Southeastern Geology: Volume 5, No. 1
September 1963

Editor in Chief: S. Duncan Heron, Jr.

Abstract

Academic journal published quarterly by the Department of Geology, Duke University.

SOUTHEASTERN GEOLOGY

PUBLISHED AT DUKE UNIVERSITY DURHAM, NORTH CAROLINA

VOL. 5 NO. 1 SEPTEMBER, 1963

SOUTHEASTERN GEOLOGY

PUBLISHED QUARTERLY BY THE
DEPARTMENT OF GEOLOGY
DUKE UNIVERSITY

This journal welcomes original papers on all phases of geology, geophysics, and geochemistry as related to the Southeast. Transmit manuscripts to S. DUNCAN HERON, JR., BOX 6665, COLLEGE STATION, DURHAM, NORTH CAROLINA. Please observe the following:

(1) Type the manuscript with double space lines and submit in duplicate.
(2) Cite references and prepare bibliographic lists in accordance with the method found within the pages of this journal.
(3) Submit line drawings and comples tables as finished copy.
(4) Make certain that all photographs are sharp, clear, and of good contrast.
(5) Stratigraphic terminology should abide by the Code of Stratigraphic Nomenclature (AAPG, v. 45, 1961).

Proofs will not be sent authors unless a request to this effect accompanies the manuscript.

Reprints must be ordered prior to publication. Prices are available upon request.

* * * * *

Subscriptions to Southeastern Geology are $5.00 per volume. Inquiries should be addressed to WM. J. FURBISH, BUSINESS AND CIRCULATION MANAGER, BOX 6665, COLLEGE STATION, DURHAM, NORTH CAROLINA. Make check payable to Southeastern Geology.

SOUTHEASTERN GEOLOGY

Table of Contents

Vol. 5, No. 1

1963

A REPORT ON GEOLOGICAL AND GROUND-WATER INVESTIGATIONS IN PIGEON ROOST CREEK WATERSHED, MARSHALL COUNTY, MISSISSIPPI [1]

by

Loris E. Asmussen
and
Farris E. Dendy
U. S. Department of Agriculture
Sedimentation Laboratory
Southern Branch

ABSTRACT

A relatively comprehensive geological and ground-water investigations of a severely eroded Mississippi watershed was made as a supporting study for sedimentation research. Detailed information is presented on outcrop areas of geological formations; stratigraphy; topography; structure; land use; and ground-water occurrence, fluctuation, and flow.

Three major stratigraphic units - Kosciusko, Tallahatta, and Meridian Formations - are present in the study area. Surface features consist of broad flat flood plains with rolling severely dissected interfluvial uplands ranging in elevation from 300 to 600 feet. The data indicate relationships between area outcrops of the various geological formations and surface runoff from comparable subwatersheds. Annual ground-water outflow from the 117 sq. miles study area is approximately 3 inches per year from the Meridian Formation alone. Ground-water storage in this formation is estimated at 4 million acre-feet. The studies indicate the need for geological investigations as an

---

[1] Contribution from the USDA Sedimentation Laboratory, Southern Branch, Soil and Water Conservation Research Division, Agricultural Research Service, U.S. Department of Agriculture, Oxford, Mississippi, in cooperation with the University of Mississippi and Mississippi State University.

integral part of any watershed evaluation program.

INTRODUCTION

In 1956, the Agricultural Research Service initiated an extensive sedimentation research program on Pigeon Roost Creek Watershed, Marshall County, Mississippi, directed toward determining causes and effects of sediment production, transportation, and deposition. To support these studies, geologic and ground-water investigations were undertaken in 1960.

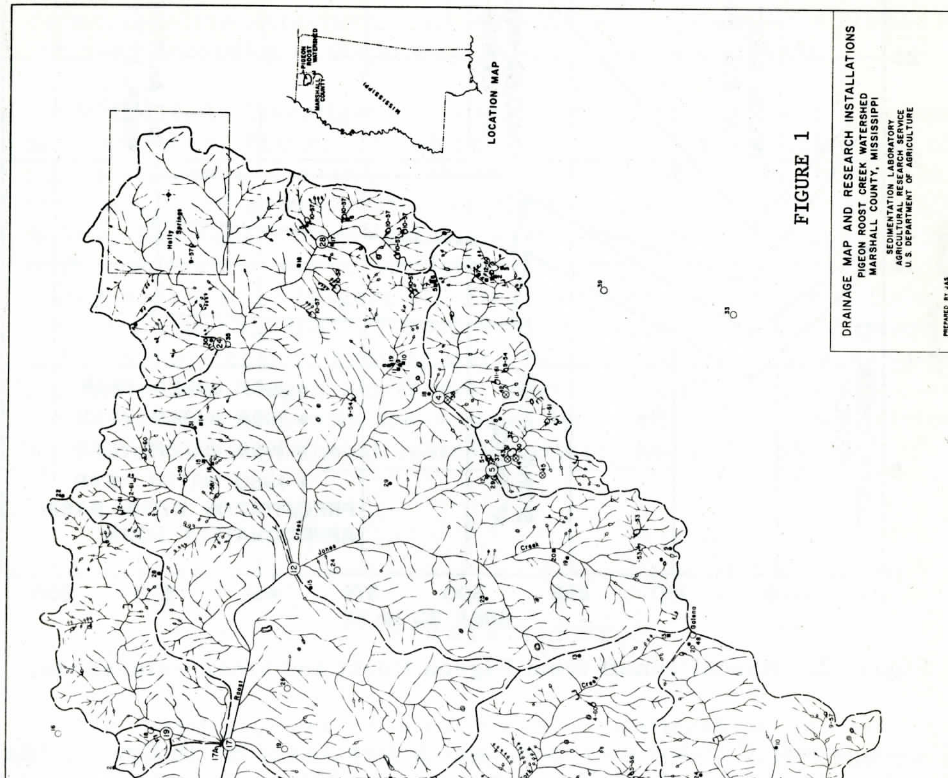
The experimental watershed contains 117 square miles of hilly, severely eroded upland with broad flat alluvial flood plains (Figure 1). Approximately 22 percent of the area is cultivated, 18 percent is woodland, 12 percent is pasture, 44 percent is idle, and the balance is wasteland and roads. Initial measurements showed runoff to be considerably less than from other watersheds in the area. A comparison of annual runoff from Pigeon Roost Creek and several nearby watersheds is shown in Figure 2. Wide variation in runoff also occurs between the 11 gaged subwatersheds within the study area. Some of this variation appears to be related to geological and ground-water conditions.

NATURE AND EXTENT OF INVESTIGATIONS

Hydrogeological investigations consisted primarily of an evaluation of stratigraphy, structure, and ground water. The geological interpretations were made from surface investigations, exploratory wells, resistivity measurements, and laboratory examinations of field samples. Ground-water levels were established from observation wells situated throughout the area. Quantitative analysis of ground water appearing in the streams as base flow was made from limited studies of streamflow records.

GEOLOGICAL INVESTIGATIONS

Geological investigations were confined to the aforementioned



DRAINAGE MAP AND RESEARCH INSTALLATIONS
PIGEON ROOST CREEK WATERSHED
MARSHALL COUNTY, MISSISSIPPI
SEDIMENTATION LABORATORY
AGRICULTURAL RESEARCH SERVICE
U.S. DEPARTMENT OF AGRICULTURE
JANUARY 1962
LOCATION MAP
MISSISSIPPI
MARSHALL COUNTY
PIGEON ROOST WATERSHED
LEGEND
Watershed Boundary
Perennial Stream
Intermittent Stream
Gully Plug
Structure With Pipe Control and Date Built
Stock Pond
Streamflow and Sediment Sampling Station
Precipitation Gage
Soil Moisture Site
Ground Water Observation Well
Ground Water Observation Well (Perched)
Ground Water Observation Well (Recording)
Upstream Limit of Channel Ranges
Radio Transmission Tower
SCALE IN MILES
Cuffawa Creek
Jones Creek
Roost Creek
Holly Springs
Galena

FIGURE 1

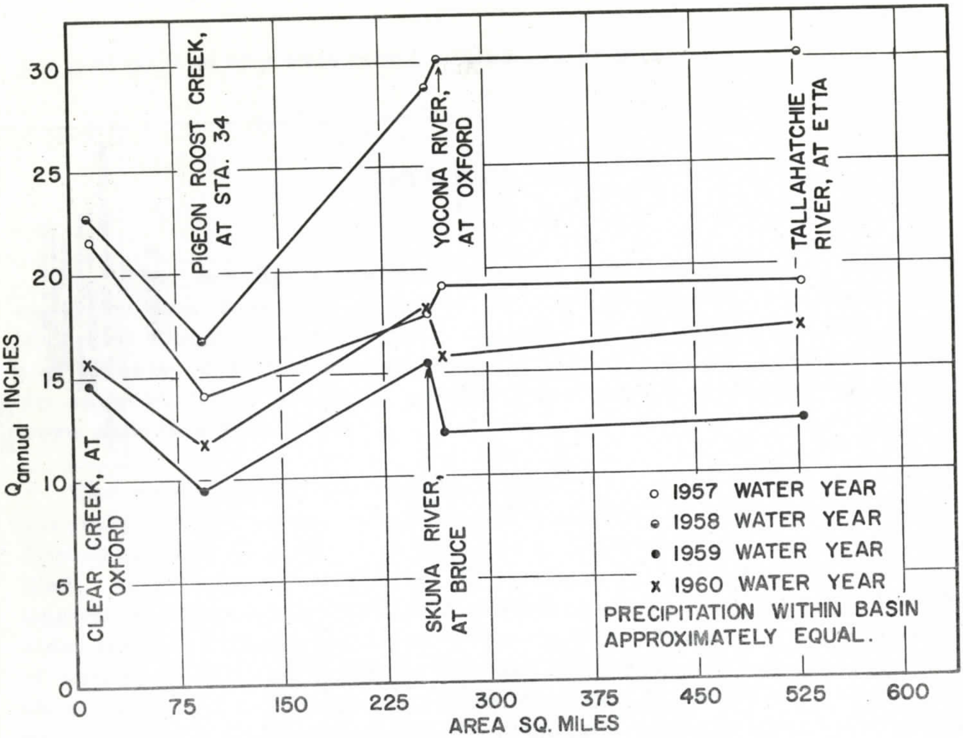


Figure 2. Annual runoff from Pigeon Roost and other watersheds.

Pigeon Roost Creek Watershed, which lies in the North Central Plateau region of the East Gulf Coast physiographic section of the Coastal Plain province. The topographic elevation ranges from approximately 300 feet at Station 34 (Figure 1) to between 500 and 600 feet on the watershed boundary. The surface features consist of broad flat flood plains with both natural and dredged channels and rolling severely dissected interfluvial areas. Adjoining watersheds north and south of Pigeon Roost Creek Watershed have similar topography, geology, and stratigraphy. Topographic configuration east of the watershed is also similar, but differs in stratigraphy. West of the watershed, the loess bluff area topography is developed and continues to the Mississippi River Delta. Previous studies of this area have been made by the Mississippi State Geological Survey (Vestal, 1954).

A vacuum-type drill rig was used in the geological and groundwater explorations (Figure 3). Visible samples are easily obtained with this rig, which is adaptable to drilling in water-saturated sands (Asmussen, 1961).

Resistivity measurements were made along with the drilling program to reduce the number of exploratory wells required. This method offers a relatively cheap and rapid assessment of shallow subsurface conditions such as: depth of valley alluvium, water table elevation, shallow structure, and stratigraphy. Data were plotted and analyzed according to the Moore summation method (1945).

Initial field investigations were confined to the lower reaches of the watershed, Station 34, which made possible the development of a geological cross section (Figure 4) showing the stratigraphy, structure, and ground-water configuration of the valley and valley flanks. Subsequent investigations were conducted in the upper reaches of the watershed where an intensive geological study was made of Watersheds 4 and 5 (Figure 1). Ground-water observation wells were drilled throughout the 117-square-mile watershed. Field measurements of in situ permeability were made in the principal water-bearing formation using a small well point device (Dendy and Asmussen, 1963) in conjunction with the vacuum-type drill rig. Field samples were analyzed for mineral content, texture, and permeability.

STRATIGRAPHY

The establishment of stratigraphic relationships in the Pigeon Roost Creek Watershed is a complex problem. The contacts are graduational, poorly exposed, and a large part of the stratigraphic units are sands which have very few distinguishing characteristics. The geological formations present in the area are shown in Table 1. These Eocene fresh-water sediments, Citronelle gravel, loess, and soils, make up the sediment load transported by Pigeon Roost Creek.

The three major stratigraphic units present in Pigeon Roost Creek Watershed are the Kosciusko, Tallahatta, and Meridian Formations (Figure 5). Other geological strata present are the Citronelle Gravel and the loess cover. Also, in several small areas the Winona Sand and Zilpha Clay strata may exist. These, except for small outliers, have been removed by erosion occurring after deposition of the Tallahatta formation.

Kosciusko outcrops are found in the higher area bounding the watershed, and in some instances in the central areas as reworked material. Large iron concretions occur primarily in the Kosciusko Formation. Although they occur in several locations within the watershed, the larger concretions occur near Holly Springs. Iron concretions and iron staining also occur in the Tallahatta and Meridian,

Figure 3. Vacuum-type drill rig used in geological investigation.

but these concretions are smaller with the formations showing less iron staining. Generally, the lower permeability of the Kosciusko is due to a more even dissemination of clay throughout the formation.

The Tallahatta Formation outcrops throughout the central portion of the watershed and occurs between the Kosciusko Formation and the Meridian. Perched water occurs within the Tallahatta above white to gray-black clay lenses. Presumably these perched water bodies, in varying depths and lateral extent, occur extensively throughout the formation. Several were located during drilling of the observation wells shown in Figure 6. Thickness of the clay lenses is highly variable. This variation ranges from a few inches to 30 feet. The total thickness of the Tallahatta varies from 120 to 150 feet over the watershed, which is slightly less than other areas in the state. This is

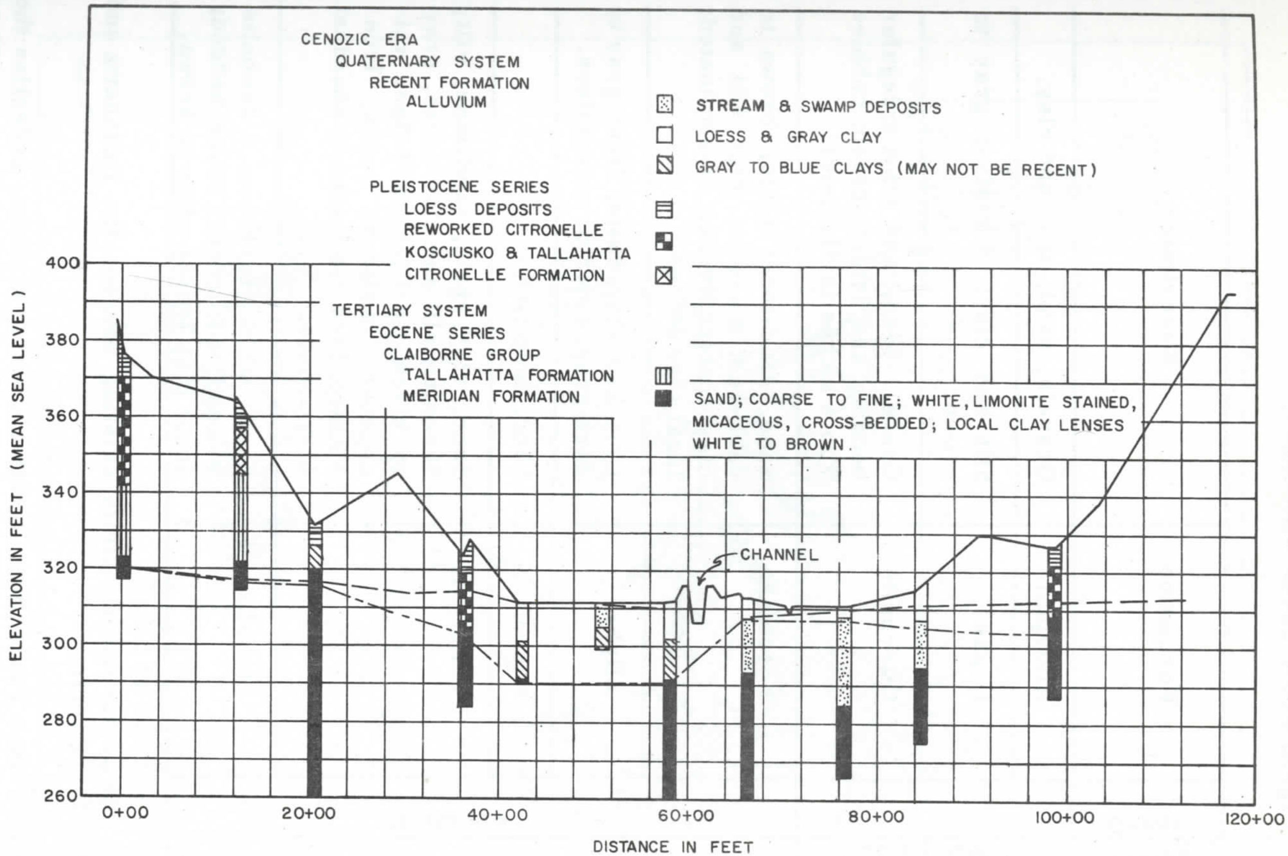


Figure 4. Geological cross-section, station 34, Pigeon Roost Watershed.

Table 1. Stratigraphic column of geological formations observed in Pigeon Roost Creek Watershed.

Era	System	Series	Group	Formation	Description
Cenozoic	Quaternary	Pleistocene and Recent		Alluvium	Gravels, sand, silt, and clay.
				Loess	Silt and clay; massive; gray to brown.
				Citronelle	Gravel, sand, and clay; irregular bedding and interfingered; cobbles 3 to 4 inches in diameter.
	Tertiary	Eocene	Claiborne	Kosciusko	Sand, sandstone; white, brown to dark red; massive; high silt and clay content evenly disseminated; local clay lenses.
				Zilpha	Clay and clay shale; light gray to dark gray; siderite concretions.
				Winona	Sand; deep red.
				Tallahatta	Sand, clay shale, sandstone, silty limonite; silt and clay-white, gray to black lignitic; sand-fine, micaceous, white to brown, iron stained; iron concretions; abundant clay lenses.
				Meridian	Sand; white to brown, limonite stained; micaceous; cross-bedded; local clay lenses white to brown.

probably due to the unconformity existing between the Tallahatta and Kosciusko formations.

