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GEOLOGY OF THE PRINGLETOWN, RIDGEVILLE, SUMMERVILLE, AND SUMMERVILLE NORTHWEST 7.5-MINUTE QUADRANGLES, BERKELEY, CHARLESTON, AND DORCHESTER COUNTIES, SOUTH CAROLINA

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INTRODUCTION

The Pringletown, Ridgeville, Summerville, and Summerville Northwest quadrangles, comprising an area of about 250 mi^2, are located in the outer Atlantic Coastal Plain about midway between the Cape Fear Arch (to the northeast) and the Southeast Georgia Embayment (to the southwest). Open-marine, marginal-marine, and freshwater sediments, ranging in age from middle Eocene to Holocene, crop out or are present just beneath the land surface in these quadrangles. The area is characterized by a gently rolling topography developed predominantly on the Penholoway and Wicomico terraces; altitudes generally range between 50 and 95 ft above sea level. Two major swamps, Four Hole Swamp and Cypress Swamp, are underlain by upper Quaternary sediments. Four Hole Swamp drains southwestward to the Edisto River, while Cypress Swamp drains southward to the Ashley River (fig. 1). Within Four Hole Swamp (Pringletown quadrangle) lies Beidler Forest, a National Audubon Sanctuary comprising the largest stand of original-growth bald cypress and tupelo gum forest in the United States (Brunswig and Winton, 1978; Porcher, 1981).

In the shallow subsurface, there are 16 discrete depositional assemblages that record high stands of sea level during the last 45 million years (fig. 2). Tertiary transgressions of the Atlantic Ocean extended well to the northwest of this area; their original inland extent has not yet been determined. These deposits are mainly marine in origin. They accumulated during the more recent stages of a prolonged interval of Coastal Plain subsidence, beginning about 100 million years ago, during which the Charleston region subsided a total of about 3,000 ft in Late Cretaceous and early Tertiary time (Gohn and others, 1977). There has been little or no net subsidence in the Charleston area since the Oligocene (about 25 million years ago). However, the area to the north has risen over the Cape Fear Arch, and the area to the south has continued to subside beneath the Southeast Georgia Embayment. This has resulted in a tilting of geologic strata in the Charleston region that causes Oligocene and older beds to crop out in broad east-west-trending belts that dip gently toward the south. Because the Charleston area is near the axis of this tilting, post-Oligocene stratigraphic units have been dissected and reworked repeatedly by successive transgressions of the Atlantic Ocean, producing a mosaic of small upper Oligocene to lower Pleistocene unit remnants distributed more commonly side by side than in superposition.

The map area presently is both suburban and rural in character. The Summerville area in the southeast has been most heavily developed, and continued expansion of this suburban area toward the west appears to be inevitable along the U.S. Highway 78 and Interstate 26 corridors.

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Tertiary Deposits

Each Tertiary marine deposit in this area is lithologically distinct and is bounded above and below by disconformities. Basal disconformities commonly are recognized in auger holes by nodular phosphate and (or) glauconite-rich lag deposits that formed during the initial stages of deposition of each unit. Burrows concentrated in the upper three feet of each deposit are filled with poorly sorted matrix and pebbles from the overlying unit.

Santee Limestone

The Santee Limestone was used informally by Lyell (1845) and later formally named by Sloan (1908). Subsequently it has been divided into a lower Moultrie Member and an upper Cross Member by Ward and others (1979). The upper Cross Member of middle Eocene (Bartonian) age (about 44 Ma) seems to represent all of the Santee Limestone encountered in the map area.

Cross Member

The Cross generally is a well-lithified, white to pale-yellow calcarenite that is difficult or impossible to penetrate with a power auger. Its fossil invertebrate fauna indicates that it accumulated on a firm-bottomed but unlithified, open-marine shelf (Hazel and others, 1977). This unit was encountered at shallow depths in the Pringletown and Summerville Northwest quadrangles and occurs at greater depths in the Ridgeville and Summerville quadrangles. At some horizons the Cross Member is cavernous and may be tapped for a reliable ground-water supply.

Cooper Group

Soft, impermeable limestones that overlie the Santee Limestone were called the "marls of Ashley and Cooper Rivers" by Tuomey (1848). Later, Sloan (1908) referred to this sequence of beds as the "Ashley-Cooper Phase". Ward and others (1979) designated this entire sequence as the Cooper Formation and subdivided it into three members, the Harleyville, Parkers Ferry, and Ashley Members. These members were raised to formation rank and the Cooper was raised to group rank by Weems and Lemon (1984b) to conform to the usage of formation and group ranks for rock units farther north in Virginia that are of similar diversity, thickness (about 500 ft), and areal extent. Use of the term Cooper Group has also been advocated by Colquhoun and others (1982). The Harleyville, Parkers Ferry, and Ashley Formations all occur at shallow depths in the map area.

Harleyville Formation

This semilithified, light-greenish-gray to olive-gray or brownish-gray, very fine grained calcarenite was encountered only in the Pringletown and Ridgeville quadrangles, but probably occurs at depth in the Summerville quadrangle as well. The Harleyville Formation formed in a soft-bottomed, open-marine environment. Macrofossils are sparsely distributed, but Foraminifera and other calcareous microfossils are abundant. Remains of the large, elongate archeocete whale, *Basilosaurus*, have been found in this unit (Sanders, 1974). A late Eocene (Priabonian) age (about 40 Ma) has been established on the basis of calcareous nannofossil assemblages characteristic of zones NP 18 and NP 19/20 (Laurel Bybell, U.S. Geological Survey (USGS), written commun., 1986).

Parkers Ferry Formation

This dense, sticky, light-blue-green or grayish-blue-green to moderate-yellowish-green calcilutite to very fine grained calcarenite was encountered in the Ridgeville, Summerville, and Summerville Northwest quadrangles. Its presence is inferred in the southern Pringletown quadrangle as well (cross sections *A–A′* and *D–C*). The Parkers Ferry Formation is inferred to have accumulated in a soft-bottomed, open-marine-shelf environment (fig. 2) on the basis of the abundant echinoid spines that it contains. A late Eocene (Priabonian) age (about 38 Ma) has been established on the basis of calcareous nannofossil assemblages characteristic of zones NP 19/20 (Hazel and others, 1977). The Parkers Ferry is difficult to excavate but is easily eroded when exposed to air and water.

Ashley Formation

The most widespread unit in the shallow subsurface of the map area is the Ashley Formation, which consists of dense, light-olive-brown, phosphatic and quartzose calcarenite that is only weakly cemented. Its abundant and diverse marine fauna indicates that it accumulated in an open-marine-shelf environment (Hazel and others, 1977). The presence of sepiolite suggests that a much drier climate existed, at least locally, than at present. Remains of fish, reptiles, birds, and mammals are locally present. A late Oligocene (early Chattian) age (about 30 Ma) has been established on the basis of Foraminifera that are characteristic of zones P 20/21 and calcareous nannofossil assemblages that are characteristic of zone NP 24 (Hazel and others, 1977). The Ashley tends to harden upon exposure to air. Manmade cuts in this material resist erosion and may persist for a few years before becoming overgrown. Natural outcrops of this unit occur intermittently along the bluffs adjacent to Four Hole Swamp and Cypress Swamp.

