Carolina Bay Geoarchaeology and Holocene Landscape Evolution on the Upper Coastal Plain of South Carolina

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Surface water on the mainly dry, upland interfluves of the Upper Coastal Plain of South Carolina occurs currently as a sporadic distribution of shallow ponds held within Carolina bays and other small, isolated basins. At seven bays on the U.S. Department of Energy's Savannah River Site on the Upper Coastal Plain of South Carolina, we investigated Holocene changes in bay morphology, ecology, and prehistoric human activity. At Flamingo Bay, we employed archaeological survey and testing, shovel and auger testing, sediment analysis, and ground-penetrating radar to document stratigraphy and chronology of the sand rim on the eastern side of the bay. Artifact assemblage indicate changes in intensity of human use of the bay. Radiocarbon dates from a sediment core establish time scales for depositional processes at the center of the basin. Ground-penetrating radar data from the other bays indicate that the stratigraphy of all seven bays is broadly similar. We conclude that: (1) Significant modification of the bays, including rim development and basin infilling, occurred during the Holocene; (2) ponds on the early Holocene landscape were larger and more permanent than at present; (3) early Holocene climate, as indicated by both depositional processes and human activity, was not characterized by prolonged periods of extremely dry conditions; and (4) fluvial-centric models of terminal Pleistocene–early Holocene human adaptations require revision to include intensive use of isolated upland ponds. © 1996 John Wiley & Sons, Inc.

INTRODUCTION

Understanding the history of environmental changes in a landscape is critical to understanding the history of human occupation of that landscape. On the Upper Coastal Plain of South Carolina, studies of the evolution of the alluvial terraces of the Savannah River have contributed substantially to our knowledge of fluvial environments as loci of prehistoric activity in the region (Brooks

and Sassaman, 1990; Sassaman et al., 1990). Much less is known about the upland landscape, particularly the dry interfluves of the Aiken Plateau where surface water is currently limited to a sporadic distribution of Carolina bays and other isolated, shallow ponds. The character and distribution of surface water and evolution of the landscape are intimately linked to regional climate. Because prehistoric populations tended to track surface water (Brooks et al., 1986, 1990; Brooks and Sassaman, 1990; Sassaman et al., 1990), these ponds should provide evidence of changes in the nature and intensity of human activity in the uplands and of changes in Holocene environmental conditions.

Carolina bays are ponds and wetlands that occur in shallow, ellipsoidal depressions, usually without apparent surface inlet or outlet, on undissected land surfaces of the Atlantic Coastal Plain from southeast New Jersey to northeast Florida (Johnson, 1942; Richardson and Gibbons, 1993). The long axes of most of the bays in the South Atlantic Coastal Plain have northwest-southeast orientations. For counties of the Upper Coastal Plain of South Carolina, the average lengths of Carolina bays range from 200 to 500 m (Bennett and Nelson, 1991). Bays of the Lower Coastal Plain are typically larger, with average lengths as great as 1600 m (Georgetown County, South Carolina). Subaerial sand rims are common features of Carolina bays and are generally developed best on the eastern margins of the bays. A few,well-known Carolina bays are large, shallow lakes; the majority are wetlands or wetland ponds with widely fluctuating water levels. These fluctuations are driven mainly by precipitation and evapotranspiration, and hydrologic budgets of the ponds are extremely responsive to weather and climate (Taylor and Brooks, 1994; Lide et al., 1995).

Current data indicate that Carolina bays are of late Pleistocene age, although multiple generations of bays are possible (Soller and Mills, 1991). The origin of Carolina bays has been controversial (Johnson, 1942; Prouty, 1952; Kaczorowski, 1977; Savage, 1982). The hypothesis that bays developed their distinctive shape and orientation through strong, directional winds blowing over water in upland surface depressions (Kaczorowski, 1977) has gained some measure of acceptance (Bliley and Burney, 1988; Carver and Brook, 1989; Markewich and Markewich, 1994). According to this hypothesis, the depressions were expanded and oriented by wave erosion, resulting in bay elongation perpendicular to wind direction and the formation of peripheral, downwind sand rims and shorelines.

Because of their hydrologic responsiveness to weather and climate, these shallow ponds may be sensitive indicators of paleoenvironmental conditions. Useful information about southeastern paleoenvironments has been obtained from peat cores of Carolina bays (Frey, 1951; Whitehead, 1981) and other isolated ponds (Watts, 1980; Watts et al., 1992). However, on the U.S. Department of Energy's Savannah River Site (SRS), our study area on the Upper Coastal Plain of South Carolina, the shallow basins and the hydrologies of the ponds, under warm climate, are not conducive to accumulation or preservation of organic materials. Sparse siliceous microfossils (E. E. Gaiser, personal com-

munication) and pollen (A. Cohen, personal communication) are present in the sediments, and analyses of them are in progress.

We present results from studies that utilize a variety of techniques to infer the history of Holocene changes in basin morphology, ecology, and human activity at Flamingo Bay, a Carolina bay on the SRS. Archaeological dates established time scales for depositional processes on the rim of the basin, and radiocarbon dates established time scales for depositional processes at the center of the basin. Composition of the archaeological assemblages documented intensity of human use. Ground-penetrating radar (GPR), supplemented with auger, core, and sediment column data, was used to map stratigraphy of the bay margin at Flamingo Bay and six other upland bays on the SRS. These results describe changes to the rim and basin of Flamingo Bay during the Holocene, and they also provide information concerning early Holocene climate and the formation of Carolina bays. In light of the archaeological evidence, we reconsider the adequacy of our fluvial-centric models for early Holocene human occupation of the uplands.

PROJECT BACKGROUND

Sampling Design

The SRS is a 803 km^2 federal reserve on the Upper Coastal Plain of South Carolina (see Brooks et al. [1990] for a synthesis of the SRS physiography, geomorphology and surficial geology). According to Schalles et al. (1989), there are at least 194 Carolina bays and other isolated ponds on the SRS (Figure 1). The ponds range from 0.5 to 50 ha in area, and many of them dry seasonally.

Seven bays were chosen for this study: Flamingo Bay (#3 according to Shields et al., 1982), Bay 58, the paired Mona (#66) and Woodward (#67) Bays, the paired Craig Pond (#77) and Sarracenia Bay (#78), and Thunder Bay (#83) (Figure 1). Selection criteria included large size, long hydroperiod, archaeological potential, accessibility to GPR equipment, and background data from ecological studies conducted by the Savannah River Ecology Laboratory (SREL). All seven of the bays are located in the uplands (Aiken Plateau). Because archaeological sites, as well as bays, are more sparsely and discretely distributed in the uplands than on the alluvial terraces, we judged that ascertaining direct associations between archaeological sites and bays would be easier for the uplands and that the inferences about relationships between prehistoric activity and environmental conditions at the bays would therefore be stronger. Because studies of the modern ponds provide baselines against which inferred variation in the past can be compared, we focussed our main efforts on Flamingo Bay, which is the best-studied ecologically.