The Meridian Formation, a water bearing stratum, underlies the entire Pigeon Roost Creek Watershed and ranges in depth from 180 to 200 feet. Surface outcrops do not occur within the watershed boundaries. Outcrops do occur, however, three or four miles east of the

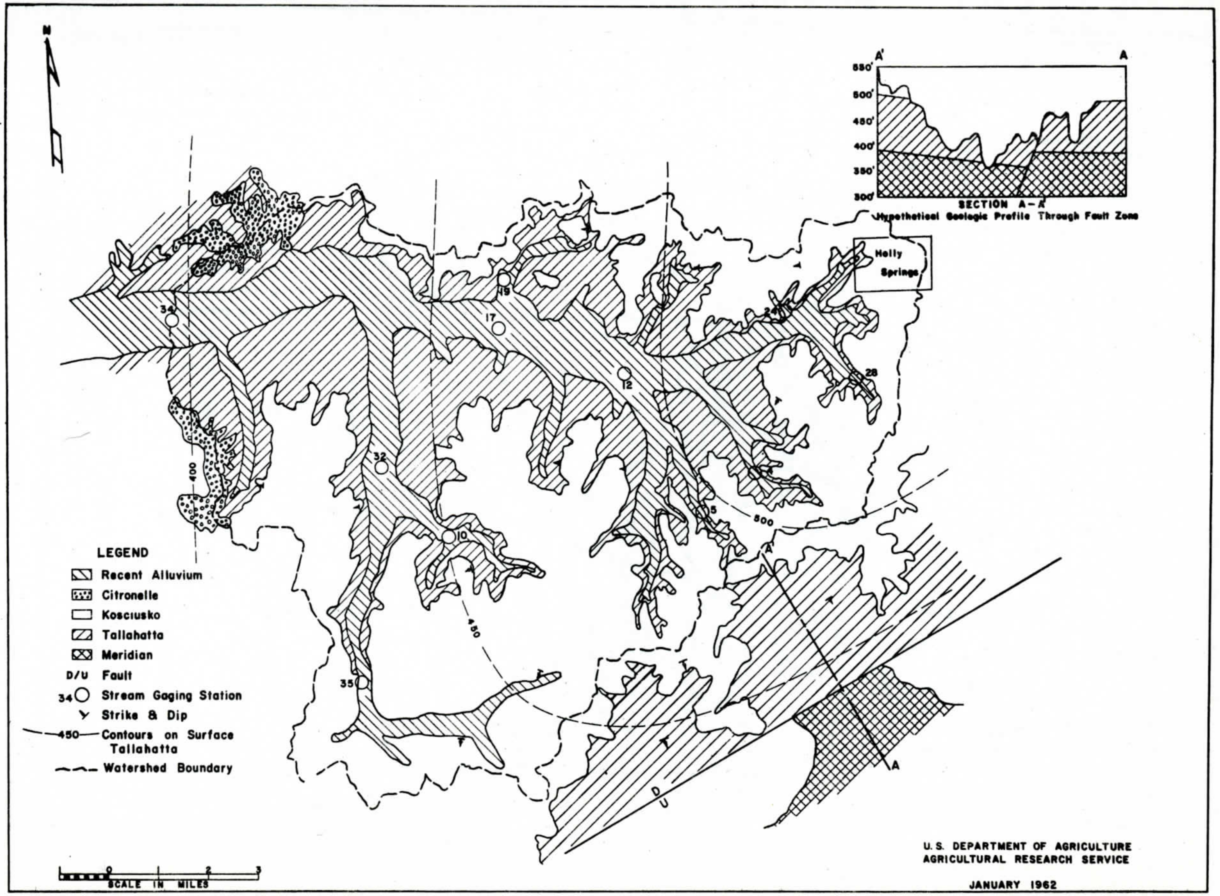


Figure 5. Preliminary geologic map, Pigeon Roost Creek watershed, Marshall County, Mississippi.

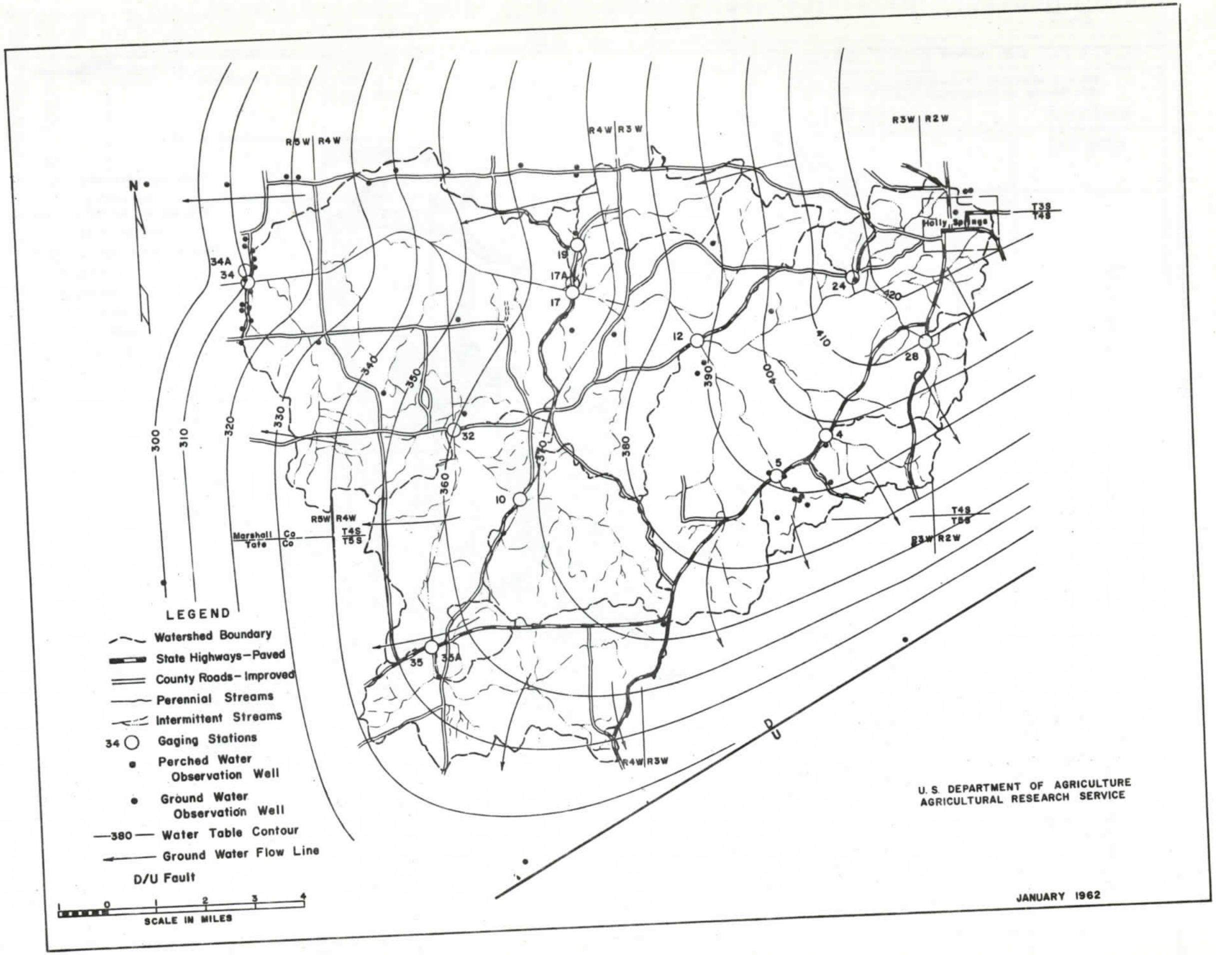


Figure 6. Preliminary ground water contour map showing stream flow and sediment gaging stations.

study area. Locally, between Stations 12 and 34 (Figure 5) the Meridian lies in contact with the alluvial fill below the stream channels. In these areas abundant springs occur, and the streams are effluent.

The only other surface outcrop in the study area is the Citronelle Gravel, which is of minor importance. It occurs along the extreme western boundary of the watershed but is not found in the stream channels and apparently has a very minor effect on the sediment load. The formation is primarily gravel but has some sand, silt, and clay, which is probably reworked Tallahatta and Kosciusko incorporated during the deposition of the gravel.

Loess and surface-soil cover varies from as much as 15 feet to complete absence. In many places the surface cover has been completely eroded because of poor farming and land management practices in the past years. These areas, where the predominantly sand-bearing Tallahatta and Kosciusko Formations outcrop, are the primary sources of sands in the stream channels. Residents in the area state that the channels have been only sand-bed streams for the last 40 to 50 years due to the accelerated erosion induced by man.

Present in very small amounts or totally absent are the Zilpha and Winona Formations. The sporadic appearance of those formations is primarily due to the unconformity that exists between the Tallahatta and the Kosciusko. Only small erosional outliers have been noted in the Pigeon Roost Creek Watershed.

From the visual logs and resistivity measurements, a preliminary geological map of the watershed (Figure 5) was developed. Measured areas of the geologic formations and land use have been tabulated for the Pigeon Roost Creek Subwatersheds in Table 2.

STRUCTURE

Structural features in Pigeon Roost Creek Watershed are of two types--regional and local. The regional structure is controlled by the Mississippi Embayment, which is a coastal geosyncline produced by a broad, gentle down warping beginning in Cretaceous and continuing through Tertiary time. This gentle down warping is responsible for the dip of the Eocene sediments in the watershed to the west, and it also controls the regional water table gradient.

The sharp change of strike and dip of the surface stratigraphy

Table 2. Watershed characteristics and conditions

Watershed Number		34	5	35	32	10	17	24	12	4	19	28
Elevation of gaging station (ft MSL)		306.1	453.6	406.2	366.4	397.2	355.8	454.2	383.9	453.3	380.2	489.5
Surface outcrop of Geological Formations (% of total area)	Tallahatta	26	10	0	11	15	26	13	26	29	0	11
	Kosciusko	52	88	87	76	80	54	81	56	64	87	88
	Citronelle	1	0	0	0	0	0	0	0	0	0	0
	Alluvium	21	2	13	13	5	20	6	18	7	13	1
Total Area (sq. mi.)		117.00	1.76	13.50	31.30	8.64	55.20	.80	35.60	3.13	.38	1.69
Land Use as Percent of Total Area 1/	Forest Planted	1	0	2	0	0	1	6	0	3	0	6
	Active Gullies	2	2	2	2	2	2	1	2	2	1	5
	Urban	1	0	0	0	0	2	0	3	0	0	0
	Forest	18	20	7	11	17	25	56	23	32	41	25
	Pasture	12	35	19	13	11	13	2	13	13	4	7
	Idle	44	21	53	48	51	42	33	43	33	52	46
	Cultivated	22	22	17	26	19	15	2	16	17	2	11

1/ Land use percentage computed by J. A. Spraberry.

(Figure 5) and the change of the piezometric gradient (Figure 6) indicate the presence of a fault bounding the south side of the watershed. This fault can be traced both northeast and southwest by a line of springs through Marshall county into Benton county to the northeast and Panola county to the southwest. Stratigraphy, piezometric contours, and the regional structure suggest that the northwest side of the fault is the downthrow side, which indicates a normal fault. The presence of this fault is also supported by the presence of other faults in the Mississippi Embayment, most of which have a northeast-southwest strike. This regional structural characteristic is associated with the subsidence of the embayment and development of major systems of gravity faults.

GROUND WATER

The principal water-bearing stratum beneath the Pigeon Roost Watershed is the Meridian Formation. Generally, this formation is an unconfined aquifer with certain areas having the characteristics of a partially confined aquifer. Clay lenses causing this partially confined aquifer appear to occur over a larger percentage of the Cuffawa drainage basin and along the western boundary of the Pigeon Roost Creek Basin. Several other subsurface water bodies occur throughout the area as perched water, mostly in the Tallahatta, above the Meridian Formation. The number and areal extent of these perched bodies is unknown, but it is assumed that they exert only limited influence on total runoff and base flow in the area. A schematic representation of ground-water occurrence in the Pigeon Roost Creek basin is shown in Table 3.

A piezometric contour map (Figure 6) shows ground-water level contours in the Meridian Formation. The map indicates outward flow of ground water to the west and south of the watershed through this formation. Lateral inflow is limited to small areas near Holly Springs and along the north boundary.

Observations of 22 wells over an 18-month period indicate little fluctuation in water levels. Measurements at several key wells are shown in Figure 7. Wells number 18, 19, and 6 are located in the valley alluvial plain, whereas wells number 3 and 10 are located on the uplands.

Ground-water quality in the area is excellent as shown by the chemical analysis in Table 4. Water quality is such that little treatment is

Table 3. Schematic diagram of ground-water occurrence in Pigeon Roost Creek Basin

<table>
<tr><th colspan="4">Subsurface Water</th><th>Geology</th></tr>
<tr><td rowspan="9">Zone of Interconnected Openings</td><td rowspan="6">Zone of aeration
Understaurated Zone
Suspended Water</td><td rowspan="4">Types of Water
in Zone of aeration</td><td>Soil Water</td><td>Loess</td></tr>
<tr><td>Pellicular Water</td><td>Soils
Citronelle</td></tr>
<tr><td>Gravity (or) Vadose Water</td><td>Kosciusko</td></tr>
<tr><td>Perched Water</td><td>Tallahatta</td></tr>
<tr><td colspan="2">Capillary Water</td><td></td></tr>
<tr><td colspan="2">Free Water</td><td rowspan="3">Meridian
(aquifer)</td></tr>
<tr><td rowspan="3">Saturated Zone
Ground Water
Phreatic Water</td><td colspan="2">Confined Water</td></tr>
<tr><td colspan="2">Fixed Ground Water</td></tr>
<tr><td colspan="2"></td><td>Wilcox
(aquiclude)</td></tr>
</table>

necessary for consumption by municipalities, farms, and industries.

The fault zone (Figure 6) apparently exerts considerable influence on ground-water performance in the area. As a result of this fault, outward flow is occurring to the south-southeast from approximately 32 percent of the watershed. Normally, this water would flow in a westerly direction. The effect of this fault is further shown by spring-fed streams lying immediately south of the watershed which have relatively constant base flows. Annual base flow, estimated from weekly stage observations and occasional measurements in two of these streams for a 1-year period, is shown in Table 5. Compared to approximately 4 inches average annual base flow at Station 34, the annual values of base flow for Little Spring and Oak Chewalla Creeks (Table 5) are extremely high. Apparently, most of the base flow in these spring-fed streams is ground-water outflow from the Pigeon

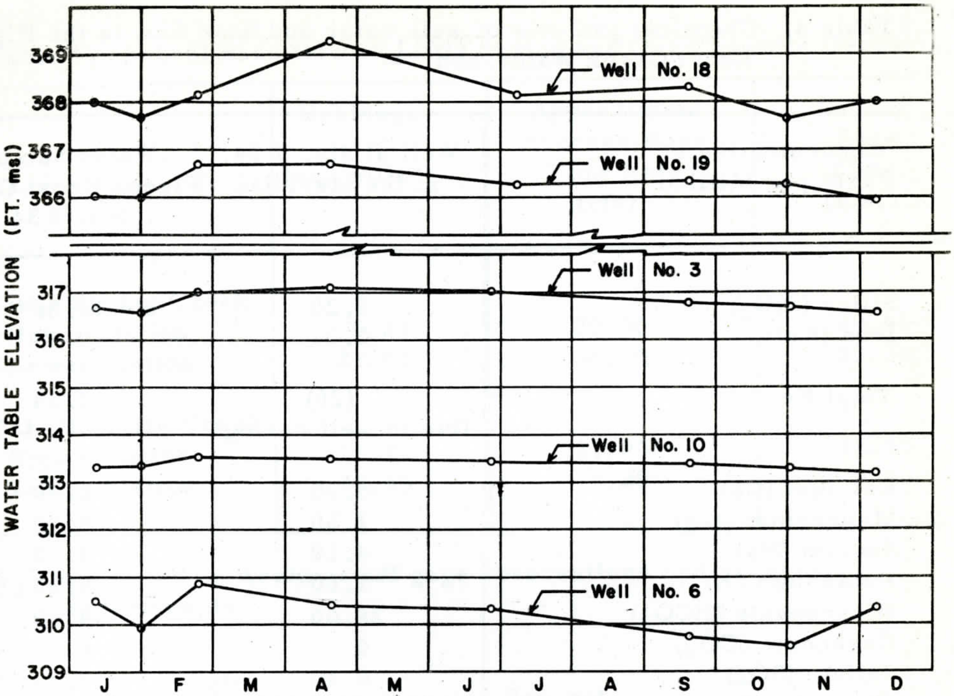


Figure 7. Water levels in selected wells (1961).

Roost Creek Watershed. This is also indicated by the piezometric contour map (Figure 6). Regional and local topographic and structural configuration indicate the possibility of a dome in the Holly Springs area. This could also influence the ground-water performance in the area.

Permeability of the water-bearing Meridian Formation is highly variable. Laboratory tests on fragmented samples indicate permeabilities ranging from 50 ft./day to 266 ft./day and a uniformity coefficient variation of 6.11 to 2.81. The uniformity coefficient represents the ratio of D_{60} size to the D_{10} size of a granular material. A low ratio indicates a uniform material.

Point measurements of field permeability with small well points range from 19 to 106 ft./day. The mean value computed from 19 tests in the upper 30 ft. of the Meridian Formation was 47 ft./day. The higher values determined from the laboratory samples can logically be attributed to disturbance and slight washing of the material. Presumably the field measurements more nearly represent the true permeability of the formation.

By drawing a flow net along the watershed boundary (Figure 6) and assuming the depth of the Meridian Formation to be 180 ft., with an

Table 4. Chemical analysis of well water and base flow in the Pigeon Roost Creek Watershed 1/

Concentration in Parts per Million	Well at Sta. # 34 in the Meridian	Water Sample Pigeon Roost Creek, Sta. # 34
Silica (SiO_2)	5.20	14.00
Iron (Fe)	0.01	0.03
Total Fe	(26) Due to well casing	0.54
Calcium (Ca)	5.70	2.80
Magnesium (Mg)	1.50	0.70
Sodium (Na)	4.10	3.50
Potassium (K)	1.60	0.80
Bicarbonate (HCO_3)	28.00	14.00
Carbonate (CO_3)	0	0
Sulfate (SO_4)	0.40	0.30
Chloride (Cl)	3.20	3.80
Fluoride (F)	1.40	0
Nitrate (NO_3)	0.20	2.10
Dissolved Solids		
Calculated	37.00	35.00
Residue on evap. at 180° C.	35.00	33.00
Hardness as $CaCO_3$	20.00	10.00
Noncarbonate hardness as $CaCO_3$	0	0
Specific conductance microhms at 25° C	(61.00) Due to well casing	34.00
pH	6.30	6.40
Color	10.00	10.00

1/ Sample analysis by USGS, U. S. Department of Interior.

average permeability of 50 ft./day, the approximate annual groundwater outflow through this formation was computed using the following equations:

Table 5. Annual base flow in Little Spring and Oak Chewalla Creek[1]

	Drainage Area (sq. miles)	Approximate Average Base Flow Rate (cfs)	Annual Base Flow (ins.)
Little Spring Creek			
Upper Station	9.21	20.00	29.50
Lower Station	22.07	38.00	23.30
Oak Chewalla Creek			
Upper Station	11.72	11.00	12.70
Lower Station	20.59	15.00	9.90

1/ Data based on weekly staff gage observations and occasional measurements.

$$d_q = K \frac{dh}{ds} \text{ for a rectangular flow net}$$

or

$$d_q = K\,dh \text{ for a square flow net } (ds \cong dm)$$

where

dm = distance between flow lines
K = permeability
ds = distance between isopotential lines in the direction of flow
dh = head differential between isopotential lines
d_q = flow rate

These computations show an annual average ground-water outflow from the watershed through the Meridian Formation of 2.9 inches per year.