Chandler Bridge Formation

The medium-gray to dusky-green quartz and phosphate sands of the Chandler Bridge Formation accumulated in lagoonal to shallow-marine-shelf environments of deposition, as indicated by the admixture of marine vertebrate and terrestrial plant remains in this unit (Sanders and others, 1982). The flora suggests that deposition occurred in a warm, temperate climate comparable to the present. Vertebrate remains are common, diverse, and well preserved. A late Oligocene (middle Chattian) age (about 28 Ma) is inferred from the odontocete whale fauna collected from this unit and stored at the Charleston Museum (Sanders and others, 1982). The Chandler Bridge is soft and erodes readily. For this reason it has been extensively stripped by erosion and persists mostly as thin patches in low areas overlying the Ashley Formation. The unit was penetrated in the subsurface only in the Summerville and Ridgeville quadrangles.

Edisto Formation

The olive-gray to greenish-gray, phosphatic, shelly, calcareous sands of the uppermost Oligocene and (or) lowermost Miocene Edisto Formation (about 24 Ma) were deposited in a shallow-marine-shelf environment. Sloan (1908) considered this unit to be the parent lithology for the "phosphate rock" that once was mined extensively in the Charleston area. This formation, in an unphosphatized state, was penetrated in a number of auger holes northwest of the town of Summerville along the margins of Cypress Swamp in the Summerville quadrangle. Analysis of samples in this area yielded only Oligocene microfossils, but elsewhere in the Charleston area parts of the Edisto have yielded basal Miocene Foraminifera (Weems and Lemon, 1993). Therefore this unit here is considered to straddle the Oligocene-Miocene boundary. It is also possible that two discrete units are present in this interval, of which this is the older. In the map area, the Edisto is typically very calcareous in auger holes. In outcrop, however, it is commonly leached of its calcareous content and consists only of a well-sorted, fine-grained residual sand.

Rudd Branch beds

The Rudd Branch beds, informally named for phosphatic sands that occur in the vicinity of Rudd Branch in the Summerville Northwest quadrangle, were penetrated at three localities (*SN 13*, *SN 14*, and *SN 20*). The Rudd Branch beds consist of dusky-green to grayish-olive-green quartz-phosphate sands that commonly contain crumbling, aragonitic mollusk shells. This unit probably accumulated in a shallow-marine-shelf environment. Dinoflagellates, recovered from the unit at localities *SN 14* and *SN 20*, indicate that it lies somewhere in the vicinity of the middle to upper Miocene boundary (Lucy Edwards, USGS, written commun., 1984). It is unlike any other unit in the Charleston area, but it possibly could be an updip equivalent of the Coosawhatchie Clay of middle Miocene age, which occurs well to the south of the Charleston area (Abbott and Huddlestun, 1980).

Raysor Formation

The Raysor Formation was named by Cooke (1936) for an exposure of very shelly quartz sand on the Edisto River near Raysor Bridge, west of the map area. This locality has not been relocated in recent decades, and it presumably has become overgrown or removed for fill earth. Blackwelder and Ward (1979) sought to equate this unit with beds exposed at Givhans Ferry (west of the map area), but Weems and others (1982) demonstrated that the lithologies of these two sections do not match and that the Givhans Ferry locality lithologically is much closer to the Goose Creek Limestone. Recently, Campbell (1989) has shown that the Goose Creek is older than the Raysor. Sloan (1908) described a unit called the "Salkehatchie Phase", which consists of soft, dark-greenish-gray, glauconitic and phosphatic sands along the Salkehatchie River in southern South Carolina. These beds occur unconformably beneath the seaward edge of the Wicomico terrace. Beds referrable to the Raysor in the Pringletown and Summerville Northwest quadrangles also underlie the seaward edge of the Wicomico terrace, and are very similar to the Salkehatchie beds of Sloan (1908) where slightly weathered. These two units may be correlative. Ward and Huddlestun (1988) have determined that the Raysor falls within Berggren's (1985) Zone PL 3 (basal upper Pliocene). The Raysor was deposited in a shallow-marine-shelf environment.

Pringletown beds

This name is applied informally to a subsurface unit composed of dark-bluish-gray to dark-gray sandy clay and clayey fine-grained sand. These beds, which are found only in a limited area in the Pringletown and Summerville Northwest quadrangles (*PR 4, SN 2, SN 18*), overlie the Raysor Formation (*SN 2*) and unconformably underlie the Waccamaw(?) Formation (*PR 4*). The Pringletown beds seem to represent an estuarine to lagoonal deposit similar to that represented by the Daniel Island beds (Weems and Lemon, 1993), but they occur at much higher altitudes and much farther inland than any beds that can be directly associated with the Daniel Island unit. On the basis of their position within the local stratigraphic sequence, the Pringletown beds are either late Pliocene or early Pleistocene in age.

Quaternary Deposits

Quaternary deposits form terrace complexes containing sediments that accumulated in freshwater, marginal-marine, and open-marine environments (fig. 2). These deposits formed during interglacial times, during which sea level was high due to extensive melting of the polar icecaps. They are very similar to the deposits forming along the Atlantic coastline today. This similarity suggests that each barrier-island deposit represents the position of the Atlantic shoreline at the time it was formed.

Regionally, there are five Pleistocene terrace complexes (fig. 1). Their ages have been established by using biostratigraphic methods, uranium-disequilibrium-series dates obtained from corals, and observations of the relative degree of weathering of clay and heavy minerals in each unit (McCartan and others, 1984). The ages and stratigraphic relations indicate that the terrace deposits record successive transgressive and regressive sea-level oscillations, presumably climatically controlled during interglacial and glacial ages, respectively. Although barrier and backbarrier deposits are preserved, each succeeding transgression largely reworked the shallow-marine-shelf deposits seaward of each immediately older barrier ridge. Because of this, younger beach-ridge and lagoonal deposits lie immediately seaward of and at slightly lower altitudes than the next older coastal deposits. Sediments of younger units also fill the bottoms of what were water-filled estuaries and lagoons during older transgressions (see Cypress Swamp area on cross section *A′–A″* in the Summerville quadrangle).

