PRELIMINARY BIOSTRATIGRAPHY AND MOLLUSCAN FAUNA OF THE GOOSE CREEK LIMESTONE OF EASTERN SOUTH CAROLINA

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I. ABSTRACT

Despite 150 years of study, the stratigraphic relationship among Pliocene beds in South Carolina has not been clearly demonstrated. The Goose Creek Limestone and the closely related Raysor Marl have been particularly perplexing. Previously reported Goose Creek faunules have been too meager for effective comparison. Discoveries at the Martin Marietta Berkeley County Quarry and the Mason Dixon pit tripled the total number of documented species from the Goose Creek Limestone and provided a basis for correlating various literature records and Charleston Museum collections. The Goose Creek Limestone is divisible biostratigraphically into informal lower and upper units. These faunal units appear coincident with a lithic division, separated by an unconformity. The Raysor Marl unconformably overlies the lower Goose Creek Limestone, reversing the inferred stratigraphic sequence prevailing in current literature. Raysor Marl and upper Goose Creek Limestone faunules share numerous index taxa and appear to be laterally equivalent, coeval lithofacies. Both units are distinct from, and older than, the Duplin Formation at its Natural Well stratotype. The Bear Bluff Formation, at its stratotype locality, is lithically and faunally congruent with the upper Goose Creek Limestone.

II. INTRODUCTION

The Goose Creek Limestone is a moldic calcarenite of Pliocene age, originally described from Charleston, South Carolina (Tuomey, 1848; Sloan, 1907; Weems *et al.*, 1982). Its precise age and areal extent have been difficult to ascertain because of limited outcrops and sparse and disparate fossil assemblages. The present study is based on new localities in the Charleston area, in Berkeley County, and in Horry County, South Carolina. Limestone blocks from the Martin Marietta Berkeley Quarry and from the Mason Dixon pit south of Conway, South Carolina, are sufficiently indurated to preserve detailed molds, which were cast with latex to document the fauna. The Goose Creek Limestone is found in northeastern Georgia (Porter's Landing), eastern South Carolina, and southeastern North Carolina.

The Pliocene stratigraphy of the Carolinas is complex. Almost every stratigraphic unit discussed herein rests unconformably at some point on Eocene or Cretaceous bedrock. In contrast with the Virginia Yorktown, which is represented by laterally extensive beds exposed in bluffs of major rivers flowing across strike, the southern North Carolina and South Carolina Pliocene is represented by a patchwork of scour-and-fill deposits occasionally and ephemerally exposed by river cuts, sink holes, marl pits, or quarries. Eventually, a stratigraphic consensus emerged, largely built on the work of C. Wythe Cook (1936) and Jules DuBar (see Oaks and DuBar, 1974; Campbell *et al.*, 1975; Ward, Bailey, and Carter, 1991; Owens, 1991). Our work challenges this consensus (Text-figure 1, column 1) at several points. As Pliocene stratigraphic patterns began to emerge in Virginia (L. Campbell, 1993), Georgia (Huddlestun, 1988) and Florida (Scott and Allmon, 1992), the South Carolina section required reexamination. Mapping around Charleston (Weems and Lemon, 1988; McCartan *et al.*, 1990) found numerous units that poorly fit the pattern. The stratigraphic model proposed here (Text-figure 1, column 2) challenges the supposed Pleistocene age of the Waccamaw, places the Goose Creek Limestone beneath the Raysor Marl, narrowly interprets the age of the Duplin based on the Natural Well stratotype, argues for a Duplin age younger than the Raysor and Goose Creek, and provides evidence for equating the Goose Creek Limestone and the stratotype section of the Bear Bluff Formation. Central to the argument is the first thorough documentation of the Goose Creek Limestone fauna.

This revision is based on field work done from 1986 to 1991. The senior author was responsible primarily for the field work, stratigraphy, faunal analysis, and casting the latex peels. The junior author assisted in logistics, statistical analysis, zoogeography, and systematics.

III. ACKNOWLEDGMENTS

We would like to thank our reviewers for suggestions that improved the manuscript. We also wish to express our appreciation to A. Sanders of the Charleston Museum and to Thomas Waller of the U.S. National Museum for permitting access to published and unpublished collections, and to Joseph Carter for the initial supply of latex. A South Carolina Academy of Sciences grant supported the field work. Daniel Cooke of the University of South Carolina at Spartanburg helped with the computer programming. Thanks also to those, too numerous to mention, who have shared locality information, specimens, and other support during the various phases of this study.

IV. METHODS AND MATERIALS

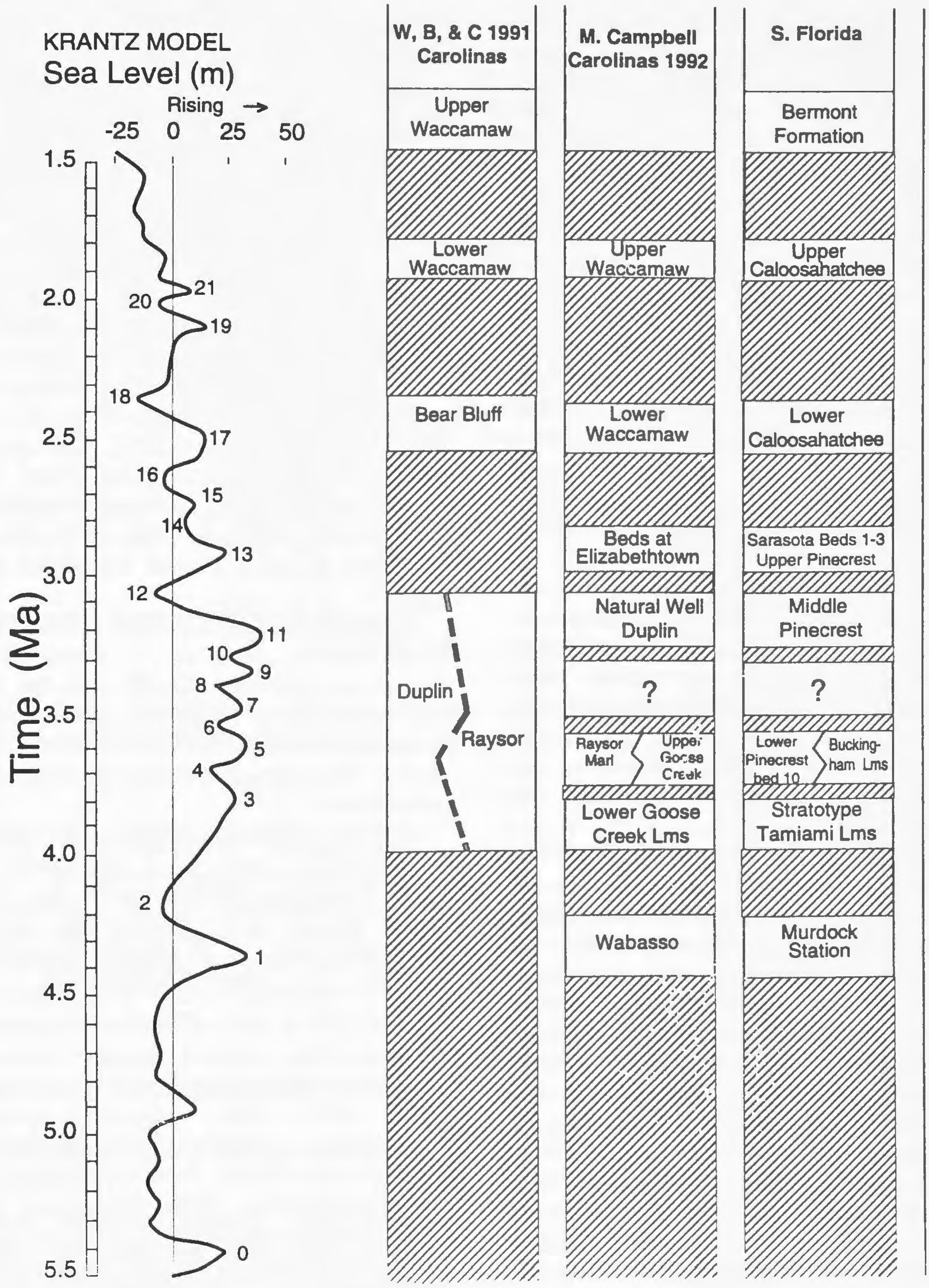
Latex Casting

The Goose Creek Limestone is a leached, moldic limestone that once contained an abundance of molluscs and other invertebrates. Where soft, the calcarenite preserves few fossils, but several new localities preserve a more indurated lithology with good to exquisitely detailed molds. These were cast with liquid latex. The faunal listing (Appendix II) was based on over 700 individual castings. An illustrated systematic catalog is planned.

Database and Statistical Methods

We have attempted to place Carolinian Pliocene units in a biostratigraphical context by comparison with a comprehensive database consisting of distribution data for 1127 molluscan species from approximately 180 Pliocene localities in Virginia and the Carolinas. The species list in Appendix II is the Goose Creek subset of the larger data base. Appendix I lists localities and literature sources for 19 Goose Creek Limestone sites, plus data on Duplin, Raysor, and Tamiami sites for comparison. Statistical analysis of the Virginia portion of the data has been published (L. Campbell, 1993); analysis of the complete data set is in progress.

Dice similarity coefficients and percentages-held-in-common were used for statistical analysis (Table 2; Appendix I). The Dice coefficient also is known as the Sorensen coefficient (Sneath and Sokal, 1973; Pielou, 1984). It is one of the best coefficients for representing sparse data sets (Archer and Maples, 1987; Maples and Archer, 1988), and has demonstrated utility in distributional analysis of ostracodes (Hazel, 1971) and of molluscan populations (Leal and Bouchet, 1991; Leal, 1991). The Dice similarity formula is $2C/(A + B)$, where A is the total number of species from one locality, B is the total number of species from a second locality, and C is the number of species in common between the two localities. An alternative formula is Dice $= 2A/(2A + B + C)$ in which A = the number of species in common, B and C are the number of single occurrences in the two populations being compared. Dice values may be expressed with the multiplier, "x 100," but this is not used in this study.



Text-figure 1. Correlation chart comparing the Krantz Oxygen Isotope model with Pliocene stratigraphy of southeastern North Carolina and South Carolina (M. Campbell, 1992), and of southern Florida. Comparison also is made with the stratigraphic model of Ward, Bailey, and Carter (1991), and with southern Florida. The stratigraphy of southern Florida is taken from Scott and Allmon (1992) and Lyons (1991). The South Carolina and southern Florida correlations with the Krantz curve are our interpretations. The chronostratigraphic placement of the Ward, Bailey, and Carter model is based on their age assignments *and is not intended to show parallel correlations.* For example, the Ward, Bailey, and Carter model places the lower Waccamaw beds at the K-19-21 level, our model places the upper Waccamaw at this level. We are not cross-correlating these units, but rather pointing out the differences in age interpretations.

The Dice coefficient relates to the more familiar Jaccard coefficient by the algebraic identity, Dice = Jaccard value x 2/(1 + Jaccard value) and is, therefore, "monotonic with and always greater than or equal to the Jaccard coefficient" (Sepkoski, 1974, p. 2). Dice coefficients are a comparative statistic only. They provide high values when there is a small range of data values, when the two populations being compared are equally diverse, and when the commonality is high. Lower Dice values result from partial and incomplete data sets. In one study, unity values among samples taken from the same stratum in a single outcrop fell between Dice values of 0.700 and 0.800 for a sequence of molluscan-rich beds in the Yorktown Formation (L. Campbell, 1976). The Dice values for the Recent and the Miocene are not exactly comparable with the remaining matrix because the distributional data contains only overlap occurrences rather than documenting the entire Recent and Miocene faunas. Therefore, for Recent and Miocene Dice values, "A" remains the comparison locality, and "C" remains the commonality, but the value of "B" is the sum of all Pliocene species extending into the Recent or originating in the Miocene. The Dice values for the Recent and Miocene are not equivalent conceptually with the remaining comparisons. To emphasize the limitation, the first and last columns in the statistical matricies are coded "ALSO RECENT" and "ALSO MIOCENE." This limitation does not apply to percentage data in which the Miocene or Recent totals are irrelevant.

Such percent-in-common statistics have been called the Simpson coefficient (Sneath and Sokal, 1973), when they are calculated as commonality divided by the smaller of the two populations being compared. We differ by calculating the percentage for the population in consideration, whether it be larger or smaller than the population being compared. Ward and Gilinsky (1993) have questioned such use of "Lyellian faunal percentages" by L. Campbell (1993). Lyellian percentages reference the Recent only. Percentage-in-common with the Recent is one of eight biostratigraphic comparisons calculated in our analysis.

Concept of Faunal Standards

Widely disparate species richness data are awkward to analyze. Incomplete distribution, habitat changes between outcrops, varied taphonomies, and variable collecting effort all contribute to the disparity. However, uniting a set of unequivocally contemporaneous faunules into a standard fauna can reduce some of the randomizing effects inherent within comparisons of individual localities. Such composite faunas become standards against which more variable or equivocal assemblages may be examined. For the Pliocene of southeastern North Carolina and South Carolina, six composite standard faunas were determined from their high Dice similarity levels and shared index species. The faunules compiled to produce the standard faunas were:

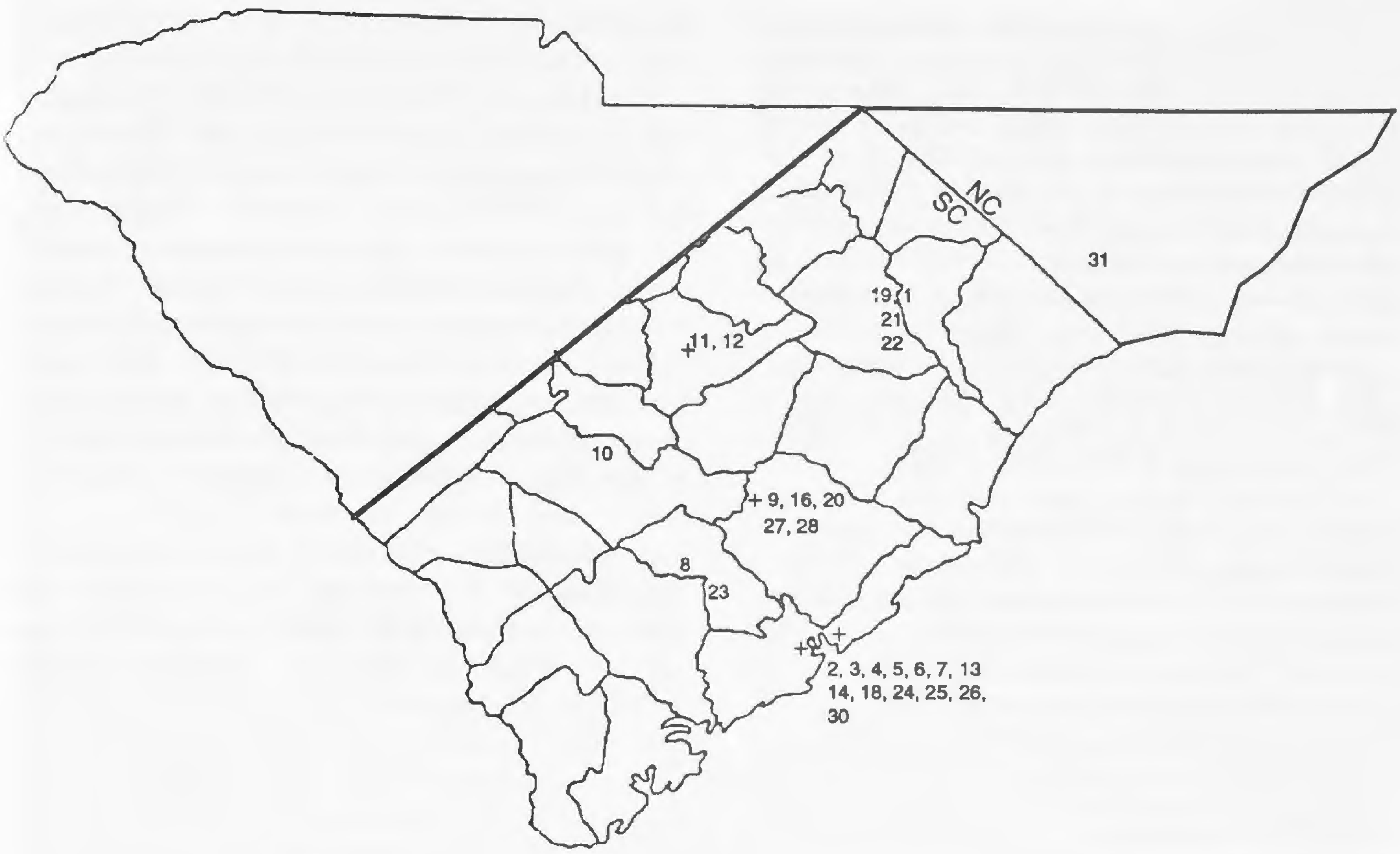
LOWER GOOSE CREEK LIMESTONE STANDARD, sum of 3 localities: the stratotype at Goose Creek and the Grove Plantation (both Tuomey, 1848); and the aragonite-leached Pliocene bed at the Martin Marietta Berkeley Quarry (USCS collections).

UPPER GOOSE CREEK LIMESTONE STANDARD, sum of 4 localities: Giles Bluff (Tuomey, 1848); plus the Mason Dixon pit, G & C Mining Co. pit, and Thompkins pit, all in the Conway, South Carolina, area (USCS collections).

RAYSOR MARL STANDARD, sum of 3 localities: the original Raysor material in the Sloan collection (Ward and Huddlestun, 1988); the aragonite-preserved faunule at the Martin Marietta Berkeley Quarry near Cross, South Carolina (Ward and Huddlestun, 1988; Campbell *et al.*, 1975; USCS collections); and the *Chama* beds at Lynchburg, South Carolina (USCS collections).

STRATOTYPE DUPLIN STANDARD, sum of 3 localities: Natural Well (Campbell, Campbell, and Carter, 1994, this volume); Muldrow Place (Gardner and Aldrich, 1919); and Tearcoat Branch (S. Campbell, 1974; and in preparation).

LOWER WACCAMAW STANDARD, sum of 3 localities: the lower beds at Calabash; the lower beds at Windy Hill, South Carolina; and the faunule at Old Dock, North Carolina.



Text-figure 2. Distribution of Goose Creek Limestone localities in North and South Carolina. Locality numbers refer to the localities listed in Appendix I.

UPPER WACCAMAW STANDARD, sum of 12 localities: mostly from DuBar, plus faunules from the Waccamaw lectostratotype of Blackwelder (1979), Dall (1892), USCS collections; and the upper beds at Calabash, North Carolina (USCS collections).

V. DISCUSSION OF STRATIGRAPHY

Described Pliocene Formations of Eastern South Carolina

Current literature cites at least seven formations of Pliocene age from South Carolina, but application of these units continues to be problematical. A summary of the various formations and their use follows. Although the Pliocene is formally subdivided into upper and lower units, an informal "mid-" or "middle" Pliocene continues to be a useful concept (*e.g.*, Behrednt and Cooper, 1991). Dowsett and Cronin (1990) define middle Pliocene as 3.5 to 2.5 Ma. We use mid-Pliocene to indicate those strata younger than the Wabasso and older than the lower Waccamaw, *i.e.*, between 3.9 and 2.5 Ma.

(1) *Wabasso Beds*

The "Wabasso" formation is an informally named stratigraphic unit (Huddlestun, 1988, p. 98) of early Pliocene subsurface deposits extending from southeastern South Carolina to Florida. The sediments are calcareous, phosphatic, and probably preserve calcitic shell only. Unusually large specimens of ***Chesapecten jeffersonius*** (indicative of Pliocene-aged deposits; Ward and Blackwelder, 1975) were found by SCUBA divers in probable Wabasso beds at the bottom of the Savannah River. The specimens were on display at the 1988 South Carolina fossil fair, and remain in the possession of their collectors. The age of the Wabasso, based upon planktic foraminifera is zone N-18, or PL-1, between 4.5 and 5.0 Ma (Huddlestun, 1988, p. 100).

