F5	53	G7	69	I4	85	E2
6	L3	22	G3	38	F5	54	H3	70	G3	86	G3
7	L3	23	H3	39	F5	55	G4	71	F4	87	G3
8	L3	24	I4	40	F5	56	G4	72	J3	88	D4
9	L3	25	I4	41	--	57	G4	73	J5	89	I4
10	B10	26	F4	42	H5	58	G4	74	G6	90	--
11	C8	27	F4	43	H5	59	G4	75	--	91	C3
12	J5	28	A6	44	H5	60	G6	76	--	92	D8
13	J5	29	M2	45	H7	61	F4	77	--	93	B3
14	D8	30	F7	46	H5	62	J5	76	--	94	--
15	N1	31	F7	47	C7	63	G2	77	--	95	--
16	C7	32	J5	48	H3	64	F2	78	--	96	--

from the Goose Creek Limestone are mostly benthonic taxa and reveal little about the age of that unit. The Edisto, however, has yielded *Globigerinoides trilobus*, which definitely places that unit above the Oligocene-Miocene boundary (R.Z. Poore, written commun., 1983). The late Pleistocene units yielded mainly very shallow shelf benthonic taxa.

MOLLUSKS

Mollusks were among the first fossils reported from the Charleston area (for example, Drayton, 1802, p. 7), and they have been a favorite subject of both paleontologists and stratigraphers over the years (Conrad, 1832; Tuomey and Holmes, 1857; Pugh, 1905; Cooke, 1936; Richards, 1936, 1943; Malde, 1959; Blackwelder, 1967, 1981; Colquhoun and others, 1968; DuBar, 1971; Campbell and others, 1975; Blackwelder and Ward, 1979; Ward and others, 1979). Locally, mollusks are a major lithic component of the Miocene Edisto Formation and the Pliocene Givhans beds, Bear Bluff Formation, and Goose Creek Limestone (table 4, fig. 1). In all of these units, mollusks once were much more numerous, but they have been leached out extensively, so that, in many places, only molds and casts remain. No mollusks have been recovered yet from the lower Pleistocene Waccamaw(?) Formation in the Charleston area, presumably because they have been dissolved. In many places, the Pliocene Raysor Formation is composed dominantly of mollusk shells, as are the marine facies of the Pleistocene Penholoway Formation, Ten Mile Hill beds, and Wando Formation. Locally, the Wando may be so shelly that it can be called a coquina.

The molluscan faunas of the Tertiary units are distinctive (Ward and others, 1979; Blackwelder, 1981; Ward and Blackwelder, this volume), but the molluscan biostratigraphy of the Pleistocene is in need of further refinement. Blackwelder (1981) proposed a threefold molluscan biostratigraphic subdivision of the South Carolina Pleistocene that was based principally on the first appearances of *Lunarca ovalis* and *Cunearca brasiliana*. The first appearance of *L. ovalis* was between 1.4 and 0.45 Mega-annum (Ma, 10^6 years), and the first appearance of *C. brasiliana* was between 0.45 and 0.13 Ma. The absence of *L. ovalis* in the Penholoway (table 5) suggests that it probably appeared in this region after 1.0 Ma, and the absence of *C. brasiliana* in the Ten Mile Hill beds suggests that this fossil appeared in the region after 0.2 Ma. However, because the depositional environments of the Penholoway and Ten Mile Hill beds were not fully marine, it is possible that *Lunarca* was not present locally due to fluctuating and (or) low salinities. Thus, caution is advised in accepting these revised age-range estimates until more open-marine facies of the Penholoway and Ten Mile Hill beds can be found and sampled.

Besides *C. brasiliana*, a number of other species are so far known only as fossils from the Wando Formation (table 5). It is possible that, like *C. brasiliana*, some of these may also prove to be index fossils for the Sangamon interglacial interval of 130–70 kilo-annum (ka, 10^3 years), but more open-marine collections are needed from the Ten Mile Hill beds to verify that these species were not already present during the interglacial interval of 240–200 ka.

More convincing cases for the local absence of species can be made for the pectinid *Amusium mortoni* and the gastropod *Ecphora quadricostata*. *A. mortoni* is well documented from the Raysor Formation (Blackwelder, 1967) and the Goose Creek Limestone (Weems and others, 1982) (table 5) but is not present at numerous localities and in numerous drill holes in the Penholoway Formation, even though other pectinids do occur there. Therefore, in the Charleston region, the presence of *A. mortoni* probably indicates that a unit is pre-Penholoway in age. This fossil is listed as a Waccamaw species (fig. 1) in the Myrtle Beach region of northern South Carolina (DuBar, 1971), but beds in the Charleston region that are presumed to be equivalent to the Waccamaw have not yet yielded mollusks of any sort. However, many other species considered to be typical of the Waccamaw (such as *Carditamera arata*, *Anadara aequicostata*, and *Noetia limula*) do persist into the Penholoway (table 4). Therefore, it appears possible that a unique molluscan faunal assemblage will be defined eventually for the Penholoway that is intermediate in character between the assemblages of the lower Pleistocene Waccamaw Formation and the middle Pleistocene Canepatch Formation of the Myrtle Beach area. Similarly, the distinctive snail *Ecphora quadricostata* is known from the Raysor Formation (table 5) at Cross quarry, about 60 km (40 mi) north-northwest of Charleston, and from the

◀ FIGURE 2.—Quaternary geology of the Charleston, S.C., area (modified from McCartan and others, this volume) showing fossil localities discussed in this report. See the "Locality register" section for details of localities within the map area and localities outside the map area. Geologic units: Qh, Holocene deposits (lithostratigraphic unit Q1 of McCartan and others, 1984, and of McCartan and others, this volume); Qw, Wando Formation (Q2); Qtm, Ten Mile Hill beds (Q3); Ql, Ladson Formation (Q4); Qp, Penholoway Formation (Q5); and Qww, Waccamaw(?) Formation (Q6). Units are associated correctly with fossils in tables 2–4 and 6; apparent discrepancies between the units given in the tables and those shown here are due to the generalized nature of this map or to the presence of subsurface formations that do not extend to the ground surface. Table in the figure gives the grid coordinates for each locality within the map area and a dash for each locality outside the map area.

TABLE 2.—*Summary of selected stratigraphic occurrences of Miocene and Quaternary fossil diatoms in the Charleston, S.C., area*

[47, locality number (see "Locality register" section); (S2), sample designation; X, positive identification; —, not identified at this locality]

	MIOCENE	PLEISTOCENE						HOLOCENE	
		Q3			Q2			Q1	
	Coosawhatchie Formation	Ten Mile Hill beds			Wando Formation				
	47	33	40 (S2)	40 (S3)	39	26	37 (S3)	12 (S3)	12 (S6)
Diatom									
Achnanthes sp.	—	—	—	—	—	—	—	—	X
Achnanthes brevipes Agardh	—	—	—	—	—	—	X	—	—
Actinocyclus aff. *A. tenellus* (Brebisson) Andrews	—	—	—	X	—	—	—	—	—
Actinocyclus ellipticus var. *javanica* Grunow	X	—	—	—	—	—	—	—	—
Actinocyclus octonarius Ehrenberg	—	—	—	—	—	—	X	X	—
Actinocyclus sp.	—	—	—	X	—	X	—	—	—
Actinoptychus australis (Grunow) Andrews	—	—	—	—	X	X	—	X	X
Actinoptychus senarius (Ehrenberg) Ehrenberg	—	—	X	X	X	X	X	X	X
Actinoptychus splendens (Shadbolt) Ralfs	—	—	—	—	—	—	X	X	X
Actinoptychus virginicus (Grunow) Andrews	X	—	—	—	—	—	—	—	—
Amphora sp.	—	—	—	—	—	—	X	—	X
Anaulus mediterraneus Grunow	—	—	—	—	—	—	—	—	X
Aulacodiscus argus (Ehrenberg) Schmidt	—	—	—	X	X	X	X	—	X
Auliscus caelatus var. *strigillata* Schmidt	—	—	—	—	—	—	—	X	—
Auliscus reticulatus Greville	—	—	—	—	X	—	—	—	—
Auliscus sp.	—	—	X	—	—	—	—	—	—
Biddulphia sp.	—	—	X	—	—	—	X	—	—
Biddulphia mobilensis Bailey	—	—	—	—	—	—	X	—	—
Biddulphia rhombus (Ehrenberg) W. Smith	—	—	X	—	X	—	—	X	X
Caloneis westii (W. Smith) Hendey	—	—	—	—	—	—	—	X	—
Cocconeis placentula Ehrenberg	—	—	—	—	—	—	—	X	—
Cocconeis placentula var. *euglypta* (Ehrenberg) Cleve	—	—	X	X	X	X	X	X	X
Cocconeis sp.	—	—	—	—	—	—	—	—	X
Coscinodiscus biangulatus Schmidt	X	—	—	—	—	—	—	—	—
Coscinodiscus granulosus Grunow	—	—	—	—	X	—	—	—	—
Coscinodiscus kurzii Grunow	—	—	—	X	—	—	X	—	—
Coscinodiscus radiatus Ehrenberg	—	—	—	—	—	—	—	X	X
Coscinodiscus subtilis Ehrenberg	—	X	X	X	X	X	X	X	X
Cyclotella kutzingiana var. *planetophora* Fricke	—	X	—	—	—	—	—	—	—
Cyclotella striata var. *ambigua* Grunow	—	—	—	—	X	X	X	—	—
Cyclotella stylorum Brightwell	—	—	—	—	—	—	—	X	X
Cymatogonia amblyoceros (Ehrenberg) Hanna	X	—	—	—	—	—	—	—	—
Cymatosira lorenziana Grunow	—	—	—	—	—	—	X	—	X
Delphineis angustata (Pantocsek) Andrews	X	—	—	—	—	—	—	—	—
Delphineis biseriata (Grunow) Andrews	X	—	—	—	—	—	—	—	—
Delphineis novaecaesaraea (Kain & Schultze) Andrews	X	—	—	—	—	—	—	—	—
Delphineis penelliptica Andrews	X	—	—	—	—	—	—	—	—
Delphineis surirella (Ehrenberg) Andrews	—	—	—	—	—	—	X	—	—
Denticula sp.	—	X	X	—	—	—	—	—	—
Diploneis gruendleri (Schmidt) Cleve	—	—	—	—	—	—	—	X	X
Diploneis ovalis (Hilse) Cleve	—	—	—	—	—	—	X	X	X
Diploneis smithi (Brebisson) Cleve	—	X	—	—	—	—	—	X	—
Diploneis weissflogi (Schmidt) Cleve	—	X	X	—	—	—	X	X	X
Diploneis sp.	—	—	X	—	X	—	—	—	—
Eupodiscus radiatus Bailey	—	—	—	—	—	—	—	X	X
Frustulia sp.	—	—	X	—	—	—	—	—	—

TABLE 2.—*Summary of selected stratigraphic occurrences of Miocene and Quaternary fossil diatoms in the Charleston, S.C., area*—Continued