On tectonically stable coasts, littoral erosion associated with successive high-sea-level stands normally should erode and thus destroy nearly all deposits of previous high-sea-level stands. The preserved depositional record of many of the older Quaternary sea-level oscillations in the Charleston region attests to a net emergence of broad areas of the Coastal Plain throughout the Quaternary. This emergence has left older beach complexes out of reach of later littoral erosion during subsequent high-sea-level stands. Traditionally, this emergence has been attributed to a broad crustal uplift of the Coastal Plain throughout the Quaternary (Clark and Miller, 1912; Cooke, 1936). Present elevations of successive deposits suggest that the average rate of this uplift would be about 0.7 in. (1.8 cm)/1,000 years (Cronin and others, 1981). However, evidence has been obtained recently for a Pliocene meltdown of most of the Antarctic ice sheet about 3 Ma (Barrett and others, 1992). This offers the possibility that the subsequent rebuilding of the Antarctic ice sheet, by accumulation of water from the world oceans, could account for most or all of the observed net drop in relative sea level in the Coastal Plain during the last 3 Ma.

The base of the various Quaternary transgressive-regressive sediment sequences was located from shallow auger holes and outcrops, which are numbered and shown on the map. These auger holes serve as control for the structure contours drawn on the base of the Quaternary units on this map and for the smaller scale isopach map of the same area (fig. 3). This contoured surface is of variable age, but it separates the unconsolidated Quaternary sediments from underlying well-compacted to partly lithified Tertiary sediments.

Quaternary map units used in this report correspond to numbered interglacial chronolithologic units of the South Carolina Coastal Plain of McCartan and others (1984). Generally, each lithologic sequence is found beneath a recognizable terrace surface, to which Colquhoun (1974) has applied the names shown in figure 1. Sporadic outliers are occasionally penetrated when drilling through younger deposits found beneath terraces which lie at lower altitudes. Formal status is assigned to these units herein because (1) the local and regional stratigraphic relations are known from extensive new subsurface data, (2) biostratigraphic control for the lithologically subdivided units is now available, and (3) absolute ages determined for these units show they vary widely in age. Although all of these units are somewhat similar in lithology (Lemon, 1979), they can be easily differentiated because the base and top of each sequence of Quaternary beds typically are 10–20 ft higher or lower than the boundaries of adjacent Quaternary sequences.

Within each wholly Pleistocene map unit, as many as four facies based on association of lithology, texture, and fossils are readily recognized and are mapped separately. They correspond to fluvial or riverine (r), clay-rich marsh-estuary-backbarrier (c), sandy barrier-island (s), and fossiliferous open-marine-shelf (f) depositional environments (fig. 2; equivalent to r, l, b, and o, respectively, in McCartan and others, 1984). The last letter on each Quaternary unit label designates the facies. These facies typically grade into each other over a vertical distance of 1–3 ft, although in places where barrier sands have migrated over backbarrier clays or where estuary channels have produced cut-and-fill structures, the contact may be quite sharp. Commonly, coarse-grained pebbly lag beds occur at the base of each interglacial facies complex but not between facies. The thickness of the Quaternary deposits ranges up to 65 ft (fig. 3), and is dependent on local variations in spatial relations between paleochannels, on barrier-island morphology, and on postdepositional erosion.

Waccamaw(?) Formation

The Waccamaw(?) Formation (equivalent to unit Q_6 of McCartan and others, 1984) underlies the Wicomico terrace of Colquhoun (1974). Outliers of this unit occasionally were penetrated in auger holes beneath the younger Penholoway terrace that lies southeast of the main outcrop belt of this unit (fig. 1). The sediments beneath the Wicomico terrace represent estuarine to lagoonal deposits (**Qwwc**) and barrier-island deposits that form the Dorchester barrier (**Qwws**). They formed at a time when sea level rose to an altitude of 95 ft above present sea level relative to the land. No fossiliferous Pleistocene deposits were encountered beneath the Wicomico terrace. However, a marine fossiliferous outlier of the Waccamaw(?) was encountered beneath the Penholoway terrace in the Summerville quadrangle at locality *SU 6*. Although small *Gephyrocapsa* from this locality suggest that this erosionally isolated shallow-marine-shelf deposit is early Pleistocene in age, a latest Pliocene age cannot be rigorously precluded. Because the shallow-marine-shelf deposit at locality *SU 6* lies within the area occupied by the Penholoway backbarrier marsh, it must correspond to a transgression that was older and that extended farther to the west than the Penholoway backbarrier marsh. Therefore, association with the northwestward-lying Wicomico terrace is reasonable. The Waccamaw(?), on the basis of foraminiferal and calcareous nannofossil assemblages, probably accumulated between 1.6 and 1.4 Ma. This is the age range that has been determined for the Waccamaw Formation in the Myrtle Beach region, so the deposits beneath the Wicomico terrace northwest of Charleston are tentatively assigned to that unit.

Penholoway Formation

The Penholoway Formation, equivalent to unit Q_5 of McCartan and others (1984), consists of sand, clayey sand, and clay deposited in shallow-marine to marginal-marine environments at a time when sea level stood about 75 ft above its present level relative to the land. Within the map area, the Penholoway mostly underlies the Penholoway terrace. Two separate barrier ridges (**Qps**) are present on the Penholoway terrace, the Ridgeville barrier and the Pinopolis/Summerville barrier. Either the Ridgeville barrier formed slightly before the Pinopolis/Summerville barrier and was cut off by the growth of the Pinopolis/Summerville barrier, or the Ridgeville barrier grew out of a complex open lagoonal water-circulation pattern coevally with the Pinopolis/Summerville barrier. The direction of imbrication of the sand bodies composing the Ridgeville barrier indicates that at least its later development was controlled by longshore currents flowing toward the northeast. The basal beds of the Penholoway Formation in the vicinity of Summerville (locality *SU 1*) have yielded sparse calcareous nannofossils, none of which suggests an age older than the upper part of the Quaternary Zone NN19 of Martini (1971), which is no older than 970 ka (Laurel Bybell, USGS, written commun., 1984). Equivalent beds in the northern part of the Stallsville quadrangle yielded a piece of coral with a U-Th disequilibrium age greater than 700 ka (Szabo, 1985). Therefore, on the basis of the data locally available from the Summerville area, the Penholoway can be assigned an early Pleistocene age. The Penholoway in the map area is poorly consolidated, easily excavated, and readily eroded.