(2) *Goose Creek Limestone*

Weems *et al.* (1982, p. H140) characterized this unit as follows:

"In the Charleston area, the Goose Creek Limestone . . . is a medium to coarse-grained, quartzose and phosphatic, sparsely shelly, pale buff-gray (wet) to chalk white (dry) calcarenite. Shell material was once abundant, but aragonitic forms have been extensively leached, leaving only molds and casts. It contains kaolinite in the greater than 2 micron-size fraction and both kaolinite and illite-smectite in the less than 2 micron-size fraction. Locally its composition is influenced by the nature of the substrate. For example, near Mount Holly, a channel containing Goose Creek Limestone is incised deeply into the Eocene Parkers Ferry Member of the Cooper Formation (Ward *et al.*, 1979); there the Goose Creek is nearly a calcilutite, like the Parkers Ferry, and contains calcilutite clasts obviously derived from the subjacent and adjacent beds of the Parkers Ferry. Where the Goose Creek Limestone lies on the Oligocene Ashley Member of the Cooper Formation, which is a compact, quartzose and phosphatic, fine-grained calcarenite, it is similar to that lithology, though coarser grained, much less dense, and light-buff-gray rather than olive-brown. Locally, in the Charleston area, the distribution of the Goose Creek is well known . . . Except for five localities, however, it is known only from auger holes."

Weems and Lemon (1988) mapped the Goose Creek Limestone within an approximate radius of 80 km around Charleston.

(3) *Duplin Formation and Raysor Marl*

The Duplin Formation was described by Dall (1898b, p. 338) for beds at Natural Well, a sink hole in Duplin County, North Carolina. Huddle (1940, p. 227) restricted the Duplin to the top meter of Dall's type section. Much confusion exists over the interpretation of the Duplin. The question essentially centers on whether to interpret the unit narrowly in strict terms of its stratotype section, or broadly, to include several transgressive-regressive sequences. At the stratotype locality, the Duplin sediments consist of quartz sand with abundant, well-preserved aragonitic shells. The fauna of the Natural Well stratotype has been published piecemeal by Conrad (1841), Dall (1890-1903), Mansfield (1930-1932), Gardner (1944, 1948), and others. However, the majority of species recorded by Dall (1903) from "Natural Well and vicinity of Magnolia" came from the Strickland Farm rather than from Natural Well (Campbell, Campbell, and Carter, this volume). S. Campbell (1974) published a listing of the fossils and index species from the Natural Well-equivalent Tearcoat Branch locality in Sumter County, South Carolina, and demonstrated an age of zone N-20, or about 3.0 to 3.5 Ma for that site.

The Raysor Marl, as described by Sloan (1907a, 1907b), Cooke (1936), and Weems *et al.* (1982), is a silty quartz sand. The original type locality near Raysor's Bridge on the Edisto River, has not been rediscovered and probably lies buried under slumped stream bank deposits (Pooser, 1965). Lithostratigraphically and biostratigraphically equivalent, silty sand and aragonite-preserved shell beds are present at the Martin Marietta Berkeley Quarry near Cross, South Carolina.

Blackwelder and Ward (1979) described the "Raysor Formation" as a calcareous sediment containing shells, and redefined the formation in terms of a neostratotype section at Givhans Ferry State Park. However, the neostratotype section is not typical of the Raysor Marl, *sensu* Sloan (1907), but is lithically conformable with the Goose Creek Limestone (Weems *et al.*, 1982, p. H142-144). The Givhans bluffs site also provides the informal stratotype section of the "Givhans Beds" of McCartan (1990). Weems *et al.* (1982) argued for abandoning the Givhans Ferry neostratotype for the Raysor Marl. Ward and Huddlestun (1988) illustrated the Raysor macrofauna from Sloan collection specimens, and documented a substantial planktic foraminiferal faunule from matrix removed from Sloan specimens. These yielded an age of zone N-20 or PL-3.

(4) *Bear Bluff Formation*

According to McCartan (1990, p. 3), "The oldest known horizons of the Goose Creek are possibly slightly older than the oldest known horizons of the Bear Bluff (Bybell, 1990), 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."

The Bear Bluff Formation was described by DuBar *et al.* (1974, p. 156) with a stratotype section at Bear Bluff on the Waccamaw River, north of Conway, South Carolina. DuBar *et al.* (1974) ascribed to the Bear Bluff a number of lithologies, including basal limestone at the stratotype and at Lake Waccamaw, North Carolina, and upper unconsolidated sand with an abundant, aragonite-preserved molluscan fauna at other localities. Ward and Gilinsky (1993) assert that a well-preserved assemblage at Elizabethtown, North Carolina, is the nearshore, lateral equivalent of the leached calcarenites at the Bear Bluff stratotype.

The stratotype section consists only of DuBar's lower unit, a moldic comminuted shell calcarenite capped by unfossiliferous sand and soil. Numerous studies have suggested a late Pliocene age (zone N-21) for the upper unit (Cronin *et al.*, 1984). However, no previous study apparently has documented macrofauna from the stratotype section of the Bear Bluff Formation. Appendix II (locality 105) records 27 species from the Bear Bluff stratotype, including 19 wide ranging species found in Waccamaw, Duplin, Raysor Marl, and upper Goose Creek faunas; seven species restricted to the Duplin, Raysor Marl, and upper Goose Creek faunas; and one variety, *Carolinapecten eboreus* var. *walkerensis*, uniquely restricted to the upper Goose Creek fauna. The latter taxon, a warped scallop shell exceeding 200 mm in maximum diameter, is abundant at nearby Conway area pits including the G & C mining company, the Mason Dixon pit, and the Tompkins Quarry (see Appendix I). These correlative localities contain calcarenites with far richer faunules, including such age-indicative taxa as *Ecphora quadricostata*, *Ecphora bradleyae*, *Chesapecten septenarius*, *Glycymeris americana* var. *abberans*, *Pecten brouweri*, and *Encope macrophora*, most of which are pre-Duplin (*sensu* Natural Well) species (Tables 1 and 3).

Carbonate percentages from the leached calcarenite sediments of the Bear Bluff stratotype are similar to those of the Goose Creek Limestone (M. Campbell, in preparation), and the faunule (locality 105, Appendices I and II) is compatible with that of the Mark Clark pit and the Seaboard Railroad ditch (localities 13 and 14) in Charleston. Therefore, the Bear Bluff stratotype is pre-Natural Well Duplin in age, lithically and faunally equivalent with the upper Goose Creek Limestone. The remaining, upper Bear Bluff units of DuBar *et al.*

	DUPLIN SANDS	**RAYSOR SANDS**	**GOOSE CREEK UPPER BED**	**LIMESTONE LOWER BED**
Barbatia leonensis	r	x	x	
Glycymeris americana abberans		x	x	r
Pecten hemicyclicus		r	r	x
Pecten brouweri			x	
Leptopecten leonensis		r	r	x
Carolinapecten eboreus walkerensis		x	x	
Chesapecten septenarius		x	x	x
Chesapecten madisonius ssp.			r	r
Chesapecten jeffersonius				x
Nodipecten collierensis				x
Nodipecten peedeensis			x	
Placunanomia plicata (typical form)		x	x	x
Placunanomia burnsi				x
Spondylus n.sp.		r	r	r
Hyotissa haitensis			x	x
Diplodonta subvexa			x	
Malea sp. cf. M. densecostata			r	
Ecphora bradleyae		r	x	
Terebraspira elegans		r	r	
Encope macrophora			r	x

Table 1. Molluscan and echinoid index species of the lower and upper zones of the Goose Creek Limestone. Detailed locality and distribution data in Appendices I and II. X = common r = rare.

(1974) contain a Waccamaw-equivalent, post-Duplin macrofauna (Campbell *et al.*, 1975) and ostracode fauna (lower *Puriana mesocostalis* zone; Hazel and Cronin, 1979). Multi-transgressional formations are valid, and common in the Atlantic Coastal Plain (Huddlestun, 1988). However, if a proposed formation contains members older and younger than beds of another well-defined formation in the same region,

PERCENT IN COMMON

	R	UW	LW	E	D	RA	UGC	LGC	W	M	
R	-	48.2	38.6	33.8	21.1	21.1	20.0	22.7	-	-	R
UW		-	75.6	67.7	49.1	25.6	19.3	12.5	-	10.1	UW
LW			-	66.1	45.4	23.1	17.2	11.5	-	7.6	LW
E				-	64.5	40.3	37.1	24.2	-	14.5	E
D					-	39.1	30.5	20.1	-	12.5	D
RA						-	53.1	36.4	-	27.3	RA
UGC							-	51.7	-	25.3	UGC
LGC								-	-	28.6	LGC
W									-	-	W
M										-	M

% calculations based on the number (N) of the younger of the two units compared

DICE SIMILARITY COEFFICIENTS

	R	UW	LW	E	D	RA	UGC	LGC	W	M	
R	-	.540	.468	----	.265	.186	.167	.141	-	-	R
UW		-	.684	.211	.418	.316	.253	.185	-	.212	UW
LW			-	.175	.430	.305	.239	.179	-	.183	LW
E				-	.155	.184	.192	.166	-	----	E
D					-	.535	.437	.318	-	.267	D
RA						-	.574	.463	-	.360	RA
UGC							-	.620	-	.315	UGC
LGC								-	-	.300	LGC
W									-	-	W
M										-	M

R = ALSO RECENT N = SPECIES RICHNESS
UW = UPPER WACCAMAW N = 336 molluscan species
LW = LOWER WACCAMAW N = 407
E = ELIZABETHTOWN BEDS N = 62
D = STRATOTYPE DUPLIN AND EQUIVALENTS N - 453
RA = STRATOTYPE RAYSOR AND EQUIVALENTS N = 209
UGC = UPPER GOOSE CREEK N = 178, Calcitic an moldic preservation
LGC = LOWER GOOSE CREEK N = 119, Calcitic and moldic preservation
W = WABASSO N = 2 Number too small for meaningful comparison
M = ALSO MIOCENE

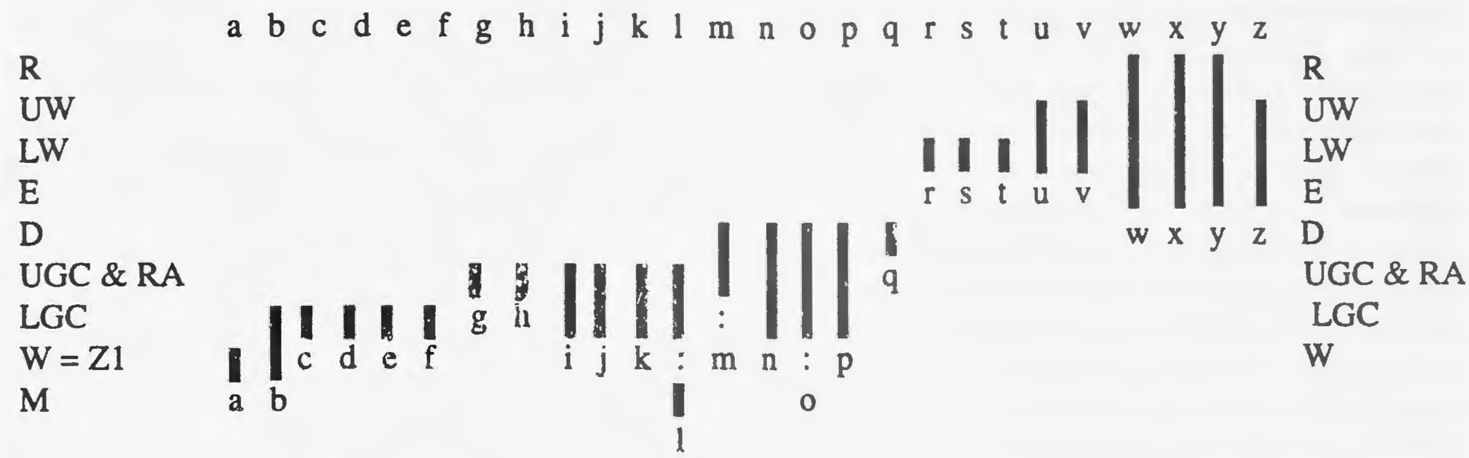
Table 2. Percentage and Dice Similarity Coefficient matrices for Pliocene faunas of southern North Carolina and South Carolina.

yet excludes the other formation, then the proposed formation becomes discoherent and should be abandoned.

(5) *Waccamaw and Cypresshead Formations*

The Waccamaw Formation was described from the Waccamaw River, South Carolina, by Dall (1892, p. 209). Blackwelder (1979, p. 54) proposed a lectostratotype section at the Tilly Lake outcrop (Waccamaw River, South Carolina). Aragonitic shell preservation is typical. The catalog by L. Campbell *et al.* (1975, "WA-"

CAROLINA PLIOCENE INDEX SPECIES



a. *Placopecten clintonius (at Aurora, NC)*
b. *Chesapecten jeffersonius*
c. *Placunanomia burnsi*
d. *Chesapecten madisonius 10-14 rib average*
e. *Chlymys decemnarius*
f. *Nodipecten collierensis*
g. *Nodipecten peedeensis*
h. *Ecphora bradleyae,*
i. *Chesapecten septenarius*
j. *Encope macrophora*
k. *Anadara propatula*
l. *Striarca centenaria*
m. *Glycymeris americana abberans*
n. *Hemimetis magnoliana*
o. *Ecphora quadricostata*
p. *Plioptygma carolinensis*
q. *Coralliophila leonensis*
r. *Pecten holmesi*
s. *Stralopecten ernestsmithi*
t. *Scaphella precursor*
u. *Carolinapecten eboreus senescens*
v. *Argopecten vicenarius*
w. *Abra aequalis*
x. *Mulinia lateralis*
y. *Crassostrea virginica*
z. *Carolinapecten solaroides*

Table 3. Range zones of 27 Pliocene molluscan and echinoid index species from the Carolinas.

localities, especially "WA-4") contains the most thorough published listing of Waccamaw Formation molluscs (*sensu* Dall, 1892). Beds with Waccamaw-related faunas older than the stratotype section have been called the "shelly facies of the Bear Bluff Formation" by DuBar *et al.* (1974), but were included in Waccamaw by Campbell *et al.* (1975). The Waccamaw Formation contains planktic foraminiferal zone N-22, latest Pliocene to earliest Pleistocene age (Cronin *et al.*, 1984, p. 31).

The Cypresshead Formation was described by Huddlestun (1988, p. 119) for a complex of mostly subsurface Pliocene sands and clays previously ascribed to a number of different formations in South Carolina, Georgia, and Florida. Huddlestun (1988, p. 122) mapped the Cypresshead as far north as Summerville, South Carolina, where it is applied to the same beds mapped as Waccamaw by DuBar *et al.* (1974, p. 158) and Penholoway by Richards (1943), Colquhoun *et al.*, (1968), and Weems and Lemon (1988). Sediments are typically quartz sands and clay beds with rare deposits of marine shells. The shells, when present, show aragonitic preservation. A sparse microfauna of planktic and benthic foraminifera was described by Huddlestun (1988, p. 124). The ages of the Cypresshead Formation are Pliocene (N-21 or PL-5, Huddlestun, 1988), and lower Pleistocene (Corrado *et al.*, 1986; Bybell, 1990) for the "Penholoway" beds. Use of the Cypresshead Formation for the Charleston area follows Huddlestun (1988).

Age, Faunal Character, and Stratigraphic Placement of the Goose Creek Limestone

Age-indicative species from the Goose Creek stratotype were listed by Tuomey (1848), Cooke (1936), and by Weems *et al.* (1982). Tuomey (1848, p. 179) reported 15 calcitic and moldic species, including *Siphocypraea carolinensis*, *Encope macrophora*, *Hemimetis magnoliana* (as *Tellina biplicata*), *Amusium mortoni*, *Pecten hemicyclicus*, *Panopea reflexa*, and *Spondylus* species. Cooke (1936, p. 129) cited 11 species, including *Pecten hemicyclicus*, *Amusium mortoni*, and *Encope macrophora*. Weems *et al.* (1982, fig. 32) cited *Amusium mortoni* and *Argopecten eboreus* and the calcareous nannofossils *Reticulofenestra pseudoumbilica* (Gartner, 1967) and *Sphenolithus abies* Deflandre, 1954. Of these, *Siphocypraea carolinensis*, *Hemimetis magnoliana*, and *Panopaea reflexa* became extinct at the end of the time of Duplin deposition. *Encope macrophora*, *Pecten hemicyclicus*, and *Spondylus* are common in the lower Goose Creek Limestone, but rare and isolated in the upper Goose Creek Limestone and the Raysor Marl (Table 1). Based on nannofossils, Weems *et al.* (1982, p. H142) concluded "these fossil data imply that the Goose Creek Limestone is early to middle Pliocene (between 5 m.y. and 3 m.y.) in age."

Nearby Goose Creek calcarenite deposits at Yeaman's Hall and at Fetteressa (Appendix I, locality 14) (Seaboard Railroad ditch of Weems *et al.*, 1982) added additional elements including *Nodipecten peedeensis* and *Chesapecten septenarius*, both of which became extinct prior to deposition of the Duplin. The co-ocurrence of common *Chesapecten septenarius*, *Pecten hemicyclicus*, *Spondylus* sp., and *Encope macrophora* in the Pliocene calcarenite at the Martin Marietta Berkeley Quarry provided the basis for correlation with the faunule of the Goose Creek stratotype. *Nodipecten peedeensis* and *Chesapecten septenarius*, along with rare *Pecten hemicyclicus* and *Encope macrophora*, provided the basis for correlation with the calcarenites around Conway, South Carolina.

Determining a Goose Creek fauna from existing literature is complicated. Calcitic echinoids, pectinids, and oysters are commonly preserved but often difficult to extract from adhering matrix. The aragonitic species are either completely eliminated or preserved as molds. A literature search yielded a total of 74 species of Pliocene macro-invertebrates reported from mid-Pliocene calcarenites around Charleston and on the Pee Dee River (localities and authors in Appendix I). But a maximum of 18 species per locality and disparate assemblages suggest no obvious biostratigraphic reason for uniting them. Recently discovered Goose Creek faunules at the Martin Marietta Berkeley Quarry, and around Conway, South Carolina, preserve both a rich and abundant calcitic fauna and a diverse moldic assemblage from which latex peels were taken. The seemingly disparate faunules, including that of the stratotype at Goose Creek, are shown herein to be compatible subsets of these larger assemblages (Appendix I). Appendix II lists the distribution of approximately 250 Goose Creek macrofossil species now documentable in the Charleston Museum, the U.S. National Museum, or the USC Spartanburg collections. Additional age determinations for the Goose Creek Limestone include foraminiferal zone PL-3 (Ward and Huddlestun, 1988, p. 73), and 3.9 to 3.2 Ma, or Zone NN 15 to mid-NN 14 (Bybell, 1990).

The discovery of the Raysor Marl unconformably overlying the lower Goose Creek Limestone in the section at the Martin Marietta Berkeley Quarry contradicts the widely held opinion in literature that the Goose Creek Limestone is younger than the Duplin. The relative ages have been reversed for at least two reasons. The first problem arose with the inclusion of a relatively rich faunule of 27 molluscan species that Tuomey and Holmes (1855-1857) reported from the George H. Smith property on Goose Creek near the stratotype, a locality they called "Smith's, Goose Creek" (Appendix I, locality 7). This site has not been located with certainty, but is generally associated with Yeaman's Hall. From this site, Tuomey and Holmes reported both typically moldic Goose Creek Limestone taxa and an aragonite-preserved faunule containing several Waccamaw index species, including *Pecten holmesi* Dall, 1898 (= *Janira affinis* Tuomey and Holmes, 1855). This shelly unit belongs to the Cypresshead Formation, and should be excluded from the concept of the Goose Creek Limestone.

The influence of the "Smith's, Goose Creek" faunule on subsequent age interpretations of the Goose Creek Limestone cannot be measured because it was rarely cited. However, most subsequent authors have estimated Goose Creek ages compatible with the "Smith's" faunule rather than with those of the calcarenite localities.

The second error came from the correlation of the Goose Creek Limestone and the Tamiami Limestone (Cooke, 1936), based on the common occurrence of *Encope macrophora*. Although that faunal equivalency can now be reinforced with numerous additional co-occurrences (see Systematics), and is reasonably established, Cooke (1936) further believed the Tamiami Limestone to be a member of the Caloosahatchee Formation and, therefore, Waccamaw-equivalent. The relative placement of the Tamiami Limestone in southern Florida was rectified by Olsson and Petit (1964), but the correction was not extended into the Carolinas.