	MIOCENE	PLEISTOCENE						HOLOCENE	
		Q3			Q2			Q1	
	Coosawhatchie Formation	Ten Mile Hill beds			Wando Formation				
Diatom	47	33	40 (S2)	40 (S3)	39	26	37 (S3)	12 (S3)	12 (S6)
Grammatophora marina (Lyngbye) Kützing	—	—	—	—	—	—	—	—	X
Lithodesmium undulatum Ehrenberg	—	—	—	—	—	—	X	—	—
Melosira sp.	—	X	X	X	—	X	—	—	—
Navicula amphibola Cleve	—	—	—	—	—	—	X	—	—
Navicula clavata Gregory	—	—	—	—	—	—	X	—	—
Navicula aff. *N. cuspidata* Kützing	—	—	—	—	—	—	X	—	—
Navicula gothlandica Grunow	—	—	—	—	—	—	—	—	X
Navicula aff. *N. hennedyi* W. Smith	—	—	—	—	—	—	—	—	X
Navicula lyra Ehrenberg	—	—	X	—	—	—	—	—	X
Navicula lyroides Hendey	—	—	—	—	—	—	—	X	X
Navicula aff. *N. maculosa* Donkin	—	—	—	—	—	—	—	—	X
Navicula aff. *N. marina* Ralfs	—	—	—	—	—	—	—	X	—
Navicula pennata Schmidt	—	—	—	—	—	—	—	—	X
Navicula praetexta Ehrenberg	—	—	—	—	—	—	—	—	X
Navicula sp.	—	—	X	—	—	X	—	X	—
Nitzschia granulata Grunow	—	—	X	—	X	X	X	X	X
Nitzschia panduriformis Gregory	—	—	X	—	—	—	X	—	X
Opephora marina (Gregory) Petit	—	—	—	—	—	—	X	—	—
Opephora martyi Heribaud	—	—	—	—	—	X	—	—	—
Opephora pacifica (Grunow) Petit	—	—	—	—	—	—	—	—	X
Paralia sulcata (Ehrenberg) Cleve	—	X	X	X	X	X	X	X	X
Pinnularia sp.	—	—	—	—	—	—	X	—	—
Plagiogramma staurophorum (Gregory) Heiberg	—	—	X	X	X	—	X	X	X
Plagiogramma sp.	—	—	—	—	—	—	—	X	—
Pleurosigma salinarum Grunow	—	—	—	—	—	—	X	—	—
Podsira stelliger (Bailey) Mann	—	—	X	X	X	X	X	X	X
Psammodiscus nitidus (Gregory) Round & Mann	—	—	X	X	X	X	X	X	X
Rhaphoneis amphiceros Ehrenberg	—	X	X	X	X	X	X	X	X
Rhaphoneis angularis Lohman	—	—	—	X	X	—	—	—	—
Rhaphoneis belgica Grunow	—	—	—	X	—	—	X	—	—
Rhaphoneis lancettula Grunow	X	—	—	—	—	—	—	—	—
Rhaphoneis rhombica (Grunow) Andrews	—	—	X	X	—	X	X	—	X
Rhopalodia gibba (Ehrenberg) O. Muller	—	—	—	—	—	—	—	—	X
Rhopalodia gibberula (Ehrenberg) O. Müller	—	—	—	—	—	—	—	—	X
Stauroneis salina W. Smith	—	—	—	—	—	—	X	—	—
Stauroneis sp.	—	—	—	X	—	—	—	—	—
Surirella aff. *S. patella* Ehrenberg	—	—	—	—	—	—	X	—	—
Surirella sp.	—	—	—	—	—	—	X	—	—
Synedra affinis var. *fasciculata* (Kützing) Grunow	—	—	—	—	—	—	X	—	—
Terpsinoë americana (Bailey) Ralfs	—	—	—	—	—	X	—	—	X
Thalassionema nitzschioides Grunow	—	—	X	—	—	—	X	—	—
Thalassiosira eccentrica (Ehrenberg) Cleve	—	X	X	X	—	X	X	X	X
Thalassiosira leptopus (Grunow) Hasle & Fryxell	—	—	—	—	—	X	X	—	X
Thalassiosira sp.	—	—	X	—	—	—	—	—	—
Triceratium favus Ehrenberg	—	X	—	X	X	—	X	X	—
Triceratium reticulum Ehrenberg	—	X	X	—	X	—	X	X	X

TABLE 3.—*Summary of selected stratigraphic occurrences of Neogene and Pleistocene fossil foraminifers in the Charleston, S.C., area*

[61, locality number (see "Locality register" section); (S7), sample designation; X, positive identification; —, not identified at this locality; C, contaminated sample]

	MIOCENE	PLIOCENE		PLEISTOCENE					
				Q3		Q2			
	Edisto Formation	Goose Creek Limestone		Ten Mile Hill beds		Wando Formation			
Foraminifer	61	50	20 (S7)	34	40 (S3)	6 (S4)	6 (S8)	8	9
Ammonia beccarii (d'Orbigny)	—	—	—	—	X	X	X	X	X
Amphistegina floridana Cushman and Ponton	—	X	—	—	—	—	—	—	—
Angulogerina occidentalis (Cushman)	—	—	—	X	X	—	—	—	—
Bolivina sp.	—	—	—	—	—	—	—	—	X
Camerina(?) sp.	—	X	—	—	—	—	—	—	—
Cassidulina crassa d'Orbigny	—	—	—	—	—	—	—	—	X
Cassigerinella chipolensis (Cushman and Ponton)	X	—	—	—	—	—	—	—	—
Chiloguembelina sp.	—	—	—	—	—	—	C	—	—
Cibicides lobatulus (Walker and Jacob)	—	X	—	—	—	—	—	—	—
Cibicides n. sp.	—	—	X	—	—	—	—	—	—
Cibicidina aff. *jacksonensis dibollensis* (Cushman and Applin)	—	X	—	—	—	—	—	—	—
Cibicidina sp.	—	X	—	—	—	—	—	—	—
Discorbis sp.	—	—	—	—	—	—	X	—	—
Elphidium advenum (Cushman)	—	—	—	X	X	—	—	X	—
Elphidium clavatum Cushman	—	—	—	X	X	—	—	—	X
Elphidium exclavatum Terguem	—	—	—	—	—	X	X	—	—
Elphidium gunteri Cole	—	—	—	X	X	—	—	—	—
Elphidium limatulum Copeland	—	—	—	—	—	—	X	—	—
Elphidium poeyanum (d'Orbigny)	—	—	—	X	—	—	—	—	X
Elphidium sp.	—	X	—	—	—	—	—	—	—
Eponides repandus (Fichtel and Moll)	—	X	—	—	—	—	—	—	—
Florilus(?) sp.	—	X	—	—	—	—	—	—	—
Globigerina apertura Cushman	—	—	X	—	—	—	—	—	—
Globigerina bulloides d'Orbigny	—	—	—	—	—	X	—	—	X
Globigerina cf. *G. obesa* (Bolli)	X	—	—	—	—	—	—	—	—
Globigerina praebulloides Blow (sensu lato)	X	—	—	—	—	—	—	—	—
Globigerina cf. *G. ciperoensis* Bolli	X	—	—	—	—	—	—	—	—
Globigerina sp.	—	X	—	—	—	—	—	—	—
Globigerinoides ruber d'Orbigny	—	—	X	—	X	—	—	—	—
Globigerinoides trilobus (Reuss)	X	—	—	—	—	—	X	—	—
Globorotalia hirsuta (d'Orbigny)	—	—	X	—	—	—	—	—	—
Globorotalia siakensis Le Roy	X	—	—	—	—	—	—	—	—
Hanzawaia concentrica (Cushman)	—	—	X	—	—	—	—	X	X
Lagena substriata Williamson	—	—	—	—	—	—	X	—	—
Nonion pizarrense Berry	—	—	—	—	—	—	X	—	—
Nonion(?) sp.	—	X	—	—	—	—	—	—	—
Orbulina universa d'Orbigny	—	X	—	—	—	—	—	—	—
Planulina sp.	X	—	—	—	—	—	—	—	—
Quinqueloculina lamarckiana d'Orbigny	—	—	—	—	—	—	X	—	—
Quinqueloculina semiluna Linné	—	—	—	—	—	—	X	—	—
Reusella spinulosa (Reuss)	—	X	—	—	—	—	—	—	X
Rosalina floridana Cushman	—	—	—	—	—	—	X	—	—
Rosalina sp.	—	X	—	—	—	—	—	—	—
Textularia articulata d'Orbigny	X	—	—	—	—	—	—	—	—
Trifarina occidentalis (Cushman)	—	—	—	—	—	—	X	—	—
Uvigerina subperegrina Cushman and Kleinpell	—	—	—	—	—	—	X	—	—

TABLE 5.—*Summary of occurrences of stratigraphically significant species of mollusks in Pliocene and Pleistocene geologic units in the Charleston, S.C., area*

[Data are derived from table 4, except for Raysor Formation taxa, which are from Blackwelder (1967); X, positive identification; ?, questionable identification; —, not identified in this formation]

	PLIOCENE		PLEISTOCENE			
	Lower	Upper	Lower	Upper		
			Q5	Q4	Q3	Q2
	Raysor Formation	Goose Creek Limestone	Penholoway Formation	Ladson Formation	Ten Mile Hill beds	Wando Formation
Mollusk						
Chesapecten madisonius (Say)	X	—	—	—	—	—
Ecphora quadricostata (Say)	X	—	—	—	—	—
Mercenaria rileyi (Conrad)	X	—	—	—	—	—
Amusium mortoni (Ravenel)	X	X	—	—	—	—
Ostrea raveneliana Tuomey and Holmes	X	X	—	—	—	—
Ostrea sculpturata Conrad	X	X	—	—	—	—
Carolinapecten eboreus (Conrad)	X	X	?	—	—	—
Lucinisca cribraria (Say)	—	X	—	—	—	—
Pecten hemicyclica Ravenel	—	X	—	—	—	—
Anadara aequicostata (Conrad)	—	—	X	—	—	—
Bellucina waccamawensis (Dall)	—	—	X	—	—	—
Carolinapecten solarioides (Heilprin)	—	—	X	—	—	—
Corbula scutata Gardner	—	—	X	—	—	—
Stewartia floridana (Conrad)	—	—	X	—	—	—
Crassostrea virginica (Gmelin)	—	—	X	X	X	X
Anadara transversa (Say)	—	—	?	—	X	X
Caryocorbula contracta (Say)	—	—	X	—	X	X
Crassinella lunulata (Conrad)	—	—	X	—	X	X
Gemma gemma (Totten)	—	—	X	—	X	X
Ilyanassa obsoleta (Say)	—	—	X	—	X	X
Terebra dislocata (Say)	—	—	X	—	X	X
Nassarius acutus (Say)	—	—	X	—	—	X
Pleuromeris tridentata (Say)	—	—	X	—	—	X
Seila adamsii (H.C. Lea)	—	—	X	—	—	X
Tellina agilis Stimpson	—	—	X	—	—	X
Terebra concava Say	—	—	—	X	X	X
Bellucina amiantus (Dall)	—	—	—	X	—	X
Anomia simplex d'Orbigny	—	—	—	—	X	X
Chione cancellata (Linné)	—	—	—	—	X	X
Lunarca ovalis (Bruguière)	—	—	—	—	X	X
Sinum perspectivum (Say)	—	—	—	—	X	X
Chione grus (Holmes)	—	—	—	—	—	X
Chione intapurpurea (Conrad)	—	—	—	—	—	X
Cunearca brasiliana (Lamarck)	—	—	—	—	—	X
Donax variabilis Say	—	—	—	—	—	X
Ervilia concentrica (Holmes)	—	—	—	—	—	X
Mitrella lunata (Say)	—	—	—	—	—	X
Parvilucina multilineata (Tuomey and Holmes)	—	—	—	—	—	X

equivalent Givhans beds (fig. 1) at Givhans Ferry on the Edisto River, about 50 km (30 mi) northwest of Charleston. However, it has not been found at any of the younger Goose Creek localities or as fragments in any of the auger holes penetrating the Goose Creek in the Charleston area; therefore, it is presumed to have become extinct by that time (late Pliocene).

SPOROMORPHS

Pollen and spore assemblages from Pleistocene Coastal Plain units of the Charleston area are quite similar to assemblages of middle to late Holocene age from the southern Atlantic Coastal Plain (table 6; Holocene occurrences not shown). These assemblages generally include a mixture of warm-temperate, deciduous, broadleaf tree and shrub types (for example, *Quercus*, *Carya*, *Liquidambar*, *Ulmus*, *Nyssa*, *Fagus*, and *Castanea*) and evergreens (for example, *Pinus*, *Ilex*, and Ericaceae). Assemblages of pollen types such as these are likely to have been derived from forest communities within the broad category of the oak-pine forest type, the type that covers vast areas of the southern Atlantic Coastal Plain today. A few samples we studied contain pollen types that suggest a specialized habitat, as, for example, the abundance of *Taxodium*-like species, which are often found in combination with *Nyssa*, *Quercus*, and other taxa that also can tolerate wet conditions. Therefore, these taxa suggest a swamp-forest habitat similar to numerous bald cypress swamps that are scattered throughout the Coastal Plains of the Carolinas and Georgia and adjacent States today.

Pollen of herbaceous plants is common within many Pleistocene-age samples from the Atlantic Coastal Plain. In some samples, both the relative abundance of total herb pollen and the diversity of herb pollen types suggest a rich herb flora in the vegetation. Common herb pollens include several types of Compositae, Gramineae, Chenopodiaceae-Amaranthaceae, Cyperaceae, and others. Further, diverse herb assemblages are a useful indicator of a Pleistocene age for pollen samples from the geologic units studied thus far in the Charleston area (table 6). Many herbaceous taxa do not appear in the fossil record until Oligocene or Miocene time or later, and even then, herbs are generally poorly represented in the pre-Quaternary pollen record. Comparison of present-day pollen assemblages with present-day vegetation types suggests that herbaceous plants are often poorly represented in the pollen rain in heavily forested regions of the Southeastern United States. Where herb pollen is abundant, it often indicates an area of open vegetation, such as a meadow, freshwater marsh, or salt marsh. These areas are the most likely environments for Pleistocene-age pollen assemblages containing abundant herb pollen, and these habitats would have been most widespread close to the migrating coastline.