Porosity of the Meridian Formation, as determined by laboratory analyses of field samples, is approximately 30 percent. If the depth of the formation is 180 ft., then the ground-water storage capacity beneath the watershed is approximately 4 million acre ft. in this formation alone.

Base flow, or ground water appearing in the streams above the

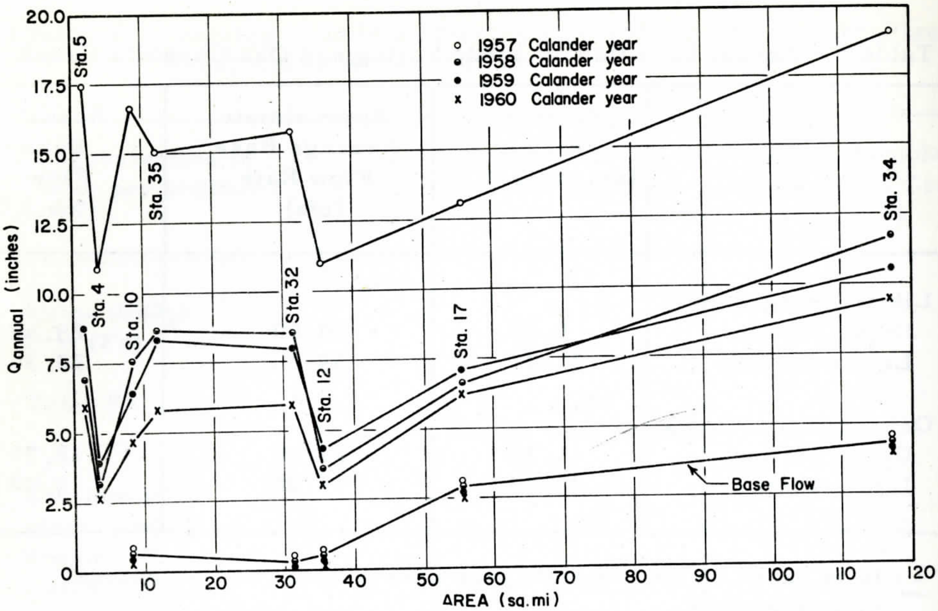


Figure 8. Total annual runoff and base flow in the Pigeon Roost Creek watershed.

gaging stations, amounts to a considerable percentage of the total annual runoff at the lower stations in the Pigeon Roost Creek Watershed. Total annual runoff and annual base flow are shown for several stations in Figure 8. Even though total runoff varied substantially for the 4-year period, 1957 through 1960, base flow remained relatively constant. This indicates that water levels in the Meridian Formation, presumably the source of most of the base flow, are not readily affected by annual fluctuations in precipitation and infiltration.

Base flows of 30 or 35 cfs occur at Station 34 for several weeks with little or no fluctuation during periods of no rainfall. In an attempt to determine the source of base flow in the Pigeon Roost Creek channel, simultaneous measurements were made between Stations 34 and 17. These measurements, shown in Figure 9, indicate that approximately two-thirds of the base flow is contributed by tributaries, and one-third is channel pick-up in the main channel.

By superimposing the water table on the geological cross section (Figure 4) at Station 34, analysis of base flow measurements (Figure 9), and observations of local structural features, it was possible to make several inferences, as follows: (1) Most of the base flow in Pigeon Roost Creek originates in tributaries along the valley flanks where erosion has exceeded deposition resulting in local contacts with

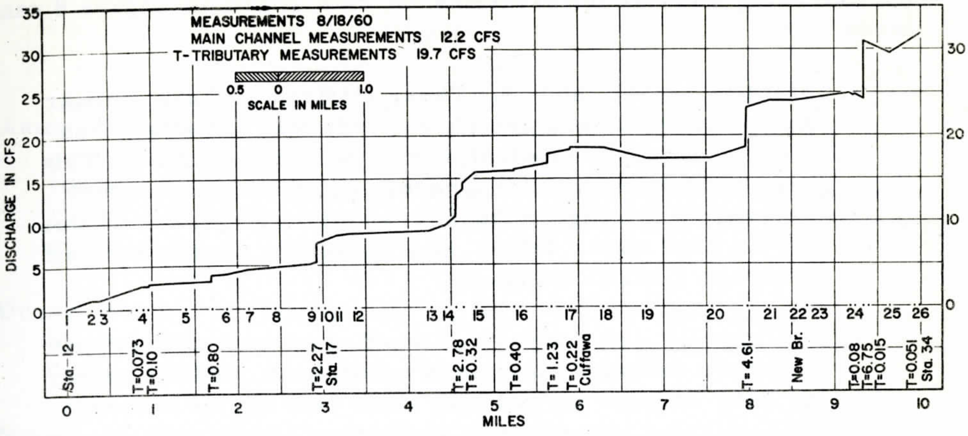


Figure 9. Simultaneous base flow measurements in Pigeon Roost Creek (1960).

the Meridian; (2) main channel pick-up is along reaches where the dredged channel crosses the original sand; silt; and clay-filled Pigeon Roost Creek channel, or where the dredged channel has cut through the valley fill into the Meridian; and (3) the piezometric surface may be as much as 20 feet above the confined water table except in areas where the old Pigeon Roost Creek channel exists. In these areas, the piezometric surface and the water table are at the same elevation.

RUNOFF AS AFFECTED BY GEOLOGY

As previously stated, substantial differences in runoff occur between comparable watersheds within the Pigeon Roost Creek basin. For example, runoff at Station 32 exceeded runoff at Station 12 by about 15.89 inches per unit area for the 4-year period, 1957 through 1960, while there was no apparent difference in precipitation over the areas. Similar differences also occurred between Stations 4 and 5.

Some of this difference in runoff can be attributed to differences in land use and cover. It is noteworthy, however, that Watersheds 32 and 5, the higher runoff producing watersheds, have a smaller percentage of recent deposits or valley fill, a higher percentage of the Kosciusko Formation, and a small percentage of the exposed Tallahatta Formation. Another significant factor may be the presence of a relatively impermeable clay lense below the valley fill above Station 5 and possibly above Station 32.

In addition to the above hydrological and geological relationships, the following general observations on data listed in Figure 8 can be made:

1. Stations 12, 17, and 34: These stations all have similar geological and land use characteristics. Surface runoff, however, is substantially higher at Station 34. This may be caused by: (1) Channel gains along the lower reaches of the Pigeon Roost channel below Station 17 due to the high water table, and (2) higher surface runoff from the Cuffawa tributary.

2. Stations 10, 32, and 35: Runoff, geology, and land use compare favorably for these watersheds, and all appear to have at least partial clay seals beneath the channels. The slightly lower runoff at Station 10 can probably be attributed to the absence of a clay sealer beneath portions of the watershed and channel.

3. Stations 4 and 5: The higher runoff at Station 5 may possibly be attributed to a continuous seal beneath the entire valley, a smaller percentage of alluvium, and a higher percentage of Kosciusko. A clay seal is also present beneath Watershed 4 but does not appear to be continuous.

SUMMARY

Subsurface investigations of the Pigeon Roost Creek Watershed have yielded information that may explain differences in runoff from subwatersheds of comparable size and land use. Preliminary stratigraphic and water table maps of the watershed have been prepared and included in this report. Three major geological formations - Kosciusko, Tallahatta, and Meridian - are present in the study area. Ground-water outflow occurs on three sides of the watershed, but inflow is limited to small areas along the north boundary and in the northeast corner. The findings in this investigation tend to point out the need for subsurface investigations in conjunction with watershed evaluation programs. Geological information is needed in both sediment and hydrological computation and predictions.

REFERENCES

Asmussen, Loris E., 1961, Utilization of drilling and resistivity equipment in ground-water research: Research Report No. 345, USDA Sedimentation Laboratory, Southern Branch, Soil and Water Conservation Research Division, Agricultural Research Service, US Department of Agriculture.

Dendy, F. E., and Asmussen, L. E., 1963, Permeability measurements with small well points: Presented before the Southeast Section, ASAE, Memphis, Tennessee.

Moore, R. W., 1945, An empirical method of interpretation of earth resistivity measurements: American Institute of Mining and Metallurgical Engineers, v. 164, p. 197-244.

Vestal, Franklin Earl, 1954, Marshall County geology: Mississippi Geological Survey, Bulletin 78.

THE CRETACEOUS-TERTIARY BOUNDARY AT THE TYPE LOCALITY OF THE CASTLE HAYNE FORMATION

by

Wallace Fallaw
and
W. H. Wheeler
University of North Carolina

ABSTRACT

Investigation of exposures at the type locality of the Eocene Castle Hayne Formation revealed that a limestone facies of the Upper Cretaceous Peedee Formation, similar to Castle Hayne limestone, apparently underlies the Eocene beds. Some reports of Cretaceous fossils in the Castle Hayne Formation are probably due to incorrect correlation of the Cretaceous limestone.

* * *

The Castle Hayne Formation, of Middle and Upper Eocene age, crops out in the southeastern North Carolina Coastal Plain. It is composed of indurated and unindurated limestone, dolomitic limestone, phosphate-pebble conglomerate, and calcareous sand (Brown, 1958, table 1). The formation was defined by B. L. Miller in 1912 (in Clark, et al., 1912, pt. 1, p. 185). The type locality is the vicinity of the village of Castle Hayne, which is about eight miles north of Wilmington, North Carolina. No type section was specified.

Underlying the Castle Hayne Formation in the area of its type locality is the Upper Cretaceous Peedee Formation. It is dominantly a greenish-gray glauconitic sandstone, with some limestone beds and lenses.

There are several marl and limestone pits and quarries near Castle Hayne. A fairly good section was observed at the well-known quarry about one mile southwest of Castle Hayne during one of the rare times when the water level was down due to pumping operations:

6.	Pleistocene sand	5 feet
5.	Unindurated fossiliferous-fragmental limestone	2.1
4.	Unindurated phosphate-pebble conglomerate	0.2
3.	Indurated limestone with abundant molluscan casts	1.1
2.	Indurated phosphate-pebble conglomerate with limestone matrix	2.9
1.	Indurated limestone with abundant molluscan molds	4.7+

Plate 1. Cretaceous fossils from the Castle Hayne quarry.

Figure

1. Trigonia haynensis Stephenson, 1923, p. 191-193, pl. 54, figs. 7-9. Replica of left valve; x1; topotype.
   Range: Upper part of Exogyra costata zone.

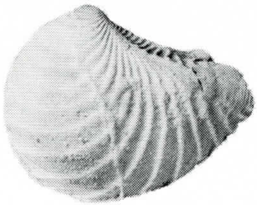
2. Cardium penderense Stephenson, 1923, p. 291-292, pl. 71, figs. 1-3. Internal mold of right valve; x1.
   Range: E. costata zone.

3. Cardium spillmani Conrad 1858.
   Description in Stephenson, 1923, p. 298-301, pl. 73, figs. 3, 5.
   Internal mold of right valve; x0.5.
   Range: Upper part of Exogyra ponderosa zone and throughout E. costata zone.

4. Exogyra costata Say 1820.
   Description in Stephenson, 1923, p. 173-179, pl. 47, figs. 2, 5; pl. 48.
   Right valve; x1.

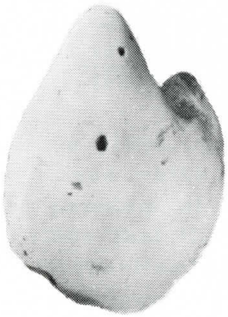
5. Ostrea subspatulata Forbes, 1845.
   Description in Stephenson, 1923, p. 158-161, pl. 40, 41.
   Right valve; internal view; x0.5.
   Range: E. costata zone.

6. O. subspatulata.
   Right valve; external view; x1.



1

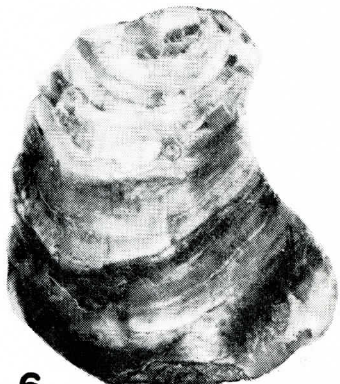
2



3

4

5



6

Plat

Figu

2

3

4

5

6

The indurated limestone beds (1 and 3) are quite similar and both conform to the lithological definition of the Castle Hayne Formation.

The Castle Hayne Formation contains many pelecypod, gastropod, echinoid, brachiopod, and bryozoan fossils. The Peedee megafauna is dominated by pelecypods, gastropods, and echinoids in the Castle Hayne area. Early investigators (Clark, 1890, p. 538; Conrad, 1865, p. 267; Tuomey, 1849, p. 32-33) reported the presence of Cretaceous fossils in the lower beds of the Castle Hayne Formation, and they attributed this to reworking by the Eocene sea.

An examination of the lower limestone at the quarry near Castle Hayne revealed that the only readily identifiable megafossils present are of Late Cretaceous age. It should be remembered, however, that most of the fossils are casts. The specimens show little evidence of reworking. The Cretaceous fossils found in this bed are Trigonia haynensis Stephenson, Exogyra costata Say, Ostrea subspatulata Forbes, Cardium penderense Stephenson, and Cardium spillmani Stephenson (Plate 1).

Stanton (1891, p. 333-334) reported a section from a creek near Castle Hayne which is similar to that described above, but the stratigraphic problem of the Cretaceous-Tertiary boundary has been neglected since that time, probably due to lack of exposures. The Castle Hayne-Peedee contact is a problem in well log correlation in this area (Brown, 1958, p. 38).

Peedee limestone beds also occur elsewhere near Castle Hayne, and have been reported lower in the Peedee Formation.

In addition to the faunal difference between the upper and lower indurated limestone beds at the Castle Hayne quarry, there are some lithologic differences. The lower limestone (bed 1) contains about 26% insoluble residue (mostly quartz with some glauconite), and the upper bed contains about 3%. The lower bed is typically medium gray, and upper bed is typically light gray to cream colored. The upper bed also contains many bryozoan fragments. This is characteristic of the Castle Hayne Formation in this area.

It is concluded that the quartzose limestone bed below the phosphate-pebble conglomerate at the Castle Hayne quarry and in nearby areas represents a limestone facies of the Peedee Formation. Some of the reports of faunal mixing were probably due to misidentification of this limestone. Cretaceous fossils in the lower conglomerate, however, are probably due to reworking (Tuomey, 1852, p. 193). It should be emphasized that lithologic correlation in this area might lead to incorrect placement of the Cretaceous-Tertiary contact.

REFERENCES

Brown, P. M., 1958, Well logs from the Coastal Plain of North Carolina: North Carolina Geol. Survey Bull. 72.

Clark, W. B., 1890, On the Tertiary deposits of the Cape Fear River region: Geol. Soc. America Bull., v. 1, p. 537-540.

Clark, W. B., Miller, B. L., Stephenson, L. W., and Parker, H. N., 1912, The Coastal Plain of North Carolina: North Carolina Geol. and Econ. Survey, v. 3, 552 p.

Conrad, T. A., 1865, Observations on the Eocene lignite formation of the United States: Am. Jour. Sci., v. 90, p. 265-268.

Stanton, T. W., 1891, Cretaceous and Tertiary strata near Wilmington, North Carolina: Am. Geologist, v. 7, p. 333-334.

Stephenson, L. W., 1923, The Cretaceous formations of North Carolina: North Carolina Geol. and Econ. Survey, v. 5, 604 p.

Tuomey, Michael, 1849, Results of observations in the Tertiary region of South Carolina: Am. Assoc. Adv. Sci. Proc., v. 1, p. 32-33.

__________ 1852, Description of some fossil shells from the Tertiary of the southern states: Acad. Nat. Sci. Phila. Proc., v. 6, p. 192-194.

PALEOECOLOGY OF THE TYPE WACCAMAW (PLIOCENE?) OUTCROPS; SOUTH CAROLINA

by

Jules R. Du Bar
Duke University

and

James F. Howard
Indiana University

ABSTRACT

The type Waccamaw (Pliocene?) deposits are exposed at only a few places along the Waccamaw River in Horry County, South Carolina. Paleoecologic interpretations of three sections were based on detailed molluscan and foraminiferal studies supplemented by binocular and grain-size analyses of the sediments.

In the type area the Waccamaw Formation consists principally of fine to medium, unconsolidated shell-bearing sands. The maximum thickness of the formation is unknown; however, the observed thicknesses range from 9 to 20 feet. Throughout the type area the Waccamaw Formation rests unconformably on the late Cretaceous Peedee Formation and is overlain unconformably by unfossiliferous Pleistocene sands.

Essentially all of the type Waccamaw Formation was deposited in an open, unrestricted ocean on the inner shelf (2-12 fathoms) or the shallow part of the intermediate shelf (12-35 fathoms). The water temperature is judged to have been in the range of that off the present coast of central and southern Florida. The salinity of the water was normal for the open ocean. Turbidity of the water was negligible, and water turbulence did not greatly affect the ocean floor, although the water appears to have been well oxygenated.

The classic section at Tilly Lake is located on the upper edge of the marine Suffolk Scarp (Pleistocene). The Waccamaw deposits there were apparently transported by mass-movement downward toward the scarp-slope during the Pleistocene.

The authors identified 126 molluscan and 60 foraminiferal species from the three sections studied.

TABLE OF CONTENTS

ILLUSTRATIONS

INTRODUCTION

Location and Purpose

The type Waccamaw (Pliocene?) exposures occur along the banks of the Waccamaw River in Horry County, South Carolina (Fig. 1 and 2). All three of the fossiliferous exposures occur in the Nixonville Quadrangle between Tilly Lake on the southwest and Red Bluff on the northeast, a distance of approximately 10 miles (Fig. 2). Generally, the banks along the river are covered by slump, soil and vegetation and thus several sections reported by earlier workers (Dall, 1892; Tuomey, 1848; and Sloan, 1907) are no longer available.