Lithostratigraphic and Biostratigraphic Subdivision of the Goose Creek Limestone

Moldic calcarenite rocks were exposed in the now flooded Mason Dixon Company pit located just east of U.S. Rt. 701, approximately two km south of Conway, Horry County, South Carolina. Rocks of this pit correlated with the Goose Creek Limestone in Charleston and at the Berkeley Quarry, based on carbonate percentages (M. Campbell, in preparation), index species (Appendix II), and a high Dice similarity index (0.516) (Appendix I). Based on these commonalities, the Mason Dixon beds were assigned to the Goose Creek Limestone (M. Campbell, 1990), the first recognition of that formation in Horry County. However, the faunal statistics (Appendix I) for the Mason Dixon pit also indicated a stronger affinity with the mid-Pliocene Duplin Formation and Raysor Marl faunas. In contrast, the Berkeley Quarry faunule showed stronger affinities for the lower Pliocene and upper Miocene faunas.

A reevaluation of the faunules of all reported sites in the Charleston area and Horry County revealed related, but biostratigraphically distinct, assemblages (Tables 1 and 2). Weems (1989, personal communication) found an unconformity within the Goose Creek Limestone in cores near Charleston, dividing the unit into upper and lower units. The Mason Dixon beds and the Berkeley Quarry beds and their respective equivalents probably conform with the upper and lower lithostratigraphic divisions. At the Martin Marietta Berkeley Quarry, the upper Goose Creek-equivalent Raysor Marl is separated from the subjacent lower Goose Creek calcarenite by an erosional, pebble bed unconformity (M. Campbell, in preparation). However, no exposed calcarenite section known to us preserves either the unconformity or the two zones. The upper and lower calcarenites are not separable lithically, and many outcrops and core samples do not contain the index species necessary to separate them. Therefore, both units should be referred to the Goose Creek Limestone. Where faunules are sufficiently rich, the two units may be distinguished biostratigraphically by index species as shown in Table 1 and Appendix II.

All Conway area and Horry County mid-Pliocene calcarentites, including the stratotype of the "Bear Bluff Formation," belong to the upper Goose Creek Limestone. Upper Goose Creek localities in the Charleston area include Feteressa, the Seaboard Railroad ditch, and the Mark Clark Expressway pit. The Berkeley Quarry, the Givhans Ferry section, and a number of Charleston localities, including the Goose Creek stratotype, belong to the lower unit. A reexamination of the Givhans Ferry collection (Appendices I and II, locality 23) housed in the U.S. National Museum and reported by Malde (1959) yielded 21 species of mollusks, 20 of which were held in common with other lower Goose Creek faunules.

Although a number of localities in our study are coincident with those studied by Cronin (1981; 1990) and Cronin *et al.* (1984), we have not studied the microfaunas and cannot apply fully the ostracode zonation. We suggest that the *Murrayina barclayi* zone is coincident with the lower Goose Creek Limestone, based on its occurrence at Givhan's Ferry State Park, and the *Paracytheridea mucra* zone is coincident with the upper Goose Creek Limestone, the Raysor Marl, and the Natural Well Duplin, based on occurrences at the Bear Bluff and Duplin stratotypes.

VI. MOLLUSCAN BIOSTRATIGRAPHY

Biostratigraphic Patterns

The biostratigraphic summaries are based on the distribution of 1127 species of Pliocene molluscs from approximately 180 localities in Virginia and the Carolinas. The analysis was made possible by stratigraphic revision in the study area (M. Campbell, 1992) and by the first documentation of statistically useful assemblages from the lower and upper units of the Goose Creek Limestone (Appendix II), from the Raysor Marl, and from the Elizabethtown, North Carolina, beds. Summary matrices for percentage and Dice statistics are provided (Table 2), which place the lower and upper Goose Creek Limestone units in biostratigraphic context with the remaining Pliocene units in the study area. The ranges of 27 index species are shown in Table 3.

Biostratigraphy or Biofacies ?

A legitimate argument against the stratigraphic model we are proposing is the premise that a number of the supposed biostratigraphic units are lateral biofacies rather than subdivisions of time (V.A. Zullo, 1991, personal communication). We are fully aware of the potential and complexities of environmental control of species distribution. The Beaufort Inlet estuary in North Carolina contains four distinct molluscan assemblages (Bird, 1970). The Recent molluscan assemblage patterns off the Carolinas from Cape Hatteras to Savannah include estuarine, littoral (inter-tidal), shallow sublittoral, inner shelf (Carolinian), mid-shelf (Caribbean), and outer shelf-upper slope assemblages (Porter and Safrit, 1981; Cerame-Vivas and Gray, 1966; USCS Recent collections). The percentage and Dice coefficient values (L. Campbell, unpublished data) between these Recent assemblages are similar in magnitude to the Pliocene values documented in Table 2. Sediment type and consolidation also influence molluscan assemblages. Species of *Nucula* and nuculanids thrive in fine-grained, silt-clay oozes, an environment hostile to most species (L. Campbell, 1993). The "live-bottom" hardgrounds off Charleston, South Carolina, provide a stable platform for hydroids, soft corals, sponges, and bryozoans, which then support an immense diversity of life, including mollusks.

Most Pliocene molluscan assemblages were, by comparison with the Recent patterns, aggregates of multiple biotopes mixed together with no discernable segregation. The lower and upper Waccamaw faunas both contain estuarine, intertidal, shallow sublittoral, inner, and mid-shelf genera and species, but the lower Waccamaw contains a greater percentage of mid-shelf taxa, the upper, a greater element of shallow sublittoral and inner shelf species. This difference results in greater diversity of lower Waccamaw faunules and contributes to the greater extinction levels, because mid-shelf species generally exhibit a greater endemism in time and space. Given assemblage patterns alone, one could argue for a shallowing-upward sequence deposited during the regressive phase of a single transgressive-regressive pulse, but the upper Waccamaw is unconformably separated from the lower unit, precluding that possibility.

The beds at Elizabethtown preserve littoral, shallow sublittoral, and estuarine species only (L. Campbell, 1993; Ward and Gilinsky, 1993), but the Duplin and Raysor returned to the diverse aggregate assemblage pattern. The Natural Well Duplin includes within a single layer, estuarine, intertidal, shallow sublittoral, inner, mid-, and outer shelf taxa. The shallow sublittoral and inner shelf species dominate in numbers of individuals, the mid-shelf species dominate in diversity of species present. *Cochliospira* (outer shelf) and *Donax* (intertidal) co-occur in the Timmonsville, South Carolina Duplin. As to aggregate assemblages, the Raysor Marl fauna differs from the Duplin Formation only in the absence of the estuarine and intertidal elements, *Donax* and ilyanassid species being conspicuously rare or absent.

In the study area, the Goose Creek Limestone calcarenites provide the only significant opportunity for lithofacies control over biofacies, and some taxa, such as *Placunanomia* and certain pectinids including *Nodipecten*, favored the calcarenites (Table 1). However, of the index species (Table 1) co-occuring in the upper Goose Creek Limestone calcarenites and Raysor Marl beds, only one also occurs (and that rarely) in the Duplin sands. The lower Goose Creek Limestone appears to consist mostly of inner-shelf species, but the upper Goose Creek fauna fully parallels the Raysor, with shallow, inner, mid-, and outer shelf elements jumbled in profusion.

Lyons (1989) has documented the nearshore molluscan assemblage of Hutchinson Island, Florida. This Recent fauna in many ways parallels the aggregate pattern of the Carolina Pliocene faunas. We suggest that milder Pliocene winters allowed a greater faunal mingling under conditions resembling the modern marine climates of the shallow shelf off central Florida. Secondly, we suggest that taxa, such as the volutid gastropods *Aurinia* and *Scaphella*, had a greater environmental tolerance during the Pliocene, based on their rare, but ubiquitous Pliocene distribution, and that their modern outer shelf-upper slope distribution is a refugium, atypical of their Neogene habitats. These premises satisfy part of the biofacies-averaging problem, but admixing and reworking of biotopes by bioturbation and physical processes was normative in the study area.

The aggregate nature of the Pliocene units argues for the greater importance of time as a causitive explanation for the statistical differences in Table 2. The Duplin estuarine fauna has no Raysor parallel, but that element was a small part of the total assemblage. Real differences existed between the Duplin and Raysor inner, mid-, and outer shelf assemblages. A comparison of Duplin and Elizabethtown estuarine, littoral, and shallow sublittoral species shows a higher similarity than a Duplin-Waccamaw comparison. Biofacies are important, and we believe that there is good evidence for a Raysor Marl-upper Goose Creek Limestone biofacies equivalency. Time, expressed by extinction, speciation, and colonization, remained the greater influence in determining the distinctive and evolving character of each successive assemblage.

Correlation with the Krantz Model and the Blackwelder M-Zones

Krantz (1991) has synthesized the global literature of oxygen isotope records to create a predictive model of Pliocene transgressions and regressions across the Atlantic Coastal Plain. Text-figure 1 illustrates the Krantz curve and our correlation of the Pliocene stratigraphic units in the study area.

The Raysor Marl and the lower and upper Goose Creek Limestone are constrained by the older, N-18, early Pliocene age of the subjacent K-1 Wabasso beds (zone 1, Yorktown equivalent) (Huddlestun, 1988) and the 3.2 Ma dating of the younger Duplin faunas. The lower Goose Creek contains a relatively high percentage of Miocene species (Table 2), and is framed by the Wabasso below and a significant unconformity above, conditions which best match the Krantz curve, K-3 transgression.

A distinct unconformity separates the Raysor Marl from the subjacent lower Goose Creek Limestone at the Martin Marietta Berkeley Quarry (M. Campbell, in preparation). The Raysor Marl and the upper Goose Creek Limestone appear to be biostratigraphically equivalent inshore siliciclastic and offshore leached calcarenite lithofacies, based on the common occurrence of a number of unusual index species (Table 1). However, the Krantz model provides three minor transgressions to which they might belong, the K-5, K-7, or K-9 incursions. Both the Raysor and upper Goose Creek contain common *Chesapecten septenarius*, a species that in Virginia disappeared before the K-9 level (L. Campbell, 1993). Finally, there is a relatively high commonality between the lower and upper Goose Creek Limestone faunas, although this could be the influence of common lithology rather than proximity of time. Of K-5 and K-7, K-5 is slightly greater in space and time (Text-figure 1). The Raysor Marl and upper Goose Creek Limestone are, therefore, assigned to K-5, but with a greater degree of uncertainty than exists for the other assignments.

Dowsett and Cronin (1990) documented an age of 3.5 to 3.0 Ma from deposits at Tar Heel, North Carolina (Robeson Farm), and the Lumber River. Although they assigned these beds to the Duplin Formation, both sites yield Raysor molluscan index species, including *Terebraspira elegans*, *Glycymeris americana* var. *abberans*, *Ecphora bradleyae*, and an undescribed *Scaphella* (Table 1). Natural Well-equivalent beds are also present at Tar Heel (Fig. 1, Bed E, of Britt *et al.*, 1992), but a bed-by-bed comparison of the Dowsett and Cronin (1990, Fig. 2, Locality 3) and the Britt versions of the Tar Heel section cannot be determined with certainty.

The Natural Well Duplin standard fauna includes 185 co-occurrences with the lower Waccamaw. In contrast, the Raysor standard fauna contains 94 co-occurences with the Waccamaw. The Duplin fauna is the most diverse Pliocene molluscan assemblage with 453 species, and contains a higher percentage of tropical species. Dowsett and Poore (1990) dated the Pliocene thermal maximum at 3.1 Ma. This maximum apparently coincides with the greatest westward incursion of the Pliocene sea. The Natural Well Duplin outcrop belt correspondingly occurs further westward, and at a higher elevation than the other Pliocene units in the study area. These lines of evidence are most consistent with the K-11 transgression. The Duplin, Raysor-upper Goose Creek, and lower Goose Creek molluscan assemblages are in the M-5 zone of Blackwelder (1981).

The beds at Elizabethtown, North Carolina (Carter *et al.*, 1988), best correlate with the Chowan River faunas in Virginia and the stratotype area (L. Campbell, 1993; Ward and Gilinsky, 1993). These contain a fauna older than the lower Waccamaw, younger than the Duplin (Table 2). Constrained by the respective ages of those two units, the Elizabethtown beds are assigned to K-13 to K-15. Zone M-4 of Blackwelder (1981) is the first-appearance-of-*Noetia limula* to last-appearance-of-*Glycymeris subovata* interval zone. *Glycymeris subovata* (= *G. hummi*) is common (Ward and Blackwelder, 1987) in an otherwise lower Waccamaw equivalent K-17 fauna at Aurora (L. Campbell, 1993), but makes its last appearance in the older Elizabethtown beds in southern North Carolina. Ward and Gilinsky (1993) document a high level of correlation between the faunules of the Elizabethtown beds and those of the stratotype Chowan River. We fully agree with that correlation, but dispute their assertion that the Elizabethtown is laterally equivalent with the Bear Bluff stratotype, a unit we document as being pre-, rather than post-, Natural Well Duplin.

The lower Waccamaw dates from 2.4 Ma based on the planktic foraminifera, and from 2.53 Ma by U-He coral dates from correlative deposits in southern Florida (Bender, 1973). These dates conform with the K-17 transgression. The lower Waccamaw fauna contains a greater diversity of mid-shelf species, the upper Waccamaw is dominated by littoral and shallow sublittoral species. This is consistent with the Krantz curve showing a greater incursion during the K-17 transgression.

The upper Waccamaw directly correlates with the upper Caloosahatchee of southern Florida, which unconformably underlies the 1.5 Ma Bermont beds. In turn, the upper Waccamaw is separated from the lower Waccamaw by an unconformity at Calabash, North Carolina. As the lower Waccamaw at Calabash contains planktic foraminifera indicative of an age of 2.4 Ma (Huddlestun, 1975, personal communication), the upper Waccamaw is restricted to the interval, 1.5 to 2.4 Ma, which is conformable with K-19-21 on the Krantz curve (Fig. 1). The consequent age for the upper Waccamaw would be 1.9 to 2.2 Ma. This is older than the substantially younger published ages (Cronin *et al.*, 1984; Cronin, 1990; Bybell, 1990) of 1.8 to about 1.0 Ma.

Possible explanations for this disparity are: (1) that the upper Waccamaw (including Penholoway) mollusks survived the end-Caloosahatchee extinction event and are Bermont-equivalent; (2) that the planktic foraminifera and nannofossils used in the dating appeared earlier than is thought; or (3) that the deposits consist of admixed Bermont-equivalent and Waccamaw fossils. No Bermont-equivalent molluscan fauna has been documented in the Carolinas.

The Bermont fauna in Florida is essentially modern (85 percent extant), with some distinctive, tropical index species. The James City-upper Waccamaw-upper Cypresshead-lower Nashua-upper Caloosahatchee faunas form a zoogeographic continuum of warm temperate to subtropical to tropical molluscan species only approximately 50 percent extant. Pliocene extinction pressures were more severe to the north (L. Campbell, unpublished data), making a northern refugium highly unlikely. Planktic range zones may change, as shown by the Pliocene records of the supposedly Pleistocene *Globorotalia truncatulinoides* (Haq *et al.*, 1977). Such refinements are relatively minor, and we assume the planktic data to be essentially correct. Consequently, the simplist explanation may be that of mixed age micro- and macrofaunas. To further complicate the matter, Huddlestun (1988) reported an age of PL-5 for the Cypresshead Formation, based on planktic foraminifera, which is totally compatible with our macrofossil dating of the lower and upper Waccamaw.

The lower and upper Waccamaw faunas belong to the Blackwelder zone M-3. L. Campbell (1993) critiqued this zone, noting that the first appearance of the key indicator species, *Anadara ovalis*, fell within, rather than above, the upper Waccamaw.

Our stratigraphic model is based upon physical stratigraphy where superposition and unconformities can be demonstrated, and upon biostratigraphy, using index species and quantitative faunal statistics for correlation and for inferred position when physical evidence is lacking. This combination of "superposition and faunal statistics" (L. Campbell, 1993, p. 15) has been criticized by Ward and Gilinsky (1993, p. 8) as "at best, a comparison of apples and oranges." Superposition and biostratigraphy are both methods of determining relative time. They should be integrated where possible in any rigorous stratigraphic analysis. Problems arise when either physical stratigraphy or biostratigraphy is made subservient to the other. In our arguments concerning the validity of the Bear Bluff Formation, biostratigraphy can test the coherency of a proposed physical unit.

Ward and Gilinsky (1993, p. 8) also took the model (L. Campbell, 1993, fig. 1) to task for proposing impossible correlations, such as equating the Moore House member of the Yorktown Formation with the Chowan River beds. This is a mis-reading of the figure. A careful reading of the text (L. Campbell, 1993) will demonstrate that all columns were not intended to cross-correlate, but rather to reference individually the time line and Krantz isotope model, emphasizing contrast of age assignments rather than coincidence of units. This intent was not plainly re-stated in the figure caption by Campbell (1993, fig. 1), and any confusion created by that omission is regretted.

Similarly Text-figure 1 of the present work contrasts the prevailing stratigraphic model (Ward, Bailey, and Carter, 1991) with the one proposed by M. Campbell (1992). The prevailing model is a synthesis of the work of many noteworthy geologists, and has served coastal plain studies reasonably well for several decades. New evidence demonstrates that the prevailing model contained errors as to the age and relative position of the Goose Creek Limestone, and the nature of the Bear Bluff Formation. Further, the degree of complexity now demonstrable within the Pliocene strata of the study area poorly conforms with the prevailing model. The new model recognizes the greater complexity and, coincidently, is compatible with most of the units predicted by the Krantz curve.

VII. SUMMARY

Recently discovered Goose Creek Limestone localities at the Martin Marietta Berkeley Quarry and around Conway, South Carolina, preserve both a rich and abundant calcitic fauna and a diverse moldic assemblage from which latex peels were taken. Small, seemingly disparate published faunules, including that of the stratotype at Goose Creek, are shown to be compatible subsets of these larger assemblages. Approximately 250 Goose Creek macrofossil species are now documentable in Charleston Museum, U.S. National Museum, or University of South Carolina Spartanburg collections, tripling the previous known diversity. Molluscan range zones support an early mid-Pliocene age for the Goose Creek Limestone, an age compatible with previous determinations from planktic foraminiferal zone PL-3 (Ward and Huddlestun, 1988, p. 73, section at Givhans Ferry State Park), and nannoplankton Zone NN 15 to mid-NN 14, or 3.9 to 3.2 Ma (Bybell, 1990).

The Goose Creek Limestone is divided by an unconformity into upper and lower units. These units are lithically identical, but may be distinguished biostratigraphically where faunules are sufficiently rich. All Conway area and Horry County mid-Pliocene calcarentites, including the stratotype of the "Bear Bluff Formation," belong to the upper Goose Creek Limestone. Upper Goose Creek localities in the Charleston area include Feteressa, the Seaboard Railroad ditch, and the Mark Clark Expressway pit. The Berkeley Quarry, the Givhans Ferry State Park section, and a number of Charleston localities, including the Goose Creek stratotype, belong to the lower unit.

Compounding errors in literature led to the placement of the Raysor Marl beneath the Goose Creek Limestone. The Goose Creek Limestone and the Tamiami Limestone contain common *Encope macrophora*. Cooke (1936) correctly correlated the two units, but he placed the Tamiami in the Waccamaw-equivalent Caloosahatchee Formation. Compounding the problem is a true Waccamaw-equivalent unit in the Charleston area, the "Smith's, Goose Creek" locality of Tuomey and Holmes (1855-1857). This upper bed at "Smith's" is best referred to the Cypresshead Formation of Huddlestun (1988). The actual order can be demonstrated in section at the Martin Marietta Berkeley Quarry, where the lower Goose Creek Limestone is unconformably overlain by the Raysor Marl.