The general similarity of pollen assemblages within the Pleistocene units from the Coastal Plain near Charleston suggests long-term vegetational stability in the region. This apparent continuity may not reflect the true vegetational history of the region, but it may reflect instead the nature of the depositional record from which the pollen samples were obtained. The Pleistocene units sampled were deposited during high sea levels that generally coincided with warm interglacial intervals. During the intervening full-glacial intervals of the Pleistocene, sea level dropped, the regional climate became cooler and generally drier, and erosional processes appear to have predominated over depositional processes in the Coastal Plain. Under full-glacial conditions, deposition and preservation are much less likely for the contemporaneous regional pollen record. From scattered localities in the Southeastern United States, we now know that during the last full-glacial interval (the Wisconsinan) significant vegetation changes occurred in the region (see Watts, 1970, 1983; Whitehead, 1973). Vegetation assumed a more boreal character in much of the Southeast, as *Picea* (spruce), *Pinus* (pines, probably including jack pine), *Alnus* (alder), and *Betula* (birch) replaced the species-rich oak-pine forests adapted to interglacial climates. Thus, it is very likely that such major changes in climate throughout the Pleistocene influenced the vegetation of the Coastal Plain at the latitude of Charleston, S.C. If the pollen record in the Charleston area were complete, it would probably show several changes in the pollen type from warmer interglacial intervals to cooler full-glacial intervals throughout the Pleistocene. Instead, the preservation of predominantly interglacial deposits in the Charleston area gives the pollen record the appearance of long-term stability and probably is not an accurate portrayal of the actual history during the Pleistocene.

Most pollen taxa in the two samples from the Marks Head Formation (table 6) are long-ranging forms typical of Oligocene and late Tertiary deposits of the Atlantic Coastal Plain. However, the presence of *Momipites spackmanianus* (Traverse, 1955) Nichols, 1973 (see Frederiksen, 1984) in both samples suggests that this deposit is Miocene rather than Pliocene in age (N.O. Frederiksen, written commun., 1984).

SUMMARY

The biostratigraphic summary presented in this chapter is complementary to other chapters in this volume by Bybell, Cronin, Lyon, Edwards, and Ward and Blackwelder. Together the chapters provide a wealth of fossil occurrences and other data, and they assess the value of the data as a basis for dating the lithostratigraphic units in which the fossils are found. Because the geologic record of the Charleston area is fragmentary, we weighed depositional and diagenetic factors and tried to remove the natural biases within the fossil assemblages as we reconstructed the geologic history of the area.

We foresee the main use of this chapter as a source reference on which future biostratigraphic studies will be partly based. The next and final section, a locality register, is, therefore, a necessary part of the text.

LOCALITY REGISTER

The fossils discussed in this volume were obtained from either surface exposures or drill holes. The following list contains descriptions of all the fossil localities that appear in tables 2–4 and table 6. Most localities are shown in figure 2, but locality numbers marked * indicate South Carolina samples outside the map area. A few sites are not located precisely. All sites at which ostracodes were found are indicated by +, and for these, CN# is a locality number of T.M. Cronin (USGS). The ostracode localities that have CN#'s in this locality register are also referred to in Cronin's chapter (this volume), but other selected ostracode sites in this locality list are not specifically referred to by Cronin. LB samples are from J.P. Owens (USGS). Other sample designations for individual samples, such as A, AA, and S1, are given in appropriate fossil tables (2–4, 6), as well as in the locality register. All quadrangles are 7½-minute quadrangles, unless noted otherwise. Altitude, as used in this report, refers to distance above or below sea level. Altitudes are given for most samples, as well as for the ground surface of drill-hole locations.

Locality register for Neogene and Quaternary fossil localities in South Carolina

1. AH–MC–1: 0.6 km (0.4 mi) north of Ebenezer Church along U.S. Route 17A; 3.7 km (2.2 mi) north of southern quadrangle border, 5.4 km (3.2 mi) west of eastern quadrangle border, Moncks Corner quadrangle, Berkeley County, S.C.; sample altitude=14 m (46 ft). See location in H2 grid block in figure 2.
2. AH–8–76: Along State route 38 8.2 km (4.9 mi) north of the junction with U.S. Route 17; 4.7 km (2.8 mi) south of northern quadrangle border, 1.8 km (1.1 mi) west of eastern quadrangle border, Jacksonboro quadrangle, Charleston County, S.C.; surface altitude=5.5 m (18 ft), sample altitude=−0.5 m (−1 ft). E5 in figure 2.
3. Moncks Corner (Whitesville) sand pit (A, B, C): On east side of U.S. Route 17A 0.6 km (0.4 mi) south of the junction of U.S. Route 17A and Pinopolis Road; 2.7 km (1.6 mi) north of southern quadrangle border, 5.4 km (3.2 mi) west of eastern quadrangle border, Moncks Corner quadrangle, Berkeley County, S.C.; sample altitudes: A (CMC–2) and B (BBH–20–76) =18.5 m (60 ft), C (MC–75–LW–16)=15 m (50 ft). H2 in figure 2.

+4. BE–8 (CN#34): 0.4 km (0.2 mi) southwest of Alligator Bridge; 1.7 km (1.0 mi) north of southern quadrangle border, 1.3 km (0.8 mi) east of western quadrangle border, Bethera quadrangle, Berkeley County, S.C.; surface altitude=9 m (30 ft), sample altitude=−3.5 m to −4.5 m (−11 ft to −14 ft). J2 in figure 2.

5. BE–10–(A, B): 3.2 km (1.9 mi) west of eastern quadrangle border, 3.7 km (2.2 mi) south of northern quadrangle border, Bethera quadrangle, Berkeley County, S.C.; surface altitude=18 m (59 ft), sample altitudes: A (R2776A)=15 m (49 ft), B (R2776B)=11.5 m (37 ft). J2 in figure 2.
6. CA–1–(S1–S5, S8): At south end of Wambaw Swamp (northwest of Bulls Bay) at end of small road about 1.6 km (1.0 mi) north of its intersection with U.S. Route 17; 5.8 km (3.5 mi) north of southern quadrangle border, 2.7 km (1.6 mi) east of western quadrangle border, Awendaw quadrangle, Charleston County, S.C.; surface altitude=5 m (17 ft), sample altitudes: S1=−2 m (−6 ft), S2=−3.5 m (−11 ft), S3=−4.5 m (−15 ft), S4=−7 m (−23 ft), S5=−8 m (−26 ft), S8=−11.5 m (−38 ft). L3 in figure 2.

Locality register—Continued

7. CA–2: In arm of Wambaw Swamp (northwest of Bulls Bay) in raised roadway across swamp; 2.9 km (1.7 mi) south of northern quadrangle border, 1.1 km (0.7 mi) east of western quadrangle border, Awendaw quadrangle, Charleston County, S.C.; surface altitude=5 m (17 ft), sample altitude=sea level. L3 in figure 2.
8. CA–3: Wambaw Swamp (northwest of Bulls Bay) at end of road on low peninsula projecting eastward into swamp; 4.2 km (2.5 mi) south of northern quadrangle border, 2.4 km (1.4 mi) east of western quadrangle border, Awendaw quadrangle, Charleston County, S.C.; surface altitude=6.5 m (22 ft), sample altitude=1 m (4 ft). L3 in figure 2.
9. CA–4: Wambaw Swamp (northwest of Bulls Bay) at bend in small road at edge of swamp; 5.0 km (3.0 mi) south of northern quadrangle border, 4.2 km (2.5 mi) east of western quadrangle border, Awendaw quadrangle, Charleston County, S.C.; surface altitude=8 m (27 ft), sample altitude=+3 m to −4 m (+10 ft to −13 ft). L3 in figure 2.

+10. CBL–1 (CN#50): On Jenkins Island at bend in State Route 278; 3.4 km (2.0 mi) south of northern quadrangle border, 2.5 km (1.5 mi) west of eastern quadrangle border, Bluffton quadrangle, Beaufort County, S.C.; surface altitude=3.5 m (12 ft), fossils from −1 m to −10 m (−4 ft to −33 ft). B10 in figure 2.

+11. CBT–3 (CN#38): About 4 km (2.4 mi) west-southwest of Beaufort, 1.5 km (0.9 mi) southwest of New Hope Church at major bend in paved road; 5.3 km (3.2 mi) north of southern quadrangle border, 1.8 km (1.1 mi) east of western quadrangle border, Beaufort quadrangle, Beaufort County, S.C.; surface altitude=4.5 m (15 ft), sample altitude=−3 m (−10 ft). C8 in figure 2.

12. CF–1–(S3, S6): Marina on west side of road between Mount Pleasant and Sullivans Island; 2.6 km (1.6 mi) north of southern quadrangle border, 2.9 km (1.7 mi) east of western quadrangle border, Fort Moultrie quadrangle, Charleston County, S.C.; surface altitude=2.5 m (8 ft), sample altitudes: S3 (6590)=−2 m (−7 ft), S6 (6591)=−8 m (−27 ft). J5 in figure 2.

+13. CF–2 (CN#67): West end of Venning pit; 5.3 km (3.2 mi) south of northern quadrangle border, 4.7 km (2.8 mi) east of western quadrangle border, Fort Moultrie quadrangle, Charleston County, S.C.; top of pit=5 m (17 ft), top of auger hole=3 m (10 ft), fossils present from +2.5 m to −3.5 m (+8 ft to −11 ft) altitude. J5 in figure 2.

+14. CFR–1 (CN#46–48): 2.5 km (1.5 mi) south of U.S. Route 21 at Frogmore at paved road junction near Bethel Church; 0.2 km (0.1 mi) north of southern

Locality register—Continued

quadrangle border, 4.5 km (2.7 mi) east of western quadrangle border, Frogmore quadrangle, Beaufort County, S.C.; surface altitude=7.5 m (25 ft), fossils from −2 m to −15 m (−7 ft to −50 ft) altitude. D8 in figure 2.

15. CG–1: About 8 km (4.8 mi) south of Maryville on U.S. Route 17; 5.0 km (3.0 mi) north of southern quadrangle border, 2.6 km (1.6 mi) east of western quadrangle border, Georgetown South quadrangle, Georgetown County, S.C.; surface altitude=10.5 m (35 ft), fossils from +4.5 m to −1 m (+15 ft to −4 ft) altitude. N1 in figure 2.

16. CGP–1: North of the Coosaw River and west of the Combahee River on east side of road about 0.5 km (0.3 mi) south of major bend in road; 9.0 km (5.4 mi) north of southern quadrangle border, 0.8 km (0.5 mi) east of western quadrangle border, Green Pond 15-minute quadrangle, Beaufort County, S.C.; surface altitude=6 m (20 ft), shells between −1 m and −2.5 m (−3 ft to −8 ft) altitude. C7 in figure 2.

17. CH–3: 1.6 km (1.0 mi) south of Old Joe along State Route 41; 4.5 km (2.7 mi) north of southern quadrangle border, 5.5 km (3.3 mi) west of eastern quadrangle border, Huger quadrangle, Berkeley County, S.C.; surface altitude=12 m (40 ft), sample altitude=−1 m to 11 m (−4 ft to 36 ft). J3 in figure 2.

18. CH–14: Fort Johnson Marine Biological Station; 0.3 km (0.2 mi) north of southern quadrangle border, 2.1 km (1.3 mi) west of eastern quadrangle border, Charleston quadrangle, Charleston County, S.C.; surface altitude=2.5 m (9 ft), sample altitude=−9 m to −14 m (−30 ft to −46 ft). I5 in figure 2.

+19. CHAS–100 (CN#62–64): South of the intersection of interstate 26 and the Seaboard Coastline Railroad; 1.1 km (0.7 mi) south of northern quadrangle border, 0.2 km (0.1 mi) east of western quadrangle border, Charleston quadrangle, Charleston County, S.C.; surface altitude=7 m (23 ft), sample altitude=2 m to 2.5 m (6 ft to 8 ft). I5 in figure 2.

+20. CK–2–(S5–S7) (CN#18): At POMFLANT Naval Weapons Station west of Back River; 0.8 km (0.5 mi) north of southern quadrangle border, 4.0 km (2.4 mi) east of western quadrangle border, Kittredge quadrangle, Berkeley County, S.C.; surface altitude=10 m (32 ft), sample altitudes: S5=1 m (2 ft), S6=sea level, S7=−1 m (−2 ft). I3 in figure 2.

+21. CM–1 (CN#59, 60): U.S. Department of Agriculture Work Center compound 550 m (1,805 ft) south of U.S. Route 17A on road to McClellanville; 3.7 km (2.2 mi) south of northern quadrangle border, 2.9 km (1.7 mi) east of western quadrangle border, McClellanville quadrangle, Charleston County, S.C.; surface altitude=3.5 m (11 ft), sample altitude=−2 m (−7 ft). M3 in figure 2.

+22. CMC–17–A: On U.S. Route 17A 0.8 km (0.5 mi) south of intersection with State Route 165; 0.5 km (0.3 mi) north of southern quadrangle border, 5 km (3 mi) east of western quadrangle border, Summerville quadrangle, Dorchester County, S.C.; surface altitude=22 m (72 ft), sample altitude between 11 m and 13.5 m (37 ft and 45 ft). G3 in figure 2.