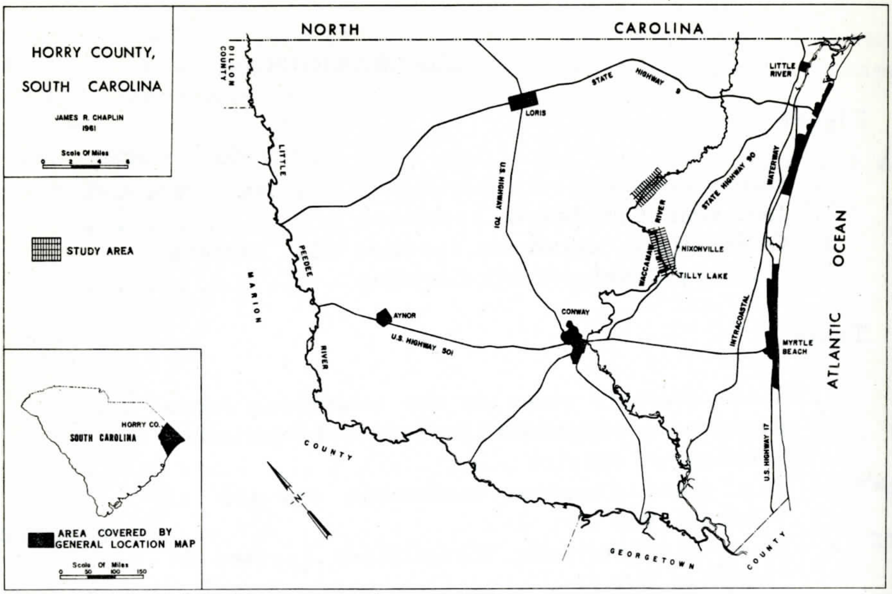


Figure 1. Horry County, South Carolina. Area of type Waccamaw exposures is hachured.

The objectives of this study are to make an accurate interpretation of the depositional environment of all of the exposed type Waccamaw Formation in order to establish paleontologic criteria that will be useful in identification of the Waccamaw deposits outside the type area, and to gain information that ultimately will help to more accurately establish the age of the Waccamaw Formation

To these ends a rather detailed paleoecologic analysis of the fauna, especially the mollusks and the foraminifers, was made, and the lithology and local stratigraphic features were closely examined.

Most geologists have agreed, since Dall's publication (1892), that the Waccamaw Formation should be considered Pliocene in age and, further, that it should be correlated with the Caloosahatchee Formation of Florida (Cole, 1931; Cooke, 1936; Gardner, 1943; Mansfield, 1936, and 1938; Miller in Clark, 1912 and Richards, 1950).

Du Bar (1958) concluded that the Caloosahatchee Formation is a Pleistocene deposit and suggested (1958 and 1959) that the Waccamaw Formation is also possibly Pleistocene. In an effort to determine which molluscan species, if any, are confined to the Waccamaw Formation, Du Bar and Solliday (1961) prepared a check list of Duplin (Late Miocene) species, and Du Bar (1962) prepared a check list of Waccamaw species.

Most recent studies of the Waccamaw fauna are those of Gardner (1945, and 1948) and Cole (1931).

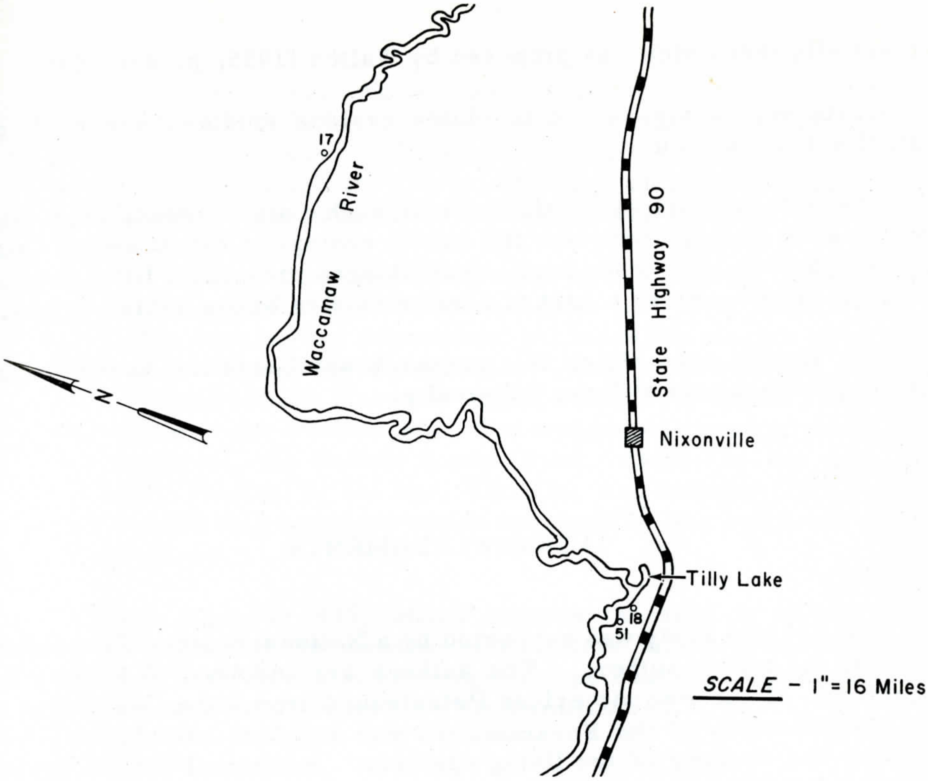


Figure 2. Location of measured sections.

Method of Study

The authors collected samples from the three exposed sections in the Waccamaw Formation type area (Fig. 2). Each bed in each section was sampled so that vertical faunal and lithologic changes in the outcrop could be studied closely and as much learned of the depositional history of the deposits as possible. Eleven samples of 0.5 cubic foot each were collected for the macrofauna; 13 smaller samples served as a source of foraminiders, and additional samples were obtained for lithologic study.

The fossils were identified and the number and percentage of each species in each sample was determined. All the Waccamaw macrofaunal collections housed at the U. S. National Museum were examined.

Foraminifera were obtained for analysis by disaggregating 100 gram samples in varsol. After disaggregation the sample was washed through a nest of 8 mesh (2.38 mm.), 30 mesh (0.595 mm.) and 230 mesh (0.062 mm.) sieves. When the micro samples were dried the fractions below 2.38 mm. were recombined and each sample was divided in a Jones Microsplit in an attempt to obtain a fraction which would contain approximately 300 individuals. Thus, the procedure followed was essentially that which was proposed by Walton (1955, p. 993-994).

Grain size analyses and insoluble residue studies were made of samples from each unit.

The paleoecological significance of each faunal assemblage was inferred by comparison with the known ecology of extant species and by comparison with other fossil assemblages previously fitted into an ecologic framework as a part of earlier studies by the senior author.

The fossils upon which this research was based are housed in the Geology Department at Duke University.

ACKNOWLEDGMENTS

The present study was supported by a National Science Foundation grant to the senior author. The authors are indebted to Robert R. Lankford, of the Pan American Petroleum Corporation, who aided in the identification of the Foraminifera and supplied valuable data regarding the ecology of the living species. Additional data on the ecology of foraminifers was given by Donald E. Cebulski of the Monsanto Petroleum Corporation. William R. Walton of the Pan American Petroleum Corporation very graciously provided the junior author with access to numerous reference samples representing a variety of recent marine environments. At the U. S. National Museum, Druid Wilson and Harald Rheder made all Waccamaw macrofaunal collections available to the senior author. John Wells of Cornell University identified the corals and Allan Cheetham of Louisian State University identified the bryozoans. The authors were aided in the field by James R. Solliday and James W. Fowler of the University of Houston, and by Hobart W. C. Furbunch of Myrtle Beach, South Carolina.

GENERAL GEOLOGY

Geomorphology

The area in the Nixonville Quadrangle through which the Waccamaw River flows is low, flat and poorly drained. The elevation is generally less than 50 feet above present sea level and except at the banks of the river, the average relief is only about ten feet. The many swamps of the area are usually elliptical in outline and oriented with their long axes southeast-northwest. These are the "Carolina Bays", and although they have attracted the attention of many geologists, their origin remains in doubt (Prouty, 1952).

The surface throughout the area is depositional in origin and was formed by regressing Pleistocene seas and later modified by fluvial and eolian erosion and deposition. At least two marine terrace-plains occur in the Nixonville Quadrangle. The lower seaward and youngest one is the Pamlico Terrace-Plain; the older, higher, landward terrace-plain is the Wicomico. The topographic boundary between these two features, the Suffolk Scarp (Flint, 1940), is not well defined; however, studies by Du Bar, Chaplin, and Solliday (1961) have fairly well located this boundary which everywhere lies southeast of the Waccamaw River.

State Highway 905, which crosses the area in an east-west traverse and which is located immediately inland from the Waccamaw River, follows an east-west ridge of sand dunes which possibly formed at maximum transgression of the Pamlico Sea.

Structure

The type Waccamaw deposits lie on the south side of the Cape Fear arch, but are essentially horizontal. The regional dip of the Waccamaw Formation is less than 1 degree and is essentially in an east-southeast direction. Locally, dips greater than 1 degree are probably primary, being related to irregularities in the Waccamaw sea floor at the time of deposition.

Stratigraphy

In its type area the Waccamaw Formation rests unconformably on the compact marine sands of the Cretaceous Peedee Formation (Fig. 3). Unconformably overlying the Waccamaw beds are nonmarine sands of late Pleistocene age. It is likely that most of these Pleistocene sands are a continental facies of the marine "Pamlico deposits" to the southeast.

The Waccamaw seems to occur as discontinuous, isolated erosional patches throughout the type area. It is probably that the formation never exceeded 35 feet in thickness; however, the average thickness of the Waccamaw Formation has not been determined. In the outcrops along the Waccamaw River the Waccamaw Formation ranges in thickness from 9.0 to 20.0 feet but at only one locality was the base of the formation observed. At Tilly Lake (Fig. 2) the lowermost part of the Waccamaw outcrop contains numerous reworked Cretaceous fossils, caliche nodules and pieces of the Peedee Formation, and the actual contact with the Peedee Formation is exposed at low water level. The composite exposed thickness of the section at Tilly Lake is about 11.0 feet. A mobile power auger hole (CW 1) drilled near Tilly Lake (Fig. 2) extended through at least 19 feet of the Waccamaw before reaching the Peedee.

Lithology

The type Waccamaw deposits are typically fine to medium unconsolidated shell-bearing sands, or argillaceous calcareous sands with a few local occurrences of hard sandy limestone and calcareous sandstone. The weathered exposures are yellow, orange, or red-brown; whereas fresh outcrops are blue-gray or gray. Generally, the fresh exposures are more calcareous than those that have been weathered.

Most of the sands are well sorted; the most fossiliferous beds give, as to be expected if the fauna is essentially in place, the highest coefficients of sorting. The range of the coefficient of sorting for units from stations WA 17, WA 18 and WA 51 is 1.36 to 4.630, with an average of 2.52.

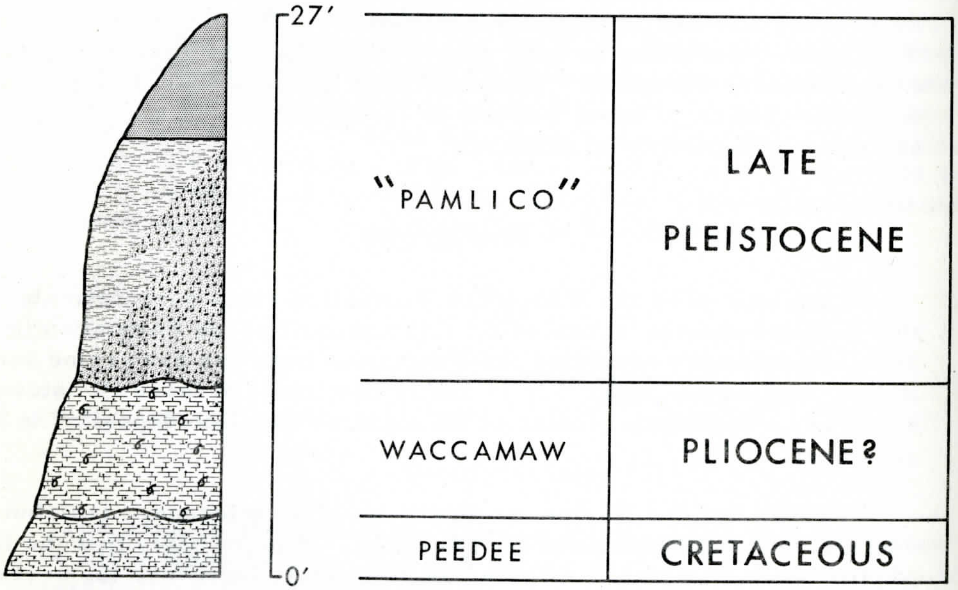


Figure 3. Generalized columnar section for eastern Horry County, South Carolina

DEPOSITIONAL ENVIRONMENTS

General Statement

The known ecology of the molluscan species represented in the type Waccamaw deposits and the ecology of closely related extant species is summarized in Table 1. The ecology of the most characteristic foraminifera is presented in Table 2. Much of the data in these two tables were derived from the writings and observations of Abbott (1954), Bandy (1954), Cebulski (1961), Cushman (1918, 1944), Dall (1890, 1903), Gardner (1943, 1948), Johnson (1934), Ladd (1951), Ladd, Hedgpeth and Post (1957), Lankford (1959), Parker, F. L. (1948), Parker, R. H. (1956, 1959, 1960), Phleger (1952, 1955, 1960a, 1960b), Phleger and Parker, F. L. (1951), Smith (1959), and Walton (1955, 1960, 1963).

The bathymetric-environmental classification used in this paper is based on the one proposed by R. H. Parker (1960) for the modern Gulf of Mexico. Parker's bathymetric subdivisions of the shelf are listed below:

a. Inner shelf (2-12 fathoms)
b. Intermediate shelf (12-40 fathoms)
c. Outer shelf (40-65 fathoms)

The moders ecology of the foraminifers (Table 2) suggests an open ocean environment for the typical Waccamaw deposits, but indicates a water depth somewhat deeper than that deduced from the mollusks.

The common occurrence of bryozoans and colonial corals would seem to result from relatively clear, well circulated water.

Gardner (1917) judged the Waccamaw Formation to be older than the Caloosahatchee Formation of Florida. Gardner contended that typical Caloosahatchee species, such as _Anadara rustica_, occur sparingly in the Waccamaw Formation because they were in an incipient stage of their evolution and had not yet had time to become numerous. It seems much more likely to the authors that these species are rate in the Waccamaw Formation because they were tropical species which could not successfully establish themselves in the cooler Waccamaw waters. In short, these typical Caloosahatchee species were at the northern extremity of their geographic range in South Carolina. It is even likely that they did not reproduce this far

Table 1. Some Ecologic Notes on the Molluscan Fauna.

PELECYPODA	ECOLOGY
1. Nucula proxima Say	1. Nova Scotia to Florida and Texas. On shelf to 100 fms.; common just offshore in mud.
2. Nuculana acuta Conrad	2. Cape Cod to West Indies. Bay to 1,000 fms. Nearshore form in Gulf of Mexico lives where water temperature never below 65° F.
3. Glycymeris americana (Defrance)	3. North Carolina to Northern Florida and Texas. 15 to 63 fms.
4. Glycymeris pectinata (Gmelin)	4. North Carolina, Florida and West Indies. 2 to 175 fms., optimum 1 to 12 fms.
5. Fossularca adamsi (Dall)	5. Cape Hatteras to Brazil. Shelf; common under rocks.
6. Anadara lienosa (Say)	6. North Carolina to Florida and Texas, to outer edge of shelf; optimum - 12 fms. or more on hard bottom, where water temperature never drops below 65° F.
7. Anadara rustica (Tuomey & Holmes)	7. Occurs in the Caloosahatchee Formation of Southern Florida and judged there to be a tropical shelf species.
8. Anadara transversa improcera Conrad	8. Anadara transversa (Say). Cape Cod, Florida and Texas. Open, high salinity bays and sound centers to outer shelf; optimum - shelf. Salinity range 23 to 40 parts; temperature range 9 to 33° C.
10. Noetia limula (Conrad)	10. Noetia ponderosa (Say.) Massachusetts to Florida and Texas. Shelf, 0 to 13 fms.; optimum - banks on shallow shelf to 10 fms. Chlorinity above 17 parts; occurs in high salinity open bays and sound centers.
12. Ostrea sculpturata Conrad	12. Known only as a fossil. Apparently ranges from Crassostrea virginica reefs to shallow shelf environments.
14. Amusium mortoni (Ravenel)	14. Amusium papyraceus Gabb. Gulf of Mexico, West Indies and Bermuda. 13 to 60 fms. on shelf. Lives where minimum water temperature never drops below 65° F.
16. Chlamys solarioides (Heilprin)	16. This fossil species is commonly found elsewhere associated with shallow shelf assemblages.
18. Plicatula marginata Say	18. Plicatula gibbosa Lamarck. North Carolina to Florida, Gulf States and West Indies. Intertidal to offshore; abundant in deeper calcareous banks of Gulf of Mexico.
19. Anomia simplex d'Orbigny	19. Cape Cod to Florida, Gulf of Mexico and West Indies, Open high salinity bay and sound centers to outer shelf; optimum - shelf or hard surfaces. Salinity range 5 to 41 parts; temperature range 4 to 34° C.
22. Verticordia ornata Conrad	22. North Carolina to West Indies. 5 to 687 fms.; optimum 40 to 65 fms. on outer shelf.

Table 1. Some Ecologic Notes on the Molluscan Fauna. Contd.