In the Horry County area, the Bear Bluff Formation in literature contains parallel errors. DuBar (1987) described the Bear Bluff Formation as having a basal, leached calcarenite (bed A), a middle member (bed B) containing aragonite-preserved molluscan assemblages, and an upper, unfossiliferous sand (bed C). The basal calcarenite is equivalent to, and mappably contiguous with, the upper Goose Creek Limestone. Bed B strata at Calabash, North Carolina, and at various sites in Horry County, South Carolina, are lower Waccamaw, biostratigraphically equivalent to the shelly beds at "Smith's, Goose Creek." The Bear Bluff stratotype section contains only the basal, bed A calcarenites. Based on the stratotype section, the Bear Bluff Formation is synonymous with the Goose Creek Limestone, and localities assigned to the middle and upper members should be distributed among other formations.

So rectified, the lithostratigraphic and biostratigraphic units of the Carolinas become compatible with Pliocene sections proposed in Virginia and northern North Carolina (L. Campbell, 1993), Georgia (Huddlestun, 1988), and southern Florida (Scott and Allmon, 1992), and with the oxygen isotope-based sea-level curve of Krantz (1991).

VIII. SYSTEMATIC PALEONTOLOGY

Several important Goose Creek species that have been confused through rarity, misidentification, multiple names, or misleading illustrations are discussed here. Distribution is taken from sources and references cited in the systematic discussion and Appendices I and II.

Resolution of all systematic problems for the species listed in Appendix II is beyond the scope of this paper. Some taxa were simple to rectify, but other names, although dubious, could not be resolved without reexamination of other relevant collections. Review of pertinent collections at Converse College (Howe, 1987), and the U.S. National Museum (Malde, 1959, and Cooke, 1936) resulted in nomenclatural changes and in a number of additional records.

GLYCYMERIS AMERICANA (Defrance)
Plate 5, figure 3

Pectunculus americanus DEFRANCE, 1826, Dict. Science Nat., v. 39, p. 225.
Pectunculus pulvinatus Lamarck. CONRAD, 1832, Foss. Shells Tert. Formations, p. 17, not of Lamarck, 1805.
Pectunculus lentiformis CONRAD, 1837, Foss. Shells Tert. Formations, p. 36.
Pectunculus carolinensis CONRAD, 1839, Foss. Medial Tertiary, inside back cover, later copies.
Pectunculus elephantopus H.C. LEA, 1846, Trans. Amer. Philos. Soc., ser. 2, v. 9, p. 230.
Pectunculus tricenarius CONRAD, 1845, Foss. Medial Tertiary, p. 63, pl. 35, fig. 1.
Pectunculus carolinensis HOLMES, 1859, Post-Pleiocene Foss. South Carolina, p. 15, pl. 3, fig. 4.
Axinaea lentiformis Conrad. MEEK, 1864, Smithsonian Misc. Coll., v. 7, p. 5.

VARIETIES OR SUBSPECIES:

Pectunculus passus CONRAD, 1845, Foss. Medial Tertiary, p. 64, pl. 35, fig. 3.
Pectunculus quinquerugatus CONRAD, 1845, Foss. Medial Tertiary, p. 63, pl. 34, fig. 3.
Pectunculus transversus TUOMEY and HOLMES, 1856, Pleiocene Foss. South Carolina, p. 51, pl. 17, fig. 6c; *non* Lamarck, 1819, Hist. Nat. Anim. Sans Vertèbres, v. 6, pt. 1, p. 55.
Glycymeris abberans NICOL, 1952, Jour. Wash. Acad. Sci., v. 42, p. 362; NICOL, 1953, Jour. Paleontology, v. 27, p. 451.

Description: In typical form, shell large, nearly circular, compressed; teeth large, taxodont with prominent hinge plate; beaks small, sharply pointed; ribs low, radial, smooth or consisting of crowded threads.

Occurrence: Glycymeris americana americana (Miocene ?) Pliocene to Recent. Virginia – Yorktown Zone 2, Chowan River; Carolinas – Yorktown Zone 2, Chowan River, lower and upper Goose Creek Limestone, Raysor, Duplin, Waccamaw; Florida – Pinecrest, Caloosahatchee; Recent – North Carolina to Florida. *Glycymeris americana* var. *quinquerugata* Pliocene. Virginia – Yorktown Zone 2; Carolinas – upper Goose Creek Limestone, Raysor, and Duplin; Florida – Pinecrest and Jackson Bluff. *Glycymeris americana* var.? *abberans* Pliocene. Carolinas – lower Goose Creek (type locality for *Pectunculus transversus* Tuomey and Holmes); upper Goose Creek Limestone and Raysor; Florida – lower or middle Pinecrest, especially around Miami.

Type localities: G. americana unknown; *G. a. abberans* Goose Creek, Charleston, South Carolina.

Discussion: Glycymeris americana (Defrance) is a large, circular, taxodont clam that is scarce in the Recent but quite common in the Pliocene of North and South Carolina. Some disparity exists in the publication date: Abbott (1974) cited 1829, whereas Sherborne (1923) cited 1826. In Duplin, Raysor, and Goose Creek populations, some specimens develop a set of strong ripples on the dorsal margins of the shell. Such shells were given the name *Glycymeris quinquerugata* (Conrad). Given this variation and intergradation, *G. quinquerugata* has been interpreted as a possible pathologic variety of *G. americana* (*e.g.*, Dall, 1898).

Tuomey and Holmes (1856) described *Pectunculus transversus* as a laterally elongate mold. Nicol (1952) noted that *Pectunculus transversus* is preoccupied and proposed the replacement name, *Glycymeris abberans*. Nicol's aragonitic specimens from Florida are laterally elongate and have a wrinkled, concentric shell ornamentation. Carter *et al.* (1988) figured a then-unique paired specimen of *Glycymeris* with sinuous concentric wrinkles completely crossing the disk. Carter (1988, personal communication) has suggested that *Glycymeris abberans* is an exceptionally rugate *Glycymeris americana* var. *quinquerugata*. The USC Spartanburg collection from the Mason Dixon pit at Conway contains over 100 internal and external molds of *Glycymeris abberans*. Most *G. americana* populations maintain a circular shell outline throughout ontogeny, but juvenile and subadult specimens of *G. abberans* display a remarkable allometric lateral expansion of the shell. The fully adult *Glycymeris abberans* specimens regain the circular shape, and the wrinkles either become obsolete or are expressed as large, concentric ripples. The Tuomey and Holmes, Nicol (1952), and University of North Carolina specimens show the elongate, subadult morphology. A small population of *Glycymeris americana* from the zone 2 Yorktown at Williamsburg, Virginia, has the laterally expanded subadult morphology, but lacks the wrinkling (USCS collections).

The rugate morphologies have different geologic ranges. *Pectunculus transversus* (= *Glycymeris americana* var. *abberans)* was originally described from the Goose Creek stratotype, a lower Goose Creek horizon. However, all subsequent records are from the upper Goose Creek Limestone and the Raysor Marl, suggesting that Tuomey and Holmes may have cited an erroneous locality. In the limestone, it co-occurs with normal and "quinquerugate" specimens. In the Raysor Marl, the three morphologies are joined by a fourth: a large, thick, and highly inflated shell, which may be the *Glycymeris americana* var. *passus* of Conrad. *Glycymeris americana* var. *quinquerugata* survived somewhat longer, co-occuring with typical, non-rugose stock in the Duplin of North and South Carolina. Only typical, non-rugate *Glycymeris americana* survived into the Waccamaw and the Recent. The diverse morphologies are considered herein provisionally to be varieties. More study will be necessary to resolve the questions of species, subspecies, genetic mutation and ecomorphism in this complex.

PECTEN HEMICYCLICUS Ravenel
Plate 1, figure 5; Plate 3, figure 6

Pecten hemicyclicus RAVENEL, 1834. Catalog of Recent Shells.

Janira hemicyclica (Ravenel). TUOMEY and HOLMES, 1855, Pleiocene Foss. South Carolina, p. 25.

Pecten ochlockoneensis MANSFIELD, 1932, Florida Geol. Survey, Bull. 8, p. 56, pl. 13, figs. 1, 3.

Pecten ochlockoneensis leensis MANSFIELD, 1939, Florida Geol. Survey, Bull. 18, p. 50, pl. 2, fig. 3.

Pecten raveneli Dall. CAMPBELL *et al.*, 1975, South Carolina Geol. Notes, v. 19, p. 82 (in part, mid-Pliocene records only).

Description: Shell large, subcircular, inequivalve, upper valve flat to weakly concave, lower valve convex, shallow in juvenile and typical adult specimens; ribs 20, low, with wider interspaces on upper valve. Very large specimens becoming laterally elongate, with the lower valve deeply cupped, the ventral margin of lower valve overlapping the upper valve.

Occurrence: Pliocene. Virginia – Yorktown, Zone 2; South Carolina – lower Goose Creek Limestone (common), upper Goose Creek Limestone (rare), Raysor (rare); Florida – Pinecrest and Jackson Bluff.

Type locality: The Grove Plantation, Charleston, South Carolina.

Discussion: *Pecten hemicyclicus* changed shape during ontogeny. Very large, laterally elongated shells, such as the type specimen, are not uncommon at Goose Creek localities but are rare in Florida. The smaller, more circular Florida

PLATE 1

Characteristic lower Goose Creek Limestone fossils from the Martin Marietta Berkeley Quarry, near Cross, South Carolina (locality 27). Illustrated specimens are deposited in the Charleston Museum.

Figures
1, 3. *Nodipecten collierensis* (Mansfield)
Size: # 1: 43 mm; Museum Catalog number ChM PI 9258
3: 43 mm; Museum Catalog number ChM PI 9259
2. *Chesapecten madisonius* (Say) subspecies ? *carolinensis* (Conrad)
Size: 84 mm; Museum Catalog number ChM PI 9260
4, 6. *Chesapecten septenarius* (Say)
Size: #4: 46 mm; Museum Catalog number ChM PI 9261
#6: 44 mm; Museum Catalog number ChM PI 9262
5. *Pecten hemicyclicus* Ravenel
Size: 49 mm; Museum Catalog number ChM PI 9263
7. *Amusium mortoni* (Ravenel)
Size: 52 mm wide; Museum Catalog number ChM PI 9264
8. *Spondylus* n. sp. ?
Size: 64 mm; Museum Catalog number ChM PI 9265
9. *Leptopecten leonensis* (Mansfield)
Size: 19 mm; Museum Catalog number ChM PI 9266

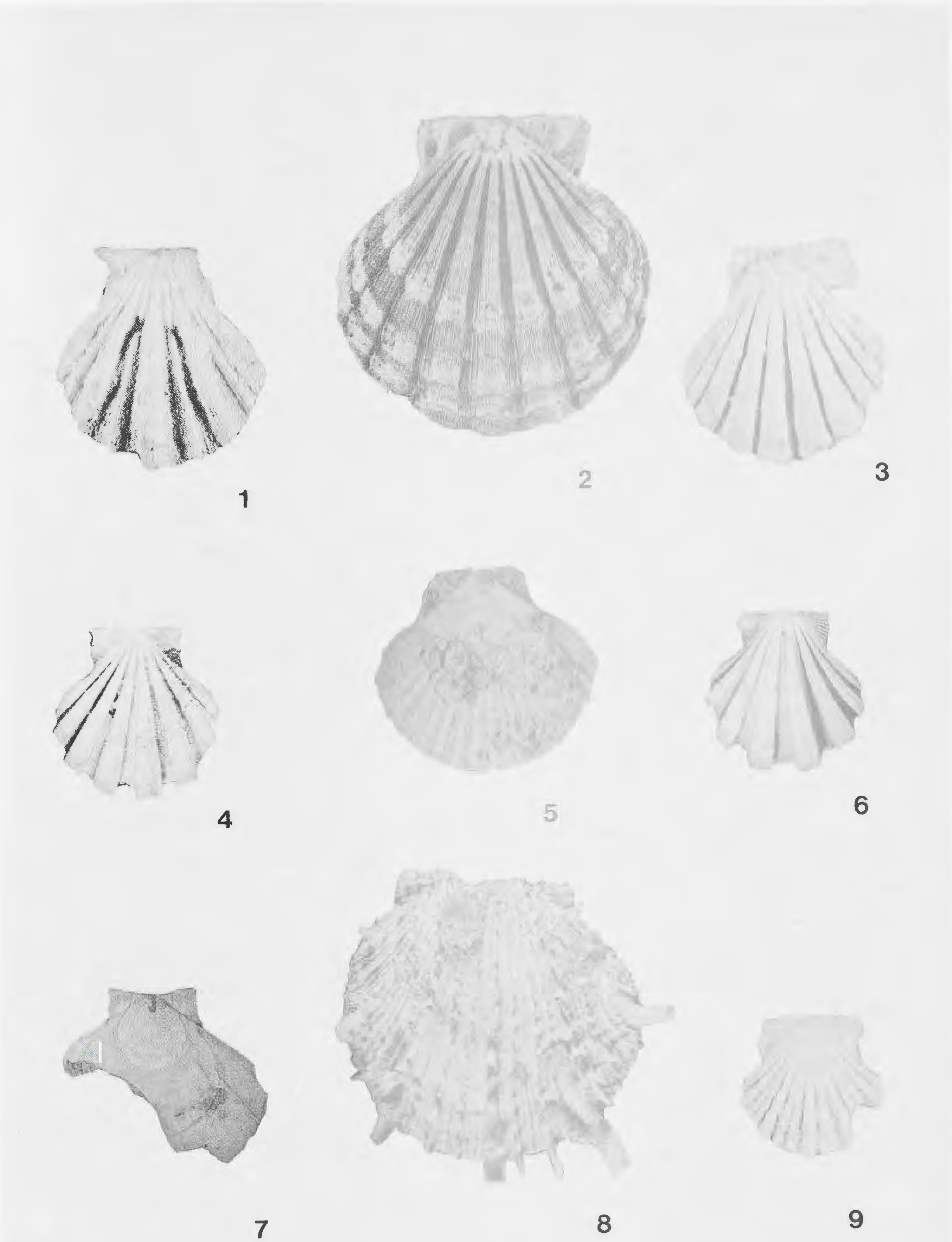


PLATE 1

specimens were named *Pecten ochlockoneensis* Mansfield, 1932, and *Pecten ochlockoneensis leensis* Mansfield, 1939. Reports of this species in the upper Pliocene Waccamaw Formation (Gibson, 1987, p. 41) or Recent (Dall, 1889, p. 32) appear to be incorrect, the Waccamaw report resulting from stratigraphic confusion, and the Recent report from misidentification.

Abbott (1974, p. 442) defined the subgenus *Euvola* as follows: "Lower or right valve very convex and with weak, rounded ribs; upper or left valve quite flat, more heavily sculptured. Type: *ziczac* (Linnaeus, 1758)." Fossil and Recent *Pecten (Euvola)* species are confused in both historic and current literature. In addition to *Pecten hemicyclicus* and its synonyms, there are *Pecten ziczac* (Linnaeus, 1758), *Pecten brouweri* Tucker, 1934 (see plate 5, figures 4 and 5), and two species covered under *Pecten raveneli* Dall, 1898.

Pecten ziczac, a Recent species, has 18 to 20 very low ribs with strong secondary ribbing in the interspaces. The right valve is convex but shallow. Its ribbing is distinct from that of the remaining taxa in which the interspaces lack the broad secondary ribbing. Its ribs are more elevated, and they are commonly grooved on the right valve. Recent shells called *Pecten raveneli* resemble *P. ziczac* and *P. hemicyclicus* in the shallow convexity of the right valve, but the Recent *P. raveneli* averages 25 ribs in contrast to about 20 ribs for *P. hemicyclicus*. The holotype of *P. raveneli* is a fossil from the "Caloosahatchee marls." Dall's figure (Dall, 1898, pl. 29, fig. 10) shows a substantially more convex shell, especially in the early growth. Fossil specimens of *P. raveneli* average 21 to 22 ribs. The Recent "*P. raveneli*" seems to be unnamed; it is being studied by Thomas Waller of the Smithsonian Institution.

Pecten brouweri differs from *P. raveneli* in having 14 to 16 ribs (Tucker, 1934). In outline, convexity of right valve, and absolute size attained, *P. brouweri* is very close to the holotype of *P. raveneli*. *Pecten brouweri* is known from only a few specimens. All recovered in South Carolina are from the Goose Creek Limestone, considerably older than the "Waccamaw" age reported by Tucker (1934). Its rarity seems to be related to past unavailability of Goose Creek age deposits. The small population of *P. brouweri* in hand has a range of rib numbers from 14 to 20, placing it in close conformity with *P. raveneli*. *Pecten brouweri* is probably only subspecifically distinct from true *P. raveneli*, if not fully conspecific. Resolution of the problem will require larger populations than are now available.

Pecten ochlockoneensis violae Tucker, 1936, is here elevated to species status. *Pecten violae* is larger than *P. raveneli* and *P. brouweri*. The upper valve is concave for the first 10 mm of the disk, then becomes nearly flat. The upper valves of *P. raveneli* and *P. brouweri* are evenly concave across the entire disk. Typical specimens of *P. violae* have 15 to 16 radial ribs.

PLATE 2

Lower Goose Creek Limestone fossils from the Martin Marietta Berkeley Quarry (locality 27). Illustrated specimens are deposited in the Charleston Museum.

Figures

1. *Placunanomia burnsi* Mansfield
   Size: 67 mm; Museum Catalog number ChM PI 9267
2. *Placunanomia plicata* Tuomey and Holmes
   Size: 70 mm; Museum Catalog number ChM PI 9268
3. *Hyotissa haitensis* (Sowerby)
   Size: 73 mm; Museum Catalog number ChM PI 9269
4. *Encope macrophora* (Ravenel)
   Size: 37 mm; Museum Catalog number ChM PI 9270
5. *Busycon contrarium* (Conrad)
   Size: 50 mm; Museum Catalog number ChM PI 9271
6. *Ecphora quadricostata* (Say)
   Size: 86 mm; Museum Catalog number ChM PI 9272
7. *Turritella holmesi* Dall
   Size: 64 mm; Museum Catalog number ChM PI 9273

PLATE 2

LEPTOPECTEN LEONENSIS (Mansfield)
Plate 1, figure 9

Pecten leonensis MANSFIELD, 1932, Florida Geol. Survey, Bull. 8, p. 58, pl. 9, figs. 2, 3.
Pecten wendelli olgensis MANSFIELD, 1939, Florida Geol. Survey., Bull. 18, p. 51, pl. 2, figs. 1, 2, 4.

Description: Shell small, very thin, fragile; both valves convex, compressed; sculpture variable, typically, ribs 10-11, narrow, with wider interspaces, interspaces may have one to three radial threads. Auricles large.

Occurrence: Pliocene. Virginia – Yorktown, lower Zone 2; Carolinas – lower and upper Goose Creek Limestone, Raysor; Florida – lower Pinecrest and Jackson Bluff.
Type locality: Jackson Bluff, Leon County, Florida.

Discussion: Leptopecten wendelli (Tucker, 1934) has been synonymized with *Leptopecten leonensis* (Mansfield, 1932) by Ward and Blackwelder (1987, p. 140). However, Waccamaw specimens of *Leptopecten wendelli* from Calabash, North Carolina, are distinctive and are not conspecific with the older *Leptopecten leonensis. Leptopecten wendelli olgensis* is not morphologically similar to *L. wendelli*, but it seems to be conspecific with *L. leonensis*. Mansfield reported *L. leonensis* from the Ecphora zone of the Jackson Bluff Formation, from Porters Landing on the Savannah River, and a single specimen from Raysors Bridge. Tucker (1938) illustrated *L. leonensis* from supposed Waccamaw beds at Walkers Bluff on the Cape Fear River, which is also the type locality for *Pecten brouweri* Tucker, and *Carolinapecten eboreus* var. *walkerensis* Tucker, taxa that otherwise are restricted to faunules of the upper Goose Creek Limestone. It appears that Walkers Bluff contains reworked material or pre-Waccamaw strata, in addition to its better-known Waccamaw beds (Gardner, 1944). At the Berkeley Quarry, *L. leonensis* is fairly common in the lower Goose Creek Limestone, but is only rarely recovered from the younger Raysor sands.
Pecten harrisi Dall, 1898, may be another species of *Leptopecten* from the Caloósahatchee Formation.

CAROLINAPECTEN EBOREUS variety WALKERENSIS (Tucker)
Plate 3, figure 1; Plate 5, figures 1, 2

Pecten eboreus walkerensis TUCKER, 1934, Amer. Midland Nat., v. 15, p. 616, pl. 27, fig. 3.
Pecten eboreus buckinghamensis MANSFIELD, 1939, Florida Geol. Survey, Bull. 18, p. 53, pl. 3, figs. 4, 5, and 8.