Ladson Formation

The sands, clays, and clayey sands present in the type section of the Ladson Formation (Malde, 1959) underlie the upper Talbot terrace northwest of the Bethera scarp (Colquhoun, 1974). This unit is equivalent to unit Q_4 of McCartan and others (1984). The present altitude of the top of the lagoonal deposits included within this unit indicates that the Ladson was deposited at a time when sea level in the Charleston area stood about 50 ft above its present level relative to the land. At the time of maximum transgression, the shoreline was marked by an elongate barrier island, the Bethera barrier, which now forms the sand deposits (unit **Qls**) preserved in the southeasternmost corner of the map area. The crest of this barrier is at an altitude of about 60–65 ft above sea level. During deposition of the Ladson, the Santee River ran well to the north of the map area and did not influence deposition in this area. Backbarrier clays of the Ladson Formation in the Stallsville quadrangle have normal magnetic polarity (Liddicoat and others, 1981), and thus are no older than the middle Pleistocene (about 730 ka). Corals from the next younger unit, the Ten Mile Hill beds, have yielded U/Th ratios indicating that those beds are 240–200 ka. Therefore, the age of the Ladson lies between 730 and 240 ka. The Ladson Formation may be equivalent to the Canepatch Formation of DuBar (1971) in the Myrtle Beach area, which has yielded U/Th ratios from contained corals suggesting an age of about 450 ka (Cronin and others, 1981). If so, the name Ladson is older and has been retained for this reason. The Ladson is poorly consolidated, easily excavated, and readily eroded. Clay-rich intervals may be quite sticky.

Ten Mile Hill beds

The clays and clayey sands here included in the Ten Mile Hill beds (**Qtc**) were deposited in marsh environments that existed far behind a barrier beach located southeast of the map area in the Ladson quadrangle. The lagoonal parts of this deposit formerly were included in the Ladson Formation (Malde, 1959) because they formed in similar environments, but they are mapped separately in this report because they record a younger transgression and regression of the sea than that recorded by the beds forming the type section of the Ladson Formation. This unit is informally called the Ten Mile Hill beds (Weems and Lemon, 1984a). The Ten Mile Hill beds mostly underlie the lower part of the Talbot terrace (fig. 1) that is southeast of the map area (Colquhoun, 1974). In the map area, fingers of these deposits extend up into and partly fill old estuaries within the Penholoway terrace area that were not completely filled during Penholoway time. The Ten Mile Hill beds are equivalent to unit Q_3 of McCartan and others (1984). They were deposited at a time when sea level in the Charleston area stood about 35 ft above its present level relative to the land, as indicated by the present altitude of the top of the lagoonal deposits of this unit. Corals recovered by the authors from marine deposits of the Ten Mile Hill beds in the Ravenel and Johns Island quadrangles yielded U/Th ratios that indicate the unit accumulated between 240 and 200 ka (Cronin and others, 1981; McCartan and others, 1982; Szabo, 1985). This age corresponds to marine oxygen-isotope Stage 7 of Shackleton and Opdyke (1973). The Ten Mile Hill beds are poorly consolidated, easily excavated, and readily eroded. Clay-rich intervals may be quite sticky.

Wando Formation

The Wando Formation is defined by McCartan and others (1980) as only slightly weathered beds of sand, clayey sand, and clay which underlie the Pamlico and Princess Anne terraces of Colquhoun (1974). This unit was mapped as unit Q_2 by McCartan and others (1984). The Wando encompasses sediments deposited during three minor but distinct late Pleistocene high-sea-level pulses (Corrado and others, 1986), all of which fall within the major high-sea-level stand defined as Stage 5 by

Shackleton and Opdyke (1973). In the map area, beds that were deposited predominantly in marsh environments are associable both with the oldest (**Qwlc**) and with the youngest (**Qwc**) transgressive pulses. Estuaries filling Cypress Swamp and Four Hole Swamp were partly filled with clay and clayey sand to altitudes as high as 25 ft above present sea level during deposition of the lower part of the Wando, and as high as 15 ft above present sea level during deposition of the upper part of the Wando. The Wando is poorly consolidated, easily excavated, and readily eroded. Clay-rich intervals may be quite sticky. Sand beds of the Wando underwent extensive liquefaction to the south and west of the map area during the 1886 Charleston earthquake (Dutton, 1889), but liquefaction features are rare to absent within the clay-rich deposits present in the map area.

Wisconsinan and Holocene deposits

Materials that accumulated in the map area within the last 70,000 years are not formally named. Some of these deposits (**Qhm**) mostly consist of peat and carbonaceous clay (muck) which date from the Wisconsinan to the present (Weems and Lemon, 1988). Areas underlain by unit **Qhm**, especially those which lie in small or irregularly shaped depressions, are termed pocosins (Richardson, 1981). Some of the larger depressions, which are characterized by a round to ellipsoidal shape, are called "Carolina bays" (Thornbury, 1965; Kaczorowski, 1977). Along stream courses, areas where sandy sediment seems to be actively prograding have been mapped as **Qal**. Thin deposits of very fine grained, windblown Holocene sand exist also, but they are localized and too poorly exposed to be mapped. These Wisconsinan to Holocene deposits, which are equivalent to unit Q_1 of McCartan and others (1984), are unconsolidated and saturated with water.

Geologic History

The map area has been inundated repeatedly by marginal-shelf seas of the Atlantic Ocean since Late Cretaceous time. A summary of the lithostratigraphy and biostratigraphy of the materials that accumulated during Late Cretaceous and early Tertiary marine transgressions is presented by Gohn and others (1977) and Hazel and others (1977). These older deposits occur in the map area only in the subsurface (65 to 3,300 ft below sea level).

The oldest unit penetrated by auger drilling within 75 ft of the surface is the middle Eocene Cross Member of the Santee Limestone. At the time this unit was deposited, the map area was located on the continental shelf under open-marine waters. The abundant epifauna and sandy calcareous texture of this unit indicate that the bottom sediment was firm and well aerated, and that the water column above it was clear. After deposition of the Cross Member, the sea withdrew eastward beyond the present coastline. It returned across the area in late Eocene time, and deposited the Harleyville Formation. The Harleyville is more muddy and less shelly than the Cross, so it probably accumulated in somewhat deeper water than the Cross. After deposition of the Harleyville the sea withdrew eastward briefly, then returned again to deposit the upper Eocene Parkers Ferry Formation. At the time this unit was deposited, the map area again was located on the continental shelf under open-marine waters, but the fine texture and restricted fossil assemblage of the Parkers Ferry indicate that the ocean bottom was soft and covered with calcareous ooze, which was foraged and extensively bioturbated by echinoids. The Santee Limestone, Harleyville Formation, and Parkers Ferry Formation contain the zeolite mineral clinoptilolite, which is considered to be an alteration product of volcanic ash (Gohn and others, 1977). No younger units have yielded this mineral, though it does occur in older local upper Paleocene units.

During most of the early and middle Oligocene (a time interval of about 6 million years), the sea withdrew far to the east of the Charleston area. The Harleyville and Parkers Ferry Formations were extensively eroded, and channels up to 100 ft deep were cut into them. After this erosional episode, the next major transgression of the sea across the Charleston area occurred at about 30 Ma in late Oligocene time, when the quartzose calcarenites of the Ashley Formation accumulated in an open-marine-shelf environment. Vast quantities of Foraminifera tests accumulated, as did minor quantities of mollusk, coral, and vertebrate remains. By the end of deposition of the Ashley, major tectonic subsidence ceased in the Charleston area and the sea regressed, probably to the east of the present coastline.