Ecological Background

Major physiographic attributes of the seven study bays are summarized in Table I. All have ellipsoidal shapes, and their long axes are oriented northwest-southeast. Their general form is illustrated by Flamingo Bay (Figure 2); the
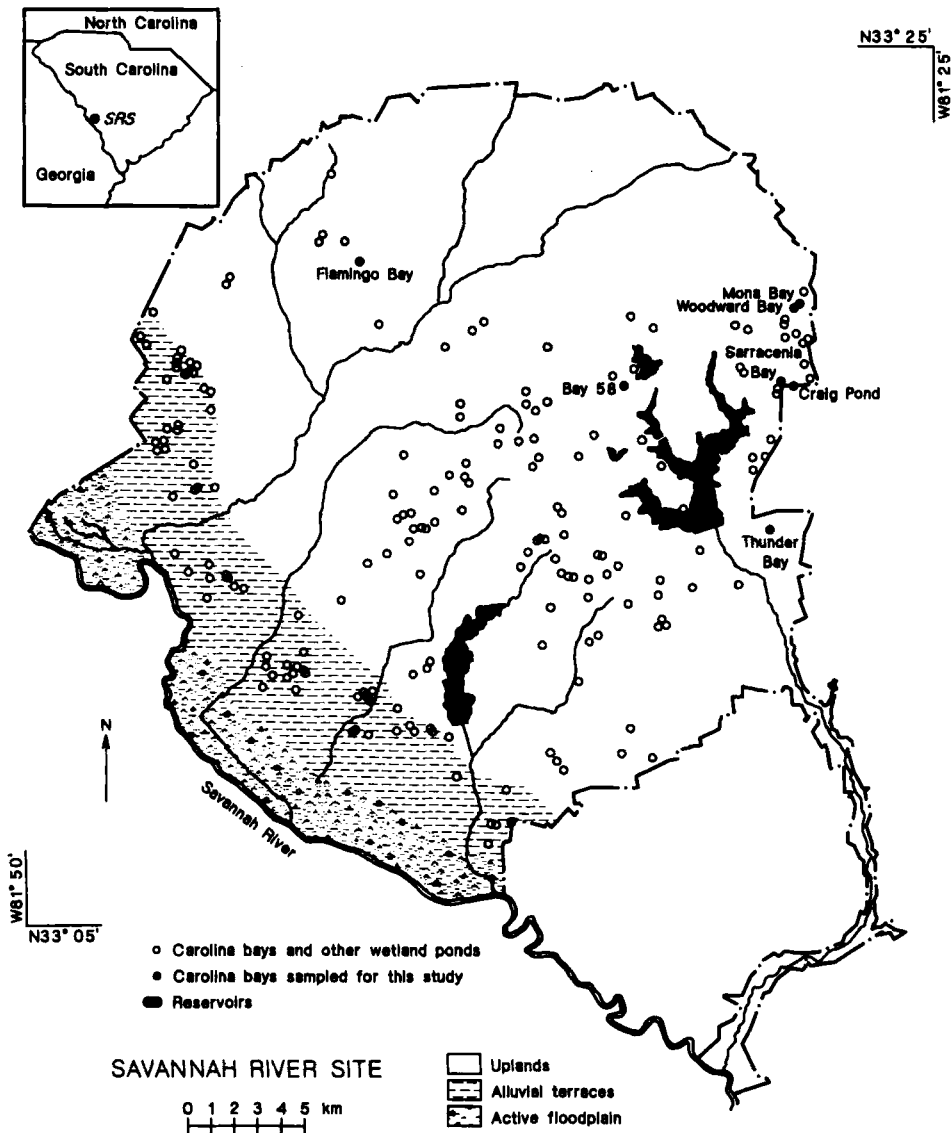
Figure 1. Carolina bays on the Savannah River Site (SRS), South Carolina. The bays and wetland ponds were mapped by Shields et al. (1982). Filled circles designate bays included in this study.

long axis of Flamingo Bay is oriented at about 15° west of true north (345° North Azimuth). At the time the SRS was acquired by the federal government in 1951, several of the bays had been ditched, and all were surrounded by agricultural lands (1951 aerial photographs: 1:12,000 series, U.S. Department of Agriculture, Salt Lake City, Utah).

**Table I.** Physiographic attributes of the seven study bays.

Pond	Area (ha)	Maximum Water Depth (cm)	Hydroperiod Index	Historic Era Ditches	Interior Vegetation
Flamingo Bay (#3)	5.7	117	5	No	Aquatic
Bay 58 (#58)	3.3	52	2	No	Herbaceous
Mona Bay (#66)	11.3	90	2	Yes	Aquatic/herbaceous
Woodward Bay (#67)	7.0	40	1	Yes	Herbaceous
Craig Pond (#77)	50.2	35	3	Yes	Aquatic
Sarracenia Bay (#78)	4.0	76	4	No	Aquatic
Thunder Bay (#83)	4.4	102	3	Yes	Aquatic

Areas, taken from Shields et al. (1982), represent an estimate of the area typically inundated. Maximum water depth and hydroperiod were measured in a 1990 survey, when the ponds were sampled five times at 2-month intervals (A. E. DeBiase, B. E. Taylor, and D. L. Mahoney, unpublished data, 1990). The hydroperiod index ranges from 1 (inundated for several months) to 5 (did not dry). Historic era ditches were identified from aerial photographs and field observations. Interior vegetation was classified by D. DeSteven (unpublished data, 1995). Aquatic habitats are deep-water ponds, dominated by aquatic macrophytes such as water lily (*Nymphaea odorata*) and water shield (*Brasenia schreberi*); herbaceous habitats are shallow-water meadows dominated by grasses (*Leersia hexandra* and/or *Panicum hemitomon*) or sedges (*Carex walteriana*), often with other emergent forbs and graminoids. All except Bay 58 have been designated as Department of Energy Research Set-aside Areas on the Savannah River Site.

The bays in this study are currently temporary or semipermanent ponds. Although water levels fluctuate seasonally, the water surface area is always much smaller than the area of the entire basin. A 16-year hydrologic record is available for Flamingo Bay (Taylor and Brooks, 1994). The pond usually holds the most water in spring, with depths as great as 164 cm in the central pool (note that this 1993 value exceeds the maximum reported in Table I). It becomes shallower in summer and fall, and it has dried completely at least twice (1981, 1988) since ecological studies at the pond began.

Aquatic or herbaceous wetland vegetation currently dominates the interior of the basin of each of the bays (Table I). At Flamingo Bay, vegetation of the north-central pool, in the deepest part of the bay, includes submerged and floating aquatic macrophytes such as smartweed (*Polygonum* sp.) and American lotus (*Nelumbo lutea*). The vegetation of the remainder of the interior, in the areas that are often inundated, is dominated by panic grasses (*Panicum* sp.) with occasional blackgum (*Nyssa sylvatica biflora*) trees and buttonbush (*Cephalanthus occidentalis*) shrubs. Further toward the rim, in areas that are occasionally inundated, water tolerant hardwood trees, including sweetgum (*Liquidambar styraciflua*), red maple (*Acer rubrum*), and blackgum, assume dominance. The sand rim and outer margins of Flamingo Bay support stands of loblolly and slash pine (planted in 1953, 1955, 1972, and 1981; U.S. Forest Service CISC stand data base) with a sparse understory of shrubs and vines.

All of the pond habitats presently support aquatic animal communities that
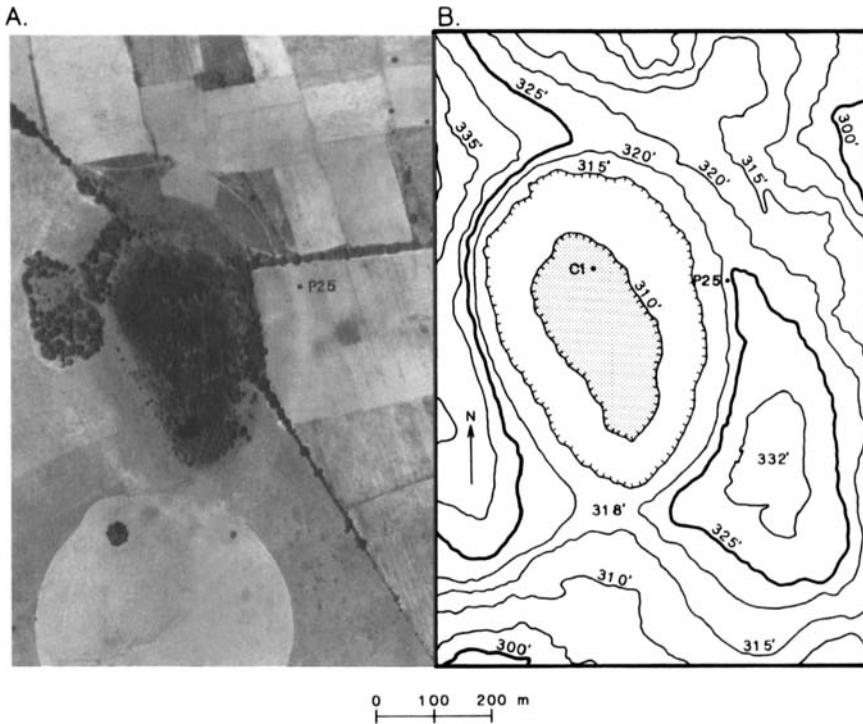
Figure 2. Flamingo Bay. **A.** The 1943 aerial photograph (1:20,000 scale) was obtained from the Cartographic and Architectural Branch of the National Archives, Washington, D.C. The eastern side of the bay was plowed; the western side was probably pasture. The trees in lines radiating outward from the bay grew up along fences at property boundaries. The grove of trees at the bottom of the photograph marks a small cemetery; it sits near the edge of an area that was plowed in a circular pattern, presumably to check erosion. **B.** The 1951 topographic map corresponding to the aerial photograph was redrawn from Savannah River Plant Map 3302 (Sheets 1006, 1007, 1036, 1037; 1:1200 scale). The contour interval is 5 ft (1.5 m). Both panels show approximate locations of sediment core C1 and Provenience 25 (P25).