+23. CMH–9 (CN#31, 32): Beside small ridge 0.7 km (0.4 mi) northeast of U.S. Route 176; 2.7 km (1.6 mi) south of northern quadrangle border, 0.8 km (0.5 mi) east of western quadrangle border, Mount Holly quadrangle, Berkeley County, S.C.; surface altitude=27.5 m (90 ft), sample altitude=15 m (50 ft). H3 in figure 2.

24. CNC–6–D4: POMFLANT Naval Weapons Station 0.5 km (0.3 mi) south of Red Bank Road; 4.9 km (2.9 mi) south of northern quadrangle border, 4.5 km (2.7 mi) east of western quadrangle border, North Charleston quadrangle, Berkeley County, S.C.; surface altitude=10 m (32 ft), sample altitude=−0.5 m (−1 ft). I4 in figure 2.

25. CNC–18: At fork in dirt road (located at 40-ft contour line) 1.2 km (0.7 mi) east of Yellow House Creek and 0.9 km (0.5 mi) southwest of St. Johns Church; 4.6 km (2.8 mi) north of southern quadrangle border, 2.9 km (1.7 mi) west of eastern quadrangle border, North Charleston quadrangle, Berkeley County, S.C.; surface altitude=12 m (40 ft), sample altitude=−3 m (−10 ft). I4 in figure 2.

26. COE–8: Beside State Route 84 0.75 km (0.5 mi) south of intersection with U.S. Route 17A at gate to logging road; 7.0 km (4.2 mi) south of northern quadrangle border, 4.3 km (2.6 mi) east of western quadrangle border, Clubhouse Crossroads quadrangle, Dorchester County, S.C.; surface altitude=7.5 m (25 ft), sample altitude=3.5 m (11 ft); sample no. is 6585. F4 in figure 2.

27. COE–13: Along Westvaco timber road west of State Route 165; 5.0 km (3.0 mi) north of southern quadrangle border, 0.2 km (0.1 mi) west of eastern quadrangle border, Clubhouse Crossroads quadrangle, Dorchester County, S.C.; surface altitude=6.5 m (21 ft), sample altitude=2 m to 2.5 m (7 ft to 8 ft). F4 in figure 2.

28. CP1–D–(A, B): Northwest of Gillisonville off State Route 278 on small road to Beaverdam Church; 8.9 km (5.3 mi) north of southern quadrangle border, 0.6 km (0.4 mi) west of eastern quadrangle border, Pineland 15-minute quadrangle, Jasper County, S.C.; surface altitude=24.5 m (80 ft), sample altitudes: A=13 m (43 ft), B=−1 m (−3 ft). A6 in figure 2.

+29. CS–2 (CN#35): 5.0 km (3.0 mi) north of North Santee beside U.S. Route 17; 1.7 km (1.0 mi) south of northern quadrangle border, 0.2 km (0.1 mi) west of eastern quadrangle border, Santee quadrangle, Georgetown County, S.C.; surface altitude=10 m (32 ft), sample altitude=sea level. M2 in figure 2.

+30. EI–2 (CN#51–53): 1 km (0.6 mi) east of Mt. Olive Church at intersection of small road to north and State Route 174; 4.8 km (2.9 mi) south of northern quadrangle border, 3.5 km (2.1 mi) east of western

Locality register—Continued

quadrangle border, Edisto Island quadrangle, Charleston County, S.C.; surface altitude=4.5 m (15 ft), fossils from +1 m to −12 m (+2 ft to −40 ft). F7 in figure 2.

+31. EI-3-(A, B, C, D) (CN#39-42): On Scanawah Island at bluff cut by meander in Bailey Creek; 6.6 km (4.0 mi) north of southern quadrangle border, 1.3 km (0.8 mi) east of western quadrangle border, Edisto Island quadrangle, Charleston County, S.C.; sample altitudes: (A) (78TC65)=sea level, (B) (78TC66)=0.3 m (1 ft), (C) (78TC67)=0.6 m (2 ft), (D) (78TC68)=1 m (3 ft). F7 in figure 2.

32. FM-26: At Porcher Bluff; 1.4 km (0.8 mi) west of eastern quadrangle border, 1.8 km (1.1 mi) south of northern quadrangle border, Fort Moultrie quadrangle, Charleston County, S.C.; surface altitude=2.5 m (8 ft), sample altitude=−2.5 m (−9 ft). J5 in figure 2.

33. GF-1: 1.8 km (1.1 mi) south of Dorchester County line; 6.0 km (3.6 mi) south of northern quadrangle border, 0.2 km (0.1 mi) west of eastern quadrangle border, Osborn quadrangle, Charleston County, S.C.; surface altitude=11.5 m (38 ft), sample altitude=1 m (2 ft); sample no. is 6588. F5 in figure 2.

+34. GF-9: Along crest of Cainhoy barrier; 3.5 km (2.1 mi) north of southern quadrangle border, 1.6 km (1.0 mi) west of eastern quadrangle border, Osborn quadrangle, Charleston County, S.C.; surface altitude=14.5 m (48 ft), sample altitude=−0.5 m to −1.5 m (−1 ft to −5 ft). F5 in figure 2.

35. GP-3: 2 km (1.2 mi) southeast of Clubhouse Crossroads; 1.1 km (0.7 mi) north of southern quadrangle border, 5.4 km (3.2 mi) west of eastern quadrangle border, Clubhouse Crossroads quadrangle, Dorchester County, S.C.; surface altitude=3.5 m to 4.5 m (12 ft to 14 ft), sample altitude=sea level to 1 m (sea level to 2 ft). F4 in figure 2.

36. GP-7: 5.6 km (3.4 mi) northeast of Clubhouse Crossroads; 6.4 km (3.8 mi) north of southern quadrangle border, 2.7 km (1.6 mi) west of eastern quadrangle border, Clubhouse Crossroads quadrangle, Dorchester County, S.C.; surface altitude=6.5 m (22 ft), sample altitude=1 m to 2 m (3 ft to 6 ft). F4 in figure 2.

37. GS-17-(S2, S3): 6.2 km (3.7 mi) south of northern quadrangle border, 3.9 km (2.3 mi) west of eastern quadrangle border, Osborn quadrangle, Charleston County, S.C.; surface altitude=4.5 m (14 ft), sample altitudes: S2=−0.5 m to −1 m (−1 ft to −3 ft), S3 (6589)=−1.5 m to −2 m (−5 ft to −7 ft). F5 in figure 2.

38. GS-24-(S1, S2, S3): In Caw Caw Swamp; 3.8 km (2.3 mi) north of southern quadrangle border, 4.2 km (2.5 mi) west of eastern quadrangle border, Osborn quadrangle, Charleston County, S.C.; surface altitude=3 m (10 ft), sample altitudes: S1=1.5 m to 2 m (5 ft to 7 ft), S2=−0.5 m to −1 m (−1 ft to −3 ft), S3=−3.5 m to −4.5 m (−11 ft to −14 ft). F5 in figure 2.

39. GS-26: Caw Caw Swamp, 0.4 km (0.2 mi) north of bench mark 13 on west side of State Route 165; 6.0 km (3.6 mi) north of southern quadrangle border, 1.9 km (1.1 mi) west of eastern quadrangle border, Osborn quadrangle, Charleston County, S.C.; surface altitude=4.5 m (14 ft), sample altitude=1 m (3 ft); sample no. is 6584. F5 in figure 2.

+40. GS-29-(S2, S3): 1.9 km (1.1 mi) north of southern quadrangle border, 4.1 km (2.5 mi) east of western quadrangle border, Osborn quadrangle, Charleston County, S.C.; surface altitude=4 m (13 ft), sample altitudes: S2 (6586)=0.5 m (1 ft), S3 (6587)=−1 m to −1.5 m (−3 ft to −5 ft). F5 in figure 2.

+*41. H-275: Near the Ida Bell dug pond; Bayboro quadrangle, Horry County, S.C.; surface altitude=29 m (95 ft), sample altitude=sea level.

42. JI-43-(I, J): Excavation; 0.2 km (0.1 mi) south of northern quadrangle border, 4.3 km (2.6 mi) east of western quadrangle border, Johns Island quadrangle, Charleston County, S.C.; surface altitude=4 m (13 ft), sample altitudes are both about 2 m to 2.5 m (7 ft to 8 ft) from different parts of the excavation. H5 in figure 2.

+43. JOI-3 (CN#61): Abandoned railroad right of way 0.8 km (0.5 mi) south of U.S. Route 17 and 1.5 km (0.9 mi) southwest of junction of U.S. Route 17 and State Route 7; 3.7 km (2.2 mi) north of southern quadrangle border, 4.2 km (2.5 mi) west of eastern quadrangle border, Johns Island quadrangle, Charleston County, S.C.; surface altitude=1.5 m (5 ft), sample altitude is between sea level and −6 m (sea level and −19 ft). H5 in figure 2.

+44. JOI-104 (CN#37): Near Dorchester Road overpass across Seaboard Coastline Railroad; 2.1 km (1.3 mi) south of northern quadrangle border, 2.3 km (1.4 mi) west of eastern quadrangle border, Johns Island quadrangle, Charleston County, S.C.; surface altitude=10 m (33 ft), sample altitude=4.5 m (15 ft). H5 in figure 2.

45. KI-2-(S1-S5): On Kiawah Island beside Ocean Drive; 3.3 km (2.0 mi) south of northern quadrangle border, 1.3 km (0.8 mi) east of western quadrangle border, Kiawah Island quadrangle, Charleston County, S.C.; surface altitude=1.5 m (5 ft), sample altitudes: S1=−4 m (−13 ft), S2=−6.5 m (−22 ft), S3=−10 m (−32 ft), S4=−11 m (−36 ft), S5=−17 m (−55 ft). H7 in figure 2.

+46. M-JI-7 (CN#54-56): Borrow pit for Mark Clark Expressway; 5.8 km (3.5 mi) south of northern quadrangle border, 2.6 km (1.6 mi) west of eastern quadrangle border, Johns Island quadrangle, Charleston County, S.C.; surface altitude=3.5 m (12 ft), sample altitudes: CN#54=−0.3 m (−1 ft), CN#55=0.3 m (1 ft), CN#56=1 m (3 ft). H5 in figure 2.

47. M-C-83-9: West side of U.S. Route 21 0.5 km (0.3 mi) south of road to Seabrook; 3.0 km (1.8 mi) north of southern quadrangle border, 0.2 km (0.1 mi) east of

Locality register—Continued

western quadrangle border, Green Pond 15-minute quadrangle, Beaufort County, S.C.; surface altitude=3.5 m (12 ft), sample altitude=−6.5 m to −8 m (−21 ft to −26 ft); sample no. is R7098. C7 in figure 2.

+48. MH–86 (CN#33): Bessinger's pond; 3.1 km (1.9 mi) north of southern quadrangle border, 0.9 km (0.5 mi) east of western quadrangle border, Mount Holly quadrangle, Berkeley County, S.C.; surface altitude=15 m (49 ft), sample altitude=8 m to 11.5 m (27 ft to 37 ft). H3 in figure 2.

+49. NC–2 (CN#13): Bluff near Yeamans Hall on Goose Creek, type section of Goose Creek Limestone; 5.8 km (3.5 mi) north of southern quadrangle border, 1.3 km (0.8 mi) east of western quadrangle border, North Charleston quadrangle, Berkeley County, S.C.; sample altitude=sea level. I4 in figure 2.

+50. NC–3–(A, B, C) (CN#14, 15): From construction pit at General Electric Company plant at Bushy Park; 1.8 km (1.1 mi) south of northern quadrangle border, 5.0 km (3.0 mi) west of eastern quadrangle border, North Charleston quadrangle, Berkeley County, S.C.; surface altitude=3.5 m (12 ft), sample altitudes: A=2 m (7 ft), B=1.8 m (6 ft), C=1.5 m (5 ft). I4 in figure 2.

+51. NC–4 (CN#19): Bluff along east bank of Clouter Creek 0.6 km (0.4 mi) west of Mary Ann Church; 1.6 km (1.0 mi) north of southern quadrangle border, 5.7 km (3.4 mi) west of eastern quadrangle border, North Charleston quadrangle, Berkeley County, S.C.; sample altitude=sea level. I4 in figure 2.

52. RA–3: 0.3 km (0.2 mi) south-southwest of Ravenel train station; 0.5 km (0.3 mi) east of western quadrangle border, 1.4 km (0.8 mi) north of southern quadrangle border, Ravenel quadrangle, Charleston County, S.C.; surface altitude=11.5 m (37 ft), sample altitude=−3.5 m to −6.5 m (−11 ft to −21 ft). G5 in figure 2.