During another late Oligocene transgression, probably 1–2 million years later, the Chandler Bridge Formation accumulated (Sanders and others, 1982). In contrast to the Ashley, this is a clastic coastal deposit. Abundant vertebrate life left numerous remains in this environment, so that the Chandler Bridge is one of the most prolific bone-producing units in the Charleston region. The sea withdrew again briefly from the Charleston area during late Oligocene time to slightly east of the present coastline, and next transgressed again across the outer Coastal Plain during latest Oligocene and (or) earliest Miocene time. During this transgression, the calcareous sands of the Edisto Formation accumulated in shallow-marine-shelf depositional environments.

At the end of deposition of the Edisto Formation, the sea withdrew far to the east of its present position. The Charleston area again was extensively eroded and channeled, so that when deposition resumed it was upon a surface having at least 100 ft of relief. About 6 million years later during early Miocene (Burdigalian) time, the area was again inundated by the sea, which deposited phosphatic, fine-grained, attapulgite-rich, clayey sands and clays of the Marks Head Formation of Abbott and Huddlestun (1980). Although well developed elsewhere in the Charleston region, this unit is unknown in the map area. During late middle or early late Miocene time, another transgression occurred which left behind the Rudd Branch beds. This unit represents a shallow-marine-shelf deposit which remains in isolated patches within the map area but was removed elsewhere from the Charleston area by later erosion. It is possible, but not certain, that this unit was the source of phosphatized late Miocene or early Pliocene ziphiid whale remains that were found in Pleistocene lag gravels to the southeast in the Ashley River phosphate district (Leidy, 1876, 1877).

Two regional Pliocene transgressions deposited the Goose Creek Limestone and the Raysor Formation in shallow-marine-shelf environments. The presence of both units to the north near Cross, S.C. (Campbell, 1989) suggests that both once continuously covered the map area. The Goose Creek has been completely removed from this area, but Raysor sediments are locally abundant as patches of erosional outliers. The present patchy distribution of this unit suggests that it was extensively stripped away in late Pliocene or earliest Pleistocene time prior to deposition of the Waccamaw(?) Formation.

The Pringletown beds suggest that a marine transgression reached the map area in late Pliocene or earliest Pleistocene time between the transgression that deposited the Raysor Formation and the transgression that deposited the Waccamaw(?) Formation. The inshore clastic facies of the Pringletown beds possibly are time equivalent to the Chowan River Formation. After the Pringletown beds accumulated, the sea withdrew from the entire Charleston region. During this regression, the Santee River became entrenched in the channel now occupied by Four Hole Swamp and drained southward from there down the present lower course of the Edisto River.

The Waccamaw(?) Formation (unit Q_6 of McCartan and others, 1984) was deposited during an early Pleistocene marine transgression around 1.6–1.4 Ma, which extended inland to the northwestern edge of the map area. There, a barrier island (**Qwws**) was formed at the inland limit of this transgression. The transgression covered the old channel of the Santee River which ran through present Four Hole Swamp, allowing the Santee River to migrate to the northeast of its old channel area. When the sea withdrew at the end of deposition of the Waccamaw(?), the Santee became entrenched to the north and northeast of the map area, approximately along its present course.

Later in the early Pleistocene, a major transgression represented by the Penholoway Formation reached westward into the map area and formed the Pinopolis/Summerville and Ridgeville barriers. These barriers, which were derived from sands being carried to the ocean edge by the Santee River, marked the inland limit of transgression during the deposition of the Penholoway, around 970–730 ka. The lagoon that formed behind the Pinopolis/Summerville barrier was initially open and had nearly normal salinities, but later became much more silty and brackish as it infilled. The younger Pleistocene deposits around the fringes of Cypress Swamp (units **Qlc** and **Qtc**) and the recent sediments underlying the swamp (unit **Qal**) demarcate the part of this lagoon that was not infilled before the regression at the end of Penholoway time.

The sea transgressed again in middle Pleistocene time (around 450 ka), reaching the southeasternmost edge of the map area, where it deposited a barrier beach deposit (**Qls**) directly against the older Penholoway terrace headland. The old Penholoway lagoon was partly flooded and partly filled by sediment (**Qlc**). Later Pleistocene transgressions did not extend inland as far as the map area. However, swamps or marshes formed along the margins of Four Hole Swamp and Cypress Swamp during transgressions that occurred around 230 ka, 120 ka, and 80 ka as the result of the lowering of stream gradients during times of high sea-level stand. Except for these two areas, the map area has been subjected mostly to erosion during the last 400,000 years. This prolonged interval of erosion and soil formation has given most of the soils in the area a distinctly reddish cast and caused the morphology of the early Pleistocene beach and marsh deposits to become greatly modified. Only areas beneath Cypress Swamp and Four Hole Swamp (**Qal**) and areas underlain by marsh deposits (**Qhm**) have undergone recent deposition.

Geomorphology

The regional geomorphic pattern of the map area was produced by nearshore coastal processes. Coastal erosion in some areas was balanced by marsh and beach-ridge sediment buildup in other areas during the transgression that deposited the Wicomico terrace and Waccamaw(?) Formation about 1.5 Ma, and during the transgression that deposited the Penholoway Formation about 970–730 ka. These transgressions resulted in the deposition of the Dorchester barrier (**Qwws**) and the Pinopolis/Summerville/Ridgeville barrier complex (**Qps**), respectively. In early middle Pleistocene time, extensive lagoonal/estuarine sedimentation up to altitudes 50 ft above present sea level occurred along the margins of Cypress Swamp, but no other major part of the map area underwent extensive deposition. Since those times, the area has dominantly undergone erosion. As a result, most of the coastal geomorphic features have been extensively modified and obscured by dissection due to the erosional stream systems that have developed around the margins of Four Hole Swamp and Cypress Swamp.

Four Hole Swamp is underlain by coarse-grained feldspathic sands (**Qwwr**) that are totally incompatible with its present drainage setting. These sands are, however, quite similar to the sands that are presently being carried down the Santee River. Therefore we infer that Four Hole Swamp once was a channel of the Santee River that was cut out in late Pliocene and (or) early Pleistocene time. This channel was buried at least partly during the advance of the sea that deposited the Wicomico terrace and Waccamaw(?) Formation, but since then headward erosion along the axis of the old channel has removed much of its soft sand fill and carried it southward to the Edisto River (see fig. 1). The "Great Bight of the Edisto", where the Edisto River makes an abrupt and dramatic turn to the south in its course, marks the old point of juncture of the Santee River and the Edisto River. From this point southward, the Edisto River has reoccupied the course of the former Santee/Edisto drainage. But without the flow of the Santee River coming down from the north, the force of the Edisto River flowing southeastward is unchecked at the old point of juncture. Therefore, the Edisto River has tended to migrate across the old Santee River valley eastward to where it becomes deflected by the tough Ashley Formation material forming the base of the old east valley wall. The force of the Edisto River's flow, where the river is abruptly deflected southward, has eroded out the high bare bluff that forms such a prominent and unusual feature at Givhans Ferry State Park just west of the map area.