are typical of temporary ponds (Mahoney et al., 1990). Fish have been observed only at Craig Pond and Sarracenia Bay.

METHODS AND RESULTS

Flamingo Bay: Archaeological Survey and Site Testing

Based on our understanding of the environmental correlates of prehistoric subsistence-settlement variability on the South Carolina Coastal Plain (Brooks and Scurry, 1978; Brooks et al., 1986), and specifically on the SRS and vicinity (Brooks and Sassaman, 1990; Brooks et al., 1990; Sassaman et al., 1990), we targeted the east–southeast sand rim of Flamingo Bay for initial investigation.

We conducted a shovel-test survey to discover and define the archaeological site, excavated a 1 × 2 m test unit to obtain more detailed archaeological and stratigraphic data, and collected sediment samples at the test unit. We also conducted shovel and auger tests to define the deeper stratigraphy at the archaeological site on the rim and the shallower stratigraphy on the laterally adjacent basin slope to the west.

Archaeological Site Definition

Using standardized field methods employed by the Savannah River Archaeological Research Program (SRARP, 1990), we discovered site 38AK469 and delineated its vertical and horizontal extent through a cruciform pattern of shovel tests (Figure 3). The 30 × 30 cm shovel tests were excavated to a depth of 60–120 cm below surface (cmbs), depending upon the depth of the archaeological deposits and/or the depth at which the BC soil horizon (see below) was encountered. Artifacts were recovered by passing all excavated soil through 6.4-mm (0.25-in.) mesh screen.

Site 38AK469 follows the crest of the sand rim for a distance of 186 m and varies from 30 to 130 m in width. It is roughly crescent-shaped, and it has a north–south orientation. Based on the shovel-test data, the site exhibits horizontal (lateral) as well as vertical archaeological stratigraphy (Figure 3). Loci containing only Archaic period components (ca. 9500–4000 yr B.P.) are found at the extreme north and south ends of the site and on the eastern side of the site toward the exterior margin of the rim. Archaic and sparse Late Woodland, and possibly Mississippian, artifacts are present in the central portion of the site along the rim crest. Only the later Woodland/Mississippian materials (ca. 1200–500 yr B.P.) are present in the west-central portion of the site, where they extend downslope to the west into the basin, and, at one location, nearly to the high-water line recorded on 6 April 1993.

Archaeological Stratigraphy at Provenience 25

Provenience 25 (see Figures 2 and 3) was chosen for a 1 × 2 m test unit because the shovel tests revealed a high density and diversity of artifacts, including temporally diagnostic artifacts, at that location. The plow zone extended to a depth of 25 cmbs. In the absence of observable depositional or cultural stratigraphy, excavation below the plow zone was by 10-cm arbitrary levels, starting at 25 cmbs and extending to a total depth of 105 cmbs. Artifacts were recovered by passing all excavated soil through 6.4-mm mesh screen. Precise vertical and horizontal positions were recorded (i.e., "plotted") for artifacts that are temporally diagnostic and/or larger than ca. 2.5 cm. The temporally diagnostic artifacts establish chronological controls, and the larger artifacts indicate buried surfaces because they are less likely to have been displaced vertically by occupational and post-depositional processes (Stockton, 1973; Hughes and Lampert, 1977; Ferring, 1986; Brooks and Sassaman, 1990; Brooks et al., 1990).
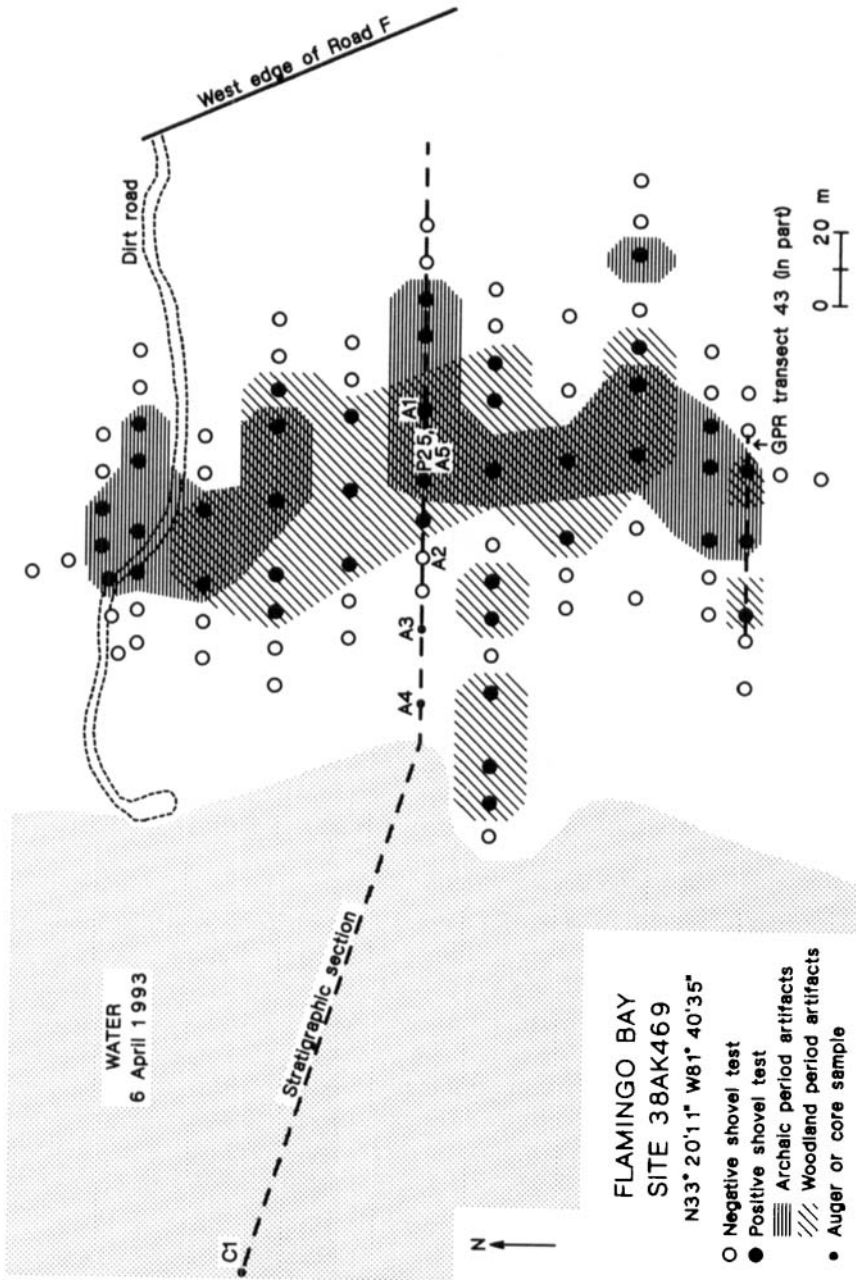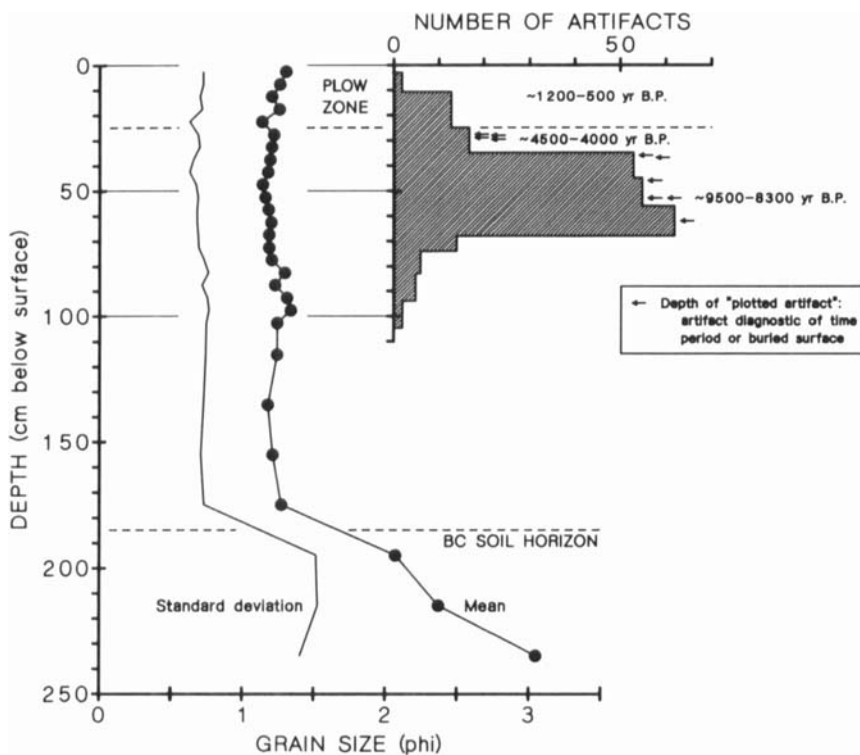
Figure 3. Site map of 38AK469. For orientation, the approximate locations of sediment core C1 and Provenience 25 (P25) are shown in Figure 2 (both panels).