PELECYPODA	ECOLOGY
23. Astarte concentrica bella Conrad	23. The genus has a bathymetric range of 6 to 600 fms. and a geographic range from the Arctic to the West Indies. Most species seem to live in cool water.
24. Eucrassatella speciosa A. Adams	24. North Carolina to West Indies. 3 to 100 fms.; most typical at water depth of 40 to 65 fms.
25. Crassinella lunulata Conrad	25. North Carolina, Florida and West Indies. Restricted inlet and shelf; optimum - shelf, depth range 1 to 540 fms.; salinity range 30 to 40 parts; temperature range 9 to 30° C.
26. Cardita arata (Conrad)	26. Cardita floridana Conrad. Southern half of Florida and Mexico. High salinity bays and shallow shelf on sandy mud bottom. Minimum temperature about 50° F.
27. Cardita granulata (Say)	27. Cardita armilla (Dall. Between Mississippi Delta and Cedar Keys, Florida, 24 to 500 fms.; most typical of upper slope - 50 to 500 fms.
28. Cardita perplana (Conrad)	28. North Carolina To Gulf of Mexico, 1 to 70 fms.; optimum - sands of shelf below 13 fms.
29. Cardita tridentata (Say)	29. North Carolina to Florida and West Indies (?). 0 to 124 fms.; optimum - shelf.
30. Chama gardnerae Olsson & Harbison	30. Chama congregata Conrad. North Carolina to West Indies. 1 to 52 fms.; optimum - shallow shelf to 12 fms. Abundant on shallow calcareous banks with Chama macerophylla Gmelin.
31. Echinochama cornuta (Conrad)	31. North Carolina, Florida, Texas, and West Indies. 0 to 45 fms.; optimum 3 to 8 fms. Shell, gravel Lithothamnium and coral bottoms
33. Phacoides multilineata (Tuomey & Holmes)	33. North Carolina to Florida. Bay to 120 fms.; optimum - shallow shelf to 11 fms. Most common on sandy bottoms.
34. Phacoides radians (Conrad)	34. North Carolina, Florida, and Puerto Rico. 5 to 85 fms.
35. Phacoides trisulcatus (Conrad)	35. North Carolina to Brazil. 10 to 20 fms.; optimum 12 fms. or more.
36. Phacoides waccamawensis Dall	36. Phacoides amiantus (Dall). North Carolina to both sides of Florida. Sound to 640 fms.; optimum - pass to 12 fms. Temperature range 10 to 34°C; salinity range 11 to 36 parts; sandy, shelly sand substrate.
37. Laevicardium sublineatum (Conrad)	37. Laevicardium laevigatum Linné. North Carolina to West Indies. 1 to 75 fms.; genus most common on shelf; typical in Gulf between 12 and 40 fms.

Table 1. Some Ecologic Notes on the Molluscan Fauna. Contd.

PELECYPODA	ECOLOGY
39. Mercenaria campechiensis (Gmelin)	39. Chesapeake Bay to Florida, Texas and Cuba. Bay to shallow shelf (0 to 12 fms.). In Gulf of Mexico - typical of open bay and sound margin assemblages. Temperature 9 to 36° C.; salinity range 15 to 69 parts.
40. Macrocallista nimbosa Solander	40. North Carolina, Florida and Texas. Common on sandy bottoms of shallow shelf (0 to 12 fms.).
41. Macrocallista sp. cf. M. maculata Linné	41. Macrocallista maculata Linné. North Carolina, Gulf of Mexico and Brazil. Common in high salinity bays with sandy mud bottom and on shelf to 30 fms. Minimum temperature about 65° F.
42. Pitar sayana (Conrad)	42. Pitar cordata Schwengel. 13 to 15 fms. on shelf of Gulf of Mexico where temperature does not drop below 65°F. The genus common on shelf but ranges to at least 801 fms.
43. Chione cancellata (Linné)	43. North Carolina to Florida, Texas, and West Indies. Open high salinity bays and sound margins, inlets and shallow shelf. Sand and silty sand bottoms; salinity range 23 to 69 parts; temperature range 9 to 36° C.
44. Chione cibraria (Conrad)	44. Chione intapurpurea Conrad. North Carolina, Texas and Honduras. 0 to 12 fms. on shallow shelf.
45. Chione grus Holmes	45. North Carolina, Key West, Louisiana. Pass to 63 fms.; optimum - 12 to 40 fms. (Intermediate shelf).
46. Chione latilirata athleta (Conrad)	46. North Carolina, Florida and Texas, shelf; 3 to 124 fms.
47. Transenella carolinensis Dall	47. The genus is most common on the intermediate shelf.
49. Gouldia metastriata (Conrad)	49. Gouldia cerina (C. B. Adams). North Carolina, Florida, and West Indies. Optimum - 12 to 40 fms. (Intermediate shelf). Minimum temperature 65° F.
50. Gemma magna Dall	50. Gemma gemma purpurea H. C. Lea. Eastern United States to Puerto Rico. Loose sands of intertidal flats.
51. Tellina dupliniana Dall	51. Genus - bay, intertidal to 640 fms.
52. Semele bellastriata (Conrad)	52. North Carolina, Florida to West Indies. 60 to 30 fms.; optimum - shelf.
54. Abra aequalis (Say)	54. North Carolina, Texas, to West Indies. Low tide to 13 fms.; typical of open bay and sound center assemblages of northern Gulf of Mexico. Salinity range 23 to 43 parts; temperature range 9 to 33° C.; sand, silty sand, clayey sand bottom.

Table 1. Some Ecologic Notes on the Molluscan Fauna. Contd.

PELECYPODA	ECOLOGY
55. Ensis directus Conrad	55. Gulf of St. Lawrence to Florida. Enclosed bays; low to intermediate salinity.
56. Donax fossor Say	56. Donax variabilis Say and D. fossor Say. Long Island to Florida and Texas. Inlet to shallow shelf, typical beach forms.
57. Spisula similis (Say)	57. Nova Scotia to South Carolina, Florida and Gulf of Mexico. Shallow continental shelf of Gulf of Mexico (0 to 12 fms.). Chlorinity above 14 to 17 parts.
58. Mulinia lateralis Say	58. Canada to Mexico. Bay to shallow shelf (0 to 12 fms.). Extremely euryhaline (nearly fresh to hypersaline). Substrate mud, sand, silty shell.
59. Caryocorbula barrattiana (C. B. Adams)	59. North Carolina, Florida to West Indies. 2 to 287 fathoms; optimum - shelf.
60. Caryocorbula inaequalis (Say)	60. Caryocorbula swiftiana C. B. Adams. North Carolina to West Indies. 7 to 450 fms. Minimum temperature 65° F. ?
GASTROPODA AND SCAPHOPODA	
62. Retusa canaliculata (Say)	62. Nova Scotia to Florida and West Indies. Enclosed bays and shelf. Salinity range 20 to 39 parts; temperature range 8 to 36° C.
63. Ringicula floridana Dall	63. Ringicula semistriata d/Orbigny. North Carolina to southeast Florida and the West Indies; 34 to 107 fms.; optimum for genus is intermediate and deep shelf.
64. Terebra concava Say	64. North Carolina to both sides of Florida. Shallow shelf.
65. Terebra dislocata Say	65. Virginia to Texas and West Indies. Pass to near beach.
66. Conus adversarius Conrad	66. Fossil species which occurs with shallow shelf faunas in Caloosahatchee Formation and late Miocene formations of southeastern U. S. A.
67. Conus jaspideus Gmelin	67. South half of Florida and West Indies. Common in shallow water on sand.
68. Clathrodrillia ebenina (Dall)	68. Florida to Vera Cruz. Nearshore.
70. Crassispira sp. cf. C. perrugata (Dall)	70. Genus - low tide to 90 fms.
72. Kurtziella sp. cf. K. limontella Dall	72. Kurtziella limontella Dall. North Carolina to both sides Florida. 5 to 48 fms.; optimum - shelf.
73. Oliva sayana Ravenel	73. North Carolina to Florida, and Gulf States. Sand and muddy sand substrate; chlorinity above 17 pts. Passes to shallow shelf; common in surf zone.

Table 1. Some Ecologic Notes on the Molluscan Fauna. Contd.

GASTROPODA AND SCAPHOPODA	ECOLOGY
74. *Olivella mutica* (Say)	74. North Carolina to Florida, Texas, and West Indies. Sandy, silty clay, shell substrate. Bay to 10 fms.; optimum - passes.
75. *Bullata dacria* (Dall)	75. Genus - 1 to 400 fms.; optimum - 0 to 12 fms.
76. *Marginella aureocincta* Stearns	76. North Carolina, Florida and West Indies. Low tide to 90 fms.; optimum - shelf.
77. *Prunum apicinum* (Menke)	77. North Carolina, Florida, Gulf States and West Indies. High salinity bays to shallow shelf; minimum temperature about 55° F.
78. *Prunum contractum* (Conrad)	78. Similar to *Prunum apicinum* (Menke)
80. *Prunum eulima* (Dall)?	80. *Prunum limatula* Dall. North limit near Cape Hatteras, North Carolina.
82. *Busycon contrarium* (Conrad)	82. South Carolina, Florida and Gulf States. Inlets, to shallow shelf. Sand and shell substrate, 3 to 30 feet; temperature range 9 to 30° C.; salinity range 30 to 40 parts.
84. *Nassarius consensa* (Ravenel)	84. North Carolina, Florida to Bahamas. Minimum temperature 65° F.; 13 to 40 fms.
87. *Anachis avara similis* (Ravenel)	89. Martha's Vineyard, Mass., Florida to Texas and Yucatan. Sound and pro-delta slopes to 50 fms.
92. *Murex brevifrons* Lamarck	92. South Florida, West Indies, south to British Guiana. Not recorded from bays; generally associated with shelf species in Caloosahatchee marl.
96. *Fossarus anomala* (C. B. Adams)	96. Jamaica. Associated in Neogene strata with shallow shelf assemblages.
97. *Trivia suffusa* Gray	97. Southeast Florida and the West. Indies. On reefs in 1 to 3 fms.; off Cedar Keys, Florida.
98. *Natica canrena* (Linné)?	98. North Carolina, Key West and West Indies. Low tide to 60 fms.; optimum - shelf; typical on outer shelf (40 to 60 fms.).
100. *Tectonatica pusilla* (Say)	100. Cape Cod to Florida, Gulf States and West Indies. Pass to 18 fms.; optimum - pass to 11 fms. on shallow shelf.
101. *Polinices duplicatus* (Say)	101. Cape Cod to Florida and Gulf states. Bay to 15 fms.; optimum - pass to shelf. Temperature range 9 to 30° C.; sand substrate; burrows into sand.
102. *Crucibulum auriculum* (Gmelin)	102. West Florida, Lower Keys and West Indies. On shelf to 54 fms.
103. *Crepidula fornicata* Linné	103. Canada, Florida and Gulf states. Passes to shelf (10 fms.); salinity range 30 to 40 pts.; temperature range 9 to 40° C.

Table 1. Some Ecologic Notes on the Molluscan Fauna. Contd.

GASTROPODA AND SCAPHOPODA	ECOLOGY
104. Cerithiopsis abrupta Watson?	104. Cerithiopsis subulata Montagu. Massachusetts to West Indies. Shelf from 1 to 33 fms.
105. Seila adamsi H. C. Lea	105. Massachusetts to Florida, Texas and West Indies. Bay to shallow shelf (4 fms.). Occurs associated with Crassostrea virginica reefs in Texas bays, Temperature range 4 to 34° C.; salinity range 5 to 41 pts.
106. Turritella subannulata Heilprin	106. North Carolina, Florida, Texas, and West Indies. Common on shallow shelf.
108. Caecum spp.	108. Inlets to shallow shelf. Most common in Pamlico formation of South Carolina in shallow shelf facies.
114. Teinostoma smikron Gardner	114. Genus found from passes to 640 fms.; optimum on shelf.
115. Littorina irrorata Say	115. New York to North Florida and Texas. Common in sedges of brackish-water marshes.
116. Epitonium sayanum Dall?	116. Genus found from bays to 120 fms.; optimum to 12 fms.
117. Melanella sp.	117. Genus found from bays to 640 fms.; optimum passes to shelf.
118. Liotia gemma (Tuomey & Holmes)	118. North Carolina to Florida. On shelf to 22 fms.
119. Odostomia seminuda C. B. Adams	119. Nova Scotia to Gulf of Mexico. Beach of 12 fms.; optimum - shallow shelf to 12 fms.
123. Calliostoma sp. cf. C. jujubinum Gmelin	123. Calliostoma jujubinum Gmelin. North Carllina to Texas and West Indies. On shelf at least to 30 fms.
125. Diodora nucula Dall	125. As a fossil it invariably occurs with typical shelf assemblages.
126. Dentalium sp.	126. Genus from bays to 1591 fms.; optimum below 12 fms.

Table 2. Reported Ecologic Occurrences of Foraminifer Indicator Species.

Amphistegina gibbosa d'Orbigny - Usually reported as A. lessonii d'Orbigny. As such, range is Miocene to Recent. Zone 4 (181-250 feet) of Bandy, 1956; indicates clear water, normally in conjunction with reef-like deposits.

Angulogerina occidentalis (Cushman) - Apparently not reported from recent seas. Abundant in Miocene and in Waccamaw Formation. The genus Angulogerina is reported to range 3-360 fathoms, maximum abundance 20-100 fathoms (Walton, 1955); zone 4 (330-680 m.) of Parker (1948); 10-18 fathoms, rare and shallower off Maine Coast (Cushman, 1944); south of Cape Cod always deeper than 63 m. (Parker, 1952); greatest frequency 50-120 m., no shallower than 30 m. (Phleger and Parker, 1951).

Asterigerina carinata d'Orbigny - Depths shallower than 50 m. (Phleger, 1951); most abundant on prominences of zone 3 (75-120 m.) Bandy, 1954; restricted to open ocean, shelf environment (Walton, 1960); apparently indicative of clear water (Cebulski, personal communication, 1963).

Bolivina marginata Cushman - Miocene to Pliocene? approximately; not reported from modern seas. The genus Bolivina ranges from shore to abyssal depths.

B. pseudoplicata Heron-Allen and Earland - Shallow water, abundant, 6-11 fathoms off coast of Maine, (Cushman, 1944); most abundant in zone 2(15-90 m.) (Parker, 1948); good shallow water indicator (Lankford, 1963, personal communication). Apparently recognized only from the coastline bordering the Atlantic Coast.

B. pseudopuncata Hoglund - Rare, off coast of New Hampshire and Greenland from cores (Phleger and Parker, 1952).

Bucella frigida (Cushman) - One of commonest shallow-water forms 1 1/2-18 fathoms off Maine (Cushman, 1944). Most abundant in Facies 2 (28-30 0/00 salinity) (Parker, 1952). Pleistocene-Recent.

Buliminella elegantissima (d'Orbigny) - Optimum frequency above 80 m. (Phleger, 1951); characteristic of zone shallower than 10-20 fathoms depth (Walton, in press); found only in zone 2 (15-90 m.) of Maryland Traverse (Parker, 1948); small specimens found off Vineyard Sound (Cushman, 1944). Paleocene-Recent.

Cassidulina caribeana Redmond - Open sea, neritic environment (Redmond, 1953); reported only as fossil. Miocene-Pliocene?

C. subglobosa (H. B. Brady) - Present at all depths samples (Phleger, 1951); 5-10 fathoms, most abundant 20-30 fathoms (Walton, 1955).

Cibicides floridanus (Cushman) - Open shelf, neritic zone. Genus Cibicides ranges from inner neritic to abyssal depths; Miocene-Recent.

C. lobatulus (Walker and Jacob) - Very common species in shallow water of New England, 8-18 fathoms (Cushman, 1944); restricted to sand facies (Parker, 1952a). Not reported from Gulf of Mexico; Eocene-Recent.

Elphidium discoidale (d'Orbigny) - Particularly characteristic of depths from beach to 100 m. (Phleger, 1951); common from shore sands, Newport, Rhode Island; typically warm-water species (Cushman, 1944); Miocene-Recent.

E. gunteri Cole - Characteristic of shallow water from brackish bay to mid-neritic zone. Most abundant in brackish and beach zones (Phleger, 1960a); fauna 1 indicator (8-40 feet) (Bandy, 1956); Miocene-Recent.

E. poeyanum (d'Orbigny) - Lower lagoon indicator (Phleger, 1960a); indicator for fauna 1 (8-40 feet) (Bandy, 1956); Miocene-Recent.

Table 2. Reported Ecologic Occurrences of Foraminifer Indicator Species. Contd.

E. orbiculare (H. B. Brady) - Off coast of Maine, shallow, (Cushman, 1944); open sea beaches of Vineyard Sound (Todd and Low, 1961).

Epistominella pontoni (Cushman) - Genus Epistominella found as ranging from typical sound and deltaic marine (Lankford, 1959) to outer portion inner neritic zone, approximately 10-30 fathoms (Walton, in press); Miocene-Pliocene.

Hanzawaia concentrica (Cushman) - Abundant shallow water species, greatest abundance at depths less than 100 m. (Phleger and Parker, 1951); normally a southern warm water species, abundant in Vineyard Sound, 6-13 fathoms, (Cushman 1944); 36 m. or less off New Jersey and 68 m. or less off Maryland (Parker, 1948). In Gulf of Mexico, greatest abundance of Hanzawaia species found 10-25 fathoms (Walton, in press); Miocene-Recent.

Neoconorbina terquemi (Rzehak) - Previously reported as Discorbis orbicularis (Terquem). Under this name, the species is reported as part of main reef assemblage (Cebulski, 1961); apparently a good, clear-water indicator (Lankford, personal communication); decidedly warm-water species (Cushman, 1933) Miocene-Recent.

Quinqueloculina seminulum (Linné) - Very common from shallow water of New England Coast. (Cushman, 1944); most abundant in facies 3 (15-90 m.) Parker, 1948; not reported from Gulf of Mexico; Miocene-Recent.

Q. lamarckiana d'Orbigny - Greatest feequency less than 100 m. (Phleger and Parker, 1951), beach assemblage (Phleger, 1960a); Oligocene-Recent.

Rosalina columbiensis (Cushman) - Open sound environment, Martha's Vineyard, (Todd and Low, 1961); restricted to nearshore stations, sand facies, (Phleger, 1952). So far reported only from the Recent. However, the range of variation of this species approaches the form R. floridana (Cushman) thus introducing a possible source of error in age range with consequent extension to Miocene.

Textularia agglutinians d'Orbigny - Most abundant in reef fauna (Cebulski, 1961). Apparently a warm, shallow-water form; common in Miocene from Florida to Maryland (Cushman, 1933); Jurassic? - Recent, (Cushman, 1933).

north and that all the specimens in the Waccamaw represent the product of spat drifted into the area from the Gulf Current or from farther south.

It can be seen from a perusal of Table 1 that most of the molluscan species are found commonly or exclusively on the shallow shelf (2-12 fathoms) or the intermediate shelf (12-40 fathoms). Some species tolerate restricted or enclosed water environments and a few are virtually restricted to such environments today. Some of the species such as Chama gardnerae and Plicatula marginata probably preferred a calcareous bank or shell bottom environment, but none of the species are today typical of the outer shelf (40-65 fathoms) or deeper water.

Most of the species are stenotherms and stenohalines; however, some, such as Mulinia lateralis, can withstand great and frequent variation in both salinity and temperature.

That the water in which these Waccamaw faunas lived was somewhat warmer than off the coast of Horry County today is attested to by the fact that most of the extant species today do not range north of Cape Hatteras and many occur most typically in Floridan waters. The most tropical species of the Caloosahatchee Formation in southern Florida are absent or very rare in the type Waccamaw.

Paleoecologic interpretations based on studies of Recent marine organisms are fraught with problems even where the deposits to be interpreted are geologically young and the faunas are well preserved, abundant, and many species are extant. The nature of these problems has been set forth very well by Theodor Sorgenfrei (1960) in his monumental treatise on the molluscan assemblages of the marine middle Miocene of Jutland.