A prominent feature in the Pringletown quadrangle is the swath of Waccamaw(?) sediment that extends southwestward, across the path of Four Hole Swamp, where the swamp turns sharply southwest. This deposit appears to represent a submarine bar that partly formed across the mouth of this old Santee River estuary, deflecting it southwestward. Its geometry indicates that it was formed by a southwestward-flowing longshore current. This direction of longshore current flow has dominated throughout all of the interglacial intervals represented by terraces in South Carolina and is the primary direction of longshore current flow today.

During the next transgression, the Pinopolis/Summerville barrier (**Qps**) grew southward and then southwestward along its present course along the axis of a topographic high on the Ashley, thereby defining the seaward margin of its exceptionally wide backbarrier lagoon (**Qpc**). Rhea (1989) considered the exceptional breadth of the backbarrier region between the Ridgeville and Pinopolis/Summerville barriers to be tectonically controlled, and Marple and Talwani (1993) included this area in their north-northeast-trending "zone of river anomalies". Therefore, early Pleistocene tectonic upwarping may have strongly influenced the development of this stratigraphic complex.

The overall geometry of the Ridgeville and Pinopolis/Summerville barrier systems suggests that the embayment between the two systems initially had a clockwise direction of current flow. The imbrication of the barrier ridges in the Ridgeville set indicates flow to the northeast, while the stacking direction of the ridges along the western margin of the Pinopolis/Summerville barrier system suggests flow to the southwest. The small, probably submarine sand ridges in the southwestern corner of the Ridgeville quadrangle indicate that the major longshore flow continued across the mouth of the intervening lagoon to the west and southwest. But within the lagoon, between the two barrier systems, there must have been a strong clockwise secondary current. This strong current, in the early stages of its development, probably kept the salinity of the lagoon near normal oceanic levels. This may explain why the fossil assemblages found in the Penholoway Formation in the vicinity of Summerville are exceptionally diverse.

Tectonics

The southeastern part of the map area includes the northwestern margin of the Middleton Place/Summerville Seismic Zone. The largest historic earthquake in or near this zone was the 1886 Charleston earthquake (fig. 1). Extensive damage from the 1886 earthquake was documented in the town of Summerville (Dutton, 1889), which was the largest town close to the earthquake epicenter. Some liquefaction features were reported in the map area, but they are rarer than in most other parts of the greater Charleston region. The reason seems to be that the surficial deposits in the map area are among the oldest exposed in this region. Therefore, they have been more pervasively weathered, cemented, and compacted than sediments that elsewhere underwent extensive liquefaction in 1886 (Weems and Obermeier, 1989). Thus, abundance of liquefaction features correlates only weakly within the map area with proximity to the epicenter of the 1886 earthquake. The instrumentally determined epicenters of 22 small, recent earthquakes in the map area are shown (Tarr and Rhea, 1983; Talwani and others, 1992, 1993). All are located northwest of the probable epicenter of the 1886 earthquake (location B on figure 1). These recent events appear to define two trends, one running northwest to southeast, and the other running west-southwest to east-northeast. All but one event in the latter set seem to define a plane dipping steeply to the north-northwest. The largest earthquake event recorded since the deployment of permanent seismic stations in 1974 was a magnitude $M_L4.1$ event with a Modified Mercalli Intensity of VI that occurred on August 21, 1992, just south of the map area and about a mile southeast of Summerville (Bagwell and Talwani, 1992; Talwani and others, 1993).

The streams around Cypress Swamp, especially along its southeastern margin, are aligned roughly parallel to each other along a west-northwest - east-southeast axis. The alignment may have resulted simply from downslope wash off of the original slope on the bottom of the backbarrier lagoon behind the Pinopolis/Summerville barrier, but it is also possible that it developed on a pervasive joint pattern present within the Ashley Formation, which immediately underlies the Penholoway Formation sediments in much of this area. The northwest orientation of the small cave observed in the Pringletown quadrangle suggests that such a joint set may be present. This joint pattern is perhaps related to the north-northeast-trending "zone of river anomalies" recognized across this region and to the north by Marple and Talwani (1993).

Economic Geology and Water Resources

"Phosphate rock", chiefly concentrated as a lag bed at the base of the Wando Formation, was mined extensively about 10 mi to the southeast of the map area in the Johns Island and Ladson quadrangles from 1867 to 1937 (Malde, 1959; Force and others, 1978). Although phosphate occurs in the map area as detrital deposits between many of the stratigraphic units, it is either in beds too thin or at depths too great to make commercial exploitation worthwhile at present.

The clayey sand and clay facies of the upper part of the Penholoway Formation were mined for brick clays in the map area (Sloan, 1908), even until the last few decades, but this resource is not being utilized currently. Sand and earth fill are the only mineral resources presently exploited in the area (Long and others, 1980; Miller and others, 1971). The barrier sands contain the best sorted sands, while the backbarrier deposits contain variable amounts of clay. Both are excavated by stripping. Some borrow pits are shown on the map; others probably exist but escaped detection during mapping.

Quaternary units in the map area generally are saturated with water. They are tapped occasionally by shallow wells either where the water table is deep enough to prevent contamination or where the water can be used for purposes other than drinking. The major aquifers in this area are located within the Black Mingo Group (Paleocene and lower Eocene) and the Santee Limestone (middle Eocene), mostly at depths below those shown in the cross sections for this report. The water in these units commonly is under partial artesian pressure.

Postscript

Before this map could be published, coauthor Earl M. Lemon, Jr., met an untimely death from a heart attack at age 39. The remaining authors are extremely grateful for the hard work and keen insights that Mr. Lemon contributed to this and other Charleston area U.S. Geological Survey maps and papers. The completeness and accuracy of these works have been enhanced greatly by Mr. Lemon's effort and dedication; he and his expertise will be sorely missed.

REFERENCES CITED

Abbott, W.H., and Huddlestun, P.F., 1980, The Miocene of South Carolina, *in* DuBar, J.R., DuBar, S.S., Ward, L.W., and Blackwelder, B.W., Cenozoic biostratigraphy of the Carolina outer Coastal Plain: Geological Society of America Field Trip Guidebook 9, p. 208–210.

Bagwell, J.B., and Talwani, Pradeep, 1992, Isoseismal study of August 21, 1992, Summerville, South Carolina earthquake: 64th Annual Meeting of the Eastern Section, Seismological Society of America, Seismic Research Letters, v. 63, no. 4, p. 606.