Figure 4. Sedimentological and archaeological stratigraphy of the eastern rim of Flamingo Bay at Site 38AK469, Provenience 25.

The archaeological stratigraphy at Provenience 25 is summarized in Figure 4. The upper zone (0–25 cmbs) is entirely in the plow zone and represents a mixed archaeological context. Temporally diagnostic artifacts give a minimum date range of ca. 1200–500 yr B.P.

The middle zone (25–68 cmbs) contains the highest frequency of artifacts. Among the plotted artifacts (Figure 4) are a quartz cobble cluster at 27.5–29.5 cmbs that indicates an *in situ,* hearth-related function (Brooks and Hanson, 1987; Sassaman et al., 1990; Sassaman, 1993: 224–235) and a Kirk Corner-Notched hafted biface at 53 cmbs with a hammerstone fragment in direct association. The cobble cluster is Late Archaic (ca. 4500–4000 yr B.P.—based on a Savannah River Stemmed [Mill Branch phase] hafted biface from the 25–35 cmbs level), and the Kirk hafted biface is Early Archaic (ca. 9500–8300 yr B.P.—Sassaman et al., 1990:144). The high frequency and continuous vertical distribution of artifacts, including plotted artifacts, suggests that the 25–68 cmbs depth range represents a relatively stable, slowly accreting surface. From the temporally diagnostic artifacts recovered at 25–35 cmbs and at 53 cmbs,

we estimate net sediment accumulation rates of 0.03–0.07 mm/yr. In contrast, at archaeological sites in alluvial and colluvial contexts on the SRS, the vertical distribution of artifacts is multimodal and discontinuous, indicating periods of surface stability punctuated by depositional events that rapidly buried occupation surfaces (Brooks and Sassaman, 1990; Sassaman, 1993).

The sparse archaeological materials in the lower zone (68–105 cmbs) are all small and consist almost exclusively of lithic debitage. They probably reflect post-depositional vertical displacement from the slowly accreting surface above.

Sediment Stratigraphy at Provenience 25 and Vicinity

Sediment column SC1 was obtained at 5-cm increments from the central area of the west wall of Provenience 25. From the base of the excavation at 105 cmbs, sampling continued at 20-cm increments with a standard soil auger (auger test A5) to a total depth of 245 cmbs, well into the BC soil horizon. Additional soil auger tests (A1–A4) were made on an east–west transect through Provenience 25 (Figure 3) to determine the depth of the BC horizon, and additional shovel tests were made in the vicinity of A3 and A4 to characterize the gravel deposits (see below) overlying the BC horizon in that area. The sedimentological field methods and laboratory analyses are described in Brooks and Sassaman (1990).

The sediment stratigraphy at Provenience 25 (sediment column SC1/auger test A5) is summarized in Figure 4 and Table II. The sediments consist of a sandy unit (0–185 cmbs) overlying a sandy silt and clay BC soil horizon. The BC horizon represents the surficial portion of the Upland Unit, which is characterized by intense lateritic weathering and was deposited during the late Eocene (D. J. Colquhoun, personal communication, 1995). The horizon forms the aquiclude/aquitard beneath the sandy rim and basin fill of Flamingo Bay.

Sediments of the sandy unit are moderately well-sorted (graphic standard deviations of 0.63–0.76ϕ) medium quartz sands (graphic means of 1.14–1.34ϕ). The modern surface horizon of Ap (plow zone) occurs at 0–25 cmbs. The Ap horizon is the only stratigraphic feature of the sandy unit that could be distinguished visually in the field; note the corresponding erratic variation in grain size (Figure 4), which is typical of stable surfaces that have been disturbed by anthropogenic or natural processes. Grain size distributions of samples within the sandy unit are near-symmetrical and, with the exception of those at 145–185 cmbs, exhibit slight positive skewness. Distributions are leptokurtic and show little variation (1.10–1.25) in this parameter. A break in grain size composition at 80–100 cmbs, the base of the archaeological zone, separates the sandy unit into two stacked packages of similar depth and composition. Overall, the two packages coarsen upward, with the upper package (0–80 cmbs) being slightly coarser grained and better sorted than the lower package (80–185 cmbs). Within the upper package, a small deviation in grain size occurs at

Table II. Descriptive statistics for sediment samples (sediment column SC1/auger test A5) at Provenience 25.

Depth (cm below surface)	Mean (ϕ)	Standard Deviation (ϕ)	Skewness	Kurtosis
0–5	1.304	0.723	0.115	1.235
5–10	1.262	0.723	0.100	1.248
10–15	1.207	0.700	0.094	1.220
15–20	1.261	0.717	0.093	1.215
20–25	1.139	0.628	0.048	1.180
25–30	1.220	0.689	0.062	1.172
30–35	1.206	0.700	0.063	1.201
35–40	1.196	0.655	0.048	1.136
40–45	1.181	0.628	0.022	1.131
45–50	1.142	0.673	0.042	1.128
50–55	1.162	0.689	0.045	1.160
55–60	1.185	0.681	0.034	1.168
60–65	1.201	0.683	0.049	1.170
65–70	1.188	0.690	0.019	1.164
70–75	1.186	0.695	0.052	1.143
75–80	1.206	0.732	0.071	1.189
80–85	1.298	0.763	0.079	1.249
85–90	1.228	0.716	0.046	1.205
90–95	1.312	0.755	0.088	1.232
95–100	1.339	0.764	0.078	1.234
100–105	1.246	0.745	0.030	1.177
105–125	1.245	0.744	0.040	1.165
125–145	1.180	0.726	0.020	1.136
145–165	1.214	0.709	−0.055	1.101
165–185	1.277	0.730	−0.031	1.157
185–205	2.071	1.519	0.283	0.962
205–225	2.375	1.533	−0.051	0.636
225–245	3.047	1.407	−0.935	0.680

45–55 cmbs, the level of the Early Archaic, Kirk phase surface indicated by the plotted artifacts.