PLATE 3

Pectenid bivalves from the upper Goose Creek Limestone at the Mark Clark Expressway pit (locality 13) and near Feteressa (locality 14). Illustrated specimens are deposited in the Charleston Museum.

Figures
1. *Carolinapecten eboreus walkerensis* (Tucker)
   Size: 92 mm; Museum Catalog number ChM PI 8365
   Locality: near Feteressa (loc. 14)
2. *Nodipecten peedeensis* (Tuomey and Holmes)
   Size: 111 mm; Museum Catalog number ChM PI 4164
   Locality: Mark Clark Expressway pit (loc. 13)
3. *Pecten* sp., possibly an immature *Pecten brouweri* Tucker
   Size: 18 mm; Museum Catalog number ChM PI 4178
   Locality: Mark Clark Expressway pit (loc. 13)
4. *Argopecten comparilis* (Tuomey and Holmes)
   Size: 63 mm; Museum Catalog number ChM PI 4166
   Locality: Mark Clark Expressway pit (loc. 13)
5. *Chesapecten septenarius* (Say), with attached *Ostrea sculpturata* Conrad
   Size: 114 mm; Museum Catalog number ChM PI 8351
   Locality: near Feteressa (loc. 14)
6. *Pecten hemicyclicus* Ravenel
   Size: 92 mm; Museum Catalog number ChM PI 4043
   Locality: Mark Clark Expressway pit (loc. 13)

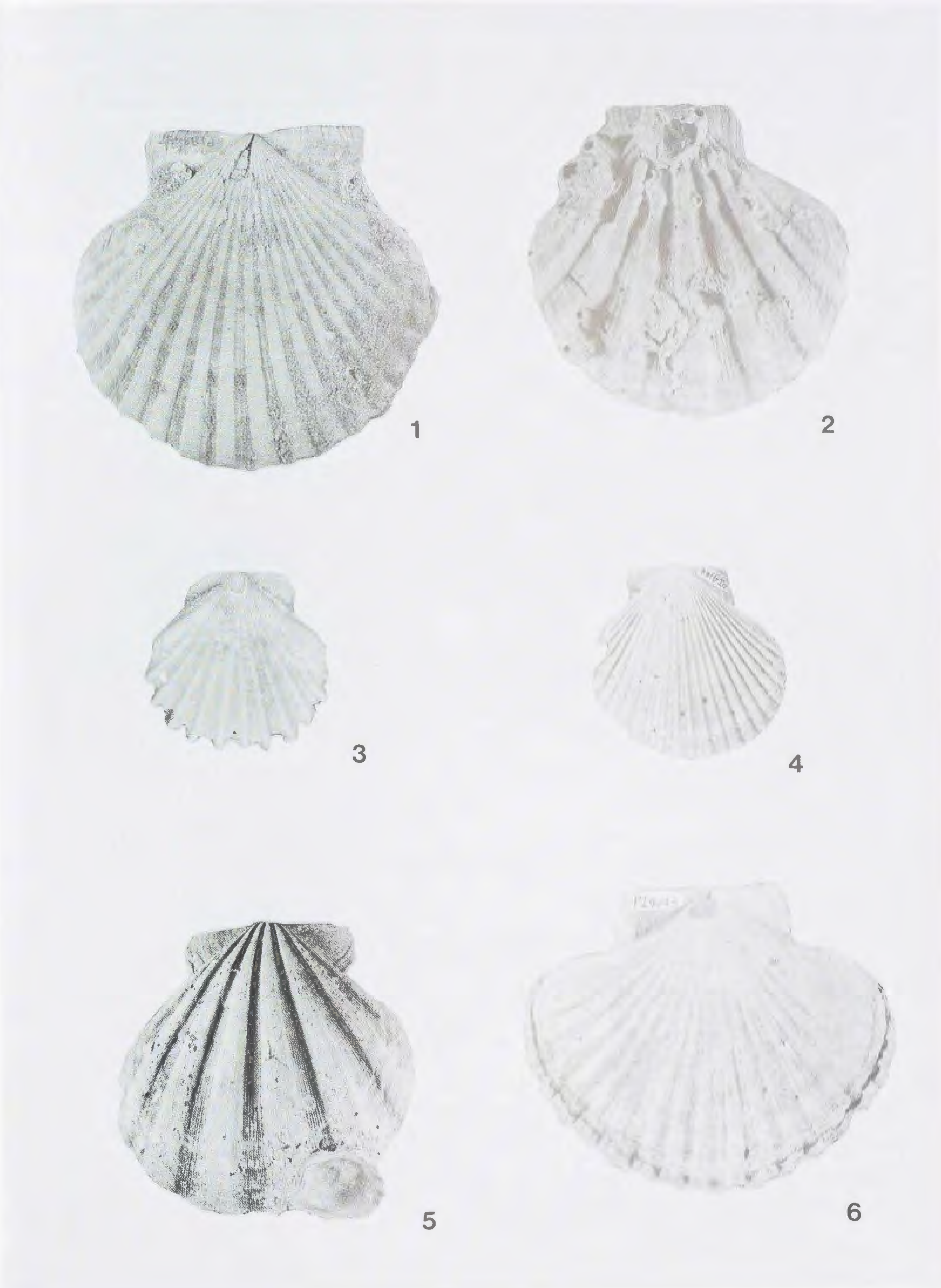


PLATE 3

Description: Shell very large, subcircular, thin; right and left valves convex, compressed; ribs 20 to 24, low, narrow, with wide interspaces; posterior margin produced, left valve depressed, warped posteriorly.

Occurrence: Pliocene. Carolinas – upper Goose Creek Limestone, Raysor; Florida – Buckingham Limestone.

Type locality: Walker's Bluff, Cape Fear River, North Carolina.

Discussion: This is the largest of the *Carolinapecten* stock, with exceptional specimens exceeding 20 cm in maximum diameter. No other lineage or variety shows the pronounced expansion of the posterior margin or the warped cross section. Mansfield (1936, p. 174) erroneously synonymized *C. e. walkerensis* with Dall's (1900) *Pecten eboreus senescens.* The latter, which is the smallest of the forms of *Carolinapecten*, has subdued, nearly obsolete radial ribs, and a more inflated shell. This synonymy was accepted by Tucker-Rowland (1938, p. 50). Meanwhile, Mansfield (1939) described *Pecten eboreus buckinghamensis* from the Buckingham Limestone. The latter taxon was also described as large and having a warped cross-section, both traits uniquely shared with *C. e. walkerensis.* The warped cross-section becomes more obvious in specimens greater than approximately 10 cm in maximum diameter. *In situ*, abundant populations of *C. e. walkerensis* seem restricted to the Raysor Marl and the equivalent upper Goose Creek Limestone. Tucker (1934) designated a type locality of Walkers Bluff, Cape Fear River, North Carolina. However, she also cited a paratype from Nixon's, a classic Waccamaw locality, and USC Spartanburg collections contain single valves from basal Waccamaw beds at Calabash, North Carolina. In the Natural Well Duplin faunas, a smaller, more symmetrical *Carolinapecten eboreus* var. *darlingtonensis* (Dall) replaces the older *walkerensis* morphology. The reappearance of very rare, unpaired *walkerensis* valves in the Waccamaw consequently represents either retrograde evolution, an undetected surviving lineage, or reworking of older, Goose Creek specimens. At both Calabash and Nixon's, the Waccamaw rests unconformably on Cretaceous strata and contains reworked species. We consider the Waccamaw records of *C. e. walkerensis* to be fortuitous.

CHESAPECTEN MADISONIUS (Say)
variety (or ?subspecies) CAROLINENSIS
(Conrad)
Plate 1, figure 2

Pecten madisonius SAY, 1824, Jour. Acad. Nat. Sci. Phila., v. 4, p. 134.

Lyropecten carolinensis CONRAD, 1873, preprint of Appendix, Report of the Geological Survey of North Carolina, p. 18.

PLATE 4

Goose Creek Limestone fossils from the vicinity of Charleston, South Carolina. Illustrated specimens are deposited in the Charleston Museum, unless otherwise noted.

Figures

1. *Pecten anisopleura* Conrad
   Size: 84 mm; Museum Catalog number ANSP-unnumbered
   Locality: "40 miles south of Beaufort, N. Car." Dr. Yarrow
2. *"Spondylus holmesi"* Mazyck (manuscript name)
   Size: 110 mm; Museum Catalog number ChM PI unnumbered
   Locality: "from phosphate mines on the Cooper River, 10 miles from Charleston. Gift of Dr. Panknin."
3. *Encope macrophora* (Ravenel)
   Size: 43 mm; Museum Catalog number ChM PI 4485
   Locality: The Grove, Ravenel collection, part of the type lot.
4. *Mellita caroliniana* Ravenel
   Size: 62 mm; Museum Catalog number ChM PI 8374
   Locality: near Feteressa (loc. 14)

5, 6. *Malea* sp. cf. *M. densecostata* (Rutsch)
   Size: 79 mm; Museum Catalog number ChM PI 8372
   Locality: near Feteressa (loc. 14)

PLATE 4

Chesapecten madisonius (Say). WARD and BLACKWELDER, 1975, U. S. Geol. Survey, Prof. Paper 861, p. 16, pl. 6, figs. 1-4; pl. 7, figs. 1, 7, 8; GIBSON, 1987, Smithsonian Contrib. Paleobiology, no. 61, p. 73, pl. 22, fig. 1; pl. 24, figs. 3-5; pl. 25, figs. 1-4, 6; pl. 26, figs. 1, 3-5.

Description: Shell large, subcircular, heavy; right and left valves convex; ribs 10 to 14, narrow, with strong, scaled cords.

Occurrence: Pliocene. Virginia – Yorktown, basal Zone 2; Carolinas – Yorktown, basal Zone 2 (Aurora), lower Goose Creek Limestone; Florida – Tamiami Limestone.

Type locality: North Carolina.

Discussion: Chesapecten madisonius is rare in the Goose Creek Limestone. The scant material present varies from 10 to 14 ribs. Gibson (1987) reported *C. madisonius* with similar low rib counts from the Lee Creek mine, Aurora, North Carolina. Typical specimens of *C. madisonius* from higher in the section have 16 to 22 ribs. This low rib-number morphology has been called *Lyropecten carolinensis* Conrad, 1873 (holotype in the Academy of Natural Sciences Philadelphia). *Lyropecten carolinensis* would become *Chesapecten madisonius carolinensis* (Conrad) if it proves to be a valid subspecies. It does not co-occur with typical *C. madisonius*. Too few specimens are presently available to resolve the question. *Chesapecten septenarius* and *Chesapecten jeffersonius* produced rare individuals with 10 to 12 ribs, but *C. madisonius* may be recognized by its narrower ribs and coarse radial threads with strong scaling.

CHESAPECTEN SEPTENARIUS (Say)
Plate 1, figures 4, 6; Plate 3, figure 5

Pecten septenarius SAY, 1824, Jour. Acad. Nat. Sci. Phila., v. 4, p. 136, pl. 9, fig. 3.

Chesapecten septenarius (Say). WARD and BLACKWELDER, 1975, U.S. Geol. Survey, Prof. Paper 861, p. 15, pl. 6, figs. 5-7, pl. 7, figs. 2, 9.

Chesapecten jeffersonius septenarius (Say). GIBSON, 1987, Smithsonian Contrib. Paleobiology, no. 61, p. 71, pl. 21, figs. 7-8, pl. 22, figs. 2-3; pl. 23, figs. 1-3; pl. 24, figs. 1-2; pl. 25, fig. 5; pl. 26, fig. 2.

Description: Shell large, subcircular, very heavy; right and left valves convex, well inflated; ribs 4 to 12, wide, squared or laterally expanded at the crest; ribs with secondary sculpture of fine striations, scaling weak at edge of ribs, or lacking.

Occurrence: Pliocene. Virginia – Yorktown, lower and middle Zone 2; Carolinas – Yorktown, lower Zone 2, lower and upper Goose Creek Limestone, Raysor; Florida – Tamiami Limestone and lower Jackson Bluff.

Type locality: "Maryland" [unknown Virginia locality].

Discussion: Chesapecten septenarius is a highly variable species, similar in some of its morphologies to the older to contemporaneous *Chesapecten jeffersonius*. *Chesapecten septenarius* has between four and twelve ribs that vary in cross-section

PLATE 5

Mollusks from the Mason Dixon pit, upper Goose Creek Limestone, Conway, South Carolina (locality 69). Illustrated specimens are deposited in the Charleston Museum.

Figures

1, 2. *Carolinapecten eboreus walkerensis* (Tucker); showing the concave outline of the right flank
Size: 110 mm; Museum Catalog number ChM PI 12420

3. *Glycymeris americana abberans* Nicol, and *Pleioptygma carolinensis* (Conrad); latex peels
Size: 59 mm; Museum Catalog number ChM PI 12421

4. *Pecten brouweri* Tucker; flat upper valve
Size: 35 mm; Museum Catalog number ChM PI 12422

5. *Pecten brouweri* Tucker; deeply cupped lower valve
Size: 44 mm; Museum Catalog number ChM PI 12423

6. *Argopecten anteamplicostatus* (Mansfield)
Size: 28 mm; Museum Catalog number ChM PI 12424

7. *Ecphora bradleyae* Petuch
Size: 34 mm; Museum Catalog number ChM PI 12425

8. *Terebrispira elegans* (Emmons); latex peel
Size: 78 mm; Museum Catalog number ChM PI 12426

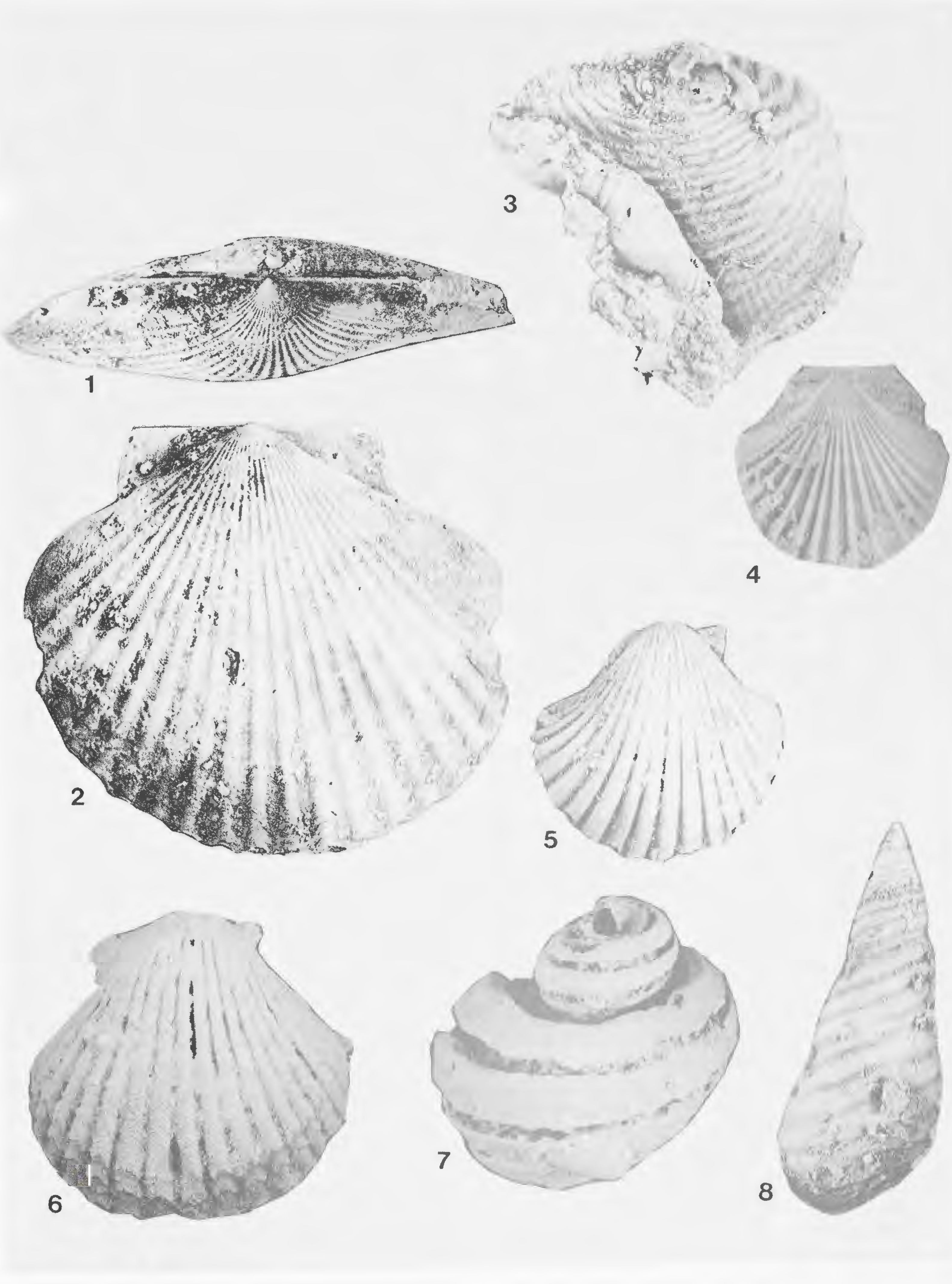


PLATE 5

between "T" topped, square, and slightly rounded morphologies. *Chesapecten jeffersonius* typically has seven to nine lower, rounded ribs. The latter is more characteristic of deposits below the Goose Creek Limestone, such as the Zone 1 Yorktown Formation to the north, or the Wabasso beds. However, Stanley (1988, personnal communication) has paired specimens of *C. jeffersonius* from the Tamiami Formation (bed 11, APAC pit, Sarasota, Florida), a formation that is faunally equivalent to the lower Goose Creek Limestone. Sloan specimens from "Raysor's Bridge" figured by Ward and Huddlestun (1988) seem to conform with *C. jeffersonius* morphologies. We have found no such specimens in either the Goose Creek or Raysor levels at the Berkeley Quarry. Pooser (1965, p. 23) and Colquhoun (1965, p. 46) reported *Chesapecten jeffersonius* from a pond near Orangeburg, but subsequent collections from the site contain only *Chesapecten septenarius.*

NODIPECTEN PEEDEENSIS (Tuomey and Holmes)
Plate 3, figure 2

Pecten peedeensis TUOMEY, 1848, Rept. Geol. South Carolina, p. 176 (nude name); TUOMEY and HOLMES, 1855, Pleiocene Foss. South Carolina, p. 30, pl. 12, figs. 1-5.

Pecten vaccamavensis OLSSON, 1914, Bulls. Amer. Paleontology, v. 5, no. 24, p. 11, pl. 1, fig. 1.

Nodipecten peedeensis (Tuomey and Holmes). M. CAMPBELL, 1988, South Carolina Acad. Sci. Bull., v. 50, p. 35; M. CAMPBELL, 1988, Amer. Malacol. Union, Program and Abstracts, p. 39; SMITH, 1991, U.S. Geol. Survey, Prof. Paper 1391, p. 94, pl. 15, figs. 1-4.

Not *Pecten peedeensis* Tuomey and Holmes. MANSFIELD, 1936, Jour. Paleontology, v. 10, no. 3, p. 180; TUCKER-ROWLAND, 1938, Mém. Mus. Royal Hist. Nat. Belgique, Ser. 2, fasc. 13, p. 23.

Description: Shell large, subcircular, well inflated; ribs high, nodes large; upper valve with seven large, prominently noded ribs, alternating in strength, lower valve with eight subequal ribs, nodes rare or absent. Secondary sculpture of coarse radial threads crossed by finer concentric lines. Concentric resting stages often stepped or shelved.

Occurrence: Pliocene. Carolinas – upper Goose Creek Limestone.

Type locality: Near Giles Bluff, Pee Dee River, South Carolina.

Discussion: Nodipecten peedeensis was originally cited (Tuomey, 1848) as occurring with two lower to mid-Pliocene taxa, *Chesapecten septenarius* and *Ecphora quadricostata* (Campbell *et al.*, 1975, p. 82, 110; Blackwelder, 1981, p. 3). The type specimens of *N. peedeensis* were temporarily misplaced in the American Museum of Natural History. In their absence, Tucker-Rowland (1938, p. 23) designated a misidentified European specimen as neotype (Smith, 1988, personal communication).