+53. RO–1: Near northeast shore of North Edisto River about 0.5 km (0.3 mi) upstream from mouth of Bohicket Creek and across the river from Point of Pines; Rockville quadrangle, Charleston County, S.C.; sample altitude approximately −1.5 m (−5 ft). G7 in figure 2.

+54. SMB–2 (near CN#29): Southwest side of U.S. Route 176 2.1 km (1.3 mi) north of the intersection of U.S. Route 176 and U.S. Route 17A; 5.0 km (3.0 mi) south of northern quadrangle border, 1.7 km (1.0 mi) east of western quadrangle border, Mount Holly quadrangle, Berkeley County, S.C.; surface altitude=25 m (82 ft), sample altitude=14.5 m to 16 m (47 ft to 52 ft). H3 in figure 2.

55. ST–15–(4A, 4AA, 4AB): Borrow pit east of Creekside Trailer Park; 3.4 km (2.0 mi) south of northern quadrangle border, 5.4 km (3.2 mi) east of western quadrangle border, Stallsville quadrangle, Dorchester County, S.C.; surface altitude=16 m (53 ft), sample altitudes: 4A (R1957A) and 4AA (R1957B) =9.5 m (31 ft), 4AB (R1957C)=7 m (23 ft). G4 in figure 2.

+56. ST–17 (CN#20): 1.8 km (1.1 mi) south of northern quadrangle border, 1.7 km (1.0 mi) west of eastern quadrangle border, Stallsville quadrangle, Charleston County, S.C.; surface altitude=19 m (62 ft), sample altitude=11.5 m (37 ft). G4 in figure 2.

+57. ST–24 (CN#21): 1.5 km (0.9 mi) south of northern quadrangle border, 0.2 km (0.1 mi) west of eastern quadrangle border, Stallsville quadrangle, Dorchester County, S.C.; surface altitude=15 m (49 ft), sample altitude=10.5 m (35 ft). G4 in figure 2.

58. ST–47: 3.0 km (1.8 mi) south of northern quadrangle border, 2.4 km (1.4 mi) east of western quadrangle border, Stallsville quadrangle, Dorchester County, S.C.; surface altitude=20 m (65 ft), sample altitude=11.5 m (37 ft). G4 in figure 2.

+59. ST–76 (CN#36): 1.6 km (1.0 mi) north of southern quadrangle border, 0.1 km (0.1 mi) west of eastern quadrangle border, Stallsville quadrangle, Charleston County, S.C.; surface altitude=14.5 m (48 ft), sample altitude=3.5 m (12 ft). G4 in figure 2.

+60. WAD–100–(A, B) (CN#22, 23, 43, 44, 45, 65, 66): At Wadmalaw Island Post Office; 3.6 km (2.2 mi) north of southern quadrangle border, 4.3 km (2.6 mi) west of eastern quadrangle border, Wadmalaw Island quadrangle, Charleston County, S.C.; surface altitude=4.5 m (14 ft), sample altitudes: A=1 m to −9 m (4 ft to −29 ft), B=−11.5 m to −12.5 m (−38 ft to −41 ft). G6 in figure 2.

61. X–CC–6: 3.0 km (1.8 mi) south of northern quadrangle border, 3.5 km (2.1 mi) east of western quadrangle border, Clubhouse Crossroads quadrangle, Dorchester County, S.C.; surface altitude=18.5 m (60 ft), sample altitude=8.5 m (28 ft); sample no. is R2794. F4 in figure 2.

62. X–FM–23: 1.8 km (1.1 mi) south of northern quadrangle border, 1.8 km (1.1 mi) west of eastern quadrangle border, Fort Moultrie quadrangle, Charleston County, S.C.; surface altitude=2.5 m (9 ft), sample altitude =1 m (3 ft); sample no. is R2777. J5 in figure 2.

+63. X–SN–(7, 12, 17) (CN#5–7): About 5.6 km (3.4 mi) east of western quadrangle border, 5.9 km (3.5 mi) south of northern quadrangle border, Summerville Northwest quadrangle, Berkeley County, S.C.; three locations within 1-km radius at nearly the same altitude: surface altitude=18.5 m to 20 m (60 ft to 65 ft), sample altitude=15 m to 17 m (50 ft to 55 ft). G2 in figure 2.

+64. X–PR–19 (CN#11): 1.7 km (1.0 mi) east of western quadrangle border, 1.8 km (1.1 mi) north of southern quadrangle border, Pringletown quadrangle, Berkeley County, S.C.; surface altitude=25 m (82 ft), sample altitude=17 m (56 ft). F2 in figure 2.

+65. X–PR–6 (CN#9): 0.5 km (0.3 mi) east of western quadrangle border, 0.9 km (0.5 mi) north of southern sample altitude=17.5 m (58 ft). F2 in figure 2.

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quadrangle border, Pringletown quadrangle, Berkeley County, S.C.; surface altitude=28.5 m (94 ft),

+66. X–SN–19 (CN#8): 0.9 km (0.5 mi) east of western quadrangle border, 1.4 km (0.8 mi) north of southern quadrangle border, Summerville Northwest quadrangle, Berkeley County, S.C.; surface altitude=21 m (69 ft), sample altitude=15 m (49 ft). G2 in figure 2.

67. X–CJ–1: 6.9 km (4.1 mi) south of northern quadrangle border, 2.9 km (1.7 mi) east of western quadrangle border, James Island quadrangle, Charleston County, S.C.; surface altitude=1.5 m (5 ft), sample altitude=−12 m (−39 ft). I6 in figure 2.

68. X–CH–12: One block northwest of intersection of McMillan Avenue and Meeting Road on northeast side of Meeting Street Road; 1.9 km (1.1 mi) south of northern quadrangle border, 1.3 km (0.8 mi) east of western quadrangle border, Charleston quadrangle, Charleston County, S.C.; surface altitude=10 m (33 ft), sample altitude=2.5 m to 3 m (8 ft to 10 ft). I5 in figure 2.

69. X–CNC–15–(S3, S4, S5): At Pine Plantation; 6.4 km (3.8 mi) north of southern quadrangle border, 1.8 km (1.1 mi) west of eastern quadrangle border, North Charleston quadrangle, Berkeley County, S.C.; surface altitude=6 m (20 ft), sample altitudes: S3=−2 m (−7 ft), S4=−2.5 m (−8 ft), S5=−3.5 m (−12 m). I4 in figure 2.

70. X–SU–1: In excavation pit beside access road northeast of interstate 26 and southeast of U.S. Route 17A; 3.8 km (2.3 mi) north of southern quadrangle border, 1.7 km (1.0 mi) west of eastern quadrangle border, Summerville quadrangle, Berkeley County, S.C.; surface altitude=18.5 m (60 ft), sample altitude=14.5 m to 15 m (47 ft to 49 ft). G3 in figure 2.

71. X–CC–9: 0.2 km (0.1 mi) south of radio tower; 0.2 km (0.1 mi) south of northern quadrangle border, 1.8 km (1.1 mi) west of eastern quadrangle border, Clubhouse Crossroads quadrangle, Dorchester County, S.C.; surface altitude=16 m (52 ft), sample altitude=9 m (30 ft); sample no. is R2795. F4 in figure 2.

72. X–Hu–1: In Francis Marion National Forest; 4.3 km (2.6 mi) north of southern quadrangle border, 5.6 km (3.4 mi) west of eastern quadrangle border, Huger quadrangle, Berkeley County, S.C.; surface altitude=12 m (40 ft), sample altitude=1 m to 4.5 m (4 ft to 15 ft). J3 in figure 2.

73. X–FM–4: Near west end of Fort Moultrie, Sullivans Island; 1.0 km (0.6 mi) north of southern quadrangle border, 1.5 km (0.9 mi) east of western quadrangle border, Fort Moultrie quadrangle, Charleston County, S.C.; surface altitude=1.5 m (5 ft), sample altitude=−10.5 m to −11 m (−35 ft to −36 ft). J5 in figure 2.

74. X–Simmons Bluff (A, B, C): South end of Yonges Island in Wadmalaw Sound; 6.9 km (4.1 mi) south of northern quadrangle border, 2.0 km (1.2 mi) east of western quadrangle border, Wadmalaw Island quadrangle, Charleston County, S.C.; sample altitudes: (A) (78TC71)=sea level, (B) (78TC73)=0.3 m (1 ft), (C) (78TC72)=0.6 m (2 ft). G6 in figure 2.

*75. Windy Hill Airport (A, B, C): Intracoastal Waterway near Myrtle Beach, S.C.; sample altitudes: (A) (78TC18) and (B) (NCSC 66)=1 m (3 ft), (C) (78TC19)=1.5 m (5 ft).

*76. Locality WA–20 of DuBar (1971) (A–H): Intracoastal Waterway near Myrtle Beach, S.C.; sample altitudes: (A) (NCSC 68)=1 m (3.5 ft), (B) (78TC85)=0.5 m (1 ft), (C) (78TC86)=1 m (3.5 ft), (D) (78TC87)=1.5 m (4.5 ft), (E) (78TC88)=2 m (7 ft), (F) (78TC89)=2.5 m (9 ft), (G) (78TC90)=3.5 m (11 ft), (H) (78TC91)=4 m (13 ft).

*77. Cedar Grove pit (A, B): 1.6 km (1.0 mi) south of Little River, S.C., on east side of U.S. Route 17; samplealtitudes: (A) (78TC93)=1 m (2.5 ft), (B) (78TC94)=2.5 m (8 ft).

+*78. (CN#57): West branch of Pee Dee River 0.4 km (0.2 mi) upstream from railroad bridge (Godfrey Ferry Bridge); Johnsonville 15-minute quadrangle, S.C.; sample altitude=0.5 m (2 ft).

*79. Parkers Landing (A, B, C, D): Waccamaw River, S.C.; sample altitudes: (A) (78TC205)=2 m (7 ft), (B) (78TC208)=2.5 m (8 ft), (C) (78TC209)=3 m (9.5 ft), (D) (78TC210)=3.5 m (11.5 ft).

*80. LB173–(S1–S5): Sumter County, S.C., southwest corner of Florence 2° sheet; surface altitude=41 m (134 ft), sample altitudes: (S1)=27.5 m (90 ft), (S2)=26.5 m (87 ft), (S3)=26 m (85 ft), (S4)=25.5 m (83 ft), (S5)=25 m (82 ft).

*81. WA–19 of DuBar (1971): Intracoastal Waterway near Myrtle Beach, S.C.

+82. CBT–1 (CN#58): 0.6 km (0.4 mi) west of U.S. Route 21; 5.2 km (3.1 mi) south of northern quadrangle border, 0.9 km (0.5 mi) east of western quadrangle border, Beaufort quadrangle, Beaufort County, S.C.; surface altitude=5.5 m (18 ft), sample altitude=−8 m (−27 ft). C8 in figure 2.

+83. CMH–6 (CN#27, 28): 1.5 km (0.9 mi) south-southwest of Ridge Church; 0.8 km (0.5 mi) east of western quadrangle border, 3.2 km (1.9 mi) north of southern quadrangle border, Mount Holly quadrangle, Berkeley County, S.C.; surface altitude=15 m (49 ft), sample altitudes: CN#27=11.5 m (37 ft), CN#28=8 m (27 ft). H3 in figure 2.

+84. CMH–7 (CN#30): 0.9 km (0.5 mi) south of Ridge Church; 1.2 km (0.7 mi) east of western quadrangle border, 3.6 km (2.2 mi) north of southern quadrangle border, Mount Holly quadrangle, Berkeley County, S.C.; surface altitude=15 m (50 ft), sample altitude=7.5 m (25 ft). H3 in figure 2.

+85. CRVNW–1 (CN#3): East edge of Dorchester; 0.4 km (0.2 mi) west of eastern quadrangle border, 0.75 km (0.5 mi) north of southern quadrangle border,

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Harleyville quadrangle, Dorchester County, S.C.; surface altitude=33.5 m (110 ft), sample altitude=19.5 m (64 ft). E2 in figure 2.

+86. CSV–1 (CN#24): 6.3 km (3.8 mi) north-northeast of intersection of interstate 26 and U.S. Route 17A; 1.1 km (0.7 mi) west of eastern quadrangle border, 1.2 km (0.7 mi) south of northern quadrangle border, Summerville quadrangle, Dorchester County, S.C.; surface altitude=26 m (85 ft), sample altitude=14 m (46 ft). G3 in figure 2.

+87. CSV–2 (CN#25, 26): 2.7 km (1.6 mi) southwest of Summerville on U.S. Route 17A; 4.3 km (2.6 mi) east of western quadrangle border, 0.3 km (0.2 mi) north of southern quadrangle border, Summerville quadrangle, Dorchester County, S.C.; surface altitude=23 m (75 ft), sample altitudes: CN#25=13.5 m (45 ft), CN#26=13 m (42 ft). G3 in figure 2.