Similarities between the modern surface horizon and the zone from 80–100 cmbs, at the top of the lower package, indicate that the latter represents a buried surface horizon. In comparison with other samples from the sandy unit, sediment composition in these two zones tends to be slightly: (1) finer-grained; (2) less well-sorted; (3) more positively skewed; and (4) more leptokurtic. Patterns of variation in mean grain size are quite similar for the 0–25 and 80–100 cmbs zones (Figure 4). The 80–100 cmbs zone lacks organics and evidence of rooting, but these absences are not atypical of buried surface horizons in well- to excessively well-drained, acidic surficial sands of the southeastern Atlantic Coastal Plain (Markewich and Markewich, 1994).

The transect of soil auger tests (Figure 5, A1–A4) shows that the BC horizon dips downward to the west (basinward) of Provenience 25, but remains rela-
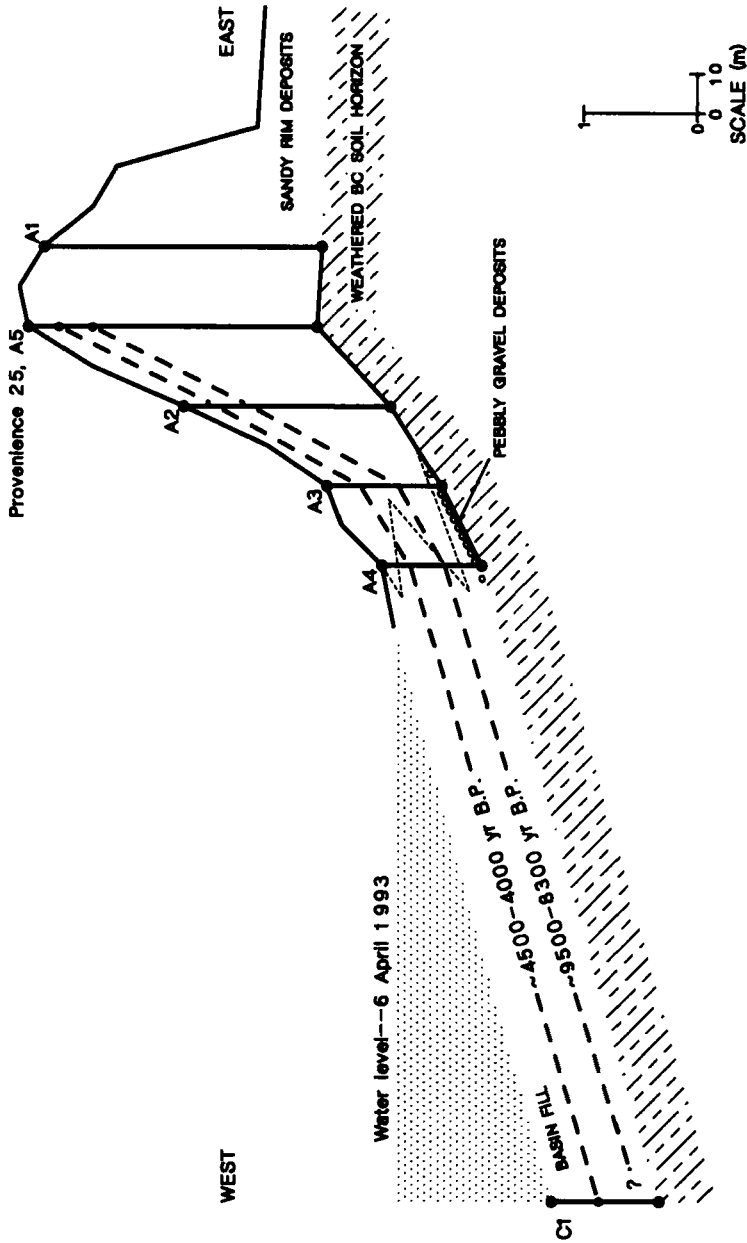
Figure 5. Stratigraphic section through the eastern side of Flamingo Bay. Vertical lines show locations of soil auger tests A1–A5 on the rim and sediment core C1 in the basin (see Figure 3 for a plan view of these locations). Ages at indicated depths are estimated from archaeological dates at Provenience 25 on the rim and from radiocarbon dates on charcoal from sediment core C1 in the basin. Note the vertical exaggeration.

Table III. Radiocarbon dates on charcoal from sediment core C1 from the basin of Flamingo Bay.[a]

Depth (cmbs)	Soil Horizon	Radiocarbon Sample Size (mg)	Radiocarbon Laboratory No.[b]	AMS Date (radiocarbon yr B.P. ± 1 std. dev.)[c]	Sedimentation Rate (mm/yr)
13–25	E2	10.44	Beta-59955/ ETH-10071	2550 ± 70	0.07
25–39	Btg, upper	10.15	Beta-59956/ ETH-10072	3055 ± 70	0.26
39–50	Btg, middle	5.15	Beta-59957/ ETH-10073	4505 ± 80	0.09

[a] Horizons of the Rembert sandy loam soil were designated on the basis of depth range, texture, and color. In estimating sedimentation rates, the radiocarbon date was assumed to apply at the midpoint of the core section sampled. The calculation was made between the midpoint of the section and the midpoint of the overlying section or, for the 13–25 cm section, the sediment surface.
[b] Beta: Beta Analytic, Inc., Miami, Florida; ETH: ETH Accelerator Laboratory, Zurich, Switzerland.
[c] Age normalized to −25 per mil carbon 13.

tively level to the east toward the exterior of the sand rim. Downslope and 30–70 m west of Provenience 25, in the vicinity of A3 and A4, deposits of fine to medium pebble-sized quartz gravel lie on top of the weathered and scoured BC soil horizon. As roughly delineated by additional shovel and auger testing, these deposits parallel the rim and modern shoreline.

Radiocarbon Dates of Basin Sediments at Flamingo Bay

The soil of the basin of Flamingo Bay is a Rembert sandy loam (Rogers, 1990). In the absence of peat, we processed a sediment core to obtain charcoal for radiocarbon analyses to determine ages of basin sediments.

Sediment core C1 (see Figures 2 and 3) was taken with a Dutch gouge auger in the deepest part of Flamingo Bay, near the center of the northern half of the basin. The spoon of the auger was 1 m in length and 2.5 cm in diameter. Impenetrable basal material, corresponding to the BC soil horizon, was encountered at 94 cm. The 94-cm core was divided into seven sections (0–13, 13–25, 25–39, 39–50, 50–60, 60–84, and 84–94 cmbs) in the field according to color and texture of the sediments. Our field observations corresponded well with Rogers' (1990) description of the depth ranges and physical characteristics of the pedostratigraphic horizons. In the laboratory, the quartz sand-dominated sediments were processed by gentle wet sieving. Material retained on 500- and 250-μm sieves was air-dried, then examined under a dissecting microscope. Charcoal fragments were removed with fine forceps. Charcoal particles were typically 0.5–1.0 mm in length; they included fragments of both linear and spheroidal structures.

The four sections from the upper 50 cm of the core yielded enough charcoal (5–10 mg) for AMS radiocarbon dates (Table III, charcoal from uppermost section was not sent for analysis). None of the three deeper sections yielded

enough material. The three radiocarbon dates correspond, with increasing depth, to the end of the Early Woodland period, Early Woodland-Late Archaic transition, and the beginning of the Late Archaic. Sedimentation rates estimated from the radiocarbon data are low (<0.3 mm/yr).