One very basic problem, which is gradually being alleviated, is the lack of data on the extant marine faunas. With the establishment of more marine laboratories and construction of new and efficient oceanographic vessels and the subsequent intensified efforts of marine scientists, information vital to paleoecologic interpretations will become available at an accelerating rate. The A.P.I. Project 51, which resulted in publication of "Recent Sediments, Northwest Gulf of Mexico", is an example of the type of cooperative effort of many scientists from diverse disciplines that is needed to acquire basic data and to establish principles useful to the working paleoecologist.

Most detailed marine studies have been and are still directed at shallow water, nearshore, commonly enclosed water environments. Emphasis by geologists seems to be mainly toward the dynamics of sedimentation, the physico-chemical properties of sediments, sedimentary structures, and distribution of sedimentary-mineralogic suites. Paleontologists have directed their efforts toward study of foraminiferal and ostracode populations. Macrofaunal studies have received their greatest attention from Californian and Northern European scientists.

Deductions about the paleoecology of the Waccamaw Formation, an Atlantic Ocean deposit, are based heavily on data derived from studies in the modern Gulf of Mexico. Conditions in the Gulf, a semi-enclosed body of water with mixed faunal elements, relics of Pleistocene fluctuations, and influxes of water from the Caribbean make it somewhat unique and not directly comparable to the Atlantic Ocean shelf areas off the Carolinas. Present interpretations very likely will be modified, at least slightly, as more information about the western Atlantic shelf area becomes available.

Another problem basic to study of Neogene marine faunas is the effect of Pleistocene climatic and sea level changes. For the past one million years the oceans of the world have alternately warmed and cooled relatively rapidly, and sea levels have raised or lowered with waxing and waning of continental glaciers. With each glacial or interglacial period stream regimen has been altered drastically throughout the world. Great volumes of sediments have been shifted in position both on the present coastal plain, and on the shallow shelf. Ocean currents undoubtedly have had their courses altered and physico-chemical and biological properties of great areas of the ocean have undergone repeated rapid changes.

Conditions outlined above were not typical of older Neogene shelf areas. Environments of the earlier Neogene must have been much more stable and equilibrium in faunal and floral communities must have been much greater. It is reasonable to assume that the Pleistocene still persists. Continental ice masses still cover appreciable areas of the earth's surface, and there seems no reason to suppose that we are not in the early moments of an interglacial stage and that some time in the geologically near future this stage will run its course and the continental ice masses will once again expand over the continents.

One cannot face these facts and not wonder just how atypical the distribution of modern shallow water marine organisms is and just how unusual are the present physico-chemical shelf environments in terms of the entire interval of Neogene time. For instance, how have these Pleistocene fluctuations affected the rate of evolution of marine organisms? Acceleration of both speciation and extinction seems a probably result to the authors. Have modern marine communities had time or opportunity to shift into their pre-Pleistocene bathymetric zones? It doesn't seem very likely.

The senior author has made the observation many times that older marine faunas of Neogene deposits in Southeastern United States consistently indicate deeper water conditions then can be explained in terms of other independent lines of information such as the stratigraphic framework, thickness of units, known or inferred configuration and position of shorelines, relationship of facies, and sedimentary features. Further, the foraminifers seem consistently to indicate deeper water than the macrofaunal elements.

Whatever the answers are to these problems they will not be discovered easily. It is obvious that a great deal must be learned about past and present oceanographic conditions, about community structure, biologic relationships of all kinds, speciation, factors controlling deposition of sediment types, relationship of organism to substrate, physiological ecology, preservational factors, diagenetic processes, and numerous other factors.

Progress has been, is being, and will continue to be made in the field of paleoecology. The future looks promising. What we should keep in mind is that whereas accurate stratigraphic interpretation is much dependent on paleoecologic data, paleoecologic interpretations are without real value taken out of stratigraphic context. In short, stratigraphic and paleoecologic interpretations are basically inseparable.

Finally, we must not lose sight, as we sometimes do, of the ultimate highest ideal of the science of geology--to reconstruct Earth history as accurately as the facts will allow.

Discussion of Sections

Station WA 17. The molluscan fauna from the exposure at Station WA 17 is large and varied, suggesting normal open sea conditions. This observation is substantiated by a close examination of the faunal elements. The most common macrospecies are listed below (Table 3).

Most of the species from Station WA 17 live today, or are represented by closely related species that live on the inner shelf (2-12 fathoms) and intermediate shelf (12-35 fathoms). With rare exceptions none of the species live exclusively or typically on the outer shelf (40-65 fathoms), and surf species are not common.

Table 3. The Most Abundant Molluscan Species at Station WA 17.

(P = less than 1%; C = common; numbers in extreme left correspond to position in check list, Table 9).

	Species	Units 1	2	3	4	5
	Pelecypoda			Percentage		
1.	Nucula proxima	0.0-10.1%	-	-	1.4%	-
3.	Glycymeris americana	0.0- 1.1	-	4.3	9.6	4.0
4.	Glycymeris pectinata	-	-	20.9	11.1	6.4
12.	Ostrea sculpturata	P	-	P	4.3	-
16.	Chlamys solarioides	0.0-92.5	C	3.8	P	P
18.	Plicatula marginata	12.9-19.1	-	3.8	8.2	10.5
23.	Astarte concentrica bella	-	-	4.3	6.1	7.2
25.	Crassinella lunulata	-	-	-	3.3	6.8
27.	Cardita granulata	0.0- 9.0	-	15.2	14.1	5.9
29.	Cardita tridentata	-	-	1.9	P	6.0
30.	Chama gardnerae	0.0- 9.0	-	-	2.8	4.4
36.	Phacoides waccamawensis	-	-	9.5	4.3	6.4
39.	Mercenaria campechiensis	-	-	2.4	-	P
45.	Chione grus	-	-	3.8	3.3	3.8
46.	Chione latilirata athleta	0.0- 1.1	-	5.2	4.9	10.0
59.	Caryocorbula barrattiana	-	-	9.5	5.6	-
60.	Caryocorbula inaequalis	-	-	-	-	8.5
	Gastropoda					
68.	Conus jaspideus	-	-	5.5	-	P
73.	Oliva sayana	-	-	5.5	P	P
74.	Olivella mutica	-	-	-	7.3	11.5
78.	Prunum contractum	-	-	-	57.8	28.9
100.	Tectonatica pusilla	-	-	-	-	7.3
102.	Crucibulum auriculum	-	-	-	-	2.1
103.	Crepidula fornicata	-	-	-	4.2	8.1
106.	Turritella subannulata	-	-	-	1.9	8.4
107.	? Turritella sp.	-	-	44.3	-	-
108.	-110. Caecum spp.	-	-	-	5.4	1.0
118.	Liotia pergemma	-	-	-	3.6	1.0
120.	Odostomia sp. cf. O. stimpsoni	-	-	-	-	2.1
124.	Diodora sp. cf. D. cayenensis	-	-	-	-	2.1
125.	Diodora nucula	-	-	-	3.6	6.3

The faunas are characteristic of the deeper outer portion of the inner shelf, or the inner shallow part of the intermediate shelf where the water is 10 to 15 fathoms in depth. These faunas are similar in many aspects to those of the lower transgressive units of the late Miocene Choctawhatchee deposits at Jackson Bluff, Florida (Du Bar and Taylor, 1962), but contain relatively fewer intermediate shelf forms. The lower Choctawhatchee beds at Jackson Bluff were concluded by Du Bar and Taylor to have been deposited at a depth of 17 to 21 fathoms.

Station WA 17 faunas are also similar to the uppermost fossiliferous unit of the Caloosahatchee Formation exposed on Shell Creek in southwestern Florida (Du Bar, 1962a, p. 30). Du Bar concluded that this fauna lived in the open ocean at a water depth of approximately 12 fathoms.

It is apparent that the Waccamaw molluscan species at WA 17 lived where salinity was normal for the open ocean, where the water was well oxygenated, on a loose sand and shell substrate that was occasionally disturbed by mild wave and current action. The mean annual water temperature was about that found off the coast of central and southern Florida today.

In the lower and middle part of the section, particularly in Units 2 and 3, Chlamys solarioides makes up a relatively high percentage of the macrofauna. In some layers or lenses valves of this pelecypod species are stacked in clusters, one valve on another, with the convex sides facing upward. The fauna of the lower part of the section is neither as diversified or abundant as in the upper part. This sparseness of individuals and species is possibly a factor of greater rate of sediment accumulation, or it could be related to selective leaching or unfavorable ecologic conditions. The heavy concentrations of valves of Chlamys, many with affixed barnacles, speaks against uninterrupted rapid deposition. It would seem that at least the Chlamys layers accumulated slowly so that there was time for the barnacles to become affixed and to attain the adult stage. In addition, considerable time might be required to account for the accumulation of six-inch layers of Chlamys valves unless, of course, they were transported to their present site by currents, as is possibly suggested by their orientation with the convex sides upward. It is to be noted that layers comprised of Chlamys solarioides have been observed by the senior author in the Caloosahatchee Formation (Du Bar, 1958a) and elsewhere. It is possible that these concentrations are related to the observed swarming habit of some living species of Chlamys.

There is no significant difference in grain size, degree of sorting, or skewness between the lower units (1 and 2) and the upper units

(3, 4 and 5). Further, the macrofossils of the lowest deposits point generally to deposition at a water depth essentially the same as for the uppermost units.

The forams are notably more poorly preserved in the lower unit, being considerably encrusted with calcium carbonate deposits. Unlike the macrofossils, the foraminifers are more abundant in the middle part of the section (Unit 2) and are well preserved. The paucity of macrofossils could be interpreted as a factor of selective leaching, however, had leaching of this unit been a significant factor either in the past or at present it seems likely that the tiny foram tests would have been removed more rapidly than the molluscan shells.

The weight of the evidence seems to be against significant selective leaching of unit 2, and is somewhat inconclusive regarding relative rates of deposition. It is the authors' opinion that weathering of the lower deposits (1 and 2) is very recent, affecting only the face of the outcrop to a depth of a few feet or more.

It is likely that local bottom conditions during deposition were responsible for the relative abundance of <u>Chlamys solarioides</u> in the lower and middle units (1 and 2) and the sparsity of other species. Precisely what these conditions were cannot be ascertained with the evidence at hand.

The foraminiferal fauna (Table 10) also points to deposition on the shallow or intermediate shelf in a depth range of 10 to 20 fathoms.

The most characteristic foraminifer species in the section are listed in Table 4.

From the foraminifers it seems possible to detect three parts of a transgressive-regressive cycle. The lower unit (1) appears to be in the upper part of a transgressive phase. Maximum transgression seemingly is represented by the middle unit (2). The abundance of foraminifers rises sharply in this unit. <u>Cibicides floridanus</u>, a common middle shelf indicator, rises to approximately 20 percent of the total assemblage. <u>Asterigerina carinata</u>, a good clear water indicator, is restricted to this unit, and <u>Amphistegina gibbosa</u>, also a clear water indicator, is especially characterized by its fresh unweathered appearance.

The upper deposits (Units 3, 4 and 5) represent the beginning of regressive conditions. Here the ratio of foraminifers to sediment weight drops to its lowest value.

<u>Rosalina columbiensis</u> and <u>Bolivina marginata</u>, species indicative

Table 4. Most Characteristic Foraminifer Species at Station WA 17.

Species	Units Lower (1)	Middle (2)	Upper (3, 4, and 5)
		Percentage	
Amphistegina gibbosa	P-6	3-5	2
Asterigerina carinata	-	3-4	P
Angulogerina occidentalis	5-19	9-14	2-8
Bolivina marginata	10-12	0-3	10-11
Bolivina pseudoplicata	2-5	2-5	0-2
Buccella frigida	0-P	P-2	0-P
Cassidulina caribeana	11-15	7-9	10-14
Cassidulina subglobosa	7-14	4-6	5-6
Cibicides floridanus	2-7	15-23	0-5
Epistominella pontoni	7-14	P-2	7-10
Hanzawaia concentrica	1-4	4-0	4
Lamarckina atlantica	0-3	P-1	-
Rosalina columbiensis	5-19	6-14	4

of shallow open seas, rise in abundance, whereas, indicators of deeper water such as Cibicides floridanus and Angulogerina occidentalis decrease sharply.

Throughout the section reworked Cretaceous fossils are found, but are readily recognized.

Cole (1931), after examining forams from the type Waccamaw, concluded that the formation was deposited at a water depth of no more than 16 fathoms and at a water temperature at or slightly higher than 20° C.

The bryozoan, Discoporella denticulata (Conrad) is common at Station WA 17, particularly in Unit 4. This is a species which today is restricted to the Atlantic from the straits of Florida to Beaufort, North Carolina, on the American coast and from Madeira to the Mediterranean. It has been recorded from depths of 3 to 63 fathoms and requires a loose, granular substrate and open marine water.

Clypeastroid echinoids are also common in this section, but all the specimens are fragmented and have not been identified.

Station WA 18 (Tilly Lake). The section at Tilly Lake has been studied by geologists for many decades and, historically, could be considered the classic exposure of the formation in South Carolina. It is kept clean and fresh by the undercutting action of the Waccamaw River during rainy seasons.

To the authors' knowledge it has not been noted previously that the Waccamaw deposits at Tilly Lake appear to have been transported. Above the basal 1 or 2 feet the section is characterized by well preserved macrofossils which generally range in diameter from 1.0 to 25.0 mm. This fauna is comprised of small adults and juvenile stages and fragments of larger species, none of which are in life orientation. Most of the shells are not greatly abraded. No indication of bedding is apparent in the upper 7 to 8 feet of the section, a fact inconsistent with the generally thin-bedded character of the formation at most localities in the Carolinas. Further, at Station WA 51, approximately 100 yards downstream, the deposits are apparently bedded, undisturbed and contain a fauna comprised of fossils of normal size range.

The lower 1 or 2 feet of the section contains large fragments of the Peedee Formation, large quartz and phosphate pebbles, caliche nodules and valves of the Cretaceous pelecypod Exogyra. These occur with abundant, commonly life oriented valves of <u>Mercenaria campechiensis</u>, a nearshore, generally enclosed water species. It is apparent that this lower part of the section represents the shallow water, nearshore, transgressive deposits of the Waccamaw Sea and that they are essentially in the place where they were originally deposited.

Proof that the upper part of the section at Tilly Lake has been transported is supplied by study of samples from drill holes located southeast of the exposure. In these holes abraded, small shells and lithology virtually identical to that of the Tilly Lake section are seen to grade into and to interfinger with typical "Pamlico" lithologies and fossil assemblages. Subsurface studies show that the Tilly Lake section is poised near the upper edge of a northeast-southwest trending scarp which is interpreted by the authors to be the Suffolk Scarp, and to have been cut by the "Pamlico Sea" (Sangamonian).

It is clear that a large portion of the Waccamaw in the vicinity of Tilly Lake was carried, during Pamlico Time, into the Pamlico Sea. It is surmised by the authors that movement of Waccamaw sediments was in response to stream action and mass wastage on land aided by nearshore marine currents in the Pamlico Sea. Additional drilling in the area should more precisely locate old stream channels and accurately delineate the area and volume of Waccamaw materials transported during Pamlico Time. It seems to the authors that mass wastage could have accounted for most of the movement at Tilly Lake. This conclusion is suggested by the following facts:

Table 5. Most Abundant Molluscan Species at Station WA 18.

(P = present, but less than 1%; numbers in extreme left correspond to position in Check list, Table 9).

	Species	Units 1	Units 2
		Percentage	
	Pelecypoda		
2.	*Nuculana acuta*	3.2%	1.8%
4.	*Glycymeris pectinata*	5.0	9.6
18.	*Plicatula marginata*	3.2	2.7
25.	*Crassinella lunulata*	5.0	6.5
29.	*Cardita tridentata*	6.5	10.2
30.	*Chama gardnerae*	5.9	2.8
50.	*Gemma magna*	21.6	30.6
58.	*Mulinia lateralis*	23.8	13.9
59.	*Caryocorbula barratiana*	9.5	5.6
	Gastropoda		
62.	*Retusa canaliculata*	3.9	-
64.	*Terebra concava*	-	4.5
74.	*Olivella mutica*	26.6	11.3
75.	*Bullata dacria*	1.3	2.3
76.	*Marginella aureocincta*	2.6	6.8
78.	*Prunum contractum*	-	33.1
79.	*Prunum contractum*?	6.8	-
82.	*Busycon contrarium*	4.5	-
100.	*Tectonatica pusilla*	7.3	8.0
101.	*Polynices duplicatus*	-	3.9
102.	*Crucibulum auriculum*	3.9	4.5
103.	*Crepidula fornicata*	P	25.1
105.	*Seila adamsi*	3.9	-
108.	-110. *Caecum* spp.	2.6	2.3
119.	*Odostomia seminuda*	3.9	-
120.	*Odostomia* sp. cf. *O. stimpsoni*	-	2.3
121.	-122. *Turbonilla* spp.	-	9.1
125.	*Diodora nucula*	1.3	2.3

(1) abrasion of shells slight, although larger shells broken
(2) sediments not oxidized
(3) lithology very similar to typical Waccamaw of general area
(4) ecologic suites of assemblages not greatly mixed
(5) the lower 1 to 2 feet of the section apparently disturbed only by wave action.
(6) sorting coefficient of 4.630 suggests that material was literally dumped in its present site.

For the most part the molluscan assemblages from the upper part of Section WA 18 represent an open marine shallow shelf (2 to 12 fathoms) environment. The fauna appears to have lived slightly nearer to shore in more shallow water than that a Station WA 17. This is indicated by the reduction of such shelf forms as Glycymeris americana, Chione grus, Chione latilirata athleta, Astarte concentrica bella, Conus adversarius, Natica canrena, and the influx of shallow water and semirestricted water forms such as Gemma magna, Retusa canaliculata, Olivella mutica, and Polynices duplicatus (Table 5).

The presence of the shallow water foraminiferal species, Bolivina marginata, Rosalina columbiensis, and numerous miliolids indicate shallow water, open marine deposition. The abundance of the clear water species Neoconorbina terquemi shows an abrupt increase in the uppermost part of the section, possibly indicating a clearer water stage (Table 6).

The shallow shelf bryozoan Discoporella denticulata (Conrad) is common at Station WA 18, and the coral Septastraea crassa Holmes, judged to be a shallow shelf form, occurs sparingly.

Station WA 51. Only the upper 2 feet of the 17 foot section of the Waccamaw Formation is exposed well enough to allow adequate sampling. All the lower slope is presently covered with a dense growth of vegetation.

Despite the fact that this section is located only 100 yards downstream from WA 18, there is no indication of significant transportation or reworking of the fauna.