+88. CW–1 (CN#10): 13.5 km (8.1 mi) northeast of Walterboro at Sidney; 6.3 km (3.8 mi) west of eastern quadrangle border, 0.2 km (0.1 mi) south of northern quadrangle border, Walterboro 15-minute quadrangle, Colleton County, S.C.; surface altitude=30.5 m (100 ft), sample altitude=15.5 m (51 ft). D4 in figure 2.

+89. CNC–20 (CN#16, 17): On Yeamans Hall Golf Course; 1.7 km (1.0 mi) east of western quadrangle border, 5.9 km (3.5 mi) north of southern quadrangle border, North Charleston quadrangle, Charleston County, S.C.; surface altitude=5 m (16 ft), sample altitudes: CN#16=−1.5 m (−5 ft), CN#17=−2.5 m (−8 ft). I4 in figure 2.

*90. N4293: Locality of Sloan (1908) at "838 Muldrow Place, 5 miles S. 45° E. of Mayesville, 0.5 miles north of Brick Church" at edge of swamp, Sumter County, S.C.; surface altitude=41 m (134 ft), sample altitude=33.5 m to 37 m (110 ft to 122 ft).

+91. (CN#2): Sloan's (1908) locality 336 on west side of Edisto River, "8 miles S. 25° W. of St. George, 1/4 mile southeast of Raysor Bridge"; sample altitude=23 m (75 ft). C3 in figure 2.

+92. (CN#49): At Doe Point 4.3 km (2.6 mi) north-northeast of Frogmore; 6.0 km (3.6 mi) west of eastern quadrangle border, 6.2 km (3.7 mi) north of southern quadrangle border, center of Frogmore quadrangle, Beaufort County, S.C.; surface altitude=3 m (10 ft), sample altitude=−3 m (−10 ft). D8 in figure 2.

+93. (CN#12): East edge of Smoaks; 5.3 km (3.2 mi) west of eastern quadrangle border, 10.2 km (6.1 mi) north of southern quadrangle border, Lodge 15-minute quadrangle, Colleton County, S.C.; surface altitude=35 m (115 ft), sample altitude=28 m (92 ft). B3 in figure 2.

+*94. (CN#1): Tearcoat Branch 8.8 km (5.3 mi) southeast of Sumter on county road 255, immediately south of bridge; Mayesville 15-minute quadrangle; surface altitude=38 m (125 ft), sample altitude=28 m (92 ft).

+*95. CP–1 (CN#4): Northwest of Gillisonville off State Route 278 on small road to Beaverdam Church; Pineland 15-minute quadrangle, Jasper County, S.C.; surface altitude=24 m (79 ft), sample altitude=13 m (43 ft).

+*96. LB179: 7.0 km (4.2 mi) west-northwest of Darlington, S.C.; surface altitude=55.5 m (182 ft), sample altitude=16 m (52 ft).

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TABLES 4 AND 6

TABLE 4.—*Summary of selected stratigraphic occurrences of Pliocene*

[49, locality number (see "Locality register" section); (C), sample designation; X, positive

	PLIOCENE											
		Q5					Q4	Q3				
	Goose Creek Limestone[1]	Penholoway Formation[2]					Ladson Formation	Ten Mile Hill beds				
	49	54	3 (C)	60 (B)	42 (I)	42 (J)	58	17	25	34	59	40 (S3)
Mollusk												
Pelecypod												
Abra aequalis (Say)	—	—	—	—	—	—	—	—	—	—	—	—
Aligena striata H.C. Lea	—	—	X	—	—	—	—	—	—	—	—	—
Amusium mortoni (Ravenel)	X	—	—	—	—	—	—	—	—	—	—	—
Anadara aequicostata (Conrad)	—	X	X	—	X	X	—	—	—	—	—	—
Anadara transversa (Say)	—	—	—	—	—	—	—	X	—	—	—	X
Anadara cf. *A. transversa* (Say)	—	—	—	X	—	—	—	—	—	—	—	X
Anadara sp.	—	X	—	—	—	—	—	—	—	—	—	—
Anomia simplex d'Orbigny	—	—	—	—	—	—	—	—	—	—	—	X
Anomia sp.	—	—	—	X	—	—	—	—	—	—	—	—
Argopecten sp.	X	—	—	—	—	—	—	—	—	—	—	—
Atrina sp.	—	—	—	—	—	—	—	—	—	—	—	—
Barbatia sp.	—	—	—	—	X	X	X	—	—	—	—	—
Bellucina amiantus (Dall)	—	—	—	—	—	—	X	—	—	—	—	—
Bellucina waccamawensis (Dall)	—	X	—	—	X	—	—	—	—	—	—	—
B. cf. *B. waccamawensis* (Dall)	—	X	X	—	—	—	—	—	—	—	—	—
Bellucina sp.	—	—	—	X	—	—	X	—	—	—	—	—
Brachiodontes sp.	—	—	—	—	—	—	—	—	—	—	—	—
Callucina keenae Chavan	—	—	X	—	—	—	—	—	—	—	—	—
Carditamera arata (Conrad)	—	—	—	—	—	X	—	—	—	—	—	—
Carditamera cf. *C. arata* (Conrad)	—	—	X	—	—	—	—	—	—	—	—	—
Carolinapecten eboreus (Conrad)	?	?	—	—	—	—	—	—	—	—	—	—
Carolinapecten solarioides (Heilprin)	—	X	—	—	—	—	—	—	—	—	—	—
Caryocorbula conradi (Gardner)	—	X	—	—	—	—	—	—	—	—	—	—
Caryocorbula contracta (Say)	—	—	—	—	X	X	—	X	X	—	X	X
Caryocorbula dietziana (C.B. Adams)	—	—	—	—	—	—	X	—	—	—	—	—
Caryocorbula sp.	—	X	X	—	—	—	—	—	—	—	—	—
Chama congregata Conrad	—	—	—	—	—	—	—	—	—	—	—	—
Chama emmonsi Nicol	—	—	—	X	—	X	—	—	—	—	—	—
Chama sp.	—	—	X	—	—	—	—	—	—	—	—	—
Chione cancellata (Linné)	—	—	—	—	—	—	—	—	—	—	—	X
Chione grus (Holmes)	—	—	—	—	—	—	—	—	—	—	—	—
Chione intapurpurea (Conrad)	—	—	—	—	—	—	—	—	—	—	—	—
Corbula scutata Gardner	—	—	—	X	X	—	—	—	—	—	—	—
Corbula sp.	—	—	—	—	—	—	—	—	—	X	—	—
Crassinella lunulata (Conrad)	—	—	—	—	X	—	—	—	—	—	—	X
Crassinella sp.	—	—	—	X	—	—	—	—	—	—	—	—
Crassostrea virginica (Gmelin)	—	—	X	—	—	—	—	—	—	—	—	X
Crassostrea sp.	X	X	—	X	—	—	?	?	?	?	?	—
Cumingia tellinoides (Conrad)	—	—	—	—	—	—	—	—	—	—	—	—
Cunearca brasiliana (Lamarck)	—	—	—	—	—	—	—	—	—	—	—	—
Cyrtopleura costata (Linné)	—	—	—	—	—	—	—	—	—	—	—	—
Cyrtopleura sp.	—	X	—	X	—	—	—	X	—	—	?	—
Dinocardium robustum (Solander)	—	—	—	—	—	—	—	—	—	—	—	—
Dinocardium sp.	—	X	—	—	X	?	X	—	—	—	—	—
Diplodonta cf. *D. acclinis* (Conrad)	—	—	X	—	—	—	—	—	—	—	—	—
Divaricella quadrisulcata d'Orbigny	—	X	—	—	—	—	—	—	—	—	—	—
Divaricella sp.	—	—	X	—	—	—	—	—	—	—	—	—
Donax fossor Say	—	—	X	—	—	—	—	—	—	—	—	—

and Pleistocene fossil mollusks in the Charleston, S.C., area

identification; ?, questionable identification; —, not identified at this locality]

PLEISTOCENE																	
Q2																	
Wando Formation																	
Lower member								Upper member	Undivided[3]								
6 (S1–3)	7	8	9	15	19	29	44	13	10	11	14	16	67	21	30	45	60 (A)
—	X	—	X	—	X	—	—	X	—	—	—	X	—	—	—	X	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	X	X	X	X	—	X	X	—	—	—	—	X	—	X	X	X
X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	X	X	—	—	—	—	—	—	—	—
—	—	—	—	—	X	—	X	—	—	—	—	—	—	—	—	—	X
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	?	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	?	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
X	—	X	X	—	X	—	—	—	X	—	—	—	X	—	—	—	X
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	X	—	X	—	—	—	—	—	—	—	—	—	—	X
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	?
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
?	—	—	—	—	—	—	X	—	—	—	—	—	X	—	X	—	X
—	—	—	—	—	—	—	—	X	—	—	—	—	X	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	X	—	—
—	—	—	—	—	—	—	X	—	—	—	—	—	—	X	—	—	—
—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—
—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	X	X
—	—	—	X	X	X	X	—	X	X	—	—	?	—	X	X	?	X
—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	X	X	—	X	X	—	—	—	—	—	—	X	—	X
—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	?	—	X	—	—	—	—	—	—	—	—	—	—	—	—	X	X
—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	X	—
—	—	—	—	X	—	—	—	X	—	?	—	—	—	—	X	X	X
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

TABLE 4.—*Summary of selected stratigraphic occurrences of Pliocene*

[49, locality number (see "Locality register" section); (C), sample designation; X,

	PLIOCENE											
		Q5					Q4	Q3				
	Goose Creek Limestone[1]	Penholoway Formation[2]					Ladson Formation	Ten Mile Hill beds				
	49	54	3 (C)	60 (B)	42 (I)	42 (J)	58	17	25	34	59	40 (S3)
Mollusk												
Pelecypod												
Donax texasianus Phillippi	—	—	—	—	—	—	—	—	—	—	—	—
Donax variabilis Say	—	—	—	—	—	—	—	—	—	—	—	—
Donax sp.	—	—	—	—	—	X	—	—	—	—	—	—
Dosinia sp.	—	X	X	—	—	—	—	—	—	—	—	—
Ensis sp.	—	X	X	X	—	—	—	X	—	—	—	—
Ervilia concentrica (Holmes)	—	—	—	—	—	—	—	—	—	—	—	—
Ervilia lata Dall	—	—	—	X	—	—	—	—	—	—	—	—
Ervilia sp.	—	—	—	—	—	—	—	—	—	—	—	—
Gemma gemma (Totten)	—	—	X	—	X	—	—	X	—	—	—	—
Gemma sp.	—	—	—	—	—	—	—	—	—	—	—	—
Glycymeris americana (DeFrance)	—	—	—	—	X	X	—	—	—	—	—	—
Glycymeris cf. *G. americana* (DeFrance)	—	—	—	—	—	—	—	—	—	—	—	—
Glycymeris pectinata (Gmelin)	—	—	—	—	—	—	—	—	—	—	—	—
Hemimactra solidissima (Dillwyn)	—	—	—	—	—	—	—	—	—	—	—	—
Lunarca ovalis (Bruguière)	—	—	—	—	—	—	—	X	X	—	—	—
Lucinisca cribraria (Say)	X	—	—	—	—	—	—	—	—	—	—	—
Macrocallista sp.	—	X	—	—	—	X	—	—	—	—	—	—
Mercenaria rileyi (Conrad)	X	—	—	—	—	—	—	—	—	—	—	—
Mercenaria cf. *M. rileyi* (Conrad)	X	—	—	—	—	—	—	—	—	—	—	—
Mercenaria sp.	—	—	X	—	—	—	—	—	—	—	—	X
Mulinia lateralis (Say)	—	X	—	X	X	X	X	X	—	—	X	—
Mulinia sp.	—	X	—	—	—	—	—	—	—	—	—	—
Mysella cf. *M. planulata* (Stimpson)	—	—	—	—	—	—	—	—	—	—	—	—
Mysella sp.	—	—	—	—	—	—	—	—	—	—	—	—
Naeromya sp.	—	X	—	—	—	—	—	—	—	—	—	—
Noetia limula (Conrad)	—	—	X	—	—	—	—	—	—	—	—	—
Noetia ponderosa (Say)	—	—	—	—	—	—	—	—	—	—	—	—
Noetia sp.	—	—	—	—	—	—	—	X	X	X	—	X
Nucula proxima Say	—	X	—	—	—	X	—	—	X	—	—	—
Nucula sp.	—	X	X	—	—	—	—	—	—	—	—	—
Nuculana acuta (Conrad)	—	—	—	—	—	—	—	—	X	—	—	—
Nuculana concentrica (Say)	—	X	—	—	—	—	—	—	X	—	—	—
Nuculana sp.	—	—	—	—	—	—	—	—	—	—	—	—
Ostrea raveneliana Tuomey and Holmes	X	—	—	—	—	—	—	—	—	—	—	—
Ostrea sculpturata Conrad	X	—	—	—	—	—	—	—	—	—	—	—
Ostrea sp.	—	—	X	—	—	—	—	—	—	—	—	—
Pandora sp.	—	X	X	X	—	—	—	—	—	—	—	—
Parvilucina multilineata (Tuomey and Holmes)	—	X	X	—	—	X	—	X	X	—	—	—
Pecten hemicyclica Ravenel	X	—	—	—	—	—	—	—	—	—	—	—
Petricola sp.	—	—	—	—	—	—	—	—	—	—	—	—
Pitar sp.	—	X	—	—	—	X	—	—	—	—	—	—
Pleuromeris tridentata (Say)	—	X	—	X	X	X	—	—	—	—	—	X
Pleuromeris cf. *P. decemcostata* Conrad	—	—	X	—	—	—	—	—	—	—	—	—
Plicatula gibbosa Lamarck	—	—	—	—	—	—	—	—	—	—	—	—
Plicatula marginata Say	—	—	—	—	—	—	—	—	—	—	—	—
Plicatula sp.	X	—	—	—	—	—	—	—	—	—	—	—
Pteromeris perplana (Conrad)	—	—	X	—	—	—	—	—	—	—	—	—
Raeta canaliculata (Say)	—	—	—	—	—	—	—	—	—	—	—	

and Pleistocene fossil mollusks in the Charleston, S.C., area—Continued

positive identification; ?, questionable identification; —, not identified at this locality]