Holocene Changes in the Rim and Basin at Flamingo Bay

A stratigraphic section of Flamingo Bay, with interpolated continuities between the eastern rim and the north-central basin, is shown in Figure 5. From the archaeological and radiocarbon dates, we infer that significant deposition occurred both on the rim and in the basin of Flamingo Bay during the Holocene. Plowing during modern times undoubtedly lowered the surface of the rim crest. Around 9500–8300 yr B.P., the crest of the rim was at least 50 cm lower than at present, and by 4500–4000 yr B.P., it was at least 30 cm lower. Around 4500 yr B.P., the basin was about 45 cm deeper. Applying the sedimentation rate estimated for the deepest dated stratum (Table III) to the underlying sediments yields an extrapolated date of 10,000 yr B.P. for the basal sediments.

As a consequence of basin infilling, Flamingo Bay now has a maximum inundated area of about 6 ha and a maximum depth of 1.6 m. If we assume that the shape of the pond remains similar, the area changes in proportion to the square of the radius shown in Figure 5. We thus estimate that the inundated area was about 7.8 ha (or 30% larger) at 4500 yr B.P. and about 11.4 ha (or 90% larger) before infilling of the basin began, perhaps in the early Holocene, according to the extrapolated basal date, or perhaps in the late Pleistocene.

Several lines of evidence, including the archaeological stratigraphy described above, suggest that the two inferred packages of sandy sediments comprising the southeastern rim of Flamingo Bay represent eolian deposition or, more likely, eolian over upper shoreface deposition. The evidence for eolian deposition is, we believe, compelling. Most importantly, the geomorphic and topographic setting reasonably precludes alluvial or colluvial deposition: the rim is raised above the surrounding land surface, and thus there are currently no laterally adjacent sources for such sediments (see Figure 2b).

Eolian processes do not always leave a characteristic signature in the textural data, particularly if deposition is slow, and such data are best used as complementary evidence (Ahlbrandt and Fryberger, 1982). Markewich and Markewich (1994) note that the unstratified character of the inland dune sands in the Coastal Plain of Georgia and South Carolina is likely due in part to the interference of vegetation with airfall layering and grain transport. Further, some bedding may simply not be recognized because of the uniform grain size and monomineralogy (quartz) of the sand, which tend to inhibit internal layering or structure. The grain size data for Flamingo Bay (Table II) indicate moderately well-sorted, positively skewed, leptokurtic, medium-grained sands that tend to coarsen upward slightly. These characteristics are consistent with an eolian interpretation, particularly for inland dunes (Friedman and Sanders, 1978; Ahlbrandt and Fryberger, 1982). Specifically, the ranges of values for each parameter at Flamingo Bay are consistent with ranges reported by

Markewich and Markewich (1994) for inland dunes on the Coastal Plain of Georgia and the Carolinas. Given that most shore-related sand dunes are derived from adjacent wave-lain sand and that transport was probably eolian, upslope, and into standing vegetation, the comparatively coarse mean grain size of the rim sands at Flamingo Bay suggests that transport onto the rim occurred over short distances.

The aerial photograph and topographic map of Flamingo Bay (Figure 2) illustrate features of rim morphology that are also consistent with an eolian origin. The semicircular shape of the rim around the bay's eastern margin, with the easterly bulge in the rim's southeastern portion, resembles the filled-in crescent or U-shape that Markewich and Markewich (1994) recognize as the most common shape of inland dunes in Georgia and the Carolinas. The configuration further suggests that sediments were derived from the west. The scoured and deflated condition of the relatively steep slope on the western side of the bay (Figure 2b) is consistent with our interpretation that it was a primary source of sediments to the basin. Westerly wind-generated wave action and longshore currents probably caused shoreline erosion and redistribution of sediments within the basin, producing eastern shoreface deposits from which eolian sediments of the rim were subsequently derived. Given the short transport distances implied by the coarse grain size of these rim sediments, upper shoreface deposits plausibly served as their immediate source.

The pebbly gravel overlying the BC horizon in Figure 5 may represent lower shoreface lag deposits of a paleoshoreline. If this interpretation is correct, these deposits suggest a high energy, open water phase with a shoreline situated 30–40 m east of the modern shoreline at the water level shown in Figure 5. We speculate that the date for these deposits was very early Holocene, or perhaps much earlier, because dated stratigraphy indicates that substantial deposition had occurred by the early Holocene on the rim and by the mid-Holocene in the basin. The modern shoreline is densely vegetated, and depositional processes now occur in a low energy environment.

If the pebbly gravel deposit does represent lower shoreface lag, then sandy upper shoreface deposits should exist upslope to the east in the vicinity of the rim. The lower depositional package at Provenience 25 thus becomes a good candidate for such a deposit. Gamble et al. (1977) described a similar lateral and stratigraphic relationship where "primary" rims were simply associated with the edge (upper shoreface) of the original depression and "secondary" rims were the overlying eolian manifestations that created the topographic expression. The hypothesized presence of upper shoreface deposits at Flamingo Bay will be confirmed or refuted only through additional, detailed stratigraphic investigation and correlation.

Ground-Penetrating Radar (GPR) Survey

GPR was used on the margin of Flamingo Bay to extend the picture of subsurface topography that we obtained by excavating and augering. GPR surveys at the six additional bays enabled us to evaluate the generality of

features observed at Flamingo Bay. GPR provides a tool for rapid, noninvasive probing of the shallow subsurface to depths of several meters. A transmitted bipolar radar pulse is reflected off dielectric contrasts in the subsurface and detected by an antenna receiver. As the received signal is processed and displayed during a continuous scan across a surface, reflectors are displayed and generally reproduce the underlying stratigraphy, although several properties of the GPR can cause distortion in the data. When these characteristics of GPR data are recognized and accounted for, the instrument can help to define stratigraphy over broad areas with minimal subsurface verification.

GPR data were collected using a Geophysical Survey System SIR-3 analogue GPR with a 500 mHz transducer with a sensitivity setting of 800 (unitless) and a two-way pulse travel time of 50 ns. Test pits (25–125 cm deep) were excavated at each bay to identify soil and sedimentologic properties. The bottom of each pit was then lined with metal plates and backfilled, and the GPR was run across and adjacent to the filled pit. This process allowed derivation of the dielectric constant and pulse travel times for both disturbed and undisturbed material above the buried plates. Stratigraphic differentiation included: (1) the zone disrupted by historic/modern era cultivation (0–~25–30 cmbs), (2) depths previously identified at archaeological site 38AK469 (Provenience 25— see Figure 4) as corresponding to subtle grain-size variations (~45–55 and ~80–90 cmbs), and (3) fine-grained bay fill. Dielectric constants (unitless) and pulse travel times in the vicinity of all bays were fairly uniform within a given sedimentary environment. Calculated values for the dielectric constant and one-way pulse travel time are, respectively: (1) approximately 7.8 and 2.8 ns/ 30.48 cm (=1.0 ft) for the 25–30 cm thick cultivated zone, (2) 3.2–5.3 and 1.8–2.3 ns/30.48 cm throughout the well-sorted, dry, coarse-medium sand below the cultivated zone and extending to depths of several meters, and (3) 10 and 3.2 ns/30.48 cm in finer, wet to saturated, bay-filling sediments. These values were used to calculate the depths to reflectors identified in subsequent radar transects. Interpretation of GPR data (reflectors) was via augering or excavation.