The preservation of the fauna is very similar to that at WA 17, but the composition is closer to that of WA 18 with the exception that at WA 51 larger species, such as Glycymeris americana are more abundant, and a few small species such as Gemma magna are less common. Discoporella denticulata (Conrad), regular echinoid spines and barnacles are common.

Table 6. The Most Important Foraminifer Species at Station WA 18.

Species	Units	
	Lower (1)	Upper (2)
Neoconorbina terquemi	5	2-11
Bolivina marginata	12	9-10
Epistominella pontoni	9	8-10
Quinqueloculina lamarckiana	5	P-2
Rosalina columbiensis	3	4-9
Textularia agglutinans	-	3-8

Table 7. The Most Abundant Molluscan Species at Station WA 51.

(P = present, but less than 1%; numbers in extreme left correspond to position in Check list, Table 9)

		Percent
	Pelecypoda	
3.	Glycymeris americana	7.0%
11.	Ostrea sculpturata	16.4
16.	Chlamys solarioides	3.6
18.	Plicatula marginata	3.1
29.	Cardita tridentata	3.1
42.	Pitar sayana	3.3
46.	Chione latilirata athleta	2.1
50.	Gemma magna	1.5
51.	Tellina dupliniana	3.1
57.	Spisula similis	1.8
58.	Mulinia lateralis	23.6
59.	Caryocorbula barrattiana	12.5
	Gastropoda	
72.	Kurtziella sp. cf. K. limontella	13.9
74.	Olivella mutica	27.8
101.	Polynices duplicatus	13.9
103.	Crepidula fornicata	14.3
105.	Seila adamsi	13.9
116.	Epitonium sayanum	13.9

It appears from the macrofauna that the part of the Waccamaw Formation sampled was deposited in warm, clear, open, shallow shelf water at a depth near to 6 or 7 fathoms. This conclusion is particularly supported by the large percentage of Olivella mutica, Polynices duplicata, Mulinia lateralis, and Ostrea sculpturata (Table 7).

An examination of the foram fauna shows that Hanzawaia concentrica and Elphidium spp. comprise 48% of the fauna, suggesting a depositional environment on the open shelf in warm water with a maximum depth of 50 feet (Table 8).

Table 8. Most Characteristic Foraminifera at Station WA 51.

	Percentage
Hanzawaia concentrica	27
Cibicides sp. cf. C. floridanus	27
Elphidium sp. cf. E. poeyanum	11
Cassidulina subglobosa	4
Epistominella pontoni	6
Buccella frigida	3
Globigerinoides ruber	2

SUMMARY AND CONCLUSIONS

1. The type Waccamaw (Pliocene?) deposits are exposed at only a few places along the Waccamaw River in Horry County, South Carolina.

2. Paleoecologic interpretations of three sections were based on detailed molluscan and foraminiferal studies supplemented by binocular and grain-size analyses of the sediments.

3. In the type area the Waccamaw Formation consists of fine to medium, unconsolidated shell-bearing sands, or argillaceous calcareous sands with a small amount of hard sandy limestone and calcareous limestone.

4. The total thickness of the Waccamaw Formation is unknown, but the observed thicknesses in the type area range from 9 to 20 feet.

5. Throughout the type area the Waccamaw Formation rests unconformably on the Late Cretaceous Peedee Formation, and is overlain unconformably by unfossiliferous Pleistocene sands.

6. The beds are essentially horizontal in the type area.

7. The following conclusions were made by the authors regarding the depositional environment of deposits studied:

   a. Nearly all of the type Waccamaw Formation was deposited in an open, unrestricted ocean on the inner shelf (2-12 fathoms) or the shallow part of the intermediate shelf (12-40 fathoms).

   b. The water temperature is estimated to have been in the range found today off the east coast of central and southern Florida.

   c. Most of the assemblages lived in water of normal salinity for the open ocean.

   d. Turbidity of the water was at a minimum.

   e. Water turbulence did not greatly affect the bottom; however, the water was apparently well oxygenated.

   f. The section at Tilly Lake (Station WA 18) is located on the upper edge of the Suffolk Scarp (Pleistocene). These Waccamaw deposits seem to have been transported by mass movement downward toward the scarp-slope during the Pleistocene.

9. It is anticipated that this study will aid in recognition of the Waccamaw Formation in subsurface and will ultimately help to establish the precise stratigraphic relationship of the unit.

BIBLIOGRAPHY

Abbott, R. T., 1954, American Seashells: Van Nostrand Co., New York, 541 p.

Bandy, O. L., 1954, Distribution of some shallow water Foraminifera in the Gulf of Mexico: U. S. Geological Survey Prof. Paper 254F., p. 125-140, 4 pls.

__________, 1956, Ecology of Foraminifera in Northeastern Gulf of Mexico: U. S. Geological Survey Prof. Paper 274B., p. 179-204, 3 pls.

Bandy, O. L. and Arnal, R. E., 1960, Concepts of foraminiferal paleoecology: Bull. American Association Petroleum Geologists, v. 44, p. 1921-1932.

Cebulski, Donald E., 1961, Distribution of Foraminifera in the barrier reef and lagoon of British Honduras: Tech. Rept., Texas A. & M. Univ., Dept. Oceanography and meteorology, p. 1-97.

Clarke, W. B., Miller, B. L., and Stephenson, L. W., 1912, The Coastal Plain of North Carolina: North Carolina Geological and Economic Survey Bull., v. 3, 540 p.

Cole, W. S., 1931, The Pliocene and Pleistocene Foraminifera of Florida: Florida Geological Survey Bull. 6, 76 p.

Cooke, C. W., 1936, Geology of the Coastal Plain of South Carolina: U. S. Geological Survey Bull. 867, 196 p., 18 pls.

Cooke, C. W., and MacNeil, F. S., 1952, Tertiary stratigraphy of South Carolina: U. S. Geological Survey, Prof. Paper 243B, p. 19-29.

Cushman, J. A., 1918, Some Pliocene and Miocene Foraminifera of the Coastal Plain of the United States: U. S. Geological Survey Bull. 676, 100 p.

__________, 1944, Foraminifera of the shallow waters of the New England Coast: Cushman Lab. Foraminiferal Research, Sp. Publ. No. 12, 37 p., 4 pls.

__________ and Cahill, E. D., 1933, Miocene Foraminifera of the Coastal Plain of Eastern United States: U. S. Geological Survey Prof. Paper 175-A, 37 p., 13 pls.

Dall, W. H., 1889, Reports on the results of dredging---in the Gulf of Mexico (1877-78) and in the Caribbean Sea (1879-80) by the---'Blake', Report in the Mollusca, part 2, Gastropoda and Scaphopoda; Bull. Museum Comparative Zoology, v. 18, 492 p.

__________, 1890-1903, Contributions to the Tertiary fauna of Florida, with especial reference to the Miocene Silex beds of Tampa and the Pliocene beds of the Caloosahatchie River: Trans. Wagner Free Inst. Science, v. 3, (6 parts), 1654 p.

Doering, J. A., 1960, Quaternary surface formation of southern part of Atlantic Coastal Plain: Jour. Geology, v. 68, N. 2, p. 182-202.

Du Bar, Jules R., 1957, Age and stratigraphic relationship of the Caloosahatchee Marl of Florida: Trans. Illinois Acad. Science, v. 50, p. 187-193.

__________, 1958A, Neogene stratigraphy of southwestern Florida: Trans. Gulf Coast Assoc. Geological Societies, v. VII, p. 129-155.

__________, 1958B, Stratigraphy and paleontology of the late Neogene strata of the Caloosahatchee River area of southern Florida: Florida Geological Survey, Bull. 40, 267 p.

__________, 1959, The Waccamaw and Croatan deposits of the Carolinas: Geologic Notes, v. 3, N. 6, p. 1-9.

Du Bar, Jules R., 1962A, Neogene biostratigraphy of the Charlotte Harbor area in southwestern Florida: Florida Geological Survey, Bull, 43, 83 p.

__________, 1962B, New radiocarbon dates for the Pamlico Formation of South Carolina and their stratigraphic significance: Geologic Notes, v. 6, N. 2, p. 21-24.

__________, 1962C, Check List of Waccamaw and Croatan (Pliocene?) macrofossils of North and South Carolina: Geologic Notes, v. 6, N. 3, p. 25-41.

__________, and Chaplin, J. R., 1963, Paleoecology of the Pamlico Formation (Late Pleistocene), Nixonville Quadrangle, Horry County, South Carolina: Southeastern Geology, v. 4, n. 3, p. 127-165.

__________, Chaplin, J. R., and Solliday, J. R., 1962, Paleoecology of the Pamlico deposits (Late Pleistocene) of Horry County, South Carolina (Abstract): Program Ann. Mtg. American Association Petroleum Geologists, Bull, American Association Petroleum Geologists, v. 46, n. 2, p. 264.

__________, and Solliday, J. R., 1961, Check list of Duplin (Late Miocene) molluscan species of Georgia and the Carolinas: Geologic Notes, v. 5, n. 2, p. 15-30.

__________, and Taylor, D. S., 1962, Paleoecology of the Choctawhatchee deposits at Jackson Bluff, Florida: Trans. Gulf Coast Association Geological Societies, v. XII, p. 349-376.

Folk, Robert L. and Ward, W. C., 1957, Brazos River Bar--a study in the significance of grain size parameters: Jour. Sedimentary Petrology, v. 27, no. 1, p. 3-26.

Gardner, J. A., 1917, The environment of the Tertiary marine faunas of the Atlantic Coastal Plain: Johns Hopkins Univ. Circular, n. 5, n. 293, p. 36-44.

__________, 1943, Mollusca from the Miocene and Lower Pliocene of Virginia and North Carolina, Part 1, Pelecypoda; U. S. Geological Survey Prof. Paper 199A, p. 1-78.

__________, 1948, Mollusca from the Miocene and Lower Pliocene of Virginia and North Carolina, Part 2, Scaphopoda and Gastropoda: U. S. Geological Survey Prof. Paper 199B, p. 179-310.

Gould, H. R. and Stewart, R. H., 1955, Continental terrace sediments in the northeastern Gulf of Mexico; Finding Ancient Shorelines; a symposium with discussions, Society Economic Paleontologists and Mineralogists, p. 2-21.

Johnson, C. W., 1934, List of marine Mollusca of the Atlantic Coast from Labrador to Texas: Proceedings Boston Society Natural History, v. 40, n. 1, 204 p.

Johnsonia, 1941-1959, Monographs of the marine mollusks of the western Atlantic: v. I-III.

Ladd, H. S., 1951, Brackish water and marine assemblages of the Texas Coast with special reference to mollusks: Inst. Marine Science, v. 2, n. 1, p. 125-164.

__________, Hedgpeth, J. W. and Post, Rita, 1957, Environments and facies of existing bays on the central Texas Coast: Geological Society America Memoir 67, p. 599-640.

Lankford, R. R., 1959, Distribution and ecology of Foraminifera from east Mississippi Delta margin: Bull. American Association Petroleum Geologists, v. 43, n. 9, p. 2068-2099, 3 pls.

Legrand, H. E., 1961, Summary of geology of the Atlantic Coastal Plain: Bull. American Association Petroleum Geologists, v. 45, no. 9, p. 1557-1571.

Miller, D. N., 1953, Ecological study of the Foraminifera of Mason Inlet, North Carolina: Cushman Foundation for Foraminiferal Research, v. 4, pt. 2, p. 40-62.

Parker, F. L., 1948, Foraminifera of the continental shelf from the Gulf of Maine to Maryland: Bull. Museum Comp. Zoology, v. 100, no. 2, p. 213-241, 7 pls.

_________, 1952a, Foraminiferal distribution in the Long Island Sound - Buzzards' Bay area: Bull. Museum Comp. Zoology, v. 106, n. 10, p. 428-473, 5 pls.

_________, 1952b, Foraminifera species off Portsmouth, New Hampshire, Bull. Museum Comparative Zoology, v. 106, no. 9, p. 391-423, 6 pls.

_________, 1954, Distribution of Foraminifera in the northeastern Gulf of Mexico: Harvard Coll. Museum Comparative Zoology, Bull., v. III, n. 10, p. 453-588.

Parker, R. H., 1956, Macro-invertebrate assemblages as indicators of sedimentary environments in east Mississippi Delta region: Bull. American Association Petroleum Geologists, v. 40, n. 2, p. 295-376.

_________, 1959, Macro-invertebrate assemblages of central Texas coastal bays and Laguna Madre: Bull. American Association Petroleum Geologists, v. 43, n. 9, p. 2100-2166.

_________, 1960, Ecology and distributional patterns of marine macro-invertebrates northern Gulf of Mexico; in Recent Sediments, Northwest Gulf of Mexico; A.P. I. Project 51, Symposium, American Association Petroleum Geologists, p. 302-337.

Phleger, F. B., 1951, Gulf of Mexico Foraminifera distribution: Geological Society America, Mem. 46.

_________, 1954, Ecology of the Foraminifera and associated micro-organisms from Missisippi Sound and environs: Bull. American Association Petroleum Geologists, v. 38, n. 4, p. 584-647, 28 figs., 3 pls.

_________, 1955, Ecology of Foraminifera in southeastern Mississippi Delta area: Bull. American Association Petroleum Geologists, v. 39, n. 5, p. 712-752, 40 figs.

_________, 1960a, Sedimentary pattern of microfaunas in the Northern Gulf of Mexico; in Recent Sediments, Northwest Gulf of Mexico: A. P. I. Project 51, Symposium, American Association Petroleum Geologists, p. 267-302.

_________, 1960b, Ecology and distribution of Recent Foraminifera: Johns Hopkins Press, Baltimore, 297 p.

Prouty, W. F., 1952, Carolina Bays and their origin; Bull. Geological Society America, v. 63, p. 167-224.

Richards, H. G., 1945, Correlation of Atlantic Coastal Plain, Cenozoic formations, a discussion: Bull. Geological Society America, v. 56, p. 401-408.

_________, 1950, Geology of the Coastal Plain of North Carolina: Trans. Amer. Philos. Soc., v. 40, pt. 1, p. 1-83.

_________, 1962, Studies of the marine Pleistocene; Part I, The marine Pleistocene of the Americas and Europe; Part II, The marine Pleistocene mollusks of eastern North America: Trans. Amer. Philos. Soc., n. 5, v. 52, pt. 3, 141 p.

Shepard, F. P. and Moore, D. G., 1955, Central Texas coast sedimentation, characteristics of sedimentary environment, recent history and diagenesis: American Association Petroleum Geologists, Bull., v. 39, n. 8, p. 1463-1593.

Sloan, Earle, 1907, A summary of the mineral resources of South Carolina, South Carolina Dept. Agriculture, 66 p.

Smith, L. A., 1959, Recognition of Plio-Miocene environments from megafaunas in well cuttings of southern Louisiana: M. S. thesis, Texas Christian Univ., Fort Worth, Texas.

Sorgenfrei, Theodor, 1958, Molluscan assemblages from the marine middle Miocene of South Jutland and their environments: Geological Survey of Denmark, series no. 79, pts. I and II, 503 p., 76 pls.

Tuomey, Michael, 1848, Report on the geology of South Carolina; Columbia, South Carolina, 293 p.

Tuomey, Michael and Holmes, F. S., 1857, Pleiocene fossils of South Carolina: Charleston, South Carolina, 152 p.

Walton, W. R., 1955, Ecology of living benthonic Foraminifera, Todos Santos Bay, Baja, California; Jour. Paleont., v. 29, no. 6, p. 952-1018, 6 pls.

__________, 1960, Diagnostic faunal characteristics on and near a barier island, Horn Island, Mississippi: Trans. Gulf Coast Assoc. Geological Societies, v. X, p. 7-24.

__________, 1963, Northeastern Gulf of Mexico Foraminifera and environments: (In press).

Warmke, G. L., and Abbott, R. T., 1961, Caribbean Seashells: Livingston Publishing Co., Narberth, Pa., 346 p.

Weiss, Lawrence, 1954, Foraminifera and origin of the Gardiner's clay (Pleistocene), Eastern Long Island, New York: U. S. Geological Survey Prof. Paper 254-G, p. 143-163, 2 pls.

APPENDIX

Stratigraphic Sections

Station WA 17. Nixonville Quadrangle, Horry County, South Carolina. Right bank of Waccamaw River near Parker's Landing, about one mile west of Red Bluff Road Bridge.

Unit	Description	Thickness (feet)
Pleistocene		
7.	Sand, quartz, fine with a few medium and large grains, subrounded, slightly consolidated, fairly well sorted, moderate yellowish-brown (10 YR 5/4); no fossils observed.	10.0
7A.	Sand, quartz, fine to medium, subrounded, slightly consolidated, well sorted, light brown (5 YR 5/6), gradational to Unit 7, no fossils observed	1.0
6.	Sandy, conglomeratic quartz, chert, subangular to subrounded, pebbles up to 0.5 inch in diameter, loosely consolidated, poorly sorted, moderate brown (5 YR , 3/4); no fossils observed. . . .	0.4

Unit	Description	Thickness (feet)
Unconformity		
Pliocene (?)		
	Waccamaw Formation	
5.	Sand, calcareous, quartz, fine to medium, subrounded, a few large subangular grains, moderately well sorted, grayish-orange (10 YR 7/4), stained light brown (5 YR 5/6); fossils abundant, well preserved, but slightly leached, no apparent orientation	2.0
4.	Sand, quartz, gradational to and essentially the same as Unit 5, but contains fewer fossils than Unit 5	2.5
3.	Sand, calcareous, silty, quartz, fine to medium, subrounded, slightly consolidated, fairly well sorted, very pale orange (10 YR 8/2); Chlamys solarioides common, convex sides up. Insoluble residue 78.0% by weight	0.5
2.	Sand, calcareous, silty, quartz, very similar to Unit 3 but has fewer macrofossils and more foraminifers	3.3
1.	Sand, calcareous, quartz, fine to medium, subrounded, slightly consolidated forms a low ledge at water's edge, well sorted, very pale orange, (10 YR 8/2); fossils fairly common, especially Chlamys solarioides, no special orientation. Insoluble residue 86.5% by weight	4.5

Station WA 18. Noxinville Quadrangle, Horry County, South Carolina. Bluff on left bank of Waccamaw River about 200 yards downstream from Tilly Lake.