PLEISTOCENE																	
Q2																	
Wando Formation																	
Lower member								Upper member	Undivided³								
6 (S1–3)	7	8	9	15	19	29	44	13	10	11	14	16	67	21	30	45	60 (A)
—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	X	X	X	—	—	X	—	—	—	—	—	—	—	—	X
—	X	—	—	—	—	X	—	X	—	—	—	—	—	—	X	X	—
—	—	—	—	—	—	—	—	X	—	—	—	—	?	—	—	X	—
—	—	—	X	X	—	X	X	X	—	—	—	—	—	—	—	X	X
—	—	—	—	X	—	X	—	X	—	—	—	—	X	—	—	X	X
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	X	—	—	—	?	—	—	—	—	—
X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	?	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—
—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	X	—
—	—	—	—	—	—	X	—	—	—	—	—	—	—	X	—	—	—
—	X	X	X	?	X	X	X	X	—	—	—	—	—	X	X	X	X
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
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—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
X	—	—	X	—	—	X	—	X	X	—	—	—	X	—	X	?	X
X	X	X	X	X	X	X	X	X	X	X	X	?	X	X	X	X	X
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
X	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	?	—	X	—	X	—	X	X	—	—	—	—	—	—	X	X	X
—	—	X	X	—	—	X	X	X	—	—	—	—	X	X	X	X	X
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	X	X	X	X	X	—	X	—	—	—	—	—	—	X	X
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	?	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	X	—	—	—	—	X	X	—	X	X
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X
—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—
—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	X	—
—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	X

TABLE 4.—*Summary of selected stratigraphic occurrences of Pliocene*

[49, locality number (see "Locality register" section); (C), sample designation; X,

	PLIOCENE											
		Q5					Q4	Q3				
	Goose Creek Limestone[1]	Penholoway Formation[2]					Ladson Formation	Ten Mile Hill beds				
	49	54	3 (C)	60 (B)	42 (1)	42 (J)	58	17	25	34	59	40 (S3)
Mollusk												
Pelecypod												
Raeta cuneata	—	—	—	—	—	—	—	—	—	—	—	—
Raeta plicatella (Lamarck)	—	—	—	—	—	—	—	—	—	—	—	—
Raeta sp.	—	X	—	—	—	—	—	X	—	—	—	—
Rangia clathrodonta (Conrad)	—	X	X	—	—	—	—	—	—	—	—	—
Semele bellastriata (Conrad)	—	—	X	—	—	—	—	—	—	—	—	—
Semele proficua (Pulteney)	—	—	—	—	—	—	—	—	—	—	—	X
Spisula sp.	—	X	X	—	X	—	—	—	—	—	—	—
Stewartia floridana (Conrad)	—	X	—	—	X	X	—	—	—	—	—	—
Strigilla mirabilis (Phillippi)	—	—	—	—	—	—	—	—	—	—	—	—
Tagelus sp.	—	—	—	—	—	—	—	—	—	—	—	—
Tellina agilis Stimpson	—	—	—	—	—	X	—	—	—	—	—	—
Tellina alternata Say	—	—	—	—	—	—	—	—	—	—	—	—
Tellina sybaritica Dall	—	—	—	—	—	—	—	—	—	—	—	—
Trachycardium sp.	—	—	—	X	—	—	—	—	—	—	—	—
Gastropod												
Acteocina canaliculata (Say)	—	—	—	—	—	—	—	X	X	—	—	—
Acteocina candei (d'Orbigny)	—	X	—	—	—	—	—	—	X	—	—	—
Acteocina sp.	—	—	—	—	—	—	—	—	X	X	X	—
Anachis avara (Say)	—	—	—	—	—	—	—	—	—	—	—	X
Anachis lafresnayi (Fischer and Bernardi)	—	—	—	—	—	—	—	—	X	—	—	—
Anachis obesa (C.B. Adams)	—	—	—	—	—	—	—	—	X	—	—	—
Anachis sp.	—	—	—	—	—	—	—	—	—	—	—	—
Busycon carica (Gmelin)	—	—	—	—	—	—	—	—	—	—	—	—
Busycon sp.	—	X	—	—	—	—	—	—	—	—	—	—
Busycotypus canaliculatum (Linné)	—	—	—	—	—	—	—	—	—	—	—	—
Crepidula aculeata (Gmelin)	—	—	—	—	—	—	—	—	—	—	—	—
Crepidula fornicata (Linné)	—	—	X	—	X	—	—	—	—	—	—	—
Crepidula sp.	—	—	—	—	—	—	—	—	—	—	—	—
Cyclostremiscus pentagonus (Gabb)	—	—	—	—	—	—	—	—	X	—	—	—
Diastoma varium (Pfeiffer)	—	—	—	—	—	—	—	—	—	—	—	—
Diodora sp.	—	—	—	—	—	—	—	—	—	—	—	X
Epitonium humphreysii (Kiener)	—	—	—	—	—	—	—	—	—	—	—	—
Epitonium cf. *E. humphreysii* (Kiener)	—	—	—	—	—	—	—	—	—	—	—	—
Epitonium multistriatum (Say)	—	—	—	—	—	—	—	—	—	—	—	—
Eupleura caudata (Say)	—	—	—	—	—	—	—	—	—	—	—	—
Eupleura sp.	—	—	—	—	—	—	—	—	—	—	—	—
Ilyanassa obsoleta (Say)	—	—	—	X	—	—	—	X	—	—	—	X
Kurtziella atrostyla (Tryon)	—	—	—	—	—	—	—	—	—	—	—	—
Kurtziella cf. *K. atrostyla* (Tryon)	—	—	—	—	—	—	—	—	—	—	—	—
Kurtziella cerina Kurtz and Stimpson	—	—	—	—	—	—	—	—	—	—	—	—
Kurtziella sp.	—	—	—	—	—	—	—	—	—	—	—	—
Littorina sp.	—	—	X	X	—	X	X	—	—	—	—	—
Lunatia sp.	—	—	—	—	—	—	—	—	—	—	—	—
Marginella apicina Menke	—	X	—	—	—	—	—	—	—	—	—	—
Marginella sp.	—	—	—	X	—	X	X	—	—	—	—	—
Melanella conoidea Kurtz and Stimpson	—	—	—	—	—	—	—	—	—	—	—	—
Mitrella lunata (Say)	—	—	—	—	—	—	—	—	—	—	—	—
Nassarius acutus (Say)	—	—	—	X	—	—	—	—	—	—	—	—

and Pleistocene fossil mollusks in the Charleston, S.C., area—Continued

positive identification; ?, questionable identification; —, not identified at this locality]

PLEISTOCENE																	
Q2																	
Wando Formation																	
Lower member								Upper member	Undivided[3]								
6 (S1–3)	7	8	9	15	19	29	44	13	10	11	14	16	67	21	30	45	60 (A)
—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—
—	—	—	—	X	—	—	—	—	—	—	—	—	?	—	—	X	X
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X
—	—	—	—	?	—	—	—	—	—	—	—	—	—	—	X	—	—
—	—	—	X	—	—	X	—	X	—	—	—	—	—	—	—	X	—
—	—	—	—	—	?	—	—	—	—	—	—	—	—	—	—	—	X
—	—	—	—	—	—	—	—	—	—	—	—	—	—	?	—	—	X
—	—	—	—	—	—	—	?	X	—	—	—	—	—	—	?	—	X
X	X	—	X	X	X	—	X	X	—	X	X	X	—	X	X	X	X
—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—
—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	X	—
—	—	—	X	X	—	X	—	—	—	—	—	—	—	—	—	X	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	X	—	—	—	—	X	—	—	—	—	—	—	—	—	X
—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X
—	—	—	X	—	X	—	—	?	—	—	—	—	—	—	—	X	—
—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	X
—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—
—	—	—	X	X	—	—	—	—	—	—	—	—	X	—	—	—	X
—	—	—	—	—	X	—	X	X	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X
—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X
—	—	—	—	X	—	—	—	?	—	—	—	—	—	—	—	—	X
—	—	—	—	—	—	—	—	?	—	—	—	—	—	?	—	?	—
X	X	—	X	X	—	—	—	X	—	—	—	—	X	X	X	?	X
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—
—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	X
—	—	—	—	—	—	—	—	—	—	—	—	—	?	—	—	—	—
—	?	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—
—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—
—	—	—	—	X	X	—	—	X	—	X	—	—	—	—	—	—	X
—	—	X	X	—	X	—	—	X	—	X	X	—	X	X	X	X	X

TABLE 4.—*Summary of selected stratigraphic occurrences of Pliocene and*

[49, locality number (see "Locality register" section); (C), sample designation; X,

	PLIOCENE											
		Q5					Q4	Q3				
	Goose Creek Limestone[1]	Penholoway Formation[2]					Ladson Formation	Ten Mile Hill beds				
	49	54	3 (C)	60 (B)	42 (I)	42 (J)	58	17	25	34	59	40 (S3)
Mollusk												
Pelecypod												
Nassarius concensus (Ravenel)	—	—	—	—	—	—	—	—	—	—	—	—
Nassarius trivittatus (Say)	—	—	—	X	—	—	—	—	—	—	—	—
Nassarius cf. *N. vibex* (Say)	—	—	—	—	—	—	—	—	—	—	—	X
Odostomia impressa Say	—	—	—	—	—	—	—	—	—	—	—	—
Oliva sayana Ravenel	—	—	—	—	—	—	—	—	—	—	—	—
Oliva sp.	—	—	X	X	X	—	X	—	—	—	—	—
Olivella floralia Duclos	—	—	—	—	—	—	—	—	—	—	—	—
Olivella mutica (Say)	—	X	—	X	—	X	—	—	—	—	—	X
Olivella sp.	—	X	X	—	—	—	—	—	X	—	—	X
Polinices duplicatus (Say)	—	X	—	—	—	—	—	—	—	—	—	—
Polinices sp.	—	—	—	—	—	X	—	—	?	—	—	X
Prunum sp.	—	—	—	—	—	—	—	—	—	—	—	—
Pyramidella crenulata (Holmes)	—	—	—	—	—	—	—	—	—	—	—	—
Pyramidella sp.	—	—	—	—	—	—	—	—	—	—	—	—
Seila adamsii (H.C. Lea)	—	—	—	—	X	—	—	—	—	—	—	—
Sinum perspectivum (Say)	—	—	—	—	—	—	—	—	—	—	—	X
Strombus cf. *S. alatus* Gmelin	—	—	—	—	—	—	—	—	—	—	—	—
Tectonatica sp.	—	—	—	—	—	—	—	—	—	—	—	—
Terebra concava Say	—	—	—	—	—	—	X	X	X	—	—	—
Terebra dislocata (Say)	—	X	—	—	—	X	—	—	—	—	X	X
Terebra sp.	—	X	—	—	—	—	—	—	—	—	—	—
Triphora sp.	—	—	—	—	—	—	—	—	—	—	—	—
Turbonilla interrupta (Totten)	—	—	—	—	—	—	—	—	X	—	—	—
Turbonilla sp.	—	X	—	—	—	—	—	—	?	—	—	—
Urosalpinx sp.	—	—	—	—	X	X	—	—	—	—	—	—
Vitrinella sp.	—	—	—	—	—	—	—	—	X	—	—	—

[1] See also Malde (1959, p. 31–32, samples D189–T–14, D191–T, D192–T, D291–T, 27, and D203–T).

[2] See also Colquhoun and others (1968) and DuBar (1971, p. 112–115, column A).