Following the constraint of subsurface dielectric properties at each bay, we obtained GPR data along intersecting transects. At Flamingo Bay, data were collected along transects on the east and southeast rim. Thirty east–west transects spaced at 3- to 6-m intervals were crossed by three north–south transects at 20-m intervals. At Bay 58, eight transects covered the northeast, southeast, and east sides of the bay. At Mona and Woodward Bays, 15 transects criss-crossed the slightly elevated area between the bays. At Craig Pond and Sarracenia Bay, 17 intersecting transects covered the area between the bays. A several hundred meter transect was also made east of Craig Pond. At Thunder Bay, 11 transects were made on the east side of the bay. An 800-m transect was made east of Thunder Bay for comparison with stratigraphy adjacent to the bay.

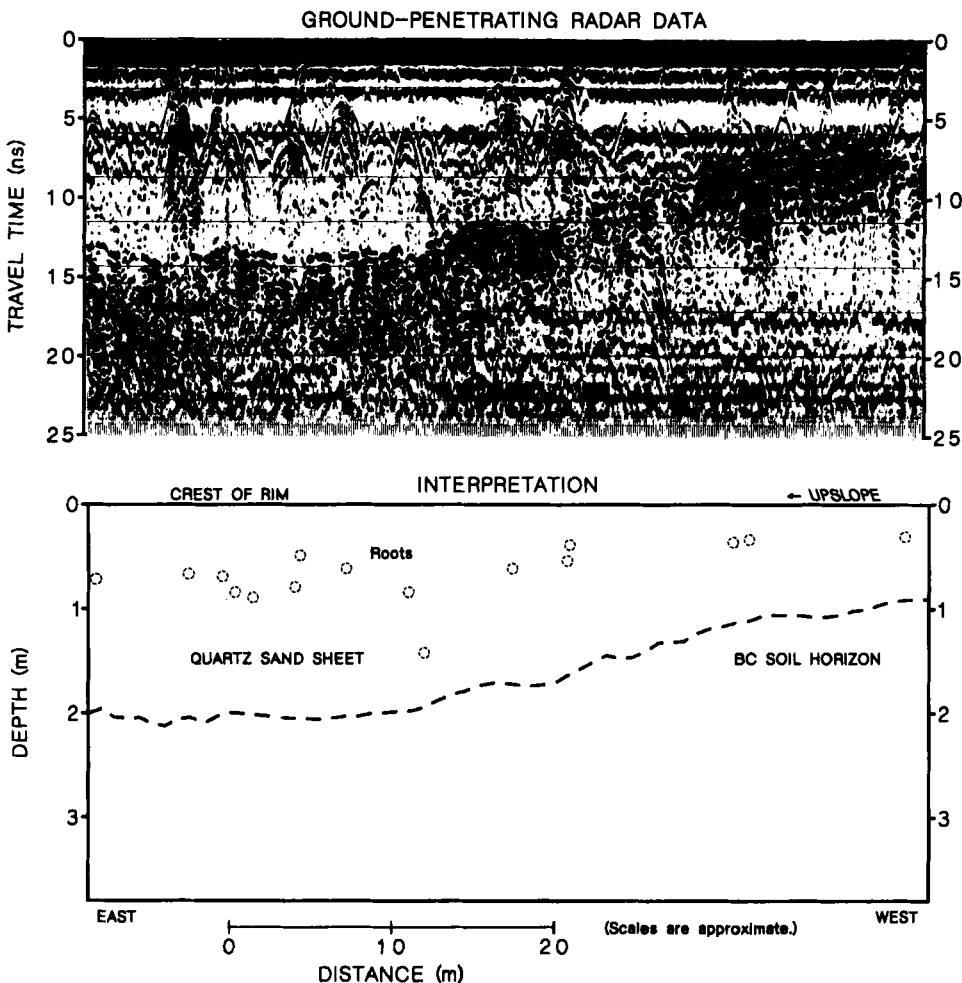Terrain in the study areas around the seven Carolina bays was generally

flat to slightly inclined, and vegetation cover ranged from open pine forest to woodland with dense undergrowth. Excellent GPR signal penetration and reflection were achieved in the cultivated and sandy horizons surrounding each bay. Oxidized, usually drier zones were more readily detected than more reduced, usually wetter horizons. In many instances, prominent hyperbolic reflectors in the uppermost 1–2 m of the section marked the locations of tree roots; no examples were identified where a reflector could be matched with a buried lithic block. Less prominent reflectors corresponding to subtle changes in sediment grain size and/or buried prehistoric occupation surfaces within the sand sheet may exist, but were not conclusively identified. As expected, GPR transects across finer, more conductive bay fill and saturated sediments produced fewer well-defined reflectors.

At Flamingo Bay, east–west transects along the east and southeast rims defined a strong reflector at slightly less than 1 m to more than 2 m depth. Excavations determined that this reflector corresponds to the relict BC paleosoil horizon shown in Figures 4 and 5. An example of one of these transects is shown in Figure 6. A decrease in the bayward extent of this reflector toward the north correlates with a transition from oxidized to more reduced conditions in the subsurface. GPR data also indicate that the elevated rim along the bay consists of an accumulation of fairly uniform sand whose thickness and width decrease from the southeast toward the north. North–south transects along topographic contours of the rim revealed generally flat topography of the underlying BC horizon. Possible exceptions include a slight incisement or "notching" of the BC horizon along the more northern east–west transects and an apparent basinward dip in the BC horizon (or its lateral equivalent) along the inner edge of the bay.

At the other six bays, stratigraphy in the near-surface, as indicated by the distribution and number of reflectors, is generally similar to that at Flamingo Bay. Most reflectors are horizontal except near the bay waterlines, where basinward dips occur at Bay 58 and Thunder Bay. Variations in the thickness of a medium/coarse sand body over a flat pedogenic B or BC horizon account for most of the local surface topography. At Bay 58 and the paired Mona and Woodward Bays, the BC horizon is similar to the BC horizon observed at Flamingo Bay; at Thunder Bay and the paired Sarracenia Bay and Craig Pond, a more incipient pedogenic B horizon is present. Data from GPR transects on the east rim of Thunder Bay suggest that an older pedogenic BC horizon may lie at a depth of ~3 m. A transect further to the east of Thunder Bay revealed few gross differences from the stratigraphy of the bay rim: The data show reflectors corresponding to both a regional pedogenic BC horizon and a superposing sand layer similar to that forming the bay rim. For both pairs of bays, no cross-cutting sequences are visible in the GPR data from the areas between the two basins.

Comparing GPR data for Flamingo Bay with that for the six other bays suggests the following first-order interpretations. First, most of the topography

GROUND–PENETRATING RADAR DATA

INTERPRETATION

CREST OF RIM   ← UPSLOPE

Roots

QUARTZ SAND SHEET   BC SOIL HORIZON

EAST   (Scales are approximate.)   WEST

DISTANCE (m)

Figure 6. Portion of GPR transect 43 from the rim at Flamingo Bay, Site 38AK469 (see Figure 3 for a plan view of the location). The transect delineates the thickness of the sandy rim overlying the Upland Unit (BC soil horizon). The near-surface parabolic reflectors indicate pine tree roots, the more prominent of which are marked on the figure.

associated with the bay rims is produced by locally greater thicknesses of a regional, surficial sand body. We do not yet know whether this sand layer extends into the interiors of the bays; however, GPR reflectors do suggest a basinward dip of a stratigraphic layer around the interior of some bays. Second, stratigraphy is similar among bays. The general stratigraphic sequence around the bay also is similar to that of the surrounding region, implying that bay formation did not significantly alter preexisting regional stratigraphy. Third,

the relict pedogenic BC horizon apparently constitutes a regional, basal strati-
graphic marker. Occurrence of this horizon remains to be confirmed at two of
the bays and must be distinguished from more incipient pedogenic B horizons
in some areas. If confirmed, such a regional marker horizon would help to
constrain relative ages and probable causes of bay formation. Fourth, distribu-
tions of shallow GPR reflectors between paired bays display no obvious evidence
of onlap- or offlap-like strata that would indicate bay transgression with time
or relative age differences between bays. Finally, there is considerable second-
order variability in the stratigraphy from bay to bay. Presumably, this second-
order variability reflects differences in the histories of the individual bays,
while the first-order similarities reflect regional processes.