Two morphologies exist within the Goose Creek Limestone material now at hand: a smoother, less sculpted shell typified by the Berkeley quarry population (over 200 specimens); and shells from the Mason Dixon pit, Conway, South Carolina, with higher ribs, somewhat stronger secondary sculpture, and higher and more frequent nodes. In addition to the stronger sculpture, the Mason Dixon specimens are very large, sometimes exceeding 160 mm in maximum diameter. The Mason Dixon population also includes abnormal morphologies, which we intrepret as genetic mutants. The weaker ribs of the mutant left valve are reduced or eliminated, producing five instead of seven ribs, and the right valve correspondingly has the four central ribs fused into two wide ribs. A small population from the Charleston area has similar normal and mutant morphologies. M. Campbell (1988a, 1988b) first interpreted the Charleston and Berkeley quarry populations as variation within a single species. With the 1989-1990 discovery of a large population (over 120 specimens) of *N. peedeensis* from the Mason Dixon pit, we now conclude that two species-level taxa are involved. The Berkeley Quarry specimens best conform with *N. collierensis* (Mansfield), but the Mason Dixon and Charleston specimens better conform with the holotype of *N. peedensis*. A detailed morphological study is in progress.

NODIPECTEN COLLIERENSIS (Mansfield)
Plate 1, figures 1, 3

Pecten (Nodipecten) pitteri collierensis MANSFIELD, 1932, U.S. Geol. Survey, Prof. Paper 170-D, p. 47, pl. 16, figs. 3, 5.

Nodipecten peedeensis (Tuomey and Holmes). M. CAMPBELL, 1988, South Carolina Acad.

Sci. Bull., v. 50, p. 35; M. CAMPBELL, 1988, Amer. Malacol. Union, Program and Abstracts, p. 39.

Nodipecten collierensis (Mansfield). SMITH, 1991, U.S. Geol. Survey, Prof. Paper 1391, p. 90, pl. 8, figs. 5-6, pl. 9, figs. 3-4, pl. 10, figs. 1-6, pl. 11, fig. 1.

Description: Shell medium to large, subcircular, slightly compressed; ribs low, nodes typically low, occasionally absent; upper valve with seven low, narrow ribs alternating in strength; lower valve with eight subequal ribs. Secondary sculpture of fine radial threads.

Occurrence: Pliocene. Carolinas – lower Goose Creek Limestone; Florida – Tamiami Limestone, lower Pinecrest.

Type locality: About 11 miles northeast of Marco, Collier County, Florida.

Discussion: Nodipecten collierensis differs from *N. peedeensis* in its smaller size, lower inflation, and less vigorous sculpture. Shelving at resting stages is weak or absent. The large population from the Berkeley Quarry is remarkably uniform in morphology, varying principally in degree of node development.

SPONDYLUS species
Plate 1, figure 8

Spondylus sp. TUOMEY and HOLMES, 1855, Pleiocene Foss. South Carolina, p. 24.

Spondylus bostrychites Sowerby. OLSSON and PETIT, 1964, Bulls. Amer. Paleontology, v. 47, no. 217, p. 515, not of Sowerby, 1850.

Description: Shell large, oval, well inflated, reaching 175 mm; larger shells becoming thick and massive. Spines irregular, low and irregular in some specimens; when well developed, with rows of well developed large, flat spines alternating with zones of much smaller, needle-like spines.

Occurrence: Pliocene. South Carolina – lower and upper Goose Creek Limestone, Raysor (on contact with lithified lower Goose Creek Limestone): Florida – Tamiami Limestone and Pinecrest beds.

Type locality: Undescribed.

Discussion: Conrad (1873) described "*Pecten anisopleura*" from "40 miles south of Beaufort, N. C." (which is off the present coast). This unique specimen is figured here for the first time (plate 4, figure 1). It is a fossil *Spondylus,* quite different from the *Spondylus* in the Goose Creek Limestone. Rather, *Spondylus anisopleura* seems conspecific with the Eocene species, *Spondylus lamellacea,* later described by Kellum (1926). "40 miles south of Beaufort, N. C." might refer to the Wilmington, North Carolina, area where *Spondylus lamellacea* is common in the Castle Hayne Limestone. Regrettably, the unique holotype of *Pecten anisopleura* was lost while being returned to the Academy of Natural Sciences by registered mail. Because of the doubt concerning the affinities of *S. anisopleura,* its decrepit condition, and its postal demise, we suggest that the species concept be restricted to the holotype (plate 4, figure 1).

Tuomey (1848) and Tuomey and Holmes (1855) documented but did not figure a species of *Spondylus* from fragments in limestone at Goose Creek. In the Charleston Museum, there is a very spiny specimen (plate 4, figure 2) of a Goose Creek species, with a note saying that Mazyck intended to describe the species as "*Spondylus holmesi.*" However, that name was not cited in the catalog of Mazyck's published species (Clench, 1967, p. 43). Stanley (personal communication, 1990) has suggested that the Mazyck specimen probably is referable to *Spondylus rotundatus* Dall. It becomes the first record of that species from the Goose Creek Limestone and the first record of the species north of Florida.

More recently, excavations at the APAC pit, Sarasota, Florida, have uncovered a number of specimens of an undescribed species that have been referred to *Spondylus bostrychites* Sowerby, 1850 (Olsson and Petit, 1964, p. 515), a species apparently restricted to the Caribbean. The new Florida species matches the common Goose Creek morphology from South Carolina. Several large fragments and rare complete single valves of this new species have been found at the Berkeley Quarry near Cross, at the G.& C. pit west of Conway, and near Charleston, South Carolina. As Stanley is describing the species from better Floridian material, the Goose Creek material will remain unnamed for the present.

PLACUNANOMIA PLICATA Tuomey and Holmes
Plate 2, figure 2

Placunanomia plicata TUOMEY and HOLMES, 1855, Pleiocene Foss. South Carolina, p. 19, pl. 6, figs. 4-6.

Description: Shell of moderate size, thin, smooth, calcitic, trigonal; margin highly plicate;

hinge structure of large cardinal crurae in right valve, corresponding socket in left valve.

Occurrence: Pliocene. Virginia – Yorktown, middle Zone 2; Carolinas – lower and upper Goose Creek Limestone, Raysor, Duplin; Florida – Tamiami Limestone, Pinecrest, Jackson Bluff.

Type locality: Smith's, Goose Creek, Charleston, South Carolina, basal beds.

Discussion: Placunanomia plicata is variable in the number and extent of the plications. Typical *Placunanomia plicata* with thin shells and well developed marginal folds are found in both the lower and upper zones of the Goose Creek Limestone, and in the Raysor Marl. In younger Duplin beds rare specimens are thicker-shelled and have smaller and more numerous marginal undulations. Insufficient material is available for determining systematic status of the latter morphology.

PLACUNANOMIA BURNSI (Mansfield)
Plate 2, figure 1

Pododesmus burnsi MANSFIELD, 1939, Florida Geol. Survey, Bull. 18, p. 55, pl. 4, figs. 1, 3, 5, 6.

Placunanomia pinella GARDNER, 1945, Nautilus, v. 59, p. 39, pl. 4, figs. 1, 2, 5, 6.

Placunanomia (Tamianomia) burnsi (Mansfield). OLSSON, 1967, Some Tertiary Mollusks from South Florida and the Caribbean, p. 9, pl. 1, figs. 4-4b.

Description: Shell of moderate size, irregularly oval; margin even or fluted; sculpture of radial threads; hinge structure of large cardinal crurae in right valve, corresponding socket in left valve.

Occurrence: Pliocene. South Carolina, lower Goose Creek Limestone; Florida – Tamiami Limestone.

Type locality: Station 3300, Shell Creek, Florida.

Discussion: The radial threads are diagnostic. *Placunanomia burnsi* is an index species for the Tamiami Formation in southern Florida (Olsson, 1967). This is the first record of the species north of Florida.

HYOTISSA HAITENSIS (Sowerby)
Plate 2, figure 3

Ostrea haitensis SOWERBY, G. B., I., 1850, Quart. Jour. Geol. Soc. London, v. 6, p. 53.

Ostrea meridionalis HEILPRIN, 1886, Trans. Wagner Free Inst. Sci., p. 100, pl. 14, figs. 35, 35a.

Ostrea tamiamiensis MANSFIELD, 1932, U.S. Geol. Survey, Prof. Paper 170-D, p. 46, pl. 14, figs. 1, 3.

Ostrea tamiamiensis monroensis MANSFIELD, 1932, U.S. Geol. Survey, Prof. Paper 170-D, p. 46, pl. 15, figs. 1-4.

Hyotissa haitensis (Sowerby). WILSON, 1987, Smithsonian Contrib. Paleobiology, no. 61, p. 16.

Description: Shell large, broadly trigonal, variably plicate; shell structure microscopically vesicular; hinge flanked by vermiform corrugations. Spines prominant, weakly developed, or absent.

Occurrence: Miocene. Florida – Chipola. Pliocene. Carolinas – lower and upper Goose Creek Limestone, Cape Fear River, North Carolina, Conway, and the Berkeley Quarry; Florida – Tamiami Limestone, Pinecrest.

Type locality: "Haiti" [unknown Dominican Republic locality].

Discussion: South Carolina specimens of *Hyotissa haitensis* are predominantly the spineless morphology.

MALEA species cf. MALEA DENSECOSTATA (Rutsch)
Plate 4, figures 5, 6

Dolium galea Linnaeus. TUOMEY and HOLMES, 1856, Pleiocene Foss. South Carolina, p. 139, in part, not pl. 28, fig. 11.

Tonna (Malea) ringens densecostata RUTSCH, 1934, Abhl. Schweiz. Paleontol. Gesell., v. 54, p. 60, pl. 111, figs. 6, 7.

Malea densecostata (Rutsch). OLSSON and PETIT, 1964, Bulls. Amer. Paleontology, v. 47, no. 217, p. 554, pl. 79, figs. 5, 5a.

Malea sp. unnamed moldic species. PETUCH, 1989, Nautilus, v. 103, p. 92.

Description: Shell large, well inflated; spire high, whorls convex; sculpture of numerous strong spiral ribs, number uncertain on the mold. Aperture distorted, typical of the genus.

Occurrence: Pliocene. Carolinas – upper Goose Creek Limestone; Florida – Tamiami Limestone, lower Pinecrest.

Type locality: Punta Gavilan, Venezuela.

Discussion: The Charleston Museum collections contain a mold of *Malea* species, probably *Malea densecostata,* from Fetteressa, a Charleston locality near the Seaboard Coast line (Weems *et al.*, 1982, p. H142). The USC Spartanburg collections contain a small population of internal molds from the Mason Dixon pit. This species probably is the *"Dolium galea"* of Tuomey and Holmes, 1856, but their illustration is not that of a tun shell. Campbell and Campbell (1977, p. 113) suggested that Tuomey and Holmes' figure represents an internal mold of a *Busycon*. With the large collection of Goose Creek molds now in hand, the Tuomey and Holmes figure best matches a broken specimen of *Ficus*.

Petuch (1989) stated that the Tamiami moldic *Malea* is a new species distinct from *M. densecostata*, but neither described nor figured the form. The South Carolina specimens are compatible with the *M. densecostata* morphologies to the extent determinable by internal molds. Discovery of an external mold will be necessary to completely resolve the question.

ECPHORA QUADRICOSTATA (Say)
Plate 2, figure 6

Fusus 4-costata SAY, 1824, Jour. Acad. Nat. Sci. Phila., v. 4, p. 127, pl. 7, fig. 5.
Colus quadricostatus (Say). TUOMEY and HOLMES, 1857, Pleiocene Foss. South Carolina, p. 149.
Fusus umbilicatus "Wagner." DALL, 1898, Trans. Wagner Free Inst. Sci., v. 5, p. 9, pl. 2, fig. 2.
Ecphora parvicostatus PILSBRY, 1911, Proc. Acad. Nat. Sci. Phila., v. 63, p. 438, fig. 1.
Ecphora striatula PETUCH, 1986, Jour. Coastal Research, v. 2, p. 406, pl. 3, figs. 15, 16.
Ecphora quadricostata (Say). WILSON, 1987, Smithsonian Contrib. Paleobiology no. 61, p. 21; WARD and GILINSKY, 1988, Notulae Naturae, no. 469, p. 11, pl. 5, figs. 1-4 (extensive discussion and synonymy).
Ecphora hertweckorum PETUCH, 1987, Nautilus, v. 101, p. 204, figs. 14, 15.
Ecphora violetae PETUCH, 1988, Bull. Paleomalacology. v. 1, p. 35, pl. 1, figs. 1-3, 6.
Ecphora floridana PETUCH, 1988, Field Guide to the Ecphoras, p. 67, fig. 30.
Ecphora quadricostata rachelae PETUCH, 1988, Field Guide to the Ecphoras, p. 69, fig. 33.
Ecphora mansfieldi PETUCH, 1988, Field Guide to the Ecphoras, p. 129, pl. A1, figs. A, E.
Ecphora quadricostata leecreekensis PETUCH, 1988, Field Guide to the Ecphoras, p. 131, pl. A2, fig. E.
Ecphora pachycostata PETUCH, 1988, Field Guide to the Ecphoras, p. 130, pl. A1, fig. D.

Description: Shell large, calcitic, well inflated; umbilicus flaring; aperture large, circular; ribs four, spiral, rib-crests narrow or slightly expanded; secondary sculpture of spiral threads weak or absent.

Occurrence: Pliocene. Virginia – Yorktown, zones 1 and 2; Carolinas – Yorktown, zones 1 and 2, lower and upper Goose Creek Limestone, Raysor, Duplin (rare); Florida – Tamiami Limestone, lower Pinecrest, Jackson Bluff (*Ecphora* zone).

Type locality: "Maryland" [unknown Virginia locality].

Discussion: Ecphora quadricostata recently has been given several names (Petuch, 1988), that seem to be, at best, varieties. Although found in beds of lower and mid-Pliocene age from Virginia to Florida, *E. quadricostata* is common from South Carolina to Florida only in the lower Goose Creek Limestone, the Raysor Marl and the *Ecphora* zone of northwestern and southern Florida.

ECPHORA BRADLEYAE Petuch
Plate 5, figure 7

Ecphora bradleyae PETUCH, 1987, Nautilus, v. 101, p. 204, figs. 1-6.

Description: Shell large, calcitic, well inflated; umbilicus flaring; aperture large, circular; ribs four, spiral, rib-crests wide, strap-like, touching or nearly touching adjacent crest; interspaces narrow, uniform in sub-adult specimens, central interspace becoming proportionally wider in large adults.

Occurrence: Pliocene. Carolinas – upper Goose Creek Limestone, Raysor; Florida – lower and middle Pinecrest.

Type locality: APAC pit, Sarasota, Florida.

Discussion: Ecphora bradleyae is the only species of *Ecphora* found in the upper Goose Creek Limestone at the Mason Dixon pit, but it co-occurs with *Ecphora quadricostata* as a rare element in Raysor assemblages at the Martin Marietta Berkeley Quarry, at Lynchburg, South Carolina, and at Tar Heel, North Carolina (Carter *et al.*, 1988). *Ecphora bradleyae* seems to be a short-lived species useful for correlation.

ENCOPE MACROPHORA (Ravenel)
Plate 2, figure 4; Plate 4, figure 3

Scutella macrophora RAVENEL, 1844, Proc. Acad. Nat. Sci. Phila., v. 2, p. 334.
Encope macrophora (Ravenel). TUOMEY and HOLMES, 1855, Pleiocene Foss. South Carolina, p. 3, pl. 1, fig. 3.
Macrophora macrophora CONRAD, 1865, Proc. Acad. Nat. Sci. Phila. v. 17, p. 74.
Macrophora raveneli CONRAD, 1865, Proc. Acad. Nat. Sci. Phila. v. 17, p. 74.
Encope macrophora tamiamiensis MANSFIELD, 1932, U.S. Geol. Survey, Prof. Paper 170-D, p. 48, pl. 17, fig. 8.
Encope tamiamiensis Mansfield. COOKE, 1959, U.S. Geol. Survey, Prof. Paper 321, p. 48, pl. 17, figs. 3, 4; KIER, 1963, Smithsonian Misc.

Coll., v. 145, no. 5, p. 36, pl. 14, figs. 1-6.

Description: Disk small to rather large (Goose Creek specimens average 30-35 mm), oval, truncate posteriorly; outline typical of the genus (arrowhead sand dollars). Lunule circular to oval. Margin rounded, may become thickened in large specimens. Relative proportions highly variable.

Occurrence: Pliocene. Virginia – Yorktown, middle Zone 2; South Carolina – lower Goose Creek Limestone (common), upper Goose Creek Limestone (rare), Raysor (rare); Florida – Tamiami Limestone, lower Jackson Bluff.

Type locality: The Grove Plantation, Charleston, South Carolina.

Discussion: Encope macrophora is common to abundant in the Tamiami Limestone of southern Florida, where it has been called *Encope tamiamiensis* Mansfield, 1931 (D. Campbell, 1987). Cooke (1936) considered *Encope macrophora tamiamiensis* to be an index fossil for the Tamiami Limestone, which he incorrectly interpreted as a member of the Caloosahatchee Formation. Consequently, *E. macrophora* was an important part of the evidence for assigning a Caloosahatchee and, therefore, Waccamaw-equivalent age to the Goose Creek Limestone. Both Cooke (1959) and Kier (1963) believed Mansfield's taxon to be distinct, but cited different criteria. The much larger population of *Encope macrophora* from the Berkeley Quarry shows a range of variation fully compatible with *E. tamiamiensis* (D. Campbell, 1987).

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X. APPENDIX I: LOCATION, STATISTICAL AND INDEX SPECIES BIOSTRATIGRAPHY, AND STRATIGRAPHIC ASSIGNMENT OF GOOSE CREEK LIMESTONE LOCALITIES

BIOSTRATIGRAPHIC UNITS

R = ALSO RECENT; UW = UPPER WACCAMAW; LW = LOWER WACCAMAW; D = NATURAL WELL DUPLIN; RA = RAYSOR; UGC = UPPER GOOSE CREEK; LGC = LOWER GOOSE CREEK; M = ALSO MIOCENE; N = NUMBER OF TAXA IN FAUNULE; K- = TRANSGRESSIVE ONLAP UNIT FROM FIGURE 1.

LOCALITIES

1. NEAR GILES'S BLUFF (Tuomey, 1848)

"Giles's Bluff (on the Pee Dee River, Marion County) on the land of Henry Davis, Esq." and "some distance from the river" (Tuomey, 1848, p. 175). Recent efforts to locate Giles's Bluff have been unsuccessful, but Tuomey (1848, p. 136) sketches Cretaceous section along the Pee Dee River, which if drawn to scale places the site about halfway between Britton's Ferry and Birch's Ferry.

		R	UW	LW	D	RA	UGC	LGC	M
% TOTAL	N = 18	38.9	50.0	38.9	72.2	72.2	88.9	72.2	11.1
DICE TOTAL		.050	.051	.033	.055	.115	.163	.190	.032

INDEX SPECIES: *Nodipecten peedeensis, Chesapecten septenarius, Ecphora quadricostata*

STRATIGRAPHIC ASSIGNMENT: upper Goose Creek Limestone (K-5).

2. GOOSE CREEK (Tuomey, 1848) (Stratotype locality)

"Bluff along Goose Creek, 0.3 km east of the Seaboard Coastline railroad bridge over Goose Creek in the North Charleston 7 1/2 min. quadrangle." (Weems *et al.*, 1982, p. H137.)

		R	UW	LW	D	RA	UGC	LGC	M
% TOTAL	N = 14	14.3	50.0	50.0	85.7	71.4	100	72.2	11.1
DICE TOTAL		.014	.040	.033	.051	.090	.146	.180	.049

INDEX SPECIES: *Encope macrophora, Pecten hemicyclicus*

STRATIGRAPHIC ASSIGNMENT: lower Goose Creek, based on common *Encope*, (K-3).