[3] Probably upper member of the Wando Formation.

Pleistocene fossil mollusks in the Charleston, S.C., area—Continued

positive identification; ?, questionable identification; —, not identified at this locality]

PLEISTOCENE																	
Q2																	
Wando Formation																	
Lower member								Upper member	Undivided[3]								
6 (S1–3)	7	8	9	15	19	29	44	13	10	11	14	16	67	21	30	45	60 (A)
—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	X
—	—	—	—	X	—	—	—	X	—	—	—	X	—	—	X	X	X
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	?	—	—	—	—	—	—	X	—	—
—	—	—	—	—	—	—	—	X	—	—	—	—	X	—	—	—	X
—	—	—	—	X	—	—	—	X	—	—	—	—	—	X	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	?
—	—	—	—	X	X	X	—	X	—	—	—	—	X	X	X	X	X
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—
—	—	—	—	—	X	—	—	—	—	—	—	X	X	X	—	—	X
X	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	?	?
—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X
—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	X
—	—	—	X	—	—	—	X	—	—	—	—	X	—	—	X	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	?	—	—	—	—
—	—	—	—	—	—	—	—	?	—	—	—	—	—	—	—	—	—
—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	X	X	X	X	—	X	—	—	—	—	X	—	X	X	X
—	?	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X	—	—
—	—	—	—	X	X	X	X	X	—	—	X	—	X	X	—	—	X
—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	X	—
—	—	—	X	?	—	—	X	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

TABLE 6.—*Summary of selected stratigraphic occurrences of Miocene and*

[52, locality number (see "Locality register" section); (A), sample designation; X, positive identification; ?, questionable identification;

	MIOCENE														
			Q5			Q4				Q3					
	Marks Head Formation		Penholoway Formation			Ladson Formation				Ten Mile Hill beds					
	52	18	1	3 (A)	3 (B)	55 (A)	55 (AA)	5 (B)	5 (A)	20 (S5)	22 (S6)	24	27	33	40 (S3)
Sporomorph															
Families and higher level taxa															
cf. Anacardiaceae (S)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X
Caprifoliaceae (S)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Chenopodiaceae-Amaranthaceae type (H)	—	X	X	X	X	X	X	X	—	X	X	X	X	X	X
Compositae (H)															
Liguliflorae	—	—	—	X	X	—	—	—	—	—	X	X	—	X	—
Tubuliflorae	—	—	X	—	—	X	X	X	—	—	—	—	X	—	X
Cyperaceae (H)	—	—	X	X	X	—	—	—	—	X	X	—	X	—	X
Ericaceae (S)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Fabaceae (H)	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—
Gramineae (H)	—	—	X	—	—	—	X	X	X	X	—	—	—	—	X
Liliaceae (H)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Moraceae (T)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Myricaceae (S)	—	—	—	—	—	X	X	—	—	—	—	—	—	—	—
Onagraceae (H)	—	—	—	X	—	—	—	—	—	—	—	X	—	—	—
Palmae (cf. Sabal) (T)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Umbelliferae (H)	—	—	X	—	X	—	—	X	—	—	—	—	—	—	X
Fern spores (SP)															
Monolete	—	—	X	X	X	—	—	—	—	X	X	X	X	X	X
Trilete	—	—	X	X	X	—	—	—	—	—	—	—	—	X	—
Fungal spores (SP)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Genus and species															
Acer rubrum (T)	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—
Alnus sp. (S)	—	—	X	—	—	—	—	X	—	X	X	X	X	—	X
Ambrosia sp. (H)	—	—	X	X	X	—	—	—	X	—	—	—	X	X	X
Arceuthobium sp. (H)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Artemisia sp. (H)	—	—	—	—	X	—	—	X	—	—	—	—	—	X	—
Betula sp. (T)	—	—	X	X	X	X	—	X	—	X	X	X	X	X	X
Carya sp. (T)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Castanea sp. (T)	—	—	—	X	X	—	—	—	—	—	—	—	—	X	—
Catalpa sp. (T)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Cephalanthus sp. (S)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Clethra sp. (S)	—	—	X	—	—	—	—	—	—	—	—	—	—	—	X
Cornus sp. (S)	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—
Corylus sp. (T)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Cyrilla-Cliftonia sp. (S, T)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
cf. *Diospyros* sp. (T)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Fagus sp. (T)	—	—	X	—	—	X	X	X	—	X	—	X	X	—	X
Fraxinus sp. (T)	—	—	—	—	X	—	—	X	—	—	—	X	—	—	X
Gordonia sp. (S)	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—
Ilex sp. (S)	—	—	—	X	—	—	—	—	X	—	X	X	—	—	—
Isoetes sp. (SP)	—	—	—	X	—	—	—	—	—	—	—	—	X	—	—
Juglans nigra (T)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Juglans sp. (T)	—	—	—	—	—	—	—	—	X	X	—	—	X	—	—
Juniperus type (T)	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—
Lemna sp. (H)	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—

Pleistocene fossil sporomorphs in the Charleston, S.C., area

—, not identified at this locality; *, possibly reworked; (H), herb; (S), shrub; (SP), spore; (T), tree; (U), unknown; (V), vine]

PLEISTOCENE															
Q2															
Wando Formation															
Lower member		Undivided													
6 (S5)	9	36	32	2	35	37 (S3)	37 (S2)	38 (S1)	38 (S2)	38 (S3)	45 (S1)	45 (S2)	45 (S3)	45 (S4)	45 (S5)
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
X	—	X	—	—	X	X	X	—	—	—	—	—	—	—	—
X	—	—	X	X	—	X	—	—	X	X	—	X	—	X	X
—	X	X	X	—	—	—	—	X	—	X	—	—	X	—	—
—	X	—	—	—	—	X	X	—	X	X	X	—	—	X	—
—	—	—	X	—	—	X	—	—	—	—	—	—	—	—	—
X	X	X	X	X	X	X	X	X	X	X	—	—	X	X	X
—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—
—	?	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
X	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	X	—	—	—	X	—	—	—	—	—	—	—
X	X	X	X	X	—	X	X	X	X	X	X	X	X	X	X
X	X	—	X	—	—	X	—	X	—	X	—	—	—	—	X
—	—	X	X	X	—	—	—	—	—	—	—	—	—	—	—
—	?	—	—	—	—	—	—	—	—	—	—	—	—	—	—
X	—	—	—	X	X	—	—	X	X	—	X	X	X	X	X
—	X	X	X	X	—	—	—	X	X	X	X	X	X	X	X
—	—	—	—	—	—	—	X	—	X	—	—	—	—	—	—
—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—
—	X	X	X	—	X	—	X	—	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X	X	—	X	—	X	X	X	X
—	—	—	—	X	—	—	—	—	—	X	—	—	—	—	X
—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—
X	X	?	—	—	—	—	X	—	—	—	—	—	—	—	—
—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
?	—	X	X	X	—	—	X	—	—	—	—	—	—	—	—
—	—	X	—	X	—	—	—	—	—	—	—	—	—	—	—
—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—
X	—	—	—	—	X	X	—	—	—	X	—	X	X	—	X
—	X	—	X	—	—	—	—	—	—	—	—	—	—	—	X
—	—	X	—	—	—	—	—	—	—	—	—	—	—	—	—
X	X	—	—	X	X	—	X	X	X	X	X	—	—	X	X
—	—	—	—	—	—	X	—	X	X	—	—	X	—	—	X
—	—	—	—	X	—	—	—	—	—	—	X	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

TABLE 6.—*Summary of selected stratigraphic occurrences of Miocene and*

[52, locality number (see "Locality register" section); (A), sample designation; X, positive identification; ?, questionable identification;

	MIOCENE														
			Q5			Q4				Q3					
	Marks Head Formation		Penholoway Formation			Ladson Formation				Ten Mile Hill beds					
	52	18	1	3 (A)	3 (B)	55 (A)	55 (AA)	5 (B)	5 (A)	20 (S5)	22 (S6)	24	27	33	40 (S3)
Sporomorph															
Genus and species															
Liliacidites sp. (T)	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Liquidambar sp. (T)	—	—	X	X	X	X	X	X	—	X	X	X	X	X	X
Liriodendron sp. (T)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Lycopodium sp. (SP)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X
Lygodium type (SP)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Momipites spackmanianus (T)	X	X	—	—	—	—	—	—	—	—	—	—	—	—	—
Myrica type (S)	—	—	—	X	—	—	X	—	—	—	—	—	—	—	X
Myriophyllum sp. (H)	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—
Nuphar sp. (H)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Nyssa sp. (T)	—	—	X	X	?	X	—	X	—	X	X	X	X	X	X
Nymphaea sp. (H)	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—
Osmunda sp. (SP)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Ostrya type (T)	—	—	X	X	X	—	—	X	X	X	X	X	X	X	X
Persicaria type (H)	—	—	—	X	—	—	—	—	—	—	—	X	—	—	X
Picea sp. (T)	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—
Pinus sp. (T)	—	—	X	X	X	X	X	X	X	X	X	X	X	X	—
Pinus (*haploxylon* type) (T)	X	X	—	—	—	—	—	—	—	—	—	—	—	—	—
Pinus (*sylvestris* type) (T)	X	X	—	—	—	—	—	—	—	—	—	—	—	—	—
Planera sp. (T)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Platanus sp. (T)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Potamogeton type (H)	—	—	—	—	—	—	—	—	—	—	—	X	—	—	—
Pterocarya sp. (T)	—	—	—	—	—	—	*	—	—	—	—	—	—	—	—
Quercus sp. (T)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Rhoipites sp. (U)	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Rhus sp. (S)	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—
Sagittaria sp. (H)	—	—	—	—	—	—	—	—	—	X	—	—	—	—	—
Salix sp. (S, T)	—	—	—	—	—	—	—	—	—	—	X	—	—	—	?
Selaginella sp. (SP)	—	—	—	—	X	—	—	—	—	—	—	—	—	—	—
Sparganium type (H)	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—
Sphagnum sp. (SP)	—	—	—	—	X	—	—	—	—	—	—	X	—	—	—
Taxodiaceaepollenites hiatus (T)	X	X	—	—	—	—	—	—	—	—	—	—	—	—	—
Taxodiaceae-Cupressaceae-Taxaceae type (T)	—	—	—	—	X	X	—	—	—	—	—	—	—	—	—
Taxodium type (T)	—	—	—	—	?	—	—	—	—	—	—	—	—	—	X
Thalictrum sp. (H)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Tilia sp. (T)	—	—	—	—	—	—	—	X	—	—	—	X	—	—	X
Tsuga sp. (T)	—	—	—	—	—	X	X	X	—	X	—	X	—	X	—
Typha sp. (H)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Ulmipollenites undulosus (T)	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Ulmus sp. (undifferentiated) (T)	—	—	X	X	X	X	X	X	X	—	—	—	—	X	X
Vitis sp. (V)	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—

Pleistocene fossil sporomorphs in the Charleston, S.C., area—Continued

—, not identified at this locality; *, possibly reworked; (H), herb; (S), shrub; (SP), spore; (T), tree; (U), unknown; (V), vine]

PLEISTOCENE															
Q2															
Wando Formation															
Lower member		Undivided													
6 (S5)	9	36	32	2	35	37 (S3)	37 (S2)	38 (S1)	38 (S2)	38 (S3)	45 (S1)	45 (S2)	45 (S3)	45 (S4)	45 (S5)
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
X	X	X	X	—	X	—	X	X	—	X	X	X	X	X	X
?	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	X	X	—	—	—	—	—	—
—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	?	X	—	X	—	—	—	X	—	—	—	—	X	X	X
—	—	—	X	—	—	—	—	X	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	—
—	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	X	X	—	—	—	—	—	—	X	X	—	—	—
X	X	—	—	—	—	X	X	—	—	X	—	—	X	X	X
X	X	—	X	—	—	—	—	—	X	X	—	—	—	—	—
X	—	—	—	—	—	—	—	—	—	—	X	—	—	—	—
X	X	X	X	X	X	X	X	—	X	X	X	X	X	X	X
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	?	—	—	—
—	—	—	—	X	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	X	X	X	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	X	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
X	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	X	—	—	—	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	X	—	—	—	—	—	—	X
—	—	—	—	—	X	—	—	—	—	—	—	X	—	X	—
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
—	X	X	X	X	—	—	X	—	—	—	—	—	—	—	—
—	—	—	—	—	X	X	—	—	—	—	—	—	—	—	—
—	—	—	—	—	—	—	—	—	X	—	—	—	—	—	—
—	—	—	—	—	—	?	—	—	—	—	—	—	—	—	—
—	X	X	X	—	X	—	—	—	—	—	X	X	—	—	X
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	X
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
X	X	—	—	—	—	—	—	—	—	—	—	—	—	—	—
X	—	—	—	—	—	—	—	—	?	—	—	—	—	—	—

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