DISCUSSION AND CONCLUSIONS

The geological processes inferred from features of Flamingo Bay are broadly
consistent with the hypothesis that Carolina bays formed through the action of
wind on water ponded in surface depressions. As shown by ground-penetrating
radar, the geomorphic and stratigraphic similarities among Flamingo Bay and
the other six bays suggest similar histories. The results from grain size analyses
on the eastern rim of Flamingo Bay, combined with the topographic setting
and morphology of the eastern rim and comparisons with other regional data,
strongly support the inference that at least the upper sediments of the rim at
Flamingo Bay are of eolian origin. The orientation of the long axis of Flamingo
Bay implies a wind direction of 255° North Azimuth, if we assume that the
wind blew from a direction 90° counterclockwise to the axis. This value is
within the range of 228–259° North Azimuth reported by Carver and Brook
(1989) in their summary of average hypothetical paleowind directions derived
from orientations of Carolina bays and parabolic dunes in Georgia and South
Carolina. Note, however, that the paraboloid morphology and orientation of
the southeastern portion of the rim (Figure 2b) suggest that the winds associ-
ated with rim formation or modification were from a more northerly quarter.
The action of longshore currents, hypothesized by Kaczorowski (1977) to have
elongated and shaped the pond by eroding the downwind shoreline, is not
evident in the low-energy environment of the modern shoreline. However, the
buried pebbly gravel deposits suggest that such processes may have occurred
early in the genesis of the bay. The archaeological data indicate that the rim
was well developed by the early Holocene, thus constraining the initial stages
of bay genesis to an earlier period.

The archaeological and radiometric dates from Flamingo Bay establish par-
tial chronologies for Holocene changes in the rim and basin of the bay. These
chronologies have direct application to the problems of reconstructing Holocene
climate and understanding prehistoric human activity in the Upper Coastal
Plain of South Carolina.

On the rim of Flamingo Bay, eolian deposition occurred at an average rate
less than 0.1 mm/yr for a period of at least 5000 years, from the early Holocene

(Early Archaic, Kirk phase—9500–8300 yr B.P.) through the mid-Holocene (Late Archaic, Mill Branch phase—4500–4000 yr B.P.). The slow depositional rate argues against climatic conditions dry enough to produce large, bare source areas on the landscape (Daniels et al., 1969). The sediments probably derived from the upper shoreface of the pond; similarly localized sources, such as floodplains, low terraces, or upper shorefaces, have been identified for other inland eolian features of the Coastal Plain (Daniels et al., 1969; Carver and Brook, 1989; Markewich and Markewich, 1994). The lack of internal structure or stratification and the low content of fines on the rim of Flamingo Bay further suggest formation in standing vegetation directly adjacent to the sand source (Markewich and Markewich, 1994). These arguments for a vegetated landscape support the inference of Watts et al. (1996) that early Holocene dryness was less severe in the Coastal Plain of South Carolina than in areas to the south, particularly Florida.

Chronological controls on the histories for most other inland eolian features in the Coastal Plain are less precise than those for the rim of Flamingo Bay, but are not inconsistent with our results for Flamingo Bay. Carver and Brook (1989) conclude, based on their own work and a review of other studies, that "the greater part of the eolian sands are of late Wisconsin to Holocene age and some [are] of early Wisconsin age" (p. 210).

Results from two other studies in this region of the Coastal Plain indicate moist climate during the early Holocene. For Little Clear Pond near Ehrhardt, South Carolina, about 44 km east of the SRS, preliminary results indicate peat accumulation since 9800 yr B.P. (J. Clark, J. Porter, and E.E. Gaiser, personal communications, 1992). Little Clear Pond is probably a subdued solution pond expressed up through a fairly thick mantle of sand (P.A. Stone, personal communication, 1993); if so, its filling suggests a regionally rising water table at or before ca. 10,000 yr B.P. For White Pond, near Elgin, South Carolina, about 165 km northeast of the SRS, pollen diagrams indicate a transition from a cold, dry climate to a cool, moist climate around 13,000 yr B.P., near the end of the Pleistocene (Watts, 1980). Around 9500 yr B.P., near the time of the basal date for Little Clear Pond, the modern assemblage of pollen taxa appeared. A gradual shift in dominance from oak to pine established a pollen spectrum representing a forest "essentially like the modern forest" by about 7000 yr B.P. (Watts, 1980:194; he estimated the date by interpolation). The modern climate of the region is warm, seasonal, and moist: Average temperatures are 8.5°C in January and 26.9°C in July, and average annual rainfall is 1.2 m (60-year averages for the National Oceanic and Atmospheric Administration weather station at Blackville, South Carolina).

Whatever the climate, archaeological evidence suggests that Flamingo Bay provided a valuable source of water during the early to mid-Holocene, from the Early Archaic (9500–8300 yr B.P.) through the Late Archaic (4500–4000 yr B.P.). Unless the climate of the early Holocene was much hotter or drier

than the modern climate, the larger, deeper pond would have been likely to fluctuate less widely, and it probably supported a permanent pond fauna, including substantial populations of fish and turtles. Relatively high densities of mesic-adapted floral (e.g., acorns, hickory nuts) and faunal (e.g., deer, turkey, squirrel) subsistence resources might have occurred on the rim crest and slopes.

The stratigraphy of the basin of Flamingo Bay records significant infilling during the latter half of the Holocene. On the eastern rim of the bay, the basinward shift in occupation during the Woodland period seems to have tracked this infilling. The lower density and diversity of artifacts representing Woodland and later cultural periods suggest that the intensity of human activity decreased after about 4500–4000 yr B.P. While social factors in settlement variability cannot be ruled out, the possibility also exists that the shift in human activity reflects hydrologic and ecological shifts in the pond. By the end of the Early Woodland period, the basin was within 20 cm of its present depth. Even without a shift in climate, a shift in the hydrologic predictability of the pond, from a permanent pond to the modern semipermanent pond, seems plausible. Ecological shifts accompanying the hydrologic transition are likely to have included the loss of fish populations and changes in composition and abundance of many other taxa. Thus, if linked to hydrologic changes in the pond, changes in human use may have reflected reduction in the predictability of the pond or the associated biotic resources. Other changes in the mid- to late Holocene landscape, including establishment of the modern floodplains of the Savannah River and its tributaries, may also have influenced shifts in loci of human activity.

Archaeological evidence suggests that Flamingo Bay was not unique in its attractiveness to humans during the early Holocene. Other Carolina bays in the vicinity of the SRS contain early Holocene archaeological assemblages in their sand rims (K. Eberhard and C. Davis, personal communications, 1993). One bay, located 8 km to the NNW of the SRS near New Ellenton, South Carolina, has also produced a Paleoindian assemblage (Eberhard et al., 1994), including Clovis phase material (ca. 11,500–11,000 yr B.P.). Collectively, the paleoenvironmental and archaeological data support the scenario in which the early Holocene landscape in the vicinity of the SRS contained many more permanent or semipermanent ponds than at present.

With regard to the origin of Carolina bays, our results suggest that: (1) Ponding conditions, such as those proposed by Kaczorowski (1977) as necessary for bay evolution, were present during the early Holocene, and (2) sand rim accretion during the early Holocene may reflect strong winds and locally available sediment supplies (e.g., upper shoreface sands), rather than dry climatic conditions (Wright, 1981; Carver and Brook, 1989). Thus, much of the distinctive Carolina bay morphology may have actually evolved during the very late Pleistocene–early Holocene. With regard to human activity, our results suggest that fluvial-centric models of terminal Pleistocene–early Holocene human ad-

aptations on the South Atlantic Coastal Plain (Brooks and Hanson, 1987; Anderson and Hanson, 1988; Sassaman et al., 1990) require substantial revision to include intensive human use of isolated upland ponds.

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