Barrett, P.J., Adams, C.J., McIntosh, W.C., Swisher, C.C., III, and Wilson, G.S., 1992, Geochronological evidence supporting Antarctic deglaciation three million years ago: Nature, v. 359, p. 816–818.

Berggren, W.A., Kent, D.V., Flynn, J.J., and Van Couvering, J.A., 1985, Cenozoic geochronology: Geological Society of America Bulletin, v. 96, p. 1407–1418.

Blackwelder, B.W., and Ward, L.W., 1979, Stratigraphic revision of the Pliocene deposits of North and South Carolina: South Carolina Geological Survey, Geologic Notes, v. 23, no. 1, p. 33–49.

Bollinger, G.A., 1977, Reinterpretation of the intensity data for the 1886 Charleston, South Carolina, earthquake, *in* Rankin, D.W., ed., Studies related to the Charleston, South Carolina, earthquake of 1886; a preliminary report: U.S. Geological Survey Professional Paper 1028–E, p. 17–32.

Brunswig, N.L., and Winton, S.G., 1978, The Francis Beidler Forest in Four Hole Swamp: New York, N.Y., National Audubon Society.

Campbell, M.R., 1989, Resolution of the Goose Creek problem in the Charleston district of South Carolina [abs.]: Bulletin of the South Carolina Academy of Science, v. 51, p. 17–18.

Clark, W.B., and Miller, B.L., 1912, The physiography and geology of the Coastal Plain province of Virginia: Virginia Geological Survey Bulletin 4, p. 1–58, 88–222.

Colquhoun, D.J., 1974, Cyclic surficial stratigraphic units of the Middle and Lower Coastal Plains, central South Carolina, *in* Oaks, R.Q., Jr., and DuBar, J.R., eds., Post-Miocene stratigraphy, central and southern Atlantic Coastal Plain: Logan, Utah, Utah State University Press, p. 179–190.

Colquhoun, D.J., Oldham, R.W., Bishop, J.W., and Howell, P.D., 1982, Updip delineation of the Tertiary limestone aquifer, South Carolina: U.S. Department of the Interior, Office of Water Policy, Technical Completion Report A–055–SC, 93 p.

Cooke, C.W., 1936, Geology of the coastal plain of South Carolina: U.S. Geological Survey Bulletin 867, 196 p.

Corrado, J.C., Weems, R.E., Hare, P.E., and Bambach, R.K., 1986, Capabilities and limitations of applied aminostratigraphy, as illustrated by analyses of *Mulinia lateralis* from the Late Cenozoic marine beds near Charleston, South Carolina: South Carolina Geology, v. 30, no. 1, p. 19–46.

Cronin, T.M., Szabo, B.J., Ager, T.A., Hazel, J.E., and Owens, J.P., 1981, Quaternary climates and sea levels of the U.S. Atlantic Coastal Plain: Science, v. 211, no. 4479, p. 233–240.

DuBar, J.R., 1971, Neogene stratigraphy of the lower Coastal Plain of the Carolinas: Myrtle Beach, S.C., Atlantic Coastal Plain Geological Association Field Conference, no. 12, 128 p.

Dutton, C.E., 1889, The Charleston earthquake of August 31, 1886: U.S. Geological Survey, Annual Report 9, p. 203–528.

Force, E.R., Gohn, G.S., Force, L.M., and Higgins, B.B., 1978, Uranium and phosphate resources in the Cooper Formation of the Charleston region, South Carolina: South Carolina Geological Survey, Geologic Notes, v. 22, no. 1, p. 17–31.

Gibbes, L.R., Mazyck, W.G., Schlepegrell, F.W., Manigault, G.E., and Colson, C.B., 1887, Report of the commission appointed to study the Charleston earthquake of August 31, 1886: Proceedings of the Elliott Society of Sciences and Art, Charleston, S.C., v. 2, p. 134–171.

Goddard, E.N., and others, 1948, Rock-color chart: Washington, D.C., National Research Council, 6 p. [Reprinted by Geological Society of America, 1951, 1963, 1970.]

Gohn, G.S., Higgins, B.B., Smith, C.C., and Owens, J.P., 1977, Lithostratigraphy of the deep corehole (Clubhouse Crossroads corehole 1) near Charleston, South Carolina, *in* Rankin, D.W., ed., Studies related to the Charleston, South Carolina, earthquake of 1886; a preliminary report: U.S. Geological Survey Professional Paper 1028–E, p. 59–70.

Hazel, J.E., Bybell, L.M., Christopher, R.A., Frederiksen, N.O., May, F.E., McLean, D.M., Poore, R.Z., Smith, C.C., Sohl, N.F., Valentine, P.C., and Witmer, R.J., 1977, Biostratigraphy of the deep corehole (Clubhouse Crossroads corehole 1) near Charleston, South Carolina, *in* Rankin, D.W., ed., Studies related to the Charleston, South Carolina, earthquake of 1886; a preliminary report: U.S. Geological Survey Professional Paper 1028–F, p. 71–89.

Kaczorowski, R.T., 1977, The Carolina Bays; a comparison with modern oriented lakes: South Carolina University, Coastal Research Division, Technical Report Number 13, 124 p.

Leidy, Joseph, 1876, Remarks on fossils from the Ashley phosphate beds: Proceedings of the Academy of Natural Sciences of Philadelphia, v. 28, p. 80–81, 86–87, 114–115.

———1877, Description of vertebrate remains, chiefly from the phosphate beds of South Carolina: Journal of the Academy of Natural Sciences of Philadelphia, series 2, v. 8, part 3, article 9, p. 209–262.

Lemon, E.M., Jr., 1979, Textural and clay-mineral differentiation of Oligocene and Pleistocene deposits in the Stallsville quadrangle, South Carolina: Geological Society of America, Abstracts with Programs, v. 11, no. 4, p. 186.

Liddicoat, J.C., McCartan, Lucy, Weems, R.E., and Lemon, E.M., Jr., 1981, Paleomagnetic investigation of Pliocene and Pleistocene sediments in the Charleston, S.C., area: Geological Society of America, Southeastern Section, 30th Annual Meeting, Abstracts with Programs, v. 13, no. 1, p. 12, 29.

Long, B.M., Hurt, G.W., Long, G.V., Love, T.R., and Andrews, L.E., 1980, Soil survey of Berkeley County, South Carolina: Washington, D.C., U.S. Department of Agriculture, Soil Conservation Service and Forest Service, 94 p., 100 map sheets.

Lyell, Charles, 1845, Observations on the White Limestone and other Eocene or older Tertiary formations of Virginia, South Carolina, and Georgia: Geological Society of London Quarterly Journal, v. 1, p. 429–442.

Malde, H.E., 1959, Geology of the Charleston phosphate area, South Carolina: U.S. Geological Survey Bulletin 1079, 105 p.