Unit	Description	Thickness (feet)
Pleistocene		
8.	Sand, quartz, fine, silty, micaceous, very slightly consolidated, well sorted, grayish-orange (10 YR 7/4); no fossils observed.	4.5
7.	Silt, argillaceous, arenaceous, micaceous, slightly consolidated, brittle when dry, plastic when wet, grayish-orange (10 YR 7/4); no fossils observed	2.5
6.	Sand, quartz, fine, subrounded, very slightly consolidated, well sorted, grayish-orange (10 YR 7/4); no fossils observed. . .	3.0
5.	Sand, quartz, fine to medium, subangular to subrounded, well sorted, unconsolidated, grayish-orange (10 YR 7/4); no fossils observed	0.5
4.	Sand, quartz, medium, subrounded, unconsolidated, well-sorted light brown (5 YR 5/6); no fossils observed	2.5

Unit	Description	Thickness (feet)
3.	Sand, quartz, medium to coarse, subrounded to subangular, micaceous, slightly consolidated, fair sorting, moderate brown (5 YR 4/4); no fossils observed	0.4
Unconformity		
Pliocene?		
	Waccamaw Formation	
2.	Sand, calcareous silty quartz, medium, subrounded, fairly well consolidated, fair sorting, light gray (N7); fossils abundant, well preserved, size sorted?, no apparent preferred orientation	7.0
1.	Sand, calcareous, quartz, fine to medium, silty, unconsolidated, fair sorting, medium blue-gray (5 B 5/1); contains lumps of Peedee (Cretaceous) argillaceous sand reworked from below and small caliche nodules; fossils abundant, well preserved, size sorted(?), most are small but not worn; some specimens of reworked *Exogyra* sp.	2.0

Station WA 51. Nixonville Quadrangle, Horry County, South Carolina. Left bank of Waccamaw River, 75 yards downstream from Station WA 18.

Unit	Description	Thickness (feet)
Pleistocene		
3.	Slump, soil, sand, and vegetation	18.5
Pliocene(?)		
	Waccamaw Formation	
2.	Sand, calcareous, quartz, fine to medium, subangular to subrounded, well sorted, slightly consolidated, moderately yellowish-brown (10 YR 5/4), color result of weathering; fossils abundant, fairly well preserved, although slightly leached, random orientation	3.0
1.	Slump, sand, soil and vegetation, apparently Waccamaw Formation extends to water level	17.0

Table 9. Waccamaw Molluscan Species from the Type Area. (Relative abundance data given as percentage of total individuals of class. P = less than 1%; C = Common)

SPECIES	UNITS							
Stations	17					18		51
Beds	1	2	3	4	5	1	2	1
Pelecypoda								
1. Nucula proxima Say	0-10.1%	-	-	1.4%	-	P	P	-
2. Nuculana acuta Conrad	-	-	-	-	1.3	3.2	1.8	-
3. Glycymeris americana (Defrance)	0-1.1	-	4.3	9.6	4.0	P	P	7.0
4. Glycymeris pectinata (Gmelin)	-	-	20.9	11.1	6.4	5.0	9.6	P
5. Fossularca adamsi (Dall)	-	-	-	P	-	1.6	P	1.6
6. Anadara lienosa (Say)	-	-	-	P	P	-	-	-
7. Anadara rustica (Tuomey & Holmes)	-	-	-	P	P	-	-	-
8. Anadara transversa improcera (Conrad)	P	-	-	P	P	1.2	1.3	1.6
9. Anadara sp. indet.	0-9.0	-	-	-	-	-	-	-
10. Noetia limula (Conrad)	-	-	-	P	-	P	P	-
11. Ostrea sp. cf. O. disparilis Conrad	P	-	P	-	-	-	-	-
12. Ostrea sculpturata Conrad	P	-	P	4.3	P	P	P	16.4
13. Ostrea sp.	0-7.4	-	-	-	-	-	-	-
14. Amusium mortoni (Ravenel)	-	-	-	P	P	-	-	-
15. ?Amusium sp.	0-3.7	-	-	-	-	-	-	-
16. Chlamys solarioides (Heilprin)	0-92.5	C	3.8	P	P	-	-	3.6
17. Chlamys sp. cf. C. solarioides (Heilprin)	11.2-18.6	-	P	-	-	P	P?	-
18. Plicatula marginata Say	12.9-19.1	-	3.8	8.2	10.5	3.2	2.7	3.1
19. Anomia simplex d'Orbigny	-	-	1.9	2.0	2.2	-	-	-
20. ?Anomia sp.	0-9.0	-	-	-	-	-	-	-
21. ?Pandora sp.	-	-	-	-	P	-	-	-
22. Verticordia ornata Conrad	-	-	-	P	-	-	-	-
23. Astarte concentrica bella Conrad	-	-	4.3	6.1	7.2	P	P	-
24. Eucrassatella speciosa A. Adams	-	-	1.9	P	P	P	P	P
25. Crassinella lunulata Conrad	-	-	-	3.3	6.8	5.0	6.5	-
26. Cardita arata (Conrad)	-	-	-	-	-	P	-	-
27. Cardita granulata (Say)	0-9.0	-	15.2	14.1	5.9	1.6	P	-
28. Cardita perplana (Conrad)	-	-	-	-	-	1.5	1.3	-
29. Cardita tridentata (Say)	-	-	1.9	P	6.0	6.5	10.2	3.1
30. Chama gardnerae Olsson & Harbison	0-9.0	-	-	2.8	4.4	5.9	2.8	-
31. Echinochama cornuta (Conrad)	-	-	-	P	P	-	P	-

SPECIES UNITS

	Stations	17					18		51
	Pelecypoda (Cont'd) — Beds	1	2	3	4	5	1	2	1
32.	Diplodonta sp.	-	-	-	-	-	-	P	-
33.	Phacoides multilineata (Tuomey & Holmes)	-	-	P	1.4	P	P	1.3	1.6
34.	Phacoides radians (Conrad)	-	-	-	P	P	-	-	P
35.	Phacoides trisulcatus (Conrad)	-	-	-	P	1.3	P	P	-
36.	Phacoides waccamawensis Dall	-	-	9.5	4.3	6.4	P	P	P
37.	Laevicardium sublineatum (Conrad)	-	-	-	P	P	-	P	-
38.	Laevicardium sp.	-	-	P	-	-	-	-	-
39.	Mercenaria campechiensis (Gmelin)	-	-	2.4	-	P	-	P	P
40.	Macrocallista nimbosa Solander	-	-	-	?P	?P	-	-	-
41.	Macrocallista sp. cf. M. maculata Linne	-	-	-	-	-	P	-	-
42.	Pitar sayana (Conrad)	-	-	-	P	-	-	-	3.3
43.	Chione cancellata (Linne)	-	-	-	-	-	-	P	-
44.	Chione cribraria (Conrad)	-	-	-	P	-	-	-	P
45.	Chione grus (Holmes)	-	-	3.8	3.3	3.8	1.2	P	1.5
46.	Chione latilirata athleta (Conrad)	0.1.1	-	5.2	4.9	10.0	P	P	2.1
47.	Transenella carolinensis Dall	-	-	1.9	-	-	-	-	P
48.	?Transenella sp. A	-	-	-	-	P	-	P	-
49.	Gouldia metastriata (Conrad)	-	-	7.6	2.3	5.1	1.5	P	-
50.	Gemma magna Dall	-	-	-	-	-	21.6	30.6	1.5
51.	Tellina dupliniana Dall	-	-	-	1.8	-	P	P	3.1
52.	Semele bellastriata (Conrad)	-	-	-	P	P	-	-	-
53.	Semele (Semelina) sp.	-	-	-	-	P	-	-	-
54.	Abra aequalis (Say)	-	-	-	-	-	-	P	-
55.	Ensis directus Conrad	-	-	-	-	-	?P	-	-
56.	Donax fossor Say	-	-	-	-	-	-	P	-
57.	Spisula similis (Say)	-	-	-	P	-	-	P	1.8
58.	Mulinia lateralis (Say)	-	-	-	-	-	23.8	13.9	23.6
59.	Caryocorbula barrattiana (C. B. Adams)	-	-	9.5	5.6	-	13.6	7.4	12.5
60.	Caryocorbula inaequalis (Say)	-	-	-	-	8.5	-	-	-
61.	Caryocorbula sp.	-	-	-	P	-	P	-	-
	Gastropoda								
62.	Retusa canaliculata (Say)	-	-	-	2.1	3.9	-	-	-

SPECIES		UNITS						
Stations	17					18		51
Gastropoda (Cont'd) / Beds	1	2	3	4	5	1	2	1
63. *Ringicula floridana* Dall	-	-	-	-	1.0	-	-	-
64. *Terebra concava* Say	-	-	-	-	P	-	4.5	-
65. *Terebra dislocata* Say	-	-	-	P	2.3	P	-	-
66. *Conus adversarius* Conrad	-	-	-	-	P	-	-	-
67. *Conus jaspideus* Gmelin	-	-	-	P	-	-	-	-
68. *Conus jaspideus* Gmelin?	-	-	5.5	-	P	-	-	-
69. *Clathrodrillia ebenina* (Dall)	-	-	-	P	-	-	-	-
70. *Crassispira* sp. cf. *C. perrugata* (Dall)	-	-	-	-	P	-	-	-
71. *"Drillia"* sp.	-	-	-	P	1.0	-	-	-
72. *Kurtziella* sp. cf. *K. limontella* Dall	-	-	-	-	-	1.3	-	13.9
73. *Oliva sayana* Ravenel	-	-	5.5	P	P	P	-	-
74. *Olivella mutica* (Say)	-	-	-	7.3	11.5	26.6	11.3	27.8
75. *Bullata dacria* (Dall)	-	-	-	-	1.0	1.3	2.3	-
76. *Marginella aureocincta* Stearns	-	-	-	-	1.1	2.6	6.8	-
77. *Prunum apicinum* (Menke)	-	-	-	-	1.2	-	-	-
78. *Prunum contractum* (Conrad)	-	-	-	57.8	28.9	-	33.1	-
79. *Prunum contractum* (Conrad) ?	-	-	-	-	-	6.8	-	-
80. *Prunum eulima* (Dall)?	-	-	-	-	-	1.3	-	-
81. *Prunum* sp. B	-	-	-	-	-	P	-	-
82. *Busycon contrarium* (Conrad)	-	-	-	P	-	4.5	-	-
83. *Busycon* sp.	-	-	-	1.8	-	P	-	-
84. *Nassarius consensa* (Ravenel)	-	-	-	-	P	-	-	-
85. *Nassarius irrorata* (Conrad)	-	-	-	-	-	P	-	P
86. *Nassarius* sp. A.	-	-	-	-	1.0	-	-	-
87. *Nassarius* sp.	-	-	-	-	-	2.3	-	-
88. *Gemophos maxwelli* Olsson & Harbison	-	-	-	-	P	-	-	-
89. *Anachis avara similis* (Ravenel)	-	-	-	-	P	-	-	-
90. *Anachis* sp	-	-	-	-	-	-	P	-
91. ?*Anachis* sp.	-	-	-	-	-	2.3	-	-
92. *Murex brevifrons* Lamarck	-	-	-	-	P	-	-	-
93. *Trophon* sp. cf. *T. lepidota* (Dall)	-	-	-	-	1.0	-	-	-

SPECIES

UNITS

Gastropoda (Cont'd)	Stations 17					18		51
Beds	1	2	3	4	5	1	2	1
94. Cantharus floridana Conrad	-	-	-	-	P	-	-	-
95. Urosalpinx sp.	-	-	-	-	P	-	-	-
96. Fossarus anomala (C. B. Adams)	-	-	-	-	1.0	-	-	-
97. Trivia suffusa Gray	-	-	-	-	-	P	-	-
98. Natica canrena (Linné) ?	-	-	-	1.9	-	-	-	-
99. "Natica" sp.	-	-	-	-	-	-	2.3	-
100. Tectonatica pusilla (Say)	-	-	-	-	7.3	8.0	6.8	-
101. Polynices duplicatus (Say)	-	-	-	-	-	3.9	-	13.9
102. Crucibulum auriculum Gmelin	-	-	-	-	2.1	3.9	4.5	-
103. Crepidula fornicata (Linne)	-	-	-	4.2	8.1	P	25.1	14.3
104. Cerithiopsis abrupta Watson?	-	-	-	1.8	-	-	-	-
105. Seila adamsi H. C. Lea	-	-	-	1.8	-	3.9	-	13.9
106. Turritella subannulata Heilprin	-	-	-	1.9	8.4	-	-	-
107. ?Turritella sp.	-	-	44.3	-	-	-	-	-
108. Caecum flemingi Gardner & Aldrich	-	-	-	3.6	-	-	-	-
109. Caecum floridanum Stimpson	-	-	-	1.8	-	1.3	-	-
110. Caecum imbricatum Carpenter	-	-	-	-	1.0	1.3	2.3	-
111. Cochliolepis sp. A.	-	-	-	-	1.0	-	-	-
112. Cochliolepis sp. aff. C. virginica Olsson & Harbison	-	-	-	-	1.0	-	-	-
113. Circulus (?Supra-nitidus Wood subsp.) orbigyni (Fisher)	-	-	-	-		1.3	-	-
114. Teinostoma smikron Gardner	-	-	-	-	1.8	-	-	-
115. Littorina irrorata Say	-	-	-	-	P	-	-	-
116. Epitonium sayanum Dall?	-	-	-	-	-	-	-	13.9
117. Melanella sp.	-	-	-	-	-	-	2.3	-
118. Liotia gemma (Tuomey & Holmes)	-	-	-	3.6	1.0	-	-	-
119. Odostomia seminuda C. B. Adams	-	-	-	-	-	3.9	-	-
120. Odostomia sp. cf. O. stimpsoni Bartsch	-	-	-	-	2.1	-	-	-
121. Turbonilla sp. B.	-	-	-	-	-	-	6.8	-
122. Turbonilla sp.	-	-	-	P	-	-	2.3	-
123. Calliostoma sp. cf. C. jujubinum Gmelin	-	-	-	-	-	1.3	-	-
124. Diodora sp. cf. D. caloosaensis (Dall)	-	-	-	-	2.1	-	-	-
125. Diodora nucula Dall	-	-	-	3.6	6.3	1.3	2.3	-
Scaphopoda								
126. Dentalium sp.	-	-	-	P	-	P	-	-

Table 10. FORAMINIFERAL CHECKLIST
(in % of Total Pop. P = less than 1%)

	WA17			WA18		WA51
	1	2	3,4,5	Lower	Upper	
Ammodiscus minutissimus Cushman and McCulloch	-	-	P-3	-	1-2	-
Amphistegina gibbosa d'Orbigny	P-6	3-5	2	-	-	-
Angulogerina occidentalis (Cushman)	5-19	9-14	2-8	3	2-4	-
Anomalina sp. cf. A. pliocenica Natland	P	P	-	-	1-4	-
Anomalina sp. undet.	2	-	-	-	P	-
Asterigerina carinata d'Orbigny	-	3-4	P	-	P	-
Bolivina marginata Cushman	10-12	P-3	10-11	12	9-10	2
Bolivina pseudoplicata Heron-Allen & Earland	2-5	2-5	0-2	2	2-4	1
Bolivina pseudopunctata Hoglund	2	P	-	-	2-3	-
Buccella frigida (Cushman)	P	P-2	P	-	1	3
Buccella mansfieldi (Cushman)?	-	1	-	-	P	-
Bulimina marginata d'Orbigny	-	-	P	-	P	-
Bulimina patagonica d'Orbigny var. glabra Cushman and Wickenden	-	P	-	-	-	-
Buliminella elegantissima (d'Orbigny)	P	P	P-3	P	-	P
Cancris sp. undet.	-	-	-	P	3	-
Cassidulina caribeana Redmond	11-15	7-9	10-14	-	P	-
Cassidulina subglobosa Brady	7-14	4-6	5-6	8	1-3	4
Cibicides floridanus (Cushman)	2-7	15-23	0-5	-	-	-
Cibicides sp. cf. C. floridanus (Cushman)	-	-	-	7	4-6	27
Cibicides lobatulus (Walker and Jacob)	P	2-3	7	-	-	-
Cibicides sp. undet.	3	-	3	5	1	1
Cristellaria sp.	P	-	-	-	-	-
Dyocibicides biserialis Cushman and Valentine	P-2	2-3	2	-	1	-
Elphidium sp. cf. E. australis Cushman and Parker	-	P	-	-	-	-
Elphidium sp. cf. E. delicatulum Bermudez	-	-	-	-	-	P
Elphidium discoidale (d'Orbigny)	-	P	-	-	P	2
Elphidium fimbriatulum (Cushman)	P	P	-	2	P-1	2
Elphidium gunteri Cole	-	-	-	3	1	3
Elphidium sp. cf. E. poeyanum (d'Orbigny)	1	2-5	3-4	2	2	11
Elphidium sp. undet.	1	P	1-5	4	3-5	2
Epistominella pontoni (Cushman)	7-14	P-2	7-10	9	7-10	6
Gaudryina sp.?	-	-	-	-	P	-
Globigerinoides ruber (d'Orbigny)	-	-	-	-	-	2
Globulina inaequalis Reuss	P	P	-	-	P	-
Globulina rotundata (Bornemann)	P	-	-	-	-	-
Guttulina lactea (Montagu) var. earlandi Cushman and Ozawa	-	-	-	P	-	-
Hanzawaia concentrica (Cushman)	1-4	4	2-4	P	2-3	27
Lamarckina atlantica Cushman	2-3	P-1	-	-	-	-
Miliolidae, undiff.	P	-	-	4	2-5	-
Neoconorbina terquemi (Rzehak)	2	P-1	3	5	2-11	-
Nonion sp.	-	P	-	-	-	-
Patellina sp.	P	-	P-1	-	-	-
Planorbulina mediterraneansis d'Orbigny	P	P	1	-	P	-
Planulina foveolata (Brady)	4	1	2-3	3	P-5	P
Poroeponides lateralis (Terquem)	-	P	1	-	2	-
Pseudopolymorphina dumblei (Cushman and Applin)	-	-	-	-	P	-
Pyrulina albatrossi Cushman and Ozawa	-	P	-	-	P	-
Quinqueloculina lamarckiana d'Orbigny	-	-	P	-	2-5	-
Quinqueloculina sabulosa Cushman	-	-	-	-	P	-
Quinqueloculina seminulum (Linne')	-	0-3	-	-	-	-
Reussella sp. cf. R. spinulosa (Reuss)	-	P	-	-	P	-
Rosaline columbiensis (Cushman) var.	5-19	6-14	0-4	3	4-9	2
Rotaliidae, undiff.	2-5	3	7	3-12	-	-

	WA17			WA18		WA51
	1	2	3, 4, 5	Lower	Upper	
Siphonina pulchra Cushman	-	P	-	-	-	-
Spiroloculina planulata (Lamarck)	-	-	-	-	P	-
Spirillina sp.	-	-	-	-	P	-
Streblus sobrinus (Shupack)	2	P	1-2	P	P	2
Streblus sp. 1	1	1	2	P	P-3	-
Textularia agglutinans d'Orbigny	P	2-3	-	-	3-8	-
Textularia articulata d'Orbigny	-	-	-	-	P	-
Textularia sp. cf. T. mayori Cushman	P	-	-	-	-	-
Trochammina sp. ?	-	P	-	P	-	-
Valvulineria sp.	-	P	-	-	-	-
Virgulina fusiformis Cushman	-	-	-	P	-	-