3. GOOSE CREEK (Tuomey and Holmes, 1855-1857)
(same as locality 2)

		R	UW	LW	D	RA	UGC	LGC	M
% TOTAL	N = 12	33.3	50.0	41.7	83.3	58.3	83.3	83.3	33.3
DICE TOTAL		.029	.034	.024	.043	.063	.105	.153	.067

INDEX SPECIES: *Encope macrophora, Glycymeris abberans**
STRATIGRAPHIC ASSIGNMENT: lower Goose Creek Limestone (K-3).

*Type locality for *Pectunculus transversus* Tuomey and Holmes, which was renamed *Glycymeris abberans* Nicol, 1953.

4. GOOSE CREEK (Weems *et al.*, 1982)
(same as locality 2)

		R	UW	LW	D	RA	UGC	LGC	M
% TOTAL	N = 4	00.0	75.0	75.0	75.0	75.0	100	100	25.0
DICE TOTAL		.000	.018	.015	.013	.028	.044	.065	.018

INDEX SPECIES: *Pecten hemicyclicus*
STRATIGRAPHIC ASSIGNMENT: lower Goose Creek Limestone, (K-3).

Encope macrophora and *Pecten hemicyclicus* are common only in the lower Goose Creek Limestone, rare and very local in the upper unit.

5. THE GROVE (Tuomey, 1848)
"Cooper River.– .. The Grove, residence of Dr. Edmund Ravenel." (Tuomey and Holmes, 1855, p. xi). Berkeley County "east of Cooper River and 5 miles northwest of Wando" (C. W. Cooke, 1936, p. 129).

		R	UW	LW	D	RA	UGC	LGC	M
% TOTAL	N = 6	16.7	67.8	67.8	83.3	83.3	100	83.3	50.0
DICE TOTAL		.007	.023	.019	.026	.047	.065	.080	.053

INDEX SPECIES: *Encope macrophora, Pecten hemicyclicus*
STRATIGRAPHIC ASSIGNMENT: lower Goose Creek, based on common *Encope* (K-3).

6. THE GROVE (Tuomey and Holmes, 1855-1857)
(see locality # 5)

		R	UW	LW	D	RA	UGC	LGC	M
% TOTAL	N = 6	16.7	67.8	67.8	83.3	83.3	100	83.3	50.0
DICE TOTAL		.007	.023	.019	.022	.047	.065	.080	.035

STRATIGRAPHIC ASSIGNMENT: Goose Creek Limestone (K-3 to 5).

7. SMITH'S GOOSE CREEK (Tuomey and Holmes, 1855-1857). Aragonite shell.
"Goose Creek.-- The plantation of the late Geo. Henry Smith, Esq." (Tuomey and Holmes, 1855, p. xi). Note: this site has been equated by Cooke (1936) with Yeaman Hall (see locality #24).

		R	UW	LW	D	RA	LGC	UGC	M
% TOTAL	N = 25	52.0	72.0	76.0	44.0	24.0	36.0	24.0	12.0
DICE TOTAL		.090	.100	.088	.046	.051	.089	.083	.045

INDEX SPECIES: *Pecten holmesi*
STRATIGRAPHIC ASSIGNMENT: lower Cypresshead Formation (lower Waccamaw equivalent) (K-17).

8. RAYSOR BRIDGE (Ward & Huddlestun, 1988)
Exact location uncertain, as Sloan gave disparate directions, see Huddlestun (1988) for details. According to Pooser (1965, p. 72), north bank of Edisto River, 7.8 miles S. 4 degrees W. from St. George, or 4.1 miles S. 84 degrees W. from Grover.

		R	UW	LW	D	RA	UGC	LGC	M
% TOTAL	N = 47	17.0	42.5	46.8	70.2	80.8	70.2	51.1	55.3
DICE TOTAL		.051	.104	.097	.132	.297	.293	.298	.335

INDEX SPECIES: *Leptopecten leonensis*, *Chesapecten jeffersonius*, *Chesapecten madisonius carolinensis*, elongate *Astarte*

STRATIGRAPHIC ASSIGNMENT: mixed Raysor (K-5) and lower Goose Creek Limestone (K-3), Raysor (aragonite preserved element) predominates.

9. CROSS (Ward & Huddlestun, 1988)
Berkeley County near Cross, SC, on the east side of County Road 59, about two miles south of State Highway Rt. 6, Chicora 7.5 minute quadrangle. From Santee, South Carolina, follow Rt. 6 east to Eutawville,and Eutaw Springs. Approximately 3 3/4 miles east of Eutaw Springs, turn south on State Route S-59. The Berkeley Quarry is approximately 2 miles south on the east side of the highway. It is obvious from the road. The quarry contains Eocene Santee Limestone, which is mined for road metal, overlain by Pliocene Raysor sands and lower Goose Creek Limestone. Active quarrying regularly expose and destroy new fossiliferous sections. Permission must be obtained at the office.

		R	UW	LW	D	RA	UGC	LGC	M
% TOTAL	N = 28	21.4	53.6	57.1	75.0	89.3	78.6	60.7	50.0
DICE TOTAL		.041	.082	.074	.087	.211	.214	.231	.206

INDEX SPECIES: *Chesapecten septenarius*

STRATIGRAPHIC ASSIGNMENT: Raysor (K-5).

10. ORANGEBURG dug pond, Pooser, 1965; Colquhoun, 1965; L. Campbell, manuscript
Orangeburg County, east of the city of Orangeburg, 400 yards from Rt. S-38-65, 4.4 miles east of the intersection of S.C. 33 and S-38-65. (Colquhoun, 1965, stop Nine, p. 45).

		R	UW	LW	D	RA	UGC	LGC	M
% TOTAL	N = 2	00.0	00.0	00.0	50.0	100	100	100	00.0
DICE TOTAL		.000	.000	.000	.004	.019	.022	.033	.000

INDEX SPECIES: *Chesapecten septenarius*

STRATIGRAPHIC ASSIGNMENT: Raysor (K-5)

11. TEARCOAT BRANCH (Ward and Huddlestun, 1988)
0.6 miles southwest of intersection of Highway 255 with County Rt. 58, 3. south of intersection of Rt. 58 and Rt. 378, about 4 miles east of the interse of Rt. 378 and the Sumter bypass. Site effectively obliterated by Hurrica Hugo.

		R	UW	LW	D	RA	UGC	LGC	M
% TOTAL	N = 24	20.8	50.0	58.3	100	95.8	75.0	62.5	66.7
DICE TOTAL		.035	.067	.065	.101	.197	.178	.210	.242

STRATIGRAPHIC ASSIGNMENT: Duplin (K-11).

Note the high Raysor correlation, which is a function of the small and selective data set.

12. TEARCOAT BRANCH S. Campbell, 1974; and manuscript in progress.
(see locality # 11)

		R	UW	LW	D	RA	UGC	LGC	M
% TOTAL	N = 336	21.4	38.4	39.9	100	47.6	38.4	25.6	19.6
DICE TOTAL		.240	.384	.361	.847	.587	.502	.378	.297

INDEX SPECIES: *Melanella magnoliana, Coralliophila leonensis, Phos sloani*
STRATIGRAPHIC ASSIGNMENT: Duplin (K-11).

13. MARK CLARK EXPRESSWAY (Charleston Museum collections)
Charleston County, South Carolina; borrow pit for Mark Clark Expressway, east of SC Rt. 61 between Bull Creek and Ashley Hall Plantation Road; 32 degrees 48.8 minutes North, 80 degrees 1.6 minutes West, John's Island 7.5' quadrangle.

		R	UW	LW	D	RA	UGC	LGC	M
% TOTAL	N = 14	7.1	35.7	57.1	50.0	57.1	100	71.4	14.3
DICE TOTAL		.007	.029	.038	.030	.072	146	.150	.033

INDEX SPECIES: *Pecten brouweri, Pecten hemicyclicus, Chesapecten septenarius, Nodipecten peedeensis*
STRATIGRAPHIC ASSIGNMENT: upper Goose Creek Limestone

14. NEAR FETTERESSA (Charleston Museum collections)
Seaboard Railroad Ditch, Charleston County, South Carolina; north ditch along Seaboard Coast Line Railroad south of Dorsey Ave., about 1.45 km west of Dorchester Road overpass (SC Rt. 642); 32 degrees 51.2 minutes North, 80 degrees 2.5 minutes West, John's Island 7.5' quadrangle.

		R	UW	LW	D	RA	UGC	LGC	M
% TOTAL	N = 10	10.0	50.0	60.0	70.0	80.0	100	70.0	20.0
DICE TOTAL		.007	.029	.029	.030	.073	.106	.109	.034

INDEX SPECIES: *Encope macrophora, Chesapecten septenarius, Nodipecten peedeensis, Malea densecostata*
STRATIGRAPHIC ASSIGNMENT: upper Goose Creek Limestone

15. LOMAX-KING PIT (Florida State Museum, new this study)
Lomax-King pit, Charlotte County, Florida, Punta Gorda 7.5 minute quadrangle, southeast quarter.

		R	UW	LW	D	RA	UGC	LGC	M
% TOTAL	N = 9	00.0	22.2	33.3	44.4	55.6	88.9	77.8	33.3
DICE TOTAL		.000	.012	.014	.017	.046	.086	.109	.051

INDEX SPECIES: *Encope macrophora, Leptopecten leonensis, Chesapecten septenarius*
STRATIGRAPHIC ASSIGNMENT: Tamiami Limestone

16. CROSS Howe, 1987, and Converse College Collections
(see locality # 9)

		R	UW	LW	D	RA	UGC	LGC	M
% TOTAL	N = 48	18.7	41.7	41.7	81.2	91.6	70.8	66.7	37.5
DICE TOTAL		.058	.104	.088	.156	.342	.301	.383	.231

INDEX SPECIES: *Encope macrophora, Pecten hemicyclicus, Chesapecten septenarius*
STRATIGRAPHIC ASSIGNMENT: mixed Raysor and lower Goose Creek

17. PINECREST BEDS, SARASOTA Petuch, 1982; Hunter, 1971
Macasphalt Co. Newburn Pit Mine, northeast of Sarasota, Florida. Bed 11.

		R	UW	LW	D	RA	UGC	LGC	M
% TOTAL	N = 23	8.7	21.7	26.1	43.5	60.9	52.2	65.2	21.7
DICE TOTAL		.014	.028	.028	.042	.121	.119	.211	.076

INDEX SPECIES: *Encope macrophora*, *Chesapecten septenarius*
STRATIGRAPHIC ASSIGNMENT: Tamiami Limestone

18. GOOSE CREEK C. W. Cooke, 1936
"Bluff on S. E. bank of Goose Creek, 1/3 mile east of S. A. L. and 3/4 mile S. E Melgrove, Berkeley Co. S. Car." (Cooke locality label).

		R	UW	LW	D	RA	UGC	LGC	M
% TOTAL	N = 6	00.0	50.0	50.0	83.3	66.7	100	66.7	16.[illegible]
DICE TOTAL		.000	.018	.015	.022	.037	.065	.064	.018

INDEX SPECIES: *Encope macrophora*, *Pecten hemicyclicus*
STRATIGRAPHIC ASSIGNMENT: Goose Creek Limestone, data insufficient for more precise assignment.

19. PEEDEE RIVER Tuomey and Holmes, 1855-1857; specific sites unknown.

		R	UW	LW	D	RA	UGC	LGC	M
% TOTAL	N = 50	26.0	46.0	40.0	90.0	58.0	78.0	44.0	26.0
DICE TOTAL		.083	.119	.088	.179	.224	.342	.260	.165

STRATIGRAPHIC ASSIGNMENT: equivocal, percentage favors Duplin, DICE favors Raysor, but the commonality with the Goose Creek Limestone and the Miocene rather strongly favor Raysor.

20. CROSS Campbell *et al.*, 1975
(see locality # 9)

		R	UW	LW	D	RA	UGC	LGC	M
% TOTAL	N = 15	26.7	20.0	20.0	53.3	73.3	33.3	40.0	13.3
DICE TOTAL		.029	.017	.014	.034	.098	.052	.090	.033

INDEX SPECIES: *Pecten hemicyclicus*
STRATIGRAPHIC ASSIGNMENT: Raysor (K-5).

21. GODFREY FERRY BRIDGE, PEE DEE RIVER, Malde, 1959
"South side of Pee Dee River at excavation for new bridge abutment on U. S. Highway 378, 7-8 feet above river level" (Malde, 1959, p. 32).

		R	UW	LW	D	RA	UGC	LGC	M
% TOTAL	N = 23	21.7	52.2	47.8	82.6	69.6	95.6	82.6	[illegible]
DICE TOTAL		.035	.067	.051	.080	.138	.219	.268	[illegible]

INDEX SPECIES: *Pecten hemicyclicus*
STRATIGRAPHIC ASSIGNMENT: upper Goose Creek Limestone.

22. DAVIS LANDING, PEE DEE RIVER, Malde, 1959
"Davis Landing, highest rock exposed, 12-15 feet above base of Duplin" (Malde locality label).

		R	UW	LW	D	RA	UGC	LGC	M
% TOTAL	N = 16	12.5	43.7	43.7	75.0	81.2	87.5	75.0	18.7
DICE TOTAL		.014	.040	.033	.051	.116	.144	.178	.048

INDEX SPECIES: *Ecphora bradleyae*
STRATIGRAPHIC ASSIGNMENT: upper Goose Creek Limestone.

23. GIVHANS FERRY, EDISTO RIVER, Malde, 1959
"Givhans Ferry State Park, East bank, Edisto River, 20 feet above stream, ca 500 feet upstream from park bldg. C. Wythe Cooke locality 170" (Malde locality label).

		R	UW	LW	D	RA	UGC	LGC	M
% TOTAL	N = 21	19.0	52.4	57.1	95.2	76.2	85.7	95.2	28.6
DICE TOTAL		.028	.062	.056	.089	.139	.181	.286	.093

INDEX SPECIES *Pecten hemicyclicus*
STRATIGRAPHIC ASSIGNMENT: lower Goose Creek Limestone.

24. 0.4 MILES SOUTH OF YEAMANS HALL, Malde, 1959
"Pridgen borrow pit 2000 ft. south of Yeaman Hall gate (Melgrove quad.) from spoil dredged from bottom of pit, midpoint south side of ponded water" (Malde locality label).

		R	UW	LW	D	RA	UGC	LGC	M
% TOTAL	N = 34	11.8	47.0	44.1	85.3	55.9	82.4	82.4	23.5
DICE TOTAL		.027	.086	.068	.119	.156	.264	.366	.113

INDEX SPECIES: *Pecten hemicyclicus, Carolinapecten eboreus walkerensis*
STRATIGRAPHIC ASSIGNMENT: somewhat equivocal, assigned to upper Goose Creek Limestone based on *C. e. walkerensis.*

25. McDOWELL TUNNEL Malde, 1959
"Inlet shaft on Foster Creek" (Malde, 1959, p. 32).

		R	UW	LW	D	RA	UGC	LGC	M
% TOTAL	N = 3	00.0	66.7	66.7	100	100	100	33.3	00.0
DICE TOTAL		.000	.012	.010	.013	.028	.033	.016	.000

STRATIGRAPHIC ASSIGNMENT: probably upper Goose Creek Limestone, but data insufficient for any certain assignment.

26. McDOWELL TUNNEL (Shaft 1), Malde, 1959
Further detail not specified.

		R	UW	LW	D	RA	UGC	LGC	M
% TOTAL	N = 25	12.0	48.0	48.0	80.0	84.0	80.0	92.0	28.0
DICE TOTAL		.021	.066	.056	.084	.179	.197	.319	.105

INDEX SPECIES: *Pecten hemicyclicus*
STRATIGRAPHIC ASSIGNMENT: lower Goose Creek Limestone (K-3).

27. CROSS, *Encope* level, new, USCS collections
(see locality # 9)

		R	UW	LW	D	RA	UGC	LGC	M
% TOTAL	N = 100	23.0	35.0	39.0	75.0	69.0	82.0	92.0	30.0
DICE TOTAL		.126	.161	.154	.271	.447	.590	.840	.288

INDEX SPECIES: *Encope macrophora, Pecten hemicyclicus, Leptopecten leonensis, Chesapecten madisonius carolinensis, Chesapecten septenarius, Nodipecten collierensis*
STRATIGRAPHIC ASSIGNMENT: lower Goose Creek Limestone (K-3).

28. CROSS, *Mercenaria* level, new, USCS collections
(see locality # 9)

		R	UW	LW	D	RA	UGC	LGC	M
% TOTAL	N = 197	22.8	40.6	45.2	89.3	94.9	53.8	39.1	27.4
DICE TOTAL		.195	.300	.295	.542	.921	.565	.487	.354

INDEX SPECIES: *Glycymeris abberans, Chesapecten septenarius, Ecphora bradleyae, Terebraspira elegans, Mercenaria tridacnoides*
STRATIGRAPHIC ASSIGNMENT: Raysor (K-5).

29. SARASOTA, *Mercenaria* level, Petuch, 1982; Hunter, 1971
(see locality # 17), Bed 10.

		R	UW	LW	D	RA	UGC	LGC	M
% TOTAL	N = 39	30.7	33.3	48.7	71.8	69.2	74.3	64.1	23.1
DICE TOTAL		.079	.069	.085	.114	.218	.267	.316	.122

INDEX SPECIES: *Anadara propatula*
STRATIGRAPHIC ASSIGNMENT: lower Pinecrest beds (K-5).

30. SMITH'S, GOOSE CREEK, Tuomey and Holmes, 1855-1857, mold and calcitic shell, basal bed.
(see locality #7).

		R	UW	LW	D	RA	UGC	LGC	M
% TOTAL	N = 2	00.0	00.0	00.0	00.0	00.0	100	50.0	00.0
DICE TOTAL		.000	.000	.000	.000	.000	.022	.017	.000

INDEX SPECIES: *Malea densecostata*
STRATIGRAPHIC ASSIGNMENT: upper Goose Creek Limestone (K-5), based on index species.

31. LAKE WACCAMAW, NC, Olsson, 1914; Richards, 1950; DuBar, 1971
Columbus County, NC, north shore of Lake Waccamaw, from the Pumping Station eastward (Richards, 1950, p. 29).

		R	UW	LW	D	RA	UGC	LGC	M
% TOTAL	N = 5	20.0	80.0	80.0	80.0	80.0	100	60.0	40.0
DICE TOTAL		.007	.023	.019	.017	.037	.055	.048	.035

INDEX SPECIES: *Nodipecten peedeensis*
STRATIGRAPHIC ASSIGNMENT: upper Goose Creek Limestone (K-5), based on index species. Note: DuBar *et al.* (1974) placed this in their Bear Bluff Formation.

69. MASON DIXON PIT, CONWAY, SC, new, USCS collections (M. Campbell). Calcite and mold preservation only.
From Conway, South Carolina, follow Rt. 701 south. From the point at which 701 changes from four to two lanes, travel approximately 2 miles south. Site is visible on east side of the highway, but was inactive in 1991.

		R	UW	LW	D	RA	UGC	LGC	M
% TOTAL	N = 152	20.4	36.8	41.4	78.3	62.5	94.0	48.7	26.3
DICE TOTAL		.149	.230	.225	.393	.526	.867	.546	.308

INDEX SPECIES: *Glycymeris abberans, Pecten brouweri, Chesapecten madisonius carolinensis, Carolinapecten eboreus walkerensis, Nodipecten peedeensis, Ecphora bradleyae*
STRATIGRAPHIC ASSIGNMENT: upper Goose Creek Limestone (K-5).

103. G & C MINING CO., new, USCS collections (M. Campbell).
From Conway, South Carolina, follow Rt. 378 west approximately 5 miles to Cedar Grove Church. High spoil piles are visible from the highway. Turn north by company sign. Permission must be obtained at the office.

		R	UW	LW	D	RA	UGC	LGC	M
% TOTAL	N = 13	00.0	23.1	23.1	69.2	76.9	92.3	53.8	38.5
DICE TOTAL		.000	.017	.014	.039	.090	.126	.106	.083

INDEX SPECIES: *Pecten brouweri, Carolinapecten eboreus walkerensis, Nodipecten peedeensis*
STRATIGRAPHIC ASSIGNMENT: upper Goose Creek Limestone (K-5).