Marple, R.T., and Talwani, Pradeep, 1993, Evidence of possible tectonic upwarping along the South Carolina coastal plain from an examination of river morphology and elevation data: Geology, v. 21, no. 7, p. 651–654.

Martini, Erlend, 1971, Standard Tertiary and Quaternary calcareous nannoplankton zonation, *in* Farinacci, Anna, ed., Proceedings of the Second Planktonic Conference, Roma 1970: Rome, Edizioni Tecnoscienza, p. 739–777.

McCartan, Lucy, Weems, R.E., and Lemon, E.M., Jr., 1980, The Wando Formation (Upper Pleistocene) in the Charleston, S.C. area, *in* Contributions to Stratigraphy: U.S. Geological Survey Bulletin 1502–A, p. A110–A116.

McCartan, Lucy, Owens, J.P., Blackwelder, B.W., Szabo, B.J., Belknap, D.F., Kriausakul, N., Mitterer, R.M., and Wehmiller, J.F., 1982, Comparison of amino acid racemization geochronometry with lithostratigraphy, biostratigraphy, uranium-series coral dating, and magnetostratigraphy in the

Atlantic Coastal Plain of the southeastern United States: Quaternary Research, v. 18, no. 3, p. 337–359.

McCartan, Lucy, Lemon, E.M., Jr., and Weems, R.E., 1984, Geologic map of the area between Charleston and Orangeburg, South Carolina: U.S. Geological Survey Miscellaneous Investigations Series Map I–1472, scale 1:250,000.

Miller, E.N., Jr., Long, B.M., McDonald, J.E., Steedly, W.M., Stuck, W.M., Ware, C.B., Love, T.R., and Andrews, L.E., 1971, Soil survey of Charleston County, S.C.: Washington, D.C., U.S. Department of Agriculture, Soil Conservation Service, 78 p., 88 map sheets.

Porcher, R.D., 1981, The vascular flora of the Francis Beidler Forest in Four Holes Swamp, Berkeley and Dorchester Counties, South Carolina: Castanea, v. 46, p. 248–280.

Rhea, Susan, 1989, Evidence of uplift near Charleston, South Carolina: Geology, v. 17, p. 311–315.

Richardson, C.J., 1981, Pocosin wetlands: Stroudsburg, Pa., Hutchinson Ross Publishing Company, 364 p.

Sanders, A.E., 1974, A paleontological survey of the Cooper Marl and Santee Limestone near Harleyville, South Carolina--Preliminary report: South Carolina Geological Survey, Geologic Notes, v. 18, no. 1, p. 4–12.

Sanders, A.E., Weems, R.E., and Lemon, E.M., Jr., 1982, The Chandler Bridge Formation; a new Oligocene stratigraphic unit in the lower Coastal Plain of South Carolina, *in* Contributions to Stratigraphy: U.S. Geological Survey Bulletin 1529–H, p. H105–H124.

Shackleton, N.J., and Opdyke, N.D., 1973, Oxygen isotope and palaeomagnetic stratigraphy of equatorial Pacific core V28–238: Quaternary Research, v. 3, no. 1, p. 39–55.

Sloan, Earle, 1908, Catalogue of the mineral localities of South Carolina: South Carolina Geological Survey Bulletin 2, 505 p. (reprinted 1958).

Szabo, B.J., 1985, Uranium-series dating of fossil corals from marine sediments of southeastern United States Atlantic Coastal Plain: Geological Society of America Bulletin, v. 96, no. 3, p. 398–406.

Talwani, Pradeep, Rajendran, Kusala, Madabhushi, Sriram, and Cannon, Richard, 1992, South Carolina seismic network: South Carolina Seismic Network Bulletin, v. 1, p. 1–53.

———1993, South Carolina seismic network: South Carolina Seismic Network Bulletin, v. 2, p. 1–52.

Tarr, A.C., and Rhea, Susan, 1983, Seismicity near Charleston, South Carolina, March 1973 to December 1979, *in* Gohn, G.S., ed., Studies related to the Charleston, South Carolina, earthquake of 1886—Tectonics and seismicity: U.S. Geological Survey Professional Paper 1313, p. R1–R17.

Thornbury, W.D., 1965, Regional geomorphology of the United States: New York, John Wiley and Sons, 609 p.

Tuomey, Michael, 1848, Report on the geology of South Carolina: Columbia, S.C., A.S. Johnston, 293 p.

Ward, L.W., Blackwelder, B.W., Gohn, G.S., and Poore, R.Z., 1979, Stratigraphic revision of Eocene, Oligocene, and lower Miocene formations of South Carolina: Geologic Notes, v. 23, no. 1, p. 2–32.

Ward, L.W., and Huddlestun, P.F., 1988, Age and stratigraphic correlation of the Raysor Formation, late Pliocene, South Carolina: Tulane Studies in Geology and Paleontology, v. 21, no. 2, p. 59–75.

Weems, R.E., and Lemon, E.M., Jr., 1984a, Geologic map of the Mount Holly quadrangle, Berkeley and Charleston Counties, South Carolina: U.S. Geological Survey Geologic Quadrangle Map GQ–1579, scale 1:24,000.

———1984b, Geologic map of the Stallsville quadrangle, Dorchester and Charleston Counties, South Carolina: U.S. Geological Survey Geological Quadrangle Map GQ–1581, scale 1:24,000.

———1988, Geologic map of the Ladson quadrangle, Berkeley, Charleston, and Dorchester Counties, South Carolina: U.S. Geological Survey Geologic Quadrangle Map GQ–1630, scale 1:24,000.

———1993, Geologic map of the Cainhoy, Charleston, Fort Moultrie, and North Charleston quadrangles, Charleston and Berkeley Counties, South Carolina: U.S. Geological Survey Miscellaneous Investigations Series Map I–1935, scale 1:24,000.

Weems, R.E., Lemon, E.M., Jr., McCartan, Lucy, Bybell, L.M., and Sanders, A.E., 1982, Recognition and formalization of the Pliocene "Goose Creek Phase" in the Charleston, S.C., area, *in* Contributions to Stratigraphy: U.S. Geological Survey Bulletin 1529–H, p. H137–H148.

Weems, R.E., Lemon, E.M., Jr., Nelson, M.O., Gohn, G.S., and Houser, B.B., 1987, Detailed sections from auger holes and outcrops in the Pringletown, Ridgeville, Summerville Northwest, and Summerville quadrangles, South Carolina: U.S. Geological Survey Open-File Report 87–524, 89 p.

Weems, R.E., and Obermeier, S.F., 1989, The 1886 Charleston earthquake—An overview of geological studies, *in* Proceedings of the U.S. Nuclear Regulatory Commission, Seventeenth Water Reactor Safety Information Meeting, October 23–25, 1989, Rockville, Md.: U.S. Nuclear Regulatory Commission Report No. NUREG/CP–0105, v. 2, p. 289–313.