104. THOMPKINS MINING CO. new, USCS collections (M. Campbell).
From Conway, South Carolina, take Rt. 905 north approximately 3 miles from the city limits. Turn left at company sign. 18 meters of leached upper Goose Creek Limestone calcarenite are preserved, unconformably overlying the Cretaceous Pee Dee Limestone. Permission must be obtained at the office.

		R	UW	LW	D	RA	UGC	LGC	M
% TOTAL	N = 35	14.3	37.1	45.7	77.1	80.0	91.4	57.1	28.6
DICE TOTAL		.033	.070	.072	.111	.230	.300	.260	.140

INDEX SPECIES: *Pecten brouweri, Carolinapecten eboreus walkerensis*
STRATIGRAPHIC ASSIGNMENT: upper Goose Creek Limestone (K-5).

105. BEAR BLUFF STRATOTYPE new, USCS collections (M. Campbell).
This site can be successfully examined only by boat. From Conway, South Carolina, take Rt. 905 north to Hickory Grove. Turn east on State Rt. 105. Travel approximately 4 miles to the Waccamaw River. Park at the public boat landing beside the bridge. Launch boat and travel approximately 1 mile north. The stratotype is on the east bank just before a large bend in the river.

		R	UW	LW	D	RA	UGC	LGC	M
% TOTAL	N = 27	31.0	62.1	62.1	93.1	89.7	100	69.0	51.7
DICE TOTAL		.061	.099	.083	.112	.218	.280	.270	.219

INDEX SPECIES: *Carolinapecten eboreus walkerensis*
STRATIGRAPHIC ASSIGNMENT: upper Goose Creek Limestone (K-5).

134. WALKER'S BLUFF CALCARENITE Walker's Bluff, Cape Fear River, North Carolina (from literature).

		R	UW	LW	D	RA	UGC	LGC	M
% TOTAL	N = 5	40.0	40.0	40.0	20.0	20.0	60.0	20.0	20.0
DICE TOTAL		.015	.012	.010	.004	.009	.033	.016	.018

INDEX SPECIES: *Leptopecten leonensis, Carolinapecten eboreus walkerensis, Pecten brouweri*
STRATIGRAPHIC ASSIGNMENT: upper Goose Creek Limestone (K-5).

XI. APPENDIX II: CHECK LIST OF GOOSE CREEK MACROFOSSILS

Locality data is coded by number: detailed locality data and statistical analyses are shown in Appendix I. Systematics follow L. Campbell (1993).

BIVALVIA

Nucula proxima Say, 1822; latex cast
27, 69, 104, 105

Nuculana acuta (Conrad, 1832); latex cast
27, 69

Barbatia leonensis Mansfield, 1932; latex cast, internal mold
69

Striarca centenaria Say, 1824; latex cast
69

Anadara (Granoarca) propatula (Conrad, 1844); internal mold
26

Anadara lienosa (Say, 1832); internal and external molds, latex cast
26, 27, 69, 104

Anadara improcera (Conrad, 1845); internal and external molds, latex cast
23, 69, 105

Anadara improcera buccula (Conrad, 1845); latex cast
69

Noetia trigintinaria (Conrad, 1862); internal mold
27, 69

Noetia incile (Say, 1824); internal mold
22, 27

Quadrilateria adamsi (Dall, 1886); latex cast
69

Glycymeris americana abberans Nicol, 1952; internal and external molds, latex cast
3, 69

Glycymeris americana americana (Defrance, 1826); internal and external molds
27, 69, 104, 105

Glycymeris americana quinquerugata (Conrad, 1841); internal and external molds
26, 27, 69

Glycymeris duplinensis Dall, 1898; latex cast
69

Glycymeris subovata (Say, 1824); internal mold
27, 69, 103, 104, 105

Modiolus gigas (Dall, 1898); internal and external molds
1, 19, 24, 27, 69

Lithophaga sp.; external mold and burrow linings
27

Atrina harrisi Dall, 1898; internal and external mold
69, 104

Pteria colymbus (Röding, 1798); calcitic shell
27, 69

Pecten brouweri Tucker, 1934; calcitic shell
13, 69, 103, 104

Pecten sp. cf. *Pecten biformis* Conrad, 1843; calcitic shell
27 (reworked Oligocene species)

Pecten hemicyclicus Ravenel, 1834; calcitic sl
2, 4, 6, 13, 18, 20, 21, 24, 26, 27

Leptopecten leonensis (Mansfield, 1932); ca shell
27, 134

Amusium mortoni (Ravenel, 1844); calcitic sh
1, 2, 4, 5, 6, 13, 14, 18, 20, 22, 24, 25, 26, 27, 104

Carolinapecten eboreus eboreus (Conrad, 18 calcitic shell
5, 6, 21, 22, 23, 24, 25, 26, 27

Carolinapecten eboreus walkerensis (Tucke 1934); calcitic shell
24, 69, 103, 104, 105

Argopecten comparilis (Tuomey and Holmes 1855); calcitic shell
13, 24, 27, 69

Argopecten anteamplicostatus (Mansfield, 1936 calcitic shell
69, 104

Chesapecten jeffersonius (Say, 1824); calciti shell
8, bed of Savannah River

Chesapecten madisonius (Say, 1824) spp.; calc tic shell
27, 69

Chesapecten septenarius (Say, 1824); calciti shell
1, 13, 14, 27, 103

Nodipecten collierensis (Mansfield, 1931); calci tic shell
27

Nodipecten peedeensis (Tuomey and Holmes 1855); calcitic shell
1, 13, 14, 31, 69, 103

Chlamys decemnarius (Conrad, 1834); calciti shell
27

Plicatula marginata Say, 1824; calcitic shell
13, 18, 21, 24, 26, 27, 69, 104

Spondylus sp.; calcitic shell
2, 3, 13, 27, 103

Spondylus rotundatus Heilprin, 1886; calc shell
Charleston, Mazyck collection

Anomia simplex Orbigny, 1842; calcitic shell
27, 69

Placunanomia burnsi (Mansfield, 1939); calcitic shell
27

Placunanomia plicata Tuomey and Holme 1856; calcitic shell
13, 27, 30, 69

Limaria pellucida (C.B. Adams, 1846); calciti shell
24, 69

Limaria carolinensis (Dall, 1898); calcitic shell
24, 27, 69
Ostrea compressirostra Say, 1824; calcitic shell
2, 4, 5, 6, 13, 14, 21, 22, 23, 24, 26, 27, 31, 69, 103, 104, 105
Ostrea sculpturata Conrad, 1840; calcitic shell
4, 13, 14, 18, 21, 22, 24, 26, 27, 69, 103, 104, 105
Ostrea locklini Gardner, 1945; calcitic shell
27, mouth of Four Hole Swamp from Sloan collections
Hyotissa haitensis (Sowerby, 1850); calcitic shell
27, 69
Cubitostrea sellaeformis (Conrad, 1832); calcitic shell
104 (reworked, Eocene species)
Exogyra costata Say, 1820; calcitic shell
69 (reworked, Cretaceous species)
Linga pensylvanica (Linnaeus, 1758); internal mold
24, 27
Lucinisca cribraria (Say, 1824); latex cast
27
Radiolucina tuomeyi (Dall, 1903); external mold, latex cast
23, 27, 69, 105
Parvilucina crenulata (Conrad, 1840); latex cast
105
Parvilucina multilineata (Tuomey and Holmes, 1856); latex cast
23, 69
Callucina keenae Chavan, 1971; latex cast
69
Ctena speciosa (Rogers and Rogers, 1837); latex cast
23, 27, 69, 103, 105
Pseudomiltha anodonta (Say, 1824); internal mold
2, 24, 27, 69
Divalinga quadrisulcata (Orbigny, 1842); latex cast
26, 27, 69, 105
Diplodonta acclinis (Conrad, 1832); latex cast
24, 69
Diplodonta punctulata (H.C. Lea, 1843); latex cast
24, 27, 69, 104, 105
Diplodonta subvexa (Conrad, 1834); latex cast
69, 103, 104
Chama congregata (Conrad, 1833); latex cast
1, 22, 69
Chama emmonsi Nicol, 1953; latex cast
69
Pseudochama corticosa (Conrad, 1833); latex cast
27, 69
Arcinella cornuta (Conrad, 1866); latex cast
1, 20, 27, 69
Aligena striata H.C. Lea, 1843; latex cast
69, 105
Cyclocardia granulata (Say, 1824); latex cast
21, 26, 27, 69, 105
Pleuromeris sp.; latex cast
69
Pteromeris abbreviata (Conrad, 1841); latex cast
69
Astarte floridana Dall, 1903; internal mold
69
Astarte vaughani Mansfield, 1916; latex cast
26, 27, 69
Astarte concentrica Conrad, 1834; latex cast
26, 27, 69, 103
Astarte undulata Say, 1824; latex cast
24, 26, 69
Eucrassatella speciosa (Adams, 1852); latex cast
23, 24, 26, 27, 69
Eucrassatella Virginica (Gmelin, 1791); internal and external molds
23, 27, 69
Crassinella lunulata (Conrad, 1834); internal mold
69
Planicardium virginianum (Conrad, 1839); internal mold
69
Planicardium acutilaqueatum (Conrad, 1839); internal mold
21, 22, 24, 26, 27, 69, 103, 104
Dinocardium robustum (Lightfoot, 1786); internal mold
1, 26, 27, 69, 104
Laevicardium sublineatum (Conrad, 1841); internal mold
1, 24, 26
Papyridae sp. aff. *P. soleniformis* (Bruguière, 1789); internal and external mold
21, 24, 69
Spisula similis (Say, 1822); internal mold
27
Raeta alta Conrad, 1873; internal mold
1
Mulina congesta (Conrad, 1833); internal and external mold
27, 69, 105
Ensis directus (Conrad, 1844); internal mold, latex cast
5, 6, 23, 26, 27, 69, 105
Tellina aequistriata Say, 1824; latex cast
69
Hemimetis magnoliana (Dall, 1900); internal and external molds, latex cast
2, 27, 69, 104
Macoma virginiana (Conrad, 1866); internal mold
23
Macoma arctata (Conrad, 1843); internal mold
69
Gari wagneriana Dall, 1900; internal mold
69
Semele carinata (Conrad, 1830); latex cast
27, 69
Semele sp. aff. *S. alumensis* Dall, 1900; external mold
26

Solecurtus cumingianus (Dunker, 1861); internal mold
1, 13, 69
Tagelus divisus (Spengler, 1794); internal mold
69
Periglypta sp.; internal mold
69
Mercenaria corrugata (Lamarck, 1818); internal and external molds
22, 26, 27, 69, 103, 104
Mercenaria corrugata "tridacnoides" (Lamarck, 1818); molds
22, 27, 69
Mercenaria sp. (triangular); internal mold
69
Chione erosa Dall, 1903; latex cast
20, 27
Chione (Lirophora) latilirata (Conrad, 1841); latex cast
1, 21, 24, 27, 69, 105
Chione cribraria (Conrad, 1843); latex cast
22, 24, 25, 26, 69, 104, 105
Gouldia metastriata (Conrad, 1838); latex mold
69, 105
Pitar sayana (Conrad, 1833); internal mold
23, 104
Macrocallista albaria (Say, 1832); internal mold
21, 27
Dosinia acetabulum (Conrad, 1832); internal mold
27
Pleiorytis centenaria (Conrad, 1833); molds, latex cast
69, 103
Corbula inaequalis Say, 1824; latex cast
69, 105
Corbula retusa Gardner, 1948; latex cast
69
Corbula nucleata Dall, 1898; latex cast
69
Hiatella arctica (Linnaeus, 1767); latex cast
21, 69, 105
Gastrochaena ligula (H.C. Lea, 1843); internal mold
13, 14, 27, 69, 105
Teredina fistula (H.C. Lea, 1843); internal mold
20, 27
Panopea floridana Heilprin, 1886; internal mold
69
Panopea reflexa Say, 1824; internal mold
2, 11, 21, 22, 27, 69, 104, 105
Panopea goldfussi Wagner, 1838; internal mold
69
Margaritaria abrupta (Conrad, 1832); internal and external mold
2, 69, 104
Thracia magna Campbell, 1993; internal mold
27
Cyathodonta dalli (Mansfield, 1929); molds, latex cast
26, 27, 69

Verticordia emmonsi (Conrad, 1862); partly preserved shell
27

GASTROPODA

Diodora auroraensis Ward and Blackwelder, 1987; latex cast
27
Diodora redimicula Say, 1824; latex cast
1, 69
Solariella gemma (Tuomey and Holmes, 1856) latex cast
18, 20, 69
Calliostoma basicum Dall, 1892; latex cast
69
Calliostoma labrosum (Conrad, 1834); latex cast
69
Turritella sp. aff. *Turritella alumensis* Mansfield, 1930; latex cast
26
Turritella fluxionalis Rogers and Rogers, 1837; latex cast
24, 26
Turritella etiwanensis (Tuomey and Holmes, 1856); latex cast
6, 21, 27, 69, 104
Turritella etiwanensis var. (slender); latex cast
27, 69
Turritella holmesi Dall, 1892; latex cast
27, 69
Turritella burdeni (Tuomey and Holmes, 1856); latex cast
21, 27, 69
Turritella perexilis Conrad, 1873; external mold and latex cast
23, 27, 69
Vermicularia recta Olsson and Harbison, 1953; latex cast
69
Petaloconchus sculpturatus H.C. Lea, 1843. latex cast
21, 27, 69, 104, 105
Serpulorbis granifer (Say, 1824); latex cast
27, 69, 104, 105
Serpulorbis granifer tenera Dall, 1892; externa mold
69
Architectonica nobilis Röding, 1798; inter and external mold
27, 69
Epitonium duplinianum (Olsson, 1916); ca shell
27
Calyptraea centralis (Conrad, 1841); latex cast
27, 69, 104, 105
Crucibulum auriculum spinosum (Sowerb. 1824); latex cast
69
Crucibulum leanum Campbell, 1993; externa mold
3, 69

Crucibulum scutellatum (Wood, 1828); latex cast
1, 3, 21, 24, 27, 69
Crepidula aculeata aculeata (Gmelin, 1791); latex cast
69
Crepidula aculeata costata (Morton, 1829); latex cast
69
Crepidula aculeata ponderosa (H.C. Lea, 1843); latex cast
69, 105
Crepidula cymbaeformis Conrad, 1845; internal mold
69
Crepidula fornicata (Linnaeus, 1758); latex cast
21, 22, 27, 31, 69, 104, 105
Crepidula plana (Say, 1822); internal mold
69
Xenophora conchyliophora Born, 1778; latex cast
23, 69
Trivia sp.; latex cast
69
Siphocypraea carolinensis (Conrad, 1841); internal mold
2, 3, 27
Neverita duplicatus (Say, 1822); internal mold
69
Polinices sp.; latex cast
69
Euspira sayana (Campbell, 1993); internal mold
2, 24, 27
Euspira interna (Say, 1824); latex cast
27
Euspira sp.; latex cast
69
Sinum perspectivum (Say, 1831); internal mold
27
Sinum chesapeakensis Campbell, 1993; internal mold
27
Natica plicatella Conrad, 1863; latex cast
69
Malea densicostata (Rutsch, 1934); internal mold
14, 69
Sconsia hodgei (Conrad, 1841); latex cast
27, 69
Ficus holmesi (Conrad, 1867); internal mold
24, 69
Ficus jacksonensis Olsson and Harbison, 1953; latex cast
27
Chicoreus sp.; latex cast
69
Urosalpinx lepidota (Dall, 1890); latex cast
69
Urosalpinx trossula (Conrad, 1834); latex cast
27
Pterorytis sp.; latex cast
26
Calotrophon ostrearum (Conrad, 1846); latex cast
27, 69
Ecphora bradleyae Petuch, 1987; calcitic shell
22, 69
Ecphora quadricostata (Say, 1824); calcitic shell
1, 27, 103
Anachis styliola obsoleta Gardner and Aldrich, 1919; latex cast
69
Pisania nux (Dall, 1892); latex cast
69
Ptychosalpinx multirugatum (Conrad, 1841); latex cast
69
Busycon contrarium (Conrad, 1840); latex cast
2, 27, 69, 105
Busycon maximum (Conrad, 1839); latex cast
1, 2, 23, 27, 69
Busycon incile (Conrad, 1833); internal mold
27, 69, 104
Busycon pyrum excavatum (Conrad, 1840); latex cast
2, 24, 27, 69
Nassarius consenoides (Olsson, 1916); latex cast
24, 69
Nassarius quadrulatus (H.C. Lea, 1843); latex cast
27, 105
Triplofusus gigantea (Kiener, 1840); latex cast
2, 3, 27, 69
Fasciolaria rhomboidea Rogers and Rogers, 1839; latex cast
21, 27, 69
Terebraspira sparrowi (Emmons, 1858); internal and external mold
23, 27, 69
Terebraspira elegans (Emmons, 1858); latex cast
69
Fusinus equalis (Emmons, 1858); latex cast
23, 24, 69
Fusinus exilis (Conrad, 1832); latex cast
69
Hesperisternia filicata (Conrad, 1834); latex cast
69
Oliva canaliculata H.C. Lea, 1843; internal mold
1, 5, 26, 27, 104
Olivella carolinae Gardner, 1948; latex cast
69
Olivella mutica (Say, 1822); latex cast
69
Pleioptygma carolinensis (Conrad, 1841); latex cast
25, 69
Vexillum elaboratum (H.C. Lea, 1843); latex cast
18
Aurinia mutabilis (Conrad, 1830); latex cast
3, 5, 24, 27, 69
Scaphella n. sp.; latex cast
69
Cancellaria rotunda Dall, 1892; latex cast
21, 69, 104
Cancellaria rapella Johnson, 1904; internal mold
69
Trigonostoma tenerum carolinensis (Emmons, 1858); latex cast

69

Trigonostoma perspectivia (Conrad, 1834); latex cast
69

Microspira antiqua (Redfield, 1851); latex cast
69

Prunum bellum (Conrad, 1868); latex cast
69

Prunum limatulum (Conrad, 1834); latex cast
69

Prunum precursor (Dall, 1890); latex cast
69

Prunum virginianum Conrad, 1868; latex cast
69

Persicula ovula Conrad, 1870; latex cast
69

Conus adversarius Conrad, 1841; internal and external molds
27, 69, 104

Conus marylandicus Green, 1830; latex cast
27, 69

Conus presozoni Olsson and Petit, 1964; latex cast
22, 27, 69

Terebra indenta Conrad, 1863; latex cast
3, 69

Terebra unilineata (Conrad, 1841); external mold
24

Drillia sp. A; latex cast
69

Drillia sp. B; latex cast
69

Crassispira antealesidota Mansfield, 1930; latex cast
69

Crassispira virginiana (Conrad, 1834); latex cast
69

Cymatosyrinx lunata (H.C. Lea, 1843); latex cast
24, 69

Glyphostoma zoster Gardner, 1948; latex cast
69

Longchaeus suturalis (H.C. Lea, 1843); latex cast
18

SCAPHOPODA

Dentalium attenuatum Say, 1824; external mold
27, 69

CNIDARIA

Paracyathus vaughani Gane
27

Septastrea marylandica (Conrad)
27

BRYOZOA

Cheilostomes, several species
27, 69

Ctenostome sp.
27

BRACHIOPODA

Discinisca lugubris (Conrad)
27

ANNELIDA

calcareous tubes
27, 69, 103, 104

ARTHROPODA

decapod claws, numerous species
27

barnacles, several species
27, 69, 103, 104, 105

Ophiomorpha burrows
27, 69

ECHINODERMATA

Arbacia improcera (Conrad)
27, 69

Mellita carolinana McCurdy
3, 5, 27, 69, 103, 104

Echinocardium orthonotum (Conrad)
5, 27, 69, 103, 104

Psammechinus philanthropus (Conrad)
27

Clypeastrea sp.
104

Encope macrophora (Ravenel)
2, 3, 4, 5, 14, 18, 27, 69

Spatangus glenni Cooke
27, 103, 104

VERTEBRATA

Deer antler
27

Artiodactyl, genus uncertain
27

porpoise
27

Balaenoptera acutorostrata
2

Balaenoptera sp.
27, 69

sperm whale
27

Morus sp.
18

Tiger shark
27

Mako shark
27

Carcharodon sp.
27

Procharodon sp. (reworked Eocene)
27

Odontaspis sp.
27

January 31